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Contents

Methods for Improving the Microstructure of Recycled Concrete Aggregate: A Review

Vivian W. Y. Tam, Harshana Wattage, and Khoa N. Le

Abstract Concrete contribute to 33% of the total waste generated in Australia with the economic acceleration and the speed of urban development. Most of the concrete waste goes into landfills and considerably low quantity is recycled and reused as recycled concrete aggregate. Nevertheless, there are several limitations of re-using of recycled concrete aggregate, for instance high porosity, high water absorption rate, micro cracks in the interfacial transition zones. Due to those limitations, the concrete produced with recycled aggregate has low properties than the concrete made with natural aggregates. To improve the properties of recycled aggregate, many methods have been adopted. This paper provides an insight into the methods, advantages and disadvantages of methods to improve the properties of recycled aggregate, methods of autogenous healing under self-healing and autonomous healing under re-hydration, bacterial and micro-encapsulation methods, two-stage mixing approaches, which are used to increase the permeability of the recycled aggregate, which result in increased durability of the same, reduce the voids and the calcium hydroxide ($Ca(OH)_2$) content of the recycled aggregate, to improve the nanomechanical properties of the interfacial transition zones, removal or strengthening of weak parts or weak mortar layers of recycled aggregate by, mechanical grinding, heat grinding, pre-soaking in water, pre-soaking in acid, micro-wave assisted removal of mortar, spraying of immersion of polymer emulsion, submergence in sodium silicate solution, use of fly-ash, silica fume, metakaolin and ground granulated blast furnace slag under mineral admixtures. Carbon-curing, carbon conditioning and other CO_2 carbonation approaches and submergence with diammonium hydrogen phosphate solution under crystal forming approaches.

Parts of this study have been published before.

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Keywords Recycled concrete aggregate · Strengthening · Improving properties · Concrete microstructure

1 Introduction

Concrete is one of the most used materials globally [5]. With the modern-day construction developments which increasingly utilize concrete products [40] contribute to 33% of all the waste generated in Australia [57]. Most of the concrete waste goes into landfills and considerably low quantity is recycled and reused as recycled concrete aggregate. It is a demolition waste of concrete which is environmental-friendly building material which can be a serious contender to save the building materials and reduce the environmental pollution [60]. Recycling and the re-use of construction demolition waste has been a topic of special interest since early 1970s [11]. Further, the researchers were investigating the feasibility of mixing the recycled aggregate into the concrete [74]. Although the researching and use of RCA has been practiced frequently [49, 66], the use of construction waste is restricted in some instances as well [17, 18]. Since, most of the construction concrete waste produces substandard recycled concrete when it compared to the concrete made with natural aggregates [34, 42]. To have a positive impact on the environmental and economic sustainability, it is vital to improve the microstructural and mechanical properties of the substandard demolished concrete and make it re-usable and widely adoptable [26, 67]. Consequently, the aim of this paper is to summarize the methods, advantages and disadvantages of methods to improve the properties of the RCA.

2 Research Methodologies

This study examines various kinds of recycled aggregate treatment methods which can be used to improve the microstructural properties. The databases of ScienceDirect, Gale, Springerlink and the keywords of 'mixing approaches for recycled concrete aggregate', 'CO_2 effects on concrete', 'self-healing of recycled concrete aggregate' 'construction demolition waste recycling', 'bacterial-deposition' and 'carbonation' were used to find relevant literature, further this study consists of 84 research papers from year 1972 to 2020.

3 Limitations of the Recycled Concrete Aggregate (RCA)

The recycled aggregate has several limitations as it shows that it has a high porosity [8], high water absorption rate [70], micro cracks in the interfacial transition zones [40], contamination [1], variance in quality [59]. Thereby, the resulting recycled aggregate concrete (RAC) made by the recycled concrete aggregate (RCA) has lower properties (low-grade) than the concrete made with the natural concrete aggregate (NCA) [34, 42].

4 Methods of Improving Properties of Recycled Concrete Aggregate (RCA)

The recycled concrete aggregate (RCA) often contains large amounts of attached mortar and cement paste and the compressive strength of the RCA is lower than the concrete made from natural aggregates [79]. The same research further states, the tensile and the shear strength are also lower than the conventional concrete and the strength values gets reduced, modulus of elasticity increases, when the used RCA quantities gets reduced. Thereby the need of strengthening of recycled concrete aggregate is a necessity to make the aggregate widely applicable and usable in producing concrete.

4.1 Self-healing Treatments

Autogenous and autonomous healing methods are widely used as self-healing methods [25, 76]. Calcium carbonates can be precipitated inside the voids of the aggregate as autogenous method by exposing it to hydration. As the autonomous healing methods, researches have done on two different methods, the bacterial method and the microcapsule method [16]. Autonomous healing can be achieved by using live bacteria which produces calcium carbonate when exposed to certain environmental conditions and the chemicals which fill the air voids inside the aggregate to increase density [22].

The bacteria used for self-healing includes '*Sporosarcina pasteurii*', '*Bacillus subtilis*', '*Bacillus sphaericus*' and '*Bacillus pasteurii*' with calcium lactate ($C_6H_{10}CaO_6$) [7]. The self-healing with bacteria has shown improved elastic modulus, tensile strength and compressive strength in concrete [6, 15, 27]. The second method of self-healing is to use chemical filled micro-capsule. When any damage to the concrete occur, the micro-capsule bursts and fills the damaged area [56]. The microcapsule method can heal a wider crack quickly [78]. The limitations of the autogenous healing such as inducing re-hydration is, it can only heal the cracks of narrow widths [24, 71]. As an autonomous method, the healing time for the bacteria method is long and should be performed in a humid environment [61] and the bacteria can only survive short period of time in the high alkaline environment [76].

4.2 Two-Stage Mixing Approach

Microstructural and mechanical properties can be increased with the two-stage mixing approach [68]. The same research states the substitution percentage can affect the properties of the mixed concrete, durability, and permeability. Further, two-stage mixing approach can reduce air gaps and hydration products of the recycled concrete aggregate [41] and it improves the nanomechanical properties of the interfacial transition zones (ITZ) and shows 4% of compressive strength improvement than the normal mixing approach (NMA).

4.3 Removal or Strengthening of Substandard RCA

There are several techniques to strengthen the substandard recycled aggregate which contains air voids inside [29]. By removing the adhered cement portions by mechanical grinding or increasing the strength of the same are two of the major techniques, by which the properties of the recycled aggregate can be improved [63]. Corinaldesi [14] states that the recycled aggregate contains between 25 and 60% of cement portions, which reflects the weak microstructural properties of the aggregate [21], pre-soaking in water [30], pre-soaking in acid [69], micro-wave assisted removal of mortar by taking the advantage of variance of electromagnetic properties of the mortar and RCA [2].

The heat grinding process can be performed to eliminate the adhered cement portions of the by exposing aggregate to a thermal treatment process with a temperature of 300 °C followed by a mechanical grinding process. After the thermal treatment process, the substandard cement portions of the aggregate can easily be removed [63]. Nevertheless, most of the masonry waste still goes into landfills [57]. To strengthen the weak mortar, polymer emulsion can be used [12, 32, 62, 83], where the 12% polyvinyl alcohol (PVA) solution gave the optimum results [33].

The aggregate can be submerged in solutions to improve the strength. Sodium silicate solution with different dissolution percentages provides improvements with varied microstructural and mechanical properties [13]. Fly ash or volcanic ash can also be sprayed', to treat the recycled aggregate to make it stronger', as a solution of pozzolan slurry [35].

Diammonium hydrogen phosphate solution can be used to immerse the aggregate to make it denser by the crystal formation inside the air voids of the aggregate as a result of the reaction with the hydration products of the cement particles. The Diammonium hydrogen phosphate solution provides 19% increase in microstructural properties of the recycled aggregate [77].

4.4 Mineral Admixtures

The mineral admixtures of, silica fume, fly ash, ground granulated blast furnace slag and metakaolin, can provide increased microstructural properties to the recycled aggregate concrete [48]. With fly ash, optimum replacement percentage range for concrete is 10–35% for grade M30 concrete and has shown increased properties of compressive strength, flexural strength and workability [9, 65]. For grade 40 mega pascal (MPa) concrete the replacement of 60% fly ash has shown resistance to chloride ion (Cl^-) penetration [72]. The percentages of 7.5 and 25% of silica-fume can be mixed with concrete to have a improved microstructural and mechanical properties for 20 and 40 MPa concrete. However, it improved density properties but decreased properties of workability of the mixed concrete [46, 54, 58]. For the metakaolin, optimum replacement percentage range for the concrete is 10–15% for the grades of 25–70 MPa concrete [10, 38, 50]. For the Ground granulated blast furnace slag (GGBS), optimum replacement percentage range for concrete is 30–40% for the grades of 30–40 MPa concrete and has shown increased compressive, flexural, split tensile, improved density properties but decrease in the workability [3]. The mineral admixtures can be beneficial in improving the properties of the recycled aggregate concrete (RAC). However, when it used in the natural aggregate concrete (NAC) the NAC become the concrete with more improved properties when it compared to the admixture added RAC. That is one of the major limitations of the use of admixtures in the RAC.

4.5 Carbonation of the Recycled Aggregate

Excessive carbon dioxide production can affect the environment where 10% of the total carbon dioxide is produced by the construction activities [55]. Carbon dioxide utilization, carbon capture and carbon storage methods are widely used to minimize the carbon dioxide in the atmosphere [4, 51]. As a treatment method for recycled concrete to increase the microstructural properties, carbon dioxide can be utilized to react with the hydration products of the cement portions to produce calcium carbonate. The same technique can be divided into two major treatment methods, carbon curing and carbon conditioning [23, 45]. Carbon curing is more suitable to treat large concrete blocks and the carbon conditioning is widely performed for recycled concrete aggregate. Structures made with concrete can react with the atmospheric carbon dioxide and calcium carbonate crystals can be precipitated in the outer most layer of concrete; however it can take 20–80 years to carbonate the out most layer with 10–20 mm depth [39]. Widely used carbonation methods include, pressurized carbonation [36, 47], standard carbonation [64, 82], Flow-through CO_2 curing [19, 28, 81] and water-CO_2 cooperative curing [20, 44, 53].

There are many practicality issues related to carbon curing than carbon conditioning [19, 52]. It is difficult to carbon cure large concrete elements such as large beams or slabs as the carbon dioxide will not reach the mid sections of the element and those areas will not get carbonated. Further, exposed concrete surface can get carbonated and can make the outer surface denser and it can prevent the carbon dioxide to reach inner sections of the concrete element. However, the recycled aggregate has more surface area/volume ratio, thereby it can be effectively carbonated with carbon conditioning [31, 73, 80].

4.6 Discussion

The recycled aggregate is a demolition waste which is low in density and weak in strength. Thereby, the re-use of the same is not widely adopted across construction industry and it is necessary to improve the aggregate to enable it for wider adoption. Several methods have been implemented by the researchers to improve the recycled aggregate.

The self-healing consists of re-hydration, bacterial and micro encapsulation, sub-methods. The bacterial methods produces calcium carbonate, re-hydration method hydrates unhydrated cement particles where it forms crystals to increase density and micro-encapsulation by which releases a chemical to fill the cracks and same improves the density. All the self-healing methods have a major advantage of automatic healing when the crack occurs in the concrete, but it also has disadvantages of bacteria need ideal environmental conditions to survive, need high humid environment, the number of bacteria which can survive in high alkaline environment is limited, bacteria cannot be mixed with concrete directly, and for micro-encapsulation method, when the capusule count increases the density of concrete can affect.

Two-stage mixing provides density for the recycled aggregate concrete mix instead of providing density to the recycled aggregate without adding or removing any mortar of the recycled aggregate, but the mixing temperature can have an effect of the density. Removal of weak mortar parts is a fast method to increase the density of the aggregate. However it involves expensive and specialized equipments, specialized labour and high energy cost to perform the removeval. Further it creates another waste stream with removed weak mortar. Strengthening of weak mortar layers of recycled aggregate is a relatively fast method to improve the density and no waste mortar materials are produced. Thereby, additional cost savings can be achieved than the removal of weak mortar method. However, identifying of low cost chemicals to strengthen the aggregate can be a difficult task.

Mineral admixtures can be readily added to the recycled aggregate concrete mix and the Improvement speed is high. However no competitive advantage to recycled aggregate concrete compared to admixture added conventional concrete. For an instance, if the admixture is added to the convensional concrete, it aslo will increase it's strength, thereby, no unique compettive advantage of this method. Carbon-curing, carbon conditioning and other CO_2 carbonation approaches can successfully carbonate high area/volume recycled concrete aggregate. However it is impractical to carbonate large concrete members which have low area/volume ratio, as outer most

Table 1 Comparison of treatment methods

Method	Advantages	Disadvantages
Self-healing methods and approaches—re-hydration, bacterial and micro-encapsulation	Automatically healing without any special intervention to heal the cracks	Bacteria need ideal environmental conditions to survive, need high humid environment, limited number of bacteria which will survive in high alkaline environment. Bacteria cannot be mixed with concrete directly, many capsules in the concrete, can affect the density
Two-stage mixing approach	Provides density increments by sequential mixing without any addition or removal of mortar	Temperature can affect the density improvement
Removal of weak parts or weak mortar layers of recycled aggregate	Relatively fast method to improve the density	Waste mortar material produced creates new waste stream, involves specialized machineries and labour to remove the weak mortar parts. High energy cost
Strengthening of weak mortar layers of recycled aggregate	Relatively fast method to improve the density, no waste mortar materials produced	Difficulty of identifying low cost and effective chemicals to improve density
Mineral admixtures	Can be readily added to the recycled aggregate concrete mix. Improvement speed is high	No competitive advantage to recycled aggregate concrete compared to admixture added conventional concrete
Carbon-curing, carbon conditioning and other CO_2 carbonation approaches	Can successfully carbonate high area/volume recycled concrete aggregate	Impractical to carbonate large concrete members

layer of aggregate get's carbonated and prevents CO_2 to penetrate into deeper areas of the concrete block, which renders the treatment process not effective for large concrete blocks. Table 1 shows the summary of the advantages adnd disadvantages of each method.

5 Conclusion

This paper anlyzed various kind of methods which have been implemented by the researchers to improve the recycled aggregate. Under the self-healing category, the bacterial methods produces calcium carbonate, re-hydration method hydrates unhydrated cement particles where it forms crystals to increase density and micro-encapsulation by which releases a chemical to fill the cracks and same improves the density. Two-stage mixing provides density for the recycled aggregate concrete mix instead of providing density to the recycled aggregate without adding or removing any mortar of the recycled aggregate, the removal of weak mortar parts is a fast method to increase the density of the aggregate. However it involves expensive and specialized equipments, specialized labour and high energy cost to perform the removeval. Strengthening of weak mortar layers of recycled aggregate is a relatively fast method to improve the density and no waste mortar materials are produced. Thereby, additional cost savings can be achieved than the removal of weak mortar method. However, identifying of low cost chemicals to strengthen the aggregate can be a difficult task. Mineral admixtures can be readily added to the recycled aggregate concrete mix and the Improvement speed is high. However no competitive advantage to recycled aggregate concrete compared to admixture added conventional concrete. Carbon-curing, carbon conditioning and other CO_2 carbonation approaches can successfully carbonate high area/volume recycled concrete aggregate. However it is impractical to carbonate large concrete members which have low area/volume ratio. This paper provides an insight into advantages, disadvantages and identifying knowledge gaps.

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Environmental Impacts for Recycled Aggregate Concrete by Adopting Life Cycle Assessment (LCA)

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Abstract The awareness of sustainability has emerged over the last few decades and been applied to different fields, including construction sector. However, some barriers exist incontestably hinder the movement of it, such as manufacturing of virgin aggregate concrete (VAC). Trying to cut down the greenhouse gas (GHG) emitted from the conventional concrete, recent research presents the interests on the replacement of virgin aggregate (VA) with recycled aggregate (RA). The advantages of RA replacement are well recognized, whilst the prerequisites for its usage should be considered are that the technical adequacy and the environmental acceptability. Having successfully proved by previous scholars that recycled aggregate concrete (RAC) processes, the comparative strength to the conventional concrete, its environmental impacts throughout the lifespan are still uncertain. Therefore, this study aims to identify how RAC influence the environment through reviewing previous articles by using life cycle assessment (LCA) approach, including cement content, transport distance, mixture design, and parameters involving in LCA stages, and LCA software. These factors and parameters lead to the limitations of current LCA accordingly. Despite that, a general conclusion can be made that RAC is beneficial to the environment.

Keywords Construction and demolition waste · Environmental impacts · Life cycle assessment · Recycled aggregate concrete

1 Introduction

Concrete is versatile and by far the most widely used construction material globally. It is reported that between 13 billion tons and 25 billion tons of concrete are produced

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annually to serve the construction industry needs [1, 2]. Such a huge demand on concrete consumes about 37.5 billion tons of VA each year in the estimated growth rate of 5% [2–5]. It truly promotes the socio-economic development; however, the broad use of the VAC seems go against it when the scope of sustainable construction is considered. The manufacturing of VAC causes the tremendous quantities of GHG emission, energy consumption, raw material depletion, and waste generation [2, 5, 6]. Hence, seeking a way for sustainable construction to decrease the raw material utilization and the reverse environmental impacts is an urgent issue to be addressed.

Another issue existing in construction industry is massive construction and demolition (C&D) waste produced but ineffective management strategies implemented. C&D wastes can be served as the resources and save the huge amount of energy if managed properly [7, 8]. But the quantity of indigenous C&D waste generated and recycled reported by various countries and regions reveals that its recycling is still in the fundamental level, for example average 55% [7] in Europe, 43% [9] in Australia, 5% [10] in China and nearly 0% [7] in Africa. An immense potential and value from C&D waste stream can be therefore extracted if recycling and reuse approaches are utilized in the waste management.

It is widely claimed that a majority of C&D waste stream is from concrete products [6, 11, 12]. Aware of the benefits of recycling C&D waste, one of the recycled materials, RA, has been reused as road-base filler material [12]. Nowadays the possibility of using RA for construction purposes to manufacture the RAC is extensively explored [11, 12]. Numerous studies have testified RAC could possess the comparative mechanical properties to the conventional concrete manufactured by VA, and advanced techniques applied to its manufacturing process successfully enhance its durability [13–15]. Nevertheless, the sustainable development potential of a material is more than its functionality and technical adequacy; the environmental footprint, and economic viability are also significant [4, 6, 16].

As a result, this research aims narrowly to review the environmental performance of RAC by comparing the change of environmental indicator values from the different studies which adopt LCA approach. Additionally, the factors and parameters influencing LCA results of RAC are identified, and the limitations of current LCA studies are summarized to assist to the further LCA model building and calculation.

2 Research Methodology

The research methodology is basically the up-to-date literature review. The range of bibliography reviewed includes the research papers published in international journal and conference proceedings, technical reports, and academic dissertations. The scope of the review is to assess the environmental behavior of RAC against VAC through using LCA approach, and find the limitations along with the current LCA studies. The keywords LCA, concrete, RAC, sustainability, environmental performance and their combinations are applied to the online database such as Science Direct and Scopus to search for the matched articles. In addition, more terms related to RAC such as C&D waste, RA and building are encompassed in the search as well. After the filtering process for the article title, keywords and abstract, 107 papers in total are reviewed in depth. Thereby the factors and parameters influencing LCA results regarding RAC product are summarized, and limitations of current LCA studies are investigated. Among the papers reviewed, 8 research journal articles are selected since their research are consistent with the functional unit (FU), system boundary, and the environmental impact indicators, therefore to compare the environmental performances between RAC and VAC.

3 Life Cycle Assessment for Recycled Aggregate Concrete

It is well recognized RAC products brings the environmental benefits compared to VAC [12, 16, 17]. Unfortunately, research on LCA of RAC is limited, although the scholars show the good interest in the topic. LCA approach as a decision-making tool is complicated which results are greatly influenced by various parameters, for instance selection of FU, system boundary, and input data quality. In addition, subjective factors such as misunderstanding of life cycle methodology and limitation, and a lack of incentive or motivation to use such approaches restrict its implementations to the critical evaluations of a material or technology [18]. Owing to aforementioned reasons, the environmental evaluations of RAC by adopting LCA approach are strategic issues but of challenges.

Among the available literatures, comparative analysis of LCA between VAC and RAC is the predominant form to illustrate the benefits obtained from the substitution of RA to conventional concrete products. Majority of studies concentrate primarily on the environmental assessment through adopting normalized life cycle impact assessment (LCIA) methodologies, in which the performance of VAC is regarded as the reference to judge the effects of RAC. In general, these studies adopt the process-based LCA approach, quantifying all the material and energy inputs, and waste and emission outputs for a given system boundary in manufacturing a concrete product. Such an LCA framework can be seen in Fig. 1. The rest employs either economic Input–Output (I-O) based LCA or hybrid LCA approach; however more assumptions and subjective choices are involved in the approaches which may lead to the higher variance and uncertainty in the results.

From the previous investigations, the results of the environmental footprint on RAC over VAC are either positive or negative, but the most scholars confirm the potential of RAC regarding to its environmental performance. Table 1 summarizes the comparative results of RAC against VAC in some representative environmental indicators from various research. In these studies, all the RAC products included in the table are manufactured without the presence of other supplementary cementitious materials (SCM), aiming to diminish the inconsistency of LCA results.

According to Table 1, it should be noted that only the study of Marinkovic et al. [21] in 2010 presents the completely larger environmental impacts of RAC of VAC,

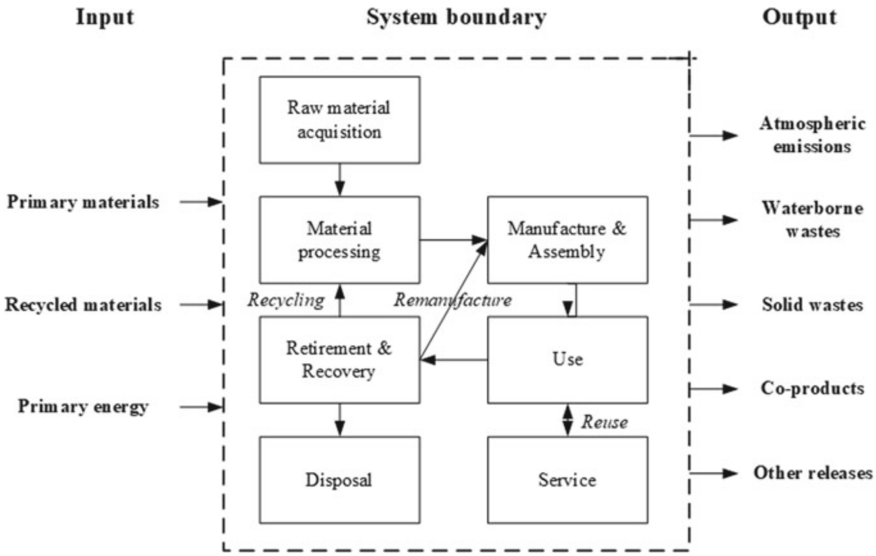

Fig. 1 Example of framework to conduct LCA for RAC

whereas other comparative studies prove the benefits obtained from the manufacturing of it to some extent. The main reasons contributing to the undesirable result of Marinkovic et al. [21] are that about 5% more cement is added to RAC mixture for inferior quality offset, and typical transport distance of RA in different regions varies significantly. Later research has gained the comparable mechanical performance of normal strength RAC with VAC without adding extra cement, further strengthening its advantages in the environmental behavior [5, 17]. As a result, referring to Table 1, it may claim that the utilization of RAC is capable to reduce ADP and ODP in comparison of the manufacturing of VAC. In addition, the environmental indicators such as EP, POCP and energy consumption normally present the declined trend. The increase of AP in the study conducted by Serres et al. [14] is largely attributed to the implementation of superplasticizer rather than the substitution of VA to RA. Besides, RAC is remarkable on human health and ecosystem based on reductions of other environmental indicators.

However, the most controversial point lies in the contribution of RAC to climate change, since some of scholars present its great reduction on GWP based on VAC behavior whilst up to 29% increase of GWP is observed by other study. The main contributor of climate change is GHG emission, which is closely connected to the energy use. Considering the difference of manufacturing process between RAC and NAC, one reasonable explanation is that the process of RA induces more operations such as crushing and removal of contaminants, which in turn consumes considerable energy than extraction of VA.

Nevertheless, a consensus achieves that cement content is the biggest contributor to the environmental impact of concrete, whatever types of concrete are tested [3, 5,

Table 1 Comparative analysis of RAC against VAC by LCA approach

Article	Comparative results of RAC against VAC in each indicator (max impact %)							
	ADP	AP	EP	GWP	ODP	POCP	Energy	Others
Knoeri et al. [19]	34%↓			5%↓				Eco-indicator 99: 31%↓ Ecological scarcity 2006: 30%↓
Serres et al. [14]	47%↓	42%↑	43%↓	25%↓	44%↓	50%↓	42%↓	Air pollution: 47%↓ Water: 33%↓
Turk et al. [6]	13%↓	13%↓	12%↓	4%↓		20%↓	11%↓	
Braga et al. [20]				25%↓			30%↓	
Marinkovic et al. [21]		14%↑	21%↑	11%↑		37%↑	22%↑	
Kim et al. [22]	16%↓	28%↓	29%↓	29%↑	28%↓	9%↓		
Yazdanbakhsh et al. [11]		4%↓	3%↑	4%↑	7%↓			Smog formation: 7%↓ Human health: 2%↓
Ding et al. [3]				6%↑			3%↑	Mineral resource: 44%↓

Note 1 ADP Abiotic depletion potential; *AP* Acidification potential; *EP* Eutrophication potential; *GWP* Global warming potential; *ODP* Ozone depletion potential; *POCP* Photochemical ozone creation potential
Note 2: ↑ is the increase rate, and ↓ represents the reduction rate based on the environmental performance of VAC

14, 20, 21]. It should account for 87–96% to the GHG emission caused by concrete varying from different studies [6, 14]. Also, transport distance is an important factor, usually considered as the next provider, which leads to 4–45.35% of the environmental burden from concrete [2, 13, 21, 23]. Various scholars have examined the sensitivity of transport by different scenarios. It normally shows the high sensitivity associated with the change of environmental footprints and energy consumption, for instance additional 15 km transport for RAC will increase the loads of GWP over VAC [19]; 76.82 km is the critical transport distance that use of RAC was beneficial than VAC [23]; and the extension of transport from 15 to 100 km could lead to 30% more on environmental impacts [21].

Furthermore, scholars also explore the strategies to improve the environmental potential of RAC. Since cement is the major factor against to the better environmental performance of RAC, cutting down the ratio of cement content is being broadly discussed. The common method is to cooperate SCMs with RAC mixture, which has been tested to be effective by Turk et al. [6] and Kim et al. [22]. For example, a type of RAC combined with fly ash yields its impact to about 65% of VAC, and the sensitivity regarding the transport distance is much lower in the meantime [6]. Besides, recycling of C&D waste instead of landfilling for producing RA generates the great savings of energy, in combination with the recovery of co-products from the recycling process, bringing up to 70% more environmental benefits accordingly [11, 19]. Also, limiting the transport distance of RA within the critical distance is essential. The present of mobile recycling plant helps immediately deal with C&D waste and reduce the transport distance.

4 Discussions

4.1 Factors and Parameters Influencing LCA Results of RAC Products

Cement and transport distance are two critical factors highly affect the LCA results, as stated in the previous section. Except for them, concrete mixture design in the manufacturing of RAC products influences the final result, although it only account for a small part of environmental burden compared to cement content and transport issue. Generally, scholars carry out the mixture design of RAC from that of VAC by simply replacing VA with RA without considering the change of concrete structural properties. And there is obvious that higher replacement ratio of VA with RA generates the better environmental impact results of RAC compared to VAC. Fully RA replacement seems the best solution in the perspective of environment, but the mechanical properties of such concrete products are seldom regarded to be practical for structural purpose enough. Current experimental outcomes still suggest that the RA replacement ratio should be limited to 30%, and fine RA ought to be avoided in use to keep the structural properties of concrete products [21, 24].

Besides, LCA approach itself contains numerous parameters having effects on LCA interpretation. Firstly, in the goal and scope, the determination of FU, system boundary, and data requirements for life cycle inventory (LCI) is a vital step for an LCA study. Majority LCA is structured around FU by volume or weight, as there is no universal FU selection standard when assessing the environmental behavior of RAC. Yet, such a simple FU is more likely to be flawed, causing the failing of strength and workability of concrete; strength, durability and strength reliability are therefore taken into account. Further, most of scholars employ cradle-to-gate as the system boundary of LCA study, however the unit processes shall be included vary greatly in different studies. For example, the ability of RAC on carbon dioxide (CO_2) absorption is usually neglected in the determination of system boundary, while the exclusion of carbonation process can lead to as much as 48% overestimation of net CO_2 emission [2].

In the stage of LCI, all the necessary data for the elementary flow from possesses involved in the product are measured and collected, which is the most time-consuming phase of LCA. Site-specific data is preferable but, in most cases, national database and global inventory database such as Ecoinvent are applied when site-specific data of raw material cannot be accessed to. Wide discrepancy is therefore detected from different LCI sources owing to different geographical locations, reducing the reliability of LCA results to RAC. What is more, approaches to construct the inventory may result in the variance. Process-based LCA is a bottom-up approach, itemizing the inputs and outputs associated with elementary flows. I-O-based LCA is top-down approach to evaluate the economy-wide environmental burden of target materials, which utilizes economic I-O matrices in combination with environmental and nonrenewable resources consumption data from the industry. Hybrid approach integrates the accuracy of process-based approach with the comprehensiveness of I-O-based LCA, hence the truncation error is prevented. Table 2 compares the strengths and weaknesses of each approach according to their characteristics. By adopting the different approach, the data input method and values to LCA model changes, which eventually influences the measurement of environmental impacts for RAC.

The LCIA methodology selection is also significant to the interpretation of LCA results. The information from LCI on elementary flows is transferred to the environmental impacts by selection of impact categories, classification, and characterization, whereas normalization, weighting and grouping are optional. For example, according to the results generated from the study of Knoeri et al. [19], different LCIA methodologies considering the same range of environmental impacts are able to generate the varied results. It actually results from the different weighting values distributed to the environmental indicators in each methodology.

The last factor inducing the variation of LCA result that should be noticed is LCA software employment. Due to complicated processes and flows involved in the analysis, a software, which supports the users to carry out a convenient and efficient unit process connections, data inputs and outputs, intermediate result calculations, and error checks, is necessary. The mainstream LCA software system well recognized by both academia and industry are GaBi and SimaPro. Both of them contain

Table 2 Comparisons of characteristics among different LCA approaches

LCA approach	Strengths	Weaknesses
Process-based approach	The precise results can be obtained from clearly defined unit process	Truncation error may occur Inventory cut-offs may introduce significant biases into the results
I-O-based approach	Truncation error can be avoided Cut-offs can be prevented by offering the full inventory of emissions	Aggregation error may occur Homogeneity and linearity assumptions
Hybrid approach	Integrating the advantages and reducing the disadvantages of above two approaches	Different subjective choices significantly affect the results

a broad quantity of features in common. Nevertheless, GaBi employs a sequential calculation algorithm to calculate each process load following the sequences of unit processes the user defines. Multiple products can be linked to a unit process, and these processes enable to demarcate the system boundary of the model. SimaPro, on the other hand, allows the user to generate all the processes in one calculation by adopting Monte Carlo analytical capabilities and customized parameters in a matrix inversion. It even has an ability to determine the potential environmental impact that a system or service produces with statistical accuracy. As a consequence, different calculation mechanisms behind the LCA software can make a big difference for the LCA interpretation, of which the claim has been illustrated by several authors [25].

4.2 Limitations of Current LCA Studies

Most of scholars select the unit volume or weight of concrete products as FU to carry out their research, while it is not necessarily the primary function of the product. Such a simple selection of FU may contribute to the incomparable mechanical and durability performances of products assessed, whilst comprehensive FU involving various parameters seems unrealized. Having been investigated the advantages and disadvantages of each possible FU, finding out a proper FU that could satisfy all the requirements is the difficult task [7].

Due to the hardship in local LCI data collection and unit process defining, scholars prefer standard LCI database and cradle-to-gate phase to assess the sustainability of concrete rather than specific data and its whole life span. Actually, the ideal LCI should be based totally on site-specific data examined by relevant stakeholders, thereby the accuracy of LCA results would be promised. Despite that, the life cycle of RAC consists of vast numbers of unit processes, it is unrealistic to collect all the information and data required to develop LCA model.

Further, the interpretation depends on the LCIA methodology and LCA software selected, which in turn affects the choice from decision-makers, having been proved by numerous researches. These methodology and software have their own criteria and major focuses, which cannot cover all the aspects regarding the sustainability assessment of the product. Therefore, limitations subjected to LCIA methodology and LCA software are inevitable when conducting the LCA study.

The most conspicuous and urgent to be addressed point identified from the literature is the lack of comprehensive evaluation of RAC from its sustainability aspects. All the previous researches focus partially on sustainability performance; however the separate and fragmentary analysis cannot truly reflect the characteristic of the product. Besides, all the different selections of parameters mentioned above enlarge the inconsistency of results. These leads to the weak trust of construction industry on RAC applications. Accordingly, the comprehensive and entire life cycle sustainability assessment should be considered in the further research to fulfil the sustainable evaluation of RAC and help to compare the results in the same standard. With such a consolidated assessment criterion, the advantages of RAC against VAC will be more obvious and recognized.

5 Conclusion

Based on up-to-date research in the field of RAC, its mechanical and durability performances can be comparable to conventional concrete products, thus suitable to structural purposes to some extent. But the environmental potential of RAC products has not been fully discussed. Therefore, it leads to the aim of this study that evaluate the environmental performance of RAC by LCA.

Through conducting a comparative analysis of RAC and VAC in terms of several environmental impact indicators, a general conclusion that RAC has a greater potential to reduce the environmental impacts than VAC can be made. In the life cycle perspective, cement content and transport distance are two critical factors affect the environmental behavior of RAC significantly. Moreover, there are several more factors and parameters, such as mixture design, FU, system boundary, LCI data collection, LCIA methodology and LCA software will influence the LCA results. As a consequence, such a complicated system determined contribute to various limitations of the current LCA studies. These factors and parameters should be integrated considered in the further research, attempting to generate the comprehensive LCA model to fulfil the sustainability evaluation of RAC.

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Green Building Clusters for Residential Developments: Developing District Cooling Systems

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Abstract Green building is widely discussed in may research arenas. There are millions of ways in developing and achieving "green status" using various green building rating tools. The main aim of green buildings is to design and construct environmentally, socially and economically sustainable buildings to reduce the negative impacts on the environment and the society as a whole. However, the real question is whether implanting one-off green building can face this challenge. Green buildings need to be integrated to the society and the cities. Even though integrating cities, into this concept is a long way ahead, this research aims to explore the possibility of developing green building clusters for mega residential projects in Australia. This paper presents a preliminary desk study of the proposed project. Currently there is an exponential growth in residential building developments within Australia. Therefore, this research identified the potential methods such as "district cooling system" as one of the resource sharing techniques among green buildings cluster in residential developments. District cooling system is one of such initiative used in Middle Eastern countries for residential developments where cooling is essential for most parts of the year. However, this is not widely used in Australia. This research study carried out a cost–benefit analysis based on a case study project. The research study reported that developing district cooling system is positive for energy savings and

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life-cycle costs, yet there are many challenges. Combining renewable energy sources into district cooling systems is one of the future directions identified.

Keywords Clusters · District cooling · Green building · Renewable energy

1 Introduction

There are many environmental and energy issues faced by many countries. Currently there is an increase in the carbon dioxide in the atmosphere posing many threats [5]. In particular, the energy generation using fossil fuels is one of the major contributors in discharging greenhouse gases (GHG). According to various studies, building sector consumes around 40% of the total energy produced and it is responsible for a major portion of the greenhouse gas (GHG) emissions [9]. A significant share of this energy consumption is used for cooling and heating purposes. District cooling system (DCS) can be used to provide the necessary cooling comfort in residential, industrial and commercial buildings because of its low cost and high energy efficiency [9].

Usually in commercial buildings, there are two types of air conditioning systems namely (1) Direct Expansion and (2) Chilled Water. The chilled water systems adopt a single central chiller plant which uses water heat transfer fluid in the buildings, of which the temperature is typically lowered to 6 °C, and supplies water at this temperature to all fan coil units [6]. The DCS use a chilled water system. It has a Central Energy Plat (CEP) which is the centralised plant for district cooling. When developing a DCS, there are three steps to follow; (1) estimating the cooling load; (2) performance prediction of the district cooling network; (3) optimization of the cooling production plant [4]. Further, it is essential to develop optimised DCS to derive fruitful benefits. An optimal design and well-scheduled DCS is crucial for the success of cooling plant(s) are intended to be connected to a group of newly-built consumers [11]. The discrepancy between the designed capacity of the cooling system and actual cooling demand usually negates the intended benefits if the DCS is not optimised.

With increasing cooling demands, DSC plays an important role as it is more efficient than stand-alone cooling systems by reducing environmental impact and promoting the use of renewable sources [13]. DCS has many environmental benefits and it shares the resources with a widespread community. The feasibility of DCS is linked to its efficiency, which is associated with the capital and operational costs [12]. Usually, the DCS replaces stand-alone air-conditioning devices and pave the way to share the air-conditioning facilities across larger number of buildings and even hundreds of residential units. In a study to compare DCS against rooftop unit (RTU), and variable refrigerant flow (VRF), Alajmi and Zedan [1] mentioned that DCS shows a reduced peak demand by around 50% and 49%, in addition to a less annual energy consumption by 55% and 18.4% compared to RTU and VRF systems, respectively. However, this calculation was carried out for low rise residential buildings.

These figures on reduction in peak energy demand and reduction in annual energy consumption strengthens that possible cost savings from DCS on larger scale.

Alghool et al. [3] mentioned that there is a possibility to combine solar thermal energy and cooling. It appears to be an exciting alternative to replace traditional electricity-driven cooling systems where electricity is generated from fossil fuels. Nevertheless, solar assisted cooling is not yet widely deployed because of many barriers amongst them the presumed high investment cost of solar cooling technology [3]. Similarly, there are many studies focusing on combining renewable energy sources to DCS. Hsu et al. [8] carried out a study combining waste heat recovery with DCS. Eveloy and Ayou [7] also highlighted the need for sustainability enhancements for DCS.

With the continuous increase in demand for energy especially for air-conditioning in commercial buildings, DCS has been a worthy solution. It derives many benefits, yet not widely researched. Combining renewable energy with DCS is another approach worth investigating. Therefore, this paper explores a cost benefits analysis considering a case study DCS. This forms a preliminary desk study of a research study focusing on integrating green building to green cities.

2 Research Methodology

This paper presents a preliminary desk study of a research focusing on developing green building clusters to integrate it with the green cities. There are several strategies proposed and DCS is one of the proposed strategies to look into green cities. Therefore, this paper carried out a cost benefits study focusing on a case study DCS at James Cook University in Townsville.

2.1 Case Study: James Cook University, Townsville

James Cook University has a district cooling system to provide the cooling requirements to all 28 academic buildings within its Townsville campus. The project reduces electrical demand and thus operating and transport costs, greenhouse gas emissions and maintenance, and provides the university with new refrigeration plant that has a projected economic life of 30 years [6]. Hereinafter this paper presents a preliminary cost benefits analysis of this DCS as the first step in analysing the feasibility of proposed green building clustering concept. All the details on the case study is obtained from the Green Building Design Guide [6].

2.2 DCS at James Cook University—Overview

The university spans through 5 ha of distributed campus with 28 academic buildings with a total air-conditioned floor area of 69,000 m^2. Previously the University had chillers which were in poor condition (up to 35 years old) with the majority requiring replacement at an estimated cost of $9M. The existing plant capacity totals approximately 11.5 MW of cooling in 29 locations around the site. However, the University had a rigorous plan of expansion over the coming years, so it was decided to construct a DCS to air-condition the 28 buildings including the proposed new spaces.

As illustrated in literature, this plant also uses a CEP. Further, Thermal Energy Storage (TES) makes use of periods of the day or night when the site demand for cooling is less than the average demand, by running central chilled water plant during these times to chill return water (from 15 °C) back to chilled water (at 6 °C). This is the system adopted in the case study.

3 Cost Savings and Benefits from DCS

This case study reported may cost benefits. Table 1 summarises most of the cost savings from the DCS at James Cook University.

According to Table 1, there are many cost savings and benefits from the DCS. Reduction in maintenance costs and operational costs are the significant benefits. Reduction in GHG emissions can lead to certain costs savings in future. There are also social benefits such as reduction in noise pollution and increase in reliability.

4 Other Costs, Challenges and Way Forward

There is a higher fixed cost for this project. This is one of the drawbacks, yet it derives significant cost savings (refer Table 1). TES is another requirement in DCS system. This also has a significant fixed cost. According to Alghool et al. [2] a chilled water tank with a capacity varying from approximately 998,786–2,707,977 kWh ranges from $626,600–913,000. Further, DCS system includes high efficiency chillers, primary and secondary chilled water pumps, condenser water pumps and several cooling towers. The whole system requires a considerable space. This is one of the challenges. For an example, if this is proposed at a high-density area, finding the required space would be a challenge. Further, if the cost of land per square meter should be higher than the cost savings per square meter for the DCS to be feasible. Shi et al. [12] also mentioned that block area block elongation has a major impact on DCS. Further, Shi et al. [12] proposed that Urban designers may apply these findings when designing street grids for efficient DCS in high-density cities.

Table 1 Cost savings and benefits from DCS

Details	Quantification	Comments
Savings on replacement costs of existing chiller	Approximate cost of $9Mn	Further to the replacements, the University had to expand the chillers due to the proposed expansion project. However, this figure only represents the replacement cost of existing chillers only
Maintenance cost of chillers		The chillers required separate maintenance costs regularly. There were several chillers, so there were higher maintenance costs included. Maintaining the central chiller in DCS is cost effective compared to separate chillers
Reduction in electricity operating costs	The reduction is approximately around 30%. Previously electricity cost was $3,200,000 and after the DCS it was $2,260,000, with a saving of $940,000 pa	
Reduces greenhouse gas emissions	Reduced greenhouse gas emissions attributable to the University from 43,000 to 31,000 t, saving approximately 12,000 t CO_2 per year	
Improved system reliability		This is a non-quantifiable benefit. The DCS has an economic life of 30 years and there is a higher system reliability
Reduction in noise pollution		This is due to the reduction in multiple air-conditioning plants

Data source [6]

Another challenge discussed in the literature is the temperature difference in supply and return water. Jangsten et al. [10] mentioned that potential solutions to resolve this issue include adjusting the supply temperature setpoint on the secondary side, restricting the flow on the primary side; providing economic incentives for the district cooling customers and ensuring compliance with the design guidelines.

One of the main concerns discussed in the literature is GHG emissions by energy generation. The DCS reduced the GHG to a certain extent, yet there are ways in which the GHG can be further reduced. Inayat and Raza [9] proposed renewable energy for DCS system. According to Inayat and Raza [9] there are several options namely, DCS via biomass, DCS via solar thermal, DCS via geothermal, DCS via solar PV, DCS via surface water and DCS vis waste heat energy. DCS operated with renewable energy resources is undoubtedly the future energy solution and also the environmental solution [9]. This approach also coincides with the green building clustering approach.

5 Conclusions

This research is a preliminary desk study on the DCS for buildings. In this research the researchers analysed the costs and benefits of the using DCS considering a case study at James Cook University. DCS derives many benefits including costs savings via reduction in operating and maintaining costs through the life-cycle. However, it has its own challenges. DCS system requires a considerable space and also a it has a high fixed initial investment. The way forward to maximise the benefits in DCS is to combine it with a suitable renewable energy source. There are several renewable energy sources that can be linked with the DCS. A feasibility study on combining a renewable energy source to DCS is one of the future research directions.

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An Overview of Freeze and Thaw Cycles Affecting the Durability of Recycled Aggregate Concrete

V. W. Y. Tam, A. C. J. Evangelista, and M. Soomro

Abstract Exposure to severe temperatures is one of the critical effects on concrete damage. Additionally, the aggregate porosity (pores in the range of 0.1–0.5 μm) is the characteristic that influences freeze–thaw resistance due to the pore saturation resulting in the concrete deterioration. Freeze and thaw is a durability property which is the volumetric contraction and expansion of hardened concrete caused by abrupt temperature change in cold climes resulting in micro or macro cracks. The mechanism results in internal stresses, such as hydraulic pressure; osmotic pressure and pressure induced by the growth of crystals in pores and their interaction with pore walls. Additionally, this process causes internal relative humidity gradients within the cement paste matrix which leads to the reduction in concrete volume, i.e. drying shrinkage. The main aim of this study is to review the literature on procedures to evaluate freeze and thaw resistance of cycled aggregate in concrete, and some discussion on the treatments to enhance its durability has been included. The most relevant and cited paper in the Scopus and Web of Science databases were analysed to identify the effective treatments and mitigation processes to improve the resistance of recycled aggregate concrete under freeze and thaw cycles.

Keywords Recycled concrete · Durability · Freeze–thaw cycles

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1 Introduction

The interest in the utilisation of more sustainable materials in concrete and the economic benefits of the use of recycled aggregate concrete (RAC) has motivated extensive research for over two decades. However, due to uncertainty of the durability of RAC, if it can withstand the external environmental effects and internal chemical reactions, its applications in structural concrete are currently limited.

Depending on the grain size, the volume of relatively soft and porous residual mortar on the grains of recycled aggregate (RA) vary from 20 to 60% due to which the physical and mechanical properties of RAC could be inferior compared to virgin aggregate concrete (VAC) [8, 10]. The porous nature of this residual mortar is responsible for high water absorption, i.e. about 2–3 times higher than virgin aggregate (VA) [5, 11, 20, 23].

The service life of the concrete structure depends on its durability factors. Permeability is one of the most critical factors that deteriorates concrete by mass transport of gases, liquids and ions through these pores and their interactions with the cement hydration products and pore water thereby altering the integrity of RAC directly and/or indirectly, deteriorating the structure.

This paper aims to review the literature on procedures to evaluate freeze and thaw resistance of recycled aggregate in concrete, and some discussion on the treatments to enhance its durability. The Scopus database was used in order to elaborate the main outcomes. Combining the main keywords "freeze–thaw" and "recycled aggregate concrete" the search brought 1040 documents within the years 1998 to 2021 (see Figs. 1 and 2). This overview focuses on the most cited papers of the past 10 years.

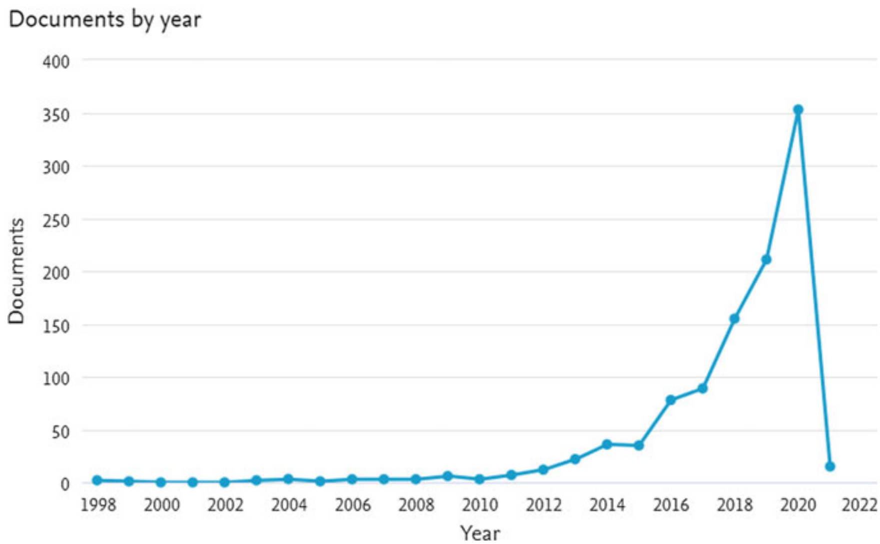

Fig. 1 Timeline of publications: RAC and freeze and thaw resistance

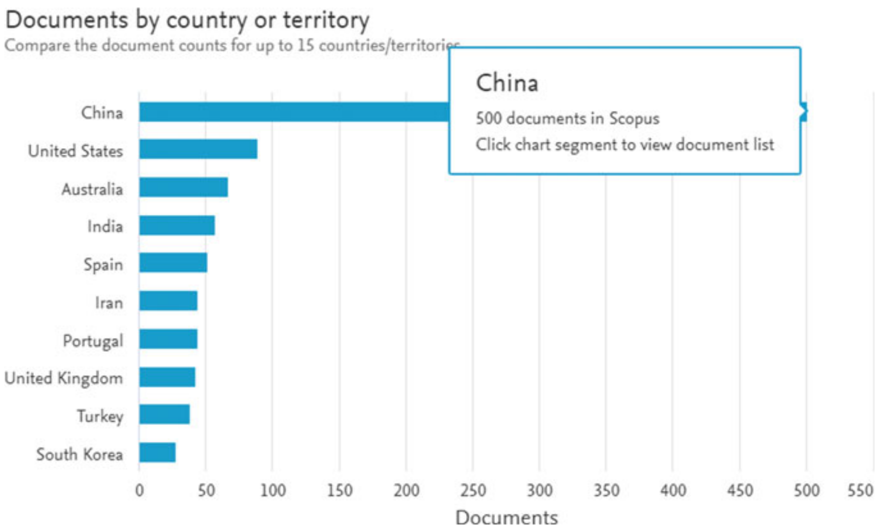

Fig. 2 Publication numbers by countries

2 Procedures to Investigate Freeze–Thaw Effects on RAC

Exposure to severe temperatures is one of the critical effects on concrete damage. Additionally, the aggregate porosity (pores in a range of 0.1–0.5 μm) is the characteristic that influences freeze–thaw resistance due to the pore saturation resulting in the concrete deterioration [16]. Freeze and thaw is a durability property which is the volumetric contraction and expansion of hardened concrete caused by abrupt temperature change in cold climes resulting in micro or macro cracks [15]. The mechanism results in internal stress, such as hydraulic pressure, osmotic pressure and pressure induced by the growth of crystals in pores [7, 15, 17]. This process induces internal relative humidity gradients within the cement paste matrix, which leads to the reduction in concrete volume, i.e. drying shrinkage.

Medina et al. [15] studied the durability of recycled concrete made with ceramic aggregate (20 and 25% of industry waste ceramic sanitary ware). Freeze–thaw resistance was assessed by weighing the scaled particles after 7, 14, 42 and 56 freeze–thaw cycles as described in the European standard CEN/TS 12390-9 EX. According to the microstructure analysis, after 56 freeze–thaw cycles, the three types of specimens exhibited much the same appearance. The main types of damage included: (a) aggregate detachment, (b) surface deterioration of the coarse aggregate, and (c) ITZ de-bonding. Recycled concrete is more freeze–thaw resistant than conventional concrete, as the cracks are narrower and the scaling rate is lower. Both effects are accentuated with the rising replacement ratios of RA.

Lei et al. [13] investigated a novel testing protocol (coupling protocol) with separated repetitive loading and freezing-thaw cycles in salt-solution aiming to evaluate the durability and deterioration of RAC (at 100% replacement). The authors used

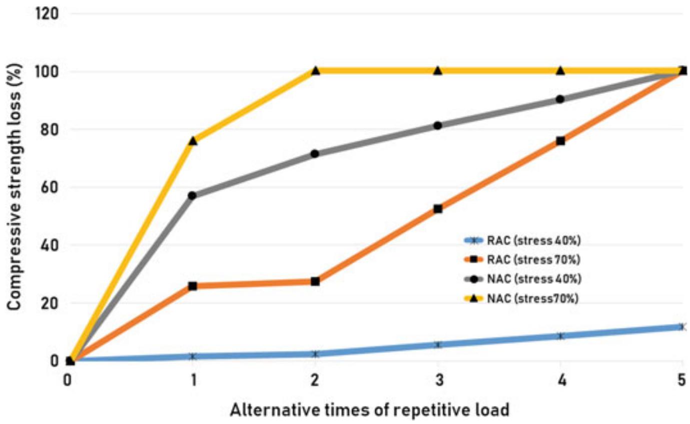

Fig. 3 Comparison on compressive strength loss after coupling protocol with different alternative times of repetitive load [13]

three methods for coupling experiment of cyclic loading and freeze–thaw cycles in salt-solution, such as, one alternative time of repetitive loading and 50 salt solution freeze–thaw cycles (Protocol 1); two alternative times of repetitive loading and 25 salt solution freeze–thaw cycles (Protocol 2) and five alternative times of repetitive loading and 10 salt solution freeze–thaw cycles (Protocol 3). In general, the principal outcomes indicated that the compressive strength of NAC after two or five freeze–thaw cycles became lower than that of RAC. Also, after freeze–thaw cycles in salt-solution, the decreasing rate of microhardness value of ITZ for NAC was higher than that of RAC. In order to evaluate the effect of stress level, the authors plotted compressive strength losses of RAC and NAC against the alternative times of repetitive load. The results showed that the compressive strength loss of NAC is always higher than that of RAC subjected to the same protocol. It is not the expected outcome when compared with previous studies [4] (Fig. 3).

Bogas et al. [4] investigated the durability of concrete produced with virgin coarse aggregate and fine recycled aggregate (replacement ratios of 0, 20, 50 and 100%). They adopted the ASTM C666 methodology subject to 300 freeze–thaw cycles. Also, the authors performed measurements of mass loss and non-destructive tests aiming to obtain dynamic modulus of elasticity. For normal strength concrete, considering different w/c ratios, they concluded that the freeze–thaw resistance is significantly influenced by w/c ratio than the aggregate type. In general, the internal freeze–thaw resistance did not decrease in the concrete produced with fine recycled concrete aggregate (FRCA), despite the concrete mix contained 100% FRCA. However, the surface scaling was more severe in the RAC.

Alexandridrou et al. [2] analysed different types of recycled aggregate (with replacement ratios of 5, 50 and 75%) in Greece. They performed freeze–thaw tests according to norm PD CEN/TR 15177 (2006) for 1, 8, 14, 28, 42 and 58 cycles monitored by measuring the relative dynamic modulus of elasticity. Also, they calculated mass loss. The results of dynamic modulus of all RAC were around 97% up to the 14th freeze–thaw cycle, similar to reference concrete. After the 14th cycle, the damage was more evident in RAC, and a significant decrease occurred compared to the reference mix.

Bassani and Tefa [3] produced RAC with unseparated construction and demolition waste (UCDW) and evaluated the degradation caused by compaction and freezing action on resilient modulus. The materials were first washed, then dried in an oven for 24 h at 105 °C and then, cooled down to room temperature. Contrary to the EN 1367–1 norm, the size distribution of samples was set between 10 and 14 mm, and the thermal cycle was set from + 20 to − 18 °C. Partially-saturated specimens of UCDW aggregates at the optimal moisture content (wopt) and wopt ± 2% were prepared at the gyratory shear compactor with 30 and 100 gyrations, and by subjecting specimens to 0, 4 and 8 two-day freeze–thaw cycles from − 18 to + 20 °C. Freeze–Thaw cycles influenced the performance of recycled UCDW. The results indicate that specimens prepared at wopt and wopt + 2% maintain their Resilience Modulus values after Freeze–Thaw action.

Abbas et al. [1] investigated the durability of structural grade concrete produced with RA. Besides, the authors adopted a new mix design, named equivalent mortar volume (EMV). The freeze–thaw tests were carried out using rapid freezing and thawing in water as specified in the Procedure A of ASTM C 666-97. The freeze–thaw damage was monitored by measuring the relative dynamic modulus of the test prisms for a maximum of 300 cycles. The main findings showed that all the test specimens presented high relative dynamic modulus (and durability factor), and the RAC can be used in severe environments according to the Canadian specifications. The author highlighted that since lower total mortar content in RCA-concrete could be achieved using the EMV method, this method produces concrete with stronger resistance against freeze–thaw action compared to RCA-concrete proportioned by conventional mix design method (containing 100% RCA).

Yildirim et al. [22] evaluated the performance of recycled concrete with internal curing. To evaluate the freeze and thaw resistance, the author developed an experimental program using three 100 × 200 mm cylinders of each concrete mix which were exposed to 300 freeze/thaw cycles according to ASTM C 666/Procedures A and B. It means that the freeze–thaw cycle resistance was determined from the weight loss and frequency of vibration according to ASTM C 215. Virgin aggregate was replaced with recycled concrete fine aggregate (0, 50, 100%), degree of recycled aggregate saturation was (0, 50, 100%) and ratio of RCA to fine virgin aggregate was (0/50, 50/0, 25/25). The best results were obtained for the control concrete, but comparable results were obtained for the specimens containing saturated RA, which was considered a positive result. The authors reported that the reason for this good performance could be the fact that the RCA promoted the formation of a more solid and denser interface. Also, full saturation and semi-saturation of the 50% RCA enhanced the concrete's durability, while semi-saturation of the 50% RCA yielded the best values among the groups containing RCA (Table 1).

Table 1 Comparison between the numbers of freeze–thaw cycles and damage on RAC

References	Method	Freeze–thaw cycles	(%) RA	Results
[15]	European standard CEN/TS 12390-9 EX	56	20 and 25% of ceramic-sanitary ware waste	Recycled concrete is more freeze–thaw resistant than conventional concrete, as the scaling rate is lower, and the cracks are narrower
[13]	Novel testing protocol (coupling protocol)	(1) 50 salt solution freeze–thaw cycles (1 time) (2) 25 salt solution freeze–thaw cycles (2 times) (3) 10 salt solution freeze–thaw cycles (5 times)	100% RCA	The main finds indicate that the compressive strength of NAC after two or five freeze–thaw cycles became lower than that of RAC
[4]	ASTM C666	300	0, 20, 50 and 100%—fine RCA	In general, the internal freeze–thaw resistance did not decrease in the concrete produced with FRCA, despite the mixture with 100% of FRCA
[2]	PD CEN/TR 15177	1, 8, 14, 28, 42 and 58	25, 50 and 75%	Dynamic modulus of all recycled concrete were found to be around 97% for up to the 14th freeze and thaw cycle, similar to reference concrete. After the 14th cycle the damage was more evident, and a significant decrease compared to the reference mix

(continued)

Table 1 (continued)

References	Method	Freeze–thaw cycles	(%) RA	Results
[1]	Procedure A of ASTM C 666-97	300	(a) 100% RCA—conventional mix design (b) 63.5 and 74.3% RCA content for RCA-concrete made with RCA-MO and RCA-VA, respectively—EMV mix design	Since lower total mortar content in RCA-concrete can be achieved using the EMV method (63.5 and 74.3% RCA content for RCA-concrete made with RCA-MO and RCA-VA, respectively), this method produces concrete with stronger resistance against freeze-and-thaw action compared to RCA-concrete proportioned by conventional mix design method (100% RCA content)
[22]	ASTM C 666/Procedures A and B	300	Recycled concrete fine aggregate (0, 50, 100%),	After exposure to 300 freeze–thaw cycles, the performance of concrete containing RCA was comparable to that of concrete containing only virgin aggregate, especially for mixes containing 50% RCA at a 50% saturation level

3 Treatments to Improve the Resistance of RAC Under Freeze and Thaw Cycles

In order to enhance the application of RAC, several researchers [9, 18, 19] have adopted different treatments and mix designs to increase both, durability and mechanical performance. According to the literature, there are promising alternatives to mitigate the freeze–thaw effect on RAC, for example, the addition of mineral admixtures, carbonation and acetic acid immersion.

Kazmi et al. [12] compared different treatments to enhance RAC durability, such as carbonated RCA, lime saturated RCA, acetic acid treated RCA, acetic acid immersed and rubbed RCA and acetic acid immersed and carbonated RAC. The author observed that the non-treated RAC specimens showed a higher reduction in weight due to freeze–thaw cycles than VAC specimens. The porosity and water absorption influence the RCA capacity to resist internal pressure during the freeze–thaw experiment. However, the treated RCA presented better results compared with non-treated RCA in RAC, mainly lime saturated RCA and acid immersed and rubbed RCA.

Additionally, the incorporation of mineral admixtures has been investigated to mitigate the deterioration of RAC. Wang et al. [21] evaluated incorporation of flyash (10, 15 and 25%) and three different silica fume contents (5, 8 and 11%) as partial replacement of Ordinary Portland cement to enhance the RAC resistance under freeze–thaw cycles. The authors submitted the prismatic specimens to 175 freezing–thawing cycles. The authors found that 25% fly ash and 5–8% silica fume by weight replacement of cement resulted in significant improvement in concrete durability.

To evaluate the fly ash content, Li et al. [14] studied Low volume of flyash (LV-FA) and High volume flyash (HV-FA) in concrete mixtures prepared by replacing specific amounts of coarse virgin aggregate with coarse RCA. The specimens were then subjected to freeze–thaw cycles and exposed to different liquid solutions. Compared with the reference concrete (without flyash), the LVFA-based concrete showed excellent improvement in the resistance to the combined action of freeze–thaw cycles and sulphate attack. Important to note that the HVFA-based concrete had a negative effect on the resistance.

Some authors investigated the common use of air-entrained agents to enhance RCA freeze–thaw resistance. Gokce et al. [6] experimented to assess the frost resistance of coarse RCAs that originated from air-entrained and non-air-entrained concrete. The authors identified a superior performance of RAC produced with air-entrainment in comparison with RAC without the chemical agent.

4 Conclusion

In this paper, the effect of freeze–thaw cycles on RAC has been discussed. Additionally, a comparison of different procedures and standards adopted to evaluate the deterioration of RAC indicated that the results depend on the level of exposure, there is no common sense regarding the performance of RAC in comparison with conventional concrete. Some researchers demonstrated that RAC presents comparable resistance to traditional concrete, others found RAC showing lower strength and even higher performance under freeze–thaw cycles. Further studies are needed to group and evaluate the results of different freeze–thaw cycles considering the same variables.

The literature shows effective treatments on RAC to enhance its resistance, as the leading cause of deterioration is related to the physical properties. For example, porosity and water absorption of aggregate. However, it is beneficial to combine the traditional use of air-entrained agents with the incorporation of mineral admixtures, such as silica fume and flyash.

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Supervision System on Construction and Demolition Waste Recycling: Lessons from Shenzhen, Hangzhou and Chongqing, China

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Abstract A large amount of construction and demolition waste is generated owing to the rapid development of the construction industry. Of all the countries in the world, China produces the largest amount of construction and demolition waste. Currently, approximately 75% of Chinese cities are surrounded by a large volume of the waste. Proper management of construction and demolition waste is expected to improve the performance of construction and demolition waste recycling. Adopting supervision system on construction and demolition waste recycling plays an important role in effective waste management. However, there is a short of supervision system in China. This study analyses challenges in current supervision system, adopting site visits to three Chinese cities (Hangzhou, Shenzhen and Chongqing). Three challenges are identified in this study: (1) a lack of accurate estimation of waste quantity and distribution, (2) a lack of coordination among different government administration departments and (3) a lack of an effective waste tracing system. Corresponding recommendations are provided to policy makers in China, in order to improve the performance of construction and demolition waste management.

Keywords Construction and demolition waste · Recycling · Supervision system · China

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1 Introduction

A large amount of construction and demolition waste is generated owing to the rapid development of the construction industry [28]. Of all the countries in the world, China produces the largest amount of construction and demolition waste, with an annual generation of 2.4 billion tonnes in 2015 [11]. However, the average recovery rate of the waste was only approximately 5% in 2017 [17]. Currently, approximately 75% of Chinese cities are surrounded by a large volume of construction and demolition waste [17]. Construction and demolition waste management performance varies among Chinese cities. The recovery rate of construction and demolition waste in most Chinese cities is between 3 and 10% [17]. The best-performing cities, such as Shanghai and Shenzhen, have achieved recovery rates of > 15% [13]. However, the recovery rates in these cities are significantly lower than that in some developed countries, such as 96% in Japan [27], 91% in United Kingdom [9] and 80% in New Zealand [18].

Without proper management, massive construction and demolition waste has inevitably occupied land resources and destroyed natural habitats [28], because a large amounts of waste are dumped or landfilled [5]. Considering the negative effects of the increasing volume of waste on the environment, effective and proper treatment is imperative. Proper management of construction and demolition waste is expected to promote the efficient use of resources [3], and reduce landfilling [12]. Government plays an important role in promoting construction and demolition waste management [23]. Currently, there is a short of supervision system on construction and demolition waste recycling in China [16]. Although there is a direct relationship between effectiveness of waste management and precise estimation of the waste volume [24, 35], there is an unavailability of systematic data collection [2]. Additionally, the existing regulations are proven to be ineffective, as illegal dumping is prevailing [40]. Because of a lack of a traceable transporting network, it is difficult to supervise illegal dumping and whether the waste has been transported to the lawful places [40]. The need for the development of supervision system is urgent.

The topic of construction and demolition waste management has attracted attention from researchers. Previous literatures carried out investigations on strategies to improve the performance of construction and demolition waste management in China, including development of waste management regulations [7, 22, 23, 39], strengthening awareness of construction and demolition waste management [22, 23], research in related technology [22, 23], considering waste reduction in design [37, 39], and provision of financial incentives [7]. Empirical studies on Chinese cities are increasingly being conducted. Jin et al. [19] analysed the composition of the waste generated in Shanghai and suggested that proper management depends significantly on accurate estimation of the quantity and composition of the waste. Zhao et al. [42] investigated the current status of construction and demolition waste management in Chongqing and provided recommendations to enhance the economic feasibility of recycling. Zhao et al. [43] performed a lifecycle assessment to evaluate solid waste management in Tianjin. However, few studies have been performed to investigate supervision system of construction and demolition waste recycling for different Chinese cities.

This paper aims to investigate the current supervision system of construction and demolition waste recycling in three Chinese cities (Hangzhou, Shenzhen, and Chongqing), and analyse the challenges in the current supervision system. Two steps are involved in the present study. Firstly, existing policies and official documents related to construction and demolition waste at a municipal level in the three Chinese cities are studied to obtain the background of current status of construction and demolition waste management. Secondly, site visits to three Chinese cities (Hangzhou, Chongqing and Shenzhen) are conducted. During the site visits, interviews were conducted with project managers and on-site workers who have adequate industrial experience and have a comprehensive understanding in the current supervision system of construction and demolition waste. The questions were closely related to: (1) penalty on illegal dumping; (2) method to calculate waste quantity; (3) planned route for waste transportation; (4) waste traceability system. The results are expected to improve the performance of construction and demolition waste management in the three cities and provide useful experiences for other Chinese cities.

2 Background

In 2018, the Ministry of Housing and Urban-Rural Development of the People's Republic of China [25] selected 35 cities to promote construction and demolition waste management as an experiment. The 35 experimental cities in China were selected with consideration of the economy, size, industrial characteristics, and national strategy. These cities are required to follow the national guidance and to implement a series of policies for regulating construction and demolition waste production, transportation, and treatment. However, it is difficult to conduct site visits to all the 35 experimental cities, as some cities are remote, with a lack of access. Thus, three Chinese cities are selected, which are among the 35 experimental cities: Hangzhou (Zhejiang Province), Chongqing (Direct-administered municipalities), and Shenzhen (Guangdong Province).

Hangzhou is featured as one of the largest economies in the Yangtze river delta. This city continuously improve its construction and demolition waste management systems and strengthen collaboration between departments and supervision systems [31]. The annual generation of construction and demolition waste in Hangzhou amounts to 12 million tonnes [36]. In recent years, as environmental protection has attracted increased attention, construction and demolition waste management has been a top priority of the municipal government [33]. In 2018, Plan for Construction and Demolition Waste Management in Hangzhou [14] was introduced to stimulate recycling of construction and demolition waste. Chongqing is one of the most populous cities in western China [41]. The average quantity of construction and demolition waste collected in urban areas of Chongqing is estimated to reach 4.03 million tonnes [21]. Because of the large number of governmental departments involved in construction and demolition waste management, it is difficult to supervise the whole waste disposal chain in Chongqing [15]. Thus, governmental supervision focuses on waste transportation [15]. Management on Construction and Demolition Waste in Chongqing [8] is the legal basis for the waste regulations in Chongqing. Shenzhen—one of the economically developed cities in southern China—has begun to recycle construction and demolition waste into recycled aggregate and bricks, whereas some underdeveloped cities have not taken measures to treat the waste [40]. Management on Construction and Demolition Waste in Shenzhen [29] forms the foundation for construction and demolition waste recycling. Over the past few years, Shenzhen has played a leading role toward achieving sustainable construction and demolition waste management in China, partly owing to its many recycling enterprises [1].

3 Results and Discussion

To investigate the current supervision system of construction and demolition waste recycling in China, three construction and demolition waste recycling plants in three different Chinese cities were visited. Information collected from the three visits is presented in this chapter.

3.1 Basic Information

These 3 recycling sites were investigated from December 2019 to January 2020. Table 1 provides basic information of the three case projects in the selected cities. The table describes characteristics of the 3 recycling plants. These 3 recycling plants are characterized by its area, ownership, source for recycling, plant type and recycling capability. The details of these characteristics are discussed below.

In Hangzhou, only state-owned companies are qualified to recycle construction and demolition waste. Hangzhou is divided into 10 areas by the authorities. Multiple

Table 1 Basic information collected from recycling plants

	Area (m^2)	State-owned or private company	Source of waste	Mobile or fixed industry	Quantity of waste recycled/day (t/d)
Hangzhou	1,066,667	State-owned	Government contract	Fixed	2000
Shenzhen	5000	Private	Contract with local contractors	Fixed	7000
Chongqing	65,333	State-owned	Purchase	Fixed	2000

construction and demolition waste recycling plants were nominated to recycle waste in each area.

There are three primary ways to obtain the source of construction and demolition waste. (1) A few companies signed contracts with the local government to ensure the supply of construction and demolition waste, including Hangzhou. For instance, the construction and demolition waste produced in certain areas must be transported to the nominated plant for recycling. (2) Industries in Shenzhen cooperate with local contractors that pay for the transportation and recycling fees. (3) The industry in Chongqing must purchase construction and demolition waste from contractors to maintain operation. The remote location of this industry has significantly increased the transportation costs. The transportation cost increases significantly when the distance from demolition site to recycling plant is > 25 km, and contractors prefer to transport the waste to landfill sites for reducing the cost. However, the closet demolition site is 28 km from this recycling plant; thus, the industry faces a lack of a waste source.

Fixed and mobile are two types of recycling plants, which adopt different levels of technology and produce recycled aggregates of different grades [4]. Fixed plants are permanently placed in a recycling centre and can produce recycled products of high quality [32], but they are forbidden to be built in urban areas in some Chinese cities, because of the emission of noise and dust [1]. Mobile recycling plants are portable, and process of recycling could be completed at demolition worksites [32]. Different types of waste can be directly separated in the mobile industries. Despite the lowest transportation cost from mobile industries, complaints from surrounding residents regarding noise and dust limit the growth of mobile industries in some cities, such as Chongqing. Fixed recycling industries should be equipped with wastewater recycling systems, dust suppression spray systems, and sealed workshops. It is difficult for private companies to establish a standard production environment, which requires substantial funding.

3.2 Supervision System

Table 2 presents the supervision system in the three cities.

3.2.1 Illegal Dumping

In Shenzhen, the penalties for illegal dumping depend on how the dumping affects the environment. The Municipal Comprehensive Law-enforcing Bureau of City Administration decides the penalty, according to the location of the illegal dumping, the potential risks, and the waste volume. Violators can be sentenced in cases where the environmental damage is significant. Hangzhou and Chongqing follow their local rules [26], and waste flipping violators are fined 5000–50,000 yuan (US$716–7166). However, the existence of inconsistent cooperation among governments at area level

Table 2 Supervision system

	Penalty for illegal dumping	Planned route for waste transportation (using GPS)	Method to calculate waste quantity	Waste traceability system
Hangzhou	Fines from 5000 to 50,000 yuan (or US $716–7166)	Yes	The calculation is based on demolition amount in disposal plan	Figure 2
Shenzhen	Fines from 5000 to 50,000 yuan (or US $716–7166); and/or sentence	Yes	The calculation is based on demolition amount in disposal plan	Figure 3
Chongqing	Fines from 5000 to 50,000 yuan (or US $716–7166)	Yes. Waste can only be transported by special yellow trucks	The calculation is based on demolition amount in disposal plan	Figure 4

is one barrier to reduce illegal dumping in Chongqing. Chongqing is divided into nine areas by the authorities. Each area government participates in the construction and demolition waste management separately, without cooperation with government in other areas. Area governments only spend efforts to avoid occurrence of illegal dumping in their administrative areas. Once the waste is exported outside the area, there is no responsibility for them to supervise the waste and check whether the waste is transported to the lawful places, even the waste is produced in their administrative area.

Because of the specific organizational structure of Chinese government, municipal regulations would be developed after issue of fundamental principles formulated by central government [40]. Regulations and policies formulated by local governments could largely influence the practice of construction and demolition waste management [34], which requires cooperative efforts made by various departments of municipal government. Approximately nine departments are involved in construction and demolition waste management in one city (Fig. 1). However, fostering cooperative relationships among various departments is complex, as each department plays a different role and has different responsibilities. For example, the Municipal Commission of Housing and Urban–Rural Development formulates municipal acts and regulations on construction and demolition waste recycling, leading engagements with other departments, e.g., subsidies for recycling industries from the Finance Bureau or tax deductions from the Municipal Tax Service. However, the Financial Bureau has the right not to follow an act issued by the Municipal Commission of Housing and Urban–Rural Development, because they are at the same administrative level. Additionally, financial constraints restrict governmental expenditures on construction and demolition waste recycling.

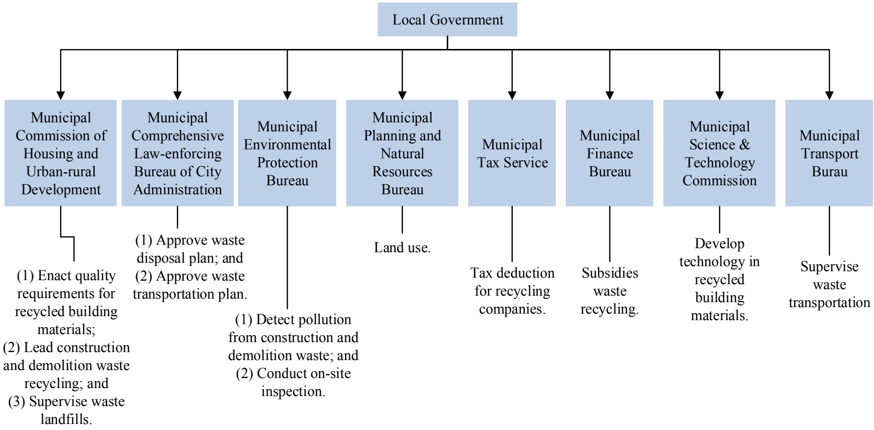

Fig. 1 Responsibilities of governmental departments in Chongqing

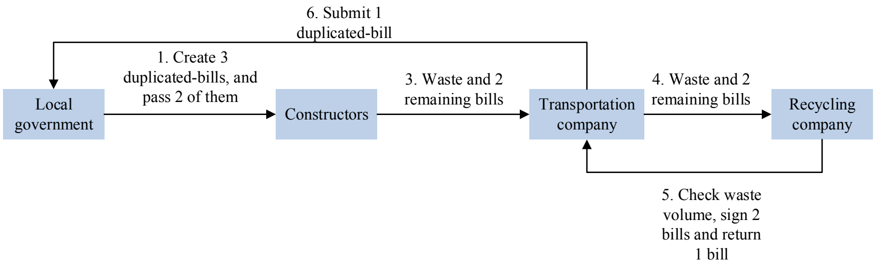

Fig. 2 Waste tracing system in Hangzhou

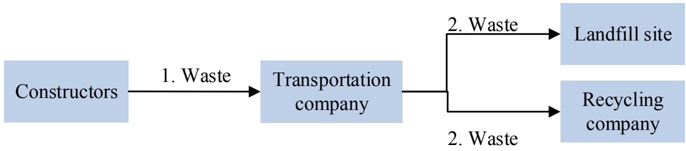

Fig. 3 Waste tracing system in Chongqing

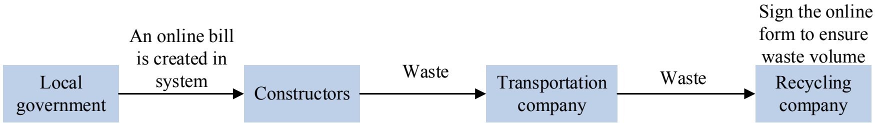

Fig. 4 Waste tracing system in Shenzhen

3.2.2 Waste Volume

Optimising waste logistics is fundamental to waste management [30]. All the vehicles used for transporting waste should be equipped with a global positioning system (GPS), follow an approved route, and be supervised by a tracing system. In Chongqing, trucks are equipped with sensors to avoid overloading. The capacity of each waste truck is approximately 20 m^3. Normally, before waste removal, contractors should submit a construction and demolition waste disposal plan to the local government and obtain permits for waste disposal. The disposal plan should include the (1) project name, location, and demolition area; (2) information about the contractors, transportation companies, and recycling companies or landfill sites; (3) types and volume of construction and demolition waste; and (4) detailed information about the transportation and disposal measures [6]. The calculation of the annual generation of construction and demolition waste is based on demolition amount noted in the disposal plan from contractors. This number could be verified by recycling companies or landfill sites, according to the number of trucks and the truck volume (or by using a weighing scale).

3.2.3 Waste Tracing System

Figures 2, 3 and 4 provide information on the waste tracing system throughout the recycling chain in the three cities. A three duplicated-bill system is used in Hangzhou to trace construction and demolition waste (Fig. 2). When the disposal plan is approved by local government, three duplicated-bills will be created and filled with relevant information. Government will keep one of the three duplicated-bills and deliver the two remaining bills to contractors. When transportation and recycling companies receive these bills, they should check the waste class, verify the waste volume, and sign the bills. Government will verify the quantity of waste recycled through comparing the original bill and the bill submitted by transportation company.

Figure 3 presents the construction and demolition waste tracing system in Chongqing. Under the present supervision system, it is difficult to verify waste volume and check whether the waste has ended up in the recycling sites.

In Shenzhen, an online bill system is used (Fig. 4). When the disposal plan prepared by contractors is approved by the Shenzhen local government, an online form is automatically created in a governmental system. Recycling companies must verify the total waste volume and sign the online form when construction and demolition waste arrives at the recycling site.

4 Challenges and Recommendations

It can be observed that some efforts have been made by local governments to promote supervision of construction and demolition waste management in the past couple of years. However, the performance varies across different regions. The supervision system needs to be further improved. Three challenges are summarised in this Chapter. Corresponding recommendations are discussed below.

4.1 Challenge 1: A Lack of Accurate Estimation of Waste Quantity and Distribution

The large generation of construction and demolition waste in China is a big challenge in the development of an effective waste management system [10]. Estimation of construction and demolition waste quantity is a prerequisite to understand the generation trend in one city and formulate reasonable recycling policies [38]. In the three selected cities, estimation of annual waste generation is based on the waste quantity notified in waste disposal plans submitted by contractors. However, the actual amount is not accurately qualified, which might further cause inappropriate resource allocation and effectiveness of management [24]. Specifically, multiple factors, including project type, function of projects and composition of waste stream, could influence the accuracy of estimation [40]. The influences from these factors could be minimised through extensive researches in a large amount of sample projects [40]. Local governments can cooperate with universities or research institutes to establish a systematic data collection method [2].

4.2 Challenge 2: A Lack of Coordination Among Different Government Administration Departments

The leading role of Municipal Commission of Housing and Urban–Rural Development in construction and demolition waste management in one city is clearly defined by central government [1]. However, internal inconsistencies arise when the leading departments of construction and demolition waste management are at the same administrative level. As numerous departments are involved in the waste management chain and are responsible for different aspects, fostering cooperative relationships among the various departments is complex. Specifically, the Municipal Commission of Housing and Urban–Rural Development plays a leading role in waste management, but other departments at the same administrative level can ignore their guidance. Therefore, a department of a higher administrative level should be nominated to take the primary responsibilities and effectively arrange activities of these departments, such as the Municipal People's Congress. Its responsibility includes leading subordinate departments, clarifying the duties of each department, promoting information sharing, formulating powerful legislation, and strengthening cooperation among different departments.

4.3 Challenge 3: A Lack of an Effective Waste Tracing System

Some recycling policies, such as landfill ban and compulsory recycling requirement, have been adopted in some cities. Behaviours of related stakeholders in the construction industry can directly influence the effectiveness of these policies [20]. The obeyance of related stakeholders is largely dependent on an effective supervision system [1]. The performance of integrated construction and demolition waste management largely relies on an effective waste tracing system. The three duplicated-bill system in Hangzhou, and the electronic bill system in Shenzhen are good examples to follow. In these waste tracing systems, bills are delivered to contractors from recycling companies or local governments. Contractors should fill these bills with relevant information such as the waste class, appearance, amount, and treatment. When transportation companies receive these bills, they should check the waste class, waste quantity, and drop-off location. Recycling companies and landfill sites should visually inspect waste, determine whether the waste can be lawfully accepted, verify the waste volume, and sign the bills. To improve the management efficiency, an electronic bill system for data sharing was developed in Shenzhen. Contractors, transportation companies, recycling companies, and landfill sites can log in to the system and record the waste details. The platform should be accessible to all the related stakeholders.

5 Conclusion

Proper management of construction and demolition waste is expected to deal with the problem of large volume of construction and demolition waste in China. Specifically, governmental supervision system plays an important role in effective construction and demolition waste management. However, there is a short of supervision system of construction and demolition waste recycling in China. Additionally, few studies have been performed to investigate supervision system of construction and demolition waste recycling for different Chinese cities. This article analysed challenges in current supervision system on construction and demolition waste recycling in China, adopting site visits to three Chinese cities (Hangzhou, Shenzhen and Chongqing). (1) A lack of accurate estimation of waste quantity and distribution, (2) a lack of coordination among different government administration departments and (3) a lack of an effective waste tracing system were identified as three challenges. Recommendations to address these challenges were presented.

This research provides information of current supervision system on construction and demolition waste recycling, which offers valuable references to researchers who are interested in related topics. Additionally, this article provides some recommendations to policymakers in China to improve the performance of construction and demolition waste management.

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State-of-the-Art of BIM-Based LCA in the Building Sector

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Abstract It is widely recognized that the integration of building information modeling (BIM) and life cycle assessment (LCA) can enhance sustainable development in the building sector. However, a comprehensive and in-depth understanding the state-of-the-art of BIM-based LCA is still scarce. This paper therefore intends to conduct a critical review and analysis of the integration of BIM and LCA in the building sector based on previous studies and provide research gaps and their future practice and development. A qualitative content analysis was adopted to analyze 71 publications. The research results indicate a growing interest in exploring the potential of BIM to facilitate the environmental performance assessment of buildings since 2013. Additionally, previous studies focused on the two topics: integration methods of BIM and LCA and the application of BIM-based LCA. Eight specific sub-topics was identified and classified within the two topics. Five sub-topics was classified within the former, including: drivers and barriers to BIM-based LCA; integrity and accuracy of data flow during integration processes; comparison and analysis of BIM software and LCA tools; material and components libraries for data structure; and effective ways to integrate BIM with LCA, and three sub-topics was classified, including: the evaluation and optimization of environmental impacts-being the most popular one; the evaluation of economic impacts of buildings; and comparative analysis and decision making of alternative scenarios. A framework is then proposed for systematically elaborating developments and gaps of BIM-based LCA. This study contributes

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to the architecture, engineering and construction literature by presenting the state-of-the-art of BIM-based LCA application and the future practice and development in the building sector.

Keywords Building information modelling · Life cycle assessment · building · Construction

1 Introduction

It is widely recognized that the building sector is one of the most important natural resources consumers and waste producers [56]. It is responsible for more than 40% world's primary energy demand and 38% greenhouse gas emissions and 30% waste is produced in the construction and demolition of building projects [34]. Sustainable design is regarded as one of the most significant strategies in reducing resources consumption and environmental impacts of the building sector [54]. LCA is a powerful tool to help the implementation of sustainable development into the built environment [3]. Nevertheless, currently the implementation of LCA in the building sector faces challenges, such as deficient or outdated databases, lack of appropriate models for impact assessment, and intrinsic uncertainty related to normative decisions made along the LCA [4, 17, 57].

BIM can tremendously improve the management of critical information in digital format and considerably reduce time and effort required to collect graphics and data throughout the life cycle of a building [28, 39]. The integration of LCA with BIM is growing in the scientific community as it would allow to quickly estimate relevant environmental impacts [53] and return this information to the designer to refine the specifications of building elements iteratively in project development. Nevertheless, the application of BIM and LCA integration in the building sector faces numerous challenges. The results of environmental impact assessment from BIM-based LCA is still not reliable due to issues of data incompatibility, building information missing, etc. [5, 26, 59]. To allow users or designers to better handle these issues, there is a need to comprehensively understand BIM-based LCA and its application. Several studies conducted reviews on the integration of BIM and LCA. Obrecht et al. [38] reviewed 60 BIM-based LCA cases and their workflows, mainly focusing on the information exchange between BIM and LCA tools [9]. Identified six problem classes involving BIM-LCA integration through reviewing 34 selected papers. Soust-Verdaguer, [54] analyzed 11 cases of BIM-based LCA application centered on methodology analysis of BIM-based LCA integration. While these studies clarify how to integrate BIM and LCA, a comprehensive and in-depth literature review on BIM and LCA integration based on historical studies is still lacking. This hinders the in-depth understanding of BIM-based LCA and thus suggestions of sustainable development in the building sector. This research therefore aims to review historical studies on BIM-based LCA and propose a framework for the future development. The research results cannot only facilitate a deep understanding of BIM-based LCA, but also provide key insights into its future development.

2 Research Method

Qualitative content analysis is a text data analysis technique that interprets the content from collected data based on systematic classification of research themes or patterns [20]. This method was adopted in this study. The selection of this method was because: first, qualitative content analysis offers valid elaborations and inferences through analysis of collected data [45]. Moreover, it reveals the intentions, methods, consequences of the literature and extracts explicit and inferred features that contain similar meanings, providing a comprehensive and systematic understanding of the research topic [22]. This research method includes two steps of data collection and data analysis, as shown in Fig. 1.

2.1 Data Collection

Hu et al. [21] stated that the procedure of data collection in qualitative content analysis includes two steps of retrieving and filtering. In the retrieving step, the academic databases of Scopus and Web of Science were used to search BIM-based

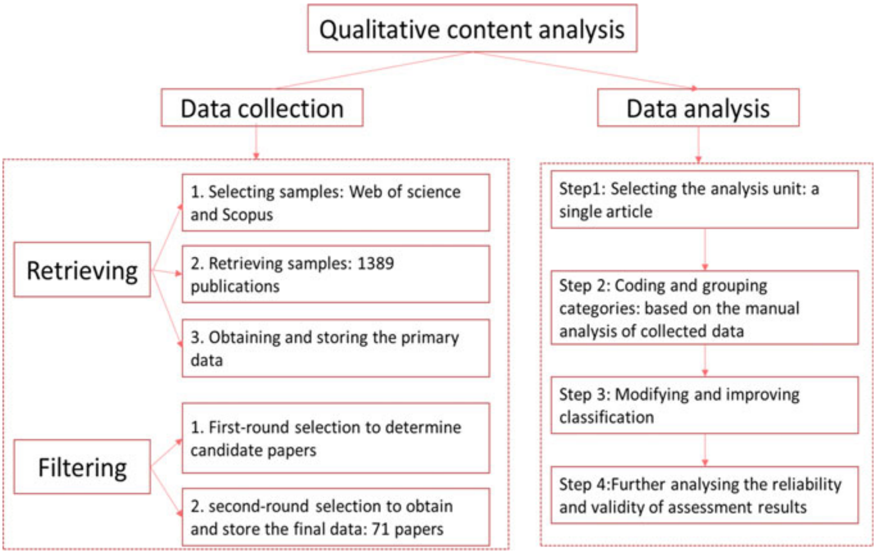

Fig. 1 The procedures of qualitative content analysis (adapted from [22])

LCA papers in this study since these two platforms are critically influential abstract and citation databases in the field of sustainable construction and project management [15]. The following keywords were used to identify related publications: (*BIM* OR *building information modeling* OR *building information model* OR *3D design* OR *3D models* OR *digital design* OR *information technology*) AND (*LCA* OR *life cycle assessment* OR *life cycle analysis* OR *environmental impacts* OR *environmental assessment* OR *environmental evaluation*). These publications were based on the sources of articles published in prominent journals (e.g., Building and Environment, Energy and Buildings, Journal of Cleaner Production, Automation in Construction, and International Journal of Construction Management), conference proceedings, and scientific reports (e.g., UN Environmental and International Energy Agency Global Status Report). A total of 1389 preliminary results were obtained from Scopus and Web of Science. Then, the preliminary results were stored in the form of web pages. Subsequently, the primary results were filtered based on the research topics, which adopted a two-round article selection to ensure the filtering quality. In the first-round selection, article title, abstract and keywords of publications were checked to determine candidate papers. Subsequently, the second-round selection reviewed the whole articles to obtain the final results, involving 71 papers.

2.2 Data Analysis

Morgan [35] stated that data analysis includes four procedures of the selection of analysis unit, the classification and codes of research content, the modification and improvement of the classification and the assessment of reliability and validity. The content analysis unit is the basic analysis objective which ranges from words, sentences, phrases, paragraphs to a whole text [12]. As for a state-of-the-art literature review, a single article was suggested to be the unit of analysis [49]. A paper therefore was employed as the elementary unit to conduct analysis. Following the identification and collection of the publications, coding and grouping were conducted on each article through iterative reading and reviewing to identify its research topic and research content. A codebook was developed to record the codes (i.e. basic information, research content and research topic) and corresponding content of each article, as shown in Table 1. The research contents of publications were reviewed and extracted into the codebook, and therefore an Excel spreadsheet with the data was established. During the review and extraction process, the codes were modified and improved according to the research contents. This review process provided an opportunity to check and ensure the reliability and validity of the codebook.

Table 1 Code book for qualitative content analysis

Topic	Sub-topic	Frequency
Integration methods of BIM and LCA	Drivers and barriers of BIM-based LCA	11
	Integrity and accuracy of data flow during integration	18
	Material and components libraries for data structure	7
	Comparison and analysis of BIM software and LCA tools	6
	Effective ways to integrate BIM with LCA	17
The application of BIM-based LCA	The evaluation and optimization of environmental impacts of buildings	25
	The evaluation of life cycle economic impacts of buildings	11
	Comparative analysis and decision making of alternative scenarios	13

Note One paper may be grouped into more than one sub-topic groups

3 Research Results

3.1 Research Overview

Figure 2 illustrates the distribution of the number of publications from 2005 to 2020. The publications before 2013 were less than 2 but have significantly increased since then. The number of publications related to BIM-based LCA has grown from 2013 to 2020, proving that the current theme is relevant.

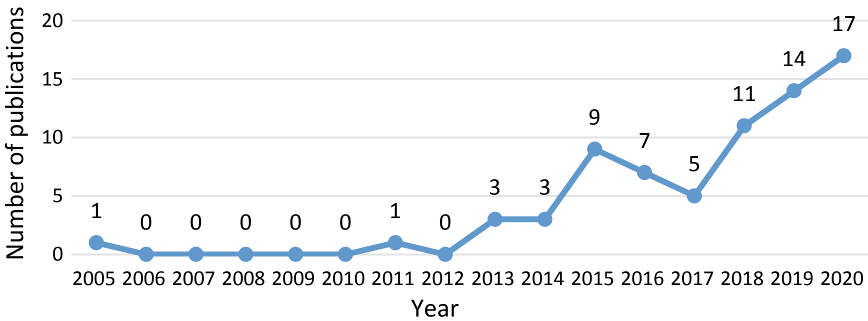

Fig. 2 Number of publications in years

The reviewed studies covered two topics of integration method of BIM and LCA and the application of BIM-based LCA (Table 1). A total of 8 sub-topics were identified. Many studies focused on the calculation of environmental impacts, while only a few studies considered economic impacts analysis over the life cycle of buildings.

3.2 Integration Methods of BIM and LCA

3.2.1 Drivers and Barriers to BIM-Based LCA

Previous research efforts have been made to investigate the drivers of BIM-based LCA implementation based on the methods such as literature review, interviews, case studies or Delphi method [1, 14, 26, 31, 38, 42, 50], which revealed the benefits of the provision of necessary building data for LCA assessment, the reduction of manually input errors and time, real-time assessment permission, the quick feedback from LCA tools, and the support in decision-making process at early stages of design. A deep exploration identified 21 specific drivers which were classified into four categories: decision making, material selection, sustainability performance, and waste reduction [50]. The most prominent one among the 21 drivers was associated with supporting the decision-making processes, which is in keeping with the increasing interests of researchers in BIM-based LCA implementation in the planning and early design processes [6, 10, 36, 41].

Although the integrated use of BIM and LCA provides great potential to enhance whole-building appraisals in a user-friendly fashion, various constraints has been identified over the years [6, 10, 36, 38, 50]. Three major barriers of the lack of interoperability, the inefficiency of data input into LCA tools, and the complexity of extracting data in BIM-based LCA implementation were retrieved from eleven studies in Table 1. The lack of interoperability between LCA and BIM tools is widely recognized as one of the greatest barriers due to the difficulties in data compatibility [1, 31], leading to a waste of time and effort for manual data re-entry and data transfer. In addition, it requires consistent data input into LCA programs for whole LCA applications to ensure the accuracy of LCA results. To mitigate this barrier, latest studies particularly focused on adopting multi-LOD approaches with consistent combination of LCA database [8, 19].

3.2.2 Integrity and Accuracy of Data During Integration Process

Data involved in the integration of BIM and LCA includes information about physical graphics of buildings retrieved from BIM model, and environmental information from LCA programs. Level of Development (LOD) defines the completeness requirements for each BIM element, which can be considered as a key point for the detailed level of BIM element information. Only a few studies have declared LOD of BIM for LCA application in design phases [1, 19, 42], where LOD 200 and LOD 300 are commonly adopted as they provide approximate quantities, size, shape, location and orientation required for quality take-off and environmental evaluation [17, 41]. The study [31] set LOD 300 as the reference LOD for the evaluation of the environmental impact of a building. The environmental impact evaluation of the main building materials in this study could be calculated at LOD 300 (except for steel). Moreover, LOD 300 was recommended by Soust-Verdaguer [54]. A deep examination compared the LCA on LOD 200, LOD 300, LOD 350 and concluded that the majority of building materials can be assessed with high accuracy by clearly state the materials in LOD 350 [19].

Moreover, the data integrity and accuracy during data exchange between BIM and LCA tools is a significant issue as there is no direct information flow between these technologies [16]. Typically, BIM model is mainly used to automatically extract quantities of building materials and elements to an Excel sheet, where the Excel sheet can be read by LCA tools or data are manually imported and organized to develop LCA application [4]. For example, in this study [26], building materials' quantity take-off was extracted from BIM model and was then imported into Athena Impact Estimator to implement environmental impact assessments via a text file. However, despite most building material categories can be extracted from BIM models, building elements' supplement should be done manually to provide sufficient data for LCA programs. Tedious manual operations required for the process may lead to high risk of errors [38].

3.2.3 Comparison and Analysis of BIM Software and LCA Tools

In spite of the usage of other BIM software, such as ArchiCAD and DProfiler in some studies [4, 52], Autodesk Revit is undoubtedly the most prominent software for building BIM models by far [1]. As for LCA tools, they were classified into three levels to simplify LCA analysis at the scale of buildings: the first level tools are centered on the analysis of building materials' LCA, such as SimaPro, Gabi, and OpenLCA; the tools in the second level are focused on the LCA analysis for whole buildings, such as ATHENA Impact Estimator, Envest, and Ecotect; the tools in the third level are interested in analyzing LCA of construction and concentrated on three pillars of sustainability: environmental, economic and social, such as Green Star, Green Globes and Leadership in Energy and Environmental Design (LEED) in the US [25, 36]. A comparative analysis of BIM-based LCA case studies showed that ATHENA Impact Estimator, SimaPro, ATHENA EcoCalculator were the most widely used LCA tools [54]. Nevertheless, the limitation of some LCA tools have been highlighted in studies. For example, Peng [39] stressed that Ecotect cannot be used to meet codes or regulations and requires long run times. The integration of LCA into BIM software provides opportunities to estimate environmental impacts of a building within the BIM environment in the form of BIM plug-ins. Previous research [13, 29] has identified four Revit plug-ins: Tally, IMPACT, eveBIM-ELODIE and Arquimedes. The BIM plugin tools are quick to learn and can produce a quick analysis of building's environmental impact [43, 47]. However, none of these tools allows the manipulation of environmental information in BIM objects [43]. This means that when additional building elements are added to the model, in spite of identifying Revit elements present in the project, the plugin cannot recognize object's information. Thus, the LCA results may not be underestimated.

3.2.4 Material and Components Libraries for Data Structure

Building material information exported from BIM needs to be manually enriched and placed into LCA programs, making the integration processes convoluted and arduous [38]. There is a consensus that a material and component library including all relevant physical characteristics and environmental performance of building materials and components for standardized use is beneficial [31, 51]. This is easy to understand in terms of data compatibility between BIM and LCA tools. Environmental properties included in BIM objects allow an automatic calculation of LCA of buildings, avoiding issues caused by data incompatibility. Shadram and Mukkavaara [51] developed a database about embodied energy and environmental performance of building material and components, which enabled an automate assessment process. Lee et al. [31] constructed a green template consisting of a major building material library of 34 building elements, an evaluation result overview table for embodied environmental impact evaluation, and the green template guideline. Jrade and Jalaei [26] built a model that included a database about sustainable materials, which was linked to an external LCA module and a certification and cost module. Rezaei et al. [41] created a functional database, which disaggregated individual building material under the same family and compiled all the different options for each assembly and corresponding life cycle inventories. These studies deepen the understanding of material and components library development. Nevertheless, there is a lack of shared understanding of the integration means among building physical information and environmental performance information in the library. In addition, the database of BIM tools and that of LCA tools in the established libraries generally do not match well due to different data formats such as the units, types and name of inputs [54]. To avoid this difficulty, studies showed that a common language about the data structure and naming convention of building materials and component should be predefined to facilitate the automate data mapping [19].

3.2.5 Effective Ways to Integrate BIM with LCA

The integration of BIM and LCA can be classified into three levels: the first one integrates BIM as a tool during the LCI stage for the quantification of building materials [26]; the second level, in addition to quantify building elements, integrates environmental information to BIM software or to Energy Building Evaluation [4] the third level involves the development of automated or semi-automatic process to perform a BIM-based LCA combing different data and software [2]. Studies utilizing BIM-LCA integration extensively explored the method in the first level for the automatic quantification of building elements [1, 4, 26, 38]. Some studies in the second level focused on adding LCA functionality to existing BIM in a form of extensions or plug-ins [1, 31]. Although only a few studies developed the automatic combination within BIM and LCA tools [31, 51], the third level approach facilitated the information integration over the life cycle of a project, where users can access to environmental performance information by merely reading a BIM model. In addition, despite the fact that both cradle-to-date and cradle-to-grave can be used as system boundaries of LCA analysis, recent BIM-enabled LCA studies in great numbers only focused on several critical stages, particularly on the cradle-to-gate environmental impacts quantification [38, 41]. This is due to the complexity of evaluation on other stages and the lack of data. As a result, most studies have focused the LCA application on the building elements that can be easily modeled and on the LCA stages that can be easily evaluated, while stages such as construction and the end-of-life were scarcely considered.

3.3 The Application of BIM-Based LCA

3.3.1 Evaluation and Optimization of Environmental Impacts of Buildings

According to EN15978, environmental impacts evaluation results are expressed via a list of environmental impact indicators (e.g., Global Warming Potential, Abiotic Depletion Potential, Primary Energy Consumption etc.). For example, the study adopted eight impact indicators to represent an overview of the environmental impacts of building designs [26]. Among the research on building sustainability, the most used environmental impact indicator is GWP. As stated earlier, many LCA studies took cradle-to-gate as system boundary of LCA analysis due to the lack of data in operational and end-of-life stages. As a result, many studies about the environmental assessment only focused on embodied carbon emission and energy consumption [7, 51]. It is worth noting that sensitivity analysis has been widely used to identify how building components' environmental impacts vary over a range of input parameters of materials and components. Several studies [1, 38] calculated the CO_2 emission over a building's life cycle and compared their distributions over each stage of the building, which contributes to the reduction of energy consumption and carbon emissions [4, 46] revealed that the largest embodied impacts reduction can be achieved by changing material and thickness for building components. Sensitivity analysis was also carried out to identify parameters that have the largest impact on the building's performance in the case study [38].

3.3.2 Evaluation of Economic Impacts of Buildings

Life cycle cost analysis (LCC) is regarded as an economic evaluation method for existing or potential investment of assets, but it is a relatively new tool in the sustainability assessment field [27, 32]. Studies indicated that LCC analysis is a crucial issue for the balance between economic and environmental impacts in decision making of building designs. For example, to encourage sustainable innovation activities, [27] considered the balance between costs, environmental impacts and facilities quality improvement. Grussing [18] carried out a method for optimal work activities selection to maximize facility performance and LCC. Marzouk, et al., [32] proposed a framework considering both economic performance and energy efficiency to support the decision-making processes. Several research efforts have been made to evaluate the economic efficiency of building through the integration of BIM and LCC by using material quantities extracted from BIM models to calculate the LCC [11, 33]. However, few studies considered a cradle-to-grave BIM-based analysis of economic feasibility of a whole building given the complexity of integration within BIM model and the lack of continuous data [44]. Hence, great efforts should be made to comprehensively comprehend the integration patterns among them.

3.3.3 Comparative Analysis and Decision Making of Alternative Scenarios

Supporting decision-making analysis of alternative designs is a key application of BIM-based LCA [38]. For users or designers, to make reasonable judgements it is crucial to understand the potential building performance of alternative scenarios, covering three main aspects of sustainability: environmental, economic and social. Building design decision-making analysis started to create a balance between environmental and economic impacts, while social impacts, which are consequences of positive or negative pressure on social endpoints (e.g., the well-being of stakeholders) has been reported to be underdeveloped [41]. Lee et al [30] evaluated the energy efficiency, CO_2 emissions, and LCC to choose suitable types of external glass for high-rise buildings. Inyim, et al., [24] introduced an integrated optimization tool with BIM, allowing designers to select different design materials and products for the desired building components in terms of construction time, initial construction cost, and CO_2 emissions. Apart from material options, BIM-based LCA decision-making analysis has also been examined in construction scenarios selection. For example, Iddon and Firth [23] used a simplistic BIM model to compare operational and embodied carbon emissions for four construction scenarios of the base case traditional masonry, a heavy weight construction, timber framed and structural insulated panels. These studies provide insights into decision-making analysis, while it is still important to develop a multi-criteria decision-making supporting system to identify appropriate alternative designs instead of the selection of material or construction scenario.

4 Further Research Directions

According to the review, studies of the integration of BIM and LCA are underdeveloped with only a few research topics being extensively explored. Moreover, these studies are relevantly scattered. Therefore, this study proposes the further research directions based on the support of a framework (Fig. 3). Seo, et al., [48] defined the steps of LCA Design consisting of data input, data analysis and output, which is in line with four phases of LCA (i.e., goal and scope, life cycle inventory, life cycle impact assessment, and interpretation) defined by ISO 14,040 (the internationally standardized LCA methodology). In this respect, BIM-based LCA can be systematically explored with an information flow structure based on the three steps of input, analysis and interpretation. This helps to systematically analyze BIM-based LCA and provides key insights for further development. A further exploration the research topics in Table 1 indicates that they can be grouped into three modules. Specially, drivers and barriers to BIM-based LCA and integrity and accuracy of data have been examined in terms of data input. The topic of and analysis of BIM and LCA tools, material and components library and effective ways to integrate BIM with LCA are related to data analysis. The research topics that make up the application of BIM-based LCA are linked to data output and interpretation.

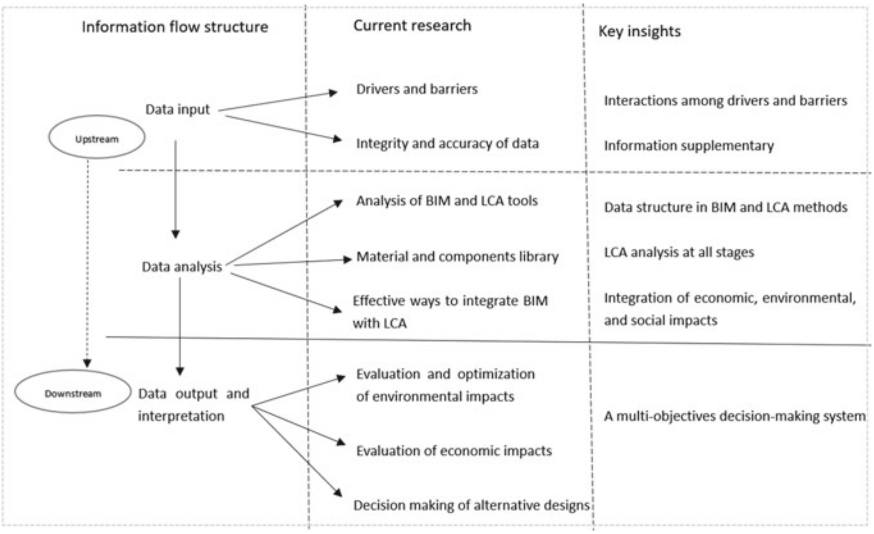

Fig. 3 A framework for further research direction

4.1 Data Input

Research on these topics focused on BIM model input and LCA method input. Among the reviewed publications, most studies have not declared appropriate LOD of BIM models for LCA analysis, while most studies that have specified the LOD of BIM models adopted LOD 200, LOD 300 and LOD 350. This is mainly due to the fact that LCA results at a high LOD do not affect the design decisions and only describe the environmental impacts of the final building, while the needed information for design are not available at a low LOD [41]. The application of BIM-LCA in design stages requires a LOD that allows to aggregate the environmental information at the building element level, where elements in the BIM model are represented in LOD 200 [1]. Additionally, it is common practice to extract building material quantities from the BIM model to calculate the environmental performance over the life cycle of a building. However, the detail tables exported from Revit are not totally reliable for building elements identification due to its poor function of classification [19, 59], leading to insufficient or manual supplementary data to be used in the LCA analysis. Hence, it is necessary to make research efforts to improve identification of building objects in a BIM model or manually manipulate data to provide sufficient information about the building elements properties in BIM-LCA integration. Studies also revealed that the integration of BIM and LCA is still in its initial stages, examining the drivers and barriers to BIM-based LCA implementation. Future studies can further explore the relationships among these drivers and barriers and their influence on the development of BIM-based LCA by using methods such as structural equation model.

4.2 Data Analysis

Most utilization of BIM-based LCA in current studies can be group into: the use of BIM models for the quantification of building elements; the development of plug-ins installed into BIM software; and automatic integration with a combination of BIM software and LCA tools. Most of the studies only investigate the former two approaches. Additionally, in order to solve the problems of data compatibility, all relevant components along with geometrical characteristics and environmental performance are recommended to be contained in a material and components library for standardized use [56], but there is a lack of consensus on the integration means among physical and environmental characteristics [38]. Further studies should be explored to adapt BIM model database to the LCA data structure to improve the information management and data transfer. The studies also evidenced that only several stages were included in LCA analysis and revealed the difficulties of including all stages into the BIM-based LCA. In future studies, great efforts should be made to comprehensively comprehend the integration patterns among them so as to develop an appropriate integration method of BIM and LCA tools for a building from the initial phase to the end of life phase to respond the poor interoperability between BIM and LCA techniques.

4.3 Data Output and Interpretation

According to the reviewed papers, only a few studies considered a cradle-to-grave LCA analysis in terms of costs and environmental impacts. Additionally, environmental or economic impacts have been emphasized in LCA analysis, while social dimension has been under researched, which poses a limitation as it disallows building users or designers to make realistic and reasonable decisions based on stakeholders' perception conditions. Further studies should be conducted to incorporate environmental performance, economic efficiency and social impact into a framework for LCA analysis. Considering building material and components revealed another problem that users or designers must select the optimum combination of building components out of thousands of combinations to meet the optimum multi-objectives. Research efforts ought to be placed to establish a multi-objectives decision making system that help the designers or users make sustainable and eco-friendly decisions, evaluate both environmental performance, cost and social well-being from the cradle to the grave, and select the optimum alternative design.

5 Conclusion

BIM-based LCA integration is a keyway to improve sustainability performance of buildings. This study conducted a critical review of historical BIM-based LCA studies based on qualitative content analysis. The research results have described 8 research sub-topics within the research topics of integration methods of BIM and LCA and BIM-based LCA application, contributing to understanding BIM-based LCA issues and facilitating the application of LCA analysis in the building sector. Based on the literature review, a variety of research gaps have been identified and further research directions have been proposed. In data input aspect, the data extracted from BIM model needs to be manually enriched and organized. In data analysis aspect, data transfer between BIM and LCA tools is still insufficient; nor is it clear how to realize accurate data mapping between BIM and LCA database. Further studies should investigate the automatic environmental performance assessment over the life cycle of buildings, which may be supported by the development of a building material and components library. In data output and interpretation aspect, research has ignored the trade-off among costs, environmental impacts and social well-being, instead focusing on environmental or economic impacts. Future studies should integrate these three dimensions to support decision-making analysis of alternative designs and achieve a comprehensive understanding of sustainable performance of buildings.

Suggestions have been provided related to the improvement of BIM-based LCA. Future studies should investigate such questions as how to provide sufficient data for LCA analysis, how to automatic transfer data and manage information, how to integrate BIM and LCA database, how to simultaneously consider environmental, economic and social impacts and create a balance among them, and how to support the decision-making analysis of alternative designs.

The limitation of this study is that research findings are commonly fragmented, making it difficult to cover every detail, which will be rectified in future work. Despite this, the research contributes to a better understanding of the BIM-based LCA in the building sector.

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A Study on the Urban Multi-center Spatial Structure Based on POI Data—Taking Guangzhou as an Example

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Abstract Since the twenty-first century, China's urbanization has entered a period of rapid development. With the expansion of the city scale and the rapid population aggregation, the urban activity characteristics and development trend become more and more complex, and various "urban diseases" problems occur frequently, such as traffic congestion in the city center due to the excessive concentration of urban functions, low land utilization rate leading to housing shortage and soaring land prices. In order to alleviate the above problems, in recent years, most cities in our country adopt the multi-center development strategy for the spatial structure, but the multi-center theory still suffers from limitations in its localization applications. Compared with the traditional survey research methods, POI data brings about new insights and innovative methods for the study of urban spatial structure, with smaller measurement errors. Under the background of a huge subway transportation system and the construction and development of Guangdong, Hong Kong and Macao Bay area, the characteristics of its urban spatial structure and the development degree and trend of each center will be more special. This paper took Guangzhou City as an example, which is a megacity with rapid expansion of urban space. Based on the reorganized POI data crawled from Baidu map open platform, we adopted spatial kernel density analysis method and DBSCAN clustering method. Considering the multi-center structure characteristics of Guangzhou city, using ArcGIS software, this paper studied the overall layout of Guangzhou City as well as its structural characteristics of the following five kinds of urban functional spaces: living, business, employment, culture education and leisure. The results of this study showed that: (1) The polycentric spatial structure of Guangzhou is composed of many factors; (2) there exists a clear evidence that the urban spatial structure of Guangzhou has a typical multi center structure, with a circular distributions of denser inside and sparser outside; (3) different functional spaces present a multi-center structure with certain differentiations; (4) the centers of Guangzhou can get rid of unbalanced development problems by means of "unban coordination".

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1 Introduction

Since the twenty-first century, China's urbanization has entered a period of rapid development. With the expansion of the city scale and the rapid population aggregation, the activity characteristics and development trend of the city become more and more complex, and various "urban diseases" problems occur frequently, such as traffic congestion in the city center due to the excessive concentration of urban functions, low land utilization rate leading to housing shortage, land price soaring, etc.

In order to alleviate the above problems, the polycentric development differentiation of urban internal spatial structure has replaced the traditional "single center spread type" and become the new normal of urban development in China [1]. However, Guangzhou has a huge subway transportation system and has become a big bay of Guangdong, Hong Kong and Macao Under the background of district construction and development, the characteristics of urban spatial structure and the development degree and trend of each center will be more special. In the process of global urbanization, the development concept of polycentric urban spatial structure has been widely applied and practiced, and has become a hot spot in urban planning [2]. However, in 2012, polycentric cities have accounted for more than 52% of all prefecture level cities, but there are still some defects in localization, which need to be improved [3]. Therefore, it is of great significance to study the polycentricity of urban spatial structure for the transformation of global urban spatial pattern.

This study takes Guangzhou City as the research object, based on the geo spatial data of Baidu map POI and other Internet era, to measure the urban function of the study area, and find the differences and connections of multi center functions. This study aims to achieve the following goals: (1) Based on Baidu map POI and other multi-source data, this paper explores the current multi center development status and future development trend of Guangzhou, identifies the functional polycentric spatial structure of Guangzhou, finds out its existing problems and puts forward reasonable suggestions, so as to provide certain guidance for future urban development and planning. (2) Based on the identified urban polycentric spatial structure of Guangzhou, this paper studies the development status of Guangzhou's polycentric situation, analyzes the functional differences and connections between the centers, puts forward suggestions for the urban development planning of Guangzhou, and broadens the thinking angle and research content of urban polycentric theory.

2 Literature Review

2.1 Application of POI in Urban Spatial Structure Research

POI, Point of Information. POI data is the real geographic point data with spatial attribute information. At present, it mainly focuses on urban spatial structure and functional area identification. Jiao and other scholars [4] reclassified POI data, identified urban single functional area and mixed functional area quantitatively and realized visualization. Zhang [5] proposed the change law of urban dynamic space and the mechanism of related factors. Jiachuan Fang [6] proposed a POI based approach to measure walking accessibility and obtained its overall spatial distribution characteristics. Yang [7] analyzes the spatial differentiation and spatial correlation characteristics between urban centers with different functions. The latest research applies POI to the study of regional economic linkage development, such as Wu [8] to study the structural characteristics of seven types of urban functional space in Greater Bay Area. The emergence of POI data has brought new perspectives and innovative methods to the study of urban spatial structure, but the related research is still in its infancy. At present, there are few researches on urban multi center spatial architecture based on POI data.

2.2 Polycentric Theory and Its Development

Polycentric urban structure first appeared at the end of the nineteenth century, which refers to the cluster distribution pattern of urban population and economic activities under the guidance of multiple urban centers at different levels [9]. Howard proposed that when a city reaches a certain size, its growth is limited, and it is integrated into the combination of regional groups, and the part of sustained growth should be accepted by another smaller neighboring city [10]. Khiali-miab [11] found that there is a close relationship between the hierarchical organization of functional links in metropolitan areas and the socio-economic status of these areas by implementing modular maximization algorithm on the settlement network. Homsy and Warner [12] Analyzed 1497 cities in the United States, and found that the internal driving force of municipal action is insufficient, and the polycentric theory can be applied to the adoption of sustainable policies. Mudliar [13] created a polycentric structure by designing power. The research results show that it is very important to improve the understanding of environmental conditions more suitable for polycentric governance to improve the theory and governance.

2.3 Research on Urban Spatial Structure

Many scholars at home and abroad have made a deep research on the characteristics and influencing factors of urban spatial structure. Zhang et al. [14] made spatial and statistical analysis by using ArcGIS and SPSS software, and discussed the spatial and temporal pattern of Guangzhou shopping center development and its relationship with the change of urban commercial spatial structure. Veneri [15] analyzed the urban spatial structure and trend of OECD from 2001 to 2011 using the standardized definition of urban functional areas of 29 OECD member countries. In relatively low density areas close to major centers and near sub centers, population growth is greater. Krehl and Siedentop [16] discussed the multi-dimensional urban spatial structure and proposed a two-level quantitative urban (sub) center typology.

The research on the spatial structure of Guangzhou mainly focuses on the factors influencing the distribution, evolution and development law of spatial structure, while the research on quantitative statistical analysis of urban spatial structure based on statistical data is less. The emergence of big data just makes up for this weak link. Therefore, the quantitative analysis of data is particularly important for Guangzhou multi center architecture.

3 Research Design

3.1 Overview of the Study Area

The study area is 11 districts under the jurisdiction of Guangzhou, as shown in Table 1.

Favorable economic conditions. The continuous optimization of industrial structure has laid a good economic foundation for the formation and development of urban polycentric space. It has political advantages. In today's background of opening to the outside world, it has strengthened the hub position of Guangzhou. Convenient transportation. The advantaged traffic conditions strengthen the connection between Guangzhou and the outside world, and provide external guarantee and advantages for the development of multi center space. The construction of Guangdong Hong Kong Macao Bay area and economic circle. Guangzhou is the core city of Greater Bay Area. It is the best bridge and link to connect and radiate the mainland, and accelerate the formation of multi center urban space. At present, the development space of Guangzhou is also further expanded. With the Belt and Road Initiative and the construction of the city of Guangzhou, Hong Kong and Macao, plus the original superior political, economic and social conditions, the industry of the city will also be upgraded and optimized. The "one center" urban space mode is gradually not suited to the new pattern of urban economic and social development. This also lays a solid foundation for the development of the city's multi center space.

Table 1 Districts and its area of Guangzhou

District	Conghua	Zengcheng	Huadu	Baiyun	Panyu	Nansha	Huangpu	Tianhe	Haizhu	Liwan	Yuexiu
Area (km^2)	1974.5	1616.0	970.0	795.8	786.2	527.7	484.2	96.3	90.4	59.1	33.8

Table 2 POI data composition of urban functional space in Guangzhou

Urban functional space	POI data type	Number
Living space	Real estate: residential area and dormitory; Life service; Medical treatment	72,287
Commercial space	Food; Hotel; Shopping; Beauty; Car service	112,225
Employment space	Corporate enterprises; Finance; Real estate: office buildings	68,115
Cultural space	Education and training; Cultural media	18,611
Leisure space	Scenic spot tourism; Leisure and entertainment; Sports and fitness	23,355

Data source Baidu map (http://lbsyun.baidu.com/index.php?title=lbscloud/POItags)

3.2 Data and Sources

The POI data used is obtained from Baidu map open platform. The original data includes 19 first-class industry types, including food, hotel, shopping, life service, beauty, tourist attractions, leisure and entertainment, sports and fitness, education and training, cultural media, medical treatment, automobile service, transportation facilities, finance, real estate, companies and enterprises, government agencies, entrances and exits, and natural features. In order to study the functional structure of urban space in Guangzhou, the data were reorganized from five aspects: living space, business space, employment space, science and education culture space, leisure space (Table 2).

3.3 Research Methods

The research methods of this paper are kernel density clustering analysis and DBSCAN clustering analysis. Among them, Kernel density clustering can be realized in the kernel density analysis tool in the toolbox of ArcGIS platform. The parameter setting mainly includes the selection of weight field, output pixel size and search area. The kernel density analysis tool is mainly used to calculate the distribution density of elements in its surrounding neighborhood. This tool can not only calculate the density of point features, but also the density of line features.

The basic principle of kernel density clustering method is to take point P as the center of the circle and R as the threshold radius. The amount of data in the range of the circle formed by P and R is counted and divided by the area. The calculation formula is as follows:

$$P(x) = \frac{\sum_{i=1}^{n}\left\{K\left[\frac{d(x,x_i)}{h}\right]\right\}}{nh}$$

where n is the total amount of data; K is the kernel density function; h is the threshold value; $d(x, x_i)$ is the Euclidean distance between two points.

DBSCAN (density based spatial clustering of application with noise) algorithm is a typical representative of density clustering, which is proposed by ester et al. The biggest advantage of DBSCAN algorithm is that the clustering speed is fast, and it can effectively deal with noise points and find spatial clustering of arbitrary shape; it can effectively solve the problem of large amount of data, overlapping and covering of interest points, find its distribution law from the macro perspective and retain the location accuracy of data. DBSCAN algorithm mainly involves two parameters: PSE and min points. PSE refers to the radius of the research area. PSE is mainly determined by the Euclidean distance between objects and the distance of descending K. min points is the minimum value of objects in the domain given by users.

4 Analysis of Spatial Structure of Guangzhou

4.1 Identification and Analysis of Urban Function Type Center

Figure 1 shows the results of core density analysis of POI of various functional centers in Guangzhou.

4.1.1 Living Space

Living space is an important part of urban spatial structure. Living space not only has the manifestation of spatial geographical position, but also contains the social relations of each space, which has an important impact on the formation and evolution of urban spatial structure. According to the POI feature classification provided by Baidu map, the POI of living space in Guangzhou mainly includes real estate (residential area and dormitory), life service and medical treatment. We analyzed the number, proportion and distribution density of POI in each district. At the same time,

(a) Living Space (b) Commercial Space (c) Employment Space (d) Cultural Space (e) Leisure Space

Fig. 1 Analysis on the core density of urban functional centers

Table 3 POI distribution of living space and the proportion of various types in Guangzhou

District	Number of POI	Proportion (%)	Distribution density (per km^2)	Real estate (%)	Life service (%)	Medical treatment (%)
Baiyunt	11,468	16.83%	14.41	39	44	17
Conghua	3082	4.52%	1.56	51	38	11
Huadu	10,610	15.57%	10.94	62	28	10
Huangpu	5172	7.59%	10.68	42	46	12
Liwan	3082	4.52%	52.15	51	30	19
Tianhe	7531	11.05%	78.18	54	31	15
Yuexiu	2235	3.28%	66.12	55	20	25
Panyu	11,353	16.66%	14.44	47	40	13
Zengcheng	5108	7.49%	3.16	38	46	16
Haizhu	5295	7.77%	58.57	48	33	19
Nansha	3219	4.72%	6.10	38	50	12
Total	68,155	100%		48	37	15

through further data processing, we analyzed the proportion of POI of real estate, life services and medical services in each district, as shown in Table 3.

In terms of quantity, Baiyun District, Panyu District and Huadu District rank in the top three. In terms of density, there are four areas with a height of 50 per km^2, which are 78.18 per km^2 in Tianhe District, 66.12 per km2 in Yuexiu District, 58.57 per km^2 in Haizhu District and 52.15 per km^2 in Liwan District. According to the data, the old urban area of Guangzhou and Tianhe District, which has developed rapidly in recent years, are densely distributed in living and living areas. We can analyze the characteristics of POI: (1) The proportion of real estate in Huadu District is the highest, accounting for 62%, while the medical support is the lowest in the whole city, only 10%; (2) In Baiyun District, Huangpu District, Zengcheng district and Nansha District, the proportion of real estate is lower than the average level of the whole city, while the living service category is higher than the average level of the whole city; (3) Yuexiu District is the only one in the city with more than 20% medical facilities, accounting for 25%.

4.1.2 Commercial Space

Commerce is an important part of urban function, as the main activity of urban citizens' life, it represents the level of economic development and the quality of life of citizens. The development of urban commerce is a dynamic process that changes with the improvement of urban construction. All elements of urban space play a traction role in the development of Commerce. The spatial scale, element combination and brand effect of Commerce evolve with the development level of the region. Commercial network is the carrier of urban commercial activities. Driven by market interests, commercial outlets spontaneously tend to be adjacent distribution in a certain place and form a business cluster area.

According to the characteristics of Baidu map POI data, the types of commercial space POI studied in this paper mainly include five types of POI data: food, hotel, shopping, beauty and car service. The distribution of POI is as follows in the Table 4.

It can be seen from Table 4 that the distribution of high-density areas of commercial space in Guangzhou is uneven. The high-density areas are mainly located in Yuexiu District, Tianhe District, Haizhu District and Liwan District. The commercial density of Conghua District, Zengcheng district and Nansha District is relatively low, while the areas with the largest proportion of commercial POI are Baiyun District, Panyu District, Huadu District and Zengcheng district.

Combined with Fig. 2c and Table 4, it can be seen that the southwest of Guangzhou has formed a belt shaped high-density agglomeration area. The commercial POI density of these areas is more than 50 per km^2, while Nansha District has not yet formed a large-scale commercial POI cluster. Zengcheng district and Conghua district are distributed with relatively scattered commercial agglomeration areas.

4.1.3 Employment Space

As the foundation of people's livelihood, employment is the most concerned problem of ordinary people. The level of employment is an important indicator to investigate the macro-economic level of a region. The level of employment directly affects people's living standards. Therefore, it is of great significance to study the spatial distribution of urban employment for the development of people's livelihood.

In Baidu map POI, the employment space in Guangzhou is a combined space system formed by companies, financial institutions, real estate and office buildings. The distribution of POI points in Guangzhou's employment space is as shown in Table 4. The POI data of Guangzhou's employment space is characterized by high density and contiguity. Haizhu District, Tianhe District, Yuexiu District and Liwan District form high POI point density continuous belt, Panyu District and Huangpu District form sub density continuous belt; Conghua district and Zengcheng district only form two high density areas, but do not form continuous belt. Secondly, the POI data of Guangzhou city is highly hierarchical, and the regions with more developed economy and higher population density have higher employment space density, which conforms to the objective law. In addition, the Employment Spatial interest points of Guangzhou are obviously dense in the South and sparse in the northeast.

4.1.4 Cultural Space

The geographic information data collection of cultural space is mainly located in education training and cultural media, that is, the space occupied by urban educational

Table 4 Distribution of POI in commercial space of Guangzhou City

District	Commercial space			Commercial space		Leisure space		
	Quantity	Proportion	Density (per km^2)	Quantity	Density (per km^2)	Quantity	Proportion	Density (per km^2)
Baiyun	22,337	19.99%	28.07	12,805	16.09	3786	16.21%	4.76
Conghua	6186	5.54%	3.13	2377	1.20	957	4.10%	0.48
Huadu	13,084	11.71%	13.49	8016	8.26	1764	7.55%	1.82
Huangpu	8618	7.71%	17.80	6191	12.79	1356	5.81%	2.80
Liwan	3905	3.50%	66.07	3293	55.72	1696	7.26%	28.70
Tianhe	10,594	9.47%	109.98	6410	66.54	2721	11.65%	28.25
Yuexiu	3932	3.52%	116.33	3045	90.09	1917	8.21%	56.72
Panyu	17,954	16.07%	33.88	11,788	14.99	4275	18.30%	5.44
Zengcheng	11,650	10.43%	7.21	5521	3.42	1482	6.35%	0.92
Haizhu	7493	6.71%	82.89	4397	48.64	2516	10.77%	27.83
Nansha	5973	5.35%	7.62	4271	8.09	885	3.79%	1.68
Total	111,726	100%				23,355	100%	

research and cultural service institutions, such as primary and secondary schools, scientific research institutions, art venues, cultural institutions, etc. According to the thermal map, the POI of Guangzhou's science and education culture space is mainly concentrated in the southwest region, showing the characteristics of high-density contiguity. Among them, Yuexiu, Tianhe and Haizhu districts are extremely dense and should have certain cultural competitiveness. Although Panyu district is only in the sub density continuous zone, the Guangzhou University City within it has great influence on the whole Guangzhou and even the surrounding areas. In addition, the density of Huadu, Zengcheng and Conghua districts is relatively small, in which the cultural spatial distribution of Huadu and Zengcheng tends to the direction of the city center, while the northeast area is rarely distributed; Conghua district does not form a cultural space gathering area and is lack of competitiveness. On the whole, cultural space tends to be distributed in areas with high economic level and high population density, which conforms to the objective law.

4.1.5 Leisure Space

As an important part of urban space structure, leisure space has become one of the important symbol spaces to measure the quality of life in modern urban space. Generally speaking, urban leisure space is a spatial system composed of physical space, leisure behavior space and social space.

In Baidu map POI, leisure space POI mainly includes scenic spot tourism, leisure entertainment and sports fitness. The distribution of POI is as follows in Table 4. We analyze the climbing results of POI in Guangzhou leisure space from the perspective of quantity and density. First of all, in terms of quantity, Panyu District, Baiyun District and Tianhe District ranked the top three, accounting for 18.30%, 16.21% and 11.65% respectively. In terms of density, there are four areas with more than 20 per km^2, which are Yuexiu 56.72 per km^2, Liwan 28.70 per km^2, Tianhe 28.25 per km^2 and Haizhu 27.83 per km^2. According to the data, the old urban area of Guangzhou and Tianhe District, which has developed rapidly in recent years, are densely distributed in leisure space.

The POI data of leisure space in Guangzhou is characterized by high density and contiguity. Haizhu District, Tianhe District, Yuexiu District and Liwan District form high POI point density continuous belt, Panyu District and Huangpu District form sub density continuous belt; Conghua district and Zengcheng district only form two high density areas, but do not form continuous belt. Secondly, the POI data of Guangzhou city is highly hierarchical, and the regions with more developed economy and higher population density have higher employment space density, which conforms to the objective law. In addition, the interest points of leisure space in Guangzhou are obviously dense in the South and sparse in the northeast.

4.2 Analysis on the Characteristics of Guangzhou Polycentric Structure

4.2.1 Multi Center Layout and Circle Development

The urban space of Guangzhou conforms to the model of "multi center, group type" and "overall dispersion and local concentration", and is affected by the landscape and terrain pattern in Guangzhou. The high-density areas of urban POI are mainly distributed in the core area with "Yunshan Zhushui" as the center, with scattered peripheral layout and low POI distribution intensity. Combined with the development of the city, the traditional polycentric pattern of Guangzhou is centered on Yuexiu District and Liwan District, and then extended to the core density zone composed of Yuexiu District, Liwan District, Haizhu District and Tianhe District. After that, the main axis of urban development moved eastward, especially the construction of Zhujiang New Town and the merger of Luogang District and Huangpu District, which promoted the development of the main city center to the East. Baiyun District, Panyu District and Huangpu District form secondary density belt, while Huadu District, Conghua District, Zengcheng district and Nansha District form relatively scattered peripheral centers.

4.2.2 The Polycentric System is Dense Inside and Sparse Outside, with Radial Distribution

The development degree of each center in Guangzhou is not balanced. The core density zone and secondary density zone have concentrated elements and strong development ability. As the original center of Guangzhou, Yuexiu District and Liwan District have reduced their commercial and employment functions, but they are still important space for life and culture. The construction of Pearl River new town makes Tianhe North to the Pearl River edge become the absolute center of Guangzhou's economic development. From the composition of POI, Tianhe has become an important gathering place for business, employment and leisure activities. Wushan university town makes Tianhe District have a strong gathering ability in the field of culture and education. Baiyun, Panyu and Huangpu have successfully become secondary density zones relying on the trickle down effect of the core belt. On the contrary, Huadu, Conghua and Zengcheng in the periphery are lack of power and slow development due to the gravity of the core density belt.

The core center of Guangzhou is forming a radial connection with the peripheral center. It can be seen from the thermal diagram that four chain links with Yuexiu District, Liwan District and Tianhe District as the center of gravity are forming. They are: Tianhe District Haizhu District Panyu District Nansha District in the south, Tianhe District Haizhu District Huangpu District Zengcheng District in the East, Liwan District Baiyun District Conghua District in the northeast and Liwan Baiyun Huadu District in the north. This is also in line with the eight character policy of

Guangzhou's overall urban development strategy, i.e., to give priority to the north and expand to the south, and to join the East and the West.

4.2.3 Adjacent Association and Regional Cooperation

Improving the complexity of urban functional space is an important goal of spatial structure optimization. To improve the complexity of urban functional space, it is necessary to comprehensively and effectively lay out the elements of various industries, improve the supporting system of various service elements, strengthen the guidance of traffic network to urban functional space, reduce the pressure of commuting, and strengthen the links between different regions, so as to promote sustainable development.

Guangzhou is solving the problem of unbalanced development of various centers. Yuexiu District takes advantage of the "Western Union" strategy of "Guangzhou Foshan City", and Xintang Town in Huangpu District has become a hot area of "eastward" in the secondary dense belt. Nansha District is one of the three major free trade zones in Dawan district.

5 Conclusion

Based on the POI data of Guangzhou, this paper uses cluster analysis and kernel density analysis to identify the spatial distribution characteristics of polycentric structure and different functions of Guangzhou city. From the perspective of urban and rural planning, this paper discusses the evolution mechanism of Guangzhou polycentric spatial pattern. The conclusions are as follows:

1. There are many factors in the formation of polycentric spatial structure: ① there is a new urban land development market, which can make large-scale migration of enterprises and workers, and make a judgment on when and where to carry out new town development through market mechanism; ② The physical and geographical conditions of the city have great heterogeneity, so it is necessary to form a new city center by leaps and bounds; ③ there are other cities and towns nearby, and the extension development of the central city is gradually continuing with them.
2. The spatial structure of Guangzhou city has a typical multi center structure, which is ring-shaped with dense inside and sparse outside. Among the core density zones, the concentration of POI in Yuexiu District, Liwan District, Tianhe District and Haizhu District is relatively high, the urban spatial elements are concentrated and continuous, and the urban activities are active; Baiyun District, Panyu District and Huangpu District become the core density belt of sub density belt due to the drip effect. Huadu District, Conghua District, Zengcheng district and Nansha District form relatively scattered peripheral centers.

3. Based on the POI analysis of different functions, Guangzhou's residential space, business space, employment space, culture and education space and leisure space also show a multi center spatial pattern, but there are some differences among the five.
4. Improving the complexity of urban functional space is an important goal of spatial structure optimization. Guangzhou can take advantage of the strategic opportunity of regional integration to get rid of the unbalanced development of various centers.

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Organizational Interaction and Dilemma Governance Strategies in Response to the COVID-19 Epidemic

Lin Yang, Xinran Hu, and Jiaming Lou

Abstract Frequent public emergencies are the significant symbol of risk society with serious social hazards. When public emergency responses are poor, the governance capabilities of relevant organizations face serious challenges in terms of heavy casualties, property losses, personal psychological shocks, and so on. Various organization dilemmas both cause and are intensified by organizational interaction abnormality or failure during the overall dilemma-governance process. As an acute respiratory infectious disease, the Coronavirus Disease 2019 (COVID-19) has been causing worldwide infections since early 2020. It is a catastrophic public health emergency that is threatening the entire world. Thus, there is an urgent need to study interactions between organizations, as well as dilemma-governance strategies used to deal with the epidemic. Organizations related to epidemic prevention and control must be identified from epidemic-related online texts by data collectors, and the topic-oriented web crawler method is used to provide organizational interaction data to model the complex network of organizational interactions during the COVID-19 epidemic. In addition, the overall characteristics of the network should be analyzed with respect to network parameters such as degree, betweenness, and eigenvectors. Finally, fault analysis based on relative scales of maximal connected components must apply to determine critical nodes and edges to facilitate the formulation of dilemma-governance strategies. The paper provides innovative theoretical support for complex network application in public dilemma governance.

Keywords Organizational interaction · COVID-19 epidemic · Complex network · Dilemma-governance strategies

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1 Introduction

Public emergencies that threaten public security may cause heavy casualties, loss of property, environmental damage, and social instability [1]. Every year, enormous worldwide direct losses are caused by public emergencies, potentially leading to long-term damage. For instance, in 2011 the September 11 attacks reduced economic growth rate by one percent, causing losses of USD 350 billion and deep psychological frustration for Americans. In March 2020, the forest fires in Xichang city led to heavy pollution in areas more than three hours away from the epicenter. Due to their suddenness, variety, destructiveness, and persistence [2], public emergencies present a serious challenge to the emergency management systems and capabilities of each country.

In social and economic transition, the development and influence of public emergencies has two main characteristics. (a) As global development enhances international and interpersonal co-movements, the dispersal of information and conflicts increases rapidly [3]. (b) The popularization of the Internet and enhancement of social media abilities, while enabling public institutions to disseminate urgent warnings, makes it difficult to control misinformation and rumors [4]. In the context of a floating population and individual demands, public emergencies can emerge suddenly and escalate rapidly; the frequent occurrence of public emergencies goes hand-in-hand with the global economy and the complexity of contemporary society [5]. Unless appropriate measures are taken at the outbreak of a public emergency, the later stages can have a negative impact on the stability of the social order. Hence, public emergencies challenge the governance capabilities of the organizations involved, and the question of how to manage them is important and urgent.

In early 2020, the COVID-19 outbreak lead to a global pandemic of acute respiratory infectious disease. The disease first broke out in Wuhan, China, and it demonstrates the importance of effective cooperation among different stakeholders in dealing with public emergencies [6]. As a result, the study of COVID-19 contributes to research on governance strategies for public emergencies. Focusing on the outbreak in Wuhan, this study identified important participants, defined and quantified interactions among organizations, and built a complex network to represent how organizations interacted to cope with the pandemic. Drawing on an analysis of network cohesiveness, centrality, and structural holes, the network structure and properties of the nodes were determined and will be useful in developing appropriate strategies for dealing with future emergencies.

2 Literature Review

2.1 Governance Methods

Since the outbreak of the pandemic, domestic and foreign scholars have attempted to find the most effective ways of responding to the emergency, and macro-policy has been explored from the perspective of governance. To cope with public emergencies such as COVID-19, Wen [7] argued that consensus must be achieved among Party committees, governments, social organizations, non-government organizations, and other stakeholders. Consensus in these areas will help to build a social community with its origins in the governance of governments, the autonomy of communities, and the co-governance of social organizations. At the local government level, Gao and Yu [8] emphasized the need for information transparency, greater preparedness for making decisions, and collaboration between stakeholders besides bureaucrats; all three factors are critical for improving public crisis governance. Agile and adaptive governance are factors in the speed of response and the operation of government at the systemic level, but these may come into conflict during a crisis [9]. Comparing strategies used in East Asia, Shaw et al. [10] showed that community behaviors had an important effect on the governance of COVID-19.

Research has also been carried out in the context of different professions, public health information platforms, advanced medical systems, and the new media. Sun and Wang [11] examined the finance and tax strategies that were proposed in the acute response stage and the medium term, applying the practice of related financial departments to the framework of financial reform and development. Information technology has a substantial influence on the national health information system, and Wang et al. [12] analyzed the basic principles of the system in terms of the Internet of Things and AI, taking technical conditions, target value, and decision mechanism as variables. Ohannessian et al. defined the telemedicine framework as a way of improving the status of public health governance [13]. Community governance has been the focus of much attention during the COVID-19 crisis, and many measures have been proposed to secure public health [14]. Public opinion on the Internet and social media may lead to huge social and economic issues if the quality and control of information is poor. Hence, Xing and Li [15] focused on national governance as guidance, on organizational behaviors and prevention as a point of emphasis, and on value orientation as a turning point.

Although much research has been carried out on COVID-19, it remains difficult to explain, either in terms of macro-policies or of research in professions, the most efficient ways to respond to a crisis and to ensure effective cooperation among multiple organizations. In contrast to previous research, network analysis, including the long short-term memory network proposed, helps track and forecast future COVID-19 outbreaks [16]. Aside from complex network (CN) theory, few methods are capable of taking account of the complex interactions involved. CN is superior to the social network analysis (SNA) in that the nodes and links of a CN can be defined as required. Therefore, CN theory was adopted to visualize the complex interactions among related organizations and to identify suitable strategies for responding to public emergencies.

2.2 Organizational Dilemma Governance in Public Emergencies

The capabilities and administrative boundaries of the organizations involved in public emergencies remain obscure [17], and both cooperation and competition played a role in organizational interactions during the COVID-19 crisis [18]. The traditional central governance model cannot handle public emergencies that change from day to day, and cooperative governance that interacts among diverse organizations has come to the fore. It has often been argued that improving the outcomes of public emergencies depends on stakeholder participation and harmonious interactions [19–21]. Inter-organizational collaboration is essential [22]; it allows resources to be integrated and knowledge and experience to be shared, thus achieving an appropriate allocation of responsibilities.

Organizational interactions within the response to COVID-19 aimed to address three kinds of issues. (1) The first issue was trust. The degree of trust in governments directly affected the implementation of emergency measures. For instance, local governments did not implement emergency measures early enough, and there was a general lack of transparency. However, efficient group discussion has been shown to enhance inter-organizational cooperation and reduce conflicts of interest [23]. (2) The second issue was interaction between multiple organizations. The usual principles of collaboration may not apply under emergency conditions, and in this case government interventions were hindered by multifactor leadership, individual self-interest, and information asymmetry [24]. A lack of clear regulations determining the responsibilities of social organizations (for victims, volunteers, and media) also disrupted attempts to deal with COVID-19 [25]. (3) The third issue was the post-truth status of information. Public sentiment can exert a significant influence on social stability [26], especially when based on unsubstantiated reports from sources other than the mainstream media.

Given the complexity of public emergencies, public safety is under constant threat from a number of issues, both external (such as the fragility of infrastructures and lack of emergency resources) and internal (including structural imbalances within organizations, unclear structures of power and responsibility, and low levels of cooperation) [27]. In this connection, qualitative research has focused on public management theory and case studies. Blackstone et al. [28] focused on regional governance in public disaster recovery and argued that competition from private capital could be helpful in perfecting a system of governance. Drawing on data from 30 provinces in China, Wu et al. [29] observed that non-government organizations play a significant role in environmental governance.

CN and SNA have also been used to quantify governance research on public emergencies. Deng et al. [30] built models to handle emergency accidents based on cyber-physical systems, whose effectiveness was demonstrated in a well-known explosion accident in Tianjin, China. In the context of tourism emergency events, He and Zou [31] measured and analyzed the traits of a cooperation network, identifying efficient strategies for managing interaction among organizations. Chen et al. [32] proposed a governance model in line with the low trust cost in China, offering a cross-sectional analysis of major developed countries. When responding to the COVID-19 crisis, governments and competent authorities had to work to contain the spread of rumors and to prevent psychological shock [33].

This review of the literature provides a strong theoretical basis for this study, showing that, in contrast to SNA, CN allows for a more complex organizational structure and presents organizational interactions in ways that can guide the practice of governance.

3 Data Sources and Network Modeling

As the COVID-19 pandemic continues to spread around the world, its governance has become a priority for every industry. Within a huge governance system, diverse organizations interact with each other in complex ways. To date, qualitative research on organizations and their interactions has not fully met the demands of modernizing state governance and adapting it to specific circumstances. This indicates that quantitative methods should be applied to compensate for the domestic weakness in governance during COVID-19, which has been characterized by strong theoretical claims and weak practical strategies. To avoid the limitations of using a questionnaire survey, including design difficulties, low reliability, and short time spans, the data were obtained by text mining the websites of the Hubei Provincial Government and National Health Commission. Organizations and interactions were identified in the period between January 1, 2020 and May 19, 2020 and then refined and quantified according to the frequency of keywords.

As shown in Table 1, organizations were divided into 10 types, in which social organizations consisted of enterprises, communities, and logistics and e-commerce companies. Because of their different functions, their ratios were calculated separately. Interactions were sorted into 15 categories, and the interactions for COVID-19 are illustrated in Fig. 1. In this study, interactions that took place in e-commerce companies and enterprises were defined as production interactions; project-based information transmission was used to represent the relationship between construction organizations and medical institutions; and information transmission for COVID-19 was used to represent the relationships among the media and other stakeholders.

NetMiner was used to visualize the CN for COVID-19, as shown in Fig. 2. The network consisted of a total of 31 nodes and 600 links, and its characteristics were subjected to parameter analysis to determine how these organizations responded to the pandemic.

Table 1 Definitions and proportions of organizations and interactions involved in the COVID-19 response

Category	Ratio	Organizations/coding	Interactions	Ratio
Government	0.177	Governments (G)	Instructions	0.067
Medical institutions	0.187	Hospitals (M1) Medical teams (M2) Medical post stations (M3) Medical companies (M4) Blood centers (M5)	Material donations	0.074
Media	0.086	Media (MD)	Material transportation	0.068
Construction organizations	0.171	Hubei Industrial Construction Group Co., Ltd (C1) CITIC General Institute of Architectural Design and Research Co., Ltd. (C2) Wuhan Real Estate Group (C3) China Construction Third Engineering Bureau Co., Ltd (C4) CCCC Second Navigation Bureau (C5) Central-South Architectural Design Institute (C6) Wuhan Airport Development Group (C7) China Railway Heavy Industry Co., Ltd (C8) Wuhan Construction Engineering Co., Ltd (C9) Municipal corporations (C10) Equipment suppliers (C11)	Working reports	0.063
Scientific research teams	0.017	Scientific research teams (S)	Loan businesses	0.049
Welfare organizations	0.033	Psychological aids (P1) Charitable organizations (P2)	Psychological services	0.099
Financial institutions	0.035	Financial institutions (F)	Production interactions	0.027
Colleges	0.049	Colleges (U)	Financing assurance	0.006
State-owned enterprises	0.004	Sinopec Group (S1) China Oil & Foodstuffs Corporation (S2) Communications companies (S3)	Finance discounts	0.004

(continued)

Table 1 (continued)

Category	Ratio	Organizations/coding	Interactions	Ratio
Social organizations	0.109	Small and medium-size enterprises (O1)	Support services	0.039
	0.071	Communities (O2)	Project-based information transmission	0.042
	0.026	Logistics companies (O3)	Technical interactions	0.004
	0.019	Hotels (O4)	Economic supports	0.009
	0.014	E-commerce companies (O5)	Meetings	0.178
			Information transmission of COVID-19	0.271

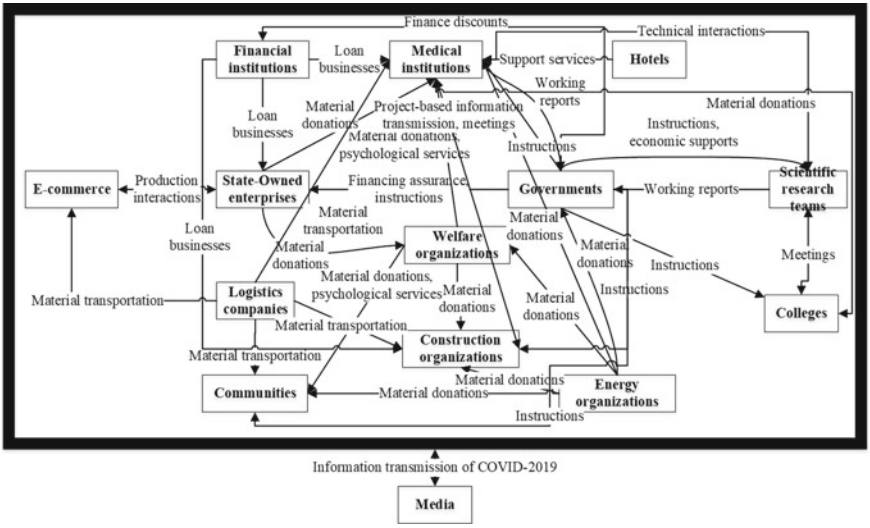

Fig. 1 Organizational interactions in COVID-19

4 Parameter Analysis

CN has been applied to many fields, including power networks, aviation systems, computer systems, and the human nervous system. The topological structure and kinetic characteristics of nodes determines the function of a CN [34]. As an interdisciplinary tool, CN offers a direct visual perception and a more complete understanding of problems. As Table 2 shows, a total of 18 parameters were analyzed in this study.

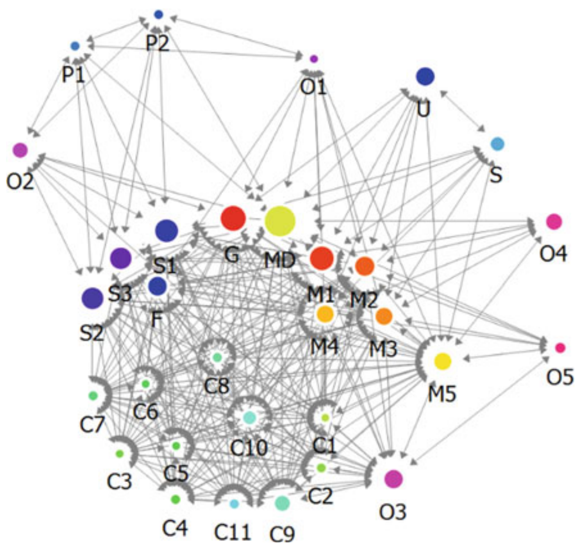

Fig. 2 Complex network of organizational interactions during COVID-19

4.1 Network Cohesiveness

Using graph density, average clustering coefficient, average path length, network diameter, modularity, and k-core, this study evaluated organizational cohesiveness and characteristics when faced with COVID-19. The network density was 0.645 in Gephi visualization software, indicating that all organizations had conducted relatively active cooperation to prevent further spread of the virus. The average path length was 1.355, the diameter was 2, and the average clustering coefficient was 0.865, showing that this is a small-world network. Thus, although great numbers of people and organizations were involved, any given node can be reached from any other node in a small number of steps.

As shown in Fig. 3, this CN was divided into four modules: the government-leading module (e.g., governments, hospitals, and China Oil & Foodstuffs Corporation), the community-leading module (e.g., communities, psychological assistance, and logistics), the construction organizations module (e.g., the Hubei Industrial Construction Group Co., Ltd, China Construction Third Engineering Bureau Co., Ltd, and equipment suppliers), and the scientific research module (e.g., colleges). The modularity analysis suggested (1) that the CN of organizational interactions consisted of four evident cohesive groups, and thus that the coordination obstacle among stakeholders still existed after the outbreak of the pandemic; (2) that there was no cooperation barrier among organizations in the same industry, such as within the construction organization module or within the scientific research module; (3) that inter-organizational cooperation may be developed between different stakeholders, such as governments and medical companies, communities and media, and communities and psychological services, although the looseness of the ties may lead to

Table 2 Parameters of complex networks and their definitions

Characteristic	Parameter	Definition
Cohesiveness	Density	How close the network is to completeness
	Average clustering coefficient	The average of all clustering coefficients
	Average length path	The average distance between any pair of nodes
	Diameter	The maximum distance between any pair of nodes
	Modularity	Community detection algorithm
	K-core	Keep graph in which all nodes have a degree of at least k
Centrality	Degree	The number of links of a node
	Weighted degree	The degree of the node taking into account the link weights
	Clustering coefficient	The average of nodes embedded in their neighborhood
	Close centrality	The reciprocal of average distance for a specific node to all other nodes
	Eigenvector centrality	Regards nodes around nodes with large eigenvector centrality as key nodes
	Betweenness centrality	The degree to which each pair of nodes is on the shortest path
Structural holes	Constraint	The degree to which a node is constrained by a single relationship
	Hierarchy	The extent to which constraints are concentrated on one node
	Effective size	The difference between the network scale and redundancy of a node
	Efficiency	The ratio of the effective size to the actual size of a node
	PageRank	Ranking of node “pages” according to how often a user following links will non-randomly reach the node page
	Betweenness centrality	The degree to which each pair of nodes is on the shortest path

stability issues; and (4) that there was greater cohesiveness in the government-leading module than in the community modules. Under the government’s strong leadership, good cooperation was developed in medical, energy, food enterprise, and Party organizations. In contrast, the community module not only decoupled from the government-leading module but was also unable to play a full role in public governance. In addition, there was a sub-network of inter-organizational governance (Fig. 4), which had the biggest k-core (40) and showed the closest collaboration in the COVID-19 crisis.

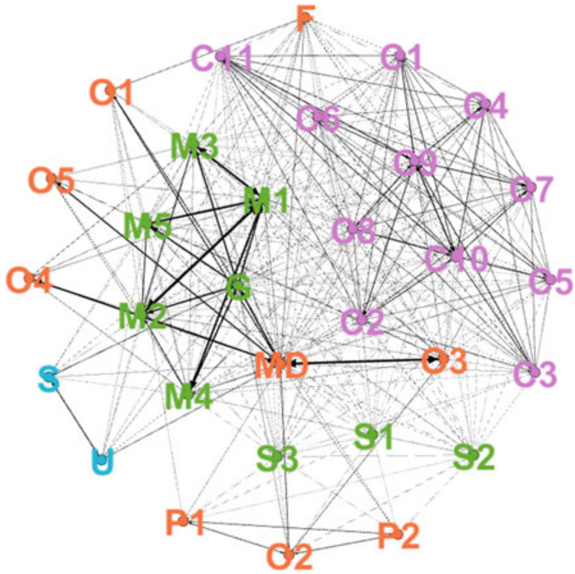

Fig. 3 Modularity of the complex network

As Fig. 4 shows, nodes belonging to the construction organization module and the government-leading module had the biggest k-core. For the community module, only media was in the sub-network. Furthermore, although contributions were made by scientific research teams and colleges, neither were at the core of governance. This confirms that basic governance capacities have been neglected. Similarly, these findings indicate that scientific research on the virus lagged behind government

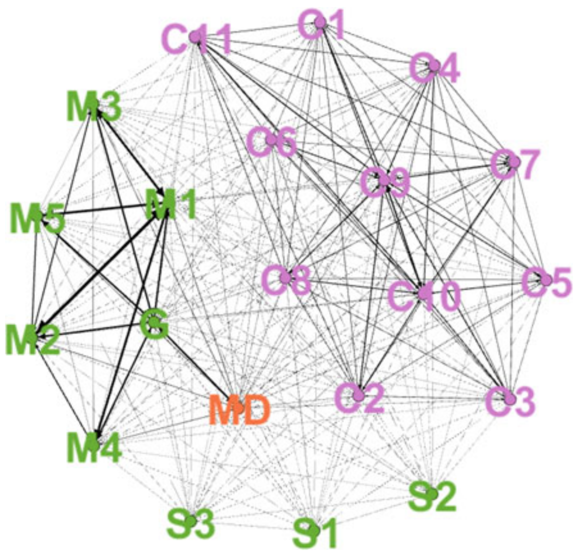

Fig. 4 Modularity of the core sub-network of the complex network

decision-making as well as the construction of medical infrastructure. The cohesiveness analysis shows that closer cooperation developed only among similar organizations and enterprises led by governments, and, more importantly, that governments had neglected the capacity for autonomy of social organizations.

4.2 Network Centrality

The centrality of the organizational interactions network can be assessed in terms of degree, weighted degree, clustering coefficient, close centrality, eigenvector centrality, and betweenness centrality. As Table 3 shows, the values for degree and weighted degree were calculated and ranked to identify the top active organizations: the media, medical institutions, and governments, followed by Sinopec Group, China Oil & Foodstuffs Corporation (COFCO), and communications companies. Therefore, in the early stages of the COVID-19 outbreak, the media surpassed the medical institutions and governments as the most connective organizations, and they contributed significantly to obtaining information. Nevertheless, wrong decisions and delays in medical actions prevented information exchange from operating as efficiently as possible, resulting in a crisis of public opinion and misguided opposition to governance plans. In addition, although energy enterprises (e.g., Sinopec Group), food enterprises (e.g., China Oil & Foodstuffs Corporation), and IT enterprises (e.g., communications companies) showed high degree values, the weights of their links were lower than for other organizations. In practical terms, these key industries played a vital role by providing material donations and relieving the shortage of emergency resources. It is therefore important to determine more productive ways to handle emergencies, such as cooperation on e-business platforms and pharmaceutical research.

Table 3 Degree and weighted degree

	Degree		Weighted degree	
	Value	Rank	Value	Rank
Media	60	1	0.790	1
Hospitals	54	2	0.739	2
Medical teams	54	2	0.532	5
Medical post stations	54	2	0.388	7
Medical companies	54	2	0.385	8
Blood centers	54	2	0.382	9
Governments	50	3	0.693	3
Sinopec Group	46	4	0.024	29
China Oil & Foodstuff Corporation	46	4	0.024	29
Communications companies	46	4	0.024	29

According to the clustering coefficient, the network was highly condensed. Scientific research teams, colleges, hotels, and e-commerce companies had a value of 1, indicating a close relationship with the node groups around them. This created a system for monitoring the development of COVID-19, taking the media as the export and governments and medical institutions as objects. Given the weight of all the media's links, information continued to be made available, and assessing its authenticity was straightforward. However, the demands of communities and welfare organizations were ignored, leading to issues of weak reporting.

The closeness, eigenvector, and betweenness values are used to analyze the centrality of a node based on its connectivity, the importance of its neighbor nodes, and its intermediary role, respectively. Node MD has the highest value for the three indexes, showing that media organizations played a significant coordination role during the response to the epidemic; frequent and consistent information exchange coexisted with epidemic governance actions. Nevertheless, when the results for node degree, weighted degree, and clustering coefficient are taken into account, it is clear that there was some tension between the coordination of work priorities, the positive guidance of public opinion, and the command of anti-epidemic actions. In this epidemic, governments and other authorities have been relatively active in publicity but less active in coordinating macro-strategic anti-epidemic efforts and directing grassroots power.

4.3 Structural Holes Analysis

In a CN, nodes establishing non-redundant connections between two other nodes occupy structural holes and therefore control resource allocation and information exchange. Accordingly, relevant organizations functioning as structural holes in the network under study (Fig. 2) have special social value in guiding the distribution of anti-epidemic resources and assets or in promoting the transparency of information about the epidemic. In this study, six indices (constraint, hierarchy, effective size, efficiency, PageRank, and betweenness) were used to investigate network structural holes (see Table 4). High-constraint and high-hierarchy nodes show their heavy dependence upon other nodes and are less likely to be structural holes; nodes with high effective size and efficiency have more non-redundant factors and are more likely to be structural holes; nodes with higher PageRank and higher betweenness attract more resources or information to become structural holes.

The results in Table 4 identify media organizations as the most obvious structural hole organizations in the COVID-19 epidemic, given the media node's low values for constraint and hierarchy and its high values for effective size, efficiency, PageRank, and betweenness. In the process of responding to the epidemic, media workers communicated the latest progress to the public on behalf of the Party and government offices and enterprises; at the same time, concerns from the public and grassroots had to be communicated to society through the media. Although media organizations have no right to control the circulation of anti-epidemic resources among the

Table 4 Parameter values for structural hole indices

Code	Efficiency	Effective size	Constraint	Hierarchy	PageRank	Betweenness
G	0.850	21.260	0.302	0.410	0.0710	21.73
M1	0.841	22.695	0.370	0.464	0.0692	27.26
M2	0.802	21.666	0.450	0.524	0.0515	27.26
M3	0.786	21.235	0.445	0.513	0.0391	27.26
M4	0.786	21.229	0.444	0.512	0.0389	27.26
M5	0.786	21.224	0.444	0.512	0.0387	27.26
MD	0.889	26.672	0.168	0.271	0.0850	74.76
C1	0.720	15.830	0.323	0.297	0.0311	0.89
C2	0.722	15.876	0.322	0.297	0.0322	0.89
C3	0.719	15.807	0.323	0.297	0.0305	0.89
C4	0.721	15.860	0.322	0.297	0.0319	0.89
C5	0.712	15.661	0.322	0.300	0.0264	0.89
C6	0.711	15.642	0.321	0.300	0.0258	0.89
C7	0.724	15.924	0.322	0.296	0.0334	0.89
C8	0.721	15.860	0.322	0.297	0.0319	0.89
C9	0.770	16.945	0.290	0.259	0.0545	0.89
C10	0.754	16.581	0.303	0.277	0.0481	0.89
C11	0.727	15.989	0.321	0.295	0.0350	0.89
S	0.762	6.099	0.536	0.402	0.0164	0.00
P1	0.723	5.061	0.686	0.472	0.0179	1.17
P2	0.723	5.061	0.686	0.472	0.0179	1.17
F	0.795	15.110	0.245	0.216	0.0163	2.75
U	0.800	6.398	0.480	0.397	0.0170	0.00
S1	0.828	19.054	0.239	0.272	0.0085	21.00
S2	0.826	19.009	0.239	0.272	0.0084	21.00
S3	0.825	18.964	0.238	0.272	0.0083	21.00
O1	0.715	7.148	0.394	0.392	0.0194	6.67
O2	0.765	6.121	0.426	0.317	0.0266	3.11
O3	0.795	15.109	0.377	0.689	0.0311	9.48
O4	0.781	4.684	0.468	0.468	0.0209	0.00
O5	0.729	5.103	0.494	0.482	0.0169	0.00

bodies involved in the response, they are megaphones for groups of enterprises, public welfare organizations, communities, and scientific research institutions, and they fill the gaps between those groups.

Because of the high dependence of organizations accepting donations from Sinopec, the COFCO, and the main mobile telecoms operators, nodes S1, S2, and S3 have low values for constraint and hierarchy (higher only than MD), as well as high values for effective size and efficiency (lower only than MD, G, and M1). This indicates that these state-owned enterprises are core organizations although they are not structural holes. Nevertheless, their low values for betweenness suggests that they did not take enough effective action during the epidemic to reflect their master status among Chinese enterprise groups. The effective size, efficiency, PageRank, and betweenness values for nodes G, M1, M2, M3, M4, and M5 show that governments and hospital-oriented medical institutions were leaders in resource deployment and promoters of information disclosure, and this had a strong influence on closely related organizations. However, these nodes have high values for constraint and hierarchy (even higher than the nodes for financial institutions and Wuhan Construction Engineering Group), reflecting the obstacles they faced in coordinating their responses and the limited anti-epidemic actions they managed to take.

5 Discussion

With human infection on an unprecedented scale, the COVID-19 epidemic brings new challenges and new opportunities to public health governance research. Taking advantage of the inclusiveness, visualization, and rich interdisciplinary achievements of CN applications, this paper built a network (Fig. 2) to represent the complex interactive response system of the epidemic-related organizations. Analysis of network cohesion, centrality, and structural holes allowed exploration of the multidimensional organization dilemmas facing the governance system in the COVID-19 epidemic. It thus enabled identification of a core concept of collaborative governance and strategies for improving governance capabilities and enhancing governance awareness.

All the organizations under study participated actively in a response system, and groups of cooperating organizations were clearly identified (Fig. 5). Compared with the fragile WHO-centered global public health governance framework, this response system embodies the advantages of the national governance system of socialism with Chinese characteristics; nevertheless, it faced significant difficulties during the process of controlling the epidemic. The modularity analysis shows that this system consists of a government-led group, a grassroots governance group, a construction enterprise group, and a scientific research institution group. This is conducive to national mobilization, involvement of large numbers of people, joint prevention and control, group governance, and coordination of all activities, as in a chess game [35]. With strong direct leadership over medical institutions and state-owned energy, mobile communications, food, and other key areas, companies, Party, and government offices form the core of the government-led group.

Owing to their high degree of industrial similarity and solid long-term cooperative foundation, the construction enterprise group and the scientific research institution group were able to break down the barriers of collaborative governance during the epidemic. The construction enterprise group created world-class medical infrastructures at Huoshenshan Hospital and Leishenshan Hospital. The scientific research

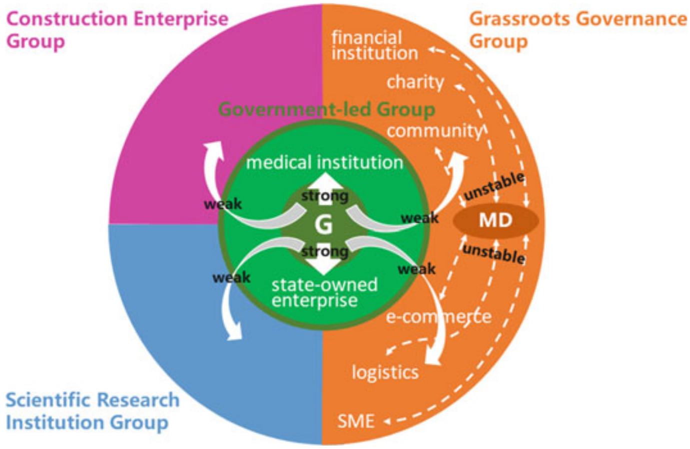

Fig. 5 Response system for the COVID-19 epidemic. *Note* G = government, MD = media, SME = small to medium enterprises

group provided a steady stream of scientific and technological advances in virus prevention and treatment.

The grassroots governance group included numerous types of organizations, such as media, communities, logistics, and charities; accordingly, their collaboration in response to the epidemic was spontaneous and unstable. Forced closure measures imposed on urban life support systems, including private enterprises and medical institutions in many Chinese cities, resulted in a lack of overall management of the primary-level rescue forces that undertake sentinel and diversion functions [36]. Clear group boundaries, unbreakable organizational barriers, inadequate anti-epidemic abilities, and lack of coordination were the negative factors in the COVID-19 response in China. They were also the root causes of the temporary stagnation in domestic control and of the public panic in the early stages of the outbreak, escalating a simple medical issue into a serious social governance problem.

5.1 Difficulties in COVID-19

The key factors in the early stages of the epidemic involved the concentrated exposure of internal and interactive tensions in various related organizations, including weak epidemic governance leadership at grassroots level, a lack of anti-epidemic resources and awareness, and divergences between public opinion and official guidance.

In terms of weak epidemic governance leadership at grassroots level, prevention and control of a pandemic requires not only the mobilization of all social resources and forces but also efficiency and speed. Concentrating on major events” is not enough; concentrating on urgent matters" is also of the essence [37]. The division of the epidemic response system into four clearly defined organization groups, and particularly the stratification of the government-led and grassroots governance groups, caused the efforts of social organizations to become poorly aligned with policy guidance and overall coordination. This severely hindered the on-the-ground efficiency of grassroots anti-epidemic materials and personnel, and it encapsulates the issue of the weak role played by governments in primary-level governance. In terms of policy implementation, grassroots governance organizations abandoned their independence and professionalism, and their positioning was not in line with that of the government [38]. As a result, further issues emerged, including ineffective coordination of responses from different government departments, neglect of governmental duty at grassroots level, disorganized emergency resource allocation, and limited action to prevent or control emergencies.

In terms of anti-epidemic resources and awareness, the capacity of an enterprise to respond is determined by its resource-providing ability and its sense of social responsibility. If either of these two is lacking, the enterprise's efforts against the epidemic will be weakened. Small to medium enterprises (SMEs) with poor operating capabilities usually do not have the ability to transform or update themselves quickly under the impact of an epidemic [39]; they risk losing their market and may struggle to survive. In contrast, large state-owned enterprises have sufficient cash flow and strength in the industrial chain to survive. However, they may be inadequate in terms of social values, such as ensuring sufficient supplies of basic necessities, promoting the resumption of work and production, and helping SMEs to survive. A similar lack of social awareness affects academic research.

According to the concept of people-oriented governance, epidemic governance involves both governance of the people and governance by the people. It is important to explore the nature of the virus and to develop medical treatments, but governments at all levels and people at grassroots level must also determine a systematic modern governance plan for public health crises. Community governance has been shown to suffer from shortcomings in both resources and awareness, not least because of insufficient reserves of emergency supplies and an emphasis on hardware investment at the expense of public education in prevention strategies [40].

In terms of the divergence of government guidance and public opinion, the suddenness, time specificity, and urgency of the COVID-19 epidemic triggered an unprecedented media opinion panic, which was made worse by exaggerations and fabrications from poor-quality media organizations, public misjudgment of the circumstances, and lack of government control [41]. As a result, rumors spread and social anxiety intensified, which makes epidemic governance difficult and may even lead to social unrest.

These difficulties in responding to the COVID-19 epidemic sound an alarm for governance organizations. In the context of the normalization of prevention and control, these difficulties can be transformed into opportunities to modernize the national governance system and its capabilities so as to provide solid theoretical support for an early victory against COVID-19 and to avoid future public health crises. Under the heading of the general requirements to boost confidence, to take scientific steps to prevent or control a crisis, and to implement measures correctly, a new governance system can be formed that takes collaboration as its core concept, strengthens modern governance capabilities, and establishes community awareness as a concrete governance strategy.

5.2 Governance Strategies

Breaking down barriers to collaboration

First, the concept of collaborative governance, in line with general attitudes toward emergencies, is essential for breaking down barriers to government cooperation. In the context of public health emergencies, people must remain alert and ready to act. The spread of COVID-19 has been curbed thanks to the efforts of the political, economic, social, and other organizations involved, but serious barriers to cooperation remain. Governments should shift the emphasis away from performance management or publicity and toward ensuring the implementation of grassroots epidemic control. Frontline organizations, including communities and public charities, should fully explore optimal cross-organization interactions and methods of coordination between themselves and the core response organizations. The media should guarantee open and transparent sharing of information. After the outbreak, all relevant bodies need to take full advantage of the small-world network characteristics of the response system by moving beyond a short-sighted small-scale group governance status and committing to building a tighter system of collaboration.

Modernizing the governance system

The keys to the public health crisis response are modernizing epidemic governance abilities, keeping the bigger picture in view, emphasizing targeted measures, and stabilizing the reaction of the public. Faced with potential abnormal organizational behaviors and rapid changes in the situation, governments, as the core of the anti-epidemic response, must perfect the law and regulatory system in the field of public health, promulgate emergency plans quickly, and actively take steps for prevention and control. In other words, they need to improve their combat efficiency while guaranteeing the rule of law [42]. Medical institutions should focus on providing an integrated public health service and treatment system, combining routine treatment and emergency rescue and achieving a deep integration of prevention and treatment. It is important for communities to prevent external input and internal rebound and to strongly encourage the normalization of prevention and control.

Improving grassroots organizations

A multidimensional interactive mechanism composed of community grid members, cadres (from higher authorities to frontline positions), district coordinators, and responsible leaders is required to consolidate what has been achieved so far. Mainstream media should actively promote full transparency of information about the epidemic, using modern intelligent information technology such as big data or block chain to weaken the power of Internet misinformation and to guide online public opinion. Large state-owned enterprises and transnational companies must pay close attention to the development of the epidemic in various countries, obtain accurate information about foreign shutdowns, be clear about their own production and operation capabilities, penetrate overseas supply chain systems, and ultimately participate in international supply chain reorganization [43]. SMEs must reduce costs, control expenditures, and implement steady cash flow management strategies.

Taking social responsibility seriously

Also crucial are establishing a systematic awareness of the epidemic governance community (especially life community awareness), enhancing the judgment and decision-making abilities of organizations, and maintaining the strength of will to win the battle. Politics, economy, and culture must give way to epidemic prevention and control. The delay of the people's government of Hubei Province and Wuhan City in reporting and making decisions about the epidemic was caused by a lack of life community awareness. At a political level, the Provincial People's Congress and the Provincial Political Consultative Conference of Hubei were taking place at the time; at an economic level, Hubei's economy has been leading the six central provinces; at a cultural level, Wuhan's Myriad Families' Feast was held as scheduled [44]. Furthermore, the principle of prevention first should be adhered to by medical institutions; this involves improving the relevant equipment and defining rights and responsibilities within the public health emergency management system [45]. Media workers must increase both political awareness and overall awareness in their reporting of the epidemic, maintaining clarity about who they represent and serve so that they can be a positive influence on the overall situation [46].

6 Conclusion

The prevention and control of the COVID-19 epidemic has been a major test for Chinese national governance systems and capabilities, as well as for national systems, government leadership, and ethical culture. During the early stages of the outbreak, the response encountered a bottleneck. Now that steps have been taken to bring the epidemic under control, scholars of public management must reflect on the difficulties of responding to a public health emergency and seek new governance systems.

This paper has presented a network (Fig. 2) developed from data from the websites of the People's Government of Hubei Province and the National Health Commission of the People's Republic of China. A total of 31 organization nodes were identified and the weights of their edges quantified. Network cohesion, centrality, and structural holes were analyzed to determine the overall network structure and node characteristics. The COVID-19 epidemic response system was then analyzed to provide insight into the internal and interactive dilemmas of the organizations involved and to form an appropriate governance system. The analysis shows that three main issues were encountered during the epidemic response: weak epidemic governance leadership at grassroots level, a lack of anti-epidemic resources and awareness, and a divergence of public opinion from official guidance. The new epidemic dilemma governance framework proposed here takes collaborative governance as its core concept, strengthening modern governance capabilities and establishing governance community awareness as two practicable governance strategies.

This study makes three main contributions. First, it is novel in applying CN to the response to the COVID-19 epidemic, taking the organizations involved as nodes and their interactions as edges. Second, it builds an epidemic response system, providing a theoretical basis for epidemic prevention and control plans in the future. Third, it analyzes the internal and interactive barriers encountered by organizations, and proposes a comprehensive governance system that will support public health crisis decision-making processes and improve the practicability of governance behaviors in public emergencies.

The research presented here has two main limitations. First, insufficient data were collected online for complete and comprehensive analysis of the network. Future research in this area can include a wider range of websites and larger amounts of analyzed text. Second, no consideration was given to the dynamics of the network, which may update and change at each stage. More advanced approaches, such as comparative analysis of cross-stage epidemic response networks or CN cascading failure index analysis, can be applied in future research to improve the adaptability of the model.

Data Availability Statement
All data, models, or code that support the findings of this research are available from the corresponding author upon reasonable request.

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A Smart Data-Driven Fault Diagnosis Method for Sustainable and Healthy Building System Operations

Xuyuan Liu, Xinghua Wang, Cheng Fan, Bufu Huang, and Jiayuan Wang

Abstract Huge amounts of building operational data are being collected by the building automation system in modern buildings, providing an ideal platform for developing data-driven methods for building energy management. Compared with traditional human-centric building management methods, data-driven methods are more efficient and have attracted significant attention from academic researchers and industry professionals. The main challenge is how to effectively extract useful insights from massive building operational data, especially when the original data are noisy and of poor quality. This study proposes a data-driven diagnosis method for the sustainable and healthy operations of building services systems. The chiller system is selected as the research target, considering it generally consumes the most energy and has the greatest energy saving potential. The method is developed based on both unsupervised and supervised machine learning techniques. Firstly, a steady-state detection method has been developed using unsupervised clustering analysis. It aims to automatically remove transient operational data to ensure the quality of the follow-up data analysis. Secondly, various supervised machine learning techniques have been used to develop classification models to identify typical faults in chiller operations. Thirdly, the method has been validated using actual chiller operational data. Different metrics, such as accuracy, fault detection rate, misdiagnosis rate and false alarm rate, have been adopted for performance evaluation. The method can be applied to enhance the efficiency for practical building management. The research outcomes are beneficial for the development of sustainable and healthy building energy management.

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1 Introduction

In recent years, the conflict between people and the environment has become increasingly prominent. As one of the most energy-intensive industries, the sustainable management of building operations plays an important role for national economy and ecology. Considering the ever-increasing trend of intelligent buildings and smart cities, it is of great need to develop advanced and automatic approaches to enhance the energy efficiency of various building services systems, such as the heating, ventilation and air-conditioning (HVAC) system.

With the development of information technologies, huge amounts of building operational data are being collected by the building automation system in modern buildings, which provides an ideal platform for developing data-driven methods for efficient and effective building energy management. Experts and scholars have conducted various kinds of studies on this topic. Shohei Miyata et al. trained convolutional neural networks with simulation data to diagnose faults in heat storage tank systems. The method obtained a diagnosis accuracy of 98.7%, which validated the value of data-driven methods for fault detection and diagnosis (i.e., FDD) [1]. Wang et al. developed a fault diagnosis tool for variable air volume (VAV) systems. The method was developed based on real measurements and can be applied for online applications [2]. Liu et al. applied association rule mining to diagnose chiller faults and the overall accuracy is around 90% for practical applications [3]. Sun et al. proposed an online FDD methods for sensors, which in turns guarantees the reliable monitoring of building automation systems [4, 5]. Du et al. developed a neural network-based method for anomaly detection of air-conditioning systems in commercial buildings [6]. The method was developed on the basis of cluster analysis and can be used to identify unseen faults in system operations.

Existing studies mainly focused on the direct application of various data mining algorithms, while ignoring potential challenges in data quality, e.g., the original building operational data may contain outliers and represent transient operations. To further enhance the practical utility of data-driven methods, it is essential to develop end-to-end tools which cover the whole data analysis process. This study proposes a smart data-driven diagnosis method for the sustainable and healthy operations of building services systems. The building chiller system is selected as the research target as it generally consumes the most energy and has the largest energy saving potential. The method is developed based on both unsupervised and supervised machine learning techniques and covers the whole data analysis process for practical applications. The paper is organized as follows. The research methodology is presented in Sect. 2. The method has been applied to actual building operational data and results are described in Sect. 3. Conclusions are drawn in Sect. 4.

2 Research Methodology

The research outline is shown in Fig. 1. It consists of two stages, i.e., the training and testing processes. Since the data collected by the building automation system can be noisy, the direct application of such data will reduce the accuracy of fault diagnosis models. Therefore, a data preprocessing method is proposed to remove transient operational data and preserve steady-state data for further analysis. Afterwards, machine learning algorithms are adopted to develop classification models for chiller FDD. Feature selection is performed to determine the optimal subset of input variables. Model optimization is performed to ensure the generalization performance. During the testing stage, the classification model is applied to the testing data, on the basis of which various precision metrics are applied for performance evaluation. There are four key steps in the methodology, i.e., steady-state data detection, feature selection, machine learning model development and performance evaluation. The details of each key step are described in the following subsections.

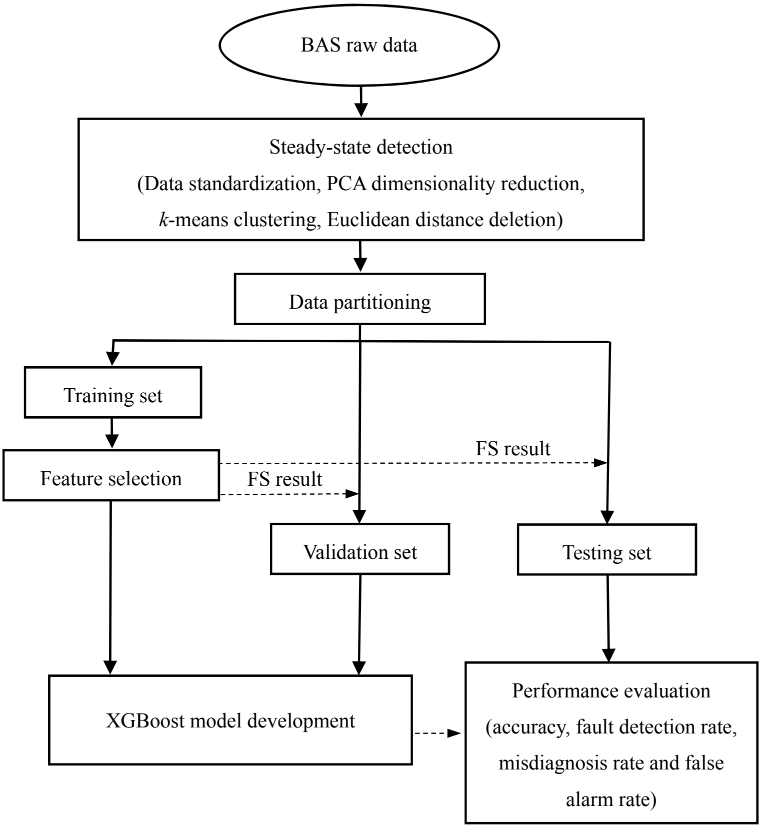

Fig. 1 Research outline

2.1 Steady-State Data Detection

When the sample size of the original data is small and the number of variables (i.e., denoted as n) is large, it is very challenging to understand the intrinsic data behaviors [7]. As a solution, dimensionality reduction techniques can be applied, which transforms the original data into data with few dimensions for information preservation. Principal component analysis (i.e., PCA) is one of the most widely used dimensionality reduction methods. It extracts m ($m < n$) main components from original data for information preservation. Each principal component is a linear combination of the original variables. It should be mentioned that data scales in original building operational data may vary and therefore, should be transformed before PCA analysis. As shown in Eq. 1, the max–min normalization method is used in this study to transform each variable into the range between zero and one.

$$x_i^* = \frac{x_i - \min(x)}{\max(x) - \min(x)} \tag{1}$$

where x_i is the original data, x^*_i is the standardized data, max(x) and min(x) are the maximum and minimum values of variable x respectively.

Afterwards, the k-means algorithm is used to identify a number of clustering centers. The Euclidean distance between each data sample in each cluster and the associated clustering center is calculated. The larger the Euclidean distance, the farther the data sample is from the clustering center and therefore, the more likely the data sample to be a transient operation. Therefore, data samples with sufficiently larger Euclidean distance to its clustering centers are removed as transient operations.

2.2 Feature Selection

In order to improve the fault diagnosis performance, multiple sensor data are often collected. Considering the data redundancy and computational costs, it is not wise to apply all variables as inputs for model development. Therefore, feature selection method has been applied to determine the optimal variable subset for model development. There are three commonly used feature selection methods, including the filter, wrapper and hybrid (or embedded) method. The filter method scores each feature according to divergence or correlation. A threshold can be predefined for feature selection. The wrapper methods select variables which optimize the objective function of the learning algorithms. As an example, the recursive elimination feature method is a popular wrapper method based on random forests. The filter method has attracted more attention considering its simplicity for implementation and reliability for practical applications [8]. In this study, the filter method is adopted for feature selection.

2.3 Machine Learning Model Development

Various machine learning algorithms have been proposed for advanced data analysis. Conventional methods, such as support vector machines and decision trees, rely on single model for decision making. Recent studies have adopted the concept of ensembles for performance enhancement. The basic idea is to develop multiple base models and combine their outputs as the final prediction. The eXtreme Gradient Boosting (XGBoost) algorithm, which is based on decision trees and gradient boosting, has gained great success due to its advantages of low computational complexity, fast running speed and high accuracy [9]. Previous studies have shown that the XGBoost model have better generalization performance when compared with other tree-based ensemble method [10]. Therefore, this study adopts the XGBoost algorithm for model development.

The XGBoost algorithm has several key parameters, i.e., learning rate, maximum iteration times, maximum depth of the tree, number of leaf nodes on the tree and etc. In order to ensure the generalization performance of the model, this study chooses the learning rate and the maximum tree depth for model optimization. In general, the smaller the learning rate is, the more conservative the subsequent learning of the model will be. The higher the maximum tree depth, the more complex the model is.

2.4 Performance Evaluation

The classification model is then applied to the testing data for performance evaluation. Table 1 shows one confusion matrix of the model diagnosis, which is represented by one normal mode and two fault modes. Such confusion matrix is taken as an example to illustrate the calculation of four evaluation metrics. N stands for normal mode and F_1 to F_2 for two fault modes. b_3 represents the number of data samples that are actually normal but are predicted to be fault F_2. A number of Performance evaluation metrics have been adopted for analysis, i.e., accuracy, fault detection rate (FDR), misdiagnosis rate (MR) and false alarm rate (FAR).

Table 1 Confusion matrix (1)

Predict	Actual		
	F_1	F_2	N
F_1	a_1	a_2	a_3
F_2	b_1	b_2	b_3
N	c_1	c_2	c_3

Table 2 Confusion matrix (2)

Predict	Actual	
	F_1	F_2
F_1	a_1	a_2
F_2	b_1	b_2

2.4.1 Accuracy and the Fault Detection Rate

Accuracy represents the overall model classification performance across all categories. The FDR of a fault indicates the proportion of successfully identified faulty operations over all the data samples of that fault. For the confusion matrix mentioned above, the model accuracy and FDR are calculated as shown in Eqs. 2 and 3 respectively.

$$Accuracy = \frac{a_1 + b_2 + c_3}{a_1 + a_2 + a_3 + b_1 + b_2 + b_3 + c_1 + c_2 + c_3} \tag{2}$$

$$FDR = \frac{a_1}{a_1 + b_1 + c_1} \tag{3}$$

2.4.2 Misdiagnosis Rate

The MR is the ratio between false positive of that fault and all data samples of other faults. For example, the MR of F_1 can be calculated according to the confusion matrix shown in Table 2. Its result is calculated as shown in Eq. 4.

$$MR = \frac{a_2}{a_2 + b_2} \tag{4}$$

2.4.3 False Alarm Rate

Similarly, the FAR defines the ratio between false positives and all normal operations. For F_1, its FAR can be calculated according to the confusion matrix shown in Table 3. Its result is calculated as shown in Eq. 5.

Table 3 Confusion matrix (3)

Predict	Actual	
	F_1	N
F_1	a_1	a_3
N	c_1	c_3

Table 4 Nomenclatures for data variables

Feature	Description	Feature	Description
TEI	Temperature of evaporator water in	TWEI	Temperature of evaporator water in
TSO	Temperature of shared HX water out	TBI	Temperature of building water in
T_suc	Refrigerant suction temperature	TO_sump	Temperature of oil in sump
TO_feed	Temperature of oil feed	VC	Condenser valve position

$$FAR = \frac{a_3}{a_3 + c_3} \tag{5}$$

3 Case Study

3.1 Experimental Data

The experimental data from ASHRAE RP-1043 has been adopted for data analysis [11]. The data set contains operational data measured from a 90-ton centrifugal chiller under 27 working conditions. The data contains normal and 7 faulty operating conditions. Each fault has 4 severity levels. The data acquisition time was 2 min. As shown in Table 4, the 7 faults are condenser fouling (*CF*), excess oil (*EO*), non-condensables in refrigerant (*NC*), reduced condenser water flow (*FWC*), reduced evaporator water flow (*FWE*), refrigerant leak (*RL*) and refrigerant overcharge (*RO*).

3.2 Identification of Steady-State Operational Data

The R programing language was selected for data analysis in this study. Before principal component analysis, it is found that four variables have constant values across all measurements and therefore, principal component analysis was carried out for the remaining 60 variables. The PCA results indicate that 11 principal components could reflect more than 90% of total variance. Such 11 principal components were used for clustering analysis. Table 5 summarizes the importance of the first 11 principal components.

Because the data of each fault under different severity levels were obtained from the chiller under 27 working conditions, the *k* values was set as 27 in *k*-means clustering analysis. The distance from each data to each cluster center was then calculated. The top 20% data with the largest Euclidean distances were removed from further analysis. Taking the first severity level data of condenser fouling as examples, there are 34 data samples in Cluster No. 2 and 27 remain after the steady-state detection. As shown in Figs. 2 and 3, visualizations have been created to present

Table 5 A summary on principal components

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6
Standard deviation	4.3699	3.4754	3.1909	1.6316	1.3975	1.3795
Proportion of variance	0.3183	0.2013	0.1697	0.0444	0.0325	0.0317
Cumulative proportion	0.3183	0.5196	0.6893	0.7336	0.7662	0.7979
	Comp.7	Comp.8	Comp.9	Comp.10	Comp.11	
Standard deviation	1.2651	1.1730	1.1288	1.0430	1.0330	
Proportion of variance	0.0267	0.0229	0.0212	0.0181	0.0178	
Cumulative proportion	0.8246	0.8475	0.8688	0.8869	0.9047	

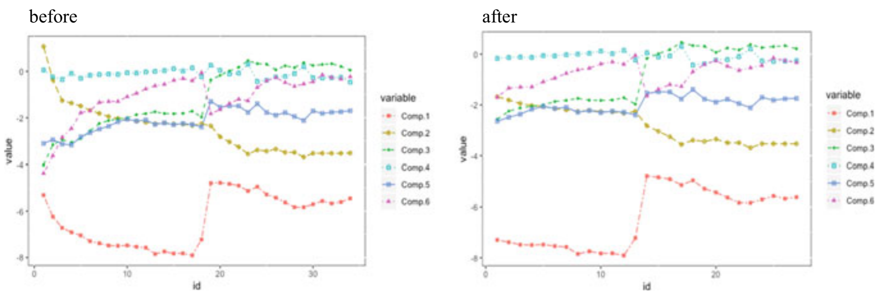

Fig. 2 Comparisons of principal components before and after steady-state detection

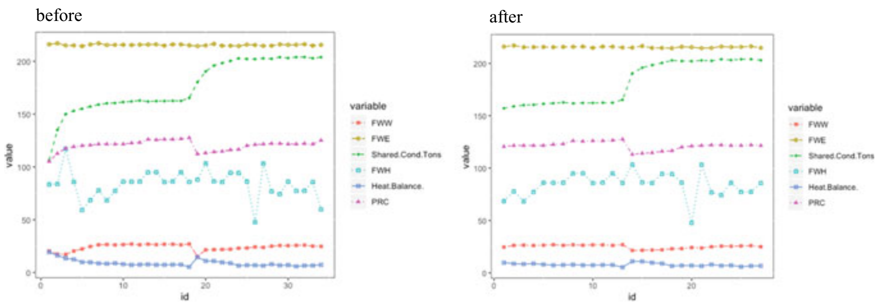

Fig. 3 Comparisons on original data before and after steady-state detection

the data trend before and after steady-state detection in both principal components and original data variables. It can be found that the steady-state detection method has sufficient capabilities in removing obvious outliers and transient operational data.

3.3 Development of FDD Classification Model

3.3.1 Input Feature Selection

According to the proportion of 70, 15 and 15%, the data set after steady-state detection was divided into training, validation and testing sets. The training and validation data were used for model development and optimization, while the testing set was used for performance evaluation. Feature selection was carried out for the training set, and then the result of feature selection is applied to the original training set, verification set and testing set. First, the approximate constant variables and the variables with the degree of autocorrelation greater than 90% were deleted. The filter method was then adopted to select the remaining 31 variables. After filter feature selection, 23 useful features were selected and the result of feature selection was shown in Table 6.

3.3.2 Model Optimization

Parameter optimization are performed for FDD model development. Different XGBoost model parameters have been tested and the detailed settings are shown in Table 7. In total, there are sixteen combinations of model parameters considering four learning rates and four maximum tree depths.

The supervised learning model is trained with a training set, and then the prediction accuracy for the validation set is calculated to select the optimal combination of model parameters. Table 8 shows prediction accuracies on validation data given different parameters combinations. It is found that the total accuracy of XGBoost model for validation sets is higher than 93%. The first three parameter groups with the highest prediction accuracy are selected for the subsequent evaluation of FDD classification performance.

3.4 Performance Evaluation of Chiller FDD Models

3.4.1 The Fault Detection Rate of Chiller FDD Models

Figure 4 presents the FDR given different parameter groups. The averaged FDR is summarized in Table 9. The FDD models have the best diagnosis performance for faults of condenser fouling (*CF*), reduced condenser water flow (*FWC*) and reduced evaporator water flow (*FWE*). The overall FDR is around 100%. The most difficult faults for diagnosis are refrigerant leak (*RL*) and refrigerant overcharge (*RO*). However, the FDR is still higher than 90%, which is acceptable for practical applications.

Table 6 Feature selection results

Feature	Description	Feature	Description
TWEO	Temperature of evaporator water out	TSO	Temperature of shared HX water out
TBI	Temperature of building water in	Cooling Tons	Calculated city water cooling rate
Shared Cond Tons	Calculated shared HX heat transfer	Evap Energy Balance	Calculated 1st law energy balance for evaporator water loop
COP	Calculated coefficient of performance	kW/Ton	Calculated compressor efficiency
FWC	Flow rate of condenser water	FWE	Flow rate of evaporator water
TEA	Evaporator approach temperature	TRC_sub	Liquid-line refrigerant subcooling from condenser
Tsh_suc	Refrigerant suction superheat temperature	Tsh_dis	Refrigerant discharge superheat temperature
Heat balance (kW)	Calculated 1st law energy balance for chiller	Heat Balance %	Calculated 1st law energy balance for chiller
Tolerance %	Calculated heat balance tolerance	TO_sump	Temperature of oil in sump
PO_net	Oil feed minus oil vent pressure	VC	Condenser valve position
TWI	Temperature of city water in	FWW	Calculated city water flow rate
FWH	Calculated hot water flow rate		

Table 7 Candidate values for supervised learning parameters

Supervised learning parameters	Candidate values
Learning rate	{0.05, 0.1, 0.3, 0.4}
Maximum depth of the tree	{3, 4, 5, 6}

3.4.2 The Fault Misdiagnosis Rate of Chiller FDD Models

Figure 5 presents fault MRs given different parameter groups. The averaged MR is summarized in Table 10. It is observed that the MR of all kinds of faults is lower than 1%. For faults like *FWC*, *FWE* and *NC*, the MR is almost 0. The average MR is less than 0.3%.

Table 8 Results on model optimization

Learning rate	Maximum depth of the tree	Accuracy	Rank	Learning rate	Maximum depth of the tree	Accuracy	Rank
0.40	3	0.9652	8	0.05	3	0.9127	16
0.10	3	0.9451	12	0.30	3	0.9683	7
0.40	**4**	**0.9762**	**1**	0.05	4	0.9310	15
0.10	4	0.9530	11	0.30	4	0.9701	6
0.40	**5**	**0.9737**	**3**	0.05	5	0.9365	14
0.10	5	0.9585	10	0.30	5	0.9725	4
0.40	6	0.9725	4	0.05	6	0.9438	13
0.10	6	0.9634	9	**0.30**	**6**	**0.9750**	**2**

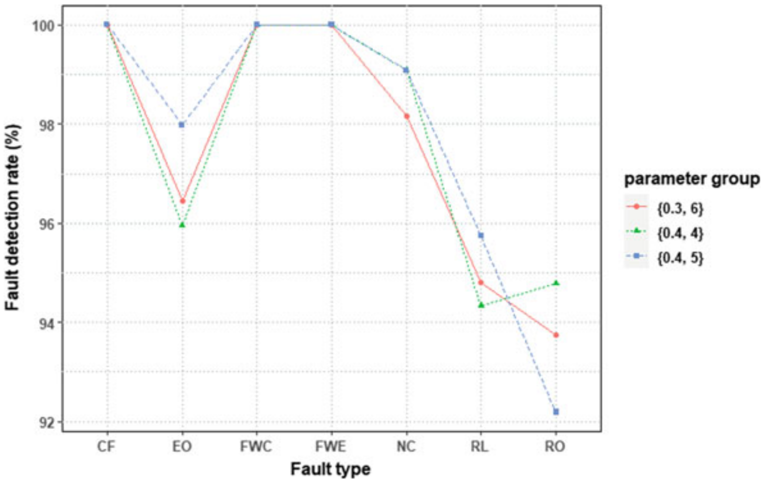

Fig. 4 FDR given different parameter groups

Table 9 Averaged FDRs given different parameter groups

Parameter groups	learning rate = 0.40 maximum depth of the tree = 4	learning rate = 0.30 maximum depth of the tree = 6	learning rate = 0.40 maximum depth of the tree = 5
Averaged FDR (%)	97.74	97.61	97.85

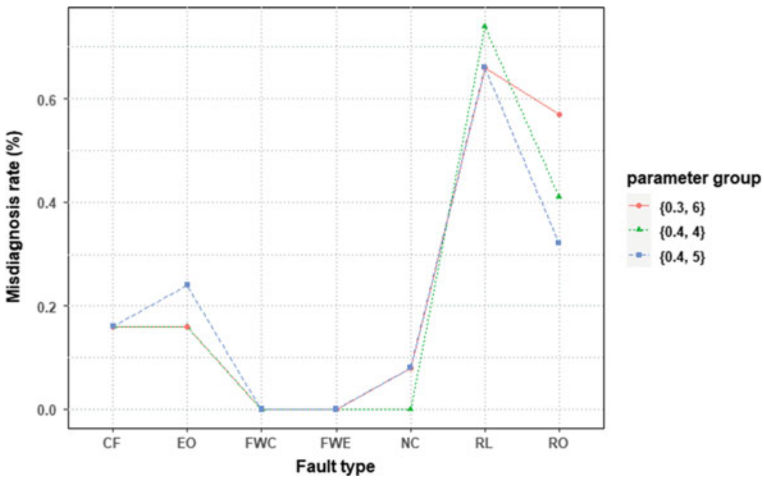

Fig. 5 Fault MR given different parameter groups

Table 10 Averaged MRs given different parameter groups

Parameter groups	learning rate = 0.40 maximum depth of the tree = 4	learning rate = 0.30 maximum depth of the tree = 6	learning rate = 0.40 maximum depth of the tree = 5
Averaged MR (%)	0.21	0.23	0.21

3.4.3 The Fault False Alarm Rate of Chiller FDD Models

Figure 6 presents the FAR given different parameter groups. The averaged FAR is summarized in Table 11. The FAR represents the probability that a normal operation is predicted as faulty. In practice, the FAR is acceptable when it is lower than 5%. According to Fig. 6 and Table 11, the average FAR is less than 0.7%. It is evident that the fault diagnosis method proposed in this paper is reliable for practical applications. In addition, it should be noted that the potential cost of not detecting faults in time are much higher than false alarms and therefore, users should rely more on other Performance evaluation metrics for performance evaluation.

4 Conclusions

This paper proposes a smart data-driven diagnosis method for the sustainable and healthy operations of building chiller systems. The method can serve as an end-to-end solution for practical applications, as it covers all essential tasks in the overall

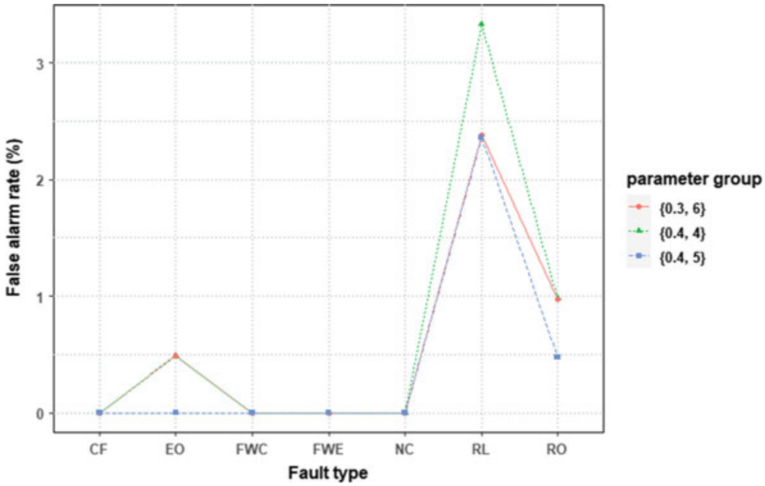

Fig. 6 FARs given different parameter groups

Table 11 Averaged FARs given different parameter groups

Parameter groups	learning rate = 0.40 maximum depth of the tree = 4	learning rate = 0.30 maximum depth of the tree = 6	learning rate = 0.40 maximum depth of the tree = 5
Averaged FAR (%)	0.69	0.55	0.41

data analysis process, i.e., data preprocessing, model development and performance evaluation. Fault diagnosis models were developed by using an advanced tree-based ensemble algorithm. Optimizations have been performed in terms of input variables and model hyper-parameters to ensure the generalization performance. The method has been validated using actual measurements with seven typical chiller faults. The average FDR is greater than 97.5%. The average MR and FAR are less than 0.3% and 0.7% respectively. The research outcomes are beneficial for the development of intelligent building energy management.

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A Review of Research on Project Transparency

Qian Zhang

Abstract At present, under the guidance of the government, "integration" has become the mainstream and trend in the construction industry, but there is still a problem of low project transparency in the construction industry. The low transparency of the project will make the participants of the project unable to effectively and comprehensively transmit information and cooperate effectively in the process of project implementation, which will have a great negative impact on the final results of the project. Project transparency mainly refers to the openness and sharing of various aspects among all participants in the whole process of construction project. Through sorting out and analyzing the existing literature on transparency and project management, this paper classifies the project transparency into three parts: information transparency, rule transparency and culture transparency, and expounds them separately. In addition, the influence of project transparency on the whole project is analyzed comprehensively. At present, there is a lack of research on project transparency, and there is no clear research results. In the future, we should strengthen the in-depth research on improving project transparency and the development of specific implementation measures, continue to combine with the actual situation, and deeply explore specific measures and methods to improve project transparency in all aspects, in order to produce more important guiding significance.

Keywords Project transparency · Project management · Project performance

1 Introduction

1.1 Research Background

In addition to the characteristics of general engineering projects, construction projects also have the characteristics of huge investment, long construction period, strong integrity and fixity. These characteristics bring great difficulties to the management

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and performance of construction projects. As the economic pillar of the construction industry, in recent years, the scale of China's construction industry output value has been rising, but the growth rate has declined as a whole. The uncoordinated relationship between the participants and the interface problems are hindering the better development of the whole industry.

China's construction industry started relatively late, in the management mode, we learn from foreign management mode. After the "Lubuge shock", the triangular mode of owner/consulting agency/contractor has appeared in China's construction project management mode. On this basis, China's construction project management model has gradually formed in the process of development, including owners, design units, contractors, supervision companies, consulting companies and other participants, each performing their own duties and cooperating with each other. After that, the construction industry has a trend of "centralization", and there are turnkey mode (EPC), construction general contract management mode (CM), agent construction system, consulting agent construction (PMA), contracting agent construction (PMC). However, this management mode of "performing their own duties" is still the core and mainstream of construction project management mode in China. In this mode, each participant is responsible for one or several stages of work. Although the degree of specialization is greatly improved, there are many problems in the actual project.

In recent years, under the guidance of the government, the requirement of "integration" has been further improved. In 2017, the general office of the State Council proposed "cultivating whole process engineering consultation" in "improving the organizational mode of engineering construction" in the opinions on promoting the sustainable and healthy development of the construction industry (GBF [2017] No. 19). The whole process engineering consultation is a consulting management service involving all stages of the whole life cycle of construction engineering. It emphasizes the integration of various parts of the construction project and the original rigid sequence of construction projects. According to the actual situation, the whole process of investment, bidding, procurement, construction, operation, etc. is designed and constructed flexibly, so as to optimize the process and reduce the number of units to achieve the goal of overall planning. It can be seen that "integration" has become the mainstream and trend of the times in the construction industry.

However, whether it is the transformation of management mode or the promotion of the whole process engineering consultation, it is inseparable from the information acquisition and interaction between the parties. Through the interview of the actual project participants and the arrangement of the documents, the following problems still exist in the field of Construction Engineering Management in the aspect of cooperation between all participants:

(1) The possibility of opportunistic behavior and the waste of supervision resources. Each participant plays different roles in construction engineering. From the standpoint of its independent enterprise, all parties pursue the maximization of interests. Because of the complexity of construction engineering process and huge capital, the opaque information makes the possibility of opportunistic behavior and moral hazard [1]. In order to avoid the harm to their

own interests, each participant will spend manpower and material resources to obtain information and supervise, which will result in waste of time and resource [2].

(2) The cooperation between the parties is not high. The communication and communication between the parties are less, the understanding is lack, and the mutual understanding and tacit understanding are lack when facing the problems, and the situation of incorrect understanding and refusal to cooperate may occur [3].

(3) Responsibilities and processes are not clear. Responsibilities are unclear. After problems occur, all parties shirk responsibilities from each other, and the handling methods are unclear, which can not solve the problems effectively, which seriously affects the project performance [4].

(4) The key information cannot be obtained in time and rework may exist. Each participant is responsible for a part of the work procedure, which has barriers to information, poor information communication, and the effective information can not be timely informed, which causes unnecessary workload, rework, and serious impact on the construction period and project quality [5].

To sum up, at present, there are still problems in the construction industry that the cooperation degree of each participant is not high due to the opacity of information. The quality of cooperation between the participants will affect the work efficiency and wage quality of the project, and affect the quality, safety, progress, cost, etc., which will restrict the further improvement of project performance. These are not conducive to the development of the construction industry. Project performance as a key indicator of the industry, its influencing factors have been the focus of industry personnel and scholars, but at present, there is less attention to the transparency of the construction industry. Effective research and analysis of project transparency is valuable.

1.2 Research Significance

For transparency, scholars at home and abroad have certain research results. In the economic field, scholars interpret information transparency as the compulsory or voluntary disclosure of financial and management information, and study its impact on the company's share price, equity financing cost, etc. In the field of enterprise management, scholars have explored the impact of information transparency on enterprise management performance through work willingness and incentive measures, and have achieved certain results, which provide effective basis for finding effective measures to improve corporate performance, and play a great role. The influence of transparency on trust and other relationships in organizations has also been verified.

At present, there is a lack of research on the transparency of construction projects. As a multi-party engineering project, the work, the way of getting along with each other and the quality of getting along with each other will affect the project performance and project success. Some scholars have confirmed the influence of trust, cooperation quality and relationship contract on project performance or project success. In theory, this paper summarizes the research results of transparency, and then combined with the actual situation in the field of construction engineering, creatively combines the concept of transparency with construction engineering, analyzes and summarizes the relevant research and puts forward its own views. And according to the current construction engineering parties in the problem of cooperation, the concept of project transparency is constructed and classified. It provides the basis and reference for the future research on the role of transparency in the field of Construction Engineering (i.e. project transparency) on project performance. In practice, it is helpful for the participants to realize the importance of project transparency and actively take measures to improve the transparency of projects.

2 Transparency

2.1 Definition of Transparency

With regard to transparency, research on roles and social coherence in Organizational Science dates back to the mid-twentieth century [6]. Before, the research on transparency has not been the focus of scholars' research, and the real concern about transparency was around 2000. In the 1990s, a small number of scholars have noticed the importance of transparency. Levitt, former chairman of the securities and Exchange Commission (SEC), proposed the concept of transparency of accounting information in 1994, and pointed out in 1998 that providing reliable and useful decision-making information for investors is necessary for formulating high-quality accounting standards, and transparency is an important feature of "high-quality accounting standards" [7]. When the Asian financial crisis broke out in 1997, many international sexual organizations analyzed the financial crisis and put the opaque accounting information counter in Southeast Asian countries as one of the reasons for the economic crisis. At the beginning of the twenty-first century, there were many corporate scandals that shocked the world, such as Enron in 2001, WorldCom in 2002, Lehman Brothers in 2008 and Madoff investment securities in 2009. The occurrence of these events made transparency a hot topic for scholars. In recent years, the research on transparency is also in a state of rising volatility.

As for the definition of transparency, various fields have different understandings based on their research starting point and specific situation, and there is still no definite conclusion.

In the field of economy and accounting, at the beginning, transparency was interpreted as the disclosure of accounting information, such as the disclosure of company's financial report and financing situation. Scholars believe that improving transparency can improve investors' understanding of the company, thus reducing the "adverse selection" of investors and increasing the investment confidence of investors. The Basel Committee on banking supervision published the Research Report on enhancing bank transparency in September 1998, which defines transparency as: disclosing reliable and timely information publicly will help information users accurately and timely evaluate the financial status and performance, business activities, risk distribution and risk management activities of banks. It can be seen that transparency is further understood as the disclosure of a variety of information including accounting information, and it is believed that disclosure alone can not improve transparency in essence. Transparency requires the quality of disclosed information. The quality characteristics of open and transparent information include: comprehensiveness, relevance and timeliness, reliability and comparability (comparison), material [8]. Later, people further developed transparency from the quality of information, and studied many aspects including the system. Wei Minghai and others interpreted accounting transparency as three levels: first, a set of authoritative, formal and universally recognized supervision system; second, accounting standards that all parties will strictly follow; and finally, it can make external personnel get timely Accurate and high quality company information including finance, operation and risk status [9].

In the field of corporate management, the definition of transparency increases the understanding of internal information transparency while disclosing information outside the company, which is often associated with salary system and incentive system.

2.2 The Role of Transparency

In the field of companies, scholars have studied the impact of transparency on the cost and performance of companies. According to David Easley and Maureen O'Hara, traders with more private information can better allocate resources, while uninformed consumers tend to hold less stocks. Private information increases the risk of uninformed investors [10]. According to the Research Report of PWC, there is a direct relationship between the transparency of a country (region) and its capital cost. The higher the transparency is, the lower the capital cost is. For example, taking Singapore and the United States, which have the highest transparency, as a reference, China, which is listed as the least transparent, has an average cost of capital 13.16% higher than that of Russia, which is 12.25% [9]. Wang Wei et al. Selected the statistical data of more than 500 A-share listed companies listed in Shanghai Stock Exchange Center as samples, and verified the relationship between disclosure degree and capital cost, and concluded that after controlling the company size and financial risk factors, improving the disclosure level of listed companies will reduce the cost of equity capital [11].

If a company leaks information, it can greatly improve the investors' understanding of the company's situation, reduce the information inequality of all parties, reduce the cost of information collection for the company, and reduce the additional costs brought by adverse selection. These costs will be reflected in the company's cost of equity capital, so improving the disclosure of company information can effectively reduce the company's comprehensive Cost of capital.

In the field of company management, the internal information transparency can improve employees' understanding of the company, and the understanding of the company's strategy and plan can promote the effective internal flow of employees. Through the guidance of salary, the focus of employees' personal work is consistent with that of the company, which is conducive to the realization of Pareto optimal allocation of human resources [12]. At the same time, it can increase the employees' sense of identity and improve their enthusiasm; each company has its own unique cultural style, the transparency of cultural style will increase the sense of belonging of employees, reduce employee turnover, and more willing to introduce new employees to the company; In terms of salary system, proper transparency of the salary system can improve the sense of achievement and self recognition of hard-working employees, encourage them to work hard to improve their salary, greatly improve their work enthusiasm and work engagement, and help the company to build a more reasonable salary incentive system. Some scholars have pointed out in the research that moderate transparency can greatly improve employees' satisfaction with salary, and be more loyal to the enterprise. At the same time, it will also enhance the trust of management. According to Rhymer Rigby, the right amount of pay transparency can help build trust among employees, and that a culture of openness about pay within a company can enhance a company's overall reputation [13].[1] Bennis, Warren and others believe that transparency is one of the criteria to measure an organization's moral health, and it is a kind of competitiveness in creating consumer loyalty, recruiting and retaining talents [14]. Therefore, in the field of corporate management, transparency and trust, performance and other related concepts also have an indispensable relationship.

3 Project Transparency

Because of its large volume and complex process, the construction project covers a large amount of information. The collection and collation of information is one of the main tasks of construction project management, which is also the key to the success of the project. A complete project needs to be completed with the cooperation of the construction unit, the construction unit, the design unit, the supervision unit, the consulting unit, the government department and so on. Therefore, project transparency has a great impact on project performance and final results.

For the classification and application of transparency, scholars mostly study according to the content and needs of the research field, on the basis of information transparency. In terms of government, there are government transparency, policy transparency and financial transparency. In marketing, there are researches on brand transparency, green transparency and relationship transparency. Similarly, in the field of construction project management, project transparency mainly refers to the openness and transparency of various aspects, including information, among all participants in the whole process of construction engineering. This paper will be based on the existing problems in the construction industry and the previous literature. The connotation of project transparency is divided into information transparency, rule transparency and cultural transparency. It covers the concept of workflow, problem handling, communication, information disclosure, team building and so on.

3.1 Information Transparency

Because in the construction project, each participant is responsible for part of the project content, so the information held by each participant is mostly different. As an independent enterprise, each party will take its own interests as the center. For example, in the relationship between the owner and the contractor, the owner pursues the goal of completing the project schedule and quality at a lower cost, while the contractor pursues the maximization of its own interests. As the actual executor of the project, the contractor has the most actual project information, so there is the possibility of opportunity behavior, and the contractor may use its own information Advantages do harm to the interests of the owner and affect the overall situation of the project [15]. For example, it will have a negative impact on the quality of the project. At the same time, opportunism has a significant negative impact on the establishment and maintenance of partnership, which will reduce the expectation of long-term relationship [16]. Moreover, due to distrust of other parties, each party needs to spend more manpower and material resources to supervise, which will also cause waste of resources. Therefore, information transparency is very important in project management.

3.2 Rule Transparency

Rule transparency mainly refers to the transparent and complete work division, process details and so on in the process of construction project progress. Due to the complexity of the construction project, there are still some problems, such as unclear handling process after problems and shifting responsibilities. If the project team can have clear and transparent rules and processes, conflicts will be greatly reduced and work coordination will be promoted. Fan Shanshan studied the work flow of gas engineering construction management, and thought that the gas engineering construction involves many engineering management levels, and needs to cooperate with many enterprises, government agencies, social organizations and other social organizations. The management framework may have certain overlap and repeatability. Good operation process and standard can effectively reduce redundant links for enterprises. The efficiency of work and management is significantly improved [17]. Chu Yuelong has been doing research on the optimization of enterprise business process. He thinks that the business process of an enterprise should fully consider the actual situation and make a person or a department complete relatively independent function as far as possible, To clarify the cooperation relationship between process nodes, reduce the coordination workload and unnecessary non value-added operation links, and make the process definition as clear as possible and quantify it, so as to improve the operation quality and efficiency and improve the performance [18]. Ma Zhenxi explored the sharing of accounting information among supply chain enterprises. He believed that the establishment of unified accounting standards among supply chain enterprises could reduce the cost of accounting information transmission. At the same time, it is necessary to strengthen the construction of various organizations and the overall operation framework of enterprises to be scientific, reasonable and standardized. So as to realize the efficient utilization of accounting information resources, build up the accounting information sharing mechanism, make the information transmission between supply chain enterprises more accurate and effective, reduce information distortion and supply chain contradictions [19]. Similarly, in the field of construction project management, the transmission of information among enterprises and the implementation of work need unified standards and scientific and clear division of labor. Rules are the basis of all work. The transparency of rules among the participants can promote the project team to form an efficient operation mode and reduce unnecessary conflicts and waste. And a good and reasonable constraint mechanism in a team is also very important, under the constraint mechanism, all participants will be able to work hard to complete their own tasks.

3.3 Cultural Transparency

Culture is a concept with humanistic meaning. Compared with economy and politics, culture is all human spiritual activities and products. Each independent organization has its own culture. The culture of an enterprise mainly refers to the long-term business philosophy, business purpose, management policy, values, business behavior, social responsibility, business image, etc., of which values are the core of corporate culture. Values include the consistent understanding of an event or a certain behavior, good and bad, right and wrong, and whether it is worth imitating. It directly affects the likes and dislikes of each member, the acceptance of things and behaviors, and thus affects the behavior of the subject. At the same time, corporate culture is also reflected in the relationship between its employees and others. Each fixed or temporary organization will form its own organizational culture, but there will also be subculture [20] within the organization. There may be conflicts between the goals and practices of individual members and the overall goals or values of the whole organization, and the overall objectives and members of the organization. There may be gaps between individual practices. At the same time, culture is not inherent in an organization. It will gradually form or change according to the behavior of its members along with the environment and the actual situation. Culture is developed through the efforts of the organization to solve its internal integration and external adaptation problems.

Similarly, in the construction project, organizational culture is also very important, because it helps to cultivate team spirit in the project and provides guidance for the behavior of team members. Due to the nature of the construction project, most of the members of the construction project come from different enterprises, such as the construction unit, the construction unit, the supervision unit, the design unit, and so on. After they form a new temporary organization, the organization will form a new culture, and its own culture may cause conflicts and contradictions, which is not conducive to the establishment of a good new culture. Ajmal and Koskinen believe that project organizations should integrate various organizational cultures to shape project culture. Culture plays an important role in human capital such as the interaction between project participants, and may evolve in the life cycle of large-scale projects, thus affecting project efficiency and organizational productivity [21]. Therefore, cultural transparency is particularly important in construction projects. If the participants can communicate and communicate widely and honestly, and the members can have enough mutual understanding, the occurrence of conflicts can be greatly reduced. At the same time, in an open and mutual understanding environment, even if there are some contradictions can be effectively solved.

4 The Role of Project Transparency

Transparency has always been regarded as an important factor in the generation of trust [22, 23]. Trust within the organization can significantly improve project performance [24, 25]. Fred O. Walumbwa believes that leaders' mastery of transparency can directly affect trust between teams. When leaders and followers share information openly and provide constructive feedback, followers often go beyond their normal responsibilities to help others and interact out of their sense of obligation. Transparency, openness and information sharing can improve team psychological capital and trust level, thus affecting team behavior and performance [24]. In the field of construction engineering, construction engineering itself has the characteristics of huge amount of money, complex process, long cycle, and many participants. Each participant is both the sender and the receiver. In recent years, the engineering project is becoming more and more complex, and the uncertain factors and the accompanying risks increase proportionally, so the trust between the parties is particularly important. At the same time, due to the increase of technical level, it is possible to outsource many modules to the contractor, so that the interface of construction engineering field is further expanded, and the benefits of sharing information and joint thinking among all parties are further expanded. A highly trusted and effective communication organization can effectively avoid some potential risks, which will have a direct impact on project performance.

The earliest research on cooperation is because of the benefits brought to the whole organization or collective by the coordination activities among its members. For a long time, good cooperative relationship has been regarded as the key factor of enterprise success [26]. Zillante compared the two construction project cases, and found that the case 1 with integration, cooperation, flexibility and people-oriented is better than case 2 in most aspects of project achievements, such as progress, function, satisfaction with process and relationship, environmental performance, business success, further business opportunities and overall performance. Meanwhile, the interviewees of case 1 mentioned that "compared with other teams, the first case is superior to case 2 in terms of project achievements The cohesion of the team and the sense of responsibility for the common cause are much higher. The team has a real heart that drives it to communicate extensively, to discuss and think, and to find ways to expand the benefits of the project" [27]. In the field of construction engineering, if multiple participants can achieve information transparency, rules transparency and culture transparency, they can form alliance relationship, partnership, relationship contract and other forms of cooperation [28]. A good cooperation relationship can increase the coordination and efficiency of the whole project department and all project participants, and ultimately achieve multi win and improve performance.

5 Analysis and Prospect

According to the problems and the actual situation, this paper analyzes the connotation of project transparency in the field of Construction Engineering in terms of information, rules and culture. After combing the literature and discussion, we realize that the transparency of the project can play a role in solving the problems existing in the construction project and the areas that can be improved. At the same time, project transparency can also affect the further improvement of project performance including quality, cost and progress, safety and satisfaction of all participants. It makes up for the lack of transparency research in the field of construction project management, provides a new idea for the research of project transparency, and also helps managers realize the important role of project transparency in practice. However, the research on project transparency still needs further excavation and exploration.

In the future, the relevant research should continue to combine with the specific construction project situation, and further increase the empirical demonstration. At the same time, researchers should deeply explore the specific measures and methods to improve the transparency of all aspects of the project, trying to produce more important and practical guiding significance. In the practice of construction project management, managers should be fully aware of the important role of project transparency, build an open and positive cultural atmosphere, formulate a smooth and reasonable workflow and system, strengthen the flow and sharing of information, so as to further improve the project performance.

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Housing Choices of Migrant Workers with Different Types of Employment: A Comparison Between Eastern, Central and Western China

Yijing Pan and Li Tao

Abstract With the outbreak of COVID-19, many informally employed migrant workers or employers in the informal sector are facing unprecedented challenges in terms of employment, housing, etc. These workers do not have access to health insurances, social securities, housing subsidies, or any other social welfare. Many of them are at risk of sharp income reduction or losing jobs because of having no labor contracts. Studies on informal employment of migrant workers often focus on labor protection. Few studies analyzed the role of informal employment in housing choices of migrant workers. This paper aims to fill this knowledge gap. Data from China Migrant Dynamic Survey 2017 were employed. Multiple logistic regression models were established. Comparisons were made between the three economic belts (i.e., eastern, central and western regions) of China. It was found that the influencing factors of housing choices of migrant workers varied from region to region, so do the influences. Informally employed migrant workers tended to live in informal housing (such as construction sites, abandoned factories, etc.), and places of employment. Formally employed migrant workers were more likely to live in dormitories provided by employers. Unexpectedly, the effect of formal employment on housing purchase of migrant workers was insignificant. The government should pay more attention to the housing issues of migrant workers in informal employment. Measures should be taken to improve the housing conditions of informally employed migrant workers. More housing options should be provided to them, such as incorporating them into the housing security system. Moreover, housing strategies should be specified according to the respective characteristics of different regions.

Keywords Migrant workers · Informal employment · Housing types · Three economic belts

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1 Introduction

The economic reform accelerated rapid industrialization and urbanization in China in the 1980s, which made population migration enter into the most active period. According to China Statistical Yearbook 2019, the floating population[1] totaled 241 million in 2018, which accounts for 17.27% of the total population in China. The floating population is mainly composed of rural migrant workers who have gradually dispersed from the industrial hubs of the eastern China to the central and western China [37]. The division of the three economic belts was proposed by the Chinese government in the "Seventh Five-Year Plan (1986–1990)".[2] In fact, the floating population usually refers to migrant workers in China. They are non-registered workers who live in the county or city for no less than half a year [25]. "Non-register" means without local *Hukou*. The *Hukou* system has long been criticized for depriving migrant workers of social benefits in the locality, such as public housing.

Housing provides shelter, security and psychological benefits to the residents. Homeownership not only contributes to wealth accumulation, but also benefits social integration of migrants [16]. Housing has been a great challenge for migrant workers in the locality, especially in first-tier cites. Migrant workers were mainly accommodated in shanty towns and urban slums in the last century. The most common choices of migrant workers are private housing, renting housing, dormitories provided by employers [35]. China is one of the countries with the highest rate of home ownership. The home ownership rate of urban families was as high as 85.39%, and that of rural families was 92.6% in 2012. The home ownership rate in the east, central and west of China was 87.35%, 94.42% and 90.41%, respectively [11]. Migrant workers generally have home ownership in the hometowns, whilst they usually own no housing in the locality. The existing studies concerning influencing factors of housing choices of migrant workers mainly focus on demographic characteristics, political factors and regional factors.

According to China Migrants Dynamic Survey (CMDS) in 2017, about 40% of the migrant workers were informal employees, and about 20% were informal employers. In recent years, China has vigorously promoted '*mass entrepreneurship and innovation*', among which migrant workers are one of the target groups. Migrant workers have a high rate of entrepreneurship. The government aims to offer supports to these migrant workers in housing, education, and medical services [18]. With the outbreak of COVID-19, many informally employed migrant workers are facing unprecedented challenges. Informal employees do not have access to benefits mentioned above. Many of them are at risk of losing jobs because of having no labor contracts. Studies on informal employment of migrant workers mainly focus on labor protection Few studies analyzed the housing choices of migrant workers in the informal sector. This paper aims to fill this knowledge gap. The emphasis will

[1] Floating population refers to people who have left their original living places without officially changing their household registration.

[2] The eastern coastal region is the most developed economic zone in China, followed by the central inland region and the western remote region.

be put on the effects of different types of employment, especially informal employment. The structure of this paper is as follows: (1) the next section is the literature review concerning housing choices of migrant workers, and informal employment; (2) section three is the research methods; and (3) section four presents the results, followed by discussion and conclusion.

2 Literature Review

2.1 Housing Choices of Migrant Workers

Housing issues of migrant workers has been widely concerned worldwide, such as the marginalization of property rights, poor housing qualities, and spatial agglomeration and isolation [28]. Different from China, studies of western countries mainly focus on international migration. Home ownership, housing quality and residential mobility of international migrants have been investigated. Whether to buy a house is considered as the core of housing issues. The influencing factors are usually subdivided into social and economic status, life cycle and institutional factors, such as professional status, length of migration, income, educational level, age, marital status, family structure, housing price, interest rates, city size, etc. [4]. More concerns have been raised about the identity of migrant workers, and the influence of cultural factors on housing choices of migrant workers, such as settlement intention, generational differences, language, social networking, segregation and discrimination, ties to origins, and social integration [1, 2, 34].

The influencing factors of housing choices of migrant workers in China can be divided into institutional factors, social demographic and economic characteristics, housing market and migration characteristics [7, 34]. The *Hukou* system has long been recognized as a determinant of housing choices of migrant workers in China. It excludes migrant workers from the mainstream housing system, especially affordable housing in the public sector [5, 10, 30, 31, 34]. Since the reform of household registration system in 2014, social welfare has been gradually separated from *Hukou* in small and medium-sized cities. Migrant workers, especially the new generation, are paying less attention to the welfare brought by *Hukou.* The role of *Hukou* in promoting house purchasing is further weakened [14, 31, 34].

On the other hand, migrant workers often choose to return home on a regular basis and are less willing to purchase housing in the locality. Rural migrant workers face the risk of land redistribution and tenure insecurity when they work outside their hometowns. Only when the land use right in rural areas is not restricted, can the policy on housing choices of migrant workers in the destination be effective [34]. Reforming the lease market of rural land may enhance the willingness of migrant workers to settle down and purchase houses in the locality [20]. In addition, policies of hometown cities may also prevent migrant workers from buying houses and settling down in the destination. In recent years, many villages and towns have introduced incentive policies to attract migrant workers to return, such as housing subsidies and entrepreneurship subsidies, to get rid of the development dilemma [19]. Self-owned housing, public housing and housing subsidies provided by employers were found to significantly correlate with the settlement intention of migrant workers [36].

Social demographic and economic characteristics are recognized as important factors influencing the housing choices of migrant workers, such as household income, savings, employment, social capital, education, marital status, family composition and gender [9, 10, 14, 16, 22, 26, 27, 29]. Specifically, married male migrant workers with higher income, higher educational level, longer working history and children have higher possibility to become homeowners [5, 33]. Migrant workers in China often choose to live in low-rent urban villages and dormitories provided by employers because of the above factors [39].

Housing choices of migrant workers show significant regional differences [9, 34]. Housing choices are significantly affected by geographical factors including the size and geographical locations of destination cities, the difficulty to obtain local *Hukou*, and housing market [36]. Housing prices and income levels are main market factors affecting housing choices and housing characteristics of migrant workers, especially the acquisition of home ownership [9]. The housing prices in the eastern region are much higher than that in the central and western regions, while there is little difference between the latter two. The housing affordability of migrant workers in the eastern region is the lowest, while it is the highest in the central region. Therefore, the proportion of migrant workers buying houses in central and western cities is obviously higher than that in the eastern area. Migrant workers in eastern cities occupy the smallest housing space, while migrant workers in western cities have the worst housing conditions. In terms of housing types, the proportion of migrant workers living in temporary housing in Western China is significantly higher than that in Central and Eastern China [9, 26]. Further, migration barriers vary among cities of different levels, which significantly affect the housing outcomes of migrant workers [34].

Nowadays, increasing number of migrant workers are migrating in a diversified family pattern. Compared with individual migrants, migrant families have higher probabilities to purchase housing or rent high-price housing. Life cycle factors affect housing conditions of migrant workers [6]. Each life stage corresponds to different housing needs. Migrants with longer distances of migration, shorter periods of migration, and no willingness to settle down are more likely to rent rather than purchase housing. Compared with local residents, migrant workers usually have a period of delay in owning houses due to the limited intergenerational transmission of wealth and lack of understanding of the local housing market [16, 22, 26]. Further, migrants workers tend to use social networks as an important way to obtain employment, housing and cultural activities [17].

2.2 Informal Employment

The concept of informal employment was first proposed by the International Labour organization (ILO) in 1972. The act of engaging in "unorganized, unregulated and largely legal but unregistered economic activities in which individuals or families own and use simple, labor-intensive technologies", and earning income is called informal employment or informal sector employment [8]. Informal employment is an important means to shaking off poverty [15]. It is a double-edged sword, providing countless job opportunities while failing to guarantee the benefits and safety of the employed.

According to the definition of informal employment and the situation in China, informally employed migrant workers not only include migrants working in the informal sector, but also include informal employees in the formal sector such as the short-term employment, part-time employment, labor dispatching employment, and subcontract related employment, etc., depending on whether to sign a labor contract. Informal employment in China can be categorized as flexible employment, periodic employment, part-time employment, seasonal employment and other temporary employment, etc. [12, 38].

Informal employment is the main way for migrant workers to enter into cities in China. There are mainly two types of employment status of migrant workers, i.e., informal employees and employers. Informal employees are usually engaged in unstable jobs with low income and no labor security. Employers usually work flexible hours with high income. Although they have different levels of income, either informal employees or employers are included in the housing welfare system in China. Migrant workers with informal jobs usually live in urban villages, suburbs and other informal housing with poor housing conditions, which leads to the clustering of migrant workers and tends to form a "culture of poverty". The research on informally employed migrant workers in China is mainly limited to labor protection and the impact on migration, but not extended to the housing level (Fig. 1).

To sum up, the conditions of the eastern, central and western regions in China are different in terms of climates, terrains, geographical locations, natural resources, population densities and economic development. Accordingly, the migration purposes, residence intentions, employment opportunities and living conditions of migrant workers in each economic belt vary to some extent. However, there have been a limited number of studies comparing regional differences concerning housing choices of migrant workers. In addition, studies on influences of employment related factors on housing choices of migrant works only involve employment types, job stability (frequency of job changes), income and industry types. The impacts of informal employment on housing of migrant workers have been overlooked.

This paper aims to fill the knowledge gap. Factors influencing housing choices of migrant workers in the eastern, central and western regions were compared. The effects of social demographic and economic factors, employment characteristics (especially informal employment), migration characteristics and social integration on housing choices of migrant workers were looked into. Specifically, this paper

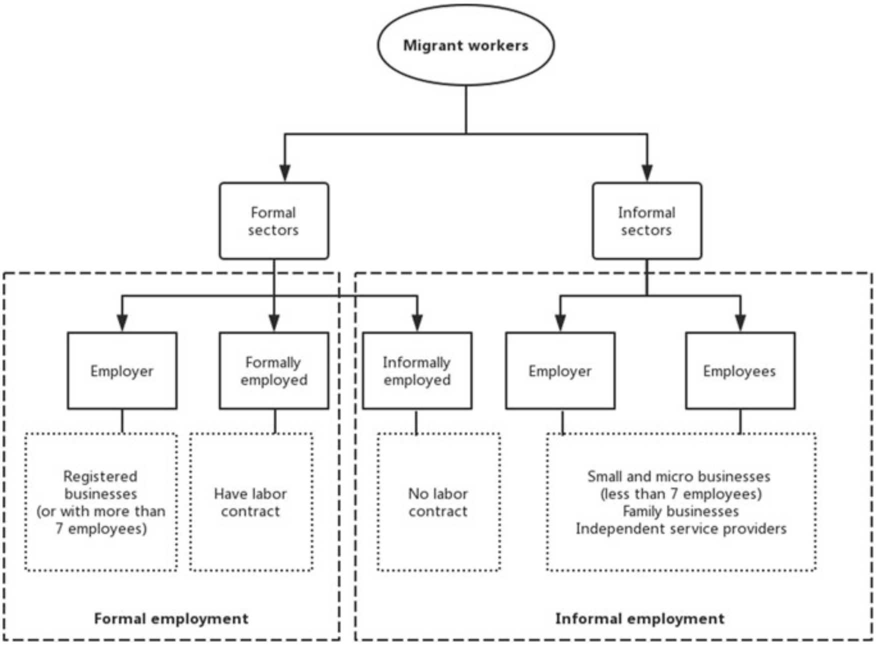


Fig. 1 Types of employment in China

aims to answer the following questions: (1) What are the housing choices of migrant workers in the three economic belts? Are there any differences? (2) Which factors affect the housing choices of migrant workers, and what are the effects? (3) Do employment characteristics (especially informal employment versus formal employment) have any effects on housing choices of migrant workers? Are there any regional differences? To this end, the following hypotheses were proposed:

H1: Housing choices of migrant workers (e.g., housing tenure, and housing type) vary in the eastern, central and western regions of China.
H2: The influencing factors and the effects on housing choices of migrant workers are different among the three economic zones.
H3: Informal employment has a significant effect on housing choices of migrant workers. The influences are different among the three regions.

3 Research Methods

3.1 Data Source

This study employed the data from China Migrants Dynamic Survey in 2017 conducted by the National Health and Family Planning Commission of China [23].

It is the latest publicly available data released by the NHFPC, and may reflect the effects of the *Hukou* reform in 2014 [24].[3] According to the definition of migrant workers, 139,458 respondents, who had lived in the locality for six months or more for the purpose of working without local *Hukou*, were selected for analysis.

3.2 Analytical Methods

This paper was to investigate the influences of social-demographic and economic characteristics, economic status, type of employment, mobility characteristics and social integration on migrant workers' choices of housing types in the eastern, central and western regions of China respectively. Housing choice is a nominal variable. The value of 1 indicates 'housing provided by employers', 2 indicates 'rental housing', 3 indicates 'purchased/self-built housing', and 4 indicates 'other types of housing'. There were both continuous and discrete independent variables in the analysis. Thus, Multinomial Logistic Regression, which mainly deals with regressions with dependent variables of nominal or ordinal types, was employed to conduct the analysis. The formula of multinomial logistic regression is as follows:

$$\text{Log it } \pi_1/\pi_4 = a_1 + \beta_{11}X_1 + \beta_{11}X_2 + \cdots + \beta_{1m}X_m$$
$$\text{Log it } \pi_2/\pi_4 = a_2 + \beta_{21}X_1 + \beta_{22}X_2 + \cdots + \beta_{2m}X_m$$
$$\text{Log it } \pi_3/\pi_4 = a_3 + \beta_{31}X_1 + \beta_{32}X_2 + \cdots + \beta_{3m}X_m$$

where π_1, π_2, π_3, and π_4 refer to the possibilities of migrant workers choosing the four types of housing; vector x includes all independent variables in the study; m is the number of independent variables; a represents intercepts; and β represents corresponding coefficients of the outcome 'm'.

4 Results

4.1 Descriptive Findings

The sample sizes of East, Central and West China were 45%, 22% and 33%, respectively. Renting housing was the main choice for migrant workers in China. The cost of housing was relatively higher in the eastern China. Migrant workers in the eastern region tend to live in free or low-cost dormitories, and were less likely to own housing than their counterparts in the central and western regions. According to *Report of*

[3] This survey covered 31 provinces (municipalities) with a sample size of around 170 thousand.

China's Floating Population Development 2018, migration of the elderly and children was on the rise. Family migration (mainly nuclear family) was obvious. This is consistent with the average household size in each region (Table 1).

The proportion of migrant workers with urban *Hukou* was the highest in the eastern region, and the lowest in the western region, so was the level of educational attainment and income. The average household income of migrant workers in the eastern region is 1.3 times that in the central region, and 1.4 times that in the western region. This is not only related to the economic development of each economic belt, but also due to the gravity of each economic belt, that the highly educated and highly skilled ones tend to concentrate in the eastern coastal area. In addition, the proportions of ethnic minorities in the central and eastern regions were relatively low, at 3.2% and 5.3% respectively, while the proportion of ethnic minorities in the western region was as high as 17.1%.

As for employment, most migrant workers were engaged in the tertiary industry. The proportion of migrant workers engaging in the secondary industry in the eastern coastal area was 42.2%, higher than that in the central and western regions. The proportion of migrant workers engaging in the tertiary industry in central China was as high as 70.9%. Most primary industry practitioners were concentrated in the west. Migrant workers in the eastern China were mainly formal employees, accounting for 48.2%. In the central and western regions, self-employment was the main employment mode, accounting for about 42%.

About 55% of the migrant workers owned homestead in their hometowns. There were no significant differences among the three regions. The owning rate of contracted land in the eastern region was only 41%, which is lower than that in the central (50.1%) and western (48.4%) regions. The central and western regions were dominated by intra-provincial migration, while the eastern coastal area attracted migrant workers nationwide. Inter-provincial migration in the eastern China was as high as 68.8%, 2–3 times that in the central and eastern China. In terms of social integration, the proportion of migrant workers in the central area planning to settle down was slightly higher than that in the eastern and western regions. From the perspectives of sense of belonging and main contacts, migrant workers in the eastern area had the lowest degree of social integration.

4.2 Regression Analysis

Three multiple logistic regression models were established for the three regions respectively (Tables 2, 3 and 4). All three models had statistical significance. Migrant workers mainly lived in rental housing. Other types of housing (including working places, residences of friends/relatives, and other informal residences) were used as the reference group of housing types. Stepwise regression (backward) was employed. In the process of stepwise regression, the variable of ethnics was removed from models of the eastern and central regions, while the place of origin was removed from the model of western China.

Table 1 Descriptive findings

	Explanatory variables		Eastern area	Central area	Western area
Social-demographic and economic characteristics	Gender	Male	57.1%	57.4%	58.8%
		Female	42.9%	42.6%	41.2%
	Type of *Hukou*	Agricultural	70.6%	78.0%	81.2%
		Non-agricultural	29.4%	22.0%	18.8%
	Education level	Junior high school and below	55.7%	57.0%	61.0%
		High school	22.0%	24.9%	21.0%
		University and above	22.3%	18.1%	18.0%
	Marital status	Unmarried	13.9%	12.3%	14.7%
		Married	84.2%	85.4%	82.3%
		Divorced or widowhood	1.8%	2.3%	3.1%
	Ethics	The Han nationality	94.7%	96.8%	82.9%
		Ethnic minorities	5.3%	3.2%	17.1%
	Family members living together	Average number (persons)	3.121	3.122	3.202
	Age	Below 29	22.7%	22.1%	23.2%
		29–36	34.5%	30.8%	30.4%
		37–44	23.3%	23.3%	22.8%
		Above 44	19.6%	23.8%	23.6%
	Monthly average family income	Below 4000	25.8%	32.2%	33.5%
		4000–6000	22.8%	18.4%	16.1%
		6000–8000	35.6%	22.4%	18.4%
		Above 8000	15.8%	26.9%	32.1%
Employment characteristics	Industry	Primary industry	1.3%	2.5%	3.7%
		Secondary industry	42.2%	26.6%	30.8%
		Tertiary industry	56.5%	70.9%	65.5%
	Type of employment	Formal-employer	6.3%	7.3%	5.9%
		Formal-employee	48.2%	28.3%	27.4%
		Informal-employer	25.3%	42.4%	41.7%
		Informal-employee	19.1%	20.1%	21.2%
		Others	1.2%	2.0%	3.8%
Migration characteristics	Contracted land in hometown		41.0%	50.1%	48.4%
	Homesteads in hometown		54.8%	56.1%	55.4%
	Regions of origin	Eastern area	48.5%	6.6%	6.1%
		Central area	36.4%	88.9%	14.4%

(continued)

Table 1 (continued)

	Explanatory variables		Eastern area	Central area	Western area
		Western area	15.1%	4.4%	79.4%
	Scope of migration	Inter-province	68.8%	20.7%	37.6%
		Cross-city (within the province)	23.5%	43.9%	41.0%
		Cross-county (within the city)	7.7%	35.5%	21.4%
	Administrative division of hometown	Villages/towns	85.9%	87.6%	89.4%
		County	12.2%	11.5%	9.6%
		Provincial capital	1.5%	0.8%	0.6%
		Municipalities	0.5%	0.2%	0.3%
	Duration of migration	Mean value (years)	7.013	6.501	7.004
Social integration	Settlement intention	Move	34.0%	39.3%	34.8%
		Settle down	24.1%	26.2%	24.1%
		Not sure	41.9%	34.5%	41.0%
	Key contacts in the locality	Migrant workers from hometown	38.6%	26.6%	31.2%
		Locals	26.1%	44.3%	41.7%
		Migrant workers from other places	14.7%	7.6%	8.3%
		Little contact with others	20.7%	21.5%	18.9%
	Sense of belonging[a]	Mean value	2.82	3.12	3.1

[a] Sense of belonging ranges from 1 to 4. The higher the value, the stronger the sense of belonging

4.2.1 Social Demographic and Economic Characteristics

Male migrant workers in eastern China were more likely to live in dormitories. Males were mainly engaged in the secondary industry, while females were mainly engaged in the tertiary industry. Employers in the secondary industry usually provide dormitories for their employees. The new generation migrant workers (born after 1980) were different from the old generation (born before 1980) in housing choices (Table 2). The old generation of migrant workers were more likely to purchase housing in the eastern region. Besides purchasing housing, the old generation tended to rent housing in the western region due to weaker settlement intention.

In terms of institutional factors, non-agricultural *Hukou* is not significant in home ownership or self-built housing in the three regions, which is consistent with the argument that migrant workers are less affected by *Hukou* than before [14, 31, 34].

Table 2 Factors affecting housing choices of migrant workers in Eastern China

			Housing provided by employers	Rental housing	Purchased/self-built housing
			B	B	B
Social-demographic and economic characteristics	Intercept		−0.837	1.518	−1.118
	Gender	Male	0.117*	0.038	−0.044
	Age (Ref.: below 29)	29–36	0.100	0.098	0.261***
		37–44	0.217**	−0.020	0.219**
		Above 44	0.066	−0.471***	−0.350***
	Type of *Hukou*	Agricultural *Hukou*	−0.256**	−0.001	−0.127
	Marital status (Ref.: divorced or widowhood)	Unmarried	0.738***	0.292*	−0.390**
		Married	0.521 ***	0.560***	0.660***
	Educational level (Ref.: university and above)	Junior high school and below	0.312***	0.023	−0.714***
		High school	0.409***	0.108	−0.304***
	Number of family members in the residence		−0.148***	−0.085***	0.049
	Monthly household income (Ref.: below 4000)	4000–6000	−0.316***	0.256***	0.423***
		6000–8000	−0.282***	0.417***	0.686***
		Above 8000	−0.489***	0.294***	0.931***
Employment characteristics	Industry (Ref.: primary industry)	Secondary industry	0.590***	1.611***	0.462***
		Tertiary industry	−0.261	1.432***	0.144
	Employment (Ref.: informal-employee)	Formal-employer	−2.102***	−0.321	0.162
		Formal-employee	0.916***	−0.086	0.084
		Informal-employer	−3.721***	−0.362***	−0.401***

(continued)

Table 2 (continued)

			Housing provided by employers	Rental housing	Purchased/self-built housing
			B	B	B
		Others	−1.325***	−0.288	−0.214
Migration characteristics	Contracted land in hometown		−0.046	−0.204***	−0.006
	Homestead in hometown		0.226**	0.109	−0.526***
	Duration of migration		−0.024***	0.000349	0.052***
	Regions of origin (Ref.: western area)	Eastern area	0.099	−0.286***	0.401***
		Central area	0.151	−0.058	0.252***
	Scope of migration (Ref.: cross-county (within the city))	Inter-province	0.222*	0.302***	−0.591***
		Cross-city (within the province)	0.084	0.489***	−0.302***
	Administrative level of hometown (Ref.: municipalities)	Villages/towns	1.300***	0.892**	0.349
		County	1.048**	0.629*	0.162
		Provincial capital	1.021*	0.624	0.551
Social integration	Key contacts in the locality (Ref.: little contact)	Migrant workers from hometown	0.184**	0.067	−0.120
		Locals	−0.262***	−0.370***	0.097
		Migrant workers from other places	0.468***	0.146	0.024
	Settlement intention (Ref.: leave)	Settle down	−0.733***	−0.325***	1.382***
		Not sure	0.041	0.019	0.322***
	Sense of belonging		0.008	0.068*	0.356***

Table 3 Factors affecting housing choices of migrant workers in Central China

			Housing provided by employers	Rental housing	Purchased/self-built housing
			B	B	B
Social-demographic and economic characteristics	Intercept		−1.610	0.879	−1.287
	Gender	Male	−0.044	−0.059	0.011
	Age (Ref.: below 29)	29–36	−0.003	0.078	0.015
		37–44	0.242	0.180	0.252**
		Above 44	0.432***	−0.022	−0.049
	Type of *Hukou*	Agricultural *Hukou*	−0.465***	0.042	0.137
	Marital status (Ref.: divorced or widowhood)	Unmarried	0.931***	0.266	−0.101
		Married	−0.147	0.027	0.624***
	Educational level (Ref.: university and above)	Junior high school and below	−0.012	0.048	−0.489***
		High school	0.207	0.223*	−0.209*
	Number of family members in the residence		0.054	−0.041	0.068*
	Monthly household income (Ref.: below 4000)	4000–6000	−0.008	0.168**	0.419***
		6000–8000	0.188	0.327***	0.651***
		Above 8000	0.409***	0.258***	0.922***
Employment characteristics	Industry (Ref.: primary Industry)	Secondary industry	0.603*	1.481***	0.067
		Tertiary industry	0.093	1.522***	0.036
	Employment (Ref.: informal-employee)	Formal-employer	−2.690***	−0.850***	−0.953***
		Formal-employee	0.725***	−0.267**	−0.183
		Informal-employer	−4.135***	−0.719***	−1.059***

(continued)

Table 3 (continued)

			Housing provided by employers	Rental housing	Purchased/self-built housing
			B	B	B
		Others	−1.828***	−0.557**	−0.386
Migration characteristics	Contracted land in hometown		−0.248**	−0.117	0.202**
	Homestead in hometown		0.514***	−0.130	−0.673***
	Duration of migration		−0.048***	−0.003	0.059***
	Regions of origin (Ref.: western area)	Eastern area	−0.334	−0.252	0.141
		Central area	−0.546**	−0.123	0.060
	Scope of migration (Ref.: cross-county (within the city))	Inter-province	0.370**	0.299***	−0.306***
		Cross-city (within the province)	0.170*	0.365***	0.051
	Administrative level of hometown (Ref.: municipalities)	Villages/towns	3.113***	1.727***	0.760
		County	2.814**	1.480**	0.573
		Provincial capital	2.899**	1.147	0.865
Social integration	Key contacts in the locality (Ref.: little contact)	Migrant workers from hometown	−0.092	−0.166**	−0.158*
		Locals	−0.087	0.026	0.337***
		Migrant workers from other places	0.620***	−0.170	−0.153
	Settlement intention (Ref.: leave)	Settle down	−0.844***	−0.108	1.329***
		Not sure	−0.254***	−0.117	0.168**
	Sense of belonging		−0.063	0.063	0.363***

Table 4 Factors affecting housing choices of migrant workers in Western China

			Housing provided by employers	Rental housing	Purchased/Self-built housing
			B	B	B
Social-demographic and economic characteristics	Intercept		0.177	2.527	−0.945
	Gender	Male	0.128*	0.081	0.131**
	Age (Ref.: below 29)	29–36	−0.049	0.27***	0.152*
		37–44	0.082	0.131	0.120
		Above 44	0.273**	−0.082	−0.100
	Type of *Hukou*	Agricultural *Hukou*	−0.462***	0.051	0.047
	Marital status (Ref.: divorced or widowhood)	Unmarried	0.107	−0.124	−0.357*
		Married	−0.110	−0.037	0.392**
	Educational level (Ref.: university and above)	Junior High school and below	−0.206	−0.346***	−0.938***
		High school	−0.026	−0.167	−0.521***
	Number of family members live together		−0.047	0.007	0.177***
	Monthly household income (Ref.: below 4000)	4000–6000	0.112	0.166**	0.436***
		6000–8000	0.084	0.059	0.617***
		Above 8000	−0.069	−0.162**	0.674***
	Ethnic	The Han nationality	0.294***	0.366***	0.690***
Employment characteristics	Industry (Ref.: Primary Industry)	Secondary industry	0.605**	1.230***	−0.482***
		Tertiary industry	−0.151	1.188***	−0.677***
	Employment (Ref.: Informal-employee)	Formal-employer	−0.921*	−0.232	−0.210
		Formal-employee	1.001***	−0.144	−0.094

(continued)

Table 4 (continued)

			Housing provided by employers	Rental housing	Purchased/Self-built housing
			B	B	B
		Informal-employer	−2.726***	−0.495***	−0.713***
		Others	−1.500***	−0.803***	−0.463***
Migration characteristics	Contracted land in hometown		−0.061	−0.136**	0.140**
	Homestead in hometown		0.376***	0.142**	−0.499***
	Duration of migration		0.010	−0.007	0.048***
	Regions of origin (Ref.: western area)	Eastern area	0.032	0.038	0.008
		Central area	−0.247*	−0.040	−0.440***
	Scope of migration (Ref.: cross-county (within the city))	Inter-province	−0.048	−0.442***	−0.586***
		Cross-city (within the province)	−0.142	−0.102	−0.238***
Social integration	Key contacts in the locality (Ref.: little contact)	Migrant workers from hometown	0.198*	0.073	0.171**
		Locals	0.083	0.004	0.414***
		Migrant workers from other places	0.573***	−0.155	−0.115
	Settlement intention (Ref.: leave)	Settle down	−0.757***	0.016	1.325***
		Not sure	−0.087	0.069	0.297***
	Sense of belonging		0.062	0.092**	0.411***

Migrant workers with non-agricultural *Hukou* were generally formally employed in the locality. Quite a few migrant workers with agricultural *Hukou* were self-employed with lower income, and were less willingness to settle down. They were more likely to live in temporary residences such as workplaces and informal residences.

In the eastern region, unmarried migrant workers were more likely to live in dormitories and rental housing. Household size had a significant impact on housing type selection, especially in the western and eastern regions. As migrant workers experienced marriage and childbirth, they tended to rent or purchase housing. This was consistent across regions. The impact of educational attainment on housing choices of migrant workers is basically consistent with existing studies. The higher the educational attainment, the more likely migrant workers became home owners. However, it varied slightly between regions. The housing price is too high in the eastern region. Migrant workers often adopt the strategy of maximizing revenues and minimizing expenses.

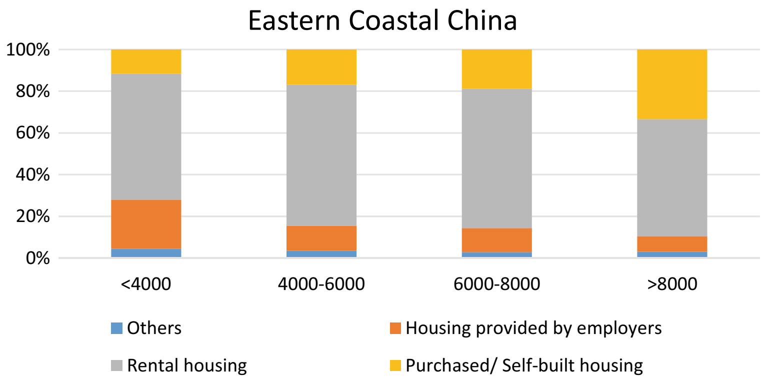
Overall, the higher the household income, the more likely migrant workers became homeowners or rented housing. An interesting finding is that migrant workers with monthly income higher than 8000 yuan had different housing choices across the three regions. In the eastern region, these migrant workers were more likely to rent or purchase housing. In the central region, these migrant workers tended to live in dormitories, rental housing, and self-purchased/self-built housing. In the western region, migrant workers with monthly income higher than 8000 yuan were more likely to live in workplaces or informal housing instead of renting housing. These high-income migrant workers were usually self-employed. They were more likely to live in workplaces (Fig. 2).

4.2.2 Employment Factors

In the eastern region, migrant workers in the secondary industry were less likely to live in workplaces, residences of friends and relatives, or informal housing. Migrant workers engaging in the tertiary industry were more likely to rent housing. The situation was similar in the central region.

Self-employed migrant workers were more likely to live in workplaces, residences of friends or relatives, and informal housing across the three regions. Most of them made the living by running their own businesses, such as selling fruit and breakfast. Compared with others, they were more likely to live in workplaces or other informal residences [3]. Formally employed migrant workers tended to live in dormitories. Formal employment was not necessarily associated with home ownership for migrant workers. On the one hand, formally employed migrant workers did not have advantages in income. The formally employed migrant workers were usually younger. Their accumulation of capital was relatively low. On the other hand, many cities provided various benefits such as free or low-cost dormitories to attract talents. Dormitories were important housing sources for young migrant workers.

The average income and expenses of formal employers in the formal sector were more than twice as high as those of migrant workers engaging in formal and



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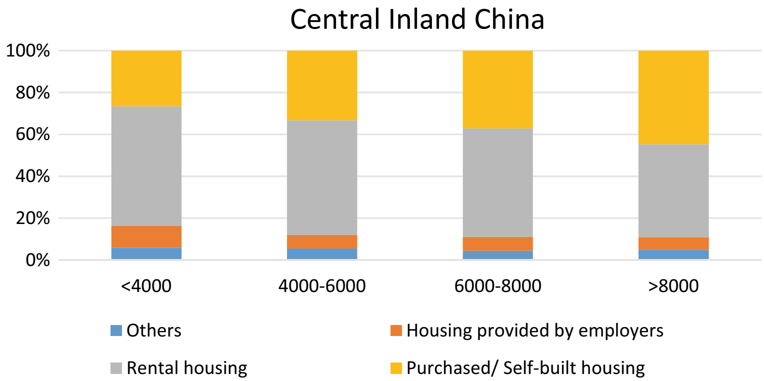

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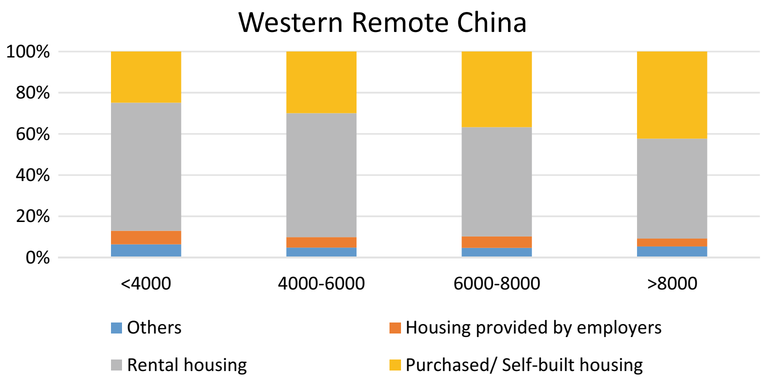

(3)

Fig. 2 Housing choices of migrant workers in different regions of China informal employment in all three regions. These migrant workers were mainly private entrepreneurs in the eastern area. They usually employed about 18 workers, compared with 20–30 workers on average in the central and western regions. Second, the eastern China has high housing prices and strict land management. It is not easy to acquire the ownership of houses or build houses privately. As for formal employers in the central and western regions, their settlement intention was far lower than their counterparts in the eastern area, and migrant workers of other types of employment in the same region.

4.2.3 Migration Characteristics

Contracted land and homestead were important factors affecting housing choices of migrant workers. Interestingly, they had opposite effects on housing choices of migrant workers. In the eastern region, having contracted land in the hometown was not conducive for migrant workers to choose rental housing in the locality. In the central and western regions, contracted land in the hometown was positively correlated with purchased/self-built housing. In the eastern region, the average income of migrant workers with contracted land was significantly lower than that of migrant workers without contracted land. However, there was little difference in the central or western regions. Wu and Zhang [34] pointed out that having contracted land had a two-way effect on migrant workers. On the one hand, these migrant workers were trapped by the land in the hometown. They tended to prefer jobs with flexible working time in order to return to hometown on a regular basis. On the other hand, the insecurity of losing land was a push from hometown. Migrant workers in the eastern region tended to save money in the locality, and return to the hometown in the long run. As for migrant workers in the central and western regions, those with contracted land tend to purchase/build housing due to the relatively lower housing price and the agricultural income.

In all three regions, having homesteads in hometowns had a significantly positive effect on migrant workers living in dormitories and rental housing, while a significantly negative effect on living in purchased/self-built housing. Migrant workers without homestead were more willing to settle down. They put more emphases on factors such as better education for children and family members' sense of belonging to the locality. On the other hand, migrant workers with homestead mainly stayed in the locality for high income, and career development. The attachment to the homeland and the expectation of reunion with families made it difficult for the migrant workers to purchase housing in the locality [21].

Places of origin had significant influences on housing choices of migrant workers. In the eastern region, migrants from the same region were more likely to purchase/build housing. In the central region, migrant workers from the same region were less likely to live in dormitories. In the western region, rural workers from the central area were less likely to live in purchases/self-built housing or dormitories. More than 70% of the migrant workers from the central region were engaged in self-employment in the western area. They tended to live in workplaces.

Secondly, the economic development of the western area was lagging behind the central area. Few inter-provincial migrant workers were willing to settle down in the west. Further, the longer the duration of migration, the more likely migrant workers lived in purchased/self-built housing in all three regions due to the accumulation of social capital and economic capital, the increase of sense of belonging, and the increase of family size.

The longer distances migrant workers migrated in the eastern and central areas, the more likely they chose dormitories and rental housing, rather than self-purchased/self-built housing. This is consistent with the findings of Hu et al. [13]. However, inter-provincial migrant workers were more likely to live in workplaces, residences of relatives and friends, and informal housing in the western region. There were 62.6% of the inter-provincial migrant workers in the western region were self-employed in informal sectors. These migrant workers often chose to live in workplaces or other informal residences. The administrative level of hometown was insignificant in affecting housing choices of migrant workers in the western region. Nearly 90% of them came from rural areas and towns. However, migrant workers from rural areas, towns and prefecture-level cities were more likely to live in dormitories and rental housing in the eastern and central regions.

4.2.4 Social Integration

Migrant workers who had frequent contacts with other migrant workers were more likely to live in dormitories in all three regions. These migrant workers generally had relatively longer migration distances, and no sense of belonging. They were reluctant to integrate into the local society. Migrant workers who mainly contacted with local people were more likely to purchase/built housing in the central and western regions, and less likely to live in dormitories or rental housing in the eastern region. This group of migrant works was mainly employers, high-income employees in the formal sector, and self-employed workers. They usually had frequent contacts with local people, and had the longest duration of migration on average. There was no difference between migrant workers in the eastern and western regions in terms of willingness to settle down. Migrant workers with intentions to move were more likely to rent housing or live in dormitories.

5 Discussion and Conclusion

This study explored housing choices of migrant workers and the affecting factors, especially employment characteristics, in the three economic belts of China. Comparisons were made across the three regions. Educational attainment, income, marital status, duration of migration, contracted land in the hometown, sense of belonging and settlement intention had positive effects on home ownership of migrant workers. On the other hand, migration distance, and homestead in the hometown had negative impacts on home ownership of migrant workers. This is consistent with the literature by large. In general, renting housing was the main housing choice of migrant workers in the three regions. Migrant workers in the eastern region were mainly migrating for job seeking, while the proportion of doing business increased rapidly in the central and western regions. The labor security of formal employment in the eastern region was generally better than that of the other regions.

Informally employed migrant workers tend to live in informal residences (such as construction sites, abandoned factories, etc.) and workplaces. Formally employees are more likely to live in Unit/Employer's room. Formal employment had no significant impact on home ownership of migrant workers. The wages of migrant workers employed in different sectors did not vary to a great extent. However, it is worth noting that formally employed migrant workers had a wider range of housing options. Informal employment is an important form of urban entrepreneurship in China. The income of informal employers even exceeded that of formal employees according to the study. Self-employment had a significant impact on housing acquisition [34]. Self-employed migrants had a stronger desire to permanently settle down and purchase housing in cities. However, they were also restricted by the household registration system when obtaining home ownership [3].

Based on the findings above, the government should formulate different strategies to accommodate migrant works in the locality according to the characteristics of each region. For example, the eastern coastal area should focus on improving the rate of home ownership and the quality of dormitories. The central region should pay attention to problems related to informal residences. Specifically, the local government can improve the living conditions, public securities, and the infrastructures of informal housing. The local government of the western area should improve the housing rental market, and encourage the provision of dormitories by employers.

Although formally employed migrant workers had better employment security, and are included in the housing security system, their settlement intention was not as strong as that of migrant workers in the informal sector. Migrant workers in the informal sector may have better economic conditions than formally employed ones. Relaxing the requirements of *Hukou* transfer for migrant workers in the informal sector may facilitate their urban integration and housing purchasing. On the one hand, the government should regulate the job market to reduce the number of informal workers in the formal employment sector. On the other hand, opportunities of further learning should be provided to migrant workers in the informal sector. A study of Thailand confirmed that the increase in the years of education yielded an objective return on wages of for informal workers [32]. Further, urban villages and other types of informal housing should be made a good use of to provide affordable housing for migrant workers.

This paper has some limitations. First, migrant workers who got unemployed were not included into the analysis. The unemployment was mainly due to retirement, raising children, layoffs, and company closures. We cannot obtain the employment data before they got unemployed. Secondly, this study made comparisons between the three economic belts of China. It may generate certain biases to generalize the findings to the whole region. For example, provinces/cities in the same region have different levels of economic development. Migrant workers from more developed provinces/cities may behave differently in housing consumption. Hence, local policies, housing prices and per capital GDP should be included into the study in the future.

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Determinants of Migrant Workers' Housing Pathways: Evidence from China

Ri Wang and Li Tao

Abstract Since the economic reform in 1978, China has undergone rapid economic development. From the late 1980s to early 1990s, the first tide of migrant workers appeared in China. An increasing number of migrant workers left their hometowns to seek jobs in another place. Housing is a common challenge for migrant workers in their working destinations. Housing choices of migrant workers have been widely investigated, albeit from the static perspective. Few studies have looked into the housing pathways of migrant workers, or their housing choices from a dynamic point of view. Housing pathway is the result of interactions between social practices of households and housing over time and space. This paper explores the housing pathways of migrant workers and its determinants from three aspects, i.e., housing tenure, housing size, and housing quality. Data from CFPS 2014 and CFPS 2016 are employed. Multiple logistic regression is used. The results show that socio-economic characteristics, mobility characteristics, and life course affects the housing pathways of migrant workers significantly. However, the effects of the above-mentioned factors on housing tenure, housing size, and housing quality of migrant workers are different. Compared with migrant workers in the Western region, migrant workers in the other two regions (i.e., the Eastern region, and the Central region) are less likely to obtain full homeownership, but more likely to improve housing quality during migration. Unemployed migrant workers or those who drop out of the labor market have higher possibilities of losing homeownership. They are also more likely to reduce the housing size. On the other hand, migrant workers who are getting married are prone to increase the housing size. The old generation and the migrant workers who have larger family sizes and longer durations of migration are more likely to have housing sizes unchanged. Moreover, the housing qualities of migrant workers who maintain the status of unemployment tend to remain unchanged. It is also true for migrant workers with larger family sizes. Based on the empirical results, the

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government is suggested to provide more employment information, job training, and job opportunities for migrant workers who are at disadvantages in housing. At the regional level, it is better for local governments to promulgate preferential housing policies for migrant workers in economically developed areas, such as widening the coverage of public housing, and encouraging employers to provide accommodations.

Keywords Housing pathway · Migrant workers · Determinants · Multiple logistic regression

1 Introduction

With the development of urbanization in China, an increasing number of migrant workers are leaving their hometowns to seek jobs in another place. The amount of floating population in China had reached 241 million by 2018 (National Bureau of Statistic, 2018), which means one sixth of people in China are floating population. Migrant workers are a category of floating population [30]. Most of the floating population are migrant workers who migrate for job seeking. Compared with local residents, migrant workers have higher degree of mobility, and their housing pathways are more complex and changeable. Housing is not only a living space, but also an important carrier to integrate to the working destinations for them [28].

Nowadays, people's housing preferences are diversified. The single improvement of living conditions may not conform to the changes of residents' housing [29]. Clapham put forward the framework of housing pathway. Housing pathway is the result of interactions between social practices of households and housing over time and space [2]. Housing career usually describes the quantitative aspects of housing (e.g. price, size and tenure), housing pathways adds social meanings and relationships on the basis of housing career [6]. Different from housing career theory [1, 3], housing ladder theory and housing cycle theory [10], housing pathway may not only be improved, but also be declined.

Few studies have looked into the housing pathways of migrant workers. Some studies have explored housing pathways of local residents and migrants together, they did not separate migrant workers out for analysis. Using the data from CFPS 2014 and CFPS 2016, this study aims to explore the determinants of migrant workers' housing pathways. Suggestions are put forward to improve the efficiency of policies on solving the housing problems of migrant workers. The rest of this paper is organized as follows. The second section provides an overview of the literature on housing pathways, including the types and determinants. The third section introduces the research methods, including data source, data processing process and methods of data analysis. The empirical results are presented in the fourth section. The fifth section discusses the findings. The last section summarizes the main findings. Policy recommendations are put forward.

2 Literature Review

2.1 Housing Pathways of Particular Population Groups

The housing pathways of particular population groups, such as disabled young people, single old women without homeownership, low-income people, and skilled migrants have been widely looked into [6, 11, 19, 21, 26]. To study the housing pathways of particular population groups (especially vulnerable groups) in the housing market, many studies examined their connections with original families. The housing pathways of British young people were divided into three categories, including direct independent living pathway, staged independent living pathway, and return independent living pathway [19]. Tomaszewski et al. [25] divided the housing pathways of Australian young people into four types, i.e., stayers at parents' home, singular movers, multiple movers, and returners to parents' home. Hartman and Darab [11] found most of the single old women without home ownership in rural Australia experienced the housing pathway of leaving parents' home, buying ideal houses, and having precarious homeownership after divorcing.

The housing pathways of Chinese residents have also been examined [16, 22]. Li and Li [16] used the retrospective life history data in Guangzhou collected in 2001 to conduct a longitudinal analysis on the road of buying houses in China, and mainly studied the factors affecting the change of ownership. Song [22] employed the 2001 Beijing Housing Survey data to explore the risk of transition to homeownership for married couples during 1980–2001.

The housing pathways of migrant workers or local residents were mostly examined based on changes of housing tenure. Eskelä [6] studied the changes of housing tenure of skilled migrants from India since they come to Finland. They reported that lack of access to local homeownership discouraged cities from retaining skilled migrants. Wang and Wang [29] explored the social integration of rural–urban migrants from the perspective of housing pathway in China. The definition of urban and rural migrants was different from the definition of migrant workers, rural local residents are included. They used the changes of housing tenure to represent the housing pathways. They argued that rural–urban migrants who had convergent housing pathway showed an upward social integration pattern. Rural–urban migrants who have discrete housing pathway showed a downward social integration pattern, and rural–urban migrants who have mobile housing pathway showed a mobile social integration pattern.

2.2 Determinants of Housing Pathways

Housing pathway is usually composed of three dimensions, i.e., housing tenure, housing size, and housing quality. Current studies have largely examined the factors affecting housing tenure, housing size, and housing quality respectively. Longitudinal analyses are scarce. Housing pathways were found largely affected by socio-economic factors, migration characteristics and Life course.

From the perspective of housing tenure, Li and Li [16] conducted a longitudinal analysis of the housing tenure transition of urban residents in Guangzhou. Age and education were found to have positive impacts on homeownership. In addition, they found changes of marital status were more significant factors than marriage status per se in affecting changes of housing tenure. Residents who were getting married were more likely to obtain homeownership. Changes of employment increased the risks of changes of housing tenure. Although residents who had large family size had higher possibility to own homeownership [12, 27], it was also found changes of family composition closely related to the changes of housing tenure [4]. Huang and Clark [12] reported that age had a significant positive influence on homeownership, but education had no significant influence. Income was another factor which had a significant positive impact on homeownership [7, 12, 27].

The housing tenure of migrant workers has been examined as well. Eskelä [6] argued that skilled migrants were more likely to buy houses than unskilled migrants in Finland due to better economic conditions. Migrant workers who had rural Hukou were more likely to rent houses than those who had urban Hukou in China [24]. In addition, migration durations, and migration pattern had impacts on migrant workers' homeownership. Migrant workers who had long migration durations were prone to own homeownership [6]. Intra-provincial migrant workers were more likely to obtain homeownership than inter-provincial migrant ones [31].

From the perspective of housing size, Huang [13] studied the housing crowding degree of urban residents in China, and found that age, family size and region had impacts on residents' choices of housing size. The paper found that old people, large families, residents who lived in small cities were prone to have larger housing size. Clark and Huang [5] reported that changes of family size were associated with changes of family's space demand. Determinants of housing size of migrant workers were also looked into. Migrant workers with higher education and higher income were found to be more likely to live in larger housing [8, 13, 17, 20]. Migrant workers who were old, married, and had large family size were more inclined to choose larger housing size [17]. In addition, migrant workers in small cities were more inclined to choose larger housing size [17]. Niu and Zhao [20] found that migration durations had a significant positive effect on housing size.

From the perspective of housing quality, migrant workers who are old, and had high education level and high income are prone to choose high quality housing [18]. Migrant workers with non-agricultural Hukou usually had better housing quality than their counterparts [14, 17]. Compared with intra-provincial migrant workers, the housing quality of inter-provincial migrant workers was better [14]. Migrant workers with longer migration durations were more likely to choose better housing quality [14, 17].

Based on the literature review, it was found that few studies have investigated the housing pathways of migrant workers in China, except for Wang and Wang [29], Li and Li [16], they studied the changes of housing tenure for residents, but they did not separate migrant workers out for analysis. In order to fill the research gap, this paper aims to explore the housing pathways of migrant workers in China, and the determinants from three dimensions, i.e., housing tenure, housing size and housing quality. The following three hypotheses were proposed:

H1: Socio-economic characteristics (e.g., gender, education, family size in the locality, income level in the locality, age, type of Hukou), mobility characteristics (e.g., regions of destination, migration pattern), and life course (e.g., changes of martial status, changes of employment status) significantly affect the changes of housing tenure of migrant workers in China.

H2: Socio-economic characteristics, mobility characteristics, and life course significantly affect the changes of housing size of migrant workers in China.

H3: Socio-economic characteristics, mobility characteristics, and life course significantly affect the changes of housing quality of migrant workers in China.

3 Research Methods

3.1 Data Source

This paper employed the data from China Family Panel Studies (CFPS), which is tracking survey conducted by Peking University. This is a nationwide comprehensive social tracking program. It aims at tracking and collecting data at the individual, family and community levels, and reflecting changes of society, economy, population, education and health in China. The CFPS launched a baseline survey in 2010, and conducted three rounds of follow-up surveys with full samples in 2012, 2014 and 2016, covering 25 provinces/municipalities/autonomous regions, representing 95% of China's population.

3.2 Data Processing

This study combined the adult questionnaire, household economic questionnaire and family structure questionnaire of Year 2014 and 2016. Although CFPS released the latest data of 2018, the data is incomplete. Therefore, this paper employed the tracking data of 2014 and 2016 to investigate the housing pathways of migrant workers.

Floating population is the population who holds non-local Hukou (not in the city or county), and leaves hometowns for more than half a year (National Bureau of Statistics, 2015). Migrant workers are the floating population who migrates for the purpose of working. According to the above definition, the respondents who left the hometowns for job searching, migrated for more than 6 months by 2014, and hold non-local Hukou both in 2014 and 2016 are screened out. Finally, 484 samples were screened out for the analysis of housing tenure, 474 samples were screened out for the analysis of housing size, and 365 samples were screened out for the analysis of housing quality.

3.3 Data Analysis

Since housing pathways (i.e., changes of housing tenure, housing size, and housing quality) are categorical variables, multiple logistic regressions were employed. Taking housing tenure change for instance, there are four values with 1 indicating "obtain home ownership", 2 indicating "lose home ownership", 3 indicating "maintain home ownership", and 4 indicating "maintain no home ownership" respectively. The calculations are shown as follows:

$$\begin{aligned}
\text{Log it } \pi 1/\pi 4 &= \mathrm{a}_1 + \beta_{11}\mathrm{X}_1 + \beta_{11}\mathrm{X}_2 + \cdots + \beta_{1\mathrm{m}}\mathrm{X}_\mathrm{m} \\
\text{Log it } \pi 2/\pi 4 &= \mathrm{a}_2 + \beta_{21}\mathrm{X}_1 + \beta_{22}\mathrm{X}_2 + \cdots + \beta_{2\mathrm{m}}\mathrm{X}_\mathrm{m} \\
\text{Log it } \pi 3/\pi 4 &= \mathrm{a}_3 + \beta_{31}\mathrm{X}_1 + \beta_{32}\mathrm{X}_2 + \cdots + \beta_{3\mathrm{m}}\mathrm{X}_\mathrm{m}
\end{aligned}$$

where $\pi 1$, $\pi 2$, $\pi 3$, and $\pi 4$ represent the possibilities of the four types of tenure change; m represents the number of independent variables; β represents coefficients; and a represents intercepts.

This study examined the three dimensions of housing pathways (i.e., housing tenure, housing size, and housing quality). The impacts of socio-economic characteristics, mobility characteristics, and life course on the three dimensions were investigated respectively. The model design is shown in Fig. 1.

4 Empirical Results

4.1 Dimension 1: Changes of Housing Tenure

4.1.1 Descriptive Analysis

Housing tenure changes of migrant workers were divided into four categories, including: (1) obtain homeownership (i.e., no full homeownership in 2014, obtain full homeownership in 2016); (2) lose homeownership (i.e., have full homeownership in 2014, no homeownership in 2016); (3) maintain homeownership (i.e., have full homeownership both in 2014 and 2016); and (4) maintain no homeownership (i.e., not have full homeownership either in 2014 or 2016).

The distribution of housing tenure changes of migrant workers is shown in Fig. 2. The proportion of migrant workers who maintain full homeownership was the largest

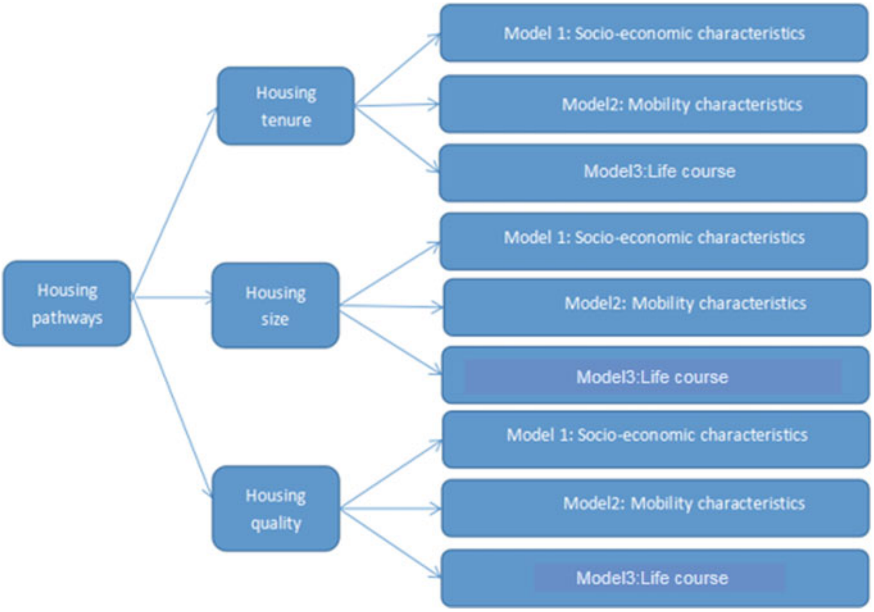

Fig. 1 Model design

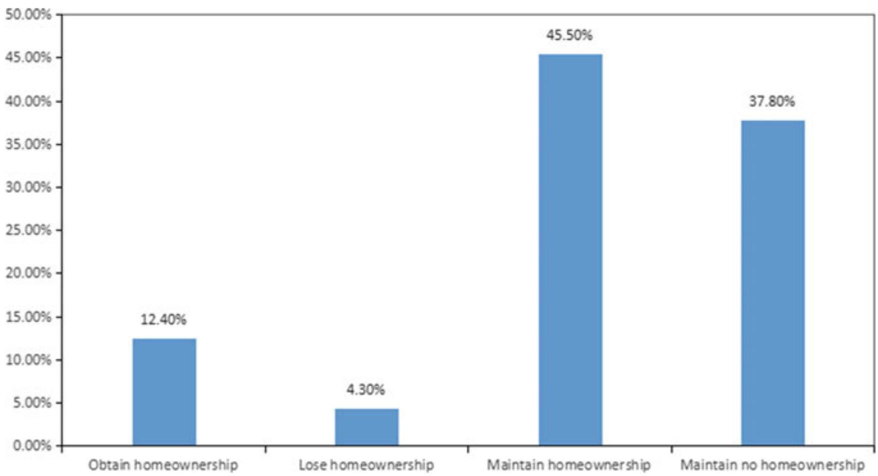

Fig. 2 Changes of housing tenure of migrant workers

(45.5%), followed by maintain no homeownership (37.8%), obtain homeownership (12.4%), and lose homeownership (4.3%). In Eastern region, the proportion of migrant workers who maintain no homeownership was the largest (47.28%), followed by maintain full homeownership (37.76%), obtain homeownership (10.54%), and lose homeownership (4.42%). In Central region, the proportion of migrant workers who maintain full homeownership was the largest (66.37%), followed by maintain no homeownership (23.01%), obtain homeownership (7.96%), and lose homeownership (2.65%). In Western region, the proportion of migrant workers who maintain full homeownership was the largest (50.77%), followed by maintain no homeownership (23.08%), obtain homeownership (18.46%), and lose homeownership (7.69%).

Among the respondents, female migrant workers (46.7%) were less than males (53.3%) (Table 1). The educational level of migrant workers was generally low. Migrant workers with junior high school education and below accounted for the largest proportion (61.4%). The average age of the respondents was 40. There were four family members in the locality on average. The average level of income in the locality ranged from low to moderate. Most migrant workers held agricultural Hukou, accounting for 66.3%. Only 2.5% of the respondents changed the regions of destination from 2014 to 2016. Most of them stayed in the same region. The number of migrant workers staying in the eastern region was the largest, accounting for 59.7%, while the number of migrant workers staying in the Western region was the smallest, accounting for 14.7%. Half of the respondents were intra-provincial migrant workers. The average duration of migration was 14 years. Most migrant workers were married, accounting for 85.7%. Only 4.1% of the respondents got married from 2014 to 2016. The majority of the respondents were in the status of being employed throughout the period of 2014–2016, accounting for 78.7%. The number of those who maintain the status of being unemployed (including those dropping out of the labor market) during 2014–2016 was the least, accounting for only 2.1%.

4.1.2 Regression Analysis

Since changes of housing tenure was a nominal variable with four values (i.e., no homeownership—own homeownership, own homeownership—no homeownership, own homeownership—own homeownership, and no homeownership—no homeownership), multinomial logistic regression was employed. "No homeownership—no homeownership" was used as the reference category. Socio-economic characteristics were included into Model 1 for analysis. Further, mobility characteristics were included into Model 1. Model 2 was established. On the basis of Model 2, Model 3 analyzed the effects of life course on changes of housing tenure of migrant workers (Table 2). There was a correlation between changes of family size and changes of marital status through cross tabulation analysis. According to Li and Li [16], changes of marital status had impacts on changes of housing tenure, residents who were getting married were more likely to obtain homeownership. This study included changes of marital status into the analysis.

Income, gender, education, family size, changes of regions of destination, migration duration, migration pattern and changes of employment status had significant impacts on changes of housing tenure of migrant workers. Migrant workers with higher income were more likely to obtain full homeownership during the migration, which is consistent with the previous findings [6, 7, 27]. Compared with males,

Table 1 Descriptive findings

Categories	Variables		Percentage/mean
Socio-economic characteristics	Gender	Female	46.7%
		Male	53.3%
	Education (2016)	Primary school and below	31.0%
		Junior high school	30.4%
		Senior high school	17.4%
		College and above	21.3%
Socio-economic characteristics	Family size (number of family members) (2016)		4
	Income level in the locality (1–5 points) (2016)		2.4
	Age (2016)		39.87
	Type of Hukou	Agricultural Hukou	66.3%
		Non-agricultural Hukou	33.7%
Mobility characteristics	Regions of destination	Eastern region–other regions	2.1%
		Other regions–eastern region	0.4%
		Eastern region–eastern region	60.7%
		Central region–central region	23.3%
		Western region–western region	13.4%
	Migration pattern	Intra-province	50.0%
		Inter-province	50.0%
	Migration duration (years)		14
Life course	Martial status	Single–married	4.1%
		Married–married	85.7%
		Single–single	10.1%
	Employment status	Unemployed–employed	9.9%
		Employed–unemployed	9.3%
		Unemployed–unemployed	2.1%
		Employed–employed	78.7%

Note Income level in the locality (1–5 points) (2016) ranges from relative low to relative high

female migrant workers were more likely to maintain full home ownership during the migration. The proportion of married females (91%) was slightly larger than that of males (89%). Married people were more likely to own full ownership [4].

Further, it was found the old generation were more likely to own full homeownership during the migration. The old generation usually had more social networks and

Table 2 Factors affecting changes of housing tenure of migrant workers

Variables	Obtain homeownership			Lose homeownership			Maintain homeownership		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B	B	B	B
Income level in the locality (1–5 points) (2016)	0.286*	0.342*	0.359**	0.43*	0.439*	0.476*	0.127	0.174	0.18
Gender (Ref: male)									
Female	0.03	0.204	0.075	0.895*	1.176**	1.033*	0.46**	0.819***	0.705***
Generation (Ref: new generation)									
Old generation	0.151	−0.249	−0.154	0.124	−0.415	−0.544	0.396*	−0.237	−0.297
Education (Ref: college and above) (2016)									
Primary school and below	−0.778*	−1.105**	−1.156**	0.579	0.454	0.268	−0.45	−0.562	−0.648*
Junior high school	−1.289***	−1.552***	−1.65***	0.122	0.037	−0.209	−0.44	−0.469	−0.583
Senior high school	−0.022	−0.232	−0.231	0.437	0.255	0.115	0.292	0.121	0.096
Type of Hukou (Ref: non-agricultural Hukou)									
Agricultural Hukou	0.595	0.57	0.589	−0.029	0.076	0.199	−0.4	−0.446	−0.391
Family size (number of family members) (2016)	−0.027	−0.039	−0.017	0.022	0.038	−0.056	0.374***	0.436***	0.4***
Regions of destination (Ref: western region—western region)									
Eastern region—other regions		1.249	1.317		−18.556***	−18.382***		−17.782	−17.759
Other regions—eastern region		14.995	14.694		−0.713	0.009		15.16	14.619
Eastern region –eastern region		−1.548***	−1.594***		−1.382**	−1.332**		−0.907**	−0.865**

(continued)

Table 2 (continued)

Variables	Obtain homeownership			Lose homeownership			Maintain homeownership		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B	B	B	B
Central region—central region		−1.239**	−1.275**		−1.304	−1.232		0.167	0.232
Migration pattern (Ref: inter-province)									
Intra-province		0.631*	0.599*		1.39***	1.416***		1.389***	1.368***
Migration duration (years)		0.073***	0.075***		0.077**	0.076**		0.093***	0.093***
Marital status (Ref: single—single									
Single–married			−0.447			−11.152			−0.66
Married–married			−0.365			1.354			0.416
Employment status (Ref: employed–employed)									
Unemployed–employed			0.77			0.503			0.337
Employed–unemployed			−0.107			1.259*			0.49
Unemployed–unemployed			0.15			−11.709			0.179
Cox & Snell R^2	0.146	0.342	0.361	0.146	0.342	0.361	0.146	0.342	0.361
Nagelkerke R^2	0.164	0.383	0.404	0.164	0.383	0.404	0.164	0.383	0.404

Note: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$

resources than the new generation, which guaranteed them with a higher possibility to own homeownership. This finding is consistent with [16]. Migrant workers with higher educational levels were more likely to own homeownership. Better educated ones usually had better job opportunities and social networks, which could explain the higher possibilities to own homeownership [16]. Migrant workers who had a large family size were more likely to maintain full home ownership (i.e., own homeownership–own homeownership). This is consistent with the findings of Huang and Clark [12], and Wu and Zhang [27].

Compared with migrant workers who stayed in the Western region for the research period (2014–2016), migrant workers who stayed in the other two regions (i.e., the Eastern region, and the Central region) were less likely to own full homeownership. Migrant workers staying in the Eastern region had the biggest difficult in obtaining full homeownership. There were huge economic gaps between the three regions. Compared with the Western region, the Eastern and Central regions were more economically developed. The housing prices in the two regions were generally higher than that of the Western region. The economic burden for migrant workers in the Eastern region was generally heavier than the other two regions. Compared with migrant workers who stayed in the Western region, those migrating from the Eastern region to other regions were more likely to maintain no home ownership. Due to the instability working destinations of migrant workers who migrate from eastern regions, the possibility of owning full homeownership is smaller than that who maintain staying in the western region. Migrant workers with longer durations of migration were more likely to have full homeownership during the research period, which is consistent with the previous findings [6, 7]. Inter-provincial migrant workers were more likely to remain the status of having no full homeownership, while intra-provincial migrant workers were more likely to obtain homeownership during the migration process. It is consistent with the conclusions of previous studies [31]. Migrant workers who dropped out of the labour market or got unemployed during the research period were more likely to lose full home ownership than those who remained employed.

4.2 Dimension 2: Changes of Housing Size

4.2.1 Descriptive Analysis

The changes of housing size of migrant workers were divided into three categories, i.e., increase, decrease and unchange. As shown in Fig. 3, the largest proportion of migrant workers did not change the housing size (78.3%). There were 14.1% of the migrant workers increasing the housing size, which is larger than the proportion of migrant workers decreasing the housing size (7.6%). This observation was in line with the theories of housing career and housing ladder, that is, the conditions of all aspects of housing show an upward trend over time.

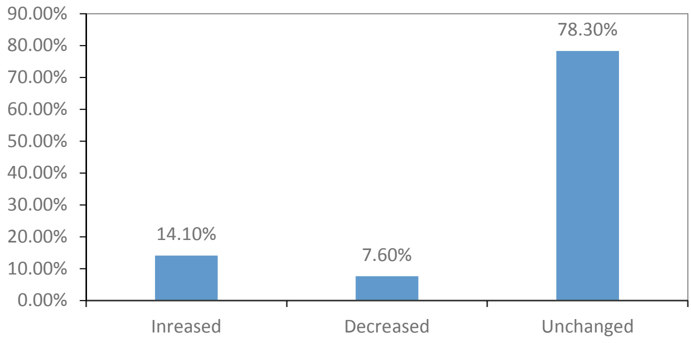

Fig. 3 Changes of housing size of migrant workers

4.2.2 Regression Analysis

Since changes of housing size was a nominal variable with three values (i.e., increasing housing sizes, decreasing housing sizes, keeping housing sizes unchanged), multinomial logistic regression was employed. "keeping housing sizes unchanged" was used as the reference category. Socio-economic characteristics were included into Model 1 for analysis. Further, mobility characteristics were included into Model 1. Model 2 was established. On the basis of Model 2, Model 3 analyzed the effects of life course on changes of housing size of migrant workers (Table 3).

Generation, family size, migration duration, changes of marital status and changes of employment status had significant impacts on changes of housing size of migrant workers. The new generation were more likely to decrease their housing sizes than the old generation. The old generation were prone to keep the housing sizes unchanged. Huang and Clark [12] found old residents were prone to choose bigger housing size. The new generation usually had less social and economic resources. Compared with the old generation, they were less stable, and had high possibilities to decrease the housing sizes. As the migration durations got longer, the new generation tend to live in larger housing. Although Hukou had an insignificant impact on changes of housing size, it was found that migrant workers with agricultural Hukou had a higher possibility to reduce the housing size, and were less likely to increase the housing size. This is consistent with the finding that migrant workers with agricultural Hukou usually lived in smaller housing than those with non-agricultural Hukou [17].

Further, migrant workers with a larger family size tend to keep housing size unchanged. Migrant workers who had more family members in the locality tend to choose larger housing [12]. Migrant workers with large family sizes were generally characterized with married status, and having children and parents in the locality. They tend to be stable, and had low possibilities to move. Compared with single ones, migrant workers who got married during the research period were more likely to increase the housing size, which was due to the increase of family size. Migrant workers who had longer durations of migration were prone to keep the housing size unchanged. It was also found that migrant workers with longer migration durations

Table 3 Factors affecting changes of housing size of migrant workers

Variables	Increased housing size			Decreased housing size		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B
Income level in the locality (1–5 points) (2016)	0.009	0.007	0.074	0.267	0.272	0.351*
Gender (Ref: male)						
Female	0.016	−0.119	−0.079	−0.173	−0.263	−0.275
Generation (Ref: new generation)						
Old generation	−0.586*	−0.304	−0.177	−1.206***	−0.854*	−0.823*
Education (Ref: college and above) (2016)						
Primary school and below	−0.219	−0.243	−0.149	0.142	0.218	0.226
Junior high school	0.15	0.099	0.195	0.173	0.185	0.187
Senior high school	0.161	0.228	0.281	−0.061	0.044	0.075
Type of Hukou (Ref: non-agricultural Hukou)						
Agricultural Hukou	−0.276	−0.266	−0.301	0.443	0.496	0.615
Family size (number of family members) (2016)	−0.386***	−0.376***	−0.311***	−0.504***	−0.501***	−0.452***
Regions of destination (Ref: western region—western region)						
Eastern region—other regions		−0.08	−0.776		−16.165	−16.806
Other regions—eastern region		1.566	1.091		−17.842	−18.36
Eastern region–eastern region		0.716	0.674		0.42	0.404
Central region–central region		0.382	0.148		−0.052	−0.176
Migration pattern (Ref: inter-province)						
Intra-province		−0.354	−0.353		−0.319	−0.314

(continued)

Table 3 (continued)

Variables	Increased housing size			Decreased housing size		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B
Migration duration (years)		−0.035	−0.034		−0.051*	−0.052*
Marital status (Ref: single–single						
Single–married			1.75***			0.539
Married–married			−0.219			−0.408
Employment status (Ref: employed–employed)						
Unemployed–employed			−0.447			−0.758
Employed–unemployed			0.574			1.044*
Unemployed–unemployed			1.347			1.527
Cox & Snell R^2	0.1	0.127	0.165	0.1	0.127	0.165
Nagelkerke R^2	0.136	0.172	0.225	0.136	0.172	0.225

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

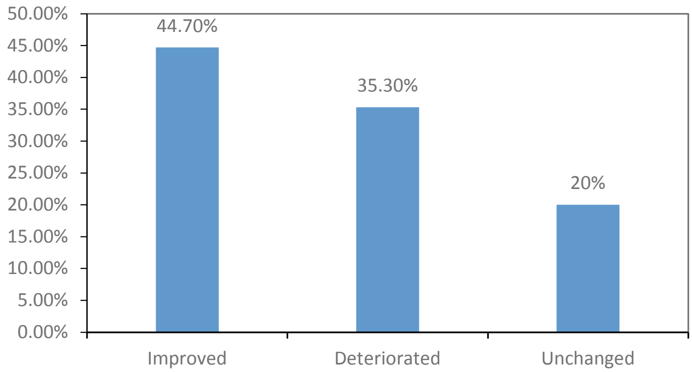

Fig. 4 Changes of housing quality of migrant workers

were more likely to choose bigger housing [17]. When migrant workers dropped out of the labor market or got unemployed, they were more likely to decrease the housing size.

4.3 Dimension 3: Changes of Housing Quality

4.3.1 Descriptive Analysis

According to literature review and the data available, the availability of tap water (yes = 1, no = 0), the availability of natural gas or pipeline gas (yes = 1, no = 0), and degree of interior decoration (1–7 points ranges from relative poor to relative luxury) were selected as the indicators of changes of housing quality [9, 14, 15, 23]. The index of housing quality was obtained from the sum of the above three indicators. By comparing the values of housing quality in 2014 and 2016, changes of housing quality were obtained. As shown in Fig. 4, most migrant workers underwent housing quality changes during the migration. The proportion of migrant workers undergoing improvement of housing quality was the highest (44.7%), followed by deterioration (35.3%) and unchanged (20%).

4.3.2 Regression Analysis

Since changes of housing quality was a nominal variable with three values (i.e., Improving housing quality, deteriorating housing quality, keeping housing quality unchanged), multinomial logistic regression was employed. "keeping housing quality unchanged" was used as the reference category. Socio-economic characteristics were included into Model 1 for analysis. Further, mobility characteristics were included into Model 1. Model 2 was established. On the basis of Model 2, Model 3 analyzed the effects of life course on changes of housing quality of migrant workers (Table 4).

The three variables of family size, working destinations, and changes of employment status had significant impacts on changes of housing quality of migrant workers. Migrant workers with larger family sizes were prone to keep housing quality unchanged. Migrant workers with more family members in the locality were more stable in general. Residents with large family size tend to choose high quality housing in general [18]. Compared with the migrant workers who stayed in the Western region during the research period, the housing quality of migrant workers staying in the Eastern region was more likely to be improved. Migrant workers staying in the Western region were prone to keep the housing quality unchanged. The proportion of migrant workers with full homeownership was bigger in the Western region than that in the Eastern and Central regions. Homeownership can reduce mobility [5]. Therefore, the residential mobility of migrant workers in the Western region was lower, so was the possibility of changes of housing quality. The residential mobility of migrant workers in the Eastern and Central regions was high. The possibility of housing quality changes was higher than that in the Western region accordingly. Migrant workers who maintained the status of being unemployed (including dropping out of the labor market) were more likely to keep housing quality unchanged.

5 Discussion

The effects of socio-economic characteristics, mobility characteristics and life course factors on the three dimensions of housing pathways of migrant workers (i.e., housing tenure, housing size, and housing quality) were different. From the perspective of housing tenure, new generation migrant workers, and migrant workers with low income low education, and small family sizes were at disadvantages that they had lower possibilities to obtain full homeownership in the locality. Compared with migrant workers who stayed in the Western region during the research period, those staying in the Eastern and Central regions had lower possibilities to own homeownership. This phenomenon was caused by economic gaps between regions. The housing price in economically developed regions was generally higher. Migrant workers were less likely to own homeownership in more economically developed regions, especially in first-tier cities such as Beijing, Shanghai, Guangzhou and Shenzhen. Migrant workers who had longer migration durations were more likely to obtain homeownership during the process of migration. The longer migrant workers migrated, the more social resources and social networks they accumulated in the locality. Intra-provincial migrant workers generally had more social networks than inter-provincial ones in the locality. They were more familiar with the local dialect and culture, thus had advantages on social integration. They were more likely to obtain full homeownership and settle down. Migrant workers who got unemployed (including dropped out of the labour market) were more likely to lose home ownership. If migrant workers

Table 4 Factors affecting changes of housing quality of migrant workers

Variables	Improved housing quality			Deteriorated housing quality		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B
Income level in the locality (1–5 points) (2016)	0.059	0.057	0.081	−0.01	−0.033	−0.092
Gender (Ref: male)						
Female	0.209	0.137	0.164	0.047	0.054	−0.026
Generation (Ref: new generation)						
Old generation	−0.133	−0.052	0.004	−0.039	−0.13	−0.154
Education (Ref: college and above) (2016)						
Primary school and below	−0.286	−0.268	−0.242	0.373	0.379	0.435
Junior high school	0.029	0.019	0.048	0.303	0.332	0.383
Senior high school	0.461	0.479	0.51	0.397	0.394	0.433
Type of Hukou (Ref: non-agricultural Hukou)						
Agricultural Hukou	0.085	0.077	0.021	0.045	0.076	−0.031
Family size (number of family members) (2016)	−0.088	−0.085	−0.061	−0.141*	−0.126	−0.163*
Destination (Ref: maintain in western region)						
Eastern region–other regions		0.653	0.676		0.451	0.833
Eastern region–eastern region		0.963**	0.931**		0.214	0.262
Central region–central region		0.965**	0.914*		−0.085	−0.018
Migration pattern (Ref: inter-province)						
Intra-province		−0.241	−0.25		0.351	0.342
Migration duration (years)		−0.015	−0.013		0.008	0.01
Marital status (Ref: single–single)						
Single–married			1.37			0.759
Married–married			−0.048			0.795
Employment status (Ref: employed–employed)						
Unemployed–employed			0.06			0.707
Employed–unemployed			−0.021			−0.462

(continued)

Table 4 (continued)

Variables	Improved housing quality			Deteriorated housing quality		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	B	B	B	B	B
Unemployed–unemployed			0.959			−20.159***
Cox & Snell R^2	0.031	0.072	0.12	0.031	0.072	0.12
Nagelkerke R^2	0.036	0.082	0.137	0.036	0.082	0.137

Note: $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

got unemployed in the locality, their housing burden would be heavier than before. They may give up the homeownership to soothe the economic burden in some cases.

In terms of changes of housing size, new generation migrant workers, and those who got unemployed were more likely to decrease the housing size. The new generation were in the early stage of housing career. They may decrease the housing size in the short term. As they accumulate more social and economic resources, they have higher possibilities to obtain full homeownership in the long run. Migrant workers with bigger family size and longer durations of migration were more likely to keep housing sizes unchanged. The household structures of migrant workers with larger family sizes were relatively stable, so was their residential mobility. They had higher possibilities to keep housing sizes unchanged. Similarly, the housing of migrant workers with a longer period of migration tend to be stable, so was their housing sizes. Due to the increase of family size, migrant workers who got married were prone to increase their housing sizes.

In terms of changes of housing quality, the housing quality of migrant workers with larger family size tend to be unchanged. The housing quality of migrant workers who remained the status of unemployment was less likely to change, largely due to the income. Migrant workers who stayed in the Eastern and Central regions were more likely to improve the housing quality than those staying in the Western region. This may be due to the proportion of migrant workers who had no homeownership in the Eastern and Central regions was larger than that in the western region. Homeownership can reduce residential mobility.

6 Conclusion

This paper investigated the housing pathways of migrant workers in China and the determinants from three dimensions (i.e., housing tenure, housing size and housing quality), which fills the research gap in the literature. The three hypotheses were supported by this study. Compared with local residents, the housing pathways of migrant workers are more complex and changeable. Upward housing pathways is conducive to social economic development and social harmony.

Policy implications can be drawn from the findings. First, since new generation migrant workers and migrant workers with low income and low educational levels are at disadvantages on housing pathways, preferential housing policies (such as providing housing subsidies) should be promulgated to solve their basic housing problems. Further, since the new generation migrant workers are at the early stage of housing career, they usually have housing difficulties in the locality. Special attention should be given to this group of population to facilitate the accumulation of their human capital and social capital, in terms of providing career training, talent housing, etc.

Second, inter-provincial migrant workers and those working in the Eastern and Central regions usually have more difficulties in obtaining homeownership than those in the Western region. Due to the heavy economic burden and high housing prices, it is difficult for migrant workers to obtain homeownership in the Eastern and Central regions, especially in the eastern region. Local governments should promulgate preferential housing policies for migrant workers in economically developed areas, such as widening the coverage of public housing. Inter-provincial migrant workers are not familiar with the local culture. They have less social networks and social resources than intra-province migrant workers, thus have disadvantages in housing pathways in the locality. Community activities should be encouraged to facilitate the communications of migrant workers with local residents.

Third, migrant workers who got unemployed are at disadvantages on housing pathways. Local governments should provide more employment information and job training for this group of migrant workers to help them get reemployed as soon as possible.

There are limitations with this study. First, only province-level data were used due to the concern of privacy of CFPS. Second, only two years tracking data (2014 and 2016) were employed to look into the housing pathways of migrant workers due to the data availability. Third, the sample size employed in this study is not large, since the proportion of respondents who meet the criteria of migrant workers in CFPS is relatively low (16.7%). Fourth, this study did not include migrant workers living in dormitories and shanty towns into analysis due to the data availability.

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Using Fuzzy Cognitive Map to Identify the Factors Influencing the Cost of Prefabricated Buildings

Lan Luo, Xia Wu, Liang Cheng, and Zhihao Tu

Abstract In recent years, prefabricated buildings are rising in China gradually. It has the characteristics of saving, high efficiency, and green compared with the traditional cast-in-place buildings. However, the application of prefabricated buildings is slow-moving due to high cost. Fuzzy cognitive map (FCM) is a combination of neural network and fuzzy logic, and it may effectively avoid the complexity of nonlinear models. Besides, its feedback mechanism may respond to the dynamic changes of the whole complex system of the prefabricated building cost. To effectively control the cost of prefabricated buildings, this paper identifies some influencing factors and constructs a causal model (i.e. FCM model) which is composed of nine concepts (nodes). Besides, predictive analysis and diagnostic analysis are carried out based on the FCM model. C_1 (scale effect), C_6 (PC component cost), C_4 (standardization degree of PC components), and C_8 (construction management level) have the greatest impact on the cost of prefabricated buildings are concluded. The possible root cause that affects the cost of prefabricated buildings is C_1 (scale effect). Accordingly, suggestions are put forward to reduce the cost of prefabricated buildings. The research is helpful in promoting the development of prefabricated buildings as well as the transformation and upgrading of the construction industry.

Keywords Prefabricated buildings · Cost · Influencing factors · Fuzzy cognitive map (FCM)

1 Introduction

With the development of construction industrialization, prefabricated buildings, which had been stagnant in the 1990s, have come back to the public's view in recent years, and set off a wave of technology research upsurge. Compared with

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the traditional cast-in-place buildings, prefabricated buildings have the characteristics of saving, efficient, green and environmentally-friendly [1], its development is of great significance to the transformation and upgrading of construction industry in China. Since the general office of the State Council issued the "green buildings action plan" (GBF [2013] No. 1), construction industrialization has been comprehensively promoted in China, a series of relevant policies and technical standards for prefabricated buildings have been issued, and the local governments have actively promoted the development of the prefabricated industry. However, the development of prefabricated buildings is not satisfactory despite the positive promotion of the industry and the favorable policies of the state. At present, the technical specifications and relevant standards are still immature, the modular construction system is not perfect. All these lead to a few market shares of prefabricated buildings. Compared with the traditional cast-in-place buildings, the cost of prefabricated buildings is higher, the market demand for prefabricated buildings is extremely low, and the industrial development is slow when lacking economic benefits [2]. Therefore, it is urgent to reduce the cost of prefabricated buildings.

Previous scholars have studied the cost of prefabricated buildings. Hong et al. [2] established a cost–benefit analysis framework to explore the basic composition of prefabrication cost, and examine the impact of prefabrication on the total cost of actual construction projects. Lee et al. [3] used the failure mode and effects analysis (FMEA) method to find out the key factors which lead to cost increase in the whole modular construction life cycle from the perspective of modular construction companies. Zhao et al. [4] used the analytic hierarchy process (AHP) to analyze prefabricated building cost from four aspects: design factors, management factors, technical factors and policy factors. Besides, suggestions for the effective cost management of prefabricated buildings are put forward based on the analysis. These studies use a certain analysis method to find out the main reasons that affect the cost of prefabricated buildings from different perspectives, providing some ideas for the cost control of prefabricated buildings. However, the research of prefabricated building cost in China is still not mature at present, and most of the researches stay at the level of single-factor analysis, lacking dynamic comprehensive analysis of multiple influencing factors of prefabricated buildings. Thus, the thesis attempts to use the fuzzy cognitive map (FCM) method to analyze the complex dynamic system of the prefabricated building cost. Besides, suggestions for reducing the cost of prefabricated buildings are put forward.

2 Research Methods

Many factors affect the cost of prefabricated buildings, and these factors are complex and intertwined, so it is difficult to describe the whole dynamic system with a linear structure. Besides, many prefabricated construction practitioners are not sensitive to the key factors because of their shallow experience. FCM is a simple and intuitive soft computing method. It is a combination of neural networks and fuzzy logic. Its model

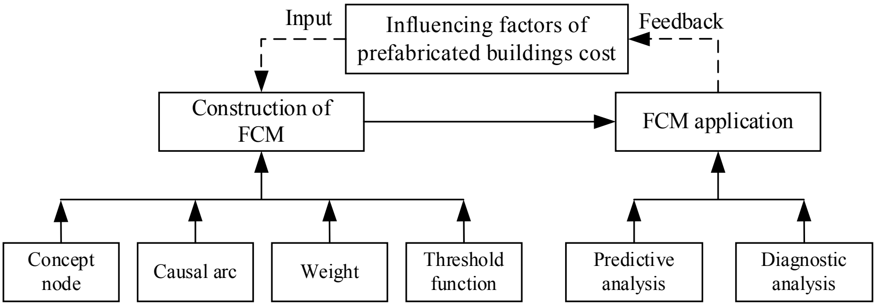

Fig. 1 The workflow of the FCM approach

can effectively avoid the complexity of a strong nonlinear model. In addition, it has the characteristics of multi-disciplinary fusion, which can acquire and integrate multi-disciplinary knowledge involving the whole life cycle of prefabricated buildings [5–7]. In particular, it has a scientific feedback mechanism, which can respond to the dynamic changes of the whole complex system of prefabricated building cost [8].

FCM method has great advantages in analyzing the cost of prefabricated buildings which is a nonlinear and complex dynamic system. To achieve the research objectives, the research on the influencing factors of prefabricated building cost is divided into two stages (FCM model establishment and model application) in this paper, the specific research workflow is shown in Fig. 1.

3 Construction of the FCM Model

3.1 Identification of Concept Nodes

Many factors affect the cost of prefabricated buildings, involving the whole life cycle. The research shows that the prefabricated building cost about the later operation and maintenance is not much different from that of traditional buildings under the same conditions [9]. Therefore, the research on the influencing factors of prefabricated building cost does not consider the operation and maintenance stage. Besides, some research tried to explore the key factors influencing the cost of prefabricated buildings. Arif and Egbu [10] pointed out the general shortage of skilled workers related to the assembly industry, and the direct and indirect cost of construction can be reduced by improving the quality of industrial workers through training. Jaillon et al. [11] indicated that the degree of standardization and transportation cost have a large effect on the construction cost of industrial buildings. Results from Lee and Kim illustrated that many of the serious risks of increased costs come from market size and the maturity of modular construction [3]. Through the case study of a prefabricated hotel project in Hong Kong, Li et al. [12] show that the application of the deepening optimization design concept in VP technology + IKEA mode can effectively reduce the cost. Hong et al. [2] stated that the prefabrication rate is an important factor affecting the cost-effectiveness of prefabricated buildings. Besides, site operation is an important reason for the increase in costs, including mechanical costs (vertical transportation), installation, connection, and site storage. Zhang et al. [13] showed a large amount of input in the early stage of component production is needed, the production cost of prefabricated components is much higher than that of other methods which is supported by Vanker's data. Based on the literature review, eight influencing factors of prefabricated building cost are finally identified, as shown in Table 1.

The eight influencing factors in Table 1 and prefabricated building cost are used as concepts (or nodes) to construct the FCM model. The concept (or node) is represented by C_i, where C_1, C_2, … C_8 represents eight factors that affect the cost of prefabricated buildings, and C_T is used to represent the target concept (i.e. the prefabricated building cost) in the model.

3.2 Determination of Causality and Weight

FCM model uses directed arcs to represent the causal relationship between concept nodes (the influence relationship between concept nodes). For two different nodes C_i and C_j in the system, if the state change of C_i causes the state change of C_j, the causal relationship between C_i and C_j can be represented by a directed arc, and the influence degree of C_i on C_j is described by a value W_{ij} in the $[-1, 1]$, the W_{ij} is called weight [5, 14]. In this paper, the expert scoring method is used to determine causality and weight. Experts and scholars with rich experience in the industry are selected to judge the causality and its weight according to their own experience and knowledge. Nine levels of fuzzy semantics are used for expert description, as shown in Table 2, and the corresponding membership function UA(x) is shown in Fig. 2.

10 experienced experts and scholars in the field of prefabricated buildings were selected to investigate the relationship and weight between the nine nodes in this paper. With the help of fuzzy cognitive mapping software, FCM analyst 1.0 and the feedback of experts, the causality and its weight are finally determined.

3.3 Selection of Threshold Function

There are two common threshold functions in the FCM model: one is S-shaped curve function I, as Eq. (1), the other is the hyperbolic tangent function, such as Eq. (2). The FCM model with S-shaped curve function I or hyperbolic tangent function can show the trend of node activity increasing or decreasing, they can also show the degree of enhancement or weakening. However, the S-shaped curve function I map value

Table 1 Identification of influencing factors of prefabricated building cost

Item	Variables	Description	Classification
C_1	Scale effect	1. The distribution, quantity and production capacity of prefabricated component manufacturers 2. Whether there is a mature industrial chain for large-scale production of prefabricated components 3. Large scale transportation and installation	Industrial environment
C_2	Quality of industrial workers	1. The skill level and technical proficiency of prefabricated component production workers 2. The construction efficiency and mechanical operation level of workers in the prefabricated construction site	
C_3	Prefabrication rate	1. The proportion of precast concrete volume to total concrete volume	Decision design stage
C_4	Standardization degree of PC components	1. Standardization of building plane, material, structure and interior decoration 2. Reasonable splitting and standard fabrication of prefabricated components	
C_5	Degree of deepening and optimizing design	1. Collision check and construction error adjustment in the design process 2. Energy-saving, decoration and other multi-functional integrated design in the same life cycle	

(continued)

Table 1 (continued)

Item	Variables	Description	Classification
C_6	PC component cost	1. The production cost of prefabricated components (Including labor cost, material cost, machinery cost, mold cost, etc.). Additional miscellaneous work is also involved, such as the cost of finished product protection, off-site maintenance and component factory storage	Production and transportation stage
C_7	Transport efficiency	1. The loading and unloading efficiency of components in the process of transportation mainly involves the separation of components, the mode of transportation, the means of shipment, and the awareness of relevant materials 2. Selection of prefabricated component plant, transportation distance and route	
C_8	Construction management level	1. Efficient management ability of cast-in-place and assembly construction mode 2. The improvement of construction scheme, construction process, safety and quality supervision mechanism. Site management level of PC components such as mobilization, stacking, storage, hoisting and installation	Construction stage

Table 2 Nine fuzzy semantic table

Number	Fuzzy semantics	Membership
1	Negative very strong	μ_{nvs}
2	Negative strong	μ_{ns}
3	Negative medium	μ_{nm}
4	Negative weak	μ_{nw}
5	Zero	μ_{z}
6	Positive weak	μ_{pw}
7	Positive medium	μ_{pm}
8	Positive strong	μ_{ps}
9	Positive very strong	μ_{pvs}

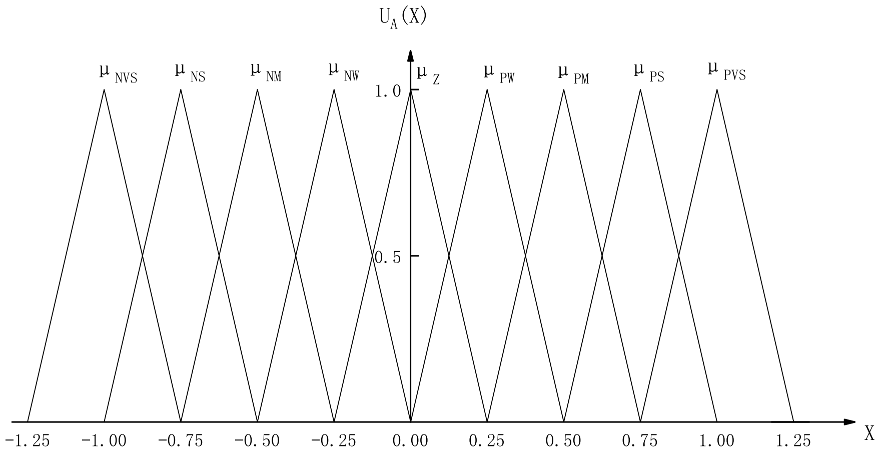

Fig. 2 The membership function

x in the interval [0,1], while the hyperbolic tangent function can map value x into the interval [−1,1] [5]. We try to evaluate the impact between influencing factors and prefabricated building cost from two aspects of "positive impact" and "negative impact", that is, the threshold function is required to convert the value to the interval of [−1,1], thus, Eq. (2) is selected as the threshold function of this study.

$$\text{S-shaped curve function I}: f(x) = \frac{1}{1+e^{-cx}} \tag{1}$$

C is a parameter that determines the slope of the curve.

$$\text{Hyperbolic tangent function}: f(x) = \tanh(\mathrm{x}) = \frac{e^{x}-e^{-x}}{e^{x}+e^{-x}} \tag{2}$$

3.4 Construction of FCM Model

After the concept or node is identified, the causal arc and weight are determined, Eq. (2) is also selected, the FCM model of prefabricated building cost was finally constructed based on the above works, as shown in Fig. 3.

The state value ${x_i}^{t+1}$ of node C_i at time t + 1 in the FCM model can be obtained by reasoning the state value ${x_i}^t$ of node C_j at time t. The reasoning process is shown in the transformation function Eq. (3), and the threshold function f(x) transforms the results of $x_i^t + \sum_{j=1, j\neq i}^{N} w_{ji} \times x_j^t$ and the initial values of each node of the system into the interval [−1,1], an equilibrium state will be achieved after many iterations [5, 15].

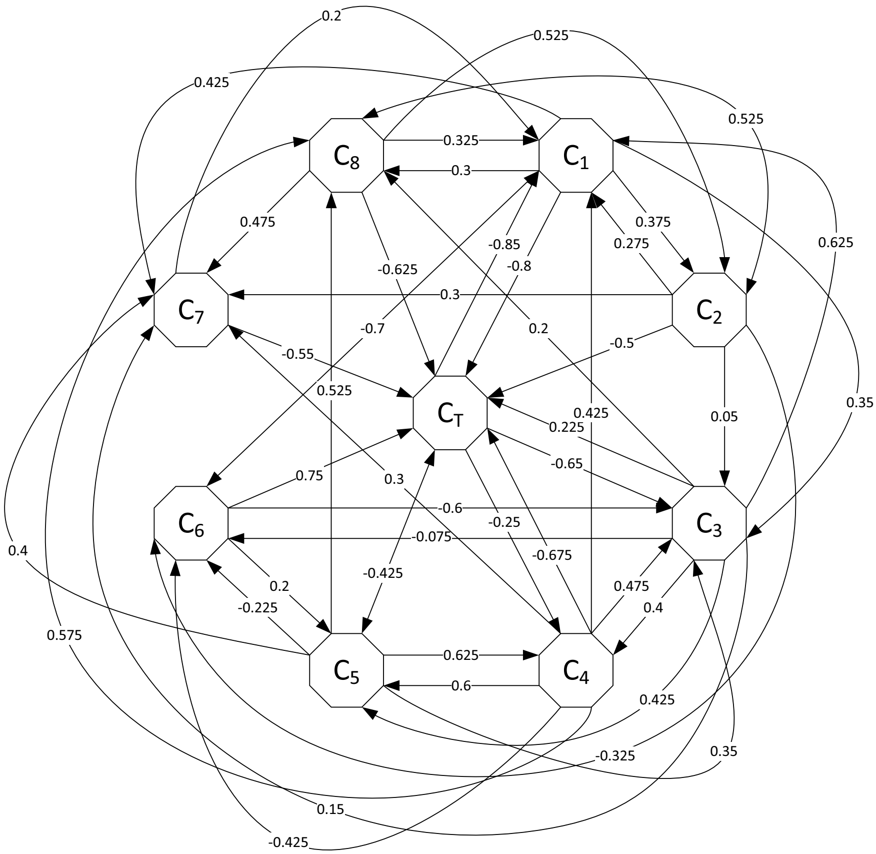

Fig. 3 FCM model of prefabricated building cost

$$x_i^{t+1} = f\left(x_i^t + \sum_{j=1, j\neq i}^{N} w_{ji} \times x_j^t\right) \tag{3}$$

4 Simulation Application of FCM Model

With the help of software FCM analyst 1.0, predictive analysis and diagnostic analysis are carried out based on the reasoning function of FCM. The software is designed according to the representation method and reasoning mechanism of the fuzzy cognitive graph, it can output the state curve and data value of concept nodes updated with time iteratively.

4.1 Predictive Analysis

The predictive analysis aims to predict the change of target event with time when a variable changes. It can be used to study the change of the target event (prefabricated building cost) with time when the influencing factors of prefabricated building cost change.

We simulated the values of the above-mentioned eight factor variables, when each factor variable is at a different initial value, it shall spread to other nodes in the network and cause the result of the target event to change. Taking the simulation of scale effect C_1 as an example, the initial values of node C_1 in the FCM model are set as -1.0 (range), -0.5 (poor), 0.5 (good), and 1.0 (excellent). The simulation value of prefabricated building cost tends to a stable value with the change of iteration times after causal reasoning and iterative operation between concept nodes. The stable values of prefabricated building cost in these four states are $P(CT| C_1 = 1.0) = -0.9403$, $P(CT|C_1 = 0.5) = -0.8476$, $P(CT| C_1 = -0.5) = 0.8476$, $P(CT| C1 = -1.0) = 0.9403$, respectively. A significant negative correlation exists between C_1 and C_T which indicating that the cost of the prefabricated buildings decreases significantly with the increase of scale effect. In the same way, the other 7 variables (influencing factors) are simulated in turn to observe the change of prefabricated building cost and its stable value. The simulation results of each variable are shown in Fig. 4. It can be seen that the value of C_T will evolve and stabilize at a fixed point after multiple interactions.

C_1, C_2, C_4, C_5, C_7 and C_8 have a significant negative correlation with C_T from the simulation results, while C_3 and C_6 have a significant positive correlation with C_T. That is to say, when the scale effect C_1, the quality of industrial workers C_2, the standardization degree of PC components C_4, the degree of deepening and optimizing design C_5, the transport efficiency C_7 and the construction management level C_8 are increased or strengthened, the cost of the prefabricated buildings will be reduced,

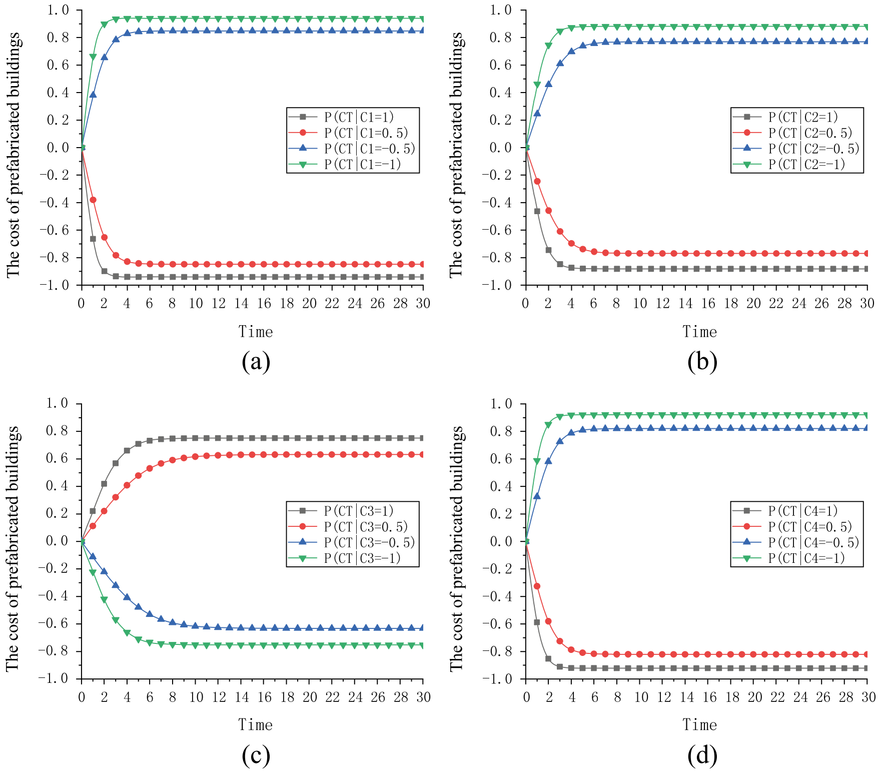

Fig. 4 The influence of the change of various factors in the predictive analysis on the cost of prefabricated buildings

when the prefabrication rate C_3 and PC component cost C_6 are reduced or weakened, the cost of the prefabricated buildings will be reduced.

The simulation results above are easy to understand, when one of C_1, C_2, C_4, C_5, C_7 and C_8 is in a favorable state, whether it is a medium or strong favorable state, the cost of prefabricated buildings will become lower and lower over time. Otherwise, the cost of prefabricated buildings is higher and higher. And the larger the slope in Fig. 4, the faster the development process. Although the unit cost of PC components shall be reduced in the process of production, transportation and construction with the increase of prefabrication rate C_3, the unit cost of PC components is still much higher than that of traditional concrete members at present in China. Therefore, with the increase of the prefabrication rate, the cost of prefabricated buildings will increase, which explains the positive correlation between C_3 and C_T. At the same time, the increase in PC component cost C_6 will lead to an increase in prefabricated building cost. The cost of the PC component is the direct factor in the cost of the whole prefabricated construction project, and the simulation results are consistent with the actual situation. When the variables are C_1, C_4, C_6, and C_8, the absolute

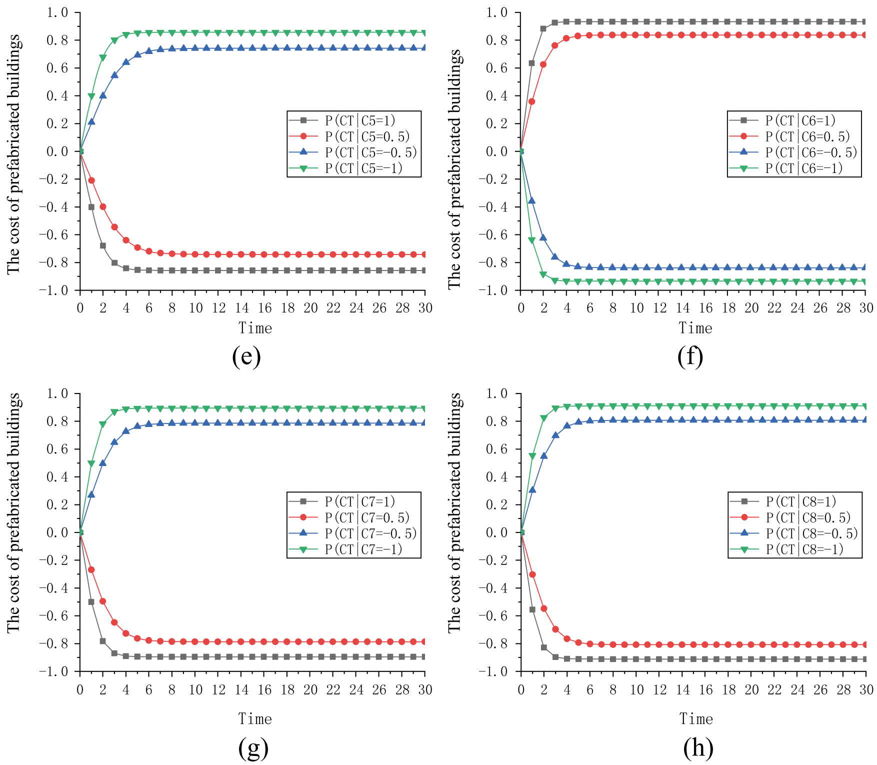

Fig. 4 (continued)

value of the slope of the curve is large, which indicates that the four concepts have the strongest correlation with C_T. that is, the scale effect, the PC component cost, the standardization degree of PC components and the construction management level have the strongest correlation with prefabricated building cost, which are $C_1 > C_6 > C_4 > C_8$. The results of the predictive analysis can help us to further understand the changing law of prefabricated building cost when the influencing factors change and provide direction for reducing the cost of prefabricated buildings.

4.2 *Diagnostic Analysis*

The purpose of the diagnostic analysis is to detect the possible root cause of the target event. The diagnostic analysis is realized by backward evolutionary reasoning of FCM. Diagnostic analysis requires inputting the state value of the result node to observe the change of the cause node. Set the result nodes C_T to 1.0, 0.5, −0.5,

−1.0, then we monitored the change of cause behavior in different scenarios. The simulation results are shown in Fig. 5.

It can be seen from Fig. 5 that when the target node changes, only C_1, C_3, C_4 and C_5 will change accordingly and remain stable at the fixed point, while the values of the other four influencing factors remain unchanged. The results above show that when the prefabricated building cost changes, it shall mainly affect the industrial environment and the preliminary decision-making and design stage. Scale effect C_1 belongs to the industrial environment, while prefabrication rate C_3, standardization degree of PC components C_4 and degree of deepening and optimizing design C_5 belong to the decision design stage. Moreover, When the initial value of prefabricated building cost is in a very high state (value is 1), C_1 tends to be the largest negative fixed value (−0.9464). The changing slope of C_1 is the largest when the prefabricated building cost C_T changes, which indicates that C_1 is the most responsive to the changes of C_T, so the scale effect C_1 is considered to be the most possible root cause. Besides, we can see that although the improvement of prefabrication rate C_3 has no great positive significance for reducing prefabricated building cost in current from the predictive analysis. the prefabrication rate of prefabricated buildings shall

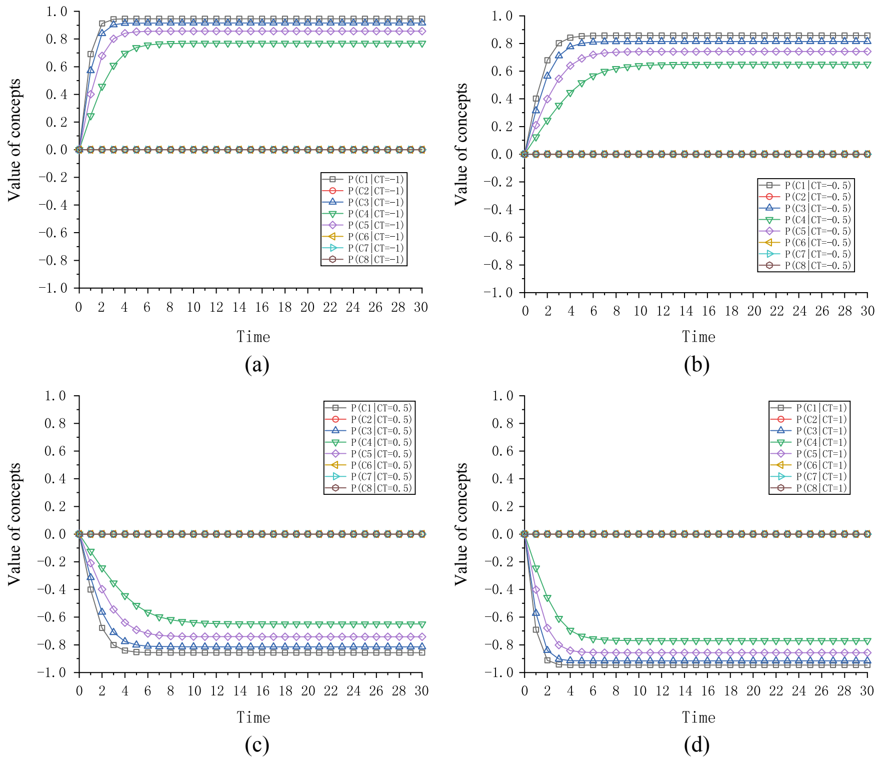

Fig. 5 The influence of the change of prefabricated building cost on various factors

be greatly improved once the cost of prefabricated buildings is effectively reduced from the analysis of this section. Decision-makers and designers shall be happy to reasonably improve the prefabrication rate of prefabricated buildings due to its advantages.

The results above show that the key point of prefabricated building cost control is scale effect C_1. Besides, it shows that effective work in the early decision-making and design stage is of great significance to reduce the cost of the prefabricated buildings, which can significantly affect the work in the later production, transportation and construction stages.

5 Conclusions

Through the predictive analysis of the FCM model, it can be concluded that the scale effect C_1, PC component cost C_6, standardization degree of PC components C_4 and construction management level C_8 have the strongest correlation with prefabricated buildings. through the diagnostic analysis of the FCM model, it can be concluded that the most possible root cause affecting the prefabricated building cost is scale effect, at the same time, attention should be paid to early decision-making stage (prefabrication rate) and design stage (standardization design of PC components and optimization design). Based on the above analysis, the following suggestions are put forward.

(1) To promote the scale effect of prefabricated buildings, the whole industry and the government need to work together. The industry needs to speed up the formulation of corresponding norms and standards, strive to solve the technical problems in the construction process and application of prefabricated buildings. Besides, the ideas of prefabricated buildings need to be publicized to society, which contributes to expanding the demand and opening up the market [16]. At the same time, the government needs to formulate corresponding preferential tax policies and industrial support policies to improve the enthusiasm of enterprises on prefabricated buildings. The cooperation between them can promote the establishment of a mature industrial chain, and solve the problems in the upstream and downstream links of the prefabricated construction industry. It contributes to procurement, production, transportation and construction.

(2) The standardization and integration of prefabricated components in the market are unsatisfactory at present in China, and the modularization is not unified, which induces the high cost of formwork. To effectively reduce the production cost of PC components, it is important to improve the utilization rate of formwork. Therefore, in the design of house type, it is necessary to reduce the type of house as far as possible, simplify the facade and its structure, and reduce the split of heterosexual construction. All of this contributes to improving the efficiency of the prefabricated component production line.

(3) Attention should be paid to the early decision-making and design stage. In the decision-making and design stage, the prefabricated buildings scheme should be perfected as much as possible to avoid all kinds of problems, instead of rescuing in the specific implementation process. Thus, the prefabrication rate should be reasonable to avoid too high or too low, the standardization of architectural design, material, structure and interior decoration need to be promoted, and the PC components need to be split reasonably. It is also important to carry out collision inspection and deepen the design scheme. All of this contributes to facilitating the later production, transportation and construction.
(4) The EPC model is encouraged to be adopted in the contract awarding. As the leader of the project during the construction, the general contractor needs to manage the overall situation, including design, procurement and construction. Thus, they need to facilitate effective communication and cooperation between all parties involved in the project. At the same time, it is important to optimize the allocation of resources in the whole process and reduce the work interface. All of this is helpful for efficient management and the cost control of the project.

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The Influence of Housing Prices on Urban Innovation Capacity: Review and Outlook

Ling Wu and Botong Song

Abstract To investigate the influence of housing prices on urban innovation capacity, the author first analyzed the connotation and manifestation of urban innovation capacity. On this basis, the author further analyzed the mechanism and orientation of the influence of fast-rising housing prices from the three aspects of government, enterprises and individuals. The research result suggested that high housing prices may promote or inhibit urban innovation capacity through influencing the expenditure preference of local government, the innovation input of enterprises, and the decision-making of individuals on innovation and entrepreneurship. However, there is great controversy over the specific orientation of influence, as most researches favor that raising housing prices inhibit urban innovation capacity while a small minority of researches suggest that raising housing prices promote urban innovation capacity.

Keywords Urban innovation capacity · Housing prices · Crowding out effect · Financing effect

1 Introduction

Since the reform and opening-up, China's economy witnessed rapid development with an average annual growth rate of over 9% which is a miracle in Chinese economy. However, the investment-driven and element-driven economic growth modes are pushing Chinese economy into a dual dilemma of sluggish "real economy" and "excessively expanded" fictitious economy [1]. Therefore, there is an urgency to seek a new growth mode to achieve sustainable economic development, giving rise to the development strategy of construction of an innovative country. In May 2016, the National Innovation-driven Development Outline was formally implemented. In October 2017, the 19th CPC Congress proposed that China's economy had been

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steering into a high-quality development stage from rapid development stage, undergoing a critical period of transformation of development mode, optimization of economic structure and updating of motive force of growth. The term of "innovation" was mentioned over 50 times in the 19th CPC Congress report. Innovation is the first motive force of development and a strategic support to construction of modern economic system [2]. However, currently, there is still a large gap between China and some developed countries in terms of innovation capacity. As urban innovation capacity is an important aspect of a nation's innovation capacity, it's critical to improve urban innovation capacity.

Since the twenty-first century, China's real estate market has remained constantly prosperous, making real estate industry an important engine of China's economic growth. However, it's much controversial that China's economic development mode is highly dependent on real estate industry in the nearly 20 years with increasing adverse effect [3] which includes reliance on land finance closely related to high housing prices [4, 5], detachment from real economy to fictitious economy [6, 7] and loss of talents [8], etc. However, the fiscal expenditure preference of government [9, 10], R&D funds input of enterprises [11, 12] and human capital [13, 14] will directly influence urban innovation capacity, raising the concerns of all sectors of the society on the impact of high housing prices on urban innovation capacity. In researches in recent years, the influence of housing price on urban innovation capacity has become a hot topic in the research field of both innovative economics and regional economics [15]. At present, the researches of influence of housing prices on urban innovation capacity are relatively scattered and lack systematic sorting of relevant literatures. In this article, the author aimed to clarify relation between housing prices and urban innovation capacity and put forward the outlook of research orientation in the future.

2 Connotation and Manifestation of Urban Innovation Capacity

Joseph Schumpeter first put forward the concept of "innovation" in 1912, marking the beginning of the research of innovation theory. He proposed that innovation is a kind of "new combination" of production function, that is, to combine production factors and natural forces in a new way to produce new products, or to produce old products in a new way [16]. Since then, scholars have constantly improved the definition of innovation [17, 18]. With the advancement of globalization, the concept of "core competitiveness" has been introduced into the study of cities. Many scholars have realized that innovation is the core competitiveness of a city. Based on this, urban innovation system has been gradually paid attention to and developed. Sun et al. [19] defined urban innovation capacity as the comprehensive capacity within a city to strengthen the driving force of urban economic growth, give full play to the initiative of urban innovation behavior organizations, allocate urban innovation resources efficiently, and transform innovative ideas into new products, new technologies and new services. The city's innovation capacity is mainly reflected in: First, local governments can proceed from the current situation and development requirements of urban economy to do a good job in macro-control, policy incentives, guidance and innovation. Second, enterprises have high innovation enthusiasm and innovation efficiency. Thirdly, talents have high innovation enthusiasm and efficiency [20]. At present, the measurement method has not yet reached a consensus on city innovation capacity, the academia mainly through the selection and innovation inputs (capital and human capital), innovation output, innovation environment supporting capacity and related economic indicators, and through the expert scoring method, principal component analysis, factor analysis method such as given weight to each index, weighted by city innovation capacity index [21–23].

3 Mechanism and Orientation of Influence of Housing Prices on Urban Innovation Capacity

From the Connotation and manifestation of urban innovation capacity, it can be found that the innovation behavior of the government, enterprises and individuals will directly affect the innovation capacity of the city. Based on this, the rise of housing price may have an impact on the city's innovation capacity through three paths: expenditure preference of government, innovation input of enterprises, and innovation and entrepreneurship decision-making of individuals. However, there are still some controversies about the influence direction of housing prices on the innovation capacity of cities.

3.1 The Influence of Housing Prices on Expenditure Preference of Government

Local government is one of the important organizations of innovation behavior. Rising house prices may affect the city's capacity to innovate by influencing the expenditure preference of government.

There are two different theories about the influence of housing prices on expenditure preference of government. Some scholars believe that high housing price means higher land fiscal revenue, and the increase of financial strength will help local governments provide more funds to support enterprises to engage in R&D and innovation while ensuring regional infrastructure construction [24]. Dai and Wang [25], based on the data of Provincial panels in China from 2005 to 2017, found that the increase of local government fiscal revenue would promote the growth of local innovation input through increasing fiscal science and technology expenditure and improving infrastructure. Landry [26] proposed that the creation of innovation foundation, innovation environment and cultural atmosphere by local governments is a key factor affecting the innovation capacity of cities. Czarnitzki and Hussinge [27] found through empirical research that government subsidies are conducive to promoting enterprises' innovation input, thus promoting urban innovation capacity.

However, more scholars hold the opposite view. They believe that under China's official promotion mechanism based on GDP, local governments are more willing to spend a large amount of fiscal revenue on infrastructure construction [28], and reduce investment in innovative R&D with long investment cycles, high risks, and slow results [3]. At the same time, government intervention in economy will also distort the function of resource allocation of market mechanism [29]. Thus, high housing prices inhibit urban innovation by changing the expenditure preference of government. Using the invention patent data of 267 prefecture-level cities in China from 2002 to 2012, Lu et al. [10] empirically tested that the expenditure preference of local governments to "emphasize infrastructure construction over innovation" hindered the improvement of the level of urban technological innovation. Du and Chen [30] found that when local governments are faced with great pressure of growth competition, they will attach importance to real estate investment and neglect technological innovation, thus inhibiting urban technological innovation.

3.2 *The Influence of Housing Prices on Innovation Input of Enterprises*

Enterprise is the most important component of urban innovation system [20]. The rise in housing prices may affect the innovation capacity of cities by affecting the innovation input of enterprises.

The crowding in effect of housing price on urban innovation is mainly reflected in two aspects: First, rising house prices could ease financing constraints for companies. R&D investment requires a large amount of capital. The rising housing price increases the assets that can be used as collateral for enterprises [31], so enterprises can get more financing to invest in innovative research. Generally speaking, in the financial system more developed areas, the rise of housing prices on the innovation capacity of the city more obvious positive role. Chaney et al. [31] found through empirical research that during 1993–2007, every dollar increase in the collateral value of American companies increased by 6 cents in investment. Gan [32] made use of the natural experiment of the land market crash in Japan and found that the change of collateral value has a significant impact on enterprise investment. If the collateral value decreases, the financing constraint of enterprises will increase; otherwise, the financing constraint of enterprises will decrease. Adelino et al. [33] found the importance of mortgage channels to small business employment by analyzing and studying the data of the past decade. In areas where housing prices had increased significantly, the employment growth of small companies was stronger than that of large companies in the same region and industry. Second, the wealth effect of rising housing prices promotes the improvement of household consumption level [34, 35], which leads to the increase of consumer demand and the expansion of enterprise market scale, which promotes the increase of research and development investment.

However, as the real estate has both the property of consumer goods and the property of investment, the rise of housing price may also restrain the city's innovation capacity through various crowding out effects. First, rising housing prices depress investment in research and development through external financing channels. The structural characteristics of the financial system have a significant impact on national or regional innovation activities [36, 37] and the financial system of most developing countries is often subject to excessive government intervention [38]. Under the background of China's bank-oriented financial system, when the housing price rises, the mentality of "buy the rise but not the fall" makes people form bullish expectations on the rising housing price. In order to avoid risks, banks are more willing to lend capital to real estate companies and reduce research and development loans [39, 40], thus leading to the reduction of enterprise research and development investment. Second, the rising housing price restrains the R&D investment of enterprises through internal financing channels. The nature of large investment, high risk and long cycle in the innovation and R&D activities of enterprises makes them especially vulnerable to financing difficulties. Therefore, the internal financing channels of enterprises are one of the important sources of innovation input [41]. However, due to the profit-driven nature of capital, the high rate of return in the real estate industry attracts productive enterprises to invest the capital originally used for research and development into the real estate industry. And, the faster housing prices rise, the weaker the innovation tendency of local companies [42–44]. This kind of influence not only exists in the local area, but also has the inhibitory effect to the surrounding area [45]. Third, the rising housing price reduces the consumption of potential home buyers other than housing consumption, which squeeses out the consumption of potential home buyers and leads to the tightening of corporate profits, thus reducing R&D investment [46].

3.3 The Influence of Housing Prices on Innovation and Entrepreneurship Decision-Making of Individuals

Talent is the subject of urban innovation activities. Rising housing prices may affect the innovation capacity of cities by affecting the flow of talents and innovation and entrepreneurship decision-making of individuals.

On the one hand, the rising house price will cause the cross-space allocation of population. Excessively high housing prices not only lead to the outflow of local human capital [47], but also limit the migration of potential human capital to local areas [48]. Zhu [49] used the housing price data of Shanghai and found through empirical research that the rising housing price would cause the outflow of innovative talents, thus inhibiting urban innovation. In recent years, in order to alleviate the crowding-out effect of rising housing prices on innovative talents, cities have launched a fierce "grabbing war" and launched a "housing policy for talents" to address the concerns of talents on housing. The "housing policy for talents" promotes urban innovation capabilities by attracting talents to enter and improving human capital levels [50]. In addition, high housing prices also have an impact on individual innovation. The increase of the ratio of housing price to wage will significantly reduce the innovation efficiency and participation of enterprise inventors, and the innovation behavior of inventors will tend to be conservative and tend to choose innovation projects with less risk and less value, thus inhibiting the overall innovation capacity of cities [51].

On the other hand, rising house prices can affect entrepreneurship. Domestic studies mostly support the "mortgage slave effect" that dominates in China, where high housing prices discourage entrepreneurship [52]. Compared with innovation and entrepreneurship, the real estate industry has the characteristics of low risk and high return. Under the continuously rising housing price, entrepreneurs are more keen on speculating on real estate rather than undertaking innovation and entrepreneurship. He rising housing price increases the pressure on young people to buy houses. As the main force of innovation and entrepreneurship, young people use a lot of wealth to buy houses, which reduces the capital of the whole society to invest in starting businesses [53]. Wu et al. [54] found in their study that residents in areas with high housing price/income ratio are less likely to start businesses. After dividing the samples into groups with and without housing, the analysis found that, for those without housing, the ratio of housing price income to entrepreneurial income had a significant negative effect, and the high housing price inhibited their entrepreneurial behavior. Gholipour [55] empirically analyzed the relationship between housing market and entrepreneurship in Middle East countries, and found that the situation in Iran and China was similar, and the rise of housing price significantly inhibited individual entrepreneurial behavior. However, for countries with more market-based financial systems, rising house prices help to ease credit constraints for potential entrepreneurs, thereby promoting entrepreneurial behaviour [56]. In addition, housing prices affect entrepreneurship differently in different industries. Access to capital is the biggest challenge facing small business growth today. The most common form of collateral for small businesses is personal property, so rising house prices have a clear boost to growth in sectors that do not require a lot of start-up capital [57].

3.4 The Influence Direction of Housing Prices on Urban Innovation Capacity

Through the analysis of the above three transmission mechanisms, it can be concluded that the rise of housing price has positive and negative effects on urban innovation ability, that is, there are both crowding out effect and crowding in effect, and whether the net effect is positive or negative depends on the strength comparison of the two effects [3].

Shao [15] found in his study that the housing price at the prefectural level not only did not have a restraining effect on regional innovation, but also improved regional innovation to a certain extent. Every 1 standard deviation increase in housing price will lead to an increase of 0.07 standard deviation in regional innovation level. However, Zhang and Wang [58] found that rising housing prices had a significant restraining effect on regional innovation performance. Some scholars also point out that there is not a simple linear relationship between housing price and urban innovation ability. Chang and Li [59], using China's provincial panel data, found an inverted U-shaped relationship between housing price and urban innovation ability. When housing price is in the medium range, R&D investment has the greatest promoting effect on technological innovation. Li [60] found in his study that the fluctuation of housing price would have different influences on urban innovation in the short term and the long term. In the short term, rising house prices can ease liquidity constraints and increase investment opportunities; But in the long run, the crowding out effect of rising house prices is more pronounced.

4 Conclusion and Outlook

In this article, the author systematically sorted and analyzed relevant domestic and foreign literatures on the influence of housing prices on urban innovation capacity. On this basis, the author analyzed the mechanism and orientation of influence of fast-rising housing prices on urban innovation capacity and put forward that high housing prices influenced urban innovation capacity through influencing expenditure preference of local government, innovation input of enterprises and innovation and entrepreneurship decision-making of individuals. However, there are still controversies over specific orientation of influence. The limit of the article is that there are relatively few discussions in relevant foreign researches on the influence of housing prices on expenditure preference of local government. Differing from Chinese real estate market which is subject to great macro control of governments, the real estate markets in most foreign countries are characterized by high marketization and housing prices are more subject to influence by market demand. However, there are relatively few researches in this aspect.

In the researches in the future, the following problems are urgently to be solved:

(1) The urban innovation is featured with apparent spatial spillover. However, currently, rare researches have taken into account the spatial spillover effect of innovation, thus possibly resulting in over-estimation or under-estimation of the role of housing prices to urban innovation. Therefore, future researches may consider addition of spatial panel model in performing empirical analysis of influence of housing prices on urban innovation.

(2) In real life, due to mutual influences between housing prices and urban innovation capacity, a series of inherent problems are caused by bidirectional causality in empirical research. Therefore, empirical techniques must be improved.

Under the settings of Chinese national conditions, the influence of state policies on real estate market is quite significant. Therefore, difference-in-differences technique, propensity score matching and other polity evaluation methods may be adopted for elimination or reduction of adverse influence brought by inherent problems.

(3) After identification of the non-linear relation between housing prices and urban innovation capacity, it's a meaningful research orientation in the future on how to further determine a reasonable range of housing prices to promote urban innovation capacity.

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A Critical Review on Data Preprocessing Techniques for Building Operational Data Analysis

Cheng Fan, Meiling Chen, Xinghua Wang, Bufu Huang, and Jiayuan Wang

Abstract The wide adoption of Building Automation System (BAS) and Building Energy Management System (BEMS) has provided building professionals with large amounts of building operational data for knowledge discovery. Considering the intrinsic complexity in building operations and common faults in data collections, data preprocessing has been recognized as an indispensable step in building operational data analysis. It can be used to enhance data quality by removing outliers and missing values, ensure data compatibility with data mining algorithms, and improve the sensitivity and reliability in data analysis. This study provides a comprehensive review on data preprocessing techniques in analyzing massive building operational data. The paper firstly reviews techniques for conventional data preprocessing tasks, including missing value imputation, outlier detection, data scaling, reduction and transformation. Afterwards, the paper proposes promising techniques for advanced data preprocessing tasks, including data partitioning, feature engineering, data augmentation and transfer learning. Based on the critical review, future research directions and potential applications for building data analysis has been summarized. This paper can provide a general picture on data preprocessing methods for building operational data analysis. The insights obtained are valuable for the development of advanced data-driven solutions for smart building energy management.

Keywords Building operational data analysis · Data preprocessing · Data analytics · Intelligent buildings · Building energy management

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1 Introduction

In recent years, the wide adoption of Building Automation System (BAS) and Building Energy Management System (BEMS) has provided building professionals with large amounts of building operational data for knowledge discovery [1]. The knowledge discovered can be very helpful for a diversity of tasks in building energy management, such as predictive modeling, fault detection and diagnosis, and control optimization. Previous studies have shown that building operational data are typically of poor quality. As a result, data preprocessing is often needed to ensure the data analysis reliability using various data mining techniques. Data preprocessing is a non-trivial task which may accounts for 80% of the total data mining effort [1].

In the building field, data preprocessing can be very challenging for practical applications considering the poor quality in building operational data and the complexity in building operations. Therefore, it has been universally acknowledged as an indispensable step in building operational data analysis. As an example, building operational data consists of many missing values and outliers due to faults in data collection, transmission and storage [1, 2]. Low-quality data will lead to low-quality data analysis. Data preprocessing can be used to enhance data quality by removing outliers and missing values, and consequently, improving the accuracy and reliability of data analysis. In addition, most data mining algorithms has certain requirements for input data. Building operational data mainly consists of numeric data, such as power, temperature, humidity, flow rate and pressure. However, some data mining algorithms, such as association rule algorithm can only handle categorical data (e.g., *High*, *Medium*, and *Low*) [3]. In such a case, data preprocessing should be conducted to ensure data compatibility with data mining algorithms.

This paper serves as a critical review on data preprocessing techniques for building operational data analysis. It aims to provide a clear picture of data preprocessing methods for smart building energy management. The paper is organized as follows. Section 2 reviews techniques for conventional data preprocessing tasks. Section 3 describes promising techniques for advanced data preprocessing tasks. Conclusive remarks are drawn in the last section.

2 Conventional Data Preprocessing Techniques

As shown in Fig. 1, data preprocessing includes four major tasks, i.e., data cleaning, data scaling, data reduction and data transformation. Data cleaning aims to enhance data quality and typical tasks include missing value imputation and outlier detection. Data scaling aims to transform the original data into similar ranges to ensure the reliability in model development. It can be conducted in two directions, i.e., data normalization and data standardization. Data reduction is applied to reduce data dimensions and thereby, reducing computational costs and improving data analysis efficiency. Building operational data are normally stored in data tables where each

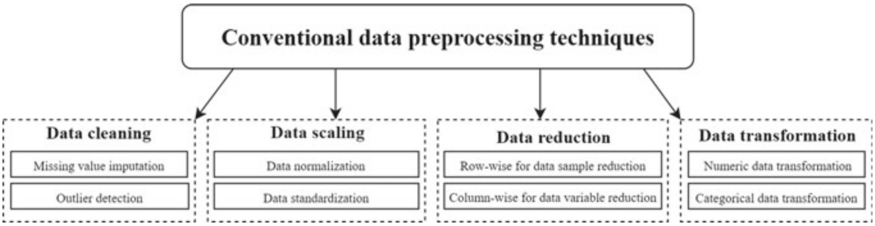

Fig. 1 Conventional data preprocessing techniques

row represents an observation sampled at a specific time step and each column represents measurements of a building [3]. As a result, data reduction can be conducted in two directions, i.e., row-wise for data sample reduction and column-wise for data variable reduction. Data transformation aims to prepare original data into the suitable format as required by various data mining algorithms. It typically includes two tasks, i.e., numeric data transformation (i.e., transforming numeric data to categorical data) and categorical data transformation (i.e., transforming categorical data to numeric data).

2.1 Missing Value Imputation Techniques

As shown in Fig. 2, the missing value imputation techniques for building operational data can be divided into two main groups. The first includes mean imputation, forward/backward imputation, moving average and etc. Such methods rely on the variable with missing values itself for data imputation. For instance, the mean imputation method will replace missing values with the mean value of that variable [4]. Although mean imputation is easy for implementation, it cannot address cross-sectional correlations among different variables and temporal correlations among different time steps. Considering that building operational data are in essence time series, Fan et al. used a simple moving average method with window size of 10 to fill up missing values in a building operational data set with a missing value ratio of 1.28% [3]. Moving average is suitable for analyzing time series data and has a fairly

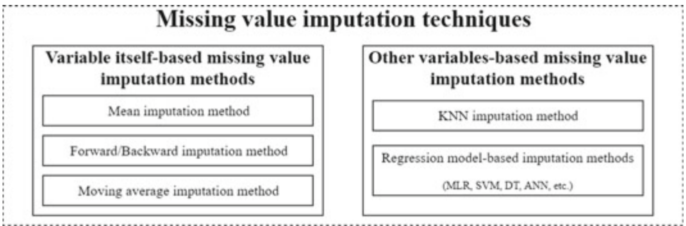

Fig. 2 Missing value imputation techniques

good performance when the duration of missing values is not long [6]. The variable itself-based missing value imputation methods are simple but sufficient, if missing value ratios are low (i.e., 1–5%). Previous studies have compared the performance of different missing value imputation methods with different missing value ratios. The results suggest that for high missing value ratios (i.e., 5–15%), sophisticated missing value imputation methods should be used [4].

The second missing value imputation method, which takes into account the impacts of other variables, can be more useful for accurate missing value imputations. Example methods include *k*-nearest neighbor (KNN) and regression model-based imputation. Such methods may perform better than the first when the missing ratio is high. KNN imputation method fills the missing value based on the values of the variables of the *k* most similar instances, where the *k* most similar instances are discovered by other variables without missing values [4]. In fact, KNN algorithm is a classification method based on analogy. It can obtain good classification performance, even with a large amount of missing value (i.e., 5–15% of total data) [5]. In regression model-based imputation methods, machine learning models can be developed using variables with and without missing values as outputs and inputs respectively [4]. Multiple linear regression, support vector machines, decision trees and artificial neural network are some examples of machine learning algorithms that are commonly used for model-based missing value imputation. It is recommended to use the regression model-based imputation methods to handle missing values with long durations [6]. In fact, there is no universal solution to achieve the optimal missing value imputation in different data sets. Suitable methods can be selected based on the missing value ratios and the requirements of computational costs.

2.2 Outlier Detection Techniques

As shown in Fig. 3, there are two main methods for outlier detection, i.e., statistical and clustering analysis-based methods. Most statistical-based methods are suitable for detecting outliers in numeric data formats, e.g., the total building power consumption [7]. Seem et al. adopted the generalized extreme studentized deviate (GESD) method to identify outliers in average daily consumption and peak demand for a day

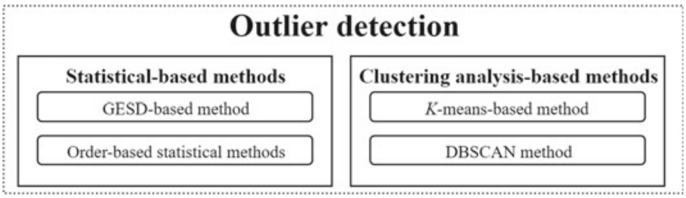

Fig. 3 Outlier detection techniques

[8]. The GESD-based method assumes that the measured data have a normal distribution, which may not be the case in different data sets. To tackle such limitations, order-based statistical methods, such as the interquartile range rule, Q-test and lower and upper quantile (Q) have been proposed [2, 7, 9]. Any observation falls beyond the range of the thresholds generated by these methods is identified as an outlier. Such methods can be applied when the data distribution does not conform to the normal distribution and may result in better performance when data sample size is small [7].

Clustering analysis-based methods primarily detect outliers in two ways. The first is through the combination of clustering methods (e.g., *k*-means) and statistical methods. For instance, users may firstly use *k*-means to identify data clusters, based on which statistical methods (e.g., GESD and boxplots) are then applied for outlier detection [10]. The second is to directly use clustering methods for outlier identification. For instance, density-based spatial clustering of applications with noise (DBSCAN) algorithm has the ability to group outliers into a separate cluster. Previous studies have shown that the DBSCAN method could be very promising for identifying outliers in multivariate building operational data, e.g., daily energy consumptions represented as 24-dimension vectors [11]. Compared with *k*-means, the DBSCAN method is more complex but does not require prior knowledge about the number of clusters. Both two clustering algorithms are sensitive to clustering parameters. Therefore, to ensure the outlier detection performance, the clustering parameters should be set with great cautions.

2.3 Data Scaling Techniques

Popular techniques to building operational data scaling include the max–min normalization and z-score standardization [3]. Ashouri et al. used max–min normalization to carry out linear transformation of the original data [9]. The equation is shown as follows:

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}}(x'_{\max} - x'_{\min}) + x'_{\min} \tag{1}$$

where indices *min* and *max* refer to minimum and maximum values of the variable. Compared with max–min normalization, z-score standardization is less affected by outliers and is therefore more suitable for data set with outliers. The equation is shown in Eq. (2).

$$x' = \frac{x - \mu}{\sigma} \tag{2}$$

where μ is the mean and σ is the standard deviation. Theoretically, z-score standardization works the best when the data are normally distributed. It is recommended to use max–min normalization when the building operational data do not conform with normal distributions and are free of obvious outliers.

2.4 Data Reduction Techniques

Data reduction are typically conducted in two directions, i.e., row-wise data sample reduction and column-wise data variable reduction. Various sampling techniques can be applied for row-wise data sample reduction, such as random sampling and stratified sampling [3]. It allows original building operational data set to be represented by a much smaller random data subset. For time series data, it is recommended to transform the original sequence data into shorter subsequences before data sampling, as the direct sampling may lead to information losses of temporal knowledge.

There are three main ways for column-wise data variable reduction. The first is to use domain knowledge to directly select variables of interests. It should be noted that such method is highly dependent on domain expertise. The second is to adopt data reconstruction methods to obtain the variables of significance. For instance, Cui et al. adopted principal component analysis (PCA) to reduce dimensions in building operational data [1]. The new low-dimensional variables derived by PCA are linear combinations of the original data variables [3]. It is recommended to apply PCA for data reduction when the original data set have the multicollinearity problem. All the original data should be scaled into similar ranges to ensure the PCA quality. The most critical challenge of PCA is how to determine the number of principal components to retain. One of the most widely used approach is to select principal components based on the proportion of total variance explained [12]. Another popular method is to simply calculate the summarizing statistics (e.g., the mean and standard deviation) of measurements over a time period. However, it is not suggested to apply such method when the window size is large and time series data are highly fluctuating, as the potential information losses may be too large [12]. The third is to use the heuristic methods to reduce the data set size by selecting significant variables or removing irrelevant or redundant variables, including the stepwise forward selection, backward elimination and decision tree induction. Heuristic methods are typically performed in a greedy way, which may result in much worst performance than the other two column-wise data variable reduction techniques [13].

2.5 Data Transformation Techniques

In the building field, data transformation is mainly applied to transform numeric data into categorical data to ensure the data compatibility with data mining algorithms. The equal-width and equal-frequency methods have been commonly used due to their simplicity [3]. The equal-width method divides the range of a variable into several intervals of equal size. In such a case, the number of intervals is typically predefined by users based on domain knowledge. For example, Xiao et al. divided the outdoor air temperature into 6 levels with the interval of 5 °C from −10 to 30 °C before mining association rules [2]. The equal-frequency method divides the data into several intervals containing approximately same number of observations. Compared with the equal-width method, the equal-frequency method is less sensitive to outlier.

Another major data transformation task is to transform categorical variables into numeric for the ease of model development. The one-hot encoding method has been widely applied for such purpose, where a matrix of $L - 1$ columns is generated for a categorical variable with L levels [12]. One potential drawback of such method is that it may result in high dimensional data when categorical variables have too many levels [14].

3 Advanced Data Preprocessing Techniques

As shown in Fig. 4, four advanced data preprocessing techniques have been proposed in this study for the development of advanced data analytics for buildings, i.e., data partitioning, feature engineering, data augmentation and transfer learning. Data partitioning aims to group original building operational data into several subsets according to typical building operation patterns, which in turns helps to enhance the sensitivity and reliability of data analysis [3, 15, 16]. Feature engineering can be applied to derive useful features from original data, based on which more accurate and efficient predictive modeling can be performed [12].

The other two address the potential data shortage problems in the building field. In practice, individual buildings may not have sufficient data due to the lack of data accumulation time of new building or the absence of advanced data collection systems [14]. Given insufficient data, advanced machine learning algorithms may not be applicable at all for practical applications due to the overfitting or non-convergence problem [17]. Data augmentation aims to enlarge existing training data sets by generating synthetic data. By contrasts, transfer learning aims to leverage the knowledge learnt from well-measured buildings to facilitate data analysis in poor-measured buildings.

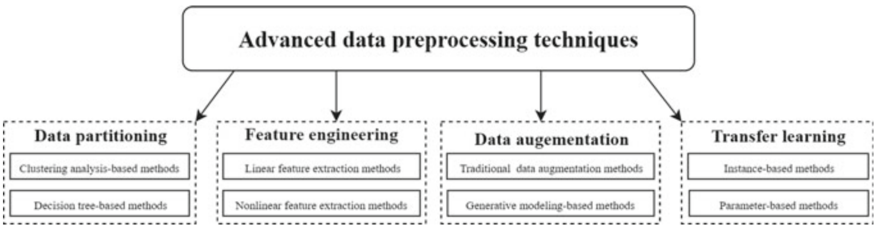

Fig. 4 Advanced data preprocessing techniques

3.1 Data Partitioning Techniques

The clustering analysis and decision tree have been used for partitioning building operational data. Many clustering algorithms have been successfully applied for data partitioning, e.g., *k*-means, hierarchical clustering, entropy weighting *k*-means (EWKM), and fuzzy c-means clustering, etc. Ashouri et al. adopted the *k*-means clustering algorithm to group building energy consumption data by weather conditions. It was claimed that such approach can reduce the impact of weather on building energy consumptions and thereby, facilitating the extraction of meaningful association rules [9]. In practice, it can be very difficult to determine the number of clusters [6]. Therefore, in order to obtain desired partitioning results, one has to conduct multiple data experiments. One solution is to apply the concept of ensemble learning on clustering analysis for performance enhancement, e.g., the evidence accumulation clustering (EAC) [6]. Compared with other conventional clustering algorithms, the ensemble clustering method is more complex but has the ability to automatically determine the optimal cluster number.

In addition, considering that none of clustering method is universally the best, it is recommended that multiple clustering methods can be used for data partitioning. Fan et al. firstly adopted five clustering methods to partition building operational data. The research result show that clustering analysis are capable of revealing typical patterns in building operations [3]. The performance of clustering methods can be evaluated by either internal (e.g., Dunn index and Silhouette index) or external validation methods (e.g., F-measure and normalized mutual information) [3]. Considering that external validation methods rely more on domain knowledge, it is suggested to use internal validation methods for the sake of simplicity.

Decision tree method is another popular method for data partitioning. In such a case, high-level variables, such as the total building energy consumptions, are typically used as outputs and time variables (e.g., *Month*, *Day type* and *Hour*) are used as inputs. The rules derived from the decision tree model can be used for data partitioning [16]. Decision tree-based methods are more suitable to partition data based on a certain high-level variable (e.g., the total building energy consumptions). By contrast, clustering analysis-based data partitioning methods can take multiple variables as inputs and therefore, are more suitable to partition data based on detailed low-level working conditions.

3.2 Feature Engineering Techniques

Feature engineering mainly includes feature selection and feature extraction [18]. Feature extraction aims to construct new features based on existing data, while feature selection only selects variables from existing data. Feature extraction is a more advanced feature engineering method and main techniques can be summarized in Fig. 5.

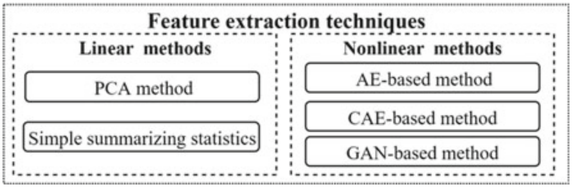

Fig. 5 Feature extraction techniques

Linear feature extraction techniques mainly include PCA and simple summarizing statistics, which have been descried in Sect. 2.4. Zhang et al. applied the PCA method for extracting features from building energy consumption data set with 124 features. The results show that the method was helpful to construct new features with more sparse data distributions [18]. It should be noted that the features extracted by linear methods have some limitations in representing high-level characteristics in the original data, as they are in essence linear transformations of the original data. To tackle this problem, various nonlinear feature extraction methods have been proposed.

Fan et al. developed three advanced feature engineering methods based on deep learning technology for building energy predictions, i.e., autoencoder (AE)-based method, convolutional autoencoder (CAE)-based method and generative adversarial network (GAN)-based method [12]. The AE-based method is an unsupervised method, which attempts to represent and reconstruct the input data (the original building operational data) by fully connected encoder and the decoder. Compared to the AE-based method, the CAE-based method may capture more useful features. The CAE-based method is also an AE-based method but relies on convolutional neural networks instead of fully connected neural networks, which can be effective in discovering the underlying temporal relationships. Unlike the previous two nonlinear methods, the GAN-based method is a promising generative model-based method, which consists of a generator and a discriminator. The generator is trained to generate synthetic data which have similar data distributions with real data to cheat the discriminator. The discriminator is trained to perform identify whether the inputs are real or synthetic. Once converged, the discriminator can capture the internal data characteristics and thereby, providing a feature extraction method for predictive modeling. The GAN-based method can be very effective in extracting high-level features from limited and poor-quality building operational data [12]. To summarize, nonlinear feature extraction methods can effectively preserve high-level interactions in original building operational data, such as the temporal dependency in time series data. In addition, compared with linear feature extraction methods, these methods are more complex but can automatically extract valuable features depending on less domain expertise [19].

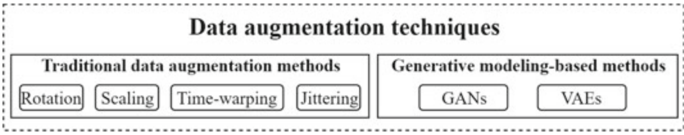

Fig. 6 Data augmentation techniques

3.3 Data Augmentation Techniques

Data augmentation techniques have been widely used in the computer vision field but seldomly applied for building operational data [20]. Therefore, in the future, researchers could work on applying data augmentation techniques for individual buildings to address potential data shortage problems.

As shown in Fig. 6, rotation, time-warping, scaling and jittering are traditional data augmentation techniques for time series data, which can create new data by introducing variability into the existing time-series data. Rashid et al. adopted abovementioned augmentation techniques to address the data imbalance problem in classification of construction equipment activity. A detailed discussion about these methods can be found in related literatures [20]. Such techniques are easy for implementation but greatly dependent on prior knowledge, i.e., researchers need to determine the conversion function and set the corresponding parameters based on data invariance properties. For example, the jittering method can generate new data by adding Gaussian noises. The main challenge in this case is to determine the suitable noise level to avoid the introduction of unreasonable data. More importantly, the data diversity gained by classic data augmentation techniques is rather limited.

The data augmentation technology based on generative model has attracted much attention due to its excellent performance in capturing complicated data distributions. The generative adversarial networks (GANs) and variational autoencoders (VAEs) are the top-2 generative modeling methods based on deep neural networks. As pointed in Sect. 3.2, the generator of a GAN model is capable of generating synthetic data with realistic data characteristics. Therefore, it can be used for enlarging training data set when the actual data is insufficient for reliable model development [21]. However, GAN models can be very difficult to train in practice. By contrast, VAEs are much easier to trained with an explicitly defined objective function of minimizing the reconstruction loss and regularization loss [22]. Compared with classic augmentation techniques, generative models can produce synthetic data with broader variations and higher quality.

3.4 Transfer Learning

Rather than generating new data, transfer learning aims to use the knowledge learnt from source buildings with sufficient data to ensure the reliable development of data-driven models in target buildings with limited data. The knowledge can be transferred using two main methods, i.e., instance-based and parameter-based methods. The instance-based method is the most direct method, where the transferred knowledge are the weights of source domain data samples. The parameter-based transfer learning methods assume that the source and target domains share similar parameters or hyperparameters and therefore, the transferred knowledge are represented as the source domain model. Such methods can be very helpful for improving the generalization performance of complicated data-driven models. Fan et al. applied transfer learning techniques for short-term building energy predictions in different data shortage scenarios. The research results show that transfer learning is not only extremely useful for solving the data shortage problem, but also for enhancement in predictive modeling [14]. In essence, there are two ways to utilize the parameters of pre-trained model. The first is to utilize the pre-trained model for feature extraction, and use the limited data of the target building to train the weights of last few layers [23]. The second is to use pre-trained model weights for initialization and the limited data of the target building is used for weight fine-tuning [24]. It should be mentioned that the selection of source buildings can be very important, since the physical and environmental differences between target and source buildings may lead to negative impacts on knowledge transfer.

4 Conclusive Remarks

This paper provides a comprehensive review on data preprocessing techniques in analyzing massive building operational data. A systematic review has been provided to summarize conventional data preprocessing techniques, including missing value imputation, outlier detection, data scaling, data reduction and data transformation. Four advanced data preprocessing techniques, i.e., data partitioning, feature engineering, data augmentation and transfer learning, have been proposed as directions for further studies. The insights obtained are valuable for the development of advanced data-driven solutions for smart building energy management.

To conclude, the contents of data preprocessing are very rich. In general, the conventional data preprocessing workflow is data cleaning (including missing value imputation and outlier detection), data reduction, data scaling, data transformation. The data partitioning task can be added in the final data preprocessing stage for detailed analysis. The researchers should adjust the abovementioned workflow according to the problem at hand. For instance, it is recommended to firstly conduct data reduction rather than data cleaning when the collected data set has too large features and contains a lot of redundant information. Such adjustment can reduce the computing load associated with the following data analysis. Each data preprocessing task can be accomplished using a variety of techniques, while none of them is optimal due to their own advantages and disadvantages. At present, the selection of data preprocessing technique is more like a trial-and-error process. Future researchers can work on common selection criteria for data preprocessing techniques and the utility of different combinations of data preprocessing techniques. Considering that the advanced data preprocessing techniques are relatively new research areas, another research direction is the popularization and application of these techniques. For instance, when the target building encounters the data shortage problem, both transfer learning and data augmentation techniques scan be applied as solutions for reliable predictive modeling. Few studies have been performed to investigate the potentials and applicability of these two techniques which opens a new research direction for researchers in the building field.

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A Bibliometric Analysis of EEG Based Mental Workload Assessment Research

Weilin Chen and Zhikun Ding

Abstract This paper aims to provide a critical review of the recent literature for mental fatigue studies using Electroencephalogram (EEG) sensor. Mental fatigue could cause many failures and dangers in workplaces. To prevent adverse effects on performance and safety, many physiological sensors are used to detect metal fatigue, especially EEG sensor. To analyze the research frontiers, 519 related articles published between 2010 and 2019 were retrieved from the Web of Science. With text mining and Latent Dirichlet Allocation (LDA) topic modeling, the number of published papers, major research countries and institutions, primary research topics and their contents were examined and discussed. It is found that with the increasing importance of work safety and technological progress, EEG based mental fatigue research has gradually become a hot research field, and many inter-discipline studies have emerged, for example, in the field of construction and education. This study provides a knowledge map of current EEG based research and suggests potential interdisciplinary studies for future research, especially in the construction industry.

Keywords EEG · Mental fatigue · LDA · Text mining · Bibliometric analysis

1 Introduction

Due to the inherent nature of specific occupations, people in some occupations (e.g. pilots, drivers, construction workers, etc.) face much higher stress and danger than

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others [1]. Much attention has been paid to solving this problem. Among them, workload which includes physical workload and mental workload can better help scholars understand workers' status [2]. There are many different definitions of workload, but in general, workload is the amount of work that can be done within a certain amount of time. Different individuals and works will result in different workloads, so there is no specific threshold value to represent the workload. Therefore, indicators such as fatigue and attention level are used to measure the workload. In the case of excessive workload, workers will become fatigued in a short time, accompanied by a decline in attention, poor work performance, and even damage to workers or accidents. Low workloads also lead to poor performance, due to losing focus and interest in the work. Therefore, reasonable arrangement of work is not only an inevitable requirement for pursuing higher work efficiency, but also an important factor to reduce work accidents [3], and its validity depends on the accurate measurement of workload.

There are several tools and devices available for measuring workloads. Since physical workload is easier to measure, current measurement techniques have been well developed, including electrooculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), body temperature measurement, and respiration rate measurement [4]. These techniques measure the workload by detecting sleepiness, concentration, muscle load, heart rate, body surface temperature and oxygen consumption. Along with the development of wearable devices, these measurement technologies have become more portable and connected, leading to the emergence of Location sensing and Physiological Status Monitoring (PSM). It will integrate the information from all parts of the body and form a real-time physiological monitoring system. The physiology-based measurement has its unique advantages [5]. The measured data is easy to explain and directly related to fatigue condition(for example, respiration and heart rate will accelerate and body temperature will rise in fatigue). And the data is relatively independent and will not be easily interfered by other data sources. Therefore, relatively pure data can be obtained, which is conducive to prediction. Secondly, these data are commonly used data types with a set of objective criteria, which is conducive to standardization and comparative experiments. Moreover, the data from different individuals will not have great specificity, which is conducive to generalization. In addition, since a single device does not need to measure too much kind of data, these devices won't be too conspicuous and hinder daily work, which is conducive to practical application.

But some advantages of physiological measurement also hinder its development. Independence makes it difficult to capture enough data from a single device to build an excellent predictive model. As a special existence, the brain is related to almost all physical information. The brain processes information and makes decisions through transmitting electrical signals between nerve cells. Therefore, psychological measurement seems to be an excellent method of measurement as a supplement or substitute for physiological measurement. When measurement technology was still scarce, subjective measurement became a mainstream psychological measurement method [6], and subjects could express their thoughts freely through questionnaire or interview. Although such methods cannot form a unified standard, they can still obtain relatively accurate results for ordinary subjects through careful arrangement, which is one of the reasons why some subjective questionnaires are still used today. However, it is difficult to get a deeper understanding of the deeper information by using subjective methods. In addition, different individuals may have deviations in their own evaluation, and even the evaluation of the same individual may change at different times [7]. Therefore, standardization and generalization are difficult. In addition, the collection and analysis cycle of the scale is too long, so it is only applicable to the research process, hardly applicable to the actual workplace.

The EEG device can indirectly measure the electrical activity in the brain, and it is simple and portable enough, so it has become one of the excellent choices to objectively measure mental activity. Because electric fields travel so fast, the EEG provides excellent temporal resolution and can even detect activity in cortical areas over sub-second time scales, making it possible to monitor workers' mental states in real time. In the process of the study, EEG data can also be well combined with EOG and ECG data, which improves the reliability of the study [8]. However, EEG is not omnipotent, and there are still many problems to be solved. For example, how to solve the interference of artifacts, EEG signals with comprehensive information bring both advantages and interference for analysis, and many electrical signals unrelated to the experimental target will also be mixed into the overall signal (including blinking, muscle contraction, and even external interference) [9]. This has brought a huge obstacle to the current analysis work, so it is an excellent solution to hand over the identification work to the deep learning algorithm and optimize the algorithm. Even if this does not solve the artifact problem, it can still get satisfactory results. In addition, EEG patterns differ widely from individual to individual, unlike physiological data, so a specific recognizer is needed, or an adaptation system needs to be added between the worker and the recognition system to make the recognition universal.

But there is little research focus on how to develop the data processing methods or analysis methods, which is nearly overlapped. Therefore, there are still many problems to be solved in using EEG to study the workload and improve the working conditions of workers. Meanwhile, only a few articles pay attention to summarizing this research. In order to fill research gaps, this paper aims to review the relevant articles published in the past decade to summarize the current hot topics, mainstream research methods and difficulties, so as to provide reference for the researchers in this area, especially the construction industry which has just begun to use EEG technology for research.

2 Method

2.1 Data Source

The Web of Science is one of the largest and most comprehensive academic databases in the world, which also includes a lot of information related to the article, which is helpful for analysis. Therefore, the online database of Web of Science core collection is selected to retrieve the articles needed for research, and the retrieve code used for this study is TS = (“EEG” AND “workload”). This study mainly focused on articles published in the last decade (2010–2019), since the EEG related research is emerging. Because this search was conducted in July 2020, articles in 2020 are excluded. In addition, some articles searched do not meet the requirements of this study, some articles are removed manually. Conference papers have not been excluded, because this subject is still in the early stage of development, and many research topics are still in the exploratory stage. Therefore, conference papers with short publication cycle can also represent the development and trend of research topics well. According to the above retrieval methods, a total of 519 articles are downloaded for research. Each article contains the following information: title, author, abstract, year of publication, keyword, citation, research institution, published journal, etc.

2.2 Text Analysis Method

This article mainly uses the Latent Dirichlet allocation (LDA) for bibliometrics analysis, which is widely used in literature topic classification [10]. By using the Bayesian probability model, LDA forms a selection probability between keywords and potential topics, so that each paper can be regarded as a word frequency vector. Since the keywords used in articles on the same topic are similar, these probabilities allow us to categorize papers into different topics and derive key words under each topic to help us further analyze each topic. The title and abstract of each article will be used in this LDA analysis, as they are not only containing the core content of the entire article, but also brief enough to avoid excessive pressure and redundant information on the analysis.

In addition to the statistical analysis of text data, data visualization is also an important consideration [11]. For processing and presenting large amounts of textual data, data visualization is a very efficient and fast method. Therefore, data visualization will be used to analyze these articles, mainly including the links between articles, namely the cooperation between the article authors and the cooperation between various areal research institutions. In cooperation network diagram, the size of the circle represents a published article by the author or the area, the number of published articles, the corresponding circle is also big, and the connection between different circles represents the cooperation between them, and the shorter the distance between the circle represents the closer cooperation between them. Data visualization is realized by using VOSviewer software [12].

2.3 Data Processing

The collected data is exported directly from WOS, stored in Endnote and VOSviewer respectively, grouped by year of publication, journal, and again exported as text analysis material for title and abstract. But since the LDA algorithm does not recognize connections between words, it cannot recognize semantic connections between words. In addition, the date of writing and the author of the difference, for the same concept of the word will be different. Therefore, before the research topic recognition, some words are restored and replaced by synonyms. For example, switch from ‘driver’, ‘driving’ to ‘drive’ and from ‘cognitive’ to ‘mental’. After initial processing, the remaining text data also needs to remove punctuation, stop words, and so on.

3 Result

3.1 Quantity and Trend of Literature

Figure 1 shows the number and trends of articles published in the last decade using EEG technology to measure mental workload. It is obvious that, around 2010, the number of relevant articles published is still limited. Although the theory of cognitive workload was initially proposed as early as 1967, limited by EEG technology, mental workload in the early stage was mainly measured subjectively using scales, and many excellent scales (i.e. subjective workload analysis technique, workload profile, multiple resources questionnaire, National Aeronautics and Space Administration task load index) are still widely used today as a supplement to objective measurement techniques such as EEG.

Similarly, the number of citations for articles published from 2010 to 2012 showed an overall trend of gradual increase and gradual leveling off. After the rapid rise, EEG technology needs to be improved in many aspects, such as the interference of artifacts, so that the current EEG research is at a stage of steady development. However, the

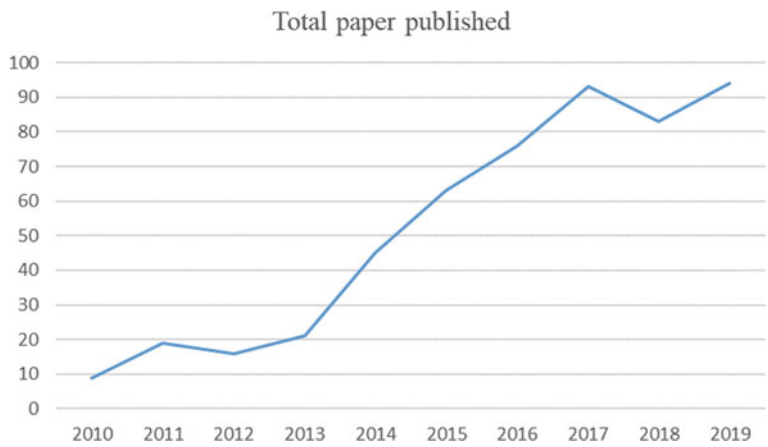


Fig. 1 Number of articles published from 2010 to 2019

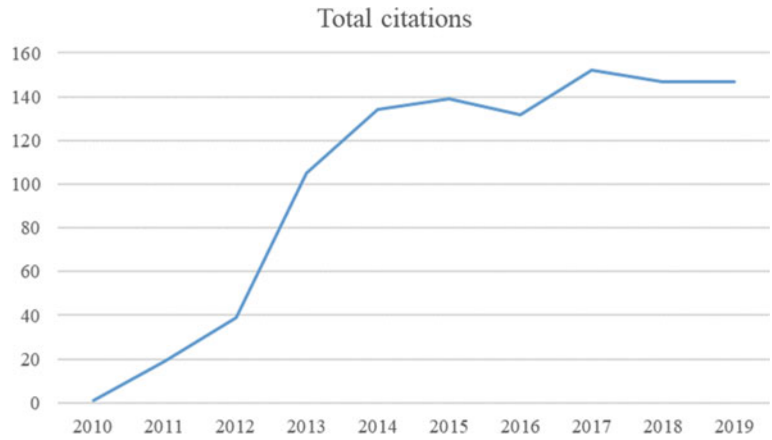


Fig. 2 Number of citations for articles published between 2010 and 2013

decrease in the number of articles published will not affect the development of this field, which has developed more and more new research directions. For example, with the improvement of the portability of EEG devices, more and more scholars have begun to study the feasibility of low-channel EEG devices, to further improve the portability and economy of EEG devices and promote the application of EEG devices in the workplace. The possibility of practical application of EEG has further led to a lot of research on the application of EEG devices in the actual workplace (such as construction sites, offices, etc.) (Fig. 2).

For different journals, there will be different topic preferences, which will help researchers to search or publish articles according to their own needs. Therefore, this paper carries out statistical analysis on the journals that have published articles on EEG and workload. The articles searched this time come from 130 different journals, and no journal has an absolute advantage in the number of publications, most of which have only published one relevant article.

Figure 3 shows the seven journals that have published the most relevant articles. The journals above are as follows: (1) Frontiers in Human Neuroscience, (2) Frontiers in Neuroscience, (3) Plos One, (4) Journal of Neural Engineering, (5) Applied Ergonomics, (6) IEEE Transactions on Neural Systems and Rehabilitation Engineering, (7) International Journal of Psychophysiology. The journals with the highest number of published articles had 30, most of which were published in 2019. It is worth noting that the first two journals are attached to the Frontiers. This journal covers a wide range of disciplines, including basic science, life science, engineering technology and humanities and social sciences. It aims to gather the top scientific research strength, reflect the latest academic achievements, and build an international and open academic exchange platform.

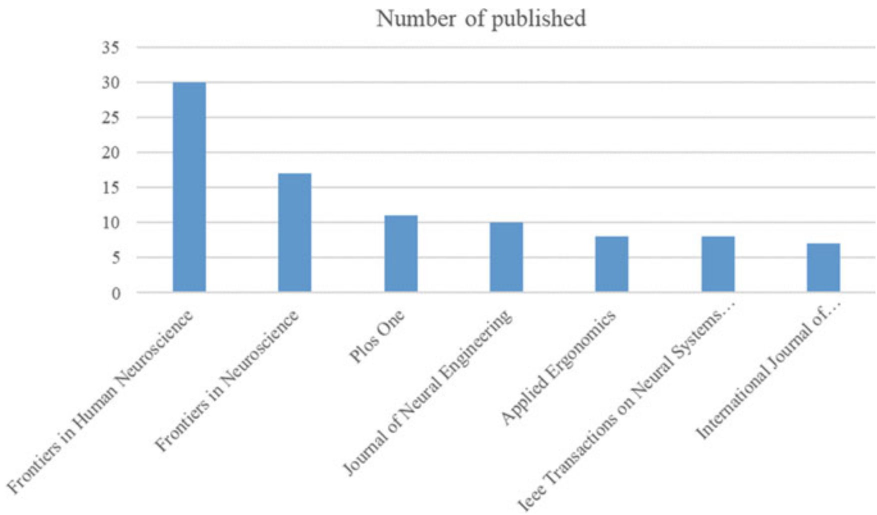


Fig. 3 Number of articles published in major journals

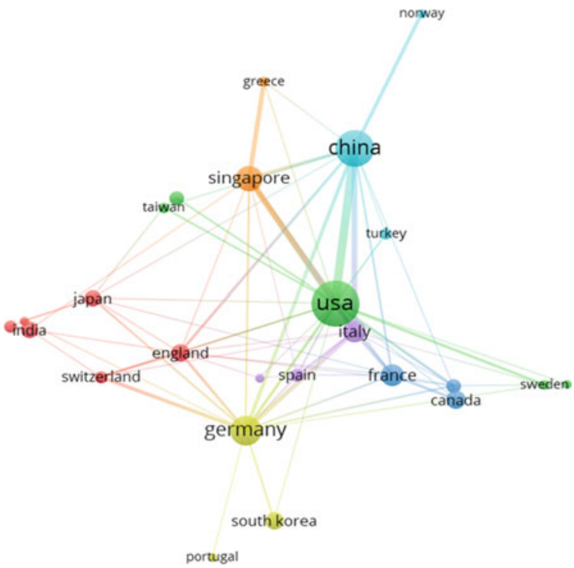
3.2 Cooperation Network

In the area cooperation network, cross-area cooperation between research institutions listed in all articles is determined according to acknowledgement and contribution, and node strength and cooperation strength are determined according to the final number of published articles. As can be clearly seen from Fig. 4, the USA has the most published volume (26.59%), followed by China (17.15%), Germany (11.37%), Singapore (8.48%) and Italy (6.16%) in terms of published volume. Among them, the United States is not only the country with the most published articles, but also has a far higher citation rate than other countries, which indicates that these articles are of high quality, generally recognized, or have opened new research directions and been cited by subsequent scholars. In terms of the connections between nodes, the United States has cooperative relations with others. In addition, the partners of China, the second largest research country, are mostly Pacific coast regions and some European regions. In Europe, there is more cooperation between European countries than between non-European countries.

In the author cooperation network, it is obvious that there are four authors with relatively important status. In Fig. 5, it can be found that Babiloni Fabio, Borghini Gianluca, Arico Pietro and Di Flumeri Gianluca have published the most articles, namely 21, 17, 15 and 12, respectively, and have a strong connection with each other. The author, Babiloni Fabio is at University of Roma La Sapienza, mainly working on Human Computer Interaction (HCI). Three other scholars were also from The University of Roma La Sapienza.

Figure 6 shows the links between journals, consistent with the results shown in Fig. 3. The journal Frontiers in Human Neuroscience has the most articles, and is

Fig. 4 Area cooperation network



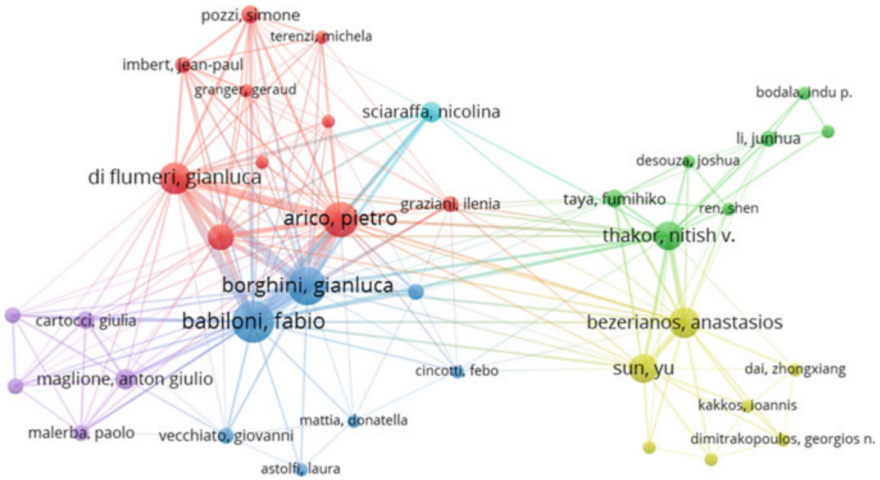


Fig. 5 Author cooperation network

closely linked with the journal Frontiers in Neuroscience, and has links with other major journals as well. There are many connections among journals, and most of the nodes are clustered together, indicating that this connection is very close.

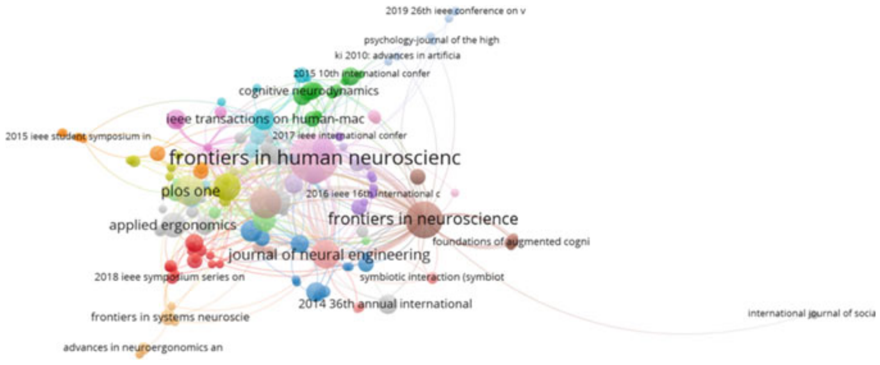


Fig. 6 Journal cooperation network

3.3 Text Analysis

With the help of the perplexity algorithm, the LDA algorithm is used to analyze the text of the retrieved articles, and it is concluded that the retrieved articles can be roughly divided into five different research topics, depending on the frequency of word. However, according to the specific content between different topics, the classification can be reclassified into three topics, namely construction safety, driving and flying fatigue and inter-discipline. Topic classifier is removed because of the lack of specific research topic. Its existence indicates that a large number of research aims at building a high-precision classifier.

3.3.1 Construction Safety

The use of EEG technology to secure construction workers is an emerging field of research in recent years, which could date back to an article published by Chen Jiayu in 2016, in the retrieved article [13]. Due to the gradual development of modern construction equipment, its failure rate has decreased a lot, but in the actual construction process, there are still many safety accidents. Because there are still many accidents caused by the negligence of the workers, and now only safety education and on-site supervision are used to avoid safety accidents, but will eventually reach the effect is limited. Since safety education can only relieve workers' subjective neglect of safety issues, and the coverage of on-site supervision is very limited, accidents may occur when workers lose their concentration due to mental exhaustion in places beyond supervision. Due to the particularity of construction work, accidents will often cause serious consequences, which is one of the reasons why the casualty rate of the construction industry is still at a high level.

Existing studies have shown that low-frequency EEG signals have a good recognition effect on mental indicators such as attention level and alertness level of construction workers [14]. Alpha waves and beta waves are the most used indicators for detecting mental workload in workers (alpha waves, about 8–12 Hz, associated with relaxation, inhibition, and attention; beta waves, about 12–25 Hz, associated with behavioral action and imitation). According to the research of Chen [15], the EEG pattern in works with high physical demand is significantly different from that in works with high mental demand, so it is possible to acquire useful information even if the activity of the worker would disturbs the EEG signal.

At present, how to translate the research results into practical applications is a big problem [16]. On the one hand, there is a lack of a real-time detection system; on the other hand, how to improve the portability and economy of EEG devices. The good news is that considerable research has shown that EEG devices with a small number of channels can produce acceptable predictive results [17, 18]. Moreover, research in other fields is also developing systems that can detect and analyze EEG, which can provide reference for research in this field.

3.3.2 Driving and Flying Fatigue

Like the construction industry, the state of the driver is largely responsible for traffic accidents. According to statistics, 10–20% of traffic accidents are caused by drivers' fatigue driving, and this probability reaches a staggering 60% in heavy vehicle accidents [19]. Therefore, in order to prevent the occurrence of traffic accidents, it is necessary to design a set of safety systems for the driver's mental condition monitoring, and timely alert to remind the driver to make timely adjustments. The difficulties faced by pilots are like those faced by drivers, but more severe, both in terms of the difficulty of driving and the consequences of an accident. Unlike construction workers, driving fatigue varies in its causes and consequences. A lot of the load brought by the construction work comes from the physical load, which feeds back to mental fatigue. How to eliminate physical interference is a problem. The driving behavior itself requires low physical strength, but for a long time to invest a lot of energy in monotonous work, people will easily be distracted, so that the response time to the driving work is reduced, unable to make the right decision quickly [20]. This makes some fatigue can't be noticed by the driver himself, but the driving work needs to maintain a high concentration to deal with various emergencies, which leads to a high risk of fatigue driving.

As mentioned above, there are subjective reporting methods, detection methods based on physiological signals, and detection methods based on physical characteristics. In addition, there are also some methods that convert the detection objects into vehicles. When abnormal activities occur, the detection system will carry out auxiliary control for the vehicle according to the situation [21]. Due to the characteristics of driving fatigue, some of the detection indicators are not obvious, and will produce delays, resulting in unsatisfactory detection effects. EEG devices, on the other hand, have a high potential for immediate detection because of their timeliness and ability to most directly reflect a person's mental state. The general paradigm for such research is to use virtual or real driving environments for participants to simulate long periods of driving. The collected EEG signals were then filtered and fed into different models to test classification accuracy. At present, offline analysis in the laboratory environment has been able to achieve a satisfactory accuracy of up to 95% [22]. However, like the research on construction safety, how to propose an algorithm model that can not only calculate the current driver's mental state in real time, but also adapt to different individuals is a major difficulty at present.

The main difference between this theme and the theme of construction safety is that the latter focuses more on low cost and portability, otherwise any research would not actually be used in the field. However, with longer research and more researchers in the field of driver fatigue, it is more likely to develop an easy-to-use detection system that can provide a reference for construction safety research and put more effort into other research.

3.3.3 Inter-discipline

This is the least thematically correlative category, containing dozens of small topics, each with only 1–2 articles, but it is proof of the rapid development of EEG related research. In these studies, although the research topics are different, the research methods are similar. The purpose of these studies is to identify the magnitude of the burden that different jobs, or different environments, impose on humans. These works could be defined as workload research that represents the mental resource needed in a specific work. It helps us identify what information is easier to be accepted, or what kind of work will overload us (Table 1).

Without considering the topic classification, the word cloud map is drawn according to the frequency of each word and the frequency of its occurrence with other words (excluding some words, such as EEG and cognitive) as shown in Fig. 7.

Table 1 Article classification details

Research topics	Key words (Top 10)	Number of literature	Percent (%)
Construction safety	Construction measure safety physical ERP literature mental management attention worker	6	1.16
Driving fatigue	Mental level cognitive performance user drive human physiological BCI learning	317	61.08
Flying fatigue	Auditory flight pilots visual team aircraft simulation activity model teams	19	3.66
Classifier	Feature classification detection accuracy mental model performance machine-learning classifier network	117	22.54
Inter-discipline	Cognitive load mental condition participant frontal frequency activity effort processing	60	11.56

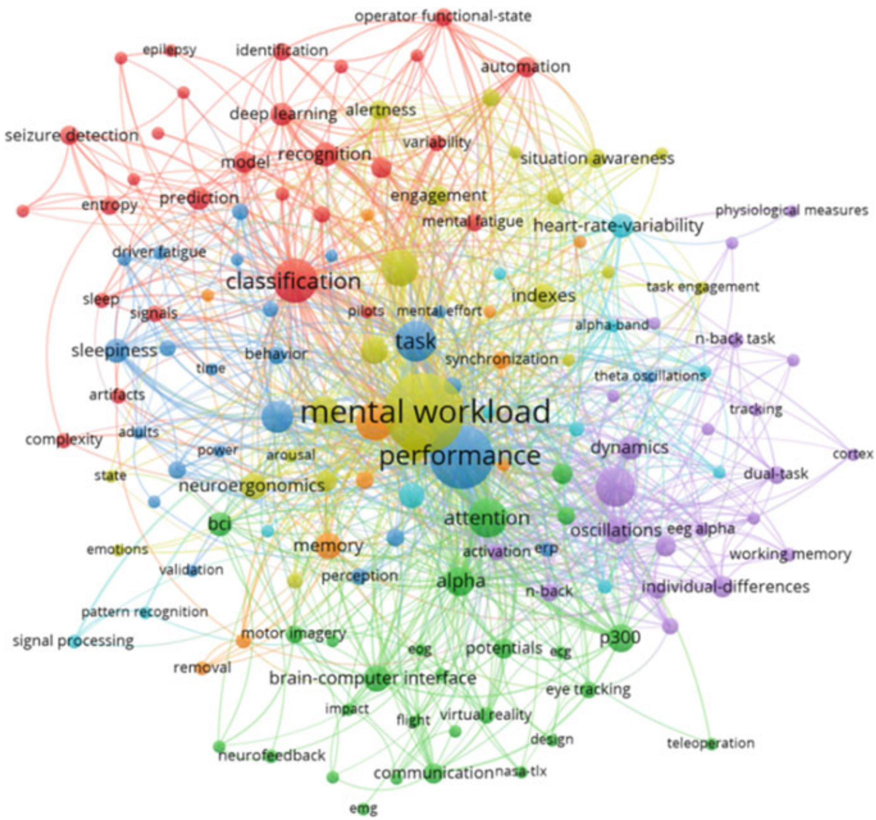


Fig. 7 Word cloud of keywords

Mental workload as the subject of the study is most closely associated with word performance. This is one of the commonly used dependent variables in this kind of research, because it is difficult to make a quantitative analysis of the fatigue degree of different subjects. However, taking task performance as a mediating variable can indirectly reflect the mental state of the subjects, and it can be applied to both inter-discipline and inter-discipline studies. Second, the two obvious words, classification and attention, are linked together by a theme Brain-computer interface (BCI). In fact, according to the current state of research, many research topics related to workload fall under the category of BCI [23]. BCI aims to receive a specific signal from the human body, identify the content expressed by the signal through the systems, and output this content to the electronic device, to form a set of automatic system controlled by the human consciousness, which is a hot subject in the field of EEG at present.

In addition, the word "classification" takes up a certain amount of weight, too. Because machine learning methods are certainly effective for analyzing EEG data, even if we don't know how the brain works. But there is too much effort on building new classifiers in this field, little research work on its application, including cost reduction, adaptability improvement, etc. Moreover, in this study the advantage of EEG has been discussed, and it would be a promising technology to carry out more study in human cognition. But the ability of EEG is still limited. Physiological measuring devices are cheaper, but less accurate. Another novel device, fNIRS, has better artifact resistance than EEG, but has a lower temporal resolution. This is why multimodal study is needed to offset the disadvantage of every device. Multimodal fusion would be and should be a focus point, which needs more attention in future research. While there is still a lot of research analyzing and discussing these data separately.

4 Conclusion

In this paper, we summarize the mental workload research based on EEG technology in the past ten years, propose the current mainstream research methods and difficulties, and highlight research in civil engineering. According to current research, EEG is a promising way to measure mental state which could reduce the risk of accidents and improve productivity. But questions about how the brain works are still unknown, so most research leaves the analysis to black-box algorithms (deep learning, etc.) that allow researchers to identify specific patterns from EEG signals, and then make a classifier which doesn't need much data interpretation. However, they need a lot of training data to provide a high precision model, and the current data filtering technology still needs to be broken through, which will reduce the accuracy of the model. Moreover, the suitability of the model is also a problem. Despite this, the current identification technology has achieved good results, and the next step is to make breakthroughs in artifact removal technology and signal acquisition technology, so that wearable EEG devices can be used to protect human safety and improve our performance at work.

Although research of combining EEG technology with construction safety management is still in the initial stage, the rapid development of EEG related research could bring many opportunities and help to them. Researchers related to civil engineering could make contributions in line with professional characteristics according to the research direction more suitable for this major highlighted in the current review, and combine the achievements of other majors to build a safety guarantee system that can be really applied to the construction site. The mainstream research using EEG in the construction field is site safety, but there are still many research directions to be studied, such as project selection process, agent-based game, etc. On the other hand, the application problem is more severe in this field. Since some research has worked on the reliability of single-channel EEG, how to put such results to use would be the next step.

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Management of Municipal Construction Waste Transportation by Integrating ABM and GIS Model: A Case Study of Shenzhen

Xiaoyan Cao and Zhikun Ding

Abstract Effective construction waste management (CWM) is a key challenge for global sustainable development. In particular, scientific transportation management of municipal construction waste (CW) is also an important way to reduce environmental pressure due to the scarcity of land resources and the lack of landfill facilities in most cities. Based on the hybrid simulation method, this paper implements dynamic regulations and analyzes the effects of different construction waste management policies by applying agent based modeling (ABM) simulation method, and designs transportation plans by loading geographic information system (GIS) data. Construction waste transportation in Shenzhen is taken as an example in which GIS and other required excel data are loaded into AnyLogic simulation software. According to the ABM simulation results, the optimal disposal route of CW transportation is identified. Simulation results show that this method can effectively provide regular path planning for waste transportation, and follow the transportation route stipulated by the traffic regulations of Shenzhen. The findings can also provide a guide for decision making of CW transportation plans.

Keywords GIS · Construction waste transportation · ABM · Routing Optimizing

1 Introduction

During the construction period, a large amount of CW is generated, which has a great impact on the natural environment. Lina et al. [1] found that approximately

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2.36 billion tons of CW were produced each year, which is about 40% of the total urban waste generation. The landfill of CW causes a huge waste of land resources, and less than 10% of CW is recycled each year [2]. In order to solve the problems caused by CW, a lot of research has been carried out in the past two decades, the purpose of which is to explore CW management and propose suggestions to reduce CW [2, 3]. The optimization of CW collection and transportation has become one of the main concerns of waste management system design. Due to the hidden traffic safety hazards in waste transportation, a large amount of transportation brings pressure on urban traffic, and irregular operations seriously endanger traffic safety [4]. Therefore, optimizing waste transportation management is one of the key issues for effective waste management.

In recent years, many models have been developed to optimize the collection and transportation of the entire garbage truck network. Das et al. [5] proposed a heuristic method to solve the optimal problem of waste collection and transportation, which calculated the optimal path for each stage. Parkitny et al. [6] proposed the possibility of a logical solution of a mixed waste management system and a separate waste management system, trying to optimize the transportation of various wastes from their sources and collections to recycling and storage locations. However, they don't consider the dynamic changes of the supply chain network in the process of transportation, and the complexity of the logistics problem has not been solved. The transportation of CW involves construction sites, landfills and resource treatment plants. When the construction site waste reaches a certain amount, it will be transported to the landfill site or the resource treatment plant after sorting. There are subject decision-making problems in how to choose transportation location and transportation route. In order to solve the complex dynamic problems in the transportation supply chain, a whole method is needed to model and analyze the coordination in the dynamic backfilling supply chain.

In recent years, it has been found that agent-based simulation provides a good method for analyzing complex logistics operation [7], and multi-agent system is more suitable for microscopic traffic network simulation [8]. ABM is considered to be the most typical distributed method of analyzing supply chain performance. ABM is a typical computing model used to simulate the behavior and interaction of autonomous entities (individuals and collective entities, such as organizations or groups) [9]. Since the concept of ABM was proposed, it has been defined as an emerging technology in which many agents interact with other agents to achieve the design goals given by model developers [10]. For example, Van Groningen et al. [11] combined the logistics process analysis tool (LPAT) based on ABM and discrete event simulation (DES) technology to improve logistics analysis. Akanle and Zhang [12] proposed an agent-based framework to optimize the configuration of the supply chain to cope with uncertain customer needs. Kiomjian et al. [13] proposed an ABM, evaluating the impact of team dynamics on construction site quality, and the model developed focuses on the interaction between team dynamics and workers. ABM can reveal the influence of agent diversity on the dynamic behavior of the system [14].

Top-down based on agent modeling considers a single agent in the system, each agent has spatiality, mobility and adaptability, and multiple agents can show emergence phenomena, thereby reflecting the regularity of the entire system [15, 16]. However, a single simulation approach can not provide visual feedback on agent actions, and the simulation model in GIS can solve this problem [8].

In recent decades, with the rapid development of spatial surveying and mapping technology and computer graphics theory, GIS has been widely concerned and applied by researchers. GIS is capable of storing, retrieving, analyzing, and applying large amounts of data and visualizing the longitudinal output [17]. For example, Ebistu and Minale [18] proposed that GIS and remote sensing technologies can be used to select a suitable solid waste dumping site for the town of Bahir Dar. Irfan et al. [19] conducted a survey of historic landfills along the Welsh coast based on GIS and identified coastal erosion in Wales in the next 100 years through GIS analysis. Nguyen et al. [20] proposed a dynamic optimization algorithm for transport network routing based on GIS, and applied the algorithm to the simulation of Hanoi traffic system in Vietnam. However, traffic flow is dynamic and affected by many factors, such as time, behavior of traffic participants and weather conditions [5]. In order to solve the spatiotemporal problem of waste transportation, an agent-based simulation model is proposed in GIS environment in this paper. Studies have shown that the problem of traffic changing with time was solved based on the ABM [5], and GIS responds to time output visualization. As a result, the combination of GIS and multi-agent modeling and simulation complements, enriching the transportation optimization program [21].

The above method is applied to the transportation system of on-going residential projects in Shenzhen in 2019, and a system management model is established for the waste generated in the GIS environment. The transportation management of CW is simulated under the benchmark policy, and optimized according to the latest Shenzhen traffic regulations.

The structure of this paper is organized as follows: In Sect. 2, the research method of this paper is introduced and the research framework of ABM and GIS model is built. Section 3 takes the Shenzhen market as an example to conduct a case study, introducing the optimization concept and the waste transportation system used in the simulation model. In Sect. 4, the paper is summarized and suggestions for future work are put forward.

2 Material and Methods

2.1 Transportation System

The disposal of municipal solid waste generally has a specified transportation route, that is, a single transportation of garbage will go to multiple designated locations for collection, and finally be delivered to a landfill [8]. Different from the disposal of household garbage, CW is generally transported directly from the construction site to the disposal site. In the process of transportation, the waste received from multiple sites is not considered. In this study, two situations are considered: (1) the CW generated in the construction project is transported to the landfill after sorting; (2) the CW generated in the construction project can not be directly used but can be recycled by the resource treatment plant after sorting. According to the latest regulations by Shenzhen government, vehicles transporting CW are required to have specific transportation routes and time constraint in order to reduce transportation safety hazards. Therefore, the original routes in Shenzhen are sorted out, that is, the routes prohibited for CW transportation vehicles by government are removed accordingly in ArcGIS, and the candidate roads that allow vehicles to run are sorted out.

2.2 Agent-Based Modeling (ABM)

ABM can implement the transportation optimization plan in the dynamic environment [8]. In many cases, by providing a model close to the real world, ABM can provide a natural description of the processes within the considered adaptive system [22] by modeling human social and organizational behavior and personal decision-making [23]. Therefore, integrating the static GIS route with the agent simulation model can reflect the real world situation. In the model, six kinds of agents are developed: Project Agent, Constructor Agent, Landfill Agent, Recycle Agent, Transport Agent, Vehicle Agent, Evaluation Agent, as shown in Fig. 1.

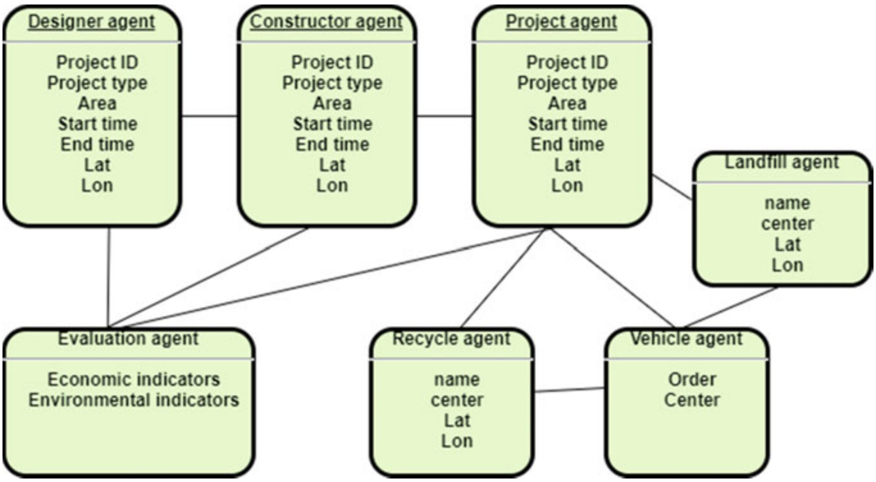


Fig. 1 Modelling of agent

2.2.1 Project Agent

The Project Agent represents the source of CW, that is, the departure point of transport vehicles. Project Agent calculates the theoretical production and actual production of waste, and determines the start and completion time of the project. The project data were collected from the Chollima website [24], and covered project indexing number, building area, start time, completion time and project location. After obtaining the project data, a residential project is located through Baidu Map and Google Map to collect its location coordinates.

2.2.2 Constructor Agent

There is an one-to-one correspondence between Contractor Agent and Project Agent. Contractor behaviors will affect the CW generation. A contractor's task is to make the quality, duration and cost of the project satisfy all requirements, and strive for the best economic and environmental effects of CWM. Different kinds of subjects will influence each other. In the Contractor Agent, carry out source reduction construction management, classification and sorting management, and whether to carry out illegal dumping management.

2.2.3 Designer Agent

There is also a one-to-one correspondence between the Design agent and the Project. The main purpose of Design Agent is to judge whether to improve the application level of green design and the degree of reduction of CW. The behavior of Agent also has a certain influence on the production of waste. When the construction project adopts reasonable and economical design, the CW will be reduced accordingly. For different design subjects, they also influence each other.

2.2.4 Landfill Agent and Recycle Agent

Landfill Agent represents the transport destination of unusable CW, while resource treatment plant Agent is the transport destination of CW that can not be directly used but can be disposed of, both of which are the end point of transport vehicles. In order to simplify the model, suppose that the transport truck departs from the resource treatment plant or landfill, receives instructions from the construction project, and then drives to the waste generation site, and finally returns to the original site. The whole process of transportation is simulated by DES in landfills and resource treatment plants. The information of existing landfills and resource treatment plants all come from the data open platform of Shenzhen Government [25]. The coordinate information of the landfill site and the resource treatment plant is obtained in the same way as the coordinate location of the projects.

2.2.5 Vehicle Agent

Vehicle Agent represents a transport vehicle for the transfer of CW from a construction site (that is, a construction project) to a landfill or resource treatment plant. The agent is basically the same as the transport agent in terms of attributes and movement behavior. In addition, it also has some attributes specific to waste transportation vehicles:

Full capacity: This attribute means that it can store the largest capacity of CW.

Order: The agent receives the message from which new project, that is, obtains the transportation request from the nearest project according to the relevant editing instruction.

The transportation attributes of the transportation vehicles are shown in Fig. 2. These behaviors make the established model dynamic and different from other models. Calculate the environmental and economic impacts of waste in the assessment of Agent.

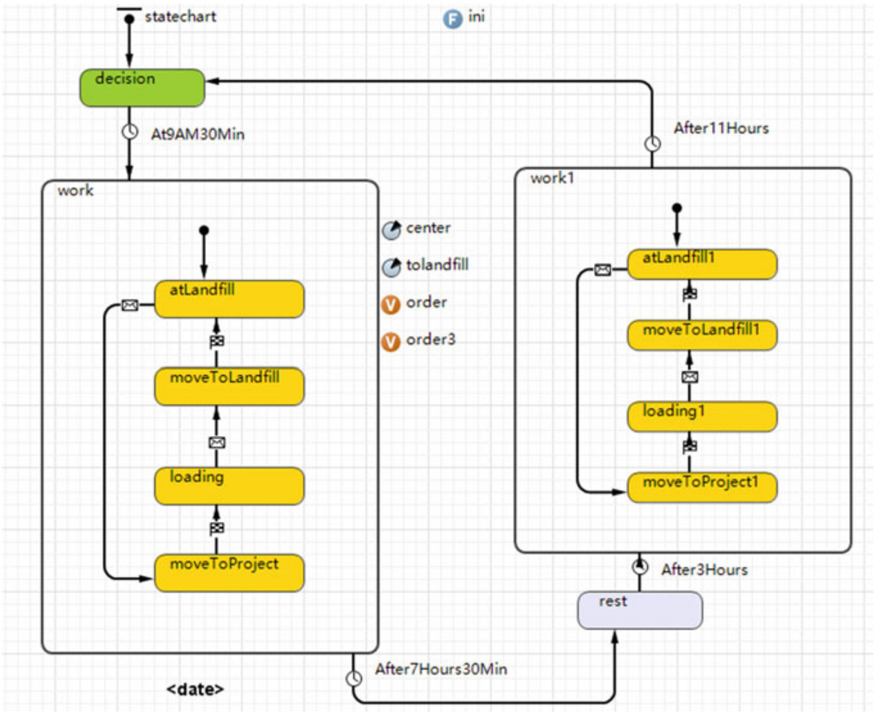


Fig. 2 The behavior of the vehicle agent

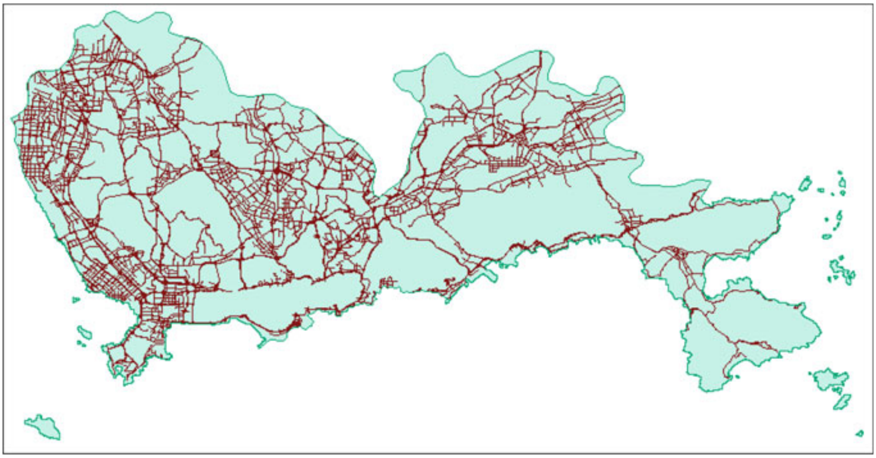


Fig. 3 The road network of Shenzhen

2.2.6 Evaluation Agent

The task of evaluating Agent is to be responsible for the environmental assessment and economic evaluation of the integrated management of CW.

2.3 Establishment of GIS Database

According to the relevant regulations of Shenzhen, the transportation of CW must be driven on designated roads and times, so it is necessary to tailor the road network in Shenzhen. The Shenzhen road network is downloaded from the OpenStreet website, and then the downloaded road network is converted into shapefile and integrated in QGIS. Cut the integrated road network in ArcMap, and the organized road network is shown in Fig. 3. Create a project in the AnyLogic environment, load the map of Shenzhen, and import the organized GIS data into the simulation model. Load landfill and resource treatment plant information through Database to locate them (see Fig. 4).

2.4 Simulation Platform

After building the relevant agents of CWM and the GIS model, we began to build a transportation simulation platform, and the general flow chart of the study is shown in Fig. 5. Our simulation of CW collection and transportation is implemented in AnyLogic 8.5.0. AnyLogic is an original simulation software, which is based

	name	longitude	latitude
1	Longgang District Pinghu bainikeng constructio...	114.158	22.656
2	Shenzhen Jinrui building materials Co., Ltd	114.38	22.768
3	Longgang District Pinghu bainikeng constructio...	114.325	22.776
4	Junlong environmental protection construction ...	114.24	22.621
5	Longgang District Pingdi Liulian construction wa...	114.33	22.789
6	Xiufeng sand field (Shenzhen Yujie Environmenta...	114.113	22.646
7	Shenzhen lvfa Pengcheng Environmental Protect...	114.341	22.776
8	Huili Debang construction waste comprehensive...	113.791	22.678
9	Shajing renewable resources processing center	113.856	22.726
10	Shenzhen heshunju building materials Co., Ltd	114.448	22.645
11	Shenzhen shenjiayuan Environmental Protection ...	113.856	22.565
12	Shenzhen Lvjing environmental protection and r...	113.995	22.737
13	Nanbu waste soil treatment plant	114.381	22.707
14	Comprehensive utilization project of constructio...	114.359	22.763
15	Junpeng building materials sand and gravel field,...	114.517	22.599

Fig. 4 Coordinate information of resource treatment plant

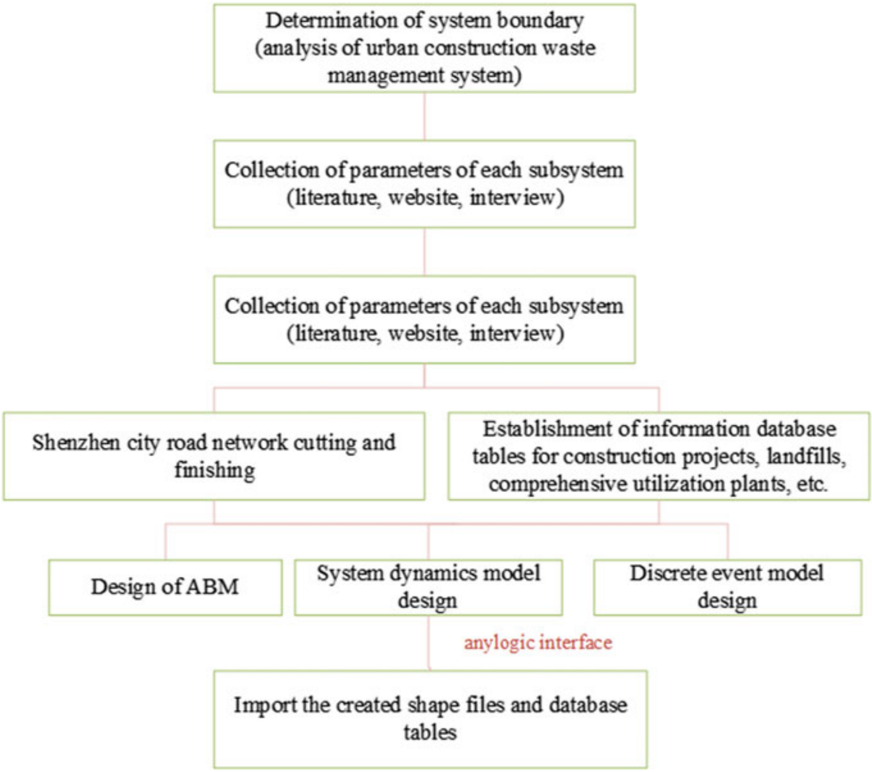


Fig. 5 Research flow chart

on the latest complex system design methodology. It is the first tool to introduce UML into the field of model simulation, and the only software that supports hybrid state machines, which can effectively describe discrete and continuous behaviors. AnyLogic can create visual tools for real dynamic models, that is, dynamic models with dynamic development structure and interconnection between components can quickly build complex interactive dynamic simulation in a modular way.

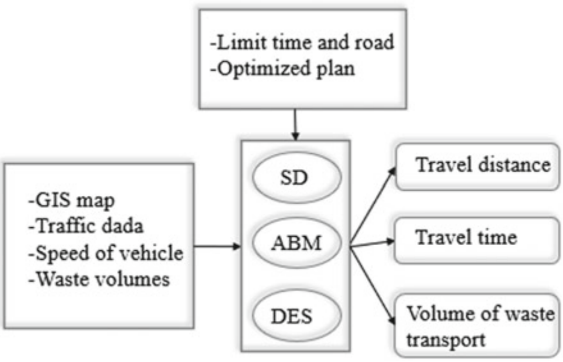
3 Model Development

This paper takes the new project in Shenzhen in 2019 as an example to carry out the simulation study on the transportation of CW. Different from the collection of domestic waste, the transportation of CW generally does not consider the transfer problem, that is, the lowest transportation cost only requires the shortest distance between the construction site and the landfill or the resource treatment plant.

3.1 Research on Shenzhen Route Optimization

Firstly, we apply the contents of Sect. 2 to the optimization model, as shown in Fig. 6. The transport truck used in this study is a medium-sized truck. According to the regulations of Shenzhen Transportation Bureau, the total weight of three-axle trucks (taking the middle value, about 10 tonnes from weight) shall not exceed 25 tons. So suppose the transport vehicle is loaded with 15 tonnes at a time. In the process of the production and production of CW, in order to avoid the long waiting time of the transport vehicle, the truck starts to start when the waste reaches a certain transport volume. This is done through the function “for (Project project: projects)/project.set_tolandfill (project.getNearestAgentByRoute (landfills));”. This function means that during the construction of the project, when the amount of

Fig. 6 Application of the model at ShenZhen city



waste reaches a specified amount, the construction site is assigned to the nearest landfill nearby. In this way, the transportation distance is the shortest, that is, the transportation cost is the lowest. In order to make the landfill receive the instructions from the construction project, the function: "if (waste > = 15) {Order order = new Order (15 this); send (order, tolandfill);} else if (waste > 0&&LastTime = = 0) {Order order = new Order (15 this); send (order, tolandfill);} else {Order order = new Order (1 this); send (order, out);}" is completed. The function means that when the amount of waste produced at the construction site reaches 15 tonnes, 15 tonnes of CW will be removed from the nearby landfill after receiving the instruction. If the waste does not reach the corresponding amount, the instruction will be received by the space intelligence body. The function to go to the resource treatment plant is the same as above. Since there are some difficulties in processing and transporting to two different wastes in the same agent, when processing the wastes transported to the resource treatment plant, another agent Project1 is established to represent the starting point of the transport to the resource treatment plant. The Project1 here has no practical meaning, and the data information is consistent with Project Agent, which is equivalent to a copy of Project Agent.

According to Shenzhen latest regulations on the restriction of dump trucks in 2020, there are four time periods to restrict the driving of dump trucks: 0:00 to 24:00, 7 a.m. to 22:00 p.m., and 7 a.m. to 9:30 a.m. And from 17 to 20 p.m., and from 7 a.m. to 9:30 a.m. All the regional routes that are restricted from 0 o'clock to 24:00 are cut, while the other three regional routes are treated separately. Since it is impossible to prohibit trucks from driving in a certain period of time when the route exists on the map, all the routes that are prohibited from passing between 7 o'clock and 22:00 are cut. For the reservation of the routes in the other two time periods, the simulation model limits the trucks to only transport waste at times other than 7 a.m. to 9:30 and 17:00 to 20:00. The CW generated by the construction project will be transported to the landfill site and the resource treatment plant respectively. Therefore, it is assumed that the two waste transport systems are independent of each other. In the simulation model, two types of trucks are set up. According to Shenzhen regulations on the driving of dump trucks: the maximum speed limit on expressways is 80 km per hour, the maximum speed limit on expressways is 60 km per hour, and the maximum speed limit on roads in other cities is 40 km per hour. To simplify the model, the speed of the truck is set to 40 km per hour. The established truck running model is shown in Fig. 2.

After setting the relevant attributes of the transport vehicle, start the road network-related settings. According to the imported GIS route, first convert the GIS space mark to form a GIS network map. Since the default driving route of the car is the online map provided in Anylogic, the driving network map of the car needs to be converted. First, set the vehicle resource library at the starting point of the trolley. When a certain condition is reached, the trolley starts to transport. At this time, the trolley is dispatched from a certain resource library. Set the type of trolley to be dispatched in the resource library. Then you need to set it up. Drag the car agent into the Main attribute interface, and then set the agent source of the car in the resource library, then fill in main.vehicles (as shown in Fig. 7a), this code means to schedule

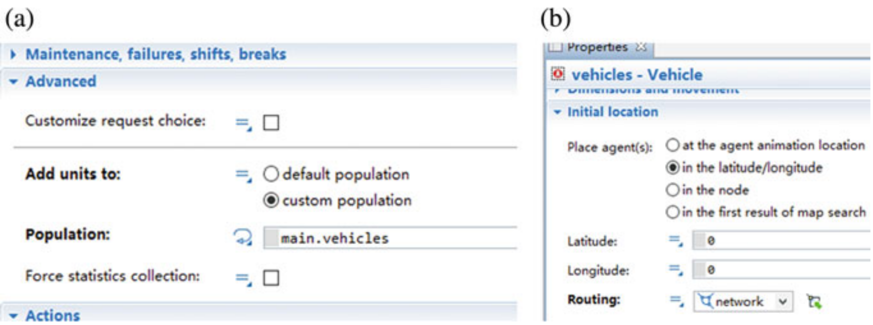


Fig. 7 Spatial tag conversion detail

vehicles of this type of intelligence. Finally, set the route in the agent of vehicles, and select the converted road network in Routing (as shown in Fig. 7b).

3.2 Model Reliability Test

Verifying the validity and rationality of the model is a prerequisite to ensure that the model meets the modeling requirements [23]. In the anylogic software platform, select "Check Model Unit" in the drop-down window of "Tools" to check whether the units in the model function expression are consistent. The inspection results show that the unit of the function expression involved in the simulation model satisfies the dimensional consistency test. Secondly, in order to avoid code errors such as capitalization errors, parameter names spelling errors, and inability to parse related fields, select "Build" in the "Model" drop-down window of the anylogic software platform function bar to check the correctness of the code in the model. After the existing coding problems are solved, the model is constructed. If the "problem" window no longer pops up, it indicates that the model has passed the code writing correctness check.

4 Results and Discussion

4.1 Analysis of CW Transportation Distribution

After completing the model stability test, this study will simulate CW transportation management under the benchmark policy. After the model is successfully constructed, experiment with the simulation model. The 51 new residential projects planned to start in Shenzhen in 2019 will have a theoretical waste generation of 298,234.446 tonnes. Under the benchmark policy, the source reduced

58,060.816 tonnes of waste, actually produced 240,173.631 tonnes of waste, collected 144,104.178 tonnes of waste, and illegally dumped 94,507.714 tonnes of waste, transporting a total of 228,427.321 tonnes of CW. Figure 8 shows the various components of waste after sorting.

Every time the waste is transported to the nearest landfill or resource utilization plant, it is mentioned earlier that it can be achieved by writing the corresponding code. Figure 9 is the map after operation, where the blue graphics represent construction projects, the red shape graphics represent the resource treatment plant, and the yellow graphics represent the landfill. In this section, through the simulation experiment under the benchmark policy, the following simulation results are obtained:

(1) Scenario 1: Using real data

Take the actual data of Shenzhen collection, transportation, planning and other aspects as input. Then the output of the simulation model is verified with the actual data. It is assumed that the truck transporting the waste from the landfill is vehicle No. 1, and the truck transported to the resource treatment plant is vehicle No. 2. As shown in Fig. 10, the red line represents the cumulative transportation time of truck No. 1 and the maroon line represents the cumulative transportation time of truck No. 2. It can be seen that the transportation time of truck No. 1 is longer than that of truck No. 2 at any time in Fig. 10. That is to say, the transportation mileage of car No. 1 is more than that of car No. 2, and more wastes are produced in the early stage of construction. The actual transportation volume of truck No. 1 and truck No. 2 is shown in Fig. 11. The total waste transportation volume of truck No. 1 is 77339.28 tonnes, and the total waste transportation volume of truck No. 2 is 14963.90 tonnes.

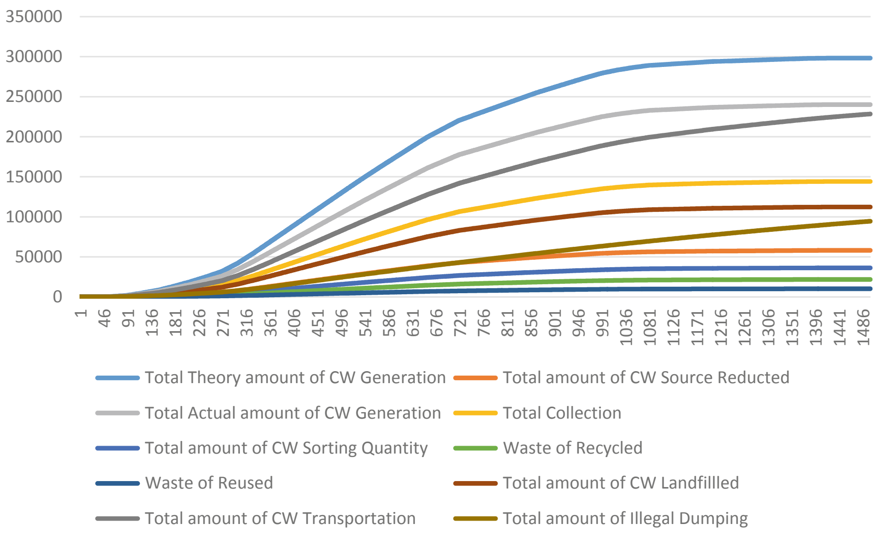


Fig. 8 Waste generation

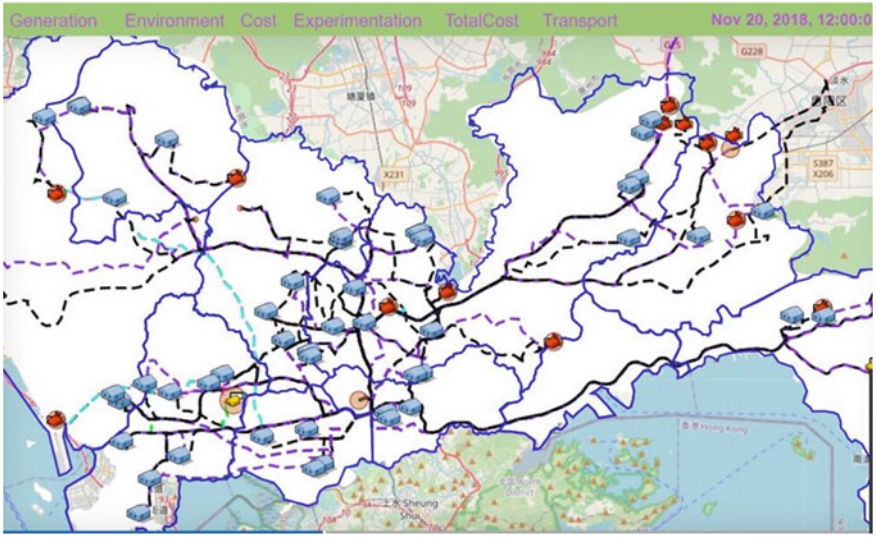
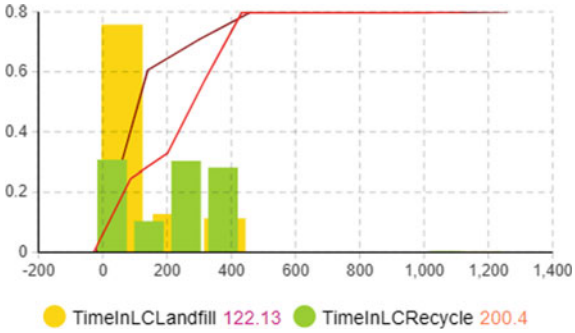


Fig. 9 Map after running model

Fig. 10 Vehicle transportation time statistics chart



Among them, the average total amount of waste transported to the “Xinwewei waste soil receiving yard” landfill is 62154.25 tonnes, and the average total amount of waste transported to the “ROC in the sand” landfill is 15185.03 tonnes, while the other two landfills in Longgang District have not received any waste. For the resource treatment plant, the waste transported to the “Xiufeng sand filed” resource treatment plant is the largest, with 3730.60 tonnes; the second is “Shenzhen shenjiayuan” resource treatment plant, which receives a total of 3290.69 tonnes of waste; there are five resource treatment plants that have not received any waste. Figure 12 shows the amount of waste received in each landfill and resource treatment plant. All vehicles shall be transported at other times from 7 a.m. to 9:30 a.m. and from 17:00 to 20 a.m. The average driving distance of truck No. 1 is 249378.51 km, and the average driving distance of truck No. 2 is 32710.87 km. The maximum speed of each vehicle

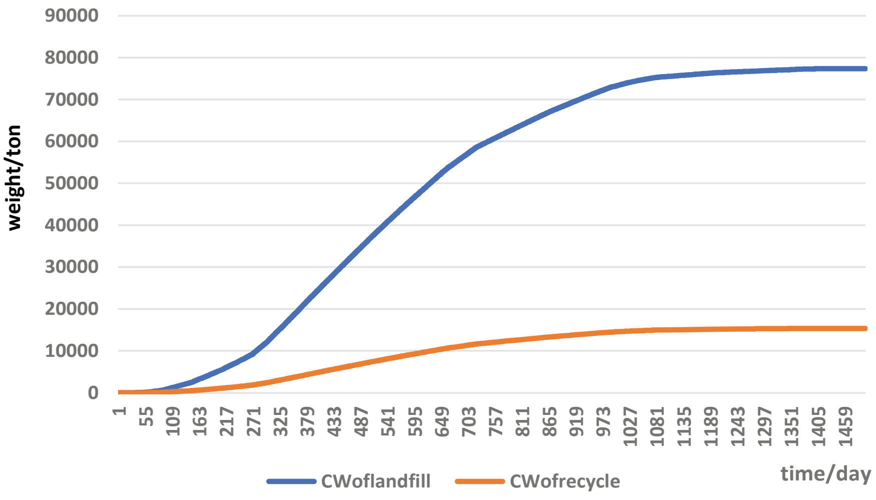


Fig. 11 Construction waste transportation volume

is 40 km per hour. In the absence of GIS data, the cost of waste transportation is 6146980.7 yuan (approx. USD 922,047), including 5,413,749.60 yuan (approx. USD 812,062) to landfill and 1,139,751.375 yuan (approx. USD 170,962) to the resource treatment plant. However, the transportation cost of waste using the combination of hybrid simulation model and GIS data is 7404846.19 yuan (approx. USD 1,110,726), of which the cost to landfill is 6546185.78 yuan (approx. USD 981,927) and that to resource treatment plant is 858660.41 yuan. The transportation time of the optimized model is 7052.23 h, which is quite different from the original transportation time.

(2) Scenario 2: Optimization plan with real input parameters

In this scenario, the steps in Fig. 7 are used to obtain an optimized plan in order to place the plan in a dynamic simulation model. Other input parameters are similar to this method.

4.2 Analysis of CW Transportation Routes

Take the operation results of two projects as an example. The newly-built project with the project number "150,381,513" will be transported to the landfill after the optimized route is "Shangchuan Road-Xin'an 3rd Road-Xin'an 2nd Road-Honglang South Road-Dabao" Road-Beijing-Hong Kong-Macao Expressway-Nanhai Avenue-Beihuan Avenue auxiliary road-Beihuan Avenue auxiliary road-Beihuan Avenue auxiliary road-Nanping Expressway" (see Fig. 13a), and finally arrived at Xinwuwei Landfill; the route to the resource treatment plant is "Shangchuan Road-Xin'an 4th Road-Xin'an 5th Road-Xin'an 6th Road-Xingye Road-Chandao Road" finally

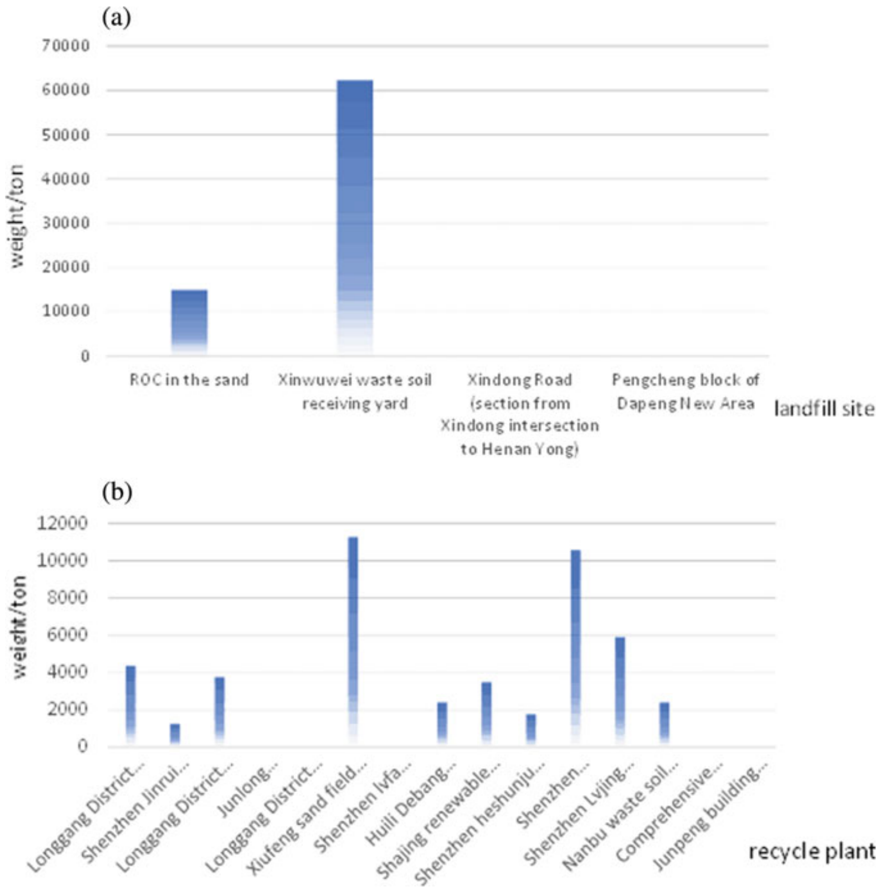
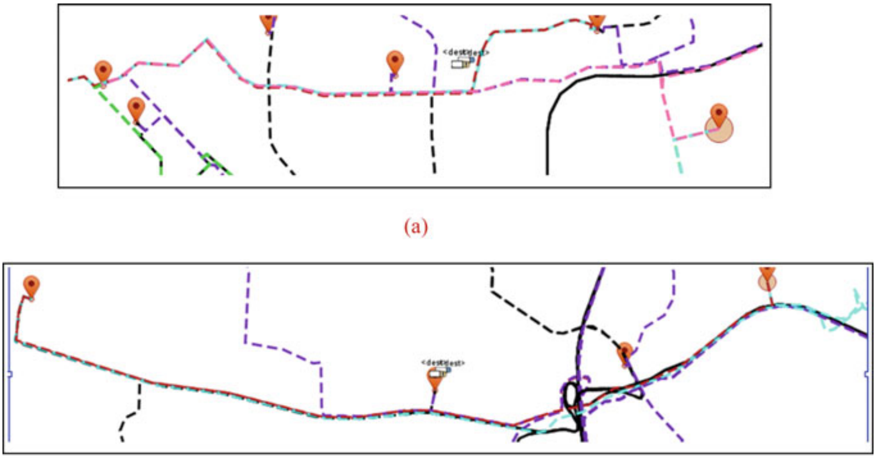


Fig. 12 **a** Waste receiving volume of each landfill site. **b** Waste receiving volume of each resource treatment plant

arrived at Shenzhen Shenjiayuan Environmental Technology Resource Treatment Plant. Another new project with the project number "153,093,714", after optimizing the route, the route to the landfill plant is "Guangqiao Road-Xinyu Road", and finally to the Shajing Renewable Resources Treatment Center; the route to the resource treatment plant is "Guangqiao Road-Songbai Road-Shiyan Beihuan Road-Shiguan Road-Fulong Road-Beihuan Avenue-Beihuan Avenue Auxiliary Road-Shenyun Interchange Qiao-Nanping Expressway-Tanglang Mountain Tunnel" (see Fig. 13b), finally arrived at Xinwuwei landfill.

Therefore, the transportation results of the simulation model not based on the actual traffic conditions have relatively large errors. The introduction of GIS data and the transportation simulation results of the actual traffic routes in Shenzhen are more realistic.



(a)

(b)

Fig. 13 Optimized transportation route map of a project

As discussed above, compared with the previous waste transportation planning, this study is more realistic for waste transportation management. According to Shenzhen's existing traffic and transportation regulations, the management of CW transportation is researched. Transportation makes CW transportation more practical and gives construction units more valuable waste transportation costs. Moreover, through simulation model research, the total amount of waste received by each landfill can be obtained, which also provides early warning for the remaining capacity of the landfill. In the model, the total amount of waste received by each resource treatment plant can also be obtained, which provides a reference for the market of the resource treatment plant.

In general, according to the results obtained, Shenzhen currently produces a large amount of waste, and the transportation of waste has potential safety hazards. Optimizing waste transportation according to traffic regulations is a very critical issue. In the process of collection and transportation of CW, the optimization results obtained only by mathematical calculation are very different in practical application. Because it depends on many factors, such as the transportation network.

5 Conclusions and Discussions

This study proposes an optimization model for the collection and transportation of CW. First of all, according to the relevant truck driving regulations of Shenzhen, the road network of Shenzhen is cut and arranged in ArcMap. Then a transportation simulation model is established by integrating GIS and SD, ABM, and DES hybrid methods to optimize the transportation of CW in Shenzhen. This method is more realistic for the simulation of waste transportation, and the simulation results are closer to the real situation. Experimental results show:

1. It is feasible to integrate the simulation model of SD, ABM, DES and GIS, and the simulation time efficiency cost is lower
2. Hybrid simulation model can intuitively display the change process of waste transportation
3. When considering the dynamic environment, the integrated model is more effective than the GIS analysis method.

Simulation results show that this method can effectively provide regular path planning for waste transportation, and follow the transportation roads stipulated by the traffic regulations of Shenzhen. The solution proposed in this study is an effective system to solve the actual CW transportation. Based on the mixed simulation experiment of GIS and ABM, it can truly visualize the CW transportation route, which also provides a certain reference for the contractor in the waste transportation planning. This research can also provide planning and warning for the corresponding landfill capacity for CW transportation. However, this study also has some limitations, traffic conditions are not taken into account in the process of CW transportation, because there may be speed limits on each road, and different types of roads may have different speed limits. In this study, the reasons for setting driving due to technical reasons are all 40 km/h. This condition can be taken into account in the future. In order to further carry out real-time monitoring of CW transportation, the capacity monitoring of landfills can be explored in the future, and the whole process of waste disposal to landfill has been monitored, which provides some reference for follow-up CWM research.

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The Perceived Value Scale Development for Recycled C&D Waste Products

Wanqi Nie and Zhikun Ding

Abstract The issue of construction and demolition (C&D) waste is getting more and more serious with the rapid development of urbanization in China. Recycled C&D waste products are applied widely by stakeholders as one of effective ways to solve the problem. At present, the promotion of recycled products is facing heavy barriers, while the future market for recycled products largely depends upon stakeholders' perceived value. But few studies focus on constructing scales to measure stakeholders' perceived value of recycled products. To fill this gap, this paper develops a three-dimensional perceived value scale including social value, economic value and environmental value. A questionnaire survey was conducted to collect data from Shenzhen, China. In total, 129 valid questionnaires were divided into two samples with which an exploratory factor analysis and a confirmatory factor analysis were conducted respectively to verify the scale validity and reliability. Results showed that the developed scale has sound reliability and validity. The developed scale provides a new instrument for future construction and demolition waste management research.

Keywords Perceived value scale · Construction and demolition waste · Recycled products · Factor analysis

1 Introduction

In recent years, the continuous development of society and economy has led to a higher urbanization rate in China, which has also driven the rapid development of the

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construction industry. At the same time, a large number of new construction, expansion, reconstruction and demolition activities renew cities, and also generate huge construction and demolition waste [1]. A large amount of construction and demolition (C&D) waste not only occupies land resources, but also consumes natural resources and non-renewable resources. Besides, the improper disposal of C&D waste that also pollutes water and air quality [2]. The generation of C&D waste has brought a huge negative impact on the environment, therefore, disposing C&D waste has become a global urgent issue to be solved [2]. At present, with the increasing concern about resource and environment issues, there are some C&D waste disposal methods have been proposed. The most environmentally friendly waste disposal method is recycling i.e. processing C&D waste into recycled products. This measure is one of the most important treatment methods for construction waste management, greatly alleviates the issues of land shortage and air pollution caused by landfilling and further reduces the consumption of natural resources. However, currently, the supply chain development of recycled C&D waste products is not mature, and it is unusual to use large number of recycled products in construction projects. Most stakeholders are unwilling to use recycled products in construction projects, so the market demand becomes the biggest obstacle in the supply chain of recycled C&D waste products [3]. The customers' purchase behavior of recycled C&D waste products is a hot issue that needs to be analyzed, understanding customers' purchase intention is an effective measure to improve the acceptance of recycled products.

Many scholars at home and abroad indicated that the perceived value has been identified as one of the most important factors for gaining competitive edge [4]. Perceived value is an important determinant indicator toward customer purchase behavior which can evaluate the value of the product from the customers' view. The higher customer perceived value shows customer can perceived higher value from products' utility, the more satisfied the customer is with the product, the more willing he is to buy it. This is "value-driven", which is one of the most recognized statements by scholars. That means that managers need to understand what customers' value and where they should pay more attention to satisfy the needs, then get market place advantage in the long term. The fundamental conception of perceived value was developed by Zeithaml [5]. Currently, Zeithaml's definition of perceived value is also the most widely cited. Within this definition, perceived value is "the consumer's over assessment of the utility of a product based on perceptions of what is received and what is given" [6]. In the other word, perceived value is trade-off between "get" and "give". In her studies, quality and price were view as two value dimensions to evaluate consumer perceived value, however, she found different value dimensions play different roles in different customers' purchase decisions. For example, some customers think that low price represents high perceived value, while some customers take quality as the leading factor in perceived value or some may balance price and quality. The weight of each value dimension in different customers' purchase decision is different. In addition, scholars have found that customers' perceived value are affected by all relevant "get" and "give", and more and more scholars also proposed that the trade-off quality and price is too simplistic, thus gradually deriving a more complex and comprehensive value compositions.

The past decades, the concept of customer perceived value had been wildly used into marketing research in many fields [7–9]. Customer perceived value can help product manufacturers to improve products' value and gain customers' recognition according to customers' feelings, thus effectively enhancing the market competitiveness of products. However, customer perceived value is an abstract concept, researchers cannot directly estimate products or services' customer perceived value. Some literature provided the value measurement method of customer perceived value of generic products or services, but few articles researched the measurement tool of customer perceived value of recycled C&D waste products. This is a gap of past researches in the field of recycled C&D waste products. Therefore, considering the differences in customer value demands of different products, this study constructed a measurement scale of recycled C&D waste products' customer perceived value according to the characteristics of recycled products, to provide enlightenment for future researches on the market development of recycled C&D waste products.

2 The Multidimensional Perceived Value

This section introduces the development and definition of the concept of customer perceived value, defines three value dimensions of perceived value, and determines an initial three-dimensional perceived value scale of recycled C&D waste products in combination with existing literature.

2.1 The Development of Perceived Value

The multidimensional value compositions of the customer perceived value lead to further discussions on how to choose different scales for measuring perceived value. This issue has been widely discussed in previous literature of many fields. Zeithaml described in her study that quality, price (monetary and non-monetary), reputation of the product or service and emotional response were value dimensions of perceived value [6]. Sweeney and Soutar developed a multiple items scale to measure consumer perceived value, in this study, emotional value, social value and functional value (include price and quality) were view as four value dimensions of perceived value [10]. Petrick constructed the perceived value scale of intangible products (services), considering behavior price, monetary price, emotional properties of services [5]. It is observed that the concept of perceived value was recognized by more scholars and cited into market research in various fields. The original products here were also divided into various types of goods in detail.

Pandža Bajs analyzed the perceived value of the quality of touristic services from multidimensional value, namely, destination appearance, emotional experience, reputation, monetary costs and non-monetary costs [11]. Peng et al. discussed the perceived value of social E-commerce sales promotion, and the research points out that price value, functional value, emotional value and social value constitute the customer perceived value [12]. In Yu's research, perceived value was cited to research the users' acceptance of media tables, Yu et al. used multidimensional value-scale to measure perceived value, and constructed multi-scale model for perceived value to analyze the influences of perceived usefulness, perceived enjoyment, social image and perceived risk on perceived value [13]. Besides, multidimensional value constructs have been applied in the research of customer perceived value in automobile [8], transportation [14] and information technology [15], etc.

2.2 Conceptual Definition

In the present study, recycled C&D waste products are green products, the promotion of recycled products is consistent with the theme of sustainable development, also contributes to the sustainable development of the construction industry. In the field of sustainable research, He et al. researched the rural households' perceived value of recycling agricultural waste. Improved Zeithaml's perceived value model to explore the key factors influencing rural households' perceived value of recycling agricultural waste [16]. He proposed that perceived value is households' evaluation of the merits of recycling agricultural waste and its ability to meet their needs and expectations in his study. Thus, perceived value was divided into three value dimensions, namely, environmental value, economic value and social value. As for perceived value of recycled C&D waste products, this study defines it is customers' overall consumer assessment of the benefits of using recycled C&D waste products. Besides, the recycled C&D waste product has similar social, economic and environmental benefits to recycled agricultural waste. In sustainability research, social, economic and environmental impacts are the most concerned perspectives, and those value dimensions often were considered in the past literature [17]. In view of this, this study divides the perceived value dimensions of recycled C&D waste products into social value, economic value and environmental value. This is to say customer could measure the perceived value of recycled C&D waste products from these three value dimensions.

Social value (SV): As Sweeney & Soutar' definition [10], Social value (enhancement of social self-concept) has been as the "perceived utility acquired from the product's ability to enhance social self-concept." People may strengthen their social identity and social self-consciousness through the perceived social value as a dimension of perceived value [12]. In this study, social value refers to enhance customers' social self-concept by using recycled C&D waste products.

Economic value (EV1): the raw material of recycled C&D waste products is construction and demolition waste that is cheap or even free [18]. Sometimes, in construction site, reusing C&D waste directly can reduce the transportation and waste disposal costs. In road engineering, some reconstruction projects will greatly reduce the costs if the waste concrete generated from the original road crushing is directly used. Therefore, in this study, economic value refers to the extent to which customers believe that they can obtain economic benefit from using recycled C&D waste products.

Environment value (EV2): The past literature have shown that the use of recycled C&D waste products in construction projects can not only reduce the consumption of natural and nonrenewable resource, but also avoid excessive consumption of land by C&D waste landfill [19, 20]. In addition, waste has not been classified and was always mixed with various kinds of garbage, which will inevitably generate harmful gases and cause air pollution [2]. Therefore, the promotion of recycled products can effectively reduce the environment pollution caused by improper disposal of C&D waste. In this study, environment value is defined as the evaluation and expectation of customer on the role of recycled C&D waste products in protecting ecological environment and land resource.

3 The Scale Development Process

The evidence already discussed shows there are distinct dimensions of perceived value, the present section describes the process of establishing the content of these dimensions and validating the value scale theoretically. The research follows Gilbert & Churchill' method to develop multiple-item perceived value scale [21].

3.1 The Development of Scale Items

After determining the value dimensions of perceived value, this study constructed items toward different perceived value dimensions respectively, referring to the related dimension items in previous research of the perceived value and large number of literatures of recycled C&D waste products. Based on these items, the present study designed a recycled C&D waste products' perceived value questionnaire. In order to ensure the quality of the questions, 10 employees in construction industry participated in the first stage. Respondents, they were all in construction industry, ranging in age from 20 to 40, and 4 of them have more than 6 years of work experience. After filling in the questionnaire, the researcher asked each respondent' suggestions and some questions needed to be added or modified, and further asked respondents why these questions are important to them in order to better understand the underlying meanings the questions provided since the meanings would be more useful in developing perceived value items. As suggested by the respondents, to made further modifications to areas that were unclear or prone to misunderstanding. Then, construction industry experts were invited to evaluate the items to ensure the items were representative of scale' domains, according to experts' suggestions, some items were deleted and some items' descriptions were modified. As consequence of this exploratory phase, 18 items (8 social value, 5 economic value and 5 environment value items) were retained as initial basis for perceived value scale for further customer perceived value scale of recycled C&D waste products development.

3.2 Data Collection and Item Reduction, Stage One

In order to guarantee validity of the items, this study used an initial quantitative procedure to reduce the number of items and to examine the perceived value scale's psychometric properties, therefore, designed initial questionnaire with the above 18-items to collect relevant data to verify the statistical significance of the scale preliminary. In the questionnaire, 5-point Likert type scale was used to evaluate items of the proposed value dimensions, ranging from strongly disagree 1 to strongly agree 5. At this stage, a pretest was constructed, 99 people was invited from construction industry participated in the questionnaire survey, 88 valid questionnaires retained. Among them are researchers, constructors, real estate developers and designers, balanced between male and female. One-third of them have more than 6 years of work experience.

Exploratory factor analysis with SPSS 24.0 was used to test the reliability and validity of items of scale. In this process, the reliability analysis was carried out separately to items of each value-dimension, the results showed that Cronbach's alphas were greater than 0.8 and Cronbach's alpha of value-dimension after Item Deletion all will be less, which shown that in the pretest phase under each dimension item has good internal consistency, so this process did not remove any item. Then, using principal component analysis and maximum variance rotation method for reducing item dimensions. The result of the rotated component matrix showed that a total 4 factors were extracted from the 18 items, which violated design principle of the scale in this study since the items were designed based on proposed three value dimensions' definition. Theoretically, these items should correspond to the assumed value dimensions. Therefore, following the factor loadings, firstly, overlap of item across dimensions and the items incorrectly corresponding to proposed value dimension were deleted iteratively until the corresponding relationship between retained items and value dimension was consistent with previous hypothesis. Secondly, in this basis, items with factor loadings less than 0.5 were deleted, suggesting these items generated more noise than information. In the end, the result revealed a clear factor pattern, 11 items were retained. SPSS calculated the KMO value and Cronbach's alpha of the three value dimensions consisting of 11 items. The output results showed that KMO value of the 11-item scale is 0.792 (KMO value $\geq$ 0.6 is acceptable), Cronbach's alphas of the three value dimensions ranging from 0.644 to 0.758 (Cronbach's alpha $\geq$ 0.6 is acceptable). It indicated that the 11-item scale provides a basis for the final scale.

3.3 Data Collection and Verification of the 11-Item Scale, Stage Two

At this stage, a clear three-factor structure have been determined, in order to further verify convergent, discriminant and criterion related validity of the scale and ensure the stability of the proposed model, the research designed a formal questionnaire on the perceived value of recycled C&D waste products following 11-item scale to collect data, and investigated the respondents' personal background information. A total of 139 respondents from construction industry in Shenzhen participated in this questionnaire survey, 129 valid questionnaires were retained, among which 101 were employees in construction industry. Most of the respondents have rich work experience, and more 70% of them have worked for above 6 years. Nearly 50% of respondents work for companies with more than 200 employees, and nearly 65% of respondents have involved using recycled C&D waste products in past projects. This indicated most respondents have some knowledge toward recycled C&D waste products. Respondents involved all stakeholders who may use recycled C&D waste products in past or future projects, including real estate developers, government workers, constructors, designers, and researchers. The background information of interviewees is shown in Table 1.

Factor analysis was used to verify the reliability and validity of the scale. SPSS 24.0 and AMOS 25.0 were used for EFA and CFA respectively. In this study, 129 valid questionnaires were divided into two sets. The first group of 64 questionnaires adopted exploratory factor analysis (EFA) to reduce the dimensions of 11 items, and the second group of 65 questionnaires adopted confirmatory factor analysis (CFA) to verify the model structure between the factors (latent variables) and items (observed variables).

In the second stage, exploratory factor analysis used the principal component analysis and maximum variance rotation similar to those used in stage one, the table of rotated component matrix showed that 11 items extracted three factors. However, because the factor loading of SV3 is greater than 0.45 on two factors, therefore, this study removed item-SV3 "Using recycled C&D waste products can improve my social image." A further exploratory factor analysis was undertaken on the 10 items retained that revealed a clear factor pattern. Then, after having established the three dimensions of scale, AMOS 25.0 was used to construct a measurement model for retained items to verify the structural relationship between items (observed variables) and factors (latent variables). According to the modification index of outcomes, in order to ensure the stability and good-fit of the model structure, item-EV13 "Using recycled C&D waste products will reduce waste due to the value of C&D waste." was deleted, and 9 items retained in the end, 3 social items, 3 economic items and 3 environment items. The Table 2 shows results from exploratory factor analysis of the finally 9-item scale. It can be seen that the KMO value of the three dimensions is 0.730 that is a moderate degree and close to a good indicator, indicating that the 9-item customers' perceived value scale of recycled C&D waste products is suitable

Table 1 Demographic information of the respondents

Variable	Category	Frequency	Percentage (%)
Industry category	Construction industry	101	78.3
	Other	28	21.7
Working experience (year)	0–5	26	26
	6–10	18	17.8
	11–15	11	10.9
	16 years or above	46	45.5
Participants	Government departments of construction industry	7	6.9
	Real estate developer	15	14.9
	Designer	38	37.6
	Contractor	14	13.9
	Researcher	7	6.9
	Other	20	19.8
Company ranking	Premium	2	2.0
	Rank 1	61	60.4
	Rank 2	15	14.9
	Rank 3	2	2.0
	Rank 4	1	1
Staff number	1–50	7	6.9
	51–100	5	5
	101–200	9	8.9
	Above 200	46	45.5
Number of project(s) involving recycled materials	0	35	34.7
	1–2	41	40.6
	3–5	15	14.9
	5–10	2	2
	Above 10	8	7.9

for factor analysis. Cronbach's alpha greater than 0.750 indicate good internal consistency of items in each dimension. Table 3 shows the final 9-item scale of recycled C&D waste products' customer perceived value.

Finally, the present study conducted confirmatory factor analysis, constructing a measurement model, as shown in Fig. 1, in which no factor was considered to underlie the observed variables, correlations between observed indicators were zero and the variances of the observed variables were not restricted. During the confirmatory factor analysis, the estimation method used was maximum likelihood. It can be seen from Fig. 1 that all of factor loadings are higher than 0.7, thus, no observed variable need to be deleted, which indicates each observed variable can represent its corresponding dimension.

Table 2 Summary of finally results from exploratory factor analysis-Stage Two

	Item	Factor 1	Factor 2	Factor 3	Cronbach's alpha	KMO
Economic value (EV1)	EV12	0.855	0.012	0.175	0.775	0.730
	EV11	0.828	0.212	−0.018		
	EV14	0.710	0.194	0.296		
Social value (SV)	SV1	−0.021	0.914	0.100	0.866	
	SV2	0.227	0.866	0.220		
	SV4	0.459	0.733	0.244		
Environment value (EV2)	EV21	0.051	0.091	0.886	0.759	
	EV22	0.357	0.161	0.836		
	EV23	0.082	0.204	0.681		
Percentage of variance extracted by the three factors was 75%						

Table 3 The 9-item customer perceived value toward recycled C&D waste products

Construct		Item
Social value (SV)	SV1	Using recycled C&D waste products would make people appreciate me more
	SV2	Using recycled C&D waste products makes me more confident in my social interactions
	SV4	Using recycled C&D waste products makes me more acceptable to others
Economic value (EV1)	EV11	Using recycled C&D waste products can obtain a certain amount of economic income
	EV12	Using recycled C&D waste products can reduce construction costs
	EV14	Recycling and reusing directly the C&D waste on construction site can reduce waste transportation costs
Environment value (EV2)	EV21	Using recycled C&D waste products helps to protect land resource
	EV22	Using recycled C&D waste products helps to improve the climate
	EV23	Recycling and reusing directly the C&D waste on site can improve the environment of construction site

The goodness-of-fit indices of the measurement model are shown in Table 4, the most of the goodness-of-fit indices satisfy their corresponding acceptable requirement that means collected data and constructed measurements model have a good fit, and the three dimensions' perceived value scale of recycled C&D waste were supported by collected data.

The convergent validity and discriminant validity of three-dimension scale are supported from Tables 5 and 6. Table 5 shows that each item' factor loading of perceived social, economic and environment value is greater than 0.7, in addition, the

Fig. 1 Confirmatory factor analysis model of 9-item scale

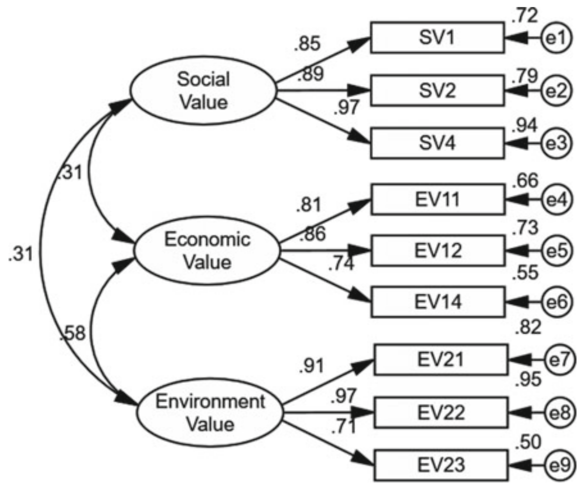

Table 4 Goodness-of-fit of the initial measurement model

Goodness-of-fit measure		Level of acceptance fit	Fit statistics
Absolute fit	λ^2/df	< 5 acceptable; < 3 good	1.231
	GFI	> 0.8 acceptable; > 0.9 good	0.911
	AGFI	> 0.8 acceptable; > 0.9 good	0.833
	RMR	< 0.05acceptable	0.036
	RMSEA	< 0.1 acceptable; < 0.08 good	0.06
Incremental fit	IFI	> 0.9	0.987
	TLI	> 0.9	0.979
	CFI	> 0.9	0.986

Table 5 The convergent validity of three-dimension scale

Path			Estimate	AVE	CR
SV1	<--	Social value (SV)	0.851	0.8184	0.9309
SV2	<--	Social value (SV)	0.89		
SV4	<--	Social value (SV)	0.969		
EV11	<–-	Economic value (EV1)	0.81	0.6465	0.8454
EV12	<--	Economic value (EV1)	0.856		
EV14	<--	Economic value (EV1)	0.742		
EV21	<--	Environment value (EV2)	0.907	0.7567	0.9017
EV22	<--	Environment value (EV2)	0.972		
EV23	<--	Environment value (EV2)	0.709		

Table 6 The discriminant validity of three-dimension scale

	Social value	Economic value	Environment value
Social value	0.8184		
Economic value	0.309*	0.6465	
Environment value	0.315*	0.578***	0.7567
AVE square root	0.905	0.804	0.870

* represents p value less than 0.01, *** represents p value less than 0.001 and the diagonal is average variance extracted (AVE)

average variance extracted (AVE) of each latent variable is greater than 0.6 indicating each item is a good reflection of the underling latent variables it represents (AVE greater than 0.5 is acceptable.) [22], and the composite reliability (CR) is greater than 0.8, the higher CR is, the stronger the internal correlation between the items is, indicating that the convergent validity is ideal. In Table 6, the diagonal data represent the AVE of each construct, the remaining data represent the path coefficients of any pair of constructs and the last row of data represents the square root of the AVE. It can be seen from Table 6. social, economic and environment value have significant correlation ($p < 0.01$), and the correlation between constructs are less than 0.6 and the square root of the AVE, as each has a certain correlation between latent variables, and have a certain degree of differentiation, namely scale data have good discriminant validity [22]. These results support the proposed three-dimension model of customer perceived value toward recycled C&D waste products, comprising the social, economic and environment value dimensions.

4 Conclusion

The concept of consumer perceived value (CPV) is used to measure the utility of a product and is cited widely in the field of marketing. It is an important factor to study customers' purchase decision [11, 23]. Research on consumer perceived value can help recycled C&D waste products manufactures and government to understand the main factors contributing to customer perceived value and how to design future recycled C&D waste products in construction industry can yield higher customer perceived value. According to the existing market research articles and questionnaire data conducted in Shenzhen, this study developed a multiple dimensional consumer perceived value scale with nine items including social, economic and environmental aspects.

The present study extent the knowledge of consumer perceived value toward recycled C&D waste products in construction industry and developed a three-dimensional scale of these constructs to understand and measure consumer perceived value of recycled products. The research result shows that multiple value dimensions can explain consumer purchase behavior better, in both statistically and qualitatively, and produce excellent results when investigating consumption value. The factor structure, reliability and validity analysis indicated that the 9-item perceived value scale of recycled C&D waste products and its three value dimensions have stable structure properties. This scale proved that customers will evaluate the value of recycled C&D waste products through social value, economic value and environmental value. Recognizing the importance of each different value dimension, in formulating more effective marketing strategies, recycled C&D waste products manufacturers and the government should not ignore any value dimension.

According to the research results, there are some suggestions for the future development of recycled products. In recent years, many provinces and cities in China have issued a series of policies related to recycled C&D waste products. At present, the use of recycled products mainly due to the promotion of the government. However, compared with traditional building materials, there are still obstacles in the promotion of recycled products, which also indicates that existing policies are insufficient, and it is urgent to develop a new management idea. To achieve the long-term stability market of the recycled product, improve the subjective initiative of stakeholders is the key. Based on the research results, social value, economic value and environmental value are main aspects of stakeholder' value perspective, the recycled product manufacturers and government departments should improve recycled products based on these aspects, and increase customer's purchase intention, eventually help get recycled product market competitiveness. At present, there are limited channels for stakeholders to understand the recycled products, which directly leads to the stakeholders' low perception of the value of the recycled products. Therefore, in addition to the promotion by the government, product manufacturers should increase their own publicity efforts, strengthen enterprise cooperation, and provide opportunities for consumers to know about recycled products. First of all, the government should strengthen the publicity of ecological protection, and let the public realize that the rapid development of the construction industry has brought huge environmental problems. The existing landfill sites in the city cannot meet the increasing demand for filling of construction waste, and a sharp contradiction has formed between the large amount of waste and the limited filling capacity of the city. Recycled product is an effective measure to solve this problem, using wastes as raw materials. Using recycled products not only alleviate the pressure of waste disposal to the environment, is also reduced the consumption of natural resources. The measure is the least impact on the environment of waste disposal methods at present and the future strategy of the development of construction industry sustainable development is indispensable. Environmental issues are that all of us need to face together, highlighting the social significance of environmental protection and thus enhancing the social value of using recycled products. In terms of economy, on the one hand, the government will increase subsidies for enterprises that use recycled products, encourage enterprises to provide priority for construction projects used recycled products. On the other hand, manufacturers of recycled products should have higher production technology, reduce the price of recycled waste products, improve market competitiveness, and obtain higher market demand. Through the above ways to increase the economic advantages of using recycled products. In conclusion, the improvement of social, environmental and economic values will effectively promote the value awareness and enthusiasm of the recycled products' stakeholders, which will help further promote the process of construction waste management.

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To Reveal the Critical Influencing Factors for Safety Behaviors of Chinese Construction Workers from Stress Management Perspective: A Machine-Learning Approach

Qi Liang and Yuan-yuan Qiu

Abstract It has widely recognized that safety behaviors of construction workers contributed to majority of construction accidents. Given its significance, lot of resources have been inputted to improve safety behaviors of construction workers. However, unsafe behavior seems inevitable. Construction workers are also under excessive occupational stress, because of performing various demanding and repetitive tasks while in shortage of necessary job resources. Previous studies have claimed the relationships between stress and safety for workers from other countries and districts, while there is lack of study for Chinese construction workers. To fill in this research gap, current study aims to apply both traditional statistical methods and machine learning approach to examine the complicated interactions between task stressors, stress and safety behavior for construction workers in Mainland China. After an extensive literature review of relevant knowledge, a conceptual model was proposed to indicate the hypothesized relationships between task stressors, stress and safety behavior for construction workers. A questionnaire survey was administered among around seventy construction workers to collect empirical data. A series of statistical analyses were conducted to confirm the theoretical classification of stressors, stress and safety for construction workers. Decision tree algorithm in supervised machine learning approach was applied to develop model for Stressors–Stress–Safety interactions for construction workers. The results of current study revealed that task stressors can affect the safety of Chinese construction workers, both directly and indirectly through the stressors–stress–safety path. Implications of the findings were discussed and practical recommendations for managing task stressors and stress were made. Current study contributed to reveal the significant effect of task stressors and stress on safety behaviors of Chinese construction workers. The results of current study also support that machine learning method is applicable for studying the health and safety issues of construction workers.

Keywords Decision tree · Machine learning · Occupational stress · Safety behavior · Stressors

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1 Introduction

Statistics shows that there were 634 safety accidents and 735 deaths in construction industry in 2016, 692 safety accidents and 807 deaths in 2017, and 734 safety accidents and 840 deaths in 2018 [1]. It is widely recognized that unsafe behavior is the major contributor of construction accidents [2]. Because of its significance, the safety behaviors have been widely researched from various aspects [3]; while the important effect of occupational stress on safety behavior of construction workers have receive more and more attentions [4]. The demanding characteristics of the construction industry and complexity of construction environment make it inevitable for construction workers to face stressors at work, causing them to excessive stress and in turn harming their safety performance [5]. While stressors were often regarded as the overwhelming external demands faced by construction workers, such as work overload, long working hours and interpersonal conflicts; it is still neglected that the repetitive, monotonous and boring routine tasks may also cause stress to the construction workers, which in turn affect their safety.

Current study aims to examine complicated relationships between task stressors, stress and safety for construction workers by using both traditional statistic methods and machine learning methods. Machine learning, as a subset of artificial intelligence, has been found as a reliable method for the safety research in construction industry [6, 7]. Based on extensive literature review of relevant knowledge about stress, safety and stressors, a questionnaire survey was administered among construction workers to collect quantitative data, which are later subjected to a series of statistical analyses and one machine learning method. The final conclusions were made based on the same results from all analyses.

2 Literature Review

2.1 Construction Business License

Construction industry has long been criticized for its notorious safety records. According to a statistic, the accident rate in construction industry is 3 times that of other industries, while the death rate is 5 times that of other industries [8]. It is widely recognized that safety behavior of construction workers is the major contributor to the accidents. Safety behavior refers to the safety related behaviors of individuals in the organization. According to the work performance theory, safety behavior can be classified into two types, namely safety compliance and safety participation. Safety compliance refers to the core safety activities that individuals need to carry out to maintain workplace safety, including program compliance, wearing safety equipment; safety participation refers to employees' voluntary participation in safety activities, such as participation in safety meetings, formulation of organizational safety plans, and other voluntary behaviors to improve workplace safety [9].

2.2 Occupational Stress

Stress is considered to be a process in which environmental events trigger a series of cognitive and physiological responses that ultimately affect health [10]. In work setting, occupational stress is stimulated by various stressors, which could develop into various health symptoms in the long term [11]. For instance, occupational stress may manifest in human as the feeling of being burned out and strained from work. Occupational stress can impose significant influence on individuals' work performance [12]. Under the influence of occupational stress, the construction workers may exhibit distracted attentions, leading to unconscious neglect of safety working procedures and preventive measures. In addition, it is very likely that the construction workers with the stress symptoms may feel they don't have additional energies to help others for the safety issue, causing to restrain the safety participation.

Hypothesis 1: Occupational stress may lead to safety compliance.
Hypothesis 2: Occupational stress may lead to safety participation.

2.3 Task Stressors

Construction industry is still a labor-intensive and demanding industry, involving amount of construction workers responsible for various construction tasks, such as heavy manual handling of construction materials, mixing concrete, laying bricks, trimming carpentry and so on [13]. While working in the industry, construction worker may face various stressors that are the stimuli of stress. The construction workers are broadly divided into two groups, namely skilled construction workers and general labors. For skilled construction workers, they are only assigned to conduct same tasks according to their specific work trades even at different construction projects (e.g., the carpenters are only assigned to perform carpentry tasks but not to mix concreting or operate equipment). For general labors, they are often assigned to perform various assistant tasks with low level of complexity, such as cleaning construction site, and moving materials [14]. Under such a circumstance, it is likely for the construction workers to encounter task stressors like low level of job complexity, job monotony, job boredom, skill underutilization and perceived overqualification.

Lack of job complexity refers to a repetitive and simple routine task, lack of changes in task-related requirements [15]. Research has found that the level of job complexity could affect the stress and safety of employees. Job monotony is defined as the state in which the task is repetitive and lack of diversity. It is often associated with job boredom that can be described as a relatively low state of arousal and dissatisfaction caused by insufficient stimulation of the work environment [16]. It has been claimed that job boredom, which are contributed by lack of job complexity and job monotony, is associated with many negative outcomes, such as turnover, stress symptoms, and counterproductive work behavior [5].

Skill underutilization refers to a state in which workers cannot make full use of their own technology, resulting in dissatisfaction [17]. In the National Institute for Occupational Safety and Health (NIOSH) General Job Stress Questionnaire, skill underutilization is proposed as a stressor that can elicit acute stress reactions, job dissatisfaction and depression. In addition, skill underutilization should be related to counterproductive work behaviors and safety compliance [18, 19]. Perceived overqualification refers to workers' self-awareness that they have higher qualifications and experience than the requirements of the work they are engaged in [20]. As a kind of job stressor, perceived overqualification means that one cannot make full use of his own skills, which is likely to trigger a lot of negative emotions and counterproductive work behaviors like safety incompliance [21]. Moreover, perceived overqualification has a significant negative impact on organizational citizenship behavior directed by the organization [20].

Hypothesis 3: Task stressors may lead to occupational stress.
Hypothesis 4: Task stressors may directly lead to safety compliance.
Hypothesis 5: Task stressors may directly lead to safety participation.

3 Conceptual Model

Based on above literature review about task stressors, stress and safety of construction workers, a conceptual model has been proposed along with research hypotheses (see Fig. 1). It hypothesizes that (1) five task stressors may directly affect the safety behaviors of the construction workers, including level of job complexity, skill underutilization, job boredom, perceived overqualification and job monotony; and (2) those task stressors can also indirectly affect the safety behaviors of construction workers through the stress–safety path.

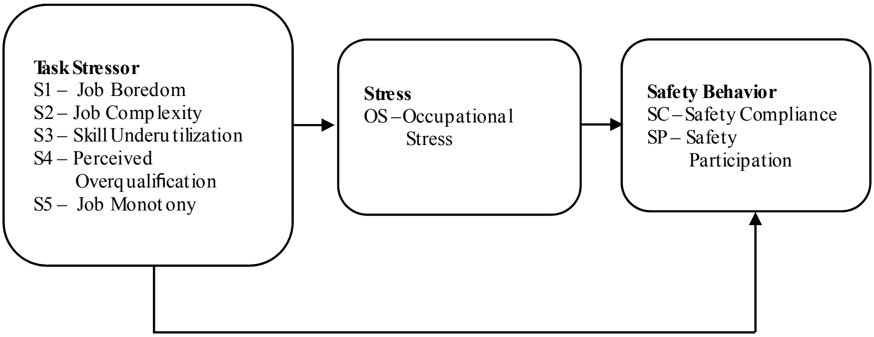

Fig. 1 A conceptual task stressors–stress–safety behavior model for construction workers

4 Research Method

4.1 Overview of Research Design

To reliably examine the effect of the task stressors on occupational stress and safety of construction workers, both traditional statistical methods and machine learning method were used in current study. Based on extensive literature review of relevant knowledge and theories, quantitative data were collected from construction workers through questionnaire survey. Factor analysis and reliability test were carried out to check the factorability and reliability of the stressor factors, stress factors and safety factors; correlation analysis was conducted to identify the direction and strength of the relationships between factors; and decision tree method was applied to develop various tree models. Only the results confirmed by multiple analyses were finally considered.

4.2 Questionnaire Survey

Measurement

A questionnaire survey was conducted to collect quantitative data in order to examine the proposed conceptual model and hypothesized relationships between stressors, stress and safety of front-line construction workers. The questionnaire was designed based on the items extracted from previously validated scale, and it includes: (1) demographic information section (age, gender, education level, etc.): (2) task stressors [22]; (3) occupational stress [23]; and (4) safety behavior [24]. A five-point Likert-type scale, ranging from 1 (strongly disagree/never) to 5 (strongly agree/always), was used by the respondents to indicate their agreement on the statement regarding their stressors, stress and safety behaviors.

Sample

Purposive sampling is used to control the quality of data collection from appropriate respondents based on certain criteria including: (1) all participants should be construction workers working in the construction industry at time of questionnaire survey; (2) all participated construction workers should have specific work trade and work for major organizations in the main construction industry (e.g., client, contractors, and subcontractors); and (3) all participants should have certain work experience. The questionnaires were distributed to construction workers through project managers or project companies between March to May 2020. Of the 120 distributed questionnaires, 70 questionnaires were returned, with one regarded as invalid because of excessive missing information. The final response rate of current study is 57.5%.

In total, 69 construction workers participated in this questionnaire survey. There are 34.8% of respondents aged between 30 and 39 years, followed by 31.9% aged at 40–49 years, 29% aged at 20–29 years, and 4.3% aged over 50 years. Majority of respondents (75.4%) were male, reflecting the male dominance status of this industry. The education level of the participants is generally low, with 34.8% of them attended high school/technical secondary school, 23.2% attended junior high school, and 4.3% attended primary school. As per the work trade of respondents, over 50% of participants are skilled workers (e.g., rebar workers, concrete workers and carpenters). The participated construction workers generally have a rich working experience in the construction industry, with 47.8% of them having 6–10 years working experience, 36.2% having 1–5 years working experience, 11–15 years working experience, 2.9% having 16–20 years and over 21 years working experience respectively.

4.3 Decision Tree Method

Decision tree is a supervised learning method, which can summarize decision rules from a series of data with features and labels, present these rules with the structure of tree graph to solve the classification problem, and determine the predictive power of each variable. As a typical machine learning approach, the decision tree allows for easy understanding and clear explanation of the complex problems in clear hierarchical form [25], which make this method ideal for achieving current research purpose that is to examine the complicated relationship between stressor, stress and safety behavior for construction workers. The algorithm used in this study were primarily derived from Python 3.7.4 (Python Software Foundation 2016) and Scikit-learn library version 0.21.3 on the Anaconda 4.6.8 platform.

The questionnaire was filled by using a five-point Likert-type scale ranging from 5 to 1. To facilitate the application of decision tree technique, it is needed to convert the continuous data into nominal data for of dependent variable (i.e., 0, 1) [26]. For instance, the dependent variable safety participation was classified into two groups depending on its value (i.e., value higher than the mean value was classified as 1, while value lower than mean is classified as 0).

By applying the top-down algorithms, decision trees select independent variable at each level that can predict dependent variable based on splitting criteria like Gini index, entropy, and information gain [27]. The results of decision tree display as a set of hierarchically structured nodes and edges. Each node of the decision tree has certain level of impurity to indicate the potential of split, while lower impurity indicates better fit of the decision tree model [28]. The impurity of the nodes can be reduced substantially by good split. In current study, information gain was used as performance criteria to determine the best split at each level of decision tree in order to minimize impurity and achieve optimal decision tree model [29]. The calculation formula of information gain is listed below Eq. 1 [30]:

$$\text{Information gain} = \sum_{i=1}^{k} p(ci)\log 2p(ci) \quad (1)$$

The data were randomly divided into the training and the test set at a ratio of 8:2, which is fit for the thumb of rules training-test division of machine learning approach [31, 32]. The training set is used to learn the sample data, train and finally establish the optimal decision tree model; while the test set is to examine the performance of the final model by revealing the prediction accuracy [33, 34]. It is confident that this arrangement for training-test set division should ensure predictive performance of the decision tree model [35]. In order to prevent the data from overfitting, the pruning parameters are used to build the decision tree after the model is initially established, and the Grid Search were performed to adjust the parameters [36]. Finally, Graphviz was applied to draw the decision tree models which express the decision rules in the data and display the important variables in hierarchically structured way.

The performance measures for decision tree are mainly derived from the Confucian Matrix which considers two conditions involving four statistics, including true positives (TP), false negatives (FN), false positives (FP), and true negatives (TN). In consideration of the Confusion matrix along with the construction safety issues. Two model evaluation criteria were introduced in current study, Including recall and accuracy. The equation to calculate the two criteria are listed below (see Eqs. 2 and 3) [6].

$$\text{Recall} = \text{TP}/(\text{TP} + \text{FN}) \quad (2)$$

$$\text{Accuracy} = (\text{TP} + \text{TN})/(\text{TP} + \text{FN} + \text{FP} + \text{TN}) \quad (3)$$

5 Results

5.1 Factor Analysis, Reliability Test and Correlation Analysis

Factor analysis with principal component approach was performed to group the large number of items into meaning factors based on the similarity of underlying construct between various items [37]. Factors were extracted based on their eigenvalues (i.e., over 1) [38]. Given the sample size of 69 in current study, items for each factor with factor loading lower than 0.65 should be removed [39]. To examine the reliability of the formed factors, a reliability test was conducted. Factor with Cronbach's alpha value lower than 0.6 is regarded as unacceptable and deleted.

The results of the factor analysis and reliability test are shown in Table 1. It shows that that items of job boredom and job monotony were grouped together to form a new factor named as "job tediousness". The Cronbach's alpha values of all factors

Table 1 Factor loadings and Cronbach's alpha for stressors, stress and safety behavior

Factors	Description	Factor loading	Alpha
S1—Job tediousness	2. My job is monotonous	0.904	0.898
	3. My work is tedious	0.839	
	4. My work pretty much the same day after day	0.830	
	1. My job seems repetitive	0.806	
	5. My job is monotony	0.802	
	6. The job requires doing the same thing over and over	0.666	
S2—Job complexity	8. The tasks on the job are simple and uncomplicated	0.820	0.725
	7. The job requires that I only do one task or activity at a time	0.781	
	9. The job comprises relatively uncomplicated tasks	0.727	
S3—Perceived overqualification	11. My education level is above the education level required by my job	0.778	0.638
	10. I have a lot of knowledge that I do not need in order to do my job	0.764	
	12. I have more abilities than I need in order to do my job	0.637	
S4—Skill underutilization	13. A lot of my work time spent doing tasks that I believe are unnecessary	0.857	0.770
	14. A lot of my work time spent doing tasks that I believe are duplicative	0.761	
	15. My work can be done by someone at a lower level	0.668	
OS—Occupational stress	3. I feel burned out from my work	0.866	0.768
	1. I feel like I am at the end of my rope	0.819	
	2. Working with people all day is really a strain for me	0.795	
SP—Safety participation	4. I express opinions on safety matters even if others disagree	0.908	0.776
	5. I speak up and encourage others to get involved in safety issues	0.818	
SC—Safety compliance	2. I use all necessary safety equipment to do my job	0.919	0.905
	1. I carry out work in a safe manner	0.897	

(continued)

Table 1 (continued)

Factors	Description	Factor loading	Alpha
	3. I ensure highest level of safety when I carry out my job	0.832	

Note All items were measured on a 5-point scale ranging from "disagree strongly" to "agree strongly";
– Kaiser-Meyer-Olkin: 0.824 for *job boredom and job monotony*; 0.674 for *job complexity, perceived overqualification and skill underutilization*; 0.656 for *occupational stress*; and 0.801 for *safety participation and safety compliance*
– % variance explained is 49.54% for *job tediousness*; 38.26% for *job complexity, perceived overqualification and skill underutilization*, 65.96% for *occupational stress*, 80.65% for *safety participation and safety compliance*

are higher than 0.6. In total, factor analysis and reliability confirmed four stressors: job tediousness (S1), job complexity (S2), perceived overqualification (S3), skill underutilization (S4); one stress factor, namely occupational stress (OS); and two safety behaviors factors, including safety participation (SP) and safety compliance (SC).

Correlation analysis was conducted to examine the strength and direction of the pair relationship between two factors [38]. The results of the correlation analysis are presented in Table 2. It shows that occupational stress (OS) is positively related to perceived overqualification (S3: 0.308) and skill underutilization (S4: 0.292). The results of correlation analysis also show that job tediousness (S1: −0.301), perceived overqualification (S3: 0.241) and skill underutilization (S4: −0.404) all have significant correlations with safety participation (SP). Meanwhile, skill underutilization

Table 2 Correlation coefficient between stressors, stress and safety behavior

Factors	S1	S2	S3	S4	OS	SP	SC
S1—Job tediousness	–						
S2—Job complexity	**0.453****	–					
S3—Perceived overqualification	−0.019	−0.037	–				
S4—Skill underutilization	**0.389****	0.210	0.088	–			
OS—Occupational stress	0.074	−0.141	**0.308****	**0.292***	–		
SP—Safety participation	**−0.301***	−0.109	**0.241***	**−0.404****	−0.135	–	
SC—Safety compliance	−0.142	0.050	0.051	**−0.267***	**−0.273***	**0.470****	**–**

**Correlation significant at the 0.01 level (2-tailed)
*Correlation significant at the 0.05 level (2-tailed)

Table 3 Prediction accuracy and ranking of the decision tree model

Decision tress model	Model 1	Model 2
Predictive performance		
Accuracy	0.714	0.786
Recall	0.875	0.800
Ranking		
Job tediousness	2	4
Job complexity	4	–
Perceived overqualification	–	2
Skill underutilization	3	1
Occupational stress	1	3

(S4: −0.267) and occupational stress (OS: −0.273) are both negatively correlated with safety compliance (SC).

5.2 Decision Tree

Two decision tree models were developed according to the proposed conceptual model and hypothesized relationships, including Stressor–Occupational Stress–Safety Compliance tree, and Stressor–Occupational Stress–Safety Participation tree. The predictive performance of the decision tree models is assessed by the criteria recall and accuracy, and the results are shown in Table 3. The safety compliance model has an accuracy value at 0.714 and a recall value at 0.875, while the safety participation mode has an accuracy value at 0.786 and a recall value at 0.800. Both the two criteria for the two models are relatively high, indicating adequate classification performance of the two models [6, 27].

The decision tree model can also display the relationships between dependent variables (i.e., safety compliance or participation) and independent variables (i.e., stressors and stress). Normally, the independent variables at higher level of decision tree model have more influence in classifying the model and in turn predict the dependent variable. In addition, current study determined the ranking of the predicting factors based on its variable importance that is the measure to indicate the importance of specific variables by computing the total reduction of impurity contributed by the variable [28]. The results of the ranking of the predictive factors are also shown in Table 3.

5.2.1 Stressor–Stress–Safety Compliance Decision Tree Model

In the Stressor–Stress–Safety Compliance decision tree model, task stressor and occupational stress were regarded as independent variables (i.e., input values), and safety compliance was regarded as dependent variable (i.e., output values). The result of the decision tree shows in Fig. 2. Result shows that 18% sample with occupational stress more than 3.253 belong to safety incompliance, and 82% sample were from occupational stress less than 3.253 that belong to safety compliance. Breaking down the 82% sample by occupational stress, 26% sample were occupational stress less than 3.253 where job tediousness more than 3.427 contributes to safety incompliance; while 56% sample was from occupational stress less than 3.253 where job tediousness less than 3.427, in which case the category belongs to safety compliance. Among the 26% sample mentioned above, 15% sample were from occupational stress less than 3.253, with job tediousness more than 3.427 and with skill underutilization more than

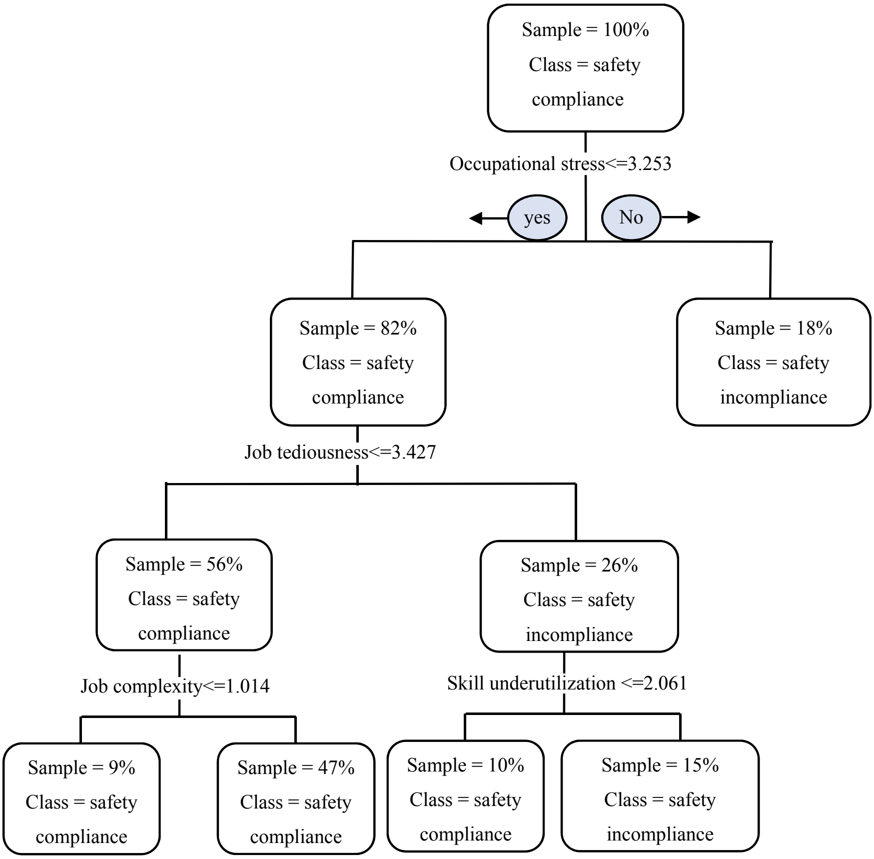

Fig. 2 The stressor–stress–safety compliance decision tree model

2.061, in which belong to safety incompliance. Likewise, among the 56% sample mentioned above, 47% sample were from occupational stress less than 3.253, with job tediousness less than 3.427 and with job complexity more than 1.014, in which belong to safety compliance. To summarize, job tediousness, job complexity, skill underutilization, and occupational stress can predict safety compliance, and their predictive power (ranking) are shown in Table 3.

5.2.2 Stressor–Stress–Safety Participation Decision Tree Model

In the Stressor–Stress–Safety Participation decision tree model, task stressor and occupational stress were regarded as independent variables (i.e., input values), and safety participation was regarded as dependent variable (i.e., output values). Result shows that 42% sample with perceived overqualification more than 2.835 belong to safety participation, and the other 58% sample were from perceived overqualification less than 2.835 that belong to low safety participation. Among 58% sample mentioned above, 9% sample belong to safety participation with skill underutilization less than 1.5, while 49% samples belong to low safety participation with skill underutilization more than 1.5. Likewise, 29% sample were from perceived overqualification more than 2.835, where job complexity less than 2.835 and belong to safety participation; while 13% sample were from perceived overqualification more than 2.835, where job complexity more than 2.835, in which belong to safety participation. In the end, 9% sample were from perceived overqualification more than 2.835, with job complexity less than 2.835, with job tediousness less than 2.585, in which belong to safety participation, whereas in the other 20% of data, it belongs to safety participation. (Fig. 3). To summarize, job tediousness, job complexity, skill underutilization, and perceived overqualification and occupational stress can predict safety participation, and their predictive power (ranking) are shown in Table 3.

6 Discussion

To ensure the reliability of the final results, current study adopted within-method research triangulation that is to conclude the findings based on the congruence of multiple analyses results [40]. The final Task Stressor–Stress–Safety Behavior model for construction workers was developed based on the results of both correlation and decision tree (see Fig. 4). The research hypotheses mentioned above are basically supported: task stressors can, either directly or indirectly through occupational stress, predict the safety behaviors of the construction workers.

Task Stressors, Stress and Safety Compliance for Construction Workers

Current study found that skill underutilization and perceived overqualification can, indirectly through occupational stress, negatively affect the safety compliance as well. This finding is consistent with previous studies regarding the interactions

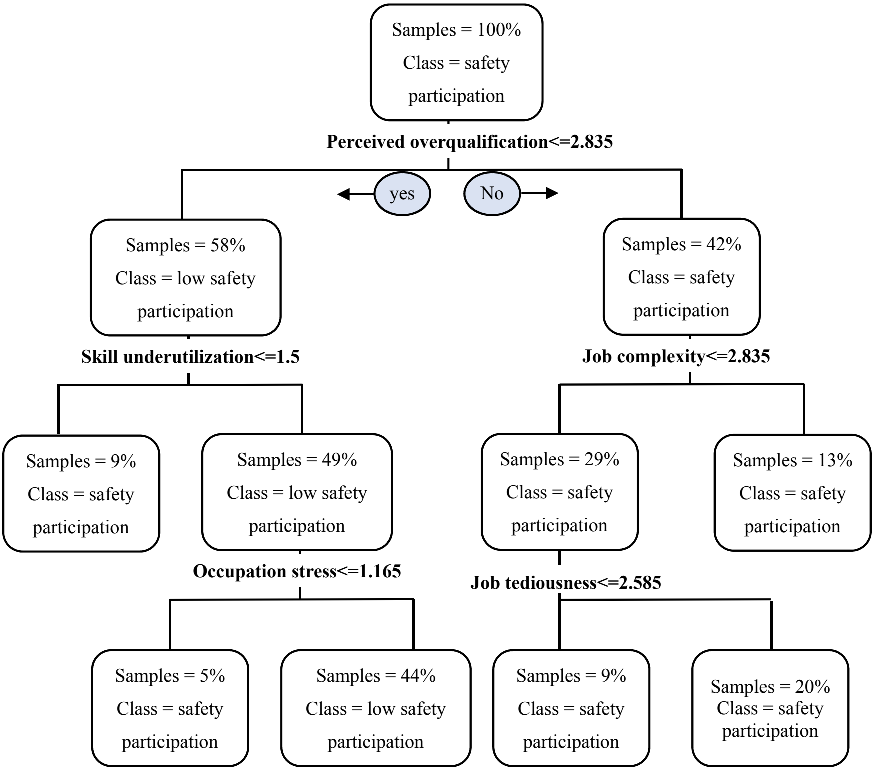

Fig. 3 Task stressor–occupational stress–safety participation decision tree model

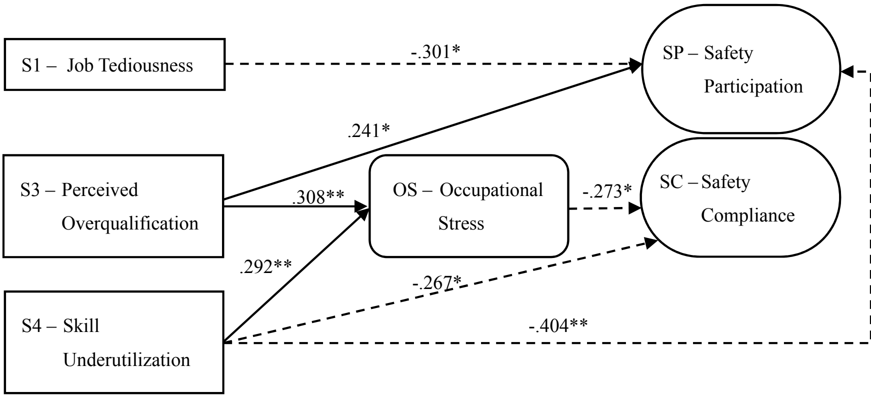

Fig. 4 The final task stressor–stress–safety behavior model. *Note* ——▶represent positive relationship confirmed by correlation and decision tree; - - - ▶represent negative relationship confirmed by correlation and decision tree

between stress and safety compliance [4, 12]. Despite the work trades of the construction workers, they are often assigned to work on same /similar tasks during their whole career. However, the workers may gradually develop the feelings that their skill was underutilized and their ability was not qualified by current tasks. Under such a situation, it is easily understandable that construction workers suffer from occupational stress, such as being strained and burned out from work, which in turn harm their safety compliance.

In addition, current study also found skill underutilization can directly and negatively predict the safety compliance of construction workers, which supports the conceptual model and extend previous studies [21]. There are safety regulations and safety working procedure stipulated by government, industry, company and project team which request the workers to follow specific safety working procedures at work. However, the workers who feel skill underutilization may think these safety working procedures are unnecessary and time-wasting, and thus, commit safety incompliance at work (e.g., not wear safety equipment and work in risk manner).

Task Stressors, Stress and Safety Participation for Construction Workers

Job tediousness was found to be negatively correlated with safety participation. The results replicated previous research [5]. Construction workers are often assigned to conduct repetitive and monotonous construction tasks while strictly follow regulated working procedures during the whole construction life cycle and even their entire career. The job tediousness may gradually develop among the construction workers, in turn depriving of their work interest, distracting their attentions to the work, and letting them become careless about the work and related issues (e.g., safety of the project team). Under such a circumstance, it is hard for them to input additional efforts to help improving safety by expressing safety opinions and encouraging others voluntarily.

It is interesting to find that the perceived overqualification can directly impose a positive influence on the safety participation, which is consistent with previous studies [20]. The task assigned to a worker on site may be often regarded as simply by the worker especially by those with extensive experiences (e.g., routine carpentry task is simple for the experienced carpenter). In this regard, the workers may feel that they are far more capable than doing the assigned tasks, and they should make additional contributions to the project team (i.e., voluntarily participate in safety issues) in order to demonstrate their capability. Therefore, it is understandable that construction workers express safety opinions (if face possible argument) and encourage others to get involved in safety issues.

This study also found that skill underutilization can directly and negatively influence safety participation. The high repetitiveness of work may cause workers to a state where they are unable to fully use their skills, leading to feelings of dissatisfaction in the long term [17]. Those workers feeling skill underutilization may gradually became indifferent to their tasks and their work crew team, in turn leading to reduction in the safety participation (e.g., not sharing safety issues with co-workers).

7 Conclusion

This study confirmed that safety behavior of construction workers can be affected by stressors either directly or indirectly through occupational stress, including job tediousness, perceived overqualification and skill underutilization. To improve the safety of workers by better managing the critical task stressors, current study suggests that: (1) construction organizations and project team should adjust task arrangement, change task assignment or set task objectives periodically to prevent the job tediousness among construction workers, as it harms the workers' safety participation; (2) it is necessary to review whether the work ability of construction workers are in line with the existing positions, and make occupational assessment on workers regularly; and (3) as occupational stress can directly and negatively harm the construction workers' safety behavior, the construction organizations and project management team are suggested to take proactive actions to prevent occupational stress or alleviate the existing one, such as provision of 24-h counselling hot-line, organization of stress management seminar and training, and offering recreational activities.

Current study collected 69 data from construction workers, while small number of sample size may be challenged for reliability and validity issue. However, the sample size is sufficient for all statistical analyses and decision tree conducted in current study. In addition, by adopting within-method triangulation, the final relationships between stressors, stress and safety for construction workers were only confirmed based on the congruence of multiple analyses, which could ensure its reliability. In order to achieve wider generatability, future study is suggested to conduct a large-scale questionnaire. This paper has shown the advantages of decision tree which is one of machine learning approaches. There are still other machine learning methods, such as support vector machine, random forest, k-nearest neighbor, naive Bayes, artificial neural network and so on. It will be interesting for future study to examine the predictive performance of various machine learning methods for the stress and safety issues of construction workers.

Current study examined the relationships among task stressors, occupational stress and safety behavior for construction workers in the construction industry by using both traditional statistical methods and machine learning method. The final conclusions are made based on the congruence of the results of multiple analyses (i.e., factor analysis, correlation and decision tree). The results revealed that the task stressors, including job tediousness, perceived overqualification and skill underutilization, can directly and indirectly through occupational stress, affect the both types of safety behaviors of construction workers. Based on the findings, several recommendations are proposed for construction organizations to improve the safety by better managing the tasks stressors.

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The Impacts of Housing Affordability Stress on Social Integration of Married Migrant Workers: A Comparison of Six Cities in Eastern China

Lei Zhong and Li Tao

Abstract Migrant workers are experiencing increasingly severe stress (especially housing stress) in urban areas, largely due to the Hukou system and the soaring housing price. Housing stress generally refers to financial stress, and is usually measured by housing affordability index. Poor housing affordability undoubtedly affects housing consumption of migrant workers, and hinders them from integrating into the local society. Housing affordability stress was found to influence social integration of migrant workers, so were city-specific factors. Because housing costs and income levels vary from city to city, this paper aims to make comparisons concerning the effects of housing affordability stress which have seldom been made from the perspective of urban hierarchy. Cities in Eastern China have undergone the most rapid social and economic development, which attracts the largest number of migrant workers. We estimate an ordinal logistic regression model in six cities in Eastern China and data from 2014 Internal Migrant Dynamic Monitoring Survey was employed. Besides the effect of housing affordability stress, the influences of individual characteristics, family factors, hometown features, and host city characteristics on social integration of migrant workers were looked into. It was found that social integration of married migrant workers associated with urban hierarchy, taking into account of individual characteristics, and features of migration, housing, neighborhood, and culture in the host city. Housing affordability stress could exert negative effects on social integration of married migrant workers, which varied in cities of different hierarchies. The effects of housing affordability stress on social integration of married migrant workers were significant in first-tier cities and third-tier cities, while the effects were insignificant in second-tier cities. The differences may be influenced by both married migrant workers' residential expectations and local policies. Hence, local governments should improve the social integration of married migrant workers by taking into account of local conditions, such as urban hierarchy.

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Besides, Family-related characteristics (such as family scale and dual-career family) also imposed significant impacts on social integration of married migrant workers.

Keywords Housing stress · Social integration · Migrant workers · Urban hierarchy

1 Introduction

The number of floating population in China reached its peak in 2014 and began to decline slowly from 2015, but still large. Migrant workers who have been working in the host cities for more than half a year are the main body of floating population. Migrant workers are widely distributed in construction, manufacturing, catering services, and other industries [39]. The limited housing affordability and the lack of housing security make them face great housing stress in the host city [16, 31]. Studies have revealed the adverse mental health impacts of housing stress and the significant effect of mental health on social integration of migrant workers [2, 11].

And now significant changes have taken place in Chinese urbanization process. It was found that more and more migrant workers preferred to go to counties instead of big cities [10]. Well-educated people continued to flock to new first-tier cities [32]. Migrant workers not only in big cities but also in cities of other scales should be concerned. The majority of migrant workers come from rural areas. The social integration of migrant workers has become a great challenge during the process of rapid urbanization in China over the past 10 years [53]. Social integration of rural migrant workers into host cities is of great importance for new-type urbanization [63]. Due to the household registration system, rural migrants cannot enjoy equal social welfare with urban residents, which discouraged migrant workers from social integration.

Family migration[1] has become the trend in China. A small number of family members started to move to host cities in search of employment opportunities and financial resources. To maintain family stability, seek higher income, and create better educational opportunities for children, other family members followed the pioneers and moved to the cities [49]. Migrants developed distinctive social structures in the locality, based on work and family relationships, which enabled integration and the forging of ties with the host society [46]. Current studies focus on the effects of policies, social networks, individual characteristics and housing factors on social integration of migrants [27, 34, 65]. Few studies investigated the influence of family factors on the social integration of migrant workers. The efforts of migrants to integrate into the local society were affected by the needs of family care, family reunification, and the restrictions of household registration system [66].

The aim of this paper is to investigate the effects of housing affordability stress on the social integration of migrant workers, especially married migrant workers. The effect of urban hierarchy and family factors were paid special attention to. And

[1] Family migration is defined as the process of family members with marriage or blood relationship moving into the city in one or several batches [49].

housing affordability of married migrant workers in six cities with different urban hierarchy were compared.

2 Literature Review

2.1 Housing Affordability Stress

2.1.1 Quantification of Housing Affordability Stress

Housing affordability stress is usually measured by housing affordability index [41]. There are mainly two approaches to measure housing affordability, including housing expenditure-to-income ratio method, and remaining income method [12]. Traditional housing expenditure-to-income ratio method can be divided into rent expenditure-to-income ratio method, housing price-to-income ratio method, and loan repayment-to-income ratio method. Housing expenditure-to-income ratio method argues that when housing cost exceeds a certain percentage of a family's income (usually 25% or 30%), the family faces an affordability problem [6]. Weicher [58] was the first to use housing price-income ratio (PIR) as a gauge of housing affordability. Thereafter, scholars used this ratio to discuss the housing affordability of residents in Hong Kong SAR of China, Russia and London respectively [12, 22, 28].

As to remaining income method, a family is considered to have inadequate housing affordability if the remaining income cannot meet the acceptable housing cost after deducting the costs of non-housing necessities [24, 39]. Remaining income varies from family to family (because of different household income and size). This method was first proposed by Stone in 1933. He argued that a better calculation of a household's real level of housing consumption was the difference between disposable household income and the cost of non-housing demand at a basic reasonable level.

2.1.2 Housing Affordability Stress of Migrant Workers

Cities around the world are facing similar housing crises [38], i.e., increasing housing demand, rising housing prices, increasing income polarization, and increasing housing burden of moderate and low-income citizens [42]. Due to the marginal property right, poor housing quality and closed space in the market, immigrant housing, including housing tenure, housing condition, housing mobility, and so on, has attracted extensive attention from scholars at home and abroad [48]. The influencing factors can be divided into social and economic status (occupational status, migration, age, income, and education, etc.), life cycle factors (age, marital status, family structure, etc.), and system factors (housing prices, interest rates, city size, etc.) [13].

The heavy involvement of the government in US, Europe, Singapore and Hong Kong and their phenomenal housing success, in contrast to the lack of the government in India and consequent large number of slum dwellers, demonstrated the importance of and the need for the government in low-income housing [3, 7, 20, 21]. In recent years, cities around the world, led by London and New York, have tried to refocus their housing policies on "affordable housing" and introduced affordable housing policies specifically targeting public services and skilled workers, with a greater emphasis on mixed-family communities and easing social isolation [38].

In the past few years, Chinese government has launched various types of affordable housing, including low-rent housing, affordable housing, commodity housing with limited prices, public rental housing and so on [64]. The cost of public rental housing is higher, so the rent is higher. This type of housing may be suitable for migrants with higher incomes, but is not available to most low-income migrant workers [60]. The higher the net population inflow, the faster the rise in housing price, which has a significant negative impact on housing affordability [25].

Housing affordability stress of migrant workers leads to problems such as low housing quality and poor living environment [51, 52]. Due to the low income and high housing prices, migrant workers are generally exposed to various forms of housing deprivation (such as inadequate housing facilities, and inadequate housing) [31]. Many migrant workers live in temporary, crowded and poor housing provided by employers, such as factory dormitories, shacks and construction sites [68]. These housing often lacks privacy which leads to practical and psychological problems. Another option is private rental housing. Migrant workers often live in very small housing and share with others to save money [56]. They also tend to live in marginalized communities, such as urban villages (villages in the city), which are often located in suburbs [17].

2.2 Social Integration

Social integration is a process of mutual cooperation and adaptation between individuals, groups, and cultures [63]. It refers to the extent to which an individual participates in a broad range of social relationships [4, 47]. Relevant terms in the literature include assimilation [18], social exclusion, and segregation [53]. Ruiz-Tagle [47] extracted four types of social integration, i.e., integrity, liability, assimilation and cultural pluralism. Social integration of migrants is a process of gradual assimilation and reduction of exclusion, a process of the unification of subjective expectations and objective acceptance of the city, and a process in which local population and immigrants go to each other and construct mutual relationships, but does not necessarily imply mixture or diversity [50].

Social integration of migrant workers has been studied from economical, political, cultural, social, and psychological perspectives [5, 19, 23, 40, 72]. Individual characteristics, nationality and family context were found to affect migrant's integration [18]. The integration process of married female migrants was associated with social and family contexts [8]. Preferences or cultural identities were key mechanisms to affect social integration of migrants in adulthood. Migrants who were younger when they arrived were more likely to live close to, work with, and marry natives [1].

In recent years, the new generation of migrant workers has attracted wide attentions. Labour market outcomes, interactions with local urban residents and individual factors were crucial for the social integration of the new generation of migrant workers [9]. New-generation migrants were argued to have more opportunities to readily integrate into the host society [35]. However, young rural-urban migrants were found to achieve a lower socio-economic status than local youths and urban-urban migratory youths due to the household registration system [62]. The existence of rural-urban disparity and the dominance of labour-intensive industries in the economy constrained more fundamental changes in the generational transition of migrants in China [71].

The integration of migrant workers is a long process. Employment, housing, Hukou and culture in the host city are factors influencing the social integration of migrant workers [70]. Migrant workers facing heavier housing burden had greater perceived pressure [33, 55]. The effect of rising housing costs on the inflow of low-educated, young and female migrant workers was even more pronounced [67]. It was found that income, housing price and urban public services were important factors affecting population mobility between cities. However, the influences on all kinds of factors would ultimately affect the decision and willingness of workers to migrate between cities through their lifetime utility [44, 63]. On the one hand, rising housing prices mean that migrant workers need to spend more of their income on housing, reducing other consumption, their relative utility, and ultimately their willingness to settle down [45]. Higher incomes and better public services attached to high housing prices will increase the willingness of migrant workers to stay in the city in the long run. Housing price had no significant impact on the long-term residence will of migrants, but housing price income ratio had a significant negative impact on the long-term residence will of the floating population [30].

The influence of city-specific factors on internal migration in China are substantial, given the vast regional disparities in demographic composition, economic development, city sizes and types, institutions, culture, and language [53]. Economic conditions of the host city can exert both positive and negative effects on social integration and settlement intention of migrant workers. City scales affect the flow and distribution of the population. However, the impacts of city-specific characteristics on social integration of migrant workers have been understudied. Besides, moving range also matters. The influence of inter-provincial mobility pattern on social integration of migrant workers is significant [66].

Further, family is a key decision-making unit. Rural-urban mobility was a family decision. Rural labor force made the decision of migration based on the comparison of the size of real wage and reserve wage [14]. Migration behavior of individuals was significantly influenced by the characteristics of households [66, 69]. A growing body of research addresses how couples sustain two careers and how their work and family lives unfold. Dual-career families[2] have been investigated on the family backgrounds, marital relationships, and work-life patterns [43, 54, 61]. Given the trend of family migration in China, household characteristics (e.g., dual-career family) have not been sufficiently discussed concerning the social integration of migrant workers. Housing stress and social integration of dual-career migrant families need to be further looked into.

This study aims to fill the knowledge gap. Comparisons will be made concerning housing stress, social integration, and the effects of housing stress on the social integration of migrant families across cities of different urban hierarchies.

3 Research Methodology

3.1 Data Source

This study employed the data from China Migrants Dynamic Survey 2014 (CMDS) released by National Health Commission of the People's Republic of China. The stratified and multi-stage PPS (Probability Proportionate to Size Sampling) sampling method was adopted to investigate the inflow population aged 15–59 who have resided in the destination for more than one month and are not registered in the district (county, city). And the special survey on social integration and mental health of migrants is lastest, which conducted in Eight cities, including Beijing, Xiamen, Qingdao, Zhengzhou, Shenzhen, Zhongshan and Chengdu. Six cities in Eastern China (i.e., Beijing, Xiamen, Jiaxing, Qingdao, Shenzhen and Zhongshan) were selected as study cases. These cities vary in geographic locations and urban hierarchies. They have undergone the most rapid social and economic development in China, which attracts a large number of migrant workers. The research objects of this study were married migrant workers who had worked in the host cities for more than half a year by 2014. Accordingly, 6548 valid samples were selected (Table 1).

3.2 Analytical Methods

3.2.1 Measures of Housing Affordability Stress and Social Integration

Housing expenditure-to-income ratio was used to measure the housing affordability of migrant workers. This method is suitable for comparing the effects of housing affordability on social integration of individuals in different cities.

According to multidimensional perspective advocated in previous works [47, 53], four dimensions (i.e., economic status, social interaction, cultural identity, and social

[2] A dual-career family is defined as one where both heads of the household pursue their professional careers at the same time and maintain a family life together that includes children [26].

Table 1 Characteristics of the six cities in Eastern China

Cities	GDP per capita (yuan)	Permanent residents (10,000 people)	Proportion of non-local population (%)	Disposable income per capita (yuan)
Beijing	102,869	2151.6	38.1	48,532
Shenzhen	149,495	1077.9	69.2	40,948
Qingdao	62,104	904.6	13.7	38,294
Xiamen	86,831	381.0	46.6	39,625
Jiaxing	96,607	457.0	23.8	37,673
Zhongshan	88,682	319.3	51.1	34,304

Table 2 Four dimensions of social integration

Dimensions	Questions in the survey	Values
Economic status (x_1)	How do you perceive your status of income and occupation compared with relatives, friends and colleagues in the locality?	1–10 (low to high)
Social tie (x_2)	Do you think that you and your family are getting on well with the locals?	1–5 (little communication to very well)
Cultural identification (x_3)	Do you agree that it is more important to keep the life style of your hometown?	1–5 (strongly disagree to strongly agree)
Social identification (x_4)	Do you consider yourself to be a local resident?	0 (no)/1 (yes)

identity) were used to measure the social integration of migrant workers. Each of these dimensions corresponds to a specific question in the survey, similar to Tian et al. [53]. The specific questions and values of these four dimensions were listed in Table 2. To quantify the social integration of migrant workers, the weighted arithmetic mean of each dimension was calculated with the following formula: $Y = \frac{\sum_1^4 x_i X_i}{\sum_1^4 X_i}$, where x is the value of each dimension, and $X_1 = 10$, $X_2 = X_3 = 5$, $X_4 = 2$.

3.2.2 Regression Method

The dependent variable was social integration of married migrant workers, which was an ordinal variable. An ordinal logistic regression was employed as follows:

$$\ln\left(\frac{P(Y \leq j)}{1 - P(Y \leq j)}\right) = \beta_{0j} - (\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_m X_m).$$

This model is a multiple-discrete choice model that takes the logical distribution as the probability distribution of the random error term. It is applicable to the analysis of behavior selection in accordance with the principle of utility maximization. Larger coefficients (β_i) indicate an association with larger scores.

4 Results

4.1 Descriptive Findings

4.1.1 Social Integration

Based on the formula presented in Sect. 3.2.1, social integration of each respondents were calculated as Y. Then, we rounded up Y, and got Y′ (Table 3).

In addition, a comparison was made concerning the social integration of married migrant workers across the six cities (Table 4). More than 45% of the population had moderate levels of social integration and above in the six cities and the social integration level of married migrant workers in the three levels of cities is medium.

Table 3 Values of social integration

Y	Y′
$0.5 \le Y < 1.5$	1
$1.5 \le Y < 2.5$	2
$2.5 \le Y < 3.5$	3
$3.5 \le Y < 4.5$	4
$4.5 \le Y < 5.5$	5
$5.5 \le Y < 6.5$	6
$6.5 \le Y < 7.5$	7

Table 4 Comparison of social integration of married migrant workers across six cities

Social integration	First-tier cities		Second-tier cities		Third-tier cities		All six cities (%)
	Beijing (%)	Shenzhen (%)	Qingdao (%)	Xiamen (%)	Jiaxing (%)	Zhongshan (%)	
1	0.3	1.1	0.3	0.8	0.2	0.7	0.6
2	5.3	9.8	3.5	4.7	3.3	5.5	5.1
3	25.9	33.8	19.8	25.2	32.5	31.4	28.1
4	43.0	41.7	51.9	48.7	48.3	43.3	46.2
5	20.5	11.6	21.1	17.3	14.3	15.7	16.9
6	4.7	2.1	3.3	3.2	1.4	3.4	2.9
7	0.2	1.1	0.1	0.1	0.2	0.1	0.1

4.1.2 Explaining Factors

Variables of demographic characteristics include gender, nationality, educational level, Hukou, state of health, and new generation of married migrant workers. Occupational characteristics of married migrant workers include employment status and industrial type. Besides, Three variables were also added to denote housing characteristics of married migrant workers, including housing type, community type, and neighborhood structure. Similarly, five variables were used to characterize household, i.e., household size in host city, status of spouse and children, the number of children, and dual-career family. Variables of hometowns include region, housing area, presence of cultivated land, childcare, and support for the elderly. Variables of host cities included urban hierarchy, duration of residence, moving range, fluency of local language, and pension accounts. The summary of demographic characteristics was shown in Table 5.

Table 5 Descriptive findings

		All six cities (n = 6548)	First-tier cities (n = 1808)	Second-tier cities (n = 2353)	Third-tier cities (n = 2387)
Female (%)		41.1	37.9	40.5	44.2
Education	Primary school and below (%)	11.2	5.1	10.4	16.6
	Middle school (%)	57.3	46.7	63.3	59.3
	High school (%)	20.9	27.1	17.8	19.2
	Junior college and above (%)	10.7	21.1	8.5	4.9
Type of Hukou	Agricultural (%)	87.3	76.6	90.8	92.0
Employment status	Employee and self-employed workers (%)	61.1	61.7	52.8	69.0
	Others (%)	0.9	1.4	0.3	1.0
	Employer (%)	38.0	36.9	46.9	30.1
Type of industry	Primary (%)	59.9	77.9	67.6	38.6
	Secondary (%)	39.0	21.6	31.3	59.9
	Tertiary (%)	1.1	0.5	1.1	1.5
New generation of migrant workers (%)		48.4	50.6	50.7	44.6
Housing expenditure-to-income ratio (mean)		0.13	0.16	0.14	0.09
Index of social integration (mean)		3.83	3.75	3.94	3.78

The age of the respondents were between 25 and 39 years old. The proportion of females was higher than that of males. The majority of respondents received secondary or high school education, and 10.7% of them received tertiary education or above. The vast majority of the respondents held agricultural Hukou. More than 60% of them worked as employees. There were 59.9% of the respondents working in the tertiary industry, while only 1.1% working in the primary industry. About half of the respondents were born after the 1980s (i.e., the new generation). In general, the basic characteristics of the respondents were young, moderately educated, and mainly employed in the service industry. About half of the respondents were from the Eastern region of China. Comparing the three ties of cities, the education level of respondents in first-tier cities was significantly higher than that in second- and third-tier cities, with 27.1% of respondents having received a junior college education or above in first-tier cities. The proportion of respondents with agricultural Hukou was smaller in first-tier cities than that in second- and third-tier cities. In second-tier cities, the proportion of self-employed migrant workers was higher than that in first-tier and third-tier cities. Respondents in first-tier and second-tier cities were mainly engaged in the tertiary industry, while respondents in third-tier cities were mainly engaged in the secondary industry. Third-tier cities had the smallest proportion of the new generation of migrant workers. Respondents of first- and third-tier cities were mainly from the Eastern and Central regions of China, while 73.4% of the respondents in second-tier cities were mainly from the Eastern region. It is worth mentioning that migrant workers in second-tier cities had the lowest housing expenditure-to-income ratio, and the highest level of social integration.

The proportion of married migrant workers living in urban villages or shanty towns was as high as 36.2% in first-tier cities, while the proportion was about 2% in second and third tier cities. Married migrant workers in all three-tier cities were mainly lived in rental housing. Most of their neighbors were non-local residents. Married migrant workers usually migrated with the spouse in all six cities. The proportion of dual-career family was the highest among married migrant workers in first-tier cities, and the lowest in third-tier cities. In addition, married migrant workers in first- and third-tier cities mainly dropped into the category of inter-provincial migration. They mainly came from Central and Eastern China. Married migrant workers in second-tier cities mainly underwent intra-provincial migration. They mainly came from Eastern China. Married migrant workers in second-tier cities mentioned responsibilities to care for children and support for the elderly in the hometown at a higher frequency than those in first- and third-tier cities.

4.2 Regression Results

Ordinal logistic regression was conducted to explore factors affecting social integration of married migrant workers in the six cities (Table 6). From the perspective of socio-economic and demographic characteristics, married migrant workers with better health conditions and higher levels of education tend to have a higher level of

Table 6 Factors affecting the social integration of married migrant workers

‘	Eastern	
	Coef	Std.err
Demographic characteristics		
Gender (Female)	0.014	0.049
Nationality (Ethnic minorities)	−0.098	0.118
Education (reference: junior college and above)		
Primary school and below	−0.469***	0.118
Middle school	−0.270***	0.093
High school	−0.211**	0.094
Type of Hukou (Agricultural)	−0.059	0.081
Health conditions	0.389***	0.025
Employment status (reference: employer and self-employed workers)		
Employee	−0.259***	0.060
Others	0.111	0.255
Type of industry (reference: primary industry)		
Tertiary	−0.289	0.231
Secondary	−0.185	0.232
New generation (Yes)	−0.002	0.051
Housing characteristics		
Housing expenditure-to-income ratio	−0.672***	0.158
Community type (Urban villages or shanty town)	−0.235**	0.088
Housing type (reference: commodity housing or self-built housing)		
Rental housing	−0.616***	0.080
Free dormitories (excluding workplaces)	−0.747***	0.130
Others (including workplaces, borrowed housing and other informal dwellings)	−0.850***	0.187
Type of neighborhood (reference: more locals)		
More non-locals	−0.244***	0.069
Same	−0.157**	0.070
Not sure	−0.430***	0.134
Household characteristics		
Family size in the locality	0.143***	0.050
Migrate with spouse (No)	0.055	0.328
Dual-career family in the locality (reference: yes)	0.246***	0.069
Number of children	−0.025	0.053
Migrate with children (No)	0.047	0.090
Hometown characteristics		

(continued)

Table 6 (continued)

‘	Eastern	
	Coef	Std.err
Region of hometown (reference: Eastern region)		
Western	−0.032	0.086
Central	0.029	0.075
Housing area in hometown	−0.002	0.002
Ownership of cultivated land in hometown	0.001***	0.000
Need to care for the elderly in hometown (No)	0.340**	0.152
Need to care for children in hometown (No)	0.061	0.119
Chidren’s educational problem in hometown (No)	0.039	0.746
Host city characteristics		
Urban hierarchy (reference: second-tier)		
First-tier	−0.440***	0.088
Third-tier	−0.241***	0.069
Duration of stay in the locality (reference: more than 5 years)		
Less than 1 *year*	−0.032	0.092
1–3 *years*	0.037	0.058
3–5 *years*	0.038	0.063
Scope of migration (reference: within-city)		
Inter-provincial	0.251	0.176
Intra-provincial	0.161	0.162
Fluency of local language	0.221***	0.027
Employee pension insurance (reference: yes)		
No	−0.234***	0.055
Not sure	−0.235	0.174
Pseudo R-square	0.048	
N	6548	

*significant at 10%; **significant at 5%; ***significant at 1%

social integration. It would be easier for employers to adapt to the host city compared with employees or workers with other types of employment. Employers could usually obtain higher income, which made it easier for them to settle in the host city.

From the perspective of housing characteristics, housing expenditure-to-income ratio did have a strong negative impact on social integration of married migrant workers. Living in rental housing, free dormitories, borrowed housing, workplaces and other informal housing had negative impacts on social integration of married migrant workers, which echoes the previous findings [36, 59]. It would be more difficult for married migrant workers living in urban villages to integrate into the locality. Married migrant workers with more local residents in the neighborhood were more likely to integrate in to the local society, which is consistent with the findings of Tian et al. [53].

Among household characteristics, household size in the locality had a strong positive impact on social integration of married migrant workers. The larger the family size was and the more children married migrant workers brought with them in the locality, the higher the social and economic costs would be in the destination, and the more difficult it was to form the unified intention of family migration [57]. On the other hand, the larger the family size was in the locality, the better the living standards and the higher the levels of social integration. Interestingly, married migrant workers of non-dual-career families tend to have higher levels of social integration, which was different from our expectation. Dual-career families were found to typically involve professional or managerial jobs [37]. The research objects of this study were married migrant workers that engaged in business, service and production industries, whose income were lower. They may put more emphases on income than professional identities, and had less time for fun or socializing than local counterparts.

In terms of factors related to hometown, married migrant workers with more housing area in the hometown tend to have higher levels of social integration, which may be related to their levels of fixed assets and incomes. The more housing area married migrant workers occupied in the hometown, the more psychological comforts they could obtain, which could eliminate certain negative effects of housing stress in the locality. In addition, married migrant workers who did not have the responsibility to care for the elderly in the hometown tend to have a higher level of social integration in the locality. This is consistent with the finding that it was more difficult for migrants whose families had care needs to acquire a sense of belonging and identity in the locality [66].

Interestingly, the effects of urban hierarchy on social integration of married migrant workers were significant in first-tier cities and third-tier cities, while insignificant in second-tier cities. The economic status in the host city had double-edged effects on the social integration of migrant workers [53]. It was difficult for migrant workers to integrate into cities with higher levels of economic development. Migrant workers were sensitive to housing rents in these cities. They tend to face greater housing stress in cities with higher per capita GDP and housing rent. To be specific, the higher the per capita GDP of the destination, the greater the gap of living standards between the host city and the hometown of migrant workers. Furthermore, fluency of local language could facilitate the process of social integration. Migrants could adapt to northern cities more easily than southern cities because of the huge differences in dialects in Southern China. The existence of language barriers deepened the divide between local residents and immigrants [53]. Meanwhile, married migrant workers with pension accounts in the locality were more likely to integrate into the locality. The study indicated that providing a public pension to migrants such polices help this population group live a more secure and comfortable life in host cities [53].

Further, we established three models to examine factors affecting the social integration of married migrant workers in first-tier, second-tier and third-tier cities respectively (Table 7). The impact of education was much more significant in first-tier cities. In second-tier cities, the effect of ethnicity became significant. It was harder

Table 7 Factors affecting social integration of migrant workers across three tiers of cities

‘	First-tier		Second-tier		Third-tier	
	Coef	Std.err	Coef	Std.err	Coef	Std.err
Demographic characteristics						
Female	0.123	0.095	−0.055	0.084	0.015	0.081
Ethnic minorities	−0.331	0.272	−0.659**	0.292	−0.104	0.149
Education (reference: junior college and above)						
Primary school and below	−0.907***	0.246	−0.149	0.204	−0.149	0.224
Middle school	−0.446***	0.150	0.004	0.16	0.044	0.200
High school	−0.304**	0.144	0.087	0.169	0.057	0.203
Type of Hukou (Agricultural)	−0.111	0.129	0.020	0.149	0.039	0.160
Health conditions	0.426***	0.048	0.411***	0.043	0.371***	0.042
Employment status (reference: employer and self-employed workers)						
Employee	−0.187*	0.107	−0.435***	0.010	−0.111	0.112
Others	0.226	0.385	−0.275	0.676	0.172	0.403
Type of industry (reference: primary industry)						
Tertiary	−0.551	0.641	0.351	0.376	−0.620	0.37
Secondary	−0.323	0.646	0.413	0.377	−0.569	0.375
New generation	0.061	0.096	−0.065	0.088	0.020	0.085

(continued)

Table 7 (continued)

‘	First-tier		Second-tier		Third-tier	
Housing characteristics						
Housing expenditure-to-income ratio	−0.907***	0.274	−0.079	0.226	−1.391***	0.415
Type of community (Urban villages or shanty town)	0.149	0.118	−0.170	0.272	−1.068***	0.264
Type of residence (reference: commodity housing or self-built housing)						
Rental housing	−0.718***	0.171	−0.551***	0.120	−0.763***	0.148
Free dormitories (excluding workplaces)	−1.490***	0.301	−0.502**	0.214	−0.855***	0.213
Others (including workplaces, borrowed housing and other informal dwellings)	−0.923***	0.349	−1.313***	0.294	−0.745**	0.371
Neighborhood structure (reference: more locals)						
More non-locals	−0.265*	0.154	−0.376***	0.104	−0.180	0.129
The same	−0.153	0.159	−0.074	0.104	−0.226***	0.130
Not sure	−0.175	0.231	−0.923***	0.246	−0.405	0.247
Household characterize						
Family size in the locality	0.078	0.102	0.226**	0.111	0.157**	0.070
Migrate with spouse (No)	1.082	1.321	−0.327	0.511	0.302	0.471
Dual-career family in the locality (reference: yes)	0.417***	0.119	0.251**	0.113	0.096	0.135
Number of children	0.011	0.107	−0.161	0.119	0.031	0.075
Migrate with children (No)	−0.039	0.174	0.260	0.178	0.004	0.137

(continued)

Table 7 (continued)

‘	First-tier		Second-tier		Third-tier	
Hometown characteristics						
Region of hometown (reference: Eastern region)						
Western	−0.030	0.149	0.008	0.255	0.027	0.127
Central	0.004	0.111	0.176	0.228	0.104	0.119
Housing area in hometown	−0.003	0.002	0.003	0.004	0.001	0.007
Ownership of cultivated land in hometown	0.001***	0.000	0.001*	0.001	0.001**	0.000
Need to care for the elderly in hometown (No)	0.415	0.332	0.513*	0.300	0.234	0.214
Need to care for children in hometown (No)	−0.170	0.236	0.231	0.198	0.094	0.199
Children's educational problem in hometown (No)	0.195	0.252	−0.139	0.191	−0.121	0.203
Host city characteristics						
Duration of stay in the locality (reference: more than 5 years)						
Less than 1 *year*	−0.055	0.177	−0.018	0.157	−0.067	0.152
1–3 *years*	0.024	0.110	0.167*	0.100	−0.083	0.096
3–5 *years*	0.052	0.120	−0.016	0.106	0.034	0.109
Scope of migration (reference: within-city)						

(continued)

Table 7 (continued)

‘	First-tier		Second-tier		Third-tier	
Inter-provincial	−0.075	1.087	0.081	0.267	−0.137	0.782
Intra-provincial	−0.387	1.089	0.095	0.173	0.032	0.781
Fluency of local language	0.370***	0.052	0.123***	0.045	0.222***	0.048
Employee pension insurance (reference: yes)						
No	−0.224**	0.110	−0.305***	0.094	−0.175*	0.092
Not sure	−0.261	0.262	−1.766**	0.774	0.107	0.256
Pseudo R-square	0.065		0.047		0.044	
N	1808		2353		2886	

*$p < 0.1$. **$p < 0.05$. ***$p < 0.01$

for married migrant workers of the ethnic minority to adapt to the locality than their counterparts. Type of employment was significant in both first- and second-tier cities. It is interesting that married migrant workers employed in secondary and tertiary industries had higher levels of social integration in both first- and third-tier cities, while the effect was opposite in second-tier cities. This may be related to the working and industrial distribution of floating population in various cities. Married migrant workers in the first- and second-tier cities were most engaged in the tertiary industry, while more migrant workers in third-tier cities were engaged in the secondary industry.

Additionally, regions of hometowns imposed different effects on married migrant workers in the three tiers of cities. It was more difficult for married migrant workers from the central and western regions to integrate into the host city in first-tier cities. As to second-tier cities, the level of social integration tend to be the lowest for married migrant workers from the western region, followed by the eastern region and the central region. Married migrant workers from Central and Western China had higher levels of social integration than those from Eastern China. Responsibilities to care for the elderly in the hometown were only significant in third-tier cities.

Interestingly, the effects of housing affordability stress on social integration of married migrant workers were significant in first-tier cities and third-tier cities, while insignificant in second-tier cities. Besides, inter-provincial married migrant workers tend to have higher levels of social integration than intra-provincial married migrant workers in second-tier cities. Second-tier cities in this study were mainly provincial capitals that attracted mainly inter-provincial migrants. Policies in these cities tend to favor migrants from the same province. This could lead to social integration problems for migrants from other provinces. By contrast, the second-tier cities in this study were mainly regional and national centres that tend to promulgate more immigrant-friendly policies, as they tend to experience mainly interprovincial inflows.

5 Discussion and Conclusion

This study investigated the effects of housing affordability stress on the social integration of migrant households from the perspective of urban hierarchy. Housing affordability of married migrant workers in three-tier cities was compared. Family factors were considered. It was found that housing affordability stress had a negative impact on social integration of married migrant workers. The housing stress in first-ties cities was the heaviest with the levels of social integration of married migrant workers the lowest, which echoes the findings of Tian et al. [53]. However, the effects of housing stress on social integration of migrant workers were found significant only in first- and third-tier cities, which may be caused by both residential expectations of migrant workers and city-specific factors.

The two second-tier cities (i.e., Qindao and Xiamen) in this study are provincial capitals. They primarily attracted intra-provincial migrant workers who had higher levels of social integration. Given provincial-level central cities tend to promulgate policies that favor intra-provincial migrants [53], the effects of housing affordability stress on intra-provincial migrant workers can be weakened. Besides, Dong [15] found that the impact of rent-income ratio on the intention of permanent migration existed a turning point. Before the inflection point, rent-income ratio was positively correlated with the persistent migration intention of rural migrants. However, after the inflection point, the two were negatively correlated. It explains why a large number of rural-urban migrants tend to choose large-scale cities with higher housing prices, rather than small- or medium-scale cities with lower housing prices.

In third-tier cities with rapid economic development, industrial structures (mainly the secondary industry) may primarily attract interprovincial inflow migrant workers. For instance, most married migrant workers in Jiaxing and Zhongshan engaged in secondary industry. They mainly came from the central and western regions. Inter-provincial migration caused large disparities in languages and cultures, which may constrain interactions between local residents and migrant workers, and induced separation [47]. Because housing system and welfare system in third-tier cities are usually not as good as that of higher-level cities, housing stress may be more severe in similar types of housing. Urban hierarchy should be emphasized when promulgating policies to improve social integration of migrant workers in the locality. In first-tier and third-tier cities, housing affordability stress is an important issue, while social contact and cultural identification should be taken seriously by local governments of second-tier cities (especially provincial capitals).

Meanwhile, household characteristics and hometown-related characteristics also matter for social integration of married migrant workers. Family factors of laborers were proved to have significant impacts on social integration [66]. This study showed that the degree of social integration was lower among married migrant workers who had elderly to look after in hometowns. Further, women in dual-career families were found to maintain a good work-life balance [26]. However, the study showed that married migrant workers of non-dual-earner families had higher levels of social integration, which was contrary to our expectation. Dual-earner families may suffer more pressure (e.g., children's education) in the locality, and had little time to maintain social networks. Local governments should make more efforts to facilitate communications between migrant workers (especially dual-earner families) and local residents.

Although this study makes up for the deficiency of existing researches to some extent, it also has the following deficiencies. First of all, the research object of this study is married migrant workers, and the research on single migrant workers is deficient. The future research can be extended to more migrant workers, and the empirical research scope should be extended to more cities. Secondly, with the development of social economy, other characteristic variables (i.e., social network platform) may have an impact on the social integration of migrant workers, thus further research can be carried out.

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Prediction and Analysis of Water Supply-Demand Balance in Binzhou City

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Abstract Binzhou, Shandong is located in the hinterland of the lower Yellow River Delta with the typical sub-humid warm temperate monsoon climate. The average per capita water resources in Binzhou (265 m^3 per person) is considerably lower than the national standards (2100 m^3 per person). To study the current situation of water resources utilization and supply pressure in Binzhou city, the grey system prediction model and quota prediction method were used to predict the near and long-term water demand. The results showed that the shortage of water resources in Binzhou would be more serious in the foreseeable future, with an estimated water shortage of 3.91×10^8 m^3 in 2025 and 2.90×10^8 m^3 in 2035. In the future, agricultural water consumption would still be the largest portion in Binzhou, but its increment would be rather small, and industrial water consumption would increase obviously, compared with 2018, the growth rates in 2025 and 2035 are 109.9% and 192.7%. The demand for domestic water and ecological water would rise due to the development of urbanization. Based on the prediction results of water supply-demand balance, over 3×10^8 m^3 shortfall in water supply, Binzhou needs to improve the water supply capacity to meet the water demand of production and living.

Keywords Water supply and demand balance · Grey system prediction · Quota method · Binzhou city

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1 Introduction

Water is one of the most basic natural resources for humans' survival and development, which makes a direct effect to the sustainable development of human society. China is deficient in water resources seriously, the average quantity of water per person is only 2200 m^3, ranking the 108th in the world [1, 2]. The average per capita water resources in Binzhou, Shandong is 270 m^3, less than 1/8 of the nation standards, which belongs to the water crisis area [2]. The shortage of water resources has become the biggest obstacle of the economic and social development. Under such water conditions, timely and accurate prediction of water supply and demand in Binzhou City is an important prerequisite for adjusting the water supply policy and realizing the long-term sustainable utilization of water resources.

The problem of water utilization in Binzhou City has a long history. As early as 2007, there was a study on the current situation and protection countermeasures of water resources in Binzhou City, but it only stayed in the simple statement of the current situation and existing problems, such as the imbalance between exploitation and replenishment of groundwater resources, the deterioration of water quality, the serious waste of irrigation water, etc., and the proposal of the problems lacked the support of relevant data [3]. In recent ten years, based on the concept of ecological footprint, some scholars have studied the sustainable utilization and optimal allocation of water resources in Binzhou City [4, 5]. The results showed that the water use in Binzhou City in 2012 was generally sustainable, but the surplus of domestic water and ecological water was less than that of production water. Therefore, measures such as quota allocation and recycling should be adopted to adjust the water structure [4]. Based on the comprehensive consideration of economic, social, and environmental objective functions and water demand and water supply constraints, the study in 2018 quantified the allocation of water resources in Binzhou City with Matlab, and obtained the proportion of water consumption in 2020 and 2030 [5].

There are lots of methods to do water demand prediction, including quota method grey system prediction model, BP neural network prediction model [6], system dynamics approach [7], etc. Each method has its own applicable situations. For example, quota method can fully consider the improvement of living standard, the development mode of social economy and the water-saving policy goal, which is suitable for forecasting water demand in district with complete industrial departments [8]. BP neural network prediction model has strict data requirement, so it is always used in areas with complete data collection. Liu established a system dynamics model for the water supply and demand balance in The Beijing-Tianjin-Hebei region to predict the water supply and demand situation from 2016 to 2030, and finally proposed an optimal control strategy for the sustainable development of water resources [9]. Based on the neural network of principal component analysis, Kong used the water consumption data from 2005 to 2015 to predict the water demand of Nanchang in 2020, and the results were relatively reliable [10]. Gharabaghi introduced a nonlinear model of water demand management to solve the limitations of the common model, and tested for the case study City of Guelph, Ontario, Canada [11].

Generally speaking, by contrast, the existing researches on water utilization in Binzhou City only stay at the level of policy theory, and there is a lack of systematic prediction of water supply and demand based on long-time series research mentioned above. Because the prediction range of this paper was a large area with complete social and economic structure, and the relevant data of domestic, agricultural, and ecological water consumption were relatively complete, the index quota method were mainly used for these three parts. However, the industrial water consumption was quite different over the years due to the inconsistency of statistical methods, which was difficult to be used for direct prediction. Considering that gross industrial output value belongs to a grey system with unclear working principle, the grey system model and index quota method were selected.

Overall, on the premise of accurately predicting the water supply and demand trend, the water supply policy should be adjusted in time. The focus of this paper is to predict the water supply and demand in Binzhou City in the next 5–15 years. On this basis, the contradiction between the supply and demand of water resources in the Binzhou area in the future is studied, focusing on the supply gap, and the direction of improvement in the development and utilization of water resources is discussed, with the hope to provide a reference for the optimal allocation of water resources.

2 Data and Study Area

2.1 Data Collection

The data sets used in this study include: water supply-demand data of Binzhou City (2010–2018), water conservancy project data, socio-economic data, and land use data. Datasets on water supply and demand from 2010 to 2018 are from Binzhou Statistics Bureau and Shandong Statistical Bureau (http://tj.binzhou.gov.cn/tjxx/class/?24.html, http://tjj.shandong.gov.cn/col/col6279/index.html). Water conservancy project data are from plans of Binzhou Water Conservancy Bureau (http://www.binzhou.gov.cn/zwgk/News/index?orgid=C9e0e16de72238a73ce991cfb7f2e68c5). The socio-economic data and land use situation are from Binzhou and Shandong statistical yearbook (2007–2018), including population, gross industrial output value and agricultural land, green coverage, road area. Water demand indexes come from *The Standard of Water Quantity for Urban Domestic Use in Shandong* and *Rural domestic water quota in Shandong Province.*

2.2 Study Area

Binzhou city, in the mid-latitude zone, situates in the northern part of Shandong Province (Fig. 1). It belongs to typical sub-humid warm temperate monsoon climate.

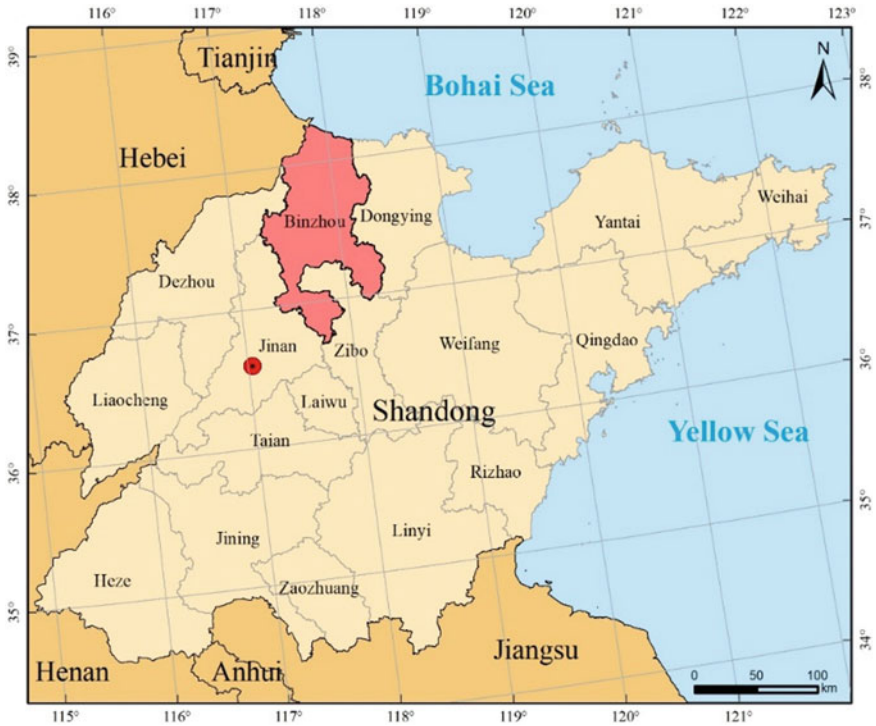

Fig. 1 Location of Binzhou city

Affected by climatic conditions and geographical location, the average rainfall in Binzhou is 575.40 mm with drought in spring and autumn, waterlogged in summer [12]. River networks in Binzhou are well-developed. The Yellow River runs through the whole city. Apart from the Yellow River Basin, there are the Haihe River and the Huaihe River Basin. Totally, there are more than 10 rivers and 3 lakes within the city.

Although passed through by the Yellow River, the average per capita water resources in Binzhou is less than 1/8 of the nation standards. In 2018, the total amount of average water resource has been 3.06×10^9 m^3, of which the amount of local surface water resources is 5.54×10^8 m^3, the groundwater 4.67×10^8 m^3; pass-by water 1.03×10^9 m^3, inter-basin transfer water 1.01×10^9 m^3. The amount of inter-basin transfer water includes 8.57×10^8 m^3 from the Yellow River and 1.51×10^8 m^3 from the Yangtze River. So, the city relies heavily on diverted water, accounting for 70% of the total water supply, of which the Yellow River is the main source.

2.2.1 Water Supply Status

The water supply sources of Binzhou city include surface water, groundwater, pass-by water, inter-basin transfer water and other water source. Other water source mainly refers to unconventional water resource, such as seawater, brackish water, sewage etc. Between 2010 and 2018, the total water supply increased from 1.59×10^9 m^3 to 1.71×10^9 m^3, of which the proportion of surface water supply increased from 85.9 to 89.1%, groundwater supply decreased from 14.1 to 10.4%.

In recent years, Binzhou government has increased water conservancy construction investment. At present, there are 23 small mountain reservoirs, with a total storage capacity of 1.25×10^7 m^3; 45 plain reservoirs, with a total storage capacity of 4.61×10^8 m^3. There are 98 river retaining projects, with a water storage capacity of 2.78×10^8 m^3; 13 irrigation areas from the Yellow River, with water-diversion volume of 1.48×10^9 m^3 and designed irrigation area of 4.28×10^5 hm. Therefore, scale central water supply projects of Binzhou city are becoming gradually perfect.

2.2.2 Water Demand Status

Total water withdrawals in Binzhou city are divided into 4 categories: agriculture, industrial, domestic, and ecological. Agriculture is the largest category of water use, making up more than 70% of total water withdrawals. The proportion by category in 2018 is shown in Fig. 2.

Since 2010, irrigation had been the category with the largest water withdrawals which showed a trend of fluctuating downward. Though fluctuating slightly, livestock water withdrawals was around 2×10^8 m^3. Consequently, agricultural water use showed the same trend of fluctuating downward. Industrial water withdrawals made less change from 2010 to 2017. But there was a sudden surge to 3.03×10^8 m^3 in 2018. It was due to the changes in the statistical method of water consumption, so the historical data of industrial water use can't be directly used to predict the future water use situation. Domestic water use increased gradually year by year, and

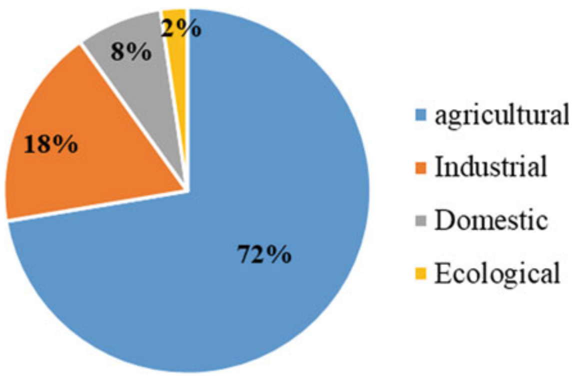

Fig. 2 The proportion by category in 2018

ecological water use almost maintained stable. Generally speaking, except for the obvious increase in 2018, which caused by industrial water withdrawals, the variation range of other years was small.

3 Methodology

3.1 The Grey System Prediction Model

The grey system prediction model is suitable for the data series affected by known or unknown factors. The main section of grey system theory is the grey prediction model. Original data will first be processed by series of mathematical methods and then directly converted into differential equations to describe the objective law of system. The law will be finally used to predict the trend in the future [13]. Model GM (1, 1) is one of the most frequently used method, which is a time series forecasting model. Its grey equation is a first order differential equation about variable and only needs one sequence [14, 15].

Assume the non-negative raw sequence as $x^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \ldots x^{(0)}(n)\right)$. A new sequence is obtained by accumulation. $x^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), \ldots x^{(1)}(n)\right) = \left(x^{(0)}(1), x^{(0)}(2), \ldots x^{(0)}(n)\right)$, where $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), \quad k = 1, 2 \ldots, n.$

The corresponding differential equation of GM (1, 1) is as follows:

$$\frac{dx^{(1)}}{d(t)} + ax^{(1)}(t) = \mu.$$

where a and μ are two parameters of the model.

The posterior difference test is carried out on the prediction model.

Let the residual of time t be $e(t) = x^{(0)}(t) - \hat{x}^{(0)}$, t = 1, 2, 3, …, m.

Then get the mean value of $x^{(0)}$ and $e(t)$:

$$\hat{x}^{(0)} = \frac{1}{m}\sum_{t=1}^{m} x^{(0)}(t), \bar{e} = \frac{1}{m}\sum_{t=1}^{m} e(t), \quad \mathrm{t} = 1, 2, 3, \ldots \mathrm{m}$$

$$S_1^2 = \frac{1}{m}\sum_{t=1}^{m}[x^{(0)}(t) - \bar{x}^0]^2, S_2^2 = \frac{1}{m}\sum_{t=1}^{m}[e(t) - \bar{e}]^2, \quad \mathrm{t} = 1, 2, 3, \ldots \mathrm{m}$$

The formulas for calculating the posterior error ratio C and the small error probability P are as follows: $C = \frac{S_2}{S_1}$; $P = P\{e(t) - \bar{e}| < 0.6745 S_1\}$, t = 1, 2, 3, …, m.

The posterior error ratio C and the small error probability P can comprehensively test the accuracy of the prediction model.

3.2 The Malthusian Population Model

Domestic water consumption is closely related to the population, so population prediction is the basis of domestic water consumption prediction. When the population growth rate changes little over the years, which means the population grows exponentially with time, and the population data is sufficient, the Malthusian population model can be used to predict [16].

The Malthusian population model is shown as follows:

$$P(t) = P(t_0)e^{r(t-t_0)}$$

where P(t) represents year t forecast population; $P(t_0)$ represents benchmark population; r represents population growth rate.

4 Results and Discussions

This part will predict the water supply and demand of Binzhou in 2025 and 2035. Then the balance of supply and demand of Water Resources will be analyzed based on the prediction.

4.1 Water Supply Prediction

According to *Basic Ideas of Water Conservancy Development Plan in the 14th Five-Year Plan Period*, by the end of 2025, Binzhou will have an additional water supply capacity of 3×10^8 m^3. The control the utilization of groundwater has always been a challenge to Binzhou [17]. Since the strictest control over water resources was imposed in 2012, Binzhou water conservancy bureau established the clear control criterion of conventional water sources consumption: the available groundwater is limited to 1.86×10^8 m^3. So, the maximum predicted value was estimated to be 1.86×10^8 m^3. According to the planning of water conservancy project of Binzhou Water Conservancy Bureau, in the future, the increase of water supply will mainly come from the unconventional water sources and the South-to-North water diversion project. The forecast data are listed in Table 1.

It can be seen from Table 1 that the increased water supply in the future will mainly come from the Yangtze River diverted by the South-to-North Water diversion Project. After 2035, Binzhou City will increase the water supply by 4.5×10^8 m^3 through the South-to-North Water transfer Project. Further development of unconventional water supply will also ease the shortage of water supply.

Table 1 The water supply forecast results of Binzhou city

Year	Surface water			Groundwater	Other water source	Total
	Local surface water	Inter-basin transfer water				
		The Yellow river	The Yangtse river			
2025	4.42	8.57	1.51	1.86	1.48	17.84
2035	4.50	8.57	4.50	1.86	2.37	21.80

Unit: $\times 10^8$ m^3

4.2 Water Demand Prediction

Water demand prediction is the crucial part of the analysis of water supply-demand equilibrium and the chief foundation of the sustainable utilization of water resources. For easy comparison and analysis, the estimation of water withdrawals was classified into 4 categories as *Shandong Statistical Yearbook*: agriculture, industrial, domestic, and ecological.

4.2.1 Domestic Water Prediction

Because of the small change in the index of average water consumption per capita, domestic water use was predicted by quota method and the population was predicted by Malthus model.

In 2018, Binzhou city had a population of 3.97×10^6, an urban population of 2.00×10^6, with urbanization rate of 50.46%. According to *Binzhou General Urban Planning* (2018–2035) and the data in 2018, the population of Binzhou city in the future was predicted by the Malthusian model: in 2025, the total population of Binzhou will reach 4.14×10^6, with an urbanization rate of 62%; in 2035, the total population will be 4.4×10^6, with an urbanization rate of 80%.

Domestic water consumption is divided into two parts: residential water consumption and public water consumption. And the residential water is divided into urban domestic and rural domestic. According to the corresponding indexes of Shandong, through comprehensive analysis, the standards were set as follows: the domestic water standard of urban residents 95 L/P·D, domestic water standard for rural residents 75 L/P·D, public water standard 30 L/P·D. Prediction results of domestic water consumption in Binzhou City are shown in Table 2.

According to the forecast, although the population of Binzhou will increase in the future, the domestic water consumption will not increase greatly. Due to natural growth and migration factors, the urban population has increased significantly, so the change of urban water consumption is the main reason for the increase of domestic water consumption. Rural water use and urban public water use will be controlled by the total population and indicators, so the increase will be small.

Table 2 Domestic water prediction of Binzhou

Year	Urban domestic	Rural domestic	Public	Total
2025	0.89	0.43	0.28	1.60
2035	1.22	0.24	0.39	1.85

Unit: $\times 10^8$ m^3

4.2.2 Agricultural Water Prediction

Agricultural water includes irrigation water and livestock water. Irrigation water includes paddy, irrigated, vegetable fields, woodland, and grassland water. Livestock water includes fish pond water replenishment. According to the water consumption of 6 kinds of agricultural land and the irrigation area over the years, the trend of agricultural water consumption index is shown in Fig. 3.

It can be seen from Fig. 3 that after 2015, the agricultural water indicators tended to be stable. Based on the average value of agricultural water indexes from 2010 to 2018, the prediction indexes of various agricultural water use were determined in Table 7. Regarding the forecast of agricultural irrigation area, on the one hand, people's requirements for material living will continually improve with the development of economy; on the other hand, the water-saving projects and water conservancy irrigation system have been much more perfect. In addition, the scale of fishing and livestock in Shandong Province has become stable in recent years. Considering these factors comprehensively, it is excepted that the vegetable fields and woodland will increase in the next ten years, while the paddy, irrigated lands, grassland and fish ponds will basically keep the present situation. The prediction of each category is shown in Table 3.

Due to the lack of relevant data on the number of livestock in Binzhou City, the water consumption of livestock over the years can only be used to predict the future water consumption. Referring to the livestock water consumption from 2010

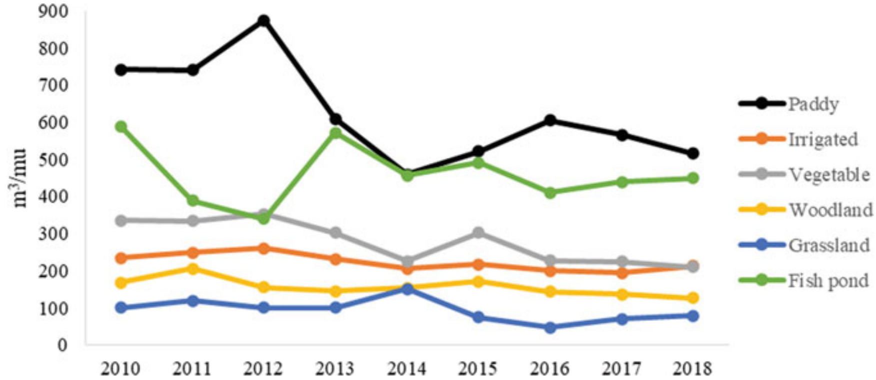

Fig. 3 Trend of agricultural water consumption index

Table 3 The prediction for agriculture

Type	Paddy	Irrigated	Vegetable	Woodland	Grassland	Fish pond
Index	500	210	210	150	90	450
2025	1	460	40.3	73.6	0.8	20
2035	1	460	43.6	79.8	0.8	20

Unit: m^3/mu, $\times 10^4$ mu

Table 4 The prediction of agricultural water

Year	Paddy	Irrigated	Vegetable	Woodland	Grassland	Fish pond	Livestock	Total
2025	0.050	9.66	0.85	1.10	0.0072	0.90	0.25	12.81
2035	0.050	9.66	0.92	1.20	0.0072	0.90	0.25	12.98

Unit: $\times 10^8$ m^3

to 2018, except for the obvious deviation of livestock water consumption in 2013, the water consumption in other years had little fluctuation, which was basically around 2.5×10^7 m^3. What's more, some data show that the development scale of animal husbandry in Shandong Province tends to be stable in recent years [18]. So the average annual water consumption of livestock in different level years is 2.5×10^7 m^3 after excluding abnormal years.

The total amount of agricultural water demand in Binzhou City in different level years is obtained by combining the prediction results of agricultural water prediction indexes and different types of agricultural land area. The prediction results are shown in Table 4.

Under the background of frequent conversion of land use types and conversion of agricultural land to construction land [19], the cultivated land area will keep the original amount, and some land type area will increase slightly. Meanwhile, the popularization of agricultural water-saving equipment and the improvement of water conservancy facilities have reduced the agricultural water consumption indexes. Therefore, the future agricultural water consumption of Binzhou City will basically remain unchanged, just as predicted in Table 4.

4.2.3 Industrial Water Prediction

The amount of industrial water is related to many factors, such as industrial structure, leakage rate of water supply network, water saving technology, etc. Take the industrial output value of Binzhou City from 2007 to 2018 as the original sequence. Establish the GM (1, 1) model based on the grey model principle, and obtain the model parameters: $a = -0.0468$; $\mu = 760.1454$.

The relative error of the prediction model only exceeded 10% in 2008 and 2009, and the average relative error was only 5.37%. The predicted result has been proved to be I-grade model with high fitness by after-residual-test: $C = 0.34 \leq 0.35$; $P =$

Table 5 The prediction of industrial water

Year	Gross industrial output value ($\times 10^8$ yuan)	Water consumption per unit industrial added value (m^3/w yuan)	Industrial water consumption ($\times 10^8$ m^3)
2025	1792.15	37	6.63
2035	2861.73	31	8.87

$1 \geq 0.95$. Therefore, this model could be used to predict the industrial output value of Binzhou city.

According to *Analysis Report on Water Resources Carrying Capacity of Binzhou*, the water consumption per unit industrial added value in Binzhou was 41 m^3/w yuan, and the report predicts that it would be 37 m^3/w yuan in 2025. Referring to the data, the water consumption per unit industrial added value in 2035 could be calculated. The prediction results are shown in Table 5.

4.2.4 Ecological Water Prediction

Ecological water demand refers to the water which is needed to maintain the stability of the ecological environment and ensure the healthy development of the ecological system in a certain area. In this paper, the ecological water prediction mainly refers to the water out of the river channel, including the water demand of urban green space and watering road.

The green coverage area, road area and urban population in Binzhou City from 2007 to 2018 were analyzed by linear regression analysis. According to *The Standard of Water Quantity for Urban Domestic Use in Shandong*, water consumption indexes of urban greening and road watering were set at 0.5 and 1.5 L/m^3. The prediction results of ecological water are shown in Table 6.

Compared with 4×10^7 m^3 in 2018, the ecological water consumption in 2025 and 2035 will increase by 77.5% and 152.5%, respectively. The main reasons behind it are the increase of urban roads, urban green space, and ecological water use index, which shows that people are paying more attention to ecological environment, hoping that it can work normally in ecological regulation.

Table 6 The prediction of ecological water

Year	Green area ($\times 10^4$ m^2)	Road area ($\times 10^4$ m^2)	Greening water use ($\times 10^8$ m^3)	Road water use ($\times 10^8$ m^3)	Total ($\times 10^8$ m^3)
2025	10,035.86	2869.09	0.55	0.16	0.71
2035	14,308.10	4055.82	0.78	0.22	1.01

Table 7 The prediction of total water demand

Year	Agriculture	Industrial	Domestic	Ecological	Total
2025	12.81	6.63	1.60	0.71	21.75
2035	12.98	8.87	1.85	1.01	24.70

Unit: $\times 10^8$ m^3

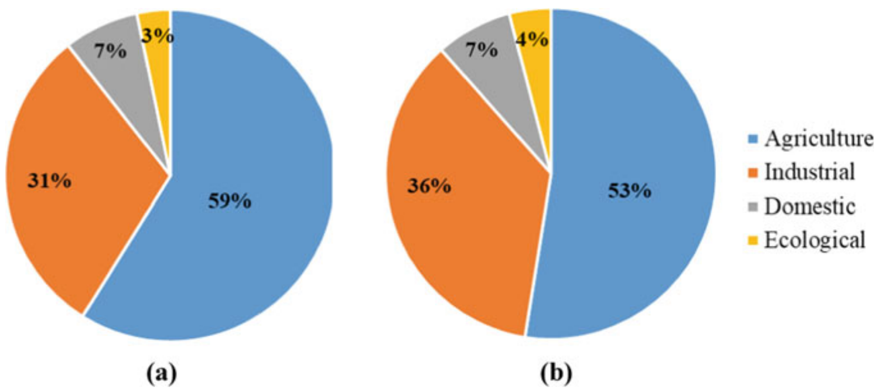

Fig. 4 **a** The proportion by category in 2025. **b** The proportion by category in 2035

4.2.5 Total Water Demand

According to the four kinds of water consumption forecast results of Binzhou City, the total water demand was obtained. The total water demand would be up to 2.18×10^9 m^3 in 2025 and 2.47×10^9 m^3 in 2035, respectively, 26.90% and 44.11% higher than that in 2018. The summary results are shown in Table 7.

The proportion of various types of water demand to total water is shown in Fig. 4a, b. In 2025, agricultural water consumption would account for 59% of the total, 13% higher than that in 2018. In 2035, industrial water consumption would account for 36%, an increase of 18 percentage points over 2018. The proportion of domestic water consumption would be relatively stable. Ecological water consumption in 2025 and 2035 would account for 3% and 4% respectively, up slightly from 2% in 2018. In the next 15 years, agricultural would still be the main consumption of water in Binzhou City, exceeding half of the total water consumption. Industry would also develop rapidly, and the proportion of industrial water consumption would increase significantly. Ecological water use would be emphasized and consumption would increase.

4.3 Analysis of Water Supply and Demand Balance

According to prediction, in 2025, the water shortage of Binzhou City would be 3.92×10^8 m^3, and the water shortage rate would be up to 17.98%; in 2035, the water shortage 2.90×10^8 m^3, and the water shortage rate 11.74%. Water resources in Binzhou City would be in short supply both in 2025 and 2035, but the amount and the rate of shortage in 2035 would be lower than those in 2025. In addition to Binzhou's active response to the call of water conservation and the improvement of water-saving renovation projects, the reason behind it is to increase water supply sources. Due to the high degree of development of the existing water resources, it is difficult to open up new conventional water resources. So, the water resources are mainly opened up from two aspects, one is the second phase of the South-to-North Water transfer Project, and the other is to further develop the utilization of unconventional water resources.

The supporting project of the second phase of the South-to-North Water transfer Project has basically completed the preliminary demonstration stage, and various preparatory works are being carried out steadily. According to the results of the investigation in Shandong Province, it can transfer 3.50×10^8 m^3 of water to Binzhou City [20]. But overall, in the near future, Binzhou will still face a large gap in the water use. According to the previous situation, the lack of water consumption will be solved mainly through the over-diversion of the Yellow River. However, due to the limitation of the Yellow River diversion index, the water supply in some areas is unstable [21].

Under the premise of strict control and gradual reduction of groundwater exploitation, Binzhou City must continue to adhere to the construction of water-saving cities and strictly control the total amount of water withdrawal in all districts. With the support of the government, key agricultural and industrial units should, according to the characteristics of industry, improve water conservancy facilities, upgrade water-saving technologies, and gradually phase out equipment products which don't meet standards. In terms of urban life, the government should vigorously popularize water-saving appliances and improve the water-saving incentive mechanism. While reducing expenditure, Binzhou City should also make full use of existing resources to further develop unconventional water resources. Take water from the sea, explore seawater desalination technology. Recycle reclaimed water to meet part of the water demand as well as reducing sewage discharge [22]. Improve the ability of collecting and utilizing rainfall, making rain water reused when water is short [23]. To summarize, in Binzhou City, where water resources are in short supply or even serious shortage, the principle of "better use of high-quality water, worse use of inferior water" must be implemented to realize sustainable utilization of water resources on the premise of orderly daily life.

5 Conclusion

Through the classified forecasting method, mainly index quota method and grey forecasting model, the total water demand and supply of Binzhou City in 2025 and 2035 were obtained, and the result was not optimistic. In the future, the utilization of water resources in Binzhou City will be in short supply. In 2025 and 2035, the water shortage rate of Binzhou City would be 17.98% and 11.74% respectively. In the future, the increase of agricultural water consumption would be not obvious, but it would always be the largest sector of water consumption; the industrial water consumption would rise rapidly, with an increase of 3.3×10^8 m^3 and 5.84×10^8 m^3 in 2025 and 2035 respectively compared with that in 2018; the proportion of domestic water consumption would remain at about 7%; the ecological water consumption would slightly increase with people's attention to the ecological environment, with the proportion increasing from 2 to 3% and 4%. The local government also foresaw the problem of water shortage and attached great importance to the construction of water-saving cities. Binzhou City needs to continually pay attention to increasing revenue and reducing expenditure of water resources, as well as find more sustainable solutions.

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Theoretical Method and Application of Assessment on Water Resources Carrying Capacity: A Case Study of Binzhou, Shandong

Chengjie Zhang, Sheng Zheng, and Yuzhe Wu

Abstract The study of water resources carrying capacity (WRCC) has vital significance for coordination of water and society, economy along with ecology. The purpose of this paper was to analyze current concept and methods of evaluation on WRCC, then carry out the assessment and obtain the carrying status. Based on the review of research on WRCC, considering water quantity, quality and social economy factors, a comprehensive evaluation model was established by application of AHP-PCA method. Both subjective and objective conditions were taken into consideration simultaneously in this method. Binzhou City was taken as a case study to assessment the carrying status of its water resources. Calculating by the AHP-PCA Synthetic Evaluation model based on data from 2010 to 2017, it is considered that the WRCC of Binzhou was mainly affected by total population, total water supply and per capita water consumption. And the result showed that the evaluation values fluctuate between 2.10 and 2.75 in recent years, which indicated the WRCC was at the level of mild overload in this city. From the above conclusion, we learned that the sustainable development of Binzhou had been limited by the level of its WRCC. Therefore, some practical policies were provided.

Keywords Water resources carrying capacity · Principal component analysis · Binzhou city

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1 Introduction

Water resources are very important to human survival and development. With the expansion of population scale and the social economic development in China, the imbalance between water supply and demand is intensifying. China's per capita water capacity is much lower than the world average level [1]. How to enhance the rational utilization of water resources has important significance upon sustainable development. The comprehensive study on water resources carrying capacity (WRCC) integrates analysis, prediction and evaluation, with complex content [2], such as economy, population, resources and environment. According to the requirements of ensuring water security in the new period, the research on WRCC is of great significance. As an important part of "Double Evaluation" in the Territorial Spatial Planning System, the evaluation of WRCC serves the compilation of the former at all levels, and through which, we can understand the characteristics of regional water resources, find out the prominent problems and possible risks, and define the capacity considering the function of ecological protection, agricultural production, urban construction, etc.

Since scholars introduced "carrying capacity" into the ecology, this concept has evolved continuously, and related research has been developed gradually with the combination of resources and environment. In the 1980s, UNESCO proposed the concept of resource carrying capacity [3] and WRCC is a category of it. Due to the water shortage, pollution and other problems, WRCC came into being and the connotation is reflected in the research of sustainable development in foreign studies, such as, "available water quantity" [4], "water supply and demand ratio" [5], "limit of water resources system" [6]. In the study of water resources management in northeast Tanzania, Ngana et al. considered that the local water resources could no longer meet the water demand, and analyzed the reasons [7]. Ait Aoudia et al. calculated the maximum population supported by water resources considering demand and water supply factors in Algiers [8]. Shelby et al. studied the carrying capacity of the Illinois River [9]. Sawunyama et al. used Remote Sensing (RS) and Geographic Information System (GIS) technology to evaluate the storage capacity of small reservoirs in southeast Africa [10]. Widodo showed controlling land conversion rate, water use and managing rainwater collection were effective strategies to improve WRCC [11]. Rijsberman used carrying capacity to evaluate urban water resources and study management system [12].

Since the concept of WRCC was clearly put forward, it has become the concerned research topic to Chinese scholars. The research on the WRCC has experienced a period of concept presentation, theoretical exploration, developing and elaboration. The academic projects carried out by a water resources research group in Xinjiang in 1980 lifted the curtain in China [13]. Then scholars paid much attention to the WRCC and conducted extensive research in the 1990s, with rich achievements, while no mainstream definition and leading method widely accepted. The problem of ecological environment became more and more serious at the beginning of the twenty-first century, which also encouraged more research on WRCC. Zhu Yizhong, Feng Yaolong, Long Tengrui and other scholars further discussed the connotation, theory and method [14–16]. Scholars such as Guo Haidan, Fang Guohua have made certain achievements in the research of evaluation model [17, 18]. During this period, the research results gradually systematized and the viewpoints gradually matured. Although there was still no unified concept or evaluation method, several representative views were formed. At present, scholars constantly improve the study and carry out empirical research by introducing new concepts, such as ecological footprints [19], metabolic theory [20], or by perfecting the method of evaluation [21, 22]. The situation of WRCC in China is still grim and the targeted research work must be carried out continuously, which also drives the scholars to explore in this field.

At present, scholars have done more research on single method while less attention was paid to balance subjective and objective conditions. This article studied the theoretical methods of WRCC and constructed a model combining subjective and objective. And an experimental area, Binzhou was selected to approach practice implication of this method. The paper was structured as follows: After the first part of introduction, the second part discussed the theories and methods, and Analytic Hierarchy Process (AHP)—Principal Component Analysis (PCA) synthetic evaluation method used in this study was introduced. The third part carried out the evaluation experiment of WRCC of Binzhou, a city with serious water problems but few researches, and finally analyzed the results. The last part came up with the conclusion.

2 Theories and Methods

2.1 Connotation of Water Resources Carrying Capacity

There is no consensus on the definition of WRCC and the current definition can be divided into two types [23, 24]: the maximum capacity of development and utilization and the maximum support scale of water resources. For the first definition, there is a definition of the maximum water resources exploit capacity considering agricultural and industrial production, living of residents and ecological environment protection in a certain social economic and technical stage put forward by Xu Youpeng. For the second definition, Shi Yafeng thinks that WRCC refers to the maximum agriculture, industry, urban scale and population level that water resources can carry at some level of scientific technological and social phase without damaging the system. Due to the different starting points and application requirements, there is also a gap in the understanding, resulting in the concept is not unified, which is also rational.

In a word, WRCC is the embodiment and application of sustainable development theory, composite system theory and water resources optimal allocation management theory. Based on this theory, the concept covers four factors: the status of water resources, the influence of socio-economic and technological development, ecological environment guarantee factor, and the support of population, social and economic system [25]. The quantitative evaluation of WRCC is the stance.

2.2 Evaluation Methods of Water Resources Carrying Capacity

There are many evaluation methods but the setting up of index system is a basic work. According to the coupling relationship between indicators, an orderly and comprehensive system can be established by selecting appropriate measurement indexes. The construction of the index system should start from the characteristics of water resources, and emphasize the operability, which can comprehensively reflect the status of coordinated social economy and ecological environment development, the status of sustainable utilization of water resources and their mutual adaptability.

At present, the evaluation methods of WRCC include index calculation method, conventional tendency method, fuzzy synthetic evaluation, principal component analysis, multi-objective analysis and evaluation, system dynamics method, etc. [26]. The index calculation method calculates the factor index directly according to the empirical formula. The characteristic is that the calculation is relatively straightforward and easy to be popularized, but the connection among resources, environment, economy and society is less considered, and it is difficult to fully oppose the dynamic change of WRCC. For the fuzzy synthetic evaluation method, the multi factor comprehensive evaluation is carried out through evaluation matrix, which can transform qualitative evaluation to quantitative evaluation, comprehensively reflect the status of WRCC [27]. The advantage is that the scientific application of mathematical theory. But there are some problems such as the difficulty to unify the selection of indicators and the difficulty to determine the evaluation criteria. Multi-objective analysis evaluation method is to seek the overall optimization of multiple objectives by means of system analysis under the main constraints that affect the water resources system [28]. From the existing research, the set of constraints can match the factors of water resources, society, economy and sustainable development, but the contradictions of various constraints are difficult to resolve. System dynamics method, as a simulation method, analyze the carrying capacity from the internal structure of the system [29]. This method has advantages in understanding, analyzing and dealing with nonlinear, high-order, multiple feedback, complex varying time system problems, but the calculation method is complex and difficult to be popularized and applied.

This paper adopted AHP-PCA synthetic evaluation method. AS a widely used method, AHP can make complex problems hierarchical and simple. Considering the influence of each index based on experience, AHP method determine the weight of the index, which is more subjective. PCA is an objective weight determination method, which has strong theoretical basis and does not rely on subjective judgment. According to the principle of this method, the optimal synthesis and simplification of multi-dimensional variables are carried out However, sometimes the calculated weight is inconsistent with the actual influence degree of indicators. In this paper, considering the defects and merits of the two methods, AHP was used to calculate the weight of indicators, and the preference of decision makers for indicators was retained. At the same time, the weight determined by PCA was revised to reduce the subjective randomness as much as possible, which made the empowerment more reliable and makes the quantitative evaluation of WRCC more accurate.

3 Evaluation of WRCC in Binzhou City

3.1 General Situations of Study Region

Binzhou, located in the north of Shandong Province and the hinterland of the Yellow River Delta. This city has two districts, four counties and one county-level city, with a total area of 9453 km^2. In 2019, Binzhou has a total population of 3.97 million and annual GDP of 245.72 billion yuan, and the industrial structure adjustment is 9.37:42.37:48.26. Due to concentrated precipitation, drought and flood disasters often occur in Binzhou. The rivers in the city can be divided into Haihe River Basin, Huaihe River Basin and Yellow River Basin, and generally flow into the Bohai Sea. The increasingly severe situation of water shortage has become an important factor restricting the development and the contradiction between supply and demand of water is becoming more serious.

3.2 Construction of WRCC Evaluation Model

3.2.1 Analytic Hierarchy Process

Analytic hierarchy process (AHP) obtains the comparison judgment matrix through the expert scoring, and calculates each index weight value. The specific steps are described briefly below: the first step, decompose the relevant factors into some levels from top to bottom according to different attributes after in-depth analysis of practical problems. The factors at the same level have influence on the factors at the upper level, and affected by the lower level factors. In the second step, a pair comparison matrix is constructed. The importance of each factor in the same level is compared according to the 9-bit scale method and the judgment value is given. Then the judgment matrix $\mathrm{M} = (\mathrm{m_{ij}})_{\mathrm{n\times n}}$ is constructed. In the third step, for each pair comparison matrix, the maximum eigenvalue and corresponding eigenvector are calculated, and the consistency index, random consistency index and consistency ratio are used for consistency test. The eigenvector (normalized) is the weight vector if the test passed, written $Q_{1i}(i = 1, 2, 3, \ldots, n)$.

The quantitative weight m_{ij} is used to compare the importance of the ith element and the jth element. Let n elements participate in the comparison, m_{ij} is between 1 and 9 and its reciprocal.

$m_{ij} = 1$ The importance of element i is the same as that of element j; $m_{ij} = 3$ Element i is a little more important than element j; $m_{ij} = 5$ Element i is more important than element j; $m_{ij} = 7$ Element i is much more important than element j; $m_{ij} = 9$ Element i is exceedingly important than element j. For example, written Formula (1):

$$M = \begin{pmatrix} 1 & 1/2 & 3 & 1/2 \\ 2 & 1 & 1/2 & 3 \\ 1/3 & 2 & 1 & 1/5 \\ 2 & 1/3 & 5 & 1 \end{pmatrix} \tag{1}$$

3.2.2 Principal Component Analysis

As a multivariate statistical method, principal component analysis (PCA) simplifies multiple related variables into several comprehensive principal components. It can reduce the dimension of variables while preserving the original variable information as much as possible. It is assumed that n indexes are included in the analysis of a problem, denoted by

$$X = (X_1, X_2, X_3, \ldots, X_n) \tag{2}$$

The synthetic random vector is obtained by linear transformation of random vector

$$Y = (Y_1, Y_2, Y_3, \ldots, Y_m) \tag{3}$$

In the process of linear transformation, the synthetic random vector should reflect the information of the original random vector as much as possible. "Information" is generally measured by variance, and the larger the variance of synthesized random variable Y_j is, the more information it contains. The linear transformation must satisfy the condition that the variance is the largest and the different components are uncorrelated. The resultant variable is called the "principal component" of the original variable. The composite variable $Y_j(j = 1, 2, \ldots, m)$ satisfying the above conditions is the jth principal component of the original variable, and the proportion of variance of each component in the total variance decreases from 1 to m. Then the eigenvectors and expressions of principal components are calculated. Finally, the weight of each index is determined according to the information contribution rate and factor load of principal components.

The detailed steps are as follows: firstly, standardize the raw data; secondly, calculate the normalized sample correlation matrix and the cumulative contribution rate after linear transformation; thirdly, calculate the eigenvector and eigenvalue of the principal component $\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_m$, then determine the parameter value of the principal component expression:

$$F_j = \mu_{1j} \times X_1 + \mu_{2j} \times X_2 + \cdots + \mu_{nm} \times X_n, \quad j = 1, 2, \ldots, m \tag{4}$$

where, F_j represents the factor score of the jth principal component and μ_{ij} is the coefficient of linear combination. The relationship between the coefficient and the initial factor load f_{ij} is as follows:

$$\mu_{ij} = \frac{f_{ij}}{\sqrt{\lambda_j}}, \quad j = 1, 2, \ldots, m \tag{5}$$

Finally, the weight of each index is determined according to the principal component expression and the information contribution rate of each principal component, written $Q_{2i}(i = 1, 2, 3, \ldots, n)$.

3.2.3 AHP-PCA Synthetic Evaluation Model

The synthetic evaluation model combines the weights obtained by AHP and PCA according to a certain proportion. In this paper, the additive synthesis method was used to determine the combination weight:

$$Q_i = a_0 \times Q_1 + (1 - a_0)Q_2 \tag{6}$$

where $Q_i(i = 1, 2, 3, \ldots, n)$ is the comprehensive weight of each index; a_0 is the proportion of AHP, generally taken as 0.5.

According to the calculated weight, the evaluation value E of WRCC can be calculated:

$$E = \sum Q_i \times x'_i \tag{7}$$

where, x'_i is the normalized value of the ith index.

In order to reflect the capacity of regional water resources more accurately and objectively, according to the international and national recognized standards and referring to the national and local development plans, the evaluation criteria is divided into five states: Grade I severe overload, grade II moderate overload, grade III mild overload, grade IV bearable and grade V full bearing. The corresponding score ranges of each level range were (0–1), (1–2), (2–3), (3–4), and ≥4.

3.3 Empirical Study on Evaluation of WRCC

3.3.1 Index Selection

The evaluation of water resources is a complex system formed by the coupling of social, economic, environment and water resources. Environment, social and increasingly advanced technology are the main factors affecting the WRCC. Influence of the current situation of water resources, social environment and economic development level on the carrying capacity of Binzhou City was fully considered in the selection of indicators. Taking into account the accessibility of data, the evaluation index system was constructed based on the principles of scientificity and comprehensiveness as well as the existing research results, including 12 indicators: GDP X_1 (100 million Yuan), Industrial Added Value X_2 (100 million Yuan), Total Population X_3 (10 thousand people), Population Urbanization Rate X_4, Total Water Supply X_5 (100 million m^3), Utilization of Unconventional Water Source is X_6(100 million m^3), Per Capita Water Consumption X_7 (m^3), Irrigation Water Consumption X_8 (100 million m^3), Industrial Water Consumption X_9 (100 million m^3), Residential Water Consumption X_{10} (100 million m^3), Ecological Environment Water Supplement Amount X_{11} (100 million m^3), Amount of Wastewater Discharged into the River X_{12} (10 thousand tons). This paper selected the data of the above 12 index factors from 2010 to 2017 to carry out dynamic comprehensive evaluation on WRCC of Binzhou. And the data were extracted from Water Resources Bulletin issued by Water Conservancy Bureau of Binzhou.

Since the initial dimensions of each index are different, the range standardization method was used to standardize the original data to eliminate the differences between dimensions and increase the comparability of data. The solve methods are as follows:

$$\text{Positive indicators} : x_i' = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{8}$$

$$\text{Negative index} : x_i' = \frac{\max(x_i) - x_i}{\max(x_i) - \min(x_i)} \tag{9}$$

where, x_i is the original data, x_i' is the processed data,$\max(x_i)$ and $\min(x_i)$ are the maximum and minimum value of the raw data, respectively. In the established index system, total water supply and unconventional water use are positive indicators, while per capita water consumption and irrigation water consumption are negative indicators. The larger the positive index value is, and the smaller the negative index value, the higher the WRCC is.

3.3.2 Weight Determining

AHP was used to calculate the index weight and the results were as follows:

$$Q_1(0.0552, 0.0304, 0.1076, 0.0336, 0.1291, 0.0814, 0, 1194, 0.1128, 0.0964, 0.0700, 0.0676, 0.0964)$$

Through the AHP, the relatively important index factors included per capita water consumption, irrigation water consumption, total water supply, total population, etc.

Table 1 Correlation coefficient matrix

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1											
X_2	0.701	1										
X_3	0.692	0.37	1									
X_4	0.927	0.406	0.646	1								
X_5	0.061	−0.601	0.299	0.352	1							
X_6	0.045	−0.388	0.192	0.316	0.411	1						
X_7	−0.606	−0.639	−0.4	−0.387	0.337	0.52	1					
X_8	−0.65	−0.37	−0.314	−0.656	−0.002	−0.361	0.347	1				
X_9	0.27	−0.486	0.24	0.584	0.859	0.568*	0.138	−0.372	1			
X_{10}	0.843	0.394	0.719	0.885	0.4	0.331	−0.234	−0.666	0.501	1		
X_{11}	0.362	0.683	0.144	0.095	−0.531	−0.489	−0.581	−0.209	−0.456	−0.018	1	
X_{12}	0.586*	−0.064	0.38	0.806	0.701*	0.357	−0.062	−0.377	0.818	0.643	−0.058	1

*Significant at $p < 0.05$

Table 2 Eigenvalue and variance contribute of principal component

principal component	Eigenvalue	Variance contribute (%)	Cumulative variance contribute (%)
1	5.257	43.805	43.805
2	3.852	32.103	75.908
3	1.005	8.371	84.279

The correlation coefficient matrix of driving factors of WRCC can be obtained by principal component analysis (PCA) with SPSS software, as shown in Table 1. The factors represented by X_1 to X_{12} were described in Sect. 3.3.1.

The result shows in Table 1 that there is correlation between the selected factors, which is the basis and condition for the PCA, and further verifies the necessity and scientificity of this method. The eigenvalues and variance contribution rates of principal components are shown in Table 2.

The three principal components comprehensively reflect the driving factors affecting the change of WRCC, which can fully reflect the interannual variation.

The component matrix (Table 3) indicates that the first principal component has a strong correlation with GDP, urbanization rate, residential water consumption, total population, ecological environment water supplement amount and waste water discharge, which cover the social, economic and ecological factors. The development level of Binzhou was the main factor affecting its WRCC. The heavy use of water resources and water pollution cause a burden in recent years. However, with the improvement of technological level and the development of social economy, the utilization capacity of water resources has been significantly enhanced, and the water

Table 3 Component matrix

Factor	Load on the 1st principal component	Load on the 2nd principal component	Load on the 3rd principal component
X_1	0.898	−0.406	0.008
X_2	0.342	−0.888	−0.141
X_3	0.724	−0.157	0.132
X_4	0.976	−0.050	0.002
X_5	0.437	0.783	0.389
X_6	0.354	0.646	−0.591
X_7	−0.370	0.736	−0.308
X_8	−0.707	0.166	0.499
X_9	0.631	0.698	0.148
X_{10}	0.929	−0.004	−0.112
X_{11}	0.085	−0.811	0.102
X_{12}	0.798	0.353	0.280

Table 4 Weights of evaluation indexes

Factor	Weight by AHP	Weight by PCA	Combination weight
X1	0.0552	0.1217	0.0884
X2	0.0304	0.0464	0.0384
X3	0.1076	0.0981	0.1028
X4	0.0336	0.1322	0.0829
X5	0.1291	0.0908	0.1100
X6	0.0814	0.0749	0.0782
X7	0.1194	0.0854	0.1024
X8	0.1128	0.0296	0.0712
X9	0.0964	0.0810	0.0887
X10	0.0700	0.1258	0.0979
X11	0.0676	0.0061	0.0368
X12	0.0964	0.1081	0.1022

supply capacity based on the natural endowment of water resources has been greatly improved.

The second principal component has a strong correlation with total water supply, unconventional water utilization, per capita water consumption and industrial water consumption, which reflect the influence of water supply and demand on carrying capacity. The introduction of unconventional water sources, such as sewage treatment and reuse and seawater utilization, has released the pressure on water resources in Binzhou City to a certain extent under the condition that the total amount of water resources is basically stable.

The third principal component is related to the water consumption of farmland irrigation. This kind of water consumption accounts for more than 60% of the total water resources use in Binzhou all the year round, and the use efficiency needs to be improved. The irrigation methods and whether the water resources can be saved and intensively used affect the irrigation water consumption and further affect the WRCC of Binzhou City.

Based on the eigenvalues and contribution rate of each principal component and the load matrix, the weight Q_2 of each index was calculated, and combined with the weight Q_1, the comprehensive weight was obtained by the method of additive synthesis The results are shown in Table 4.

Generally, total population, total water supply and per capita water consumption are three more important factors of water resources carrying capacity in Binzhou City.

Table 5 Evaluation results of WRCC of Binzhou

Year	2010	2011	2012	2013	2014	2015	2016	2017
Evaluation value	2.21	2.75	2.10	2.67	2.33	2.37	2.63	2.48

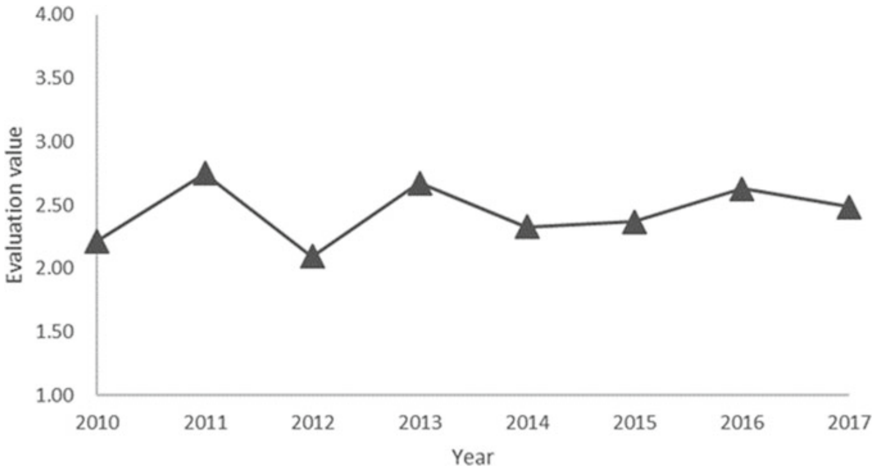

Fig. 1 Value and variable trend of WRCC of Binzhou City

3.3.3 Evaluation Results of Water Resources Carrying Capacity

By substituting the standardized data and the comprehensive weight into Formula (7), the evaluation value of WRCC of Binzhou City from 2010 to 2017 can be obtained. The results are shown in Table 5, which indicate that the local WRCC had been at the level of grade III mild overload in recent years. The overall development potential was relatively small.

As shown in Fig. 1, the WRCC fluctuated in a small range in recent years, and the overall trend was relatively stable. The study indicated that the WRCC of Binzhou was mainly affected by total population, total water supply and per capita water consumption. Under the dialectical contradiction between the demand pressure of development on water resources and the improvement of utilization level brought by development, water resources of Binzhou were in a tight balance.

In fact, the amount of groundwater exploitation and diverted water has exceeded the controlling index issued by the authority, although the total amount of water use has not After a period of rapid development, Binzhou City has entered a critical period of transformation. Measures should be taken to curb the negative effects of the fragile critical state of WRCC on economy and society, and promote comprehensive sustainable development.

In order to alleviate the constraints of water resources on development, Binzhou should follow the principles of "opening up sources and reducing expenditure", spatial balance, and systematic governance. On the one hand, Binzhou ought to enhance the level of utilization of water resources through the implementation of water conservancy projects, and gradually improve the repair and construction of rivers, lakes, ditches and reservoirs to establish a modern and efficient water conservancy network, increase the reuse of waste water and seawater desalination as well. On the other hand, it is suggested to promote the intensive and economical utilization level of water resources through improving water use efficiency, reducing the water consumption level of agriculture and industry, and strengthening the dual control of total water consumption and intensity.

4 Conclusion

This paper discussed the connotation and theoretical methods of water resources carrying capacity based on summarizing the research progress. The angles of the definition as "the maximum capacity of water resources utilization" and "the maximum supporting scale of water resources" were introduced. The index calculation method, regular trend method, fuzzy synthetic evaluation, principal component analysis, multi-objective analysis evaluation method and system dynamics method were discussed.

We constructed an index system and made an empirical study on WRCC of Binzhou by using the AHP-PCA synthetic evaluation method, considering the operability and process of coordinated development of social economy and ecological environment. And the situation of WRCC in this area was comprehensively evaluated. The results showed that the three most important factors that affected WRCC were total population, total water supply and per capita water consumption, what's more, the evaluation values fluctuated between 2.10 and 2.75 which signified the WRCC of Binzhou in recent years is at the level of slight overload according to the evaluation criteria. The article maintains that with the development of social economy, on the one hand, the utilization level of water resources improved, and on the other hand the consumption increased. Mild overload of WRCC reflects this fragile balance, which has become a limiting factor to Binzhou's future. At last, some policy proposals were provided according to the above analysis.

There are still two deficiencies of the method used in this paper. firstly, although there are certain principles to follow in the establishment of the index system, the determination of specific indicators is still subjective, and different selection will affect the evaluation results. Therefore, more researches are needed to ensure the scientificity of the index system. Secondly, "capacity" evaluated by AHP-PCA synthetic method is abstract, despite this method has an advantage of considering both subjective and objective aspects. The classification criteria for evaluation value of this capacity needs further studies to reflect the practical significance of the evaluation results.

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Resources Saving Performance Evaluation of Huizhou Residential Houses Design Scheme

Lingxiao Wang and Xuexue Yang

Abstract The contradiction between the increasing demand for housing and the shortage of resources in Huizhou makes it important to consider saving resources when designing Huizhou houses. It is particularly important to evaluate the resources saving performance of the design scheme of Huizhou houses scientifically and accurately. This paper combined the resources saving items of the GB/T 50378-2019 "Evaluation Standards of Green Building" (ESGB) with BIM software's to evaluate the performance of resources saving with the typical residential design scheme of Huizhou, and the original design scheme is optimized according to the evaluation results. The final results show that the optimized design scheme of residential house is more in line with the purpose of green building in the field of energy and material saving, and the capability of resources saving has been improved. The evaluation method proposed in this paper can accurately quantify the resources saving performance of residential house design scheme in Huizhou, which promotes the sustainable development of buildings.

Keywords Huizhou residential houses · BIM · Green building · Design scheme · Evaluation of resources saving performance

1 Introduction

With the development of tourism and the improvement of resident's living standards in Huizhou, Anhui province, the traditional residential houses need to be protected, renovated and expanded. Because Huizhou is remote from city, building materials need to be transported far away, and lacking construction resources such as land, stone and energy, so there is a higher demand for the resources saving performance of Huizhou residential houses. According to GB/T 50378-2019 "Evaluation Standard of Green Building" (ESGB) issued by Ministry of Housing and Urban-Rural Development of China, the original index system of the seven chapters are reconstructed

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to five chapters including "security and durability, healthy and comfortable, life convenient, resources saving, environmental livable" [1]. And the score of resources saving takes 35% in pre-evaluation score in for control items, thus, resources saving has an important role in the whole green building evaluation system. The reward score for using Building Information Modeling (BIM) technology also increases accordingly in the Standard's additional chapter, which will promote the application of BIM technology and make the technical realization means of green building more comprehensive and efficient.

Traditional architectural design methods cannot realize the dynamic updating of architectural information, which has influence on the scientific evaluation of the resources saving performance of building design schemes and the accuracy of the evaluation results is difficult to measure. But with the development of BIM technology, construction of whole life-cycle information achieved highly integrated, building performance analysis can be carried out. Using BIM software's to realize architecture design scheme and performance evaluation of the resources saving can simplify the evaluation process, accurately quantify the evaluation results, and quickly optimize the design according to the evaluation results to achieve the purpose of sustainable development.

In recent years, the research of BIM is developing rapidly. Its application in modern construction projects has a considerable scale and depth, which greatly accelerates the construction of digital information city in China. BIM can provide information carrier for evaluating green performance of building, then researchers can apply information to interested aspects. The carbon dioxide emission of construction production accounts for 30–40% of the global total emission [2]. It is of great significance to carry out building energy consumption assessment. The parameterized model adopted by BIM technology can realize the collection, sorting and analysis of green building design information, realize the coordinated design and data concentration of various types of work on a single data platform, so that the cross stage management and design information can be fully participated in this platform [3]. BIM model can also share data with a variety of professional analysis software's, provide strong data support for various green building environmental performance simulation tools, and ensure the efficiency and accuracy of simulation results [4]. There are some scholars have carried out relevant studies on the combination of BIM technology and Huizhou residential houses, in which BIM has played a reference role in evaluating and improving the green performance. Feng and Wu [5] Established BIM model of ancient architecture in Huizhou, Anhui province. Wang and Luo [6] analyzed the spatial performance of Huizhou ancient buildings and discussed the advanced nature of applying BIM to the analysis of Huizhou's architectural space. Gao [7] built the information model of Wu's residence in Xixi Village based on BIM platform, and constructed the unique component models including Dougong in Huizhou residential houses, which provided the data basis for green performance evaluation. According to the ESGB of 2014 edition, Fang [8] used Swell Vent, Dail and DeST to simulate the wind environment, light environment and energy consumption of Huizhou residential houses, and obtained the energy-saving effect of residential houses. Yu [9] studied the formation mechanism of indoor thermal environment in the three typical areas of the wing room, hall and patio of Huizhou residential house, found that the patio, as the “transition space” of the residential house, plays an important role in regulating the indoor thermal environment. However, on the whole, the existing research is lack of attention to the resources saving performance of Huizhou residential houses, and there are few cases about the application of the performance evaluation of residential resource saving in Huizhou residential houses.

This paper puts forward the evaluation method of Huizhou residential house design scheme based on BIM-ESGB’s resources saving items. Firstly, the characteristics of typical residential houses in Huizhou were analyzed. Then, based on the investigation and practice of BIM software, which has 18 sub evaluation indexes in the item of “resources saving” in the ESGB, the evaluation system of resource saving performance of residential houses in Huizhou was established. And then, taking typical residential house as an example, the analysis model of residential house in Huizhou was established to analyze the resource saving performance of residential houses. Finally, according to the evaluation results, the original design scheme was optimized. The evaluation method realizes the integration of evaluation process, the standardization of calculation and the quantification of evaluation results, which can guide the design scheme of Huizhou residential houses with more resource saving performance.

2 Analysis of the Characteristics of Huizhou Residential Houses

Huizhou is located in the mountains and hills of South Anhui Province. It lies at the foot of Huangshan Mountain, and belongs to the mountainous area. The residential houses, which have wide and tall white gables and gray horse-head walls with unique shapes, are close to the mountain and the water, related by narrow lanes. Huizhou belongs to subtropical humid monsoon climate, more clouds and fog, less sunshine, hot summer and cold winter with high humidity.

The structural mode of Huizhou residential houses is unique as it possess bucket-type wooden framing and beam-lifting wooden framing. The open hall in the middle adopts beam-lifting wooden frame, while the intimate bedroom on both sides uses bucket-type wooden frame. The wall is higher than the wooden frame, and also plays a role in fire prevention. The retaining gable is convex and concave or flat in the north and south. Covering the walls with small green tiles, laying ridges, making drips, and making rhino heads (horse-head walls) at the end of each step. The long tunnels and the patio in the house constitute the natural ventilation system of the settlement, so as to enhance the indoor air convection and solve the problems of heat dissipation and moisture-proof. The floor of the hall connected with the patio is also treated with special moisture-proof structure. The common method is to pave a layer of lime and a layer of fine sand on the foundation, and then pave the floor and coat the bricks. The bedrooms on both sides are usually narrow, small and dark. They are generally made of overhead wood floor, which is 30 cm higher than the ground. There are ventilation holes at both ends under the wood floor to prevent moisture and dehumidification, so that in the rainy season, there is no moisture and it's dry and bright indoor as other seasons.

Nowadays, the ancient town of Huizhou is more and more developed and utilized as a tourist attraction, and the demand for housing is increasing. However, it is faced with many difficulties, such as the shortage of housing land, the high cost of construction materials transportation, the fragile ecological environment, and the lack of natural resources. It is very important to use modern technology to evaluate and improve the resource-saving performance of the traditional residential design scheme, which will make the green buildings with energy-saving, environmental protection and high utilization rate gradually replace the original building methods.

3 Resources Saving Performance Evaluation Method

3.1 Analysis of Resources Saving Items of the ESGB

The application of BIM technology improves the efficiency of design work and green building evaluation. However, green building evaluation based on information technology mainly focuses on single environmental performance (such as acoustic environment, lighting, ventilation and energy consumption). The simulation results are segmented, and the evaluation information hidden in the model is not used well. The evaluation criteria in the corresponding standards are not effectively corresponding, so the green building design scheme integration and automatic evaluation system based on different standards cannot be formed, and the evaluation efficiency and guidance for the optimization and improvement of the design scheme are insufficient. Based on "Evaluation Standard for Green Building" (ESGB), this article1 systematically evaluates the resource saving performance of Huizhou traditional buildings.

The ESGB has reached the international leading level in general [10], which has a high reference value. The content of Chap. 7 are resources saving items, including 10 control items and 18 scoring items, covering the specific evaluation requirements of green buildings for land saving, energy saving, water saving, and material saving. In the specific items of Chap. 7, 1.1, 1.8 and 1.9 focus on whether the external characteristics of the building structure meet the requirements of energy conservation; 1.2, 1.5, 1.6, 2.4, 2.5, 2.6 and 2.8 focus on reducing building energy consumption; 1.3 and 1.4 focus on building room zoning; 1.7, 2.10, 2.11, 2.12 and 2.13 focus on building water conservation and water landscape; 1.10, 2.15, 2.16, 2.17 and 2.18 focus on green building materials; 2.1, 2.2 and 2.3 focus on land saving [1]. The evaluation of residential house design scheme by using the content of resource saving items in the ESGB is based on satisfying the requirements of control items first, then scoring the scoring items, and finally summarizing the score as the resource saving performance evaluation score of the design scheme.

Due to the small size and simple structure of Huizhou residential houses, some evaluation items in the ESGB are not applicable, such as control items 1.3 (setting temperature according to space function), 1.5 (energy consumption of each part should be measured separately), 1.6 (taking energy saving measures for elevator), score items 2.2 (developing underground space), 2.3 (using ground parking space), 2.5 and 2.6 (using cold and heat source air conditioning units that meeting energy saving regulations), 2.9 (using renewable energy), 2.11 (using water-saving equipment or technology for greening irrigation and air conditioning cooling water system), 2.12 (combining rainwater comprehensive utilization facilities to create outdoor water landscape), 2.13 (using non-traditional water source), 2.16 (selecting industrial interior decoration parts for building decoration [11]). All the above may not be considered in the resource saving performance evaluation of Huizhou residential houses design scheme. After excluding the above inapplicable items, the resource saving performance evaluation index system of Huizhou residential houses design scheme based on BIM-ESGB's resource saving items is obtained as shown in Table 1.

To make better use of BIM software to evaluate the resource saving performance of Huizhou residential houses design scheme, based on whether the evaluation data can be extracted directly, the evaluation indexes are divided into 3 categories: direct credit (DC), semi-direct credit (SC) and indirect credit (IC). The data extraction and evaluation process of the DC item is: data of the model are imported from Revit into Access database by DB Link plug-in, and detailed lists of Revit is imported into Excel for statistics, which is evaluated according to the ESGB. The data extraction and evaluation process of SC items is: each index data of residential buildings is simulated by BIM performance simulation software and evaluated according to the ESGB. The data extraction and evaluation process of IC items is to supplement the data of design scheme and evaluate it with Delphi method according to Revit 3D scene and indoor environment simulation.

3.2 BIM-ESGB Model Evaluation Score Calculation

According to the above three kinds of relevant information of resources saving evaluation, the interval evaluation value is transformed into fixed score value, and the BIM-ESGB evaluation model based on score is established, which makes up for the shortcomings of simplification and absoluteness of previous green assessment. Under the constraint of fixed score, the function expression of BIM-ESGB evaluation model is shown in Formula (1).

Table 1 Evaluation index system of Huizhou residential design scheme based on BIM-ESGB's resources saving items

Index	ESGB's resource saving items		Score	Index assignment method	Index category	Index output
	ESGB's item	Concrete content				
Land	7.2.1	Intensive land use	20	Revit schedule	DC	Per capita residential land area (m^2)
Energy	7.1.1	Space energy saving	Control item	Revit simulation	IC	Satisfied or not
	7.1.2	Energy consumption	Control item	Dest simulation	SC	Satisfied or not
	7.1.4	Room lighting control	Control item	Ecotect illumination	SC	Satisfied or not
	7.2.4	Performance of envelope	15	DeST	SC	Heating load reduction (%)
	7.2.7	Electrical equipment	10	Lighting system	SC	Lighting power and brightness
	7.2.8	Building energy consumption	10	Dest simulation	SC	Energy consumption reduction (%)
Water	7.1.7	Water utilization	Control item	Water system	SC	Satisfied or not
	7.2.10	Water use efficiency	15	Equipment schedule	DC	Sanitary appliances (%)
Material	7.1.8	Regular building structure	Control item	Revit visualization	IC	Satisfied or not
	7.1.9	Simple modeling elements	Control item	Revit visualization	IC	Satisfied or not
	7.1.10	Building materials	Control item	Expert evaluation	IC	Satisfied or not
	7.2.14	Integrated design	8	Expert evaluation	IC	Integrated design and construction
	7.2.15	Materials and components	10	Revit schedule	DC	High-strength steel (%)
	7.2.17	Materials recycling	12	Material schedule	DC	Recyclable materials (%)
	7.2.18	Green building materials	12	Revit material schedule	DC	Green building materials (%)

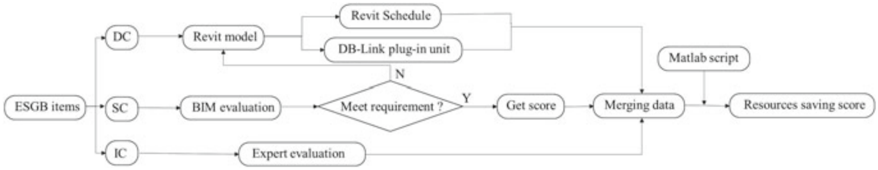

Fig. 1 Flow chart of green building resources saving evaluation based on BIM-ESGB comprehensive evaluation model

$$X_{JD} = \sum_{i=1}^{5} X_{DC_i} + \sum_{j=1}^{6} X_{SC_j} + \sum_{k=1}^{5} X_{IC_k}$$
$$s.t. X_{DC_i} \le X_{EB}, X_{SC_j} \le X_{EB}, X_{IC_k} \le X_{EB} \tag{1}$$

In above formula, X_{EB} is the fix score in ESGB, X_{DC_i}, X_{SC_j}, X_{IC_k} are score obtained for the i/j/k evaluation item in DC/SC/IC evaluation items.

Considering the types and sources of extracted information, the digitization of information is defined as four categories, and the following three forms of data processing are made for the four types of data: primary data that can be directly used for evaluation, secondary data that needs "secondary processing" and external data. After "reprocessing", the four kinds of information are transformed into three types of data, and the index score is judged by creating Matlab program to realize the linkage between the original data information and the analysis results. In this article, based on the data analysis between tables, the Matlab result spreadsheet is used to establish the data link and reference relationship, and select the function of the corresponding software's to realize the four functions of "information statistics, index calculation, resources saving score judgment and comprehensive score calculation of resources saving evaluation". The implementation process of the system is shown in Fig. 1.

4 Instance Analysis

4.1 Evaluation of Typical Design Scheme

The authors visited the ancient towns of Huizhou, such as Xidi, Hongcun and Chengkan, etc. Based on the existing research, the basic data of Huizhou typical residential houses are obtained by sorting out the supplementary data, including building size, materials used, floor area, heating mode, etc. Typical residential houses have two floors, no basement, residential land of about 191.6 m^2, building area of about 168.3 m^2, first floor height of about 3.5 m, second floor of about 2.1 m. The first floor is the main living space and the second floor is the attic. After testing, it is found that the temperature fluctuation and range of the wing room are larger than that of the bedroom, the average and minimum temperature of the wing room are

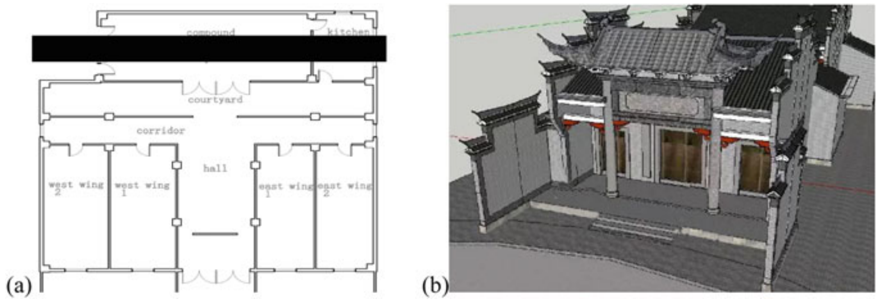

Fig. 2 The first floor plan (**a**) and renderings (**b**) of Huizhou typical residential houses

lower than that of the bedroom, and the temperature fluctuation range of the patio is between indoor and outdoor. The effect of daytime heat insulation is better, which is related to the high and closed external wall and the vertical thermal buffer layer of attic, which block the heat from entering the room. Meanwhile, the narrow and high patio can reduce the direct sunlight. The interior space of the residential house, the lattice window design of the hollowed out wing room and the thought of building gap and patio, the hot pressure ventilation effect of the patio at night, accelerate the indoor heat loss, make the temperature of the wing room at night lower than that of the bedroom, and close to the outdoor temperature. Based on the design data, a simplified model of Huizhou typical residential houses is established in Revit. The first floor plan and effect drawing are shown in Fig. 2.

Using the evaluation method based on BIM-ESGB's resource saving items, the resource saving performance of Huizhou typical residential design scheme is evaluated. In terms of land saving, through the area list in Revit, it is found that the residential building land is about 170 m^2. Based on the calculation of 7 residents in this household, the per capita residential land is about 24 m^2, which meets the requirement that the per capita residential land for residential buildings with 3 floors and below in the ESGB is less than 33 m^2, and its score is 20 points. For energy saving, the typical residential houses design scheme does not consider the energy saving measures in the ESGB, and its score is 0 point. For water saving, the typical scheme has adopted the sanitary appliances with higher water use efficiency level, and its score is 8 points. For material saving, the typical design scheme meets the minimum requirements for the proportion of recyclable materials and the proportion of green building materials, and its score is 3 points, 4 points, respectively. Based on the above scores, the resource saving performance score of the typical residential houses design scheme is 35 points, while the total score of the resource saving evaluation items is 200 points. It can be seen that the typical design scheme does not meet the requirements of the ESGB that "the score of each index should not be less than 30% of the full score of its score items". The resource saving performance is insufficient, so the design scheme needs to be optimized.

4.2 Design Scheme Optimization Based on Evaluation

In order to reduce the consumption of resources and improve the resource saving performance of Huizhou residential houses, the corresponding evaluation indexes of land saving, energy saving, water saving and material saving were optimized.

For the land saving evaluation index 2.1, the per capita residential land area of the typical residential houses design scheme meets the requirements of the ESGB, so there is no need to optimize this item. However, when considering site design and building layout, many factors such as convenient traffic, ratio of sunshade area and site runoff should also be considered.

For item 1.1 of the energy saving evaluation index, the interior of typical residential houses emphasizes sunshade and light ventilation, which makes the indoor humid. The realization of heat balance in Huizhou residential houses is reflected in the building structure. The heat insulation performance of the attic is poor, and the temperature of the wing room is obviously increased because of the direct sunlight in the daytime. Due to the temperature buffer layer of the attic and the patio and the heat insulation effect of the surrounding enclosure, the temperature of the wing room is low. There are hollow lattice windows in the attic and wing room, which is conducive to the natural ventilation and cooling at night. The temperature of the attic and wing room at night is basically the same as that of the outdoor, and the air change frequency in the room is usually more than once per hour. In the optimization design scheme, the purpose is to save energy without compromising the use requirements of residential buildings (i.e. not at the cost of reducing comfort). Because of the particularity of Huizhou residential houses, we cannot copy the method of only improving the sunshade performance of buildings in South China, but also pay attention to the requirements of room lighting, ventilation and warmth preservation, so as to avoid too cold and humid indoor in winter, which makes the light and heat load too high. Through the simulation of PTemp software, we can find the best way to optimize the thermal performance of the building envelope: adding 90 mm extruded polystyrene board insulation layer to the attic roof, the heat transfer coefficient is 0.334 W/(m^2 K) after the change; adding 80 mm EPS board to the exterior wall of the wing room, the heat transfer coefficient is 0.416 W/(m^2 K) after the change; adding 6 mm energy-saving glass to the exterior window for the energy-saving transformation, the heat transfer coefficient is reduced to 1.8 W/(m^2 K); other boundaries keep the default value of PTemp system. In order to control the influence of sunlight on the thermal environment of the building, the heat radiation distribution map is calculated by Ecotect to take flexible indoor space layout.

According to the survey results, the total construction area of typical residential houses is about 168 m^2, and the main rooms are wing rooms (bedrooms), halls (living rooms), corridors, atriums and patios. The total air conditioning area is about 51 m^2. Combined with the actual use, using DeST energy consumption simulation software to analyze the cooling and heating loads, setting the heating and cooling time of residents. By inputting the geographic latitude and longitude coordinates of Huizhou in DeST, we can know the local temperature change. Corresponding

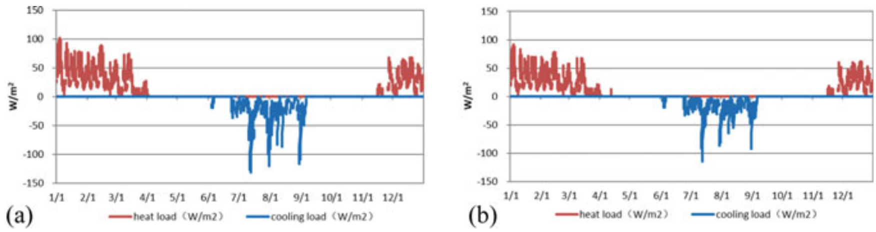

Fig. 3 Annual cooling and heating load of air conditioning unit area before (**a**) and after (**b**) optimization

equipment heat disturbance, personnel heat disturbance, lighting heat disturbance and air conditioning system heat disturbance shall be set for each main functional room to provide basis for calculating air conditioning opening time and hourly cooling and heating load per unit area of the year by DeST.

For items 1.2, 2.4 and 2.8, hourly load simulation shall be carried out respectively before and after optimization of enclosure design scheme. The annual cooling and heating load of air conditioning unit area before and after optimization can be seen in Fig. 3. The annual cumulative cooling and heating load of residential houses is 3096 kWh before optimization and 2731 kWh after optimization, which reduces 365 kWh by 11.79%. After the optimization design of residential houses envelope, the use time and cumulative load of air conditioning are reduced, which effectively improves the living environment and realizes the purpose of energy saving.

For the room illuminance control items 1.4 and 2.7, according to the indoor lighting conditions, we can use the Revit Insight Solar plug-in to analyze the illuminance of the indoor space on the first and second floors of typical residential houses in the summer morning, as shown in Fig. 4. It can be seen that the indoor stairs, the area near the north of the room and the atrium, courtyards and patios are not well lit. The reason is that because of the narrow patio and the high wall and deep courtyard, the lighting lines are mostly secondary refraction light, few natural glare, giving people a quiet and comfortable feeling. The south side of the wing room and attic has better lighting, and the illumination of the first and second floors can reach up to 6000 lx. Therefore, we can install time-sharing lamps that automatically adjust

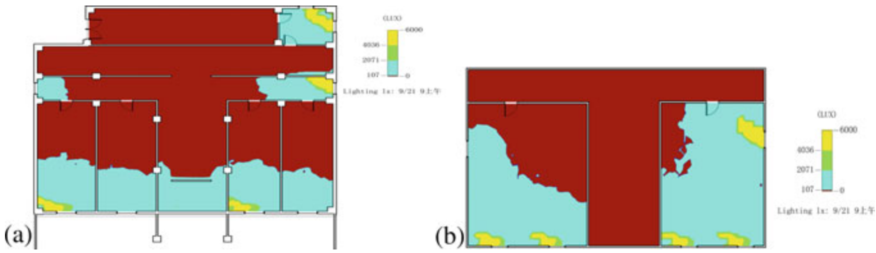

Fig. 4 Analysis of illuminance on the first floor (**a**) and the second floor (**b**) in summer morning

with the change of natural illumination in the well-lit areas, and sensor lamps in the poorly-lit areas of the main function rooms to achieve the target illumination power density in the ESGB.

In the aspect of water saving optimization, evaluation index 1.7 is SC item. In Revit MEP, reasonable water supply and drainage system is designed to improve the comprehensive water-saving performance. Optimizing underground pipeline network according to crash rules in Revit MEP can avoid leakage of pipeline network caused by crash or conflict. For the 2.10 DC item, the water efficiency level of all sanitary appliances in the optimization scheme reaches the first level. Through establishing BIM dynamic database, we can know the daily water consumption of buildings and find out the possible causes of water loss. In the statistics of rain-water collection, it is necessary to determine the impact of different landforms and materials on runoff coefficient and make full use of non-traditional water sources.

The evaluation indexes 1.8, 1.9 and 2.14 are all IC items, and the expert scoring method is used in optimization. For items 1.10, 2.15, 2.17 and 2.18, except for item 1.10, which is IC, other items are DC items, which can be evaluated in combination with Revit material list. The typical residential houses are brick-timber structures with poor seismic performance. High-strength reinforced high-performance concrete and pre-stressed concrete structures can be used in the optimization scheme. For item 2.17, reusable and recyclable materials are used in the optimization scheme, BIM virtual construction model is used for data statistics and analysis. For item 2.18, the pedestrian passage can be built around the courtyard or the house by planting grass road tiles. Due to the difficulty in obtaining green building materials and the high cost, the optimization plan does not put forward higher requirements for the proportion of green building materials used in Huizhou residential houses.

5 Conclusion

After the above optimization, the evaluation method based on the BIM-ESGB's resources saving items are used to evaluate the resources saving performance of the optimization scheme. The BIM software's system outputs the evaluation index data, then scores according to the ESGB. Figure 5 shows the scores of the evaluation items before and after the optimization of the typical residential houses design scheme. It can be seen from the figure that the total score of the resources saving items of the optimized design scheme is 82, which meets the requirements of the ESGB. The evaluation scores of items 2.4, 2.7, 2.8, 2.10, 2.14, 2.15 and 2.17 are increased by 10, 7, 10, 4, 8, 5, 3 points respectively. On the whole, after optimization, the level of resources saving has been improved obviously, and the green performance has been improved. It can be seen from the distribution of increased scores after optimization of each evaluation item that the most increased scores are in the field of energy saving, followed by the material saving, water saving and land saving. In the energy saving, the cooling and heating loads of buildings are reduced, and the overall energy-saving performance of residential houses is enhanced. In the field of

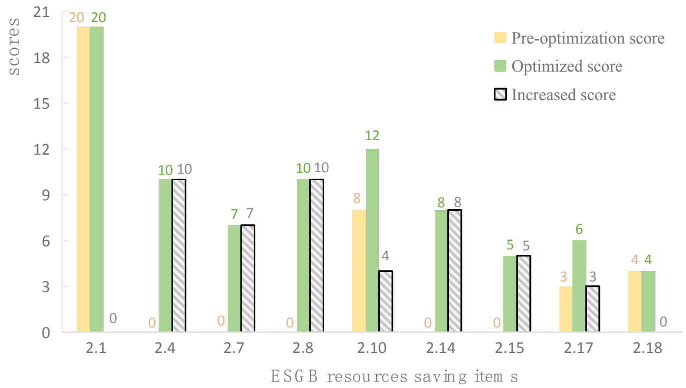

Fig. 5 Scores of evaluation items before and after optimization of typical residential houses design scheme

material saving, the optimization scheme uses more green building materials and environmental protection appliances. In general, the optimization process of the typical scheme is much more efficient in energy saving and material saving than in land saving and water saving.

Most of the traditional residential houses in Huizhou are built by the residents themselves, and the resource saving performance is low. In view of the serious problem of energy consumption in the original architectural design, this paper proposes to improve the architectural design under the guidance of ESGB, so as to reduce energy consumption in the design period. After the design optimization guided by the ESGB's resources saving items, the energy saving and material saving performance of residential houses has been greatly improved, and the overall resource saving performance has been improved. Based on the evaluation method of BIM-ESGB's resource saving items proposed in this paper, the resources saving performance of Huizhou residential houses can be analysed quickly and objectively, and provide a new idea for the sustainable development of Huizhou ancient town.

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Influence of Prefabricated Building Incentive Policy on Project Implementation Effect

Qingxiang Su, Shaoyan Wu, and Pan Xing

Abstract To promote the development of prefabricated buildings, China's provinces (autonomous regions and municipalities) have successively issued guiding documents for the development of prefabricated buildings, specified their own development goals and various incentive policies. Although various provinces (autonomous regions and municipalities) have put forward various incentive policies, there are differences in the actual development of fabricated buildings. Therefore, this paper studies the impact of the incentive policies of fabricated buildings on their project implementation effect through correlation analysis. After coding the selected research samples through text analysis method based on the perspective of policy instruments, the distribution of the three types of policy instruments, namely supply-type, environmental-type and demand-type are counted respectively, and then the incentive policies of the provinces (autonomous regions and municipalities) are quantified through policy scoring. After selecting three evaluation indexes for correlation analysis, it is found that the type of policy tool most used at present is the environmental-type, followed by the supply-type, and the demand-type accounts for the least. And the highest policy score among all provinces is Jiangsu province. Through the above analysis, it can provide reference for provinces (autonomous regions and municipalities) to optimize or innovate the existing incentive policies, and promote the development of fabricated buildings.

Keywords Prefabricatbed Building · Incentive policy · Policy tools · Correlation analysis

1 Introduction

Prefabricated buildings change the traditional construction methods, improve the efficiency and quality of construction projects, ensure the safety of projects, and contribute to the sustainable development of resources. Because of these advantages,

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prefab buildings were popularized. With the successive release of relevant policy documents of prefab buildings by governments at all levels, the incentive policies of prefab buildings are gradually strengthened and the technical standards are gradually improved, which provides policy guarantee and technical support for the development of prefab buildings and promotes the rapid development of prefab buildings in China.

Of our country based on the policy tool of 31 provincial area issued prefabricated building incentive policy document for text analysis, which according to supply-type, demand-type, environmental-type classify three kinds of policy tools and statistics, and then through the correlation, analysis of prefabricated construction in our country the actual implementation effect, for existing optimization direction of prefabricated building incentive policy to provide some idea, let the limited government incentives to play the best incentive effect, hope for the future healthy development of prefabricated buildings provide certain help.

2 Literature Review

Some scholars analyze the difficulties of assembled buildings from a technical point of view. The research shows that there are still problems in the field of assembly construction in China, such as imperfect policy system, high initial cost, imperfect system and standard norms, and lack of professionals [1–3]. Li Lihong and others [4] draw the possibility of assembly building development by comparing the current watered building with the assembly building. Lu Wanxuan and other [5] large-scale equipment safety hazards on the construction site to carry out analysis, it is concluded that in the construction process, we must strictly control the installation of large-scale equipment and safety management.

Some scholars analyze the influence factors of assembled buildings by many factors. Scholars study the differences in the factors affecting the development of assembled buildings, which are divided into five factors: economic level, market demand, policy system, technical system and industrial chain [6–8]. In addition, there are differences in the driving effect of various influence factors on the development of assembly buildings. Through empirical research, Mao Chao and Li Shixuan [9] show that the pursuit of sustainable competitiveness and government regulation are the two core factors affecting the development of assembly building, and think that the government and enterprises are the leading driving force of the development of assembly building. Skitmore and Zhang [10] through the investigation and analysis, the lack of supply chain, standards, government incentives and guidance is an obstacle to the development of assembly buildings, and cost and government influence dominate.

At the policy research level, the academic research on assembly-type construction policy tends to focus on policy combing, partial qualitative analysis, and there has not been a quantitative study from the perspective of policy tools. In view of the economic policy research on the development of assembly-type building, Ji Yingbo and Li Xiaotuan [11] classify the development policy of construction industrialization at home and abroad from the perspective of land, taxation and finance. Cen Yan and Liu Meixia [12] qualitatively evaluated the effect of the implementation of China's assembly-style construction economic policy. There is also a policy analysis based on the timeline. By examining the historical process of the start-up of China's industrial housing industry, Qiao [13] put forward some suggestions to formulate policies for the traditional current housing industry to make it less attractive. Zhang Hong [14] made an inventory of the national assembly building policy for the period 2015–2016. Chen Zhenji [15] briefly describes the policy evolution of China during the more than 60 years of construction industrialization. Wen Linfeng [16] introduced China's economic policy, regulatory mechanism and policy objectives for promoting assembly buildings.

At present, few scholars have incorporated policy and post-implementation project adoption effect into the same framework. However, deconstructing the general contracting policy of projects in various provinces and revealing the mechanism of influence of different types of policies on the effect of project implementation is of great guiding significance for further promoting the development of assembly-type buildings efficiently and rapidly. Through research, this paper tries to explore the practical achievements and main problems faced by the assembly building policy in the process of upgrading China's construction industry. In order to provide construction practitioners and policy makers with systematic information reference.

3 Quantitative Analysis of Policy Texts

Because there are many kinds of prefabricated building incentive policies [17], it is necessary to classify prefabricated building incentive policies based on a certain Angle. There are a lot of papers on policy tools of incentive policies. Liu Guiwen and others [15] said that policy tools can be divided into supply-type, demand-type and environmental-type. Rothwell and Zegveld [18] propose a systematic network analysis framework that defines innovation policy in terms of supply, demand, and environmental. They argue that good technical support, market demand and policy environment are conducive to the success of innovative industries. Li Jinhua et al. [9]studied the supply side and the demand side. Wang Qiang et al. [19] studied the incentive policies of enterprises, scientific research institutions and consumers. Weiping Jiang and other scholars [20] directly from the specific provision of the policy to start the study.

Despite the different perspectives of policy tools, combining construction industrialization is a feature of traditional construction innovation [21]. The study is intended to use Rothwell and Zegvel's classification ideas to evaluate assembly building policies. Because this policy tool is hierarchical, has clear boundaries, helps statistics, and is operability. And the national strategic level of the assembly building policy as the relevant local policy to be issued as a guide, through this classification to assess the coordination of the policy system, the follow-up policy formulation and implementation is of enlightenment significance. Then this kind of division is based on the author's multi-country empirical research in the field of scientific and technological innovation. Today, energy policy, e-commerce policy, health care policy, urban renewal policy and other aspects are interdisciplinary application, strong representation.

3.1 Contents of Policy Tools

The tool of supply policy mainly shows that the government provides assistance to the development of prefab buildings. The government provides indispensable material rights and interests or other resources for the development of prefab buildings from many aspects as a driving force to accelerate its development. Environmental policy tools of prefabricated buildings mainly release environmental and system incentives to the outside world through policy measures, and guide enterprises to actively participate in the construction of prefabricated projects, and indirectly promote the development of the construction industry. Demand-type policy tools start from the market to determine the demand for prefabricated parts, which to some extent reduces the uncertainty of the prefabricated parts market. Therefore, this paper makes the following conclusions (Table 1).

3.2 Text Selection and Coding of Incentive Policies

By browsing in the people's government at the provincial level and the ministry's official website, finally, a total of 56 provincial level prefab incentive policy texts were retrieved. The above collected incentive policy texts are screened according to the following three principles: one is the units of 31 provinces level, the ministry of the people's government or other agencies issued relevant policy documents; Second, the types of policies are opinions and methods, which are not included in the category of regulations. Third, the policy document contains clear incentives for prefab construction, such as financial support, financial incentives, land security, etc.

According to this article research topics, which in turn code sample text files in the selected policy, take "file number chapter section" of the selected manual coding, make policy text samples due to each section of the policy text may have different policy tools, so add to the next level code, to ensure that the integrity of the code of policy text, eventually form a prefabricated building incentive policy text analysis code table, as shown in Table 2.

Table 1 Types and meanings of policies

Name	Mean
Cultivation of talents	To cultivate technical and managerial talents for prefab buildings through school-enterprise cooperation; To carry out the re-education of professional and technical personnel
Excavation of science and technology	To guide enterprises to attach importance to the development of science and technology, improve the level of prefabricated building construction and production of prefabricated components. To guide the development of science and technology as the focus, improve the level of construction and production of components
Information support	Provide data and information services and support for the development of prefabricated buildings
Financial support	The government promotes prefab construction in the form of funds or subsidies
Land planning	In the annual construction land use plan, the government shall arrange special land use targets to ensure construction land. Prefab construction projects will be rewarded with floor area ratios
Goal programming	Combined with their own prefabricated building according to the development needs, put forward the overall goal
Systematic policy	In order to achieve the goal of phased development, targeted formulation of incentive or restrictive measures
Legal regulation	The government regulates the behavior of all subjects by formulating laws and regulations and maintains the market order, thus creating a fair competitive environment suitable for the development of prefab buildings
Perfect the normative text	The government will improve the technical standards and valuation quota for the modernization of the construction industry, clarify the basic requirements for industrial construction, promote the standardization, modularization and generalization of parts and components, and establish a certification system for parts and components
Financial incentives	The government facilitated financial institutions, financial institutions and non-bank loans, eased financial restrictions and reduced financing conditions
Tax preferential	The government provides financial support or tax breaks for prefab construction participants
Industry support	The government provides enterprises with a more convenient and efficient service environment

(continued)

Table 1 (continued)

Name	Mean
The transportation security	Transport vehicles that transport large and wide parts are supported in terms of transport permits and road safety
Government procurement	The government's main investment projects are prefabricated and concessionary tenders are offered to participating construction companies
Overseas exchange	Promote overseas exchanges through strategic cooperation with other countries

Table 2 Policy coding demonstration

Number	Policy name	Policy text content analysis unit	Coding
1	《Implementation Opinions of The General Office of the Beijing Municipal People's Government on Accelerating the Development of Prefab Buildings》	(1) Guiding ideology.As applicable…In new buildings	1—1
2	《Notice on The Implementation Plan of Vigorously Developing Prefab Buildings issued by The General Office of Tianjin Municipal People's Government》	I. Guiding Ideology.Adhere to standardized design, factory production, assembly construction, We will promote the transformation and upgrading of the construction industry and its sustainable development	2—1—1
	…	…	……
15	《Guidelines of Anhui Provincial People's Government on Accelerating The Modernization of Construction Industry》	3. Improve the supervision and service system	15—3—6
	…	…	……
30	《Implementation Opinions of The General Office of the Ningxia Autonomous Region People's Government on Vigorously Developing Prefab Buildings》	(ix) 2. Establish the quality and safety assurance system for prefabricated buildings	30—9—2
31	《Implementation Opinions of Xinjiang Uygur Autonomous Region on The Vigorous Development of Prefabricated Buildings in The Autonomous Region》	18. Strengthen exchanges and cooperation at home and abroad, and actively introduce professionals to participate in the research, development, production and management of prefab buildings	31—18—2

3.3 Statistics and Analysis of Incentive Policy Text Coding

According to the code, the word frequency of each policy tool is obtained. Supply policy tools accounted for 36.9% of the total sample size. Environmental policy tools accounted for 58.1%; Demand policy instruments accounted for only 5.0% of the total. The above distribution shows that the development of prefab buildings in China mainly relies on supply policy tools, while environmental policy tools, as an important factor by indirectly affecting its development, create a good development environment for it. However, the number of demand policy tools is too small to timely and effectively realize their driving effect on industrial development, so there are problems in the use of policy tools (Table 3).

It can be seen from the table that the proportion of science and technology development in the supply policy tools is the largest, about 31.6%, indicating that provinces attach importance to the development and innovation of new prefab building technologies. Secondly, the proportion of financial support and land planning is roughly the same, both at about 20%, indicating that prefab buildings are currently in the development stage, and the government invests a large amount of funds and guaranteed land to support the development of prefab buildings. Talent cultivation and information support follow, but in fact, a large number of professional and technical personnel and information data support are needed, so local governments should pay more attention to these two types of basic policy tools.

Among environmental policy tools, systematic policies account for the largest proportion, about 25%, indicating that local governments pay more attention to this policy. The second is the two basic policy tools of industry support and tax incentives, accounting for about 15%. The main purpose is to support the construction of the industry. Although other policies involve relatively few, they also show that China is implementing the prefab building development strategy in a planned and systematic way, which fully reflects the country's implementation efforts in the construction of industrial development environment. There is still a long way to go to improve the prefab building development environment.

Among demand-oriented policy tools, government procurement refers to the leading role played by government agencies and public sectors in the government's plan to promote the development of prefabricated buildings. This type of basic demand policy tools accounts for 71.4%. The proportion of overseas exchange is about 28.6%, and only 1.43% in the whole policy tool, which is a small proportion.

To sum up, environmental policy instruments are currently in a "strong" stage, supply-oriented policy tools are in a "weak" state, and demand-based policy tools in the use of policy tools in the "absent" state, little impact. The score is given according to word frequency. The specific score is shown in the figure below.

It can be concluded from Table 4 that after scoring the assembly building incentive policies in 31 provinces (regions and cities), the scores are mostly concentrated in 31–40 points. There are 13 provinces (regions and cities), namely, Shandong Province, Guangdong Province, Hainan Province, Jilin Province, Heilongjiang Province, Anhui Province, Hunan Province, Guangxi Autonomous Region, Sichuan

Table 3 Proportion of policy tools

Tool type	Name	Word frequency	The percentage (%)	The percentage (%)
Supply-type	Cultivation of talents	28	13.6	36.9
	Excavation of science and technology	65	31.6	
	Information support	25	12.1	
	Financial support	42	20.4	
	Land planning	46	22.3	
Environmental-type	Goal programming	33	10.1	58.1
	Systematic policy	29	9.0	
	Legal regulation	42	13.0	
	Perfect the normative text	30	9.3	
	Financial incentives	35	10.8	
	Tax preferential	81	25	
	Industry support	56	17.3	
	The transportation security	18	5.5	
Demand-type	Government procurement	20	71.4	5.0
	Overseas exchange	8	28.6	
A combined		558		100

Province, Shanxi Province, Ningxia Autonomous Region and Xinjiang Autonomous Region. The high segment is 41–50, with five provinces: Jiangsu, Zhejiang, Henan, Jiangxi and Guizhou. It can be seen that there are obvious differences in the policy strength of assembly-type building incentive policy among provinces (districts and cities).

Table 4 Policy scores of each province

Tool type	Name	Jiang su	Zhe jiang	…	Hai nan	Jiang xi	He nan	Hu bei	…	Qing hai	Ning xia	Xin jiang
Supply-type	Cultivation of talents	2	2	…	2	2	2	2	…	2	2	2
	Excavation of science and technology	2	2	…	2	2	2	2	…	2	2	2
	Information support	2	2	…	2	2	2	0	…	2	0	2
	Financial support	14	8	…	6	6	8	4	…	6	8	4
	Land planning	6	28		4	6	6	4		6	6	4
Environmental-type	Financial incentives	6	4		4	8	6	0		6	6	4
	Tax preferential	10	8		4	6	6	2		6	4	6
	Industry support	6	6		10	8	10	4		6	8	2
	The transportation security	0	0		2	2	2	0		2	0	2
Demand-types	Government procurement	0	2		2	2	2	2		2	0	2
	Overseas exchange	2	0		0	2	2	0		0	0	2
Total score		50	42		38	46	48	20		40	36	32
Ranking		1st	4th		7th	3rd	2nd	31st		6th	10th	18th

4 Correlation Analysis Between Prefab Incentive Policies and Implementation Effect

This chapter first determines the principle of indicator selection, and then selects the project implementation effect index according to it. Finally, the correlation between evaluation and index and incentive policy intensity is analyzed.

4.1 Selection of Evaluation Indexes

In the choice of policy implementation effect indicators can be quantitative indicators can also be quantitative indicators, qualitative indicators combined settings. It can be evaluated by the government subject, or it can be evaluated by the object. The selection range of indicators of policy implementation effect is more extensive [22].

And this paper and policy research is through the project implementation effect to establish a link with it, project implementation effect is actually the quantitative indicators of the effect of policy implementation indicators, you can see in the selection of quantitative indicators have ratio indicators. For example, “entrepreneurship as a proportion of employment” in the indicators of the implementation effect of youth entrepreneurship support policies is a component ratio indicator.Wang Hong, Sun Jihong and other scholars set the “policy implementation efficiency” refers to the “tax preferential policy output efficiency and input cost ratio”, belongs to the efficiency ratio index.

But more is the direct selection of quantitative indicators as a quantitative indicator of project implementation effect, quantitative indicators are directly able to use a specific number of sizes to reflect the indicators. Yang Xiaodong, Hui Xiaofeng and other scholars in the study of housing policy, the five implementation effect indicators are actually project implementation effect, and are quantitative indicators.

Therefore, this paper is based on scientific principles, systematic principles and operability principles, a comparative analysis is made of the project implementation effect indicators that can reflect the effect of the implementation of the assembly building policy. Finally, the indicators reflecting the effect of assembly building project implementation are the new construction area of assembly building, the number of leading enterprises of assembly building and the number of scientific research institutions of assembly building.

The specific analysis framework is shown in Fig. 1.

4.2 Correlation Analysis

Correlation analysis of the evaluation indicators identified in 4.1 with the overall policy strength was carried out. According to the development of the national

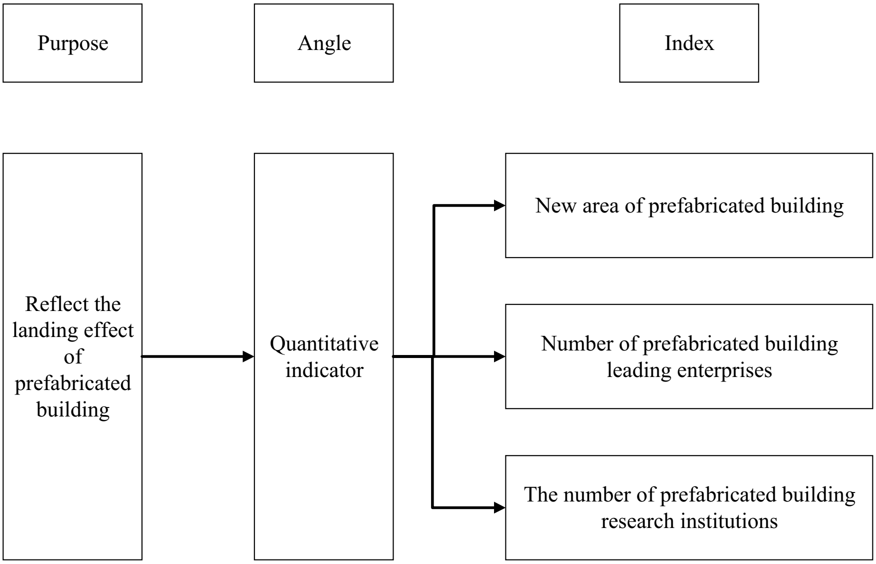

Fig. 1 Framework for evaluating the project implementation effect of prefabricated building

assembly building, the incentive policy of the assembly building has an impact on its project implementation effect and promotes the development of the assembly building.

As can be seen from Fig. 2, the policy intensity and the new construction area of prefab construction mainly fluctuated in the eastern region. In the central and western regions, the policy intensity is significantly different from the area of prefab construction. Moreover, in the case of the same policy intensity, the actual effect of the newly started area of prefabricated buildings is completely opposite. For example, Zhejiang province (No. 7) and Guizhou Province (No. 24), one is the data peak, and the other is close to 0. Therefore, although the current policy is favorable from the

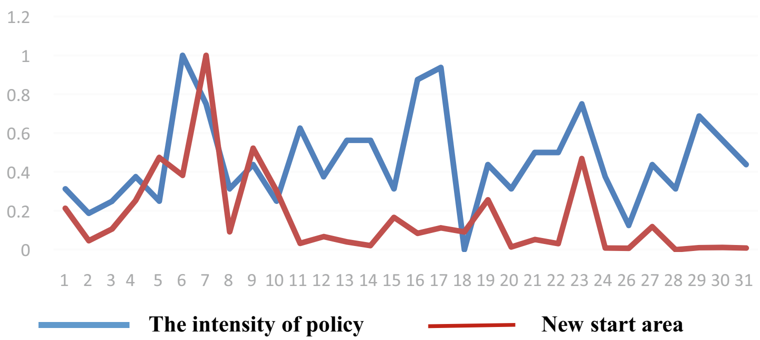

Fig. 2 Relationship between policy intensity and prefabricated building starting area

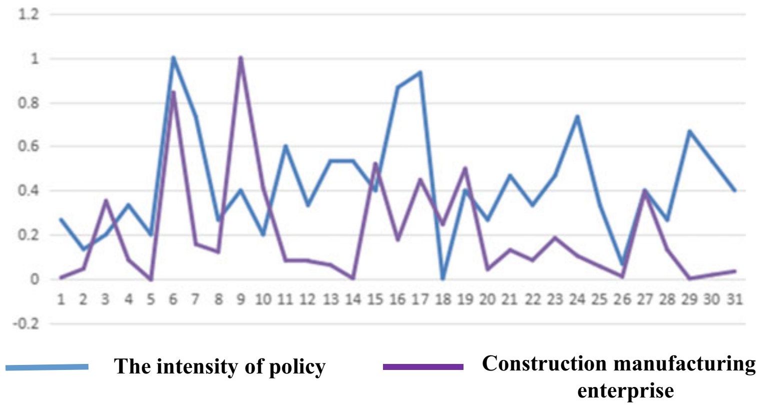

Fig. 3 Relationship between policy intensity and prefab manufacturing firms

perspective of the floor area of prefabricated buildings in the whole region, the floor area is not good after it is detailed to all provinces. The following is the correlation analysis with prefabricated construction manufacturing enterprises:

As can be seen from Fig. 3, the policy intensity and the number of prefab construction leading enterprises, the implementation effect index, also fluctuated in the eastern region. In the central and western regions, the policy intensity is obviously different from that of newly-built prefab construction leading enterprises. The policy intensity is large, but the actual implementation effect index is not ideal.

As can be seen from Fig. 4, the policy intensity and prefab construction research institutions also fluctuated mainly in the eastern region. In the central and western regions, the policy intensity is obviously different from that of prefab construction leading enterprises. The policy intensity is large, but the actual implementation effect index is not ideal.

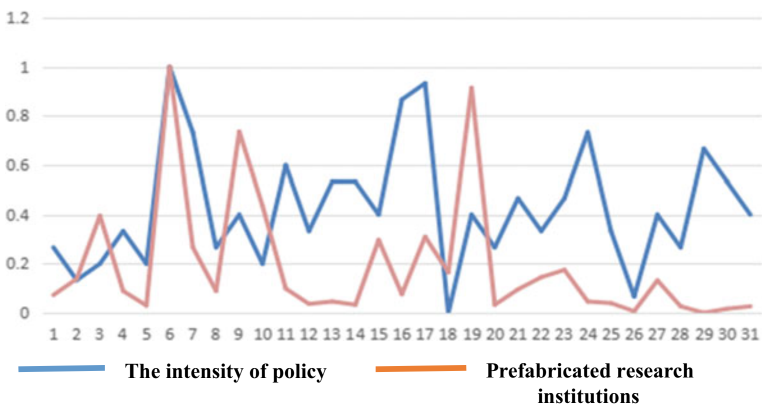

Fig. 4 Relationship between policy intensity and prefabricated building research institutions

Subsequently, this article through the correlation analysis of policy intensity and project implementation effect indicators of policy tools by SPSS software, the correlation coefficients of each type of policy tools and project implementation effect indicators were obtained respectively (Table 5).

It can be seen from the table that the correlation coefficient of the three types of project implementation effect indicators in the eastern region is strong correlation between 0.49 and 0.67, indicating that the supply-oriented policy tool in the eastern region plays a great role in the project implementation effect of its assembly buildings. Among them, the financial support category has the greatest effect on the development of leading enterprises and scientific research institutions in assembly building, and the correlation coefficients are 0.5255 and 0.7120, respectively, which are strong correlations. The correlation coefficient of the fund support category to the new construction area of the assembly building is 0.4043, which is moderately related. Secondly, the land planning category is strong correlation to the new construction area of assembly building, the correlation coefficient is 0.5799, and the leading enterprises and scientific research institutions are weak correlation. Information support also plays a role in the development of assembly buildings in the eastern region, while education and training policies have not yet had an impact on the development of assembly buildings in the eastern region. The supply-oriented policy tool in the central region is moderately related to the project implementation effect, which indicates that the policy is biased from its project implementation effect. From the data in the table, the best correlation between policy intensity and project implementation effect in the central region is also the financial support category, with a correlation coefficient of 0.6840. The correlation between the land planning category and the new construction area of the assembly building is not high, which shows that although the intensity of the land planning policy in the central region is high, the actual effect of the assembly building is not ideal. The supply-oriented policy tools in the western region do not reflect the effect of their assembly-type building development.

Among the environmental policy tools, the overall policy of the eastern region is moderately related to the leading enterprises and scientific research institutions of its assembly-type construction. Among them, the financial incentive category has high correlation to the development of assembly-type building in the eastern region, and the correlation coefficients of new construction area, leading enterprises and scientific research institutions are 0.4575, 0.7666 and 0.7193, respectively. By contrast, tax incentives are less relevant. In the industry support and traffic security, there is a moderate negative correlation between the policy intensity and the implementation effect of assembly-type buildings, and the correlation coefficient value is − 0.5 to − 0.3. The environmental policy tool as a whole showed a low negative correlation to the degree of correlation in the central region. According to the calculation of the western environmental policy tool policy strength and the eastern region and the central region is not much different, but its incentive policy on the project implementation effect of assembly buildings is not much impact at present.

Differences in policy intensity of demand-based policy tools have different effects on different regions. For example, differences in the intensity of government procurement policies played little role in the eastern region, but were moderately related in

Table 5 Correlation coefficient between policy tools and project implementation effect indicators

	The eastern region			The central region			In the western region		
	New start area	Leading enterprises	Scientific research institutions	New start area	Leading enterprises	Scientific research institutions	New start area	Leading enterprises	Scientific research institutions
Cultivation of talents	0.0101	− 0.1251	− 0.1380	0.0916	− 0.0201	0.1449	–	–	–
Information support	0.3861	0.2667	0.2943	− 0.0366	− 0.1109	0.1914	− 0.3849	− 0.4378	− 0.2369
Financial support	0.4043	0.5255	0.7120	0.4173	0.6840	0.3428	0.1641	− 0.1157	0.0239
Land planning	0.5799	0.2463	0.3433	0.1672	0.4075	− 0.0051	− 0.0125	0.0020	− 0.1831
Supply-type	0.5910	0.4942	0.6671	0.3294	0.5361	0.2978	− 0.0551	− 0.2173	− 0.1704
Financial incentives	0.4575	0.7666	0.7193	− 0.3037	− 0.1929	− 0.4101	− 0.0722	− 0.2045	− 0.4698
Tax preferential	0.3914	0.6472	0.6792	− 0.3763	− 0.2943	− 0.2612	− 0.2245	0.3951	0.2208
Industry support	− 0.3024	− 0.4970	− 0.4107	0.1798	0.1961	0.3157	0.4587	0.4604	0.6223
The transportation security	− 0.6996	− 0.3290	− 0.3541	− 0.7269	− 0.6641	− 0.6248	0.1550	− 0.1841	0.0564
Environment-type	0.0780	0.3775	0.4107	− 0.3095	− 0.2023	-0.2401	0.2107	0.3467	0.3007
Government procurement	0.2761	− 0.53	− 0.5089	0.4181	0.5412	0.4023	0.1824	− 0.1096	− 0.0907
Overseas exchange	− 0.0243	0.2048	0.364	− 0.4735	− 0.3971	− 0.4353	− 0.2019	− 0.2329	− 0.2271
Requirement types	0.2078	− 0.2999	− 0.1833	− 0.0842	0.0541	− 0.0657	− 0.0247	− 0.2366	− 0.2173

the central region, with correlation coefficients in the range of 0.4–0.55. It shows that such policies are more practical in the central region. Overseas exchanges are basically negatively related, perhaps the overseas exchange policy in practice was not put in place.

5 Revelations and Suggestions

(1) Reduce supply-oriented policy tools and enable the absence of demand-oriented policy tools

First, reduce the overall use of supply-oriented policy tools frequency, less administrative induction, improve policy-making efficiency and implementation quality. In particular, reduce the frequency of the emergence of systemic policy tools and strengthen the use of regulatory control policy tools. Second, the policy focus should be from the environment and supply-oriented to demand-oriented continuous improvement. With the gradual progress of the strategic objectives of assembly building, the demand-oriented policy of enabling vacancy should be selected in a planned manner to ensure the continuity and practicality of the policy. Encourage the implementation of the assembly construction model in shantytown renovation projects from the present stage to expand market demand.

(2) Recommendations on policies in the eastern region

The influence of policy intensity on the implementation effect of the project in the eastern region was highly positive, with Jiangsu, Zhejiang and Shandong provinces showing the most obvious performance. The regions with low policy intensity in the east should learn from these provinces, mainly strengthen the two types of financial support and land planning in supply-oriented policy tools, strengthen financial incentives and tax incentives in environmental policy tools, and increase the strength of industry support policies, so as to further promote the development of assembly-type buildings in the eastern region.

In general, the eastern region should adhere to the policy advantages and increase the integration of industry resources. On the one hand, the policy direction should pay attention to the role of scientific research institutions, including universities, in the development of assembly-type buildings, and give more environmental and demand-oriented policy support. Form the integration of industry, science and research, speed up the construction of the whole industrial chain, strengthen industrial communication and exchange, break down information barriers. On the other hand, enterprises are encouraged to participate in the national science and technology plan, so that projects reflect the real needs of the industry.

(3) Research on poor policy effects in central and western regions

Supply-type in the central region and western region, environmental and demand-type policy tools of policy strength may be the eastern intensity difference is not

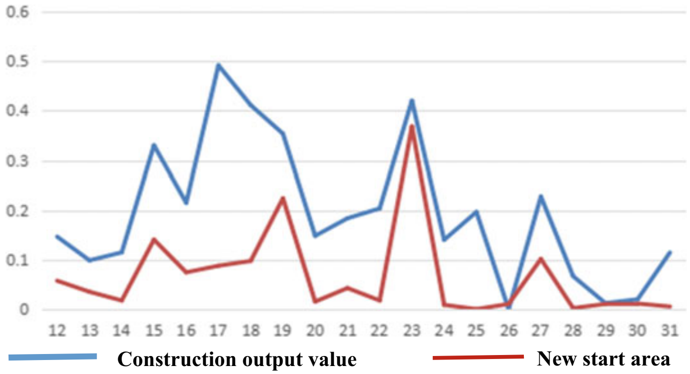

Fig. 5 The relationship between construction output value and new start are

big, but on the actual effect of prefabricated building floor, the obvious differences between possible interference by other factors can lead to the development of prefabricated construction is not perfect, so put together the two regions.

Therefore, central and western regions be prefabricated building new starts area and regional architectural production do correlation analysis, the 2019 provincial area (city) construction output value of national bureau of statistics data has not been updated, so the data used in central and western regions in 2018 prefabricated construction area and its new development in 2018 construction output waveform figure, specific content as shown in Fig. 5.

It can be seen from Fig. 4 that the trend of the waveform is roughly the same, while the correlation coefficient actually measured is 0.77, which is a high intensity correlation. This indicates that although the central and western regions have good policy intensity, the actual project implementation effect of prefabricated buildings is not as good as that of eastern regions due to economic constraints.

Therefore, the following two Suggestions are proposed for the central and western regions:

(1) Mainly put demand-type policy tools in place to indirectly drive the development of prefab construction-related leading enterprises; Local governments should respond to the "bring in" strategy, introduce leading enterprises and advanced technologies in prefab architecture at home and abroad, and improve our capabilities in design, construction and production of prefab architecture.
(2) Supply policy tools: Education and training, a basic policy tool, should be strengthened to provide prefab building professionals for the central and western regions, and financial support should be emphasized to increase economic support for prefab building; The financial incentives and tax incentives of environmental policy tools, because of the low economic level in the central and western regions, can increase the credit support for leading enterprises to promote the development of prefab buildings.

6 Deficiencies and Prospects

Due to the current literature on prefabricated building incentive policy research is relatively small, is not unified regulation, policy evaluation and prefabricated construction lagging related data updates and partly due to the limit of individual ability, this paper research on the theory and method of the deficiencies, hope in the future can have relative policy of unified, scientific grading rule, at the same time around the ministry to regularly publish prefabricated construction related development provides the basis for the accuracy of the data for further research.

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The Reconstruction of Urban Center System Based on POI Data: A Case Study of Shenzhen

Feihu Liu

Abstract Identification and evaluation of urban center is one of the important contents of urban research and urban planning. Early development planning of Shenzhen focused on SEZ (special economic zones), which led to the polarization of SEZ and non-SEZ in the urban center system. With the help of spatial big data, limitations of traditional data are broken. Based on this, spatial pattern of Shenzhen central structure is analyzed, and then the evolution characteristics of Shenzhen central system are summarized. Using POI data of Shenzhen from 2010 to 2019, we comprehensively consider the influence of functional density and functional diversity on the determination of urban center, and measures the spatial structure of urban center in Shenzhen based on a simple and intuitive method to identify urban center. The research shows that the urban center based on POI data identification can better reflect the actual urban development. The urban center system of Shenzhen is in a growth trend, gathered in SEZ and transitional zone in the middle of Shenzhen and continuously expanding to the north of Shenzhen. The period from 2010 to 2015 is the fastest growing period of the urban center system in Shenzhen. From the perspective of urban macro level, spatial pattern of the urban center structure of Shenzhen shows the overall characteristics of moving from agglomeration in SEZ to balanced development within the whole urban, and the difference in the centrality level between SEZ and non-SEZ gradually decreases. Through the evaluation of existing plans, it is found that the urban planning of Shenzhen has played an important role in reconstructing the urban spatial structure and guiding the formation and development of the urban sub-center system outside the special zone.

Keywords Urban spatial structure · Urban center · Polycentricity · POI · Shenzhen

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1 Introduction

Urban spatial structure is the spatial distribution and interaction of urban elements such as physical environment, functional activities and cultural values [3, 5, 39], and is an important content of urban research and urban planning. Urban center is the core content of urban spatial structure research [12, 22, 31], and also the key object of urban planning. Researches on urban center originates from the theory of center and Thunnen-Alonso model [34], and markets form the center through the competition for the optimal location.

The research on the urban center spatial structure in internation started early. Early research involved theoretical models and spatial models [1, 17]. Empirical research mainly focused on the identification and verification of multiple centers, including employment polycentric [15, 21], morphological polycentric [30], functional polycentric [13, 31]. Chinese scholars' research on the spatial structure of urban centers started relatively late, mainly involving: Introduction and development of theoretical models [27, 33, 35], polycentric identification, measurement and verification [29] and polycentric performance evaluation [28, 32, 38]. Empirical study of functional centers usually measures the functional relationship between the centers [11], compared with this, morphological centers are closer to the definition of urban centers in urban planning. The identification methods of urban center mainly include: (1) density threshold method [12]; (2) Semi-parameter, non-parameter and other mathematical model methods [19, 20], (3) Spatial clustering [8, 24, 25, 31].

However, existing studies have mostly analyzed from the perspective of single type of factor density, ignoring the functional diversity of urban centers [40]. According to the central place theory [4], high-level centers should have additional high-level services. Similarly, the case from Singapore also has a similar view: functional diversity and functional density are also an integral part of urban centers [37]. Merging density and diversity into a composite measure of centrality has been attempted before [2, 37]. What is clear now is that different kinds of density associated with different land uses characterise different kinds of centrality and thus one needs to be careful about the choice of density type.

In addition, most of the existing studies are based on the analysis of economic census data, population census data, and questionnaire data. Limited by the large data space unit and timeliness, it is difficult to accurately describe the urban spatial structure from the micro scale. With the progress of science and technology, spatial big data has become a new paradigm of urban research. Characteristics of high spatial precision and large sample of spatial big data break the limitation of traditional data [7]. Many empirical studies use mobile phone signaling data, social media data, POI (point of interests) data and other spatial big data to identify and evaluate the central system [8, 34], and the verification of urban polycentrics [6, 10, 18], the distribution pattern of industry centers [7, 16] content. Based on the research results in recent years, it can be found that the existing research on the spatial structure of urban centers based on spatial big data is mainly based on a particular point in time, and there are relatively few studies on the analysis of urban center spatial structure changes based on spatial big data in historical years [36]. The reason is that most of the open network data such as POI data and social media data are obtained based on web crawlers, and only the "latest" time point data can be obtained. The longitudinal comparison studies in different years lack data support.

Compared with other big data, POI data can effectively meet the definition of urban center in this research. POI data is a kind of point data representing the functional elements of a real city. It is a bottom-up land use data. The functional attributes reflect the activities and behavior types of the people in the spatial area, and can simultaneously reflect the density and the function of the city. Diversity characteristics. Based on long-term POI data obtained from navigation software companies, this paper comprehensively considers the impact of functional density and functional diversity on the determination of urban centers, and measures the spatial structure and evolution of urban centers. And Compare the identified city center with the existing urban planning, and evaluate the role of the urban planning in guiding and reconstructing the structure of the urban center.

2 Research Areas and Data

2.1 Research Areas

Shenzhen covers an area of 1997.47 km^2, with built-up areas of 927.96 km^2. By the end of 2018, the resident population of Shenzhen had reached 13.03 million, and its GDP had exceeded 2.4 trillion CNY. Shenzhen has 9 administrative districts and 1 functional district, there are Futian District, Luohu District, Nanshan District, Yantian District in central urban area (Special Economic Zone, hereinafter referred to as SEZ), and there are Baoan District, Longgang District, Longhua District, Pingshan District, Guangming District in outside central urban area (Non-special economic zone, hereinafter referred to as non-SEZ). Dapeng New District is a functional district. In order to curb the disorderly expansion and spread of urban space caused by rapid urbanization, Shenzhen promulgated the "Regulations on the Management of Basic Ecological Control Line of Shenzhen" in 2005, which delimited the boundary of ecological protection scope (Shenzhen Government online, http://www.sz.gov.cn). Construction activities are prohibited or controlled in the ecological control area, and urban functional elements are too rare and of a single type, so the influence of areas within the ecological control line on the measurement of urban center system is excluded. Therefore, study area is outside the ecological control area in shenzhen, with an area of about 962.27 km^2 (Fig. 1).

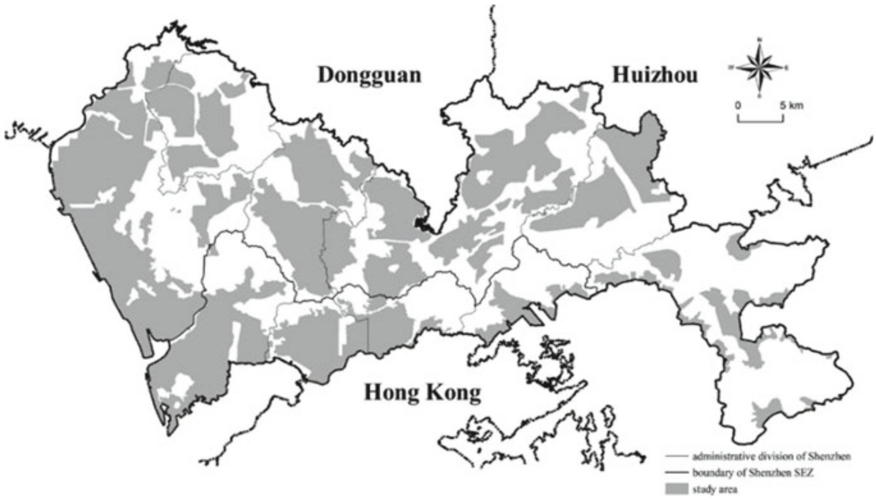

Fig. 1 Study area

2.2 Data Sources and Processing

In this research, the POI spatial data of Shenzhen from 2010 to 2019 is used, including name, category, spatial coordinates and other information. Data was obtained from a leading navigation company in China, with high data quality and guaranteed validity and comprehensiveness of POI data. POI data was divided into 10 categories and 40 sub-categories (Table 1) by referring to Chinese urban land classification standard (GB50137-2011) and considering the urban functions comprehensively. The 10 categories include residential function, industrial production function, catering service function, shopping service function, accommodation service function, leisure and entertainment function, business and finance function, administration function, medical and health function, culture and education function. By checking and processing the data, 68,965 POI data were obtained in 2010, 173,632 in 2015 and 290,315 in 2019. The spatial distribution of POI data in each year is shown in Fig. 2. It can be seen that Shenzhen had the least POI density in 2010, and there are many POI scarce areas in the north of urban (non-SEZ); those areas gradually have higher POI density in 2015; by 2019, it is difficult to distinguish the difference between inner urban area only from the POI density.

Table 1 POI classifications based on urban functions

Urban functions		POI categories
Residential function	Residential function	Residence community
Industrial function	Industrial production function	Industrial parks, science and technology parks
Business services functions	Catering service function	Chinese restaurant, foreign restaurant, snack bar, cake shop, etc.
	Shopping service function	Shopping malls, supermarkets, comprehensive markets, convenience stores, electronic home furnishing, and life service related stores
	Accommodation service function	Star hotels, budget hotels, guest houses
	Leisure and entertainment function	Sports venues, cinemas, KTV, bars, video games, beauty and beauty and other leisure and entertainment venues
	Finance function	office buildings, Banks, securities, insurance companies
Public administration service functions	Administration function	Government organs, public security organs, procuratorates, courts, industrial and commercial tax authorities, post offices
	Medical and health function	Hospitals, community service stations, clinics, disease prevention centers, professional physical examination institutions, pharmacies, animal hospitals, etc.
	Culture and education function	News media, museums, libraries, bookstores, schools, training institutions, scientific research institutions, etc,

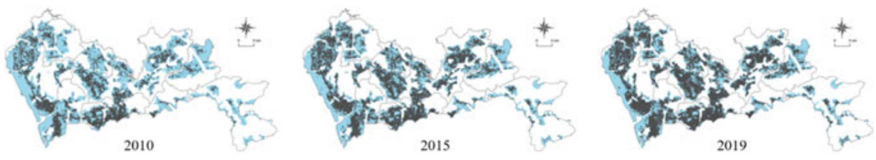

Fig. 2 The spatial distribution of POI in study area from 2010 to 2019

3 Research Methodology

3.1 Construct the Centrality Index

Research area is uniformly divided into grids of 500 m * 500 m, and each grid is taken as the spatial unit of analysis. Considering comprehensively the influence of function density and function diversity on the decision of urban center (Fig. 3), the centrality index *CI* is defined as the product of function density and function diversity. Function density index (*De*) reflects the concentration degree of urban functions in specific spatial units, which is defined as the number of POI per unit area. The calculation formula is as follows: $De = \frac{N_i}{A_i}$, where N_i is the total number of POI in spatial unit I, A_i is the area of the spatial unit *i*. Functional diversity index (*Di*) reflects the diversity of urban functions in spatial units, which is measured by Shannon entropy [9, 26] (Ran Zhao, 2019). The calculation formula is as follows: $Di_i = -\frac{\sum_{j=1}^{m} P_{ij} * \ln(P_{ij})}{\ln(\mathrm{m})}$, Where M is the number of POI subclasses, which is 40. P_{ij} is the proportion of function *j* POI in spatial unit *i*. According to Chen et al. [7], function density index and function diversity index are transformed into a dimensionless sequence with consistent distribution interval. Considering that there is only one kind of functional elements in the spatial unit, the centrality index is 0, which conceals the heterogeneity brought by the functional density, and it needs to be assigned. Non-zero minimum value of the functional diversity index before assignment is selected, and the functional diversity index of a spatial unit with only a single functional element is defined as 1/2 of it. After adjustment, new function density index is $De*$ and new function diversity index is $Di*$. At this time, $0 \leq De* \leq 1$, $0 \leq Di* \leq 1$.

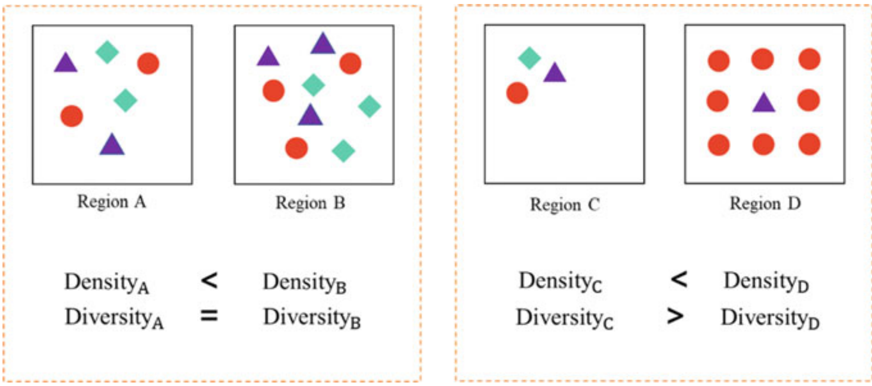

Fig. 3 Schematic diagram of functional density and diversity combination concept

3.2 Determine Scope and Functional Category of Urban Center

Based on Vasanen [31] and Niu [23], we identified the urban center through spatial clustering. This way is concise and intuitive, and the identified urban center is close to the concept of urban center in urban planning. Therefore, it can effectively compare the spatial pattern of urban center structure in different years, and planning can be evaluated in terms of actual development. As shown in the following details, select Getis-Ord Gi* index to calculate local spatial autocorrelation, spatial relation is rook contiguity, and hot spots with high centrality index clustering were obtained. The significance level of "hot spots" was defined as 1% [31], obtain the selected area of urban center accordingly. Threshold method is used to eliminate small-scale and irrelevant "center noise". Threshold is the ratio between the total number of POI in the region and the total number of POI in the study area. Combined with the existing relevant studies, after many tests, when the threshold value is set at 0.6%, isolated and small-scale "center noise" basically disappears, and the urban center boundary identified at this time is more reasonable.

We also carry out the identification of urban centers that only considers the density of the elements. The identified urban centers are large in number, small in scale, and far from the actual situation. The reason is that there are many urban villages in Shenzhen, and the nearby commercial facilities of the urban villages are developed, and the density of urban elements is high, so they are recognized as the center, which is not consistent with the actual certification.

Function category of urban center is determined by location entropy. Urban function location entropy LQ_{ij} represents the agglomeration degree of region j in function i relative to the whole city. Calculation formula is as follows:

$$LQ_{ij} = \frac{q_{ij}}{qj} \Big/ \frac{q_i}{q}$$

where, $\frac{q_{ij}}{qj}$ represents the proportion of function i in region j; $\frac{q_i}{q}$ represents the proportion of function i in all POI. Location entropy is greater than 1.2, indicating that the region has a leading level of specialization and has a significant impact on regional development [14]. The function types with the maximum function location entropy and over 1.2 are judged as the functional category of urban center, such as business and finance function center, leisure and entertainment function center, residential life function center, etc. Others are judged as comprehensive urban center.

4 Results

4.1 Spatial Pattern of Urban Centrality

4.1.1 Central Spatial Pattern: From Agglomeration to Balanced Development

According to the spatial distribution of function density index, function diversity index and centrality index (Fig. 4), the spatial pattern of urban centrality in Shenzhen shows an overall characteristic from agglomeration in SEZ to balanced development in the whole urban. In terms of the spatial distribution of the centrality index, the high value spatial units of the centrality index were concentrated in SEZ and SEZ and transitional zone in the middle of Shenzhen in 2010, such as Baoan, Longhua and Buji. 2015, the high-value region of the centrality index spread to the northern region such Gongming, Manhole, Dalang, Pinghu, Longgang and other cities, and the spatial distribution characteristics of the centrality index tended to be balanced, which was further strengthened in 2019. Evolution characteristics of functional density index are strongly correlated with the centrality index, and the Pearson correlation coefficients of the two indexes in 2010, 2015 and 2019 are 0.969, 0.972 and 0.924. Spatial distribution features of the two are similar and have obvious "center-periphery" distribution features.

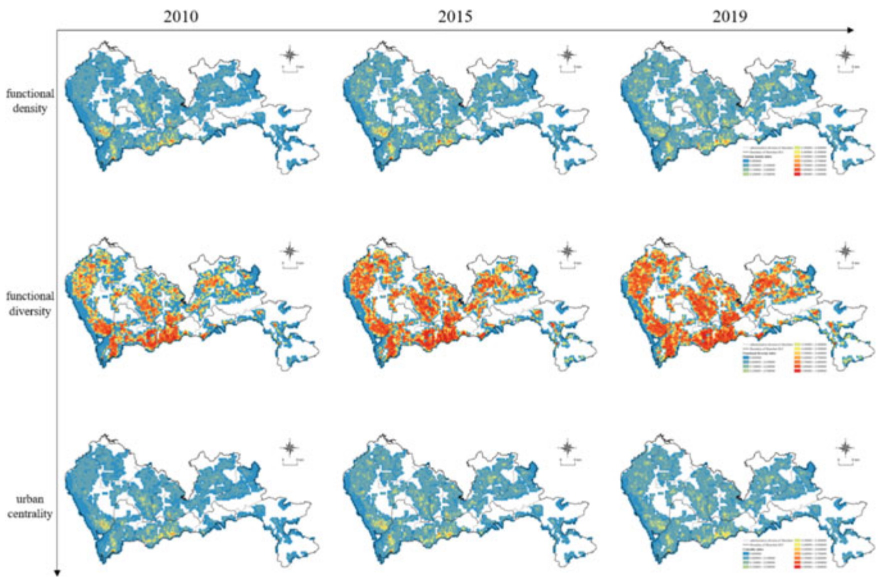

Fig. 4 Spatial distribution of functional density, functional diversity and centrality index of Shenzhen from 2010 to 2019

In 2010, the high-value spatial units of the functional diversity index were mainly concentrated in the SPECIAL zone, while the functional diversity level outside the special zone was relatively weak. With the improvement of the infrastructure of the built-up areas outside the SPECIAL zone and the enrichment of urban functions, the types of urban functional elements are increased, and the spatial distribution pattern of the functional diversity index within the whole city in 2015 and 2019 is more balanced.

4.1.2 The Centrality Gap Between SEZ and Non-SEZ

It can be seen from the spatial clustering characteristics (Table 2) that the SEZ and non-SEZ have significant clustering characteristics in function density index, function diversity index and centrality index, and the evolution characteristics of agglomeration degree show opposite trend, and the centrality level gap between SEZ and non-SEZ is narrowing. From 2010 to 2019, the Moran's I index of the three indexes in SEZ and non-SEZ is between 0.5 and 0.65, and the P value is far below 0.001, indicating that the three indexes have significant spatial clustering. General G's Z was further used to identify the clustering type. General G's Z and P value of General G were all greater than 37 and less than 0.001 respectively, then the clustering type was judged as high-value clustering.

According to the change trend of Moran's I index and General G's Z value, it is found that the concentration degree of the functional density index and the centrality index in SEZ increases gradually, while the concentration degree of the functional diversity index decreases gradually, indicating that the centrality level in SEZ continues to be strengthened on the original basis. This is because functional density index and the centrality index high-value area in the SEZ have been formed on a large scale in 2010, which has a strong Matthew effect and drives the development of the surrounding space units, so that their functional density index and centrality index have been developed from the medium–low value to the high-value area, and then form a larger high-value agglomeration area. Emergence of high-value functional diversity index regions such as Xili and Shahe region has not integrated with existing high-value clustering regions, thus reducing the degree of functional diversity clustering.

Similarly, the clustering degree of the functional density index and the centrality index of non-SEZ decreases gradually, while the clustering degree of the functional diversity index increases gradually, indicating that non-SEZ improves the overall centrality level by adding a high level of centrality area. Because, density index, centricity index is generally lower in non-SEZ, high-value regions are only distributed in central areas of Baoan and Longhua, etc. in 2010. In 2015–2019, Longgang central area, Henggang, Shiyan, Shajin and other potential development areas are gradually emerging, high-value agglomeration area is numerous and dispersed, which separates the overall agglomeration degree of functional density index and centrality index in non-SEZ. The high-value clustering area of the functional diversity index in non-SEZ is fragmented, and there are large number of low-value areas in SEZ. With

Table 2 Spatial agglomeration and statistical characteristics of the Shenzhen Centrality Index and its related indexes from 2010 to 2019

Attribute		Region								
		Citywide			SEZ			non-SEZ		
		2010	2015	2019	2010	2015	2019	2010	2015	2019
De*	Moran's I index	0.648	0.576	0.565	0.598	0.603	0.621	0.654	0.548	0.516
	Moran's I's Z	88.342	78.548	76.967	38.590	38.905	40.044	78.774	65.671	61.877
	General G's Z	89.503	81.056	79.825	39.533	39.823	40.965	79.542	68.130	65.033
	average value	0.035	0.054	0.053	0.068	0.076	0.072	0.025	0.047	0.047
	Standard deviation	0.085	0.100	0.092	0.127	0.135	0.124	0.065	0.087	0.080
Di*	Moran's I	0.570	0.5450	0.558	0.605	0.568	0.566	0.541	0.544	0.555
	Moran's I's Z	77.615	74.801	75.877	38.863	36.462	36.308	64.783	65.117	66.458
	General G's Z	82.305	80.998	82.095	39.930	37.776	37.654	69.134	70.503	71.768
	average value	0.269	0.395	0.443	0.355	0.430	0.480	0.245	0.385	0.4317
	Standard deviation	0.320	0.353	0.353	0.366	0.373	0.365	0.300	0.346	0.348
CI	Moran's I	0.641	0.579	0.574	0.591	0.607	0.628	0.646	0.547	0.524
	Moran's I's Z	87.430	78.913	78.178	38.145	39.110	40.487	77.726	65.575	62.831
	General G's Z	88.523	81.295	80.909	39.095	40.036	41.420	78.460	67.908	65.802
	average value	0.026	0.043	0.042	0.055	0.064	0.060	0.018	0.038	0.037
	Standard deviation	0.071	0.085	0.078	0.109	0.116	0.105	0.053	0.073	0.067
	Number of grids greater than 0.3	82	128	98	51	63	58	31	65	40
	Number of grids greater than 0.7	2	5	1	2	3	1	0	2	0
	max	0.736	0.834	0.793	0.736	0.834	0.793	0.683	0.748	0.610

the richness of functional categories in the region, the functional diversity index of high-value regions developed in tandem.

Data analysis shows that the mean values of functional density index, functional diversity index and centrality index in SEZ are much higher than those in non-SEZ, and there is a big gap in the number and types of urban functional elements in SEZ and non-SEZ. By comparing the mean values of the three indexes, it is found that the centrality gap is narrowing. The ratio of the mean value of the centrality index of SEZ and non-SEZ decreased from 3.06 in 2010 to 1.68 in 2015 and 1.62 in 2019. The ratios of the mean values of the functional density index and the functional diversity index in SEZ, and non-SEZ also have similar changes.

4.2 Spatial Evolution of Urban Central Structure

Based on the urban center identified in 2010, 2015 and 2019, it is found that the urban center system of Shenzhen is in a growth trend, which is concentrated in SEZ and transitional zone in the middle of Shenzhen and continuously expands to the north of the urban. In terms of quantity, the number of urban centers in Shenzhen continues to increase. The period from 2010 to 2015 is the fastest growing period of the urban center system in Shenzhen, and also the period when the urban spatial structure of Shenzhen changes greatly. The number of urban centers rose rapidly from nine in 2010 to 18 in 2015 and 21 in 2019. In 2010, original urban centers included the Futian Central Districtr, Luohu Central District, Nanshan Central District, Baoan Central District, Longhua Central District those regional commercial and political gathering places, Lianhu-Meilin Center, the Xili Center and Bantian Center for industrial gathering, and Buji Center with prominent commercial functions. In 2015, 9 new urban centers were added, including Longgang Center, Shiyan Center, Songgang Center, Shajing Center, Henggang Center, Fuyong Center, Pinghu Center, Xixiang Center and Gongming Center. In 2019, Xinqiao Center, Dalang Center and Shahe Center were identified as urban centers as the number and types of functional elements in their regions increased.

From the perspective of spatial distribution (Fig. 5), the original urban centers are distributed in SEZ and transitional zone in the middle of Shenzhen, while new urban centers are concentrated in non-SEZ. In 2010, five urban centers were distributed in SEZ and four in the transitional zone in the middle of the city. From 2010 to 2015, large number of secondary centers were formed in non-SEZ. The urban centers formed in this stage were all located outside the special zone, such as the central area of Longgang Center, Pinghu Center, and Gongming Center, etc., and the urban center system expanded to the north. In 2019, the urban center system was continued to grow. Shahe Center has been formed in SEZ, while Dalang Center and Xinqiao Center have been formed in non-SEZ. At the same time, the growth process of the central system is accompanied by the fusion and independence of the center boundary. New urban centers such as Xinqiao Center and Shajin Center break the limitation of administrative boundaries, and boundary fusion phenomenon occurs.

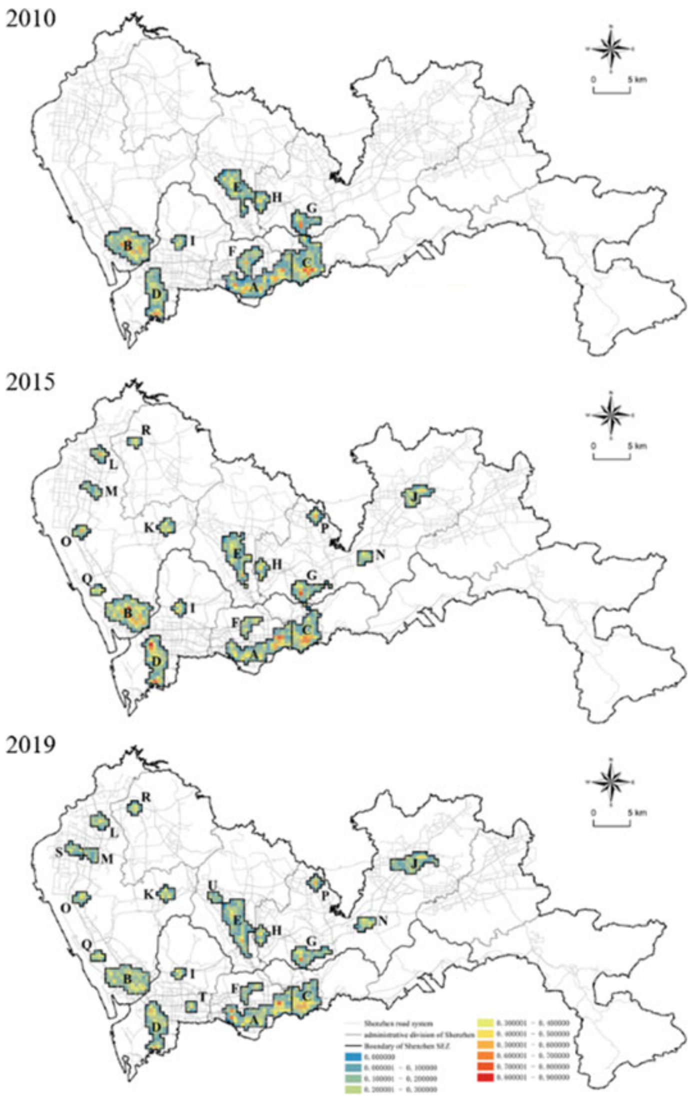

Fig. 5 Urban center of Shenzhen from 2010 to 2019 (A is Futian central district, B is Baoan central district, C is Luohu central district, D is Nanshan central district, E is Longhua central district, F is Lianhua-Meilin center, G is Buji center, H is the Bantian center, I is the Xili center, J is the Longgang central district, K is the Shiyan center, L is the Songgang center, M is Shajing center, N is the Henggang center, O is the Fuyong center, P is the Pinghu center, Q is the Xixiang center, R is the Gongming center, S is the Xinqiao center, T is the Dalang center, U is the Shahe center)

The original urban centers with boundary integration, such as Lianhua-Meilin Center, Futian Central District, Luohu Central District and Buji Center, have continuously strengthened their own characteristics and become more independent in boundary nature.

4.3 Evaluation of Urban Planning

4.3.1 Urban Master Plans of Shenzhen

With the rapid completion of urbanization, urban development is faced with spatial constraints and resource bottlenecks, and the existing urban spatial structure is facing transformation. On this context, Shenzhen launched a new round of planning in August 2006, in which to solve the problem of urban development. According to Shenzhen urban master planning (2010–2020) (hereinafter referred to as overall planning), Shenzhen takes the SEZ as the core development area, with three development axes in the west, middle and east and two development belts in the south and north as the basic framework, forming a "three-axis, two-belt and polycentric" axial belt cluster urban spatial structure (Fig. 6).

Relying on the shadow effect of the land value brought by the proximity of Hong Kong, Shenzhen started to develop from the east and west wings of Luohu and Shekou

Fig. 6 The urban master planning of Shenzhen (2010–2020)

at the same time, forming a strip-shaped urban center structure of Luohu-Shekou. In the basis of the original urban development, the planning of Shenzhen main center has broken the administrative boundary and formed Futian–Luohu center, which assumes the comprehensive service functions at the municipal level, such as administration, culture, commerce and commerce. Based on its high-tech, traffic location, preferential policies and other advantages, Qianhai, Houhai and Baoan center are gathered as the new main urban center—Qianhai Center, which take the regional modern service and headquarters economy as its main industries. Due to the marginal benefits of scale agglomeration, the creation of sub-centers greatly alleviates the negative effects of the main center caused by excessive scale. The new urban master plan for the first time put forward the concept of sub-center, including longhua center, Longgang Center, Yantian Center, Pingshan Center, Guangming Center. Eight cluster centers are integrated service centers for local area, including Shajin, Songgang, Pinghu, Buji, Henggang, Guanlan, Hangkongcheng and Kuiyong. Among them, Hangkongcheng and Kuiyong centers are new planning centers. Luster center is distributed in the horizontal development belt and the longitudinal development axis, leading the development direction within the local area, and playing a supplementary role to the main center and sub-center of Shenzhen.

4.3.2 Comparison with Existing Urban Planning

The research shows that the overall planning of Shenzhen plays an important role in reconstructing the urban spatial structure and guiding the formation and development of the sub-center system in non-SEZ. According to the urban centers in 2010 and 2019 (Fig. 7), Shenzhen urban center system has undergone tremendous changes and

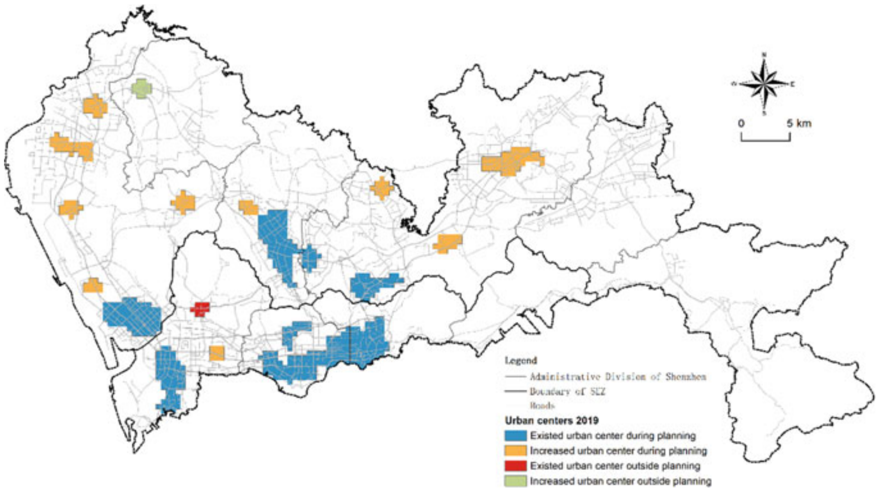

Fig. 7 The actual central classification based on overall planning

the urban spatial structure has undergone transformation. In 2019, 19 urban centers are located within the scope defined in overall planning (excluding Xili Center and Gongming Center). The spatial distribution of the actual urban centers conforms to the overall planning (Fig. 7), which is reflected in the main center, sub-center and cluster center, and the actual urban development conforms to the expected planning. During the implementation of the overall planning, 12 new urban centers has been added, of which 11 centers are located non-SEZ. The number of urban centers in non-SEZ has increased from 4 in 2010 to 15 in 2019, which greatly enhances the level of local centrality. Due to the policy advantages and resource preference brought by planning positioning, there are high level of functional density and diversified functional types in Longhua central district and Longgang central district. They are surrounded by cluster centers such as Dalang Center, bantian Center and Henggang Center, both of which are higher than cluster centers in area, size and centrality. Therefore, they are in line with the positioning of the sub- center. The formation of Longgang Central district marks the formation and improvement of the sub-center system in non-SEZ.

5 Conclusion and Discussion

5.1 Conclusion

By selecting urban function and the condition of the urban space close to polarized situation of Shenzhen as the research object, based on the POI data from 2010 to 2019 since the implementation of Shenzhen Special Economic Zone Integration Strategy, from the macro perspective of Shenzhen urban center of the structure of the spatial pattern and evolution is analyzed, and on the basis of evaluating the actual development situation of Shenzhen. The research finds that ① the identification of urban centers based on POI data can better reflect the actual development of cities, and the identification of urban centers in different years conforms to people's cognition of cities. ② The urban center system of Shenzhen is in the growth trend. The urban center system is concentrated in the transitional zone between the region and the city within the special zone and continuously expands to the north of the city. ③ The period from 2010 to 2015 is the fastest growing stage of the urban center system of Shenzhen, and it is also the stage where the urban spatial structure of Shenzhen changes greatly. ④ From the perspective of urban macro level, the spatial pattern of Shenzhen's urban center structure presents the overall characteristics of moving from agglomeration in SEZ to balanced development within the whole city. Specifically, the evolution characteristics of urban functional element agglomeration in non-SEZ show an opposite trend. The regions in SEZ continue to strengthen the centrality level on the original basis, while the regions outside the special zone improve the overall centrality level by adding a new high-level centrality area, and the difference in the centrality level between the regions inside and outside the special zone gradually decreases. ⑤The urban planning of Shenzhen ensures its implementation effect by enhancing the intensity of original land development and implementing urban renewal activities. That is to encrypt and diversify the functional elements of the original land and built environment. And then play a role in the reconstruction of urban spatial structure, especially guide the formation and development of the sub-center system in non-SEZ.

5.2 Discussion

The analysis based on POI data in this paper provides a new method and perspective for the study of urban center. This method can describe the degree of urban element aggregation in different areas within the city in a more detailed way, quickly and effectively identify the urban spatial structure, and make up for the shortage of conventional data such as economy, population, land use, and night light image. However, POI data is an abstract point of physical space and lacks information on the scope, scale and level. A single data source based on POI only focuses on describing the urban center system from a morphological perspective, ignoring the functional connection between centers. From the definition of urban spatial structure, it is found that urban center includes not only urban entity elements, but also economy, population and functional connection. Future research should add other big data and reliable traditional data to complement each other to form a multi-source heterogeneous data set, and the description of the urban center system is more comprehensive and objective.

On the other hand, the urban research paradigm based on big data helps to alleviate the problems existing in the current planning system. In view of the lack of timely and effective evaluation of the current implementation effects of urban planning, and low public participation, research based on big data can reflect the actual development of the city from the bottom up, and reflect public participation to a certain extent. Utilizing the powerful features of big data, the implementation status of urban planning can be evaluated in real time, and then the failure area of the planning can be fed back in time, and the implementation of planning goal can be guided through reasonable targeted planning revisions. This also requires that urban planning should not be a "resultant" blueprint, but a process of dynamic development, with phased planning development indicators and dynamic requirements.

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Transformation and Spatial Evolution of Industrial Land in the Process of Urban Renewal in Shenzhen, China

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Abstract With the continuous development of urbanization in China, megacities have entered the stage of urban renewal. In the process of continuous extension and expansion of the city, the edge distribution of the early old industrial areas has gradually evolved into the central area of the modern city. There is a huge contrast between the superior location conditions and inefficient land use, which makes the old industrial land become the most valuable stock zone. A spatial perspective is adopted to investigate the industrial land transformation, which is important to evaluate the spatial impacts of urban renewal yet has been rarely studied in existing literatures. Based on the urban renewal project planning data of old industrial zone from 2010 to 2018, this paper analyzes the function transformation and spatial pattern of old industrial land in Shenzhen. The research shows that the local reform on urban renewal system towards marketization has greatly promoted the industrial land transformation. The development of real estate market, the upgrading of industrial structure, and the strategic demand for intensive development of industrial land are the important factors that affect the transformation. Urban renewal has led to a sharp reduction in the scale of the old industrial land, and commercial and residential space and new industrial space are the main directions of the transformation of old industrial land. Under the innovative "urban renewal unit" system framework of Shenzhen, the redevelopment of old industrial zones have also contributed a lot of land for public facilities to local governments. The planned new industrial space is mainly located in the city center, while the new commercial and residential space gradually moves to the suburban areas. To achieve more sustainable urban development, more attention should be paid to balance the demand for industrial space and the erosion of the industrial space driven by property-led redevelopment in the urban renewal process.

Keywords Urban renewal · Old Industrial land · Spatial transformation

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1 Introduction

Urban renewal is an important activity of land reuse and space remodeling that urban development must experience to a certain stage. Its main purpose is to plan and improve the quality of the built-up area under the early extensive expansion and development mode by means of demolition and reconstruction, comprehensive renovation and functional transformation, so as to solve a series of problems to revitalize the urban economy and promote urban transformation. With the continuous expansion of cities and the rapid development of urbanization, the construction land scale of megacities in China has approached the upper limit, and it is difficult to sustain the new land resources. Urban renewal has become the main means of urban development [1]. Due to the increasingly serious problems such as low land use efficiency and unreasonable functional structure [2], the transformation and reuse of original industrial land has become the main content of urban renewal, and the redevelopment of old industrial land has become an important means of urban space regeneration.

Existing literature studies on the renewal of old industrial areas and the transformation of stock industrial land in China mainly focus on the renewal system and models [3–6], renewal strategies and planning mechanism [7–10]. By sorting out relevant studies on the transformation of old industrial land in China from western literature, Chen [11] summarized the reasons for the transformation of Chinese industrial land from three perspectives: economic transformation, political system transformation and the rise of post-industrial culture. Professor Wu analyzed the impact of urban renewal on industrial land transformation from the perspective of production-consumption transformation and believed that "land commercialization" stimulated mass consumption, turned industrial land into consumable and tradable commodities, and drove the transformation of industrial land into residential and commercial land in urban central areas [12]. Luo [13] believes that industrial upgrading, market location reselection, real estate development, new technological change and urban event catalyst are the main driving forces affecting the transformation of old industrial areas. In addition, some scholars analyzed the influence mechanism of industrial land transformation from the perspectives of policy system, social culture and stakeholders [14]. Pan and Peng [15] believe that industrial integration has injected new driving elements into the transformation and upgrading of urban industry. Technological innovation, function promotion, location function and government policy are the main driving forces to promote the transformation of urban industrial space. Zheng and Lu [16] think that in order to stimulate the urban economic development, the Shanghai municipal government pays more attention to obtaining the maximum short-term comprehensive income and maintaining relatively balanced long-term income when formulating the policy of industrial land renewal. The motivation of the government renewal is to maximize the comprehensive income and balance the long-term income. Existing studies have analyzed the renewal and transformation of the old industrial zone in China from different perspectives and obtained abundant results. However, the systematic research on the spatial transformation of industrial land in megalopolis under the background of urban renewal in China is insufficient. An in-depth investigation and analysis of the functional transformation of Chinese stock industrial land from the perspective of space is an important basis for evaluating the spatial impact of urban renewal and making a reasonable urban spatial planning, but it is rarely involved in existing studies.

Taking Shenzhen as the research area, this paper analyzes the transformation and spatial pattern of old industrial land since the practice of large-scale urban renewal. As one of the earliest megacities that have conducted institutional exploration in the field of urban renewal practice in China, Shenzhen is faced with a fierce contradiction between the extreme scarcity of space needed for industrial transformation and upgrading and the inefficient use of a large number of massive industrial land as the newly added land capacity gradually reaches the upper limit [17]. The "*Measures on Urban Renewal of Shenzhen City*" was promulgated at the end of 2009 and implemented at the beginning of 2010, marking that urban renewal activities in Shenzhen have entered the stage of scale and normalization. The practice of large-scale urban renewal in recent ten years has profoundly changed the function and pattern of Shenzhen's industrial space. Based on the existing literature, this paper firstly constructs the basic framework of the dynamic mechanism and influencing factors, then sorts out the current situation and relevant policies of urban renewal, and analyzes the economic and policy background of industrial land transformation. Collecting the renewal unit planning and the basic information of the renewal unit of the old industrial zone approved from 2010 to 2018 in the city, this paper makes a systematic analysis of the functional transformation and spatial pattern of the old industrial land by using GIS spatial analysis and statistical analysis. On this basis, the old industrial renewal practice and planning are evaluated, and corresponding suggestions are put forward.

2 The Transformation of Old Industrial Land Under the Background of Urban Renewal

The motivation mechanism and influencing factors of urban renewal are influenced by the time stage and geographical environment in which it is located, and they also present different characteristics in different regions and different historical backgrounds [18]. In recent years, a large number of literatures on the influence mechanism of cities in western countries have focused on "Gentrification" [19]. "Gentrification" focuses on the process and phenomenon of social class changes of specific space, which is essentially caused by the renewal of urban material space-oriented by real estate [20]. Regarding the gentrification in the process of urban renewal, Neil Smith (1987) put forward the Rent gap theory, and analyzed the gentrification process from the perspective of space production. Under the premise of continuous urban development, the potential rent of land (that is, the rent that can be obtained if the land in the same location can be developed for higher value functional use) will continue to increase. According to the theory of land rent, the first use function of urban land is determined by its “market value". With the increasing distance from the city center, the land use function is shown in order of Commerce, industry and residence [21]. In the process of urban expansion and development, industrial land in the original marginal areas gradually occupy the core areas of urban development, and the land rent gap is increasing. When land rent difference could attract development investment and fill the cost and risk of development, urban renewal activities will happen [22]. From the perspective of demand, the new changes of consumption, culture, and demand of the middle-class group are an important force to promote the renewal of urban material space and “gentrification” [23, 24]. Xie and Lin (2012) analyzed the functional replacement of industrial land from the perspective of stakeholders, and believed that the different value needs of local government, original enterprises, developers and residents jointly drive the transformation of industrial land [25]. Li [26] believed that with the deepening of the concept of urban innovation driven development transformation, people pay more attention to the cultural value of historical buildings, integrate cultural creativity into the urban industrial transformation, arousing the cultural resonance of consumers, and stimulate the market vitality of industrial land transformation. Although driven by both supply and demand factors, some studies also emphasize that central district renewal and “gentrification” are the results of policy guidance [27]. Urban renewal, brownfield redevelopment and mixed-use development policy issued by the central and local governments are all aimed at solving the problem of inner city decline and promoting urban renewal and the “gentrification” [28], and ultimately reshape the local image, promote the competitiveness of the city [29].

In the process of China’s urbanization, the economic and management system reform from plan oriented to market-oriented has profoundly changed the driving force of urban internal space reconstruction. First of all, the increasing decision-making power of local governments in the process of urban development is an important subject affecting urban development. The reform of land system and housing system further promoted the development of the real estate market. As a result, the old urban renewal that used to be funded and led by the government is gradually transferred to the market [30]. A large number of residential renewal and redevelopment of old industrial zones are no longer invested by local governments, but by private real estate developers. The development of the real estate market, the need for industrial structure transformation, the government’s policy guidance, and the citizens’ idea and behavior of choosing residence are the main driving forces for the redevelopment of urban space and the reconstruction of social space in China. In the past rapid urbanization stage, urban space has been expanded unprecedentedly, and it can’t support sustainable development only by incremental expansion. The contradiction between the expansion of urban land space and the shortage of land resources caused by rapid urbanization makes the urban development mode change from focusing on the development of new construction land to existing one. The city has gradually moved from extensive expansion to connotative development, seeking to improve the quality and efficiency of existing land [31]. The 2015 Central Urban Work Conference proposed to understand, respect, and adapt to urban development, transform urban development methods, and improve the urban governance system. Urban renewal, as a realistic way to solve the problem of urban development in the stock era, has become an important part at the present stage and has changed from a traditional passive "metabolism" to a strategic policy tool for urban management and decision-makers [32].

Compared with other mega first-tier cities in China, the administrative area of Shenzhen is only 1991.71 km^2,[1] of which the constructible land area is only 1004 km^2,[2] far less than that of Beijing,[3] Guangzhou[4] and Shanghai.[5] The administrative area of Shenzhen is small and space resources are scarce. With the rapid urbanization and urban land expansion in the early stage, by 2009, Shenzhen had developed more than 750 km^2 of construction land, and it is difficult to provide urban development space by adding new land. In this context, urban renewal has become an important strategy for the sustainable development of Shenzhen city. As a model of rapid urbanization development in China, Shenzhen is the first material city facing the bottleneck of land resource shortage, and also the first to carry out innovative institutional exploration and practice in the field of urban renewal, forming a unique urban renewal sample of Shenzhen. Since the promulgation of the "*Measures on Urban Renewal of Shenzhen City*" in 2009, the "urban renewal unit" has become the basic spatial unit for organizing and managing urban renewal activities [33]. Under the premise that both the landowner and the developer can reach an agreement and meet the application conditions of the "urban renewal unit" project, it can apply to the government for the renewal and transformation of the property right land. The urban renewal unit system clarifies the practice principle of "government leading and market operation", gives the market the right to carry out urban renewal and renovation independently, and encourages them to declaration and implement renovation projects by themselves, the market entities such as property rights subjects and investment subjects are playing an increasingly important role in urban renewal activities [34]. As an important part of urban renewal in Shenzhen, the reconstruction and redevelopment of old industrial areas are also based on this basic institutional arrangement.

The prosperity of the real estate market has promoted the old industrial zone transformation into a commercial and residential market. in Shenzhen. With the continuous gathering of population, capital, technology and other factors to big cities, Shenzhen has a continuous net inflow of population. According to statistics, Shenzhen's administrative area expanded by 5.83 square kilometers from 2010 to 2018, while the permanent resident population increased from 10.37 million to 13.03 million, and the population density increased from 4475 a/km^2 to 6484 a/km^2. With more people and less land, the housing market is in short supply, which makes the average

[1] According to the second land survey data of Shenzhen in 2009, the land area of the city is 1991.71 $km^{2.}$

[2] General land use planning of Shenzhen (2006–2020) (Revised version in 2017).

[3] Beijing Municipal Government: Beijing has a land area of 16,410.54 $km^{2.}$

[4] Guangzhou Municipal Government: As of 2018, the total area of Guangzhou is 7434.40 $km^{2.}$

[5] Shanghai Municipal Government: At the end of 2017, the land area of Shanghai was 6340.5 $km^{2.}$

sales price of commercial housing in Shenzhen rise year by year. In addition, with the continuous improvement of people's living standards, the market demand for urban high-quality formal living space, consumption and service-oriented space is also increasing [35]. The early form of providing low-cost housing through informal space, such as urban villages and small property houses, has been unable to meet the growing housing demand. Objectively, it needs to release a lot of living space through the transformation of old industrial areas. The current situation of the old industrial zones is characterized by low intensity of land construction, relatively simple property rights subjects, relatively low cost of property compensation for demolition, and huge increment of land interest after the transformation into commercial and residential space, making it a major urban renewal object under the market-oriented guidance.

With the development strategy of "strategic emerging industries", "Internet+", and "smart robots" successively proposed in the "*13th Five-Year National Strategic Emerging Industries Development Plan*", the "13th Five-Year" plan of Shenzhen's industrial transformation also proposed four pillar industries and five key development directions. In order to promote the upgrading of industrial structure, the "*Urban Planning Standards and Guidelines of Shenzhen City*" ("Shenzhen Standard"), issued by the Shenzhen Municipal Government in 2014, proposed the concept of "New Industrial Land M0" in the traditional land use category, According to the "Shenzhen Standard", "M0" refers to the land that integrates innovative industrial functions such as research and development, creativity, design, pilot scale test, pollution-free production and related supporting service activities.[6] Compared with ordinary industrial land, new industrial land has more diversified functions, including new-type industrial housing, supporting commerce, supporting apartment, infrastructure and other property forms. The government provides policy supports for the new industrial land by lowering the land declaration standard, raising the upper limit of plot ratio, increasing the proportion of supporting facilities, and stipulating the divisible transfer of industrial buildings, so as to promote the transformation of traditional industrial land into new industries space.

In addition, in view of the extensive utilization of industrial space resources, improving land efficiency and promoting economical and intensive utilization are also important policy objectives for industrial land renewal. According to the census data of the old industrial zones of Shenzhen in 2009, there are 3881 industrial zones with a land scale of more than 5000 m^2 in Shenzhen, of which 3628 are industrial zones outside the Special Economic Zone (Non-SEZ). The total area of industrial zones is 291 km^2, almost accounting for 39% of the total construction land. According to the *General Land Use Planning of Shenzhen City (2006–2020)*, 44 industrial zones are located outside the planned land for construction, and 210 industrial zones intersect with the planned land for construction. According to the *Master Urban Planning of Shenzhen City (2010–2020)*, 254 industrial zones are located outside the general planning construction land, 1472 industrial zones intersect with the general

[6] Concept source: Shenzhen Municipal Government (2014). *Urban Planning Standards and Guidelines of Shenzhen City.*

planning construction land, 425 industrial zones are located or intersect with the basic ecological control line, water source protection line, landslide area, etc., and 1880 industrial zones are located outside the modern manufacturing park, which is inconsistent with the direction of industrial planning. According to the cadastral statistics in 2009, the land ownership in the current industrial zone is complex, 38% of which are state-owned land, 40% are collective land, and 22% are unclear. Large scale, scattered distribution and low efficiency have become the prominent characteristics of old industrial zones in Shenzhen, which has seriously hindered the urban modernization construction and the upgrading and transformation of industrial structure. Improving land use efficiency and saving intensive land is the fundamental way to achieve efficient and sustainable urban development. In this context, Shenzhen municipal government issued a series of policies, such as the "*Opinions of the Shenzhen Municipal Government on further Strengthening Land Management and Promoting Economical and Intensive Land Use*", to encourage the high-intensity development of newly-built industrial land and the additional investment, transformation, and the improvement of plot ratio, so as to accelerate the transformation of old industrial areas, promote the economical and intensive land use and enhance the land use value.

3 Research Method and Data

Under the framework of urban renewal unit system in Shenzhen, the boundary and direction of urban renewal units are proposed by market entities and approved by government departments. The urban renewal unit planning is also prepared by the market, and the government is only responsible for the examination and approval. This process generally involves many games between the market subjects and the government departments. The government regulates, guides and controls the compilation and approval of renewal unit planning mainly by formulating relevant policies and standards. After the original plan of a project is approved, the market entities entrust the relevant qualified units to prepare the urban renewal unit planning in accordance with the requirements of the urban master planning and other upper-level planning. After the completion of the planning, the consensus on the boundary, direction, plot ratio and public supporting facilities can be reached through the negotiation between market entities and government departments, then the government departments approve the urban renewal unit planning. Finally, the approved urban renewal unit planning has legal effect, and the renewal project should be implemented in strict accordance with it. Therefore, through the analysis of the approved urban renewal unit planning, we can accurately research the spatial transformation characteristics of the old industrial land.

To classify the functions of the renewed land in the old industrial zone is an important foundation for studying the direction of industrial land transformation in the process of urban renewal. Combing the classic cases of urban renewal at home and abroad, it is found that the classification standards of industrial land transformation direction are not consistent. Such inconsistencies may be due to the differences in regional development backgrounds or research perspectives and scales. In general, the transformation direction of industrial land can be broadly divided into four categories according to functional uses: residential, commercial, industrial and public service. In China, the Ministry of Land and Resources and the Ministry of Housing and Urban–rural Development respectively adopt "*Classification of Land Use Status GB/T 21010–2017*" and "*Classification of Urban Land and Standards for Planning and Construction Land*" to classify the land use at the plot scale. In the former classification standard, industrial land is included in industrial and mining storage land, while in the latter, industrial land and logistics storage land are listed separately, but neither can cover the original new industrial land of Shenzhen. The land-use type of urban renewal unit planning in Shenzhen is mainly based on the "Shenzhen Standard", which is refined to the middle category standard of land classification. Due to the time span of this study is from 2010 to 2018, different renewal projects have different renovation time, involving the old and new editions of "Shenzhen Standard", the land classification standards are different. For land types with identical land use functions, the land classification standard in the new "Shenzhen Standard (2014)" shall be adopted uniformly in the data collation. The original land code should be adopted for the land uses whose functions are not completely consistent. Finally, the land function after renewal is divided into the residential land R, the commercial land C, the commercial and residential mixed functional land R + C, the new industrial land M0, the general industrial land M1 and public facility land. The residential land R mainly includes of type II residential land (R2) and a small amount of type III residential land (R3) in "Shenzhen Standard". Commercial land C includes commercial land C1 and a small amount of commercial apartment land C6. public facility land refers to the land occupied by urban infrastructure, public service facilities or urban public interest projects, including public management and service facility land (GIC), green square land (G), transportation facility land (S), public facility land (U) and other land (E).

This paper collects the urban renewal unit planning of old industrial land and the current land use information before the renewal in Shenzhen from 2010 to 2018, including the name of the urban renewal unit, the jurisdiction and sub-district office, the scope of demolition and reconstruction, the current land use nature, the planning land use nature, the plot area, and supporting facilities, etc. Combined with the geographic data of Shenzhen, including the boundary of administrative division, street boundary, ecological control line range, road network, subway lines, and stations, through data geolocation, data format conversion and superposition calculation, it is integrated into a data foundation that can be directly used for analysis. The data is mainly obtained from the Shenzhen Planning and Natural Resources Bureau and the district administrations, the Shenzhen Municipal Government Online and the District Government online, and the District Renewal bureau websites, and processed in a unified manner. According to statistics, a total of 223 old industrial projects have passed the approval of the renewal unit planning in 2010–2018 in Shenzhen, including 960 renewal plots, involving an old industrial land area of 1147.82 km^2.

4 Spatial Transformation Characteristics of Industrial Land in Shenzhen

4.1 *Functional Structure Transformation*

The process of urban renewal in Shenzhen has led to a significant reduction in the scale of industrial land. The transformation of old industrial land covers residential land, commercial and residential mixed-use land, commercial service land, public facility land, new industrial land and general industrial land (Table 1, Fig. 1). After renewal, the area of industrial land has shrunk from 1147.82 to 280.27 km^2, and the total scale of industrial land has decreased by more than 3/4. Commercial and residential functions are the main directions for the transformation of old industrial zones. Among them, single residential functions account for a relatively high proportion, followed by residential and commercial-led mixed functions, such as mixed-use land

Table 1 Functional composition of old industrial land after renewal (source: collated by author)

Land type after renewal	Number of plots (a)	Area (km^2)	Proportion of total area (%)
General industrial land (M1)	53	92.87	8.1
New Industrial land (M0)	112	187.40	16.3
Residential land (R)	166	287.45	25.0
Commercial and residential mixed-use land (R + C)	118	142.65	12.4
Commercial land (C)	113	264.29	23.0
Public facility land (P)	398	173.16	15.1
Total	960	1147.82	100

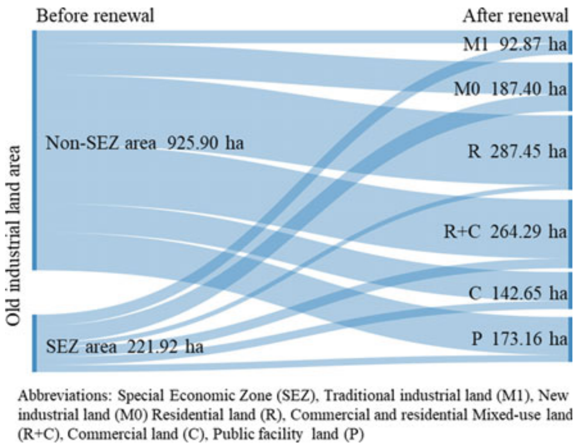

Fig. 1 Land use functions before and after the renewal of the old industrial zone

with commercial-led functions, mixed-use land with the residence as the dominant function, etc., a single commercial function occupies a relatively low area.

From the perspective of the renewed industrial land composition, a large number of traditional manufacturing space has been replaced by new industrial space. In terms of the approval time of the renewed unit planning, the proportion of the new industrial land in the planned industrial land has experienced a round of increase, and has begun to show a downward trend since 2018. In the early stage, due to imperfect policies and inadequate supervision, industrial R&D buildings built on the new industrial land are easily transformed into commercial office space in actual use, which brought higher profits to developers than ordinary industrial land. "*The 13th Five-Year Plan on Urban Renewal of Shenzhen City*" clarifies two situations of transformation into new industrial land: one is the old industrial zone within 500 m of the subway stations; the other is outside the industrial block line and located in the key area of the 13th five-year plan. Through the analysis of the relationship between the approved renewal unit planning and the above conditions, it is found that there is a conflict between the updated new industrial land and the current industrial renewal policy. More than half of the land plots with new industrial land functions are not in line with the industrial renewal policy, and a large number of plots are located within the scope of the industrial block line. After 2017, with the promulgation of renewal policies such as "*The Measures of Shenzhen Municipality on The Management of Industrial Block Lines (Draft for Comments)*", "*Notice on Further Strengthening the Architectural Design Management of Commercial R&D Buildings*", Shenzhen Municipal Government has controlled the transformation directions of the old industrial zones within the industrial block line, limited the overall proportion of the new industrial land in each industrial district, and standardized the architectural design of the R&D housing, so as to prevent the industrial R&D buildings from being transformed into commercial or residential functions in actual use. Only a small part of industrial areas retain the original function of industrial land after renewal, mainly including the single nature of ordinary industrial land and industrial and commercial mixed land.

4.2 Public Contribution Land

Under the current urban renewal unit system in Shenzhen, although urban renewal projects are implemented by market operation, the policy requires to protect public interests by contributing a certain proportion of land to the government for supporting public facilities. This principle requirement has been basically implemented in the planning and redevelopment process of the urban renewal unit project. Among the 223 old industrial projects, provided public facilities after the renewal, involving 398 plots. Therefore, the renewal of the old industrial area contributed a large amount of public facility land to the urban development, with a scale of 173.16 km^2 (Table 2). The land for public management and service facilities and green space is the

Table 2 Functional composition of public contribution land (source: collated by the author)

Land Use types	Number of plots (a)	Area (km^2)	Average plot size (km^2/a)
Public management and service facility land (GIC)	76	79.3	1.04
Green square land (G)	257	69.11	0.27
Transportation facility land (S)	18	6.53	0.36
Public facility land (U)	13	2.64	0.20
Other land	34	15.58	0.46
Total	398	173.16	0.44

largest among the contributing land. Among them, the land for public service facilities is mainly for education facilities. The land for educational facilities is mainly primary schools and nine-year schools (according to the "Shenzhen standard", kindergartens are included in residential land, and independent land-use statistics are not conducted). In terms of the average scale of contribution land, except for the average scale of public management and service facilities is more than 1 km^2, the average scale of other land use is generally small.

As the Shenzhen municipal government has issued the "*Measures on Urban Renewal of Shenzhen City*" and its implementation rules and other policy documents, it is required that "more than 3000 square meters and no less than 15% of the independent land shall be transferred to the government for free, to implement urban infrastructure, public service facilities and urban public interest projects. And in addition, the "*Provisions on Review of Plot Ratio of Urban Renewal Unit Planning in Shenzhen*" stipulates that "when the contribution area of renewal project exceeds the benchmark, the corresponding transfer plot ratio and reward plot ratio shall be given". In order to speed up project approval, some developers will increase the contribution rate as much as possible within the scope of profitability. As a result, the actual average contribution rate is far more than 15%, of which, the rate of industrial renovation projects for commercial and residential functions has exceeded 30%. However, through analyzing the scale, it is found that the public facilities provided by the old industrial areas generally have the characteristics of small average land size, which may cause some problems such as a small service radius and low land-use efficiency. Compared with the internal composition, it shows that some other facilities, such as medical facilities, sports facilities are relatively insufficient, which need to be paid attention to and improved in the follow-up urban renewal practice.

4.3 Spatial Pattern Characteristics

The transformation of the old industrial land in Shenzhen has obvious spatial characteristics. The industrial space in the Non-SEZ has been reduced significantly, and the industrial space shows the characteristics of overall westward migration and contraction to the special zone. At the same time, the overall industrial space presents the characteristics of the westward movement and shrinkage into the SEZ. Figures 1 and 2 respectively show the spatial distribution density of industrial land before and after the renewal. In the northeast of Longgang, Pingshan, Dapeng, Yantian, and other eastern areas of Shenzhen, there are very few industrial lands reserved. The newly added new industrial spaces in the Non-SEZ are mainly located in Xixiang and Shajing streets in Bao'an District, Bantian, Buji, and Longcheng streets in Longgang District and Shiyan and Dalang streets in Longhua District. The industrial land inside the SEZ has retained some agglomeration characteristics in the north of Gaoxin Park in Nanshan District, Liuxiandong Headquarters Area, Meilin-CaiTian Area in Futian District, Sungang-Qingshuihe Area in Luohu District, but the agglomeration scale has been reduced. The areas with these agglomeration characteristics are also key industrial areas in Shenzhen. Through urban renewal, the original industrial space will be transformed and upgraded, and the target industries will be concentrated in the key areas to meet the needs of the new industrial development space (Figs. 3 and 4).

The transformation of the old industrial land to commercial and residential space is mainly in the Non-SEZ, which leads to the urban commercial and residential space moving from the special zone to the outer space. Most of the projects of "Industry-to-Residence" are concentrated in Longgang, Bao'an, Longhua, and Guangming District, of which Longgang District accounts for the largest proportion. From the spatial distribution point of view, it is denser in the western and central regions than in the eastern region, and has a spatial structure of continuous belts and point clusters, forming four gathering points: "Bao'an Central District", "Longhua Central District", "Guangming Central District" and "Shajing Central District". Further research found

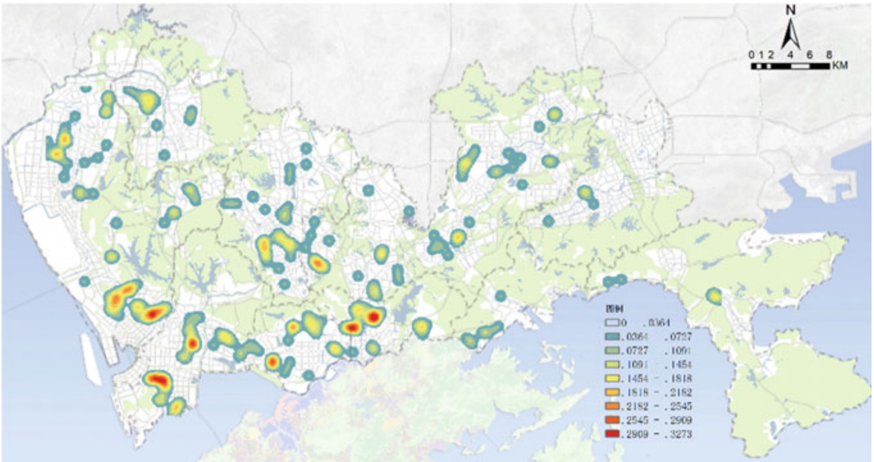

Fig. 2 Spatial distribution density of industrial land before renewal in the old industrial area

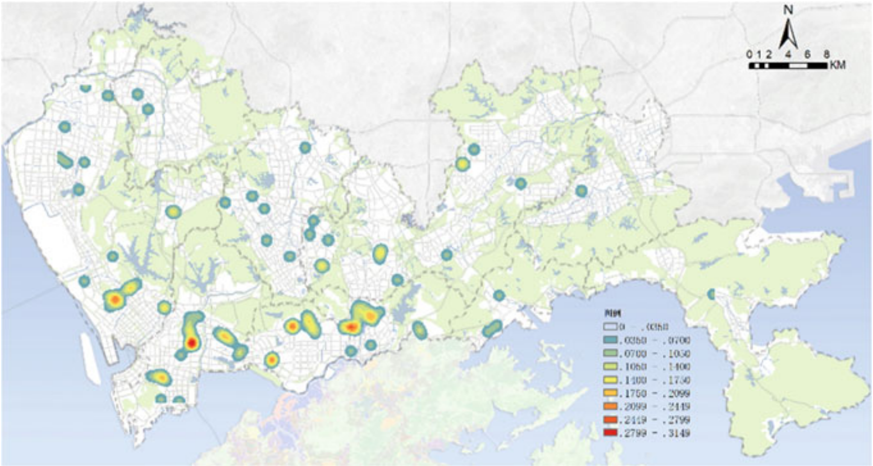

Fig. 3 Spatial distribution density of industrial land before renewal in the old industrial area

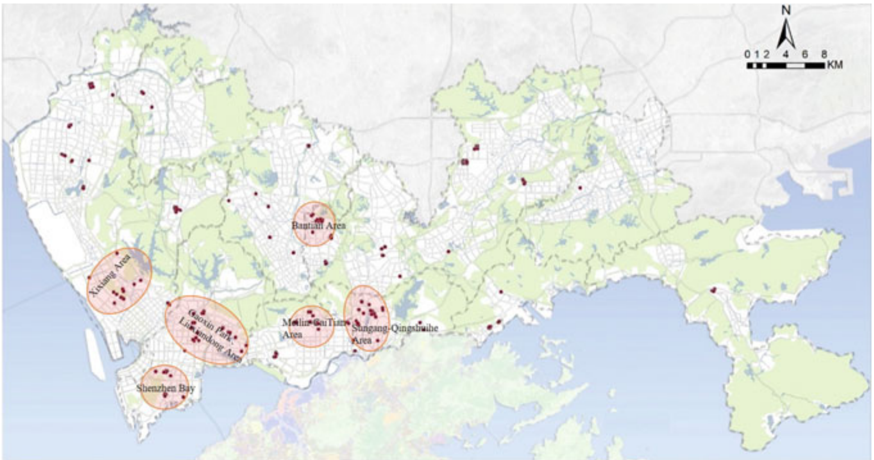

Fig. 4 Spatial distribution of new industries

that there is a certain degree of coupling between the newly added residential space and the subway line. Most of the residential projects are connected in series along Metro Line 3, Line 4 (North Extension), Line 6, and Line 12 (Fig. 5). Among them, Line 3 and Line 4 are the areas with the most density distribution of residential land. Line 3 is an important axis to expand eastward. As the renewal projects continue to be implemented, the line will undertake the urban function replacement from industrial to residential function; Line 4 serves as an important support for the central development axis of the city and connects the Futian-Luohu Center, the improvement of the residential function along this line can effectively alleviate the residential

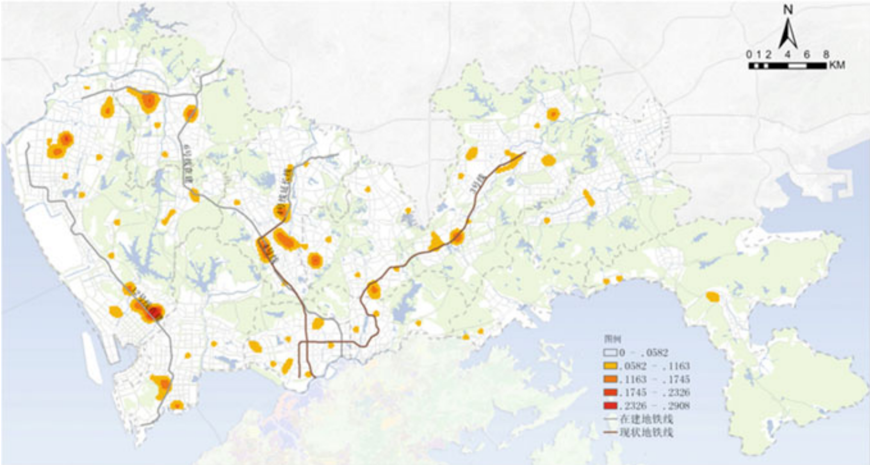

Fig. 5 The spatial distribution density of the renewal projects of "Industry-to-Residence

needs, and also play a certain role in promoting the comprehensive service capacity of Longhua District. The projects of "Industry-to-commerce" are mainly distributed near subway stations. From the perspective of urban development, the accessibility around the subway station is high, which brings the aggregation of high-end economic elements such as logistics, capital flow and information flow. At the same time, it reduces the cost of factor aggregation, improves the value of resources along the line, attracts attraction for the aggregation of enterprises, which is of great significance to the formation and development of business office layout.

Due to the differences in the system and the urbanization process within and outside the SEZ, there has always been a significant gap in the construction and provision of public services. With the expansion of the SEZ in 2010, the integration construction of the city has been accelerated, the dual phenomenon of internal and external special zones and urban imbalances, which are prominently represented by the supply of public facilities and services, have become important constraints that hinder the coordinated development of Shenzhen's economy and society. Due to the relatively mature supporting conditions, the scale of land for renewal projects in old industrial zones in the SEZ is relatively small, and the project contribution rate is generally low; while the Non-SEZ, because of the dual goal of accelerating the original historical debts in the construction of urban public facilities and the provision of public services and the construction of a "modern international advanced city", it has become the most concentrated area of high-contribution projects (Fig. 6). According to statistics, the scale of publicly-contributed land for industrial land in the Non-SEZ is about four times that of the SEZ. By comparing the number of public service facilities occupied by independent land through the renewal of the old industrial land, it is found that the land for education, sports, and medical facilities are mostly distributed in the Non-SEZ, such as Bao'an, Longgang, Longhua, Guangming District and so on, and shows a significant correlation with the distribution of planned

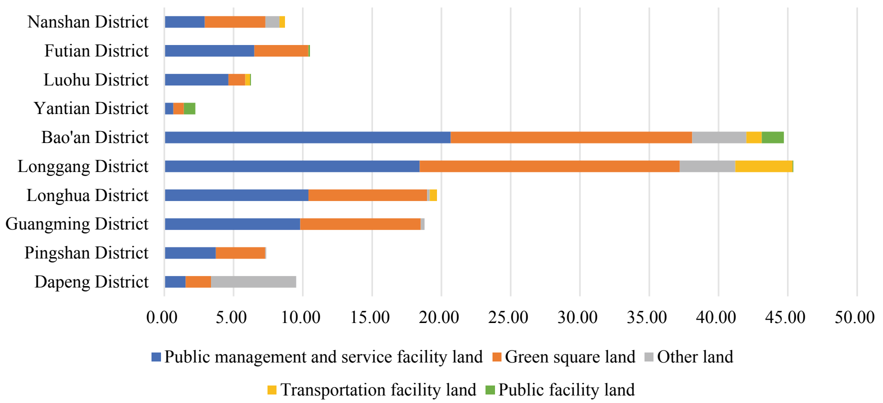

Fig. 6 Types, scale, and distribution of new public facilities in old industrial areas

residential land. This means that public service facilities are greatly affected by the distribution of the service population. With the further promotion of urban renewal, the problems of aging of the original infrastructure and unbalanced spatial layout will be solved to a certain extent. It can be predicted that the gap between the supporting level of urban public facilities inside and outside the SEZ will be further narrowed in the future.

5 Conclusion

The local government's reform of the urban renewal system to "marketization" has greatly promoted the old industrial land transformation in megacities. The real estate market development, the industrial structure upgrading, and the strategic demand of industrial land intensive development are important factors affecting the urban industrial land transformation. Urban renewal has led to a significant reduction in the scale of industrial land, and commercial and residential space, and new industrial space are the main directions Besides the redevelopment of industrial land has also contributed a lot of public facilities. At the same time, the industrial land transformation has obvious spatial characteristics. The planned new industrial space shrinks towards the city center, while the newly added commercial and residential space gradually moves in the Non-SEZ.

The transformation of the industrial zone in Shenzhen is largely shaped by the local context of urban development and economic transformation. In the early stage of urbanization, numerous migrants are accommodated by informal space, such as urban villages, small-property rights. With the continuous growth of urban population and the increasing demand for high-quality formal residential space, the market demand for urban consumption and service-oriented space is also increasing. Objectively, it is necessary to obtain more residential and commercial space through the renovation of old industrial areas. After the renewal of the old industrial zone, a large number of new commercial and residential and public facility space has been added in Shenzhen, which has made great contributions to relieving the housing pressure, improving the quality of residential functions and meeting the upgrading of urban consumption and service functions. On the other hand, the industrial zone renewal operated by the market subject is based on the real estate development orientation that pursues the goal of maximizing economic benefits. It inevitably leads to the excessively rapid loss of large-scale industrial space. A large number of manufacturing industries are moving to other surrounding cities or inland, which will have an inestimable impact on the subsequent industrial development of the city. In order to encourage and support the innovative industries development, the government innovatively formulated a series of new industrial polices. However, the study found that there were many conflicts between the new industrial land after renewal and the industrial development policy. Some new industrial lands were transformed into commercial and residential functions in the actual use, which deviated from the established goal of the transformation of the old industrial zone. How to balance the demand of urban industrial land and the erosion of commercial and residential space driven by the real estate market on industrial space is an important challenge faced by the transformation of existing industrial land at this stage in China.

Based on the summary of urban renewal and industrial land transformation practice in Shenzhen at the present stage, the following conclusions can be drawn: (1) The leading role of the government in the whole process of old industrial park transformation is the premise, the market guidance and operation are the key. In order to stabilize the total scale of industrial space, the approval process of industrial-to-industrial projects should be further optimized under the existing framework, the implementation of transformation should be accelerated, and the planned plot ratio should be moderately improved. (2) For different types of projects, the contribution rate should be comprehensively considered according to local conditions. On the basis of the original one, the contribution rate of land should be adjusted in combination with the planning plot ratio, demolition and construction ratio and development income. (3) plan the renewal unit of the area as a whole, and strengthen the demonstration and planning of large-scale public facilities. Multiple renewal units in the same area need to be planned and studied as a whole, and the new service population and the demand for public facilities also need to be considered. The sharing of large-scale public facilities supply can be realized through multiple renewal units planning in the same area, so as to promote social equity and make up for the gap of large-scale public facilities.

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Analysis of the Coordination Degree of the Construction Waste Recycling Policy Among Different Stakeholders

Zhiyu Huang, Hong Lang, and Mingxue Ma

Abstract With the acceleration of the urbanization process, the continuous demolition of old buildings and the start of new projects in China, more and more attention have been paid to the negative impact on the environment exerted by a large number of construction waste. In recent years, the state and some local governments have successively issued policies on waste from construction and demolition. Although the main components of waste have recycling potential, the recycling rate in 2017 was only 5%. These measures can only be made full use if they are highly recognized by society. However, the effectiveness of the relevant policies is currently unknown. This article evaluates the current construction waste recycling policies from three different stakeholders: the government, enterprises, and universities. The coordination degree between three different stakeholders reflects the effectiveness of the policy. 158 online questionnaires were distributed, of which including 19 measures, and 132 valid responses were received. After sorting out the collected questionnaire data and importing it into the SPSS software, using the Kruskal–Wallis H test method, analyzed the coordination degree of the government, enterprises and universities on the same measure and their differences (expressed by P). The study results show that there are differences in the degree of recognition of the same measure between different stakeholders, which may be caused by the different nature of work. There are two "good coordinated measures", which are "50% reduction in value-added tax" and "establishment Recycling quality standards"; 8 items are "moderate coordination", including "achieve source emission reduction", "land preferential use", "information platform construction", etc. There are 9 items that are "poor coordination", including "establish classification standards", "Who generates who pays", "Regular release of resource utilization product price information", etc. This study can provide a reference for improving the efficiency of construction waste resource management.

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Keywords Construction waste · Recycling policy · Coordination degree · Analysis

1 Background Research

With the urbanization process, the demolition of old buildings and the beginning of a large number of new projects will inevitably bring a lot of construction waste. According to statistics, the annual output of construction waste in 2019 is about 3.5 billion tons, accounting for 70% of the city's total waste emissions, but the recycling rate is only 5% [1]. Most of the construction waste is coped without the formal channels, just being shipped to the dumping or suburban open dumps or simple landfill, affecting appearance of the city, occupying land, polluting groundwater and causing serious damage to ecosystems [2]. In order to improve the environment and increase the recycling rate, 14 ministries and commissions, including the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the Ministry of Housing and Urban–Rural Development, jointly issued the "Circular Development Leading Action", which clearly requires that by 2020, the rate of urban construction waste recycling should reach 13%. The Ministry of Housing and Urban–Rural Development has already started building construction waste management pilots in 35 cities including Beijing, Shanghai and Xi'an since March 2013. In order to improve the rate of resources, local governments have to respond to national policy and consider local conditions, then issue a series of policies and measures for construction waste resources utilization.

Most of China's research on the recycling of construction waste focuses on the current situation of construction waste [3, 4], the improvement of the law [5, 6],the research and development and innovation of technology [7–10] and the economic benefits of construction waste [11–13], in terms of policy research on the utilization of construction waste resources, mainly comparing domestic and foreign policies [14, 15]. Hu [1, 17] and others divide the policies into mandatory, incentive and voluntary. Li [18, 19] and so on divide them into three types: mandatory, market and guidance. According to the research of scholars at home and abroad, this article summarizes the policy into three categories: mandatory, incentive and promotion.

In recent years, more and more emphasis has been put on building construction waste resource utilization policy. Beijing, Shanghai and other pilot cities have promulgated relevant policy documents 68 [20]. Are these management methods and documents useful and reasonable in the implementation of China's current construction waste recycling policy? Whether the various sectors of society agree on the policy which is related to the effectiveness of policy implementation. This article attempts to know the views of the relevant parties, namely the government, enterprises and universities, on the effectiveness of these policy measures in the process of policy implementation, in order to find measures that everyone highly agrees with and disagree with, and to find coordination high-level measures and less coordinated measures which can provide reference for the government to further promote the utilization of construction waste.

2 Research Methods

The degree of coordination in this article refers to the recognition of the effectiveness of the same measure by different stakeholders such as the government, universities, and enterprises, that is the difference in the distribution of scores given by the same measure to the respondents of different interests: the smaller the difference, the higher the degree of coordination; the greater the difference, the lower the degree of coordination. This article mainly uses the Kruskal–Wallis H test function in the SPSS software to calculate the degree of coordination between different stakeholders such as the government, universities, and enterprises in the same measure.

First, the literature review method is used to summarize and classify the domestic and foreign scholars' policies on the utilization of construction waste resources, and divide the policies into mandatory, incentive, and promotion categories. After comprehensively considering the economic, population, geographical location and other factors of the 35 pilot cities [21], 4 municipalities directly under the Central Government and 6 provincial capital cities are finally selected as sample cities, and relevant policy documents are consulted on the relevant municipal government websites to implement specific measures. Sort out one by one.

The second is a questionnaire survey, based on the specific measures sorted out in the literature review. According to the principle of the same meaning (similar), they are merged into 19 items and classified into three categories: mandatory, incentive, and promotion. The questionnaire is sent to the respondents in the form of a web link to fill out.

The third is mathematical statistics, which is collected from the questionnaire. According to the questionnaire data, calculate the average value of each measure for each measure, and use the Kruskal–Wallis H test function to analyze the degree of coordination among different measures such as government, universities, and enterprises.

3 Production and Distribution of Questionnaires

Based on the literature review, the construction waste policy measures of 4 municipalities and 6 provincial capital cities are sorted out, and the questionnaires are classified and produced in the form of network links, which are sent to the relevant workers of the government, universities and enterprises to fill out.

3.1 Policy Management Documents

The policies and management methods of the 10 sample cities are shown in Table 1.

Table 1 List of policies related to the recycling of construction waste in sample cities

No.	City	Management method name	Effective date	File No.
1	Shanghai	"Shanghai Construction Waste Management Regulations"	2018.1.1	a
		"Shanghai Construction Waste Concrete Recycling Management Measures"	2019.1.1	b
2	Beijing	"Notice on Further Strengthening the Treatment of Construction Waste"	2018.4	c
		"Opinions on Further Strengthening the Comprehensive Utilization of Construction Waste Resources"	2018.7	d
3	Tianjin	"Tianjin Municipal Construction Waste Resource Utilization Management Measures"	2016.10.1	e
4	Chongqing	Guiding Opinions on the Pilot Work of Promotion and Application of Recycling Products of Urban Construction Waste	2019.11.14	f
5	Changsha	"Changsha City Construction Waste Resource Utilization Management Measures"	2017.6.1	g
		"Changsha City Construction Waste Resource Utilization Management Measures Implementation Rules"	2019.1.2	h
6	Chengdu	"Chengdu City Construction Waste Resource Utilization Support Policy"	2016.10.8	i
7	Xi'an	"Notice on the Implementation Opinions on Strengthening the Utilization of Construction Waste Resources"	2018.5.1	j
8	Wuhan	"Wuhan City Construction Waste Management Measures"	2019.5.1	k
9	Nanjing	"Nanjing City Construction Waste Resource Utilization Management Measures"	2020.2.1	l
10	Zhengzhou	"Zhengzhou City Construction Waste Treatment Pilot Work Implementation Plan"	2018.6	m

3.2 *Making of Questionnaire*

The questionnaire is divided into two parts. The first part is the background information of the interviewees, including the nature of the work unit, working years, education, etc., used to screen out professionals with knowledge about construction waste recycling to ensure the validity of the questionnaire data. The second part is the core part of the questionnaire, which is divided into three first-level measures of compulsory, incentive and promotion categories, and a total of 19 s-level measures. The questionnaire is divided into 1 to 5 points for each measure in the form of single selection: the higher the score, the greater the effectiveness of the measure.

Table 2 Mandatory policies

No.	Measures	Reference materials
F01	Implement emission reduction at the source (including ① new standards, new technologies, new materials, and new processes; ②improve the durability of buildings ③ changes in construction engineering design, etc.)	abdfkl
F02	Incorporating special facilities into the planning of the sites required for the construction utilization facilities	lm
F03	Incorporate the filing of resource utilization plans into the construction procedures and enforce them	afk
F04	Establish classification standards and force on-site construction waste classification	bde
F05	Qualification requirements for the construction unit during the demolition process	dkl
F06	Penalty provisions (punishment for non-discharge of construction waste according to requirements, illegal installation of decoration waste, etc.)	bekl

3.2.1 Mandatory Measures

The measures strictly implemented according to the regulations required in the documents are classified as mandatory, as shown in Table 2.

3.2.2 Incentive Measures

Incentive measures are mainly about the implement of the preferential tax policy issued by the Ministry of Finance and the State Administration of Taxation, such as the "Announcement on Comprehensive Utilization of Resources and Value Added Tax Policies for Other Products", "Notice on the Comprehensive Utilization of Resources and Value Added Tax Policies for Other Products", "Regarding Printing and Distribution of Renewable Energy Saving The fiscal and preferential tax system in the "Measures for the Administration of Subsidy Funds for Construction Materials", "Notice of the State Administration of Taxation on the Value Added Tax Policy for Renewable Resources". See Table 3 for details.

3.2.3 Promotional Measures

The promotion measures are mainly aimed at the recycling of construction waste products, including the entry of recycled products into the market, the establishment of product standards and applications, etc., see Table 4 for details.

Table 3 Incentive policies

No.	Measures	Reference materials
F07	Prioritize project establishment, establish green channels for construction waste reuse project approval, and speed up the approval process	dijlm
F08	Preferential use of land (land allocation, transfer, lease, etc.)	egilm
F09	Who produces who pays (Emissions should pay construction waste disposal fees, construction waste recycling, exemption)	abjm
F10	Who disposes who benefits? (Enterprises engaged in the recycling of construction waste are subsidized according to certain standards)	hjklm
F11	50% value-added tax and tax refund policy	ij
F12	Income tax benefits: when calculating the taxable income, 90% of the total income will be charged to the current year	eij
F13	15% tax rate can be reduced to pay corporate income tax benefits	j
F14	When bidding for engineering projects, companies using recycled products will give a total of 1–3 points extra points	g

Table 4 Promotion and application policies

No.	Measures	Reference materials
F15	Information platform construction	abeklm
F16	Implement franchise management, and franchise units have priority disposal rights (including ① BOT model ② PPP model ③ extension of concession period, etc.)	ghijl
F17	Establish a catalog of recycled products and enter the market	ahkm
F18	Establish quality standards for recycled products	adflm
F19	Regularly publish price information of resource utilization products	fgkm

3.3 Issuance and Withdrawal of Questionnaires

The questionnaire is first published on the questionnaire network platform, and then sent to the respondents in the form of links to be filled out point-to-point. A total of 158 questionnaires are received, including 132 valid questionnaires.

Table 5 Respondents' list of nature of work units

Employer	Government	Universities	Engineering construction enterprise	Real estate development enterprise	Construction waste disposal company	Others (design institute, consulting)
Number of people	69	25	22	6	4	6
The proportion (%)	52.27	18.94	16.67	4.55	3.03	4.55

Table 6 List of respondents' working years

Years of experience (years)	≤ 5	5–10	10–15	15–20	20–25	≥ 25
Number of people	22	33	26	22	4	25
The proportion (%)	16.67	25.00	19.70	16.67	3.03	18.94

4 Questionnaire Data Statistics and Analysis

4.1 Basic Situation

4.1.1 The Nature of the Respondent's Work Unit

See Table 5.

4.1.2 Respondent's Working Years

See Table 6.

4.1.3 Resource Utilization of Construction Waste in the Place Where the Respondent Works

It can be seen from Tables 5, 6 and 7 that the interviewees are mainly distributed in the work units that are in contact with the utilization of construction waste, ensuring

Table 7 List of resources of construction waste in the place where the respondent works

Utilization	Very good	Good	Average	Bad	Very bad
Number of people	7	30	55	35	5
The proportion (%)	5.30	22.73	41.67	26.52	3.79

that they have a certain understanding of the construction waste recycling; interviewees with more than 5 years of work experience accounts for 83%, of which more than 25 years takes up 19%. 41.67% of the respondents think that the recycling of construction waste in their area is average, and 27% think it is not good. Only 5% of people think it is very good, and the situation of resource utilization of construction waste is not optimistic. It should speed up the process of resource recycling and promote the process of resource recycling.

4.2 Details of the Scores of Construction Waste Recycling Policy Measures

After recovering the questionnaire, this article counts the scoring of each factor from the perspective of different stakeholders, and calculates the average score of each measure. The calculation formula is as follows:

$$\bar{X} = \frac{1}{N}\sum_{j=1}^{N} X_j,\ j \in [1, 132],\ j\ takes\ an\ int$$

where $\bar{X}$ is the average value of the measure; X_j is the j-th sample score of the measure; N is the total number of samples 132;

It can be seen from Table 8 that in the evaluation of the effectiveness of the policy of resource utilization of construction measures, the average score of all respondents for all measures is 3.64, of which the average score of government respondents is 3.97 and 3.73 for universities. It is 3.00 on the enterprise side, with the highest score given by the government, followed by the college, and the score given by the enterprise is far below the average score. The scores given by government interviewees are much higher than the scores of enterprises, and the score of each measure is higher than 20% of the scores of enterprises. Among them, the scores of F04, F06, F09, F14, and F16 exceed the scores of enterprises. 40% of the total, the overall average score is higher than the proportion of enterprises: (3.97–3.00)/3.00 = 32.33%, the score of colleges and universities is always between the two parties. The average score of 10 measures such as F01 exceeds 3 points, and the average score of 9 measures of F03 and other measures is less than 3 points. The average score of colleges and universities is always in the middle.

5 Coordination Results and Analysis

The Kruskal–Wallis H test (also known as H test) tests the uniformity of the scores of various measures in the tripartite distribution of government, universities and enterprises. The uniformity is defined by the test level α value. The second is that

Table 8 List of average scores of construction waste resource utilization measures

No.	Score (average)			
	Government	College	Enterprise	Tripartite average
F01	4.16	4.04	3.45	3.93
F02	4.07	3.56	3.21	3.73
F03	3.80	3.60	2.92	3.51
F04	3.94	3.88	2.39	3.48
F05	3.48	3.24	2.63	3.19
F06	4.23	4.04	2.97	3.83
F07	3.83	3.72	3.05	3.58
F08	3.65	3.36	2.84	3.36
F09	4.39	4.20	3.05	3.97
F10	4.23	4.12	3.39	3.97
F11	4.06	3.92	3.42	3.85
F12	4.03	3.80	3.05	3.70
F13	4.01	3.68	3.05	3.67
F14	3.96	3.48	2.74	3.52
F15	3.74	3.84	3.03	3.55
F16	3.80	3.36	2.58	3.36
F17	4.06	3.84	3.16	3.76
F18	3.96	3.92	3.29	3.76
F19	3.94	3.36	2.87	3.52
The average score	3.97	3.73	3.00	3.64

the α value is between 0.001 and 0.05 is the basic coordination, and the third is that the α value is less than or equal to ($\leq$) 0.001 is uncoordinated.

5.1 Introduction to Kruskal–Wallis H Test Method

The Kruskal–Wallis H test [22, 23] (also known as the H test) is essentially a non-parametric method for testing whether two or more samples come from the same probability distribution. It is used to test whether there are significant differences in the distribution of multiple populations. Since the analysis of the coordination degree in this study involves three different and independent stakeholders, it is necessary to compare the differences in their internal distribution of measures scored, so the H test is selected for analysis.

In this paper, the H test in the non-parametric test method in SPSS statistical software is used. The output of the operation involves the rank sum statistic H(k), the degree of freedom df, and the progressive significance *P*, but only the *P* value is concerned when analyzing the results. Related concepts are as follows:

5.1.1 H(k) is the Rank Sum Statistics of Each Group of Samples

$$\mathrm{H(k)} = \frac{12}{\mathrm{n(n+1)}} \sum_{1}^{k} \frac{R_{ij}^2}{n_i} - 3(\mathrm{n}+1)$$

(n is the total number of samples, n_i is the number of observations in the i-th group of samples, k is the number of sample groups, and R_{ij} is the rank of the j-th observation in the i-th group of samples)

5.1.2 Degrees of Freedom

The degree of freedom df = k-1, which indicates the number of free changes of a set of data, that is, there are 3 sets of data in this study, as long as you know any two of the data, you can infer the data of the remaining person, so this article The degree of freedom of all measures df = 3–1 = 2;

5.1.3 Progressive Significance *P*

The *P* value is usually compared with the inspection level α. There are usually three judgment standards for α, which are 0.1, 0.05, and 0.001. Combined with the situation in this article, 0.1 is discarded, and 0.05 and 0.001 are used as the inspection level. The results of the subsequent coordination degree are determined according to the size of the *P* value. This article describes the coordination degree as follows:

$$\mathrm{P}\begin{cases} \geq 0.05 \ \textit{good coordinated} \\ 0.001 \sim 0.05 \ \textit{Moderate coordination} \\ \leq 0.001 \ \textit{Poor coordination} \end{cases}$$

5.2 Calculation Results

5.2.1 Mandatory

See Table 9.

Table 9 Inspection statistics of mandatory measures

	F01	F02	F03	F04	F05	F06
Kruskal Wallis H(K)	8.181	16.375	11.579	30.862	9.622	20.209
df	2	2	2	2	2	2
Sig	0.017	0.000	0.003	0.000	0.008	0.000

Table 10 Inspection statistics of incentive measures

	F07	F08	F09	F10	F11	F12	F13	F14
Kruskal Wallis H(K)	9.041	11.281	31.031	10.371	5.820	14.412	13.438	20.810
df	2	2	2	2	2	2	2	2
Sig	0.011	0.004	0.000	0.006	0.054	0.001	0.001	0.000

5.2.2 Incentives

See Table 10.

5.2.3 Promotion

See Tables 11.

5.3 *Results Statistics*

As can be seen from Table 12, of the 19 recycling measures, 2 are good coordination measures, one for incentives and one for promotion; 8 are moderate coordination measures, of which promotion measures account for 10.53%, less than mandatory and incentive measures Proportion of measures; 9 are poor coordination measures, accounting for 47.37% of the total, of which compulsory, incentive and promotion categories each accounted for 15.79%.

Table 11 Test statistics of promotion measures

	F15	F16	F17	F18	F19
Kruskal Wallis H(K)	10.560	20.563	10.074	5.951	16.539
df	2	2	2	2	2
Sig	0.005	0.000	0.006	0.051	0.000

Table 12 List of the proportion of coordination measures

Coordination	No	Classification ratio			
		Mandatory (%)	Incentive (%)	Promotion (%)	Total (%)
Good coordination ($P \geq 0.05$)	F_{11}, F_{18}	0	5.26	5.26	10.52
Moderate coordination ($P \in (0.001 \sim 0.05)$)	F_{01}, F_{03}, F_{05}, F_{07}, F_{08}, F_{10}, F_{15}, F_{17}	15.79	15.79	10.53	42.11
Poor coordination ($P \leq 0.001$)	F_{02}, F_{04}, F_{06}, F_{09}, F_{12}, F_{13}, F_{14}, F_{16}, F_{19}	15.79	15.79	15.79	47.37

5.4 *Discussion*

Among the 19 construction waste resource utilization measures, only 2 measures are good coordination, and the remaining 17 measures are moderate coordination and poor coordination. The number of well-coordinated measures only accounts for one-tenth of the total number of measures. Governments, enterprises, and university personnel have great disagreements on the effectiveness of these measures. This partly reflects the inability of the three stakeholders to agree on policies in assessing their effectiveness, due to the difference in the nature of their work. It is extremely detrimental to the promotion of the use of construction waste resources that the effectiveness of the policy in its implementation and practice has not been recognized.

5.4.1 The Number of Well-Coordinated Measures is Small

The good coordination shows that the three parties have affirmed the effectiveness of the policy. The data shows that the average score given by the enterprise is only 2.84 points, but from Table 8, it can be seen that the enterprise gave the two measures F_{11} and F_{18} 3.2 points. It proves that these two measures are well-effective by compared with other low-scoring measures. F_{11} and F_{18} are measures introduced at the national level. These measures have been introduced for a long time and have been implemented, they are clear in content and easy to operate. Among them, F11 is an economic measure to reduce taxes so that enterprises can feel the actual practical benefits, so it get a high score to affirm its positive role. In addition, the current recycling products on the market are mixed, and it is imperative to establish a quality standard system. This measure received a high score, which is enough to prove that the system of quality standards has been recognized. It can be seen that economic incentives and the formulation of quality standards for recycling products are the most effective measures to improve the resourceization of construction waste.

5.4.2 The Number of Measures with Moderate Coordination is in the Middle

The moderate coordination refers to the fact that the three parties have different scores for these measures, but the difference is not large. Among the 8 basically coordinated measures, the five measures, which average score from the three parties and the overall average score exceeded 3 points, have basically been recognized by the three stakeholders.

F01, F03, F05 are difficult in the implementation process. Source emission reduction (F01) requires a lot of manpower and material resources, and the resource utilization plan is not necessary for each project. For F05, there is almost no value when the house is demolished, and the company will not care too much about where the house will go and how to dispose of it. So when choosing a construction unit to demolish a building, little or no attention is paid to the qualification requirements of the demolishing unit. The actual effect of these policies is not effectiveness, and it is necessary for the policy-making unit to increase the intensity of the investigation of the actual situation, and further improve the construction waste recycling policy system. At present, the construction waste recycling work is not mature enough, so the resource utilization measures involved in F07, F08, and F10 that take advantage of corporate preferences are different in the eyes of the three stakeholders. F15 and F17 are promotion measures. According to the procedures of generation, transportation, disposal and promotion of construction waste, there are many administrative departments such as the Ministry of Housing and Urban–Rural Development, the National Development and Reform Commission, the Ministry of Finance, the Urban Management and Law Enforcement, Ministry of Transport, Ministry of Ecology and Environment involved in the construction information platform, so the work is also very difficult. And establishing a recycling product catalog and entering the market also requires collaboration between departments.

5.4.3 Poorly Coordinated Measures Accounted for Too Large Proportion, and Resource Utilization is Difficult

The reason for the poor coordination of measures is mainly reflected in the large differences in the identification attitudes between the government and enterprises, and universities have always maintained a neutral attitude. It can be seen from Table 12 that the proportion of uncoordinated measures is very large, close to 50% of the total number. As can be seen in Table 8, among these measures, the scores given by enterprises and the scores given by the government are very different. For example, in F16, the companies only gave 2.58 points, but the government and universities gave 3.80 points and 3.36 points respectively. In this context, it can be seen that the government side is obviously distributed in the area above 3 points, while the enterprise side is distributed in the area below 3 points, the distribution is extremely uneven, and the contradiction that leads to poor coordination is often here. The *P* value of 7 measures including F02 is 0.000, however, it doesn't mean that the *P* value is equal to 0, but is infinitely close to 0, indicating that the government, universities, and enterprises have very big differences in the recognition of these measures.

F02 requires the government to comprehensively consider the geographical location and economic factors, rationally arrange, simplify the land approval process, and encourage social capital investment, but why is the degree of coordination so low? Considering that urban land resources are limited, and the requirements for construction waste dump area and geographic location are relatively high, social capital investment is still relatively difficult. F04 and F06 are measures for compulsory classification of construction waste on site and punishment. At present, there is no domestic classification of construction waste [19, 20], and there is a lack of specific classification standards and implementation rules. On-site classification requires a lot of labor costs, and there is no corresponding reward for completing this regulation, and the construction enterprise can get little economic benefit, and the punishment for enterprises that have not completed the construction waste classification is not strong enough to achieve the deterrent effect of reducing violations by enterprises.

Construction waste will inevitably be generated during the construction process. The old buildings are already worthless, and no substantial benefits are embodied during the process of new constrcution project, but both have to pay for the disposal of construction waste, which will inevitably damage the interests of the enterprise. F09, the measure of who generates who pays is equivalent to being placed on the table and cannot be implemented on the ground. The implementation of F14 will be involved in the bidding, but its focus is generally on the scoring of contract types. For example, the technical bid attaches importance to the technical solutions and technical documents in the contract, and the commercial bid attaches importance to the qualifications, performance, and quotation of the unit, no attention has been paid to whether the project uses recycled products. Moreover, both parties tend to pay more attention to the economic benefits of bidding projects. In addition, the current domestic publicity of recycled products is generally lower than existing materials. The public does not understand recycled products, and the importance of this measure in the bidding process is relatively low. As a result, the implementation effect of this measure is not significant.

F16 and F19 are promotion measures, and there are two reasons for the poor coordination of them. First of all, due to the immature domestic market promotion mechanism, the number of construction waste recycling products is small, the public has misunderstandings about construction waste recycling products and even rejection, which directly affects the application of recycled products in the end market and affects the resources of enterprises' economic and social benefits. Furthermore, the government has not promoted too much, and the public has not popularized the knowledge of construction waste recycling products. Merely compulsory use of recycling products in government projects without solving the problems of audience perception and recognition, is not enough to promote the development of the entire recycling industry.

6 Suggestion

As an alternative method of processing construction waste, recycling can reduce dependence on landfills, thereby reducing environmental pollution. However, the current role of the current resource policy is obviously far from achieving the expected effect. It is particularly important to improve the resource utilization rate and improve policy. It is critical to formulate measures to be recognized by all sectors of society, because it can make the implementation of the policy convenient and useful. Based on the results of the research and fully considering the interests of related parties, the following suggestions are made:

6.1 Simplify the Implementation Procedures of Comparative Coordination Measures and Improve Efficiency

Local governments should speed up the implementation of well-coordinated measures after they have introduced policies and measures for the utilization of construction waste as resources. F11 and F18, one is to enjoy 50% of the value-added tax that is immediately refunded, and the other is to establish a quality standard of recycling products. For these two measures, simplify some unnecessary approval procedures, make full use of market mechanisms, formulate and improve resource utilization measures, really reassure the government, universities approve, and enterprises truly benefit, and then promote the development of recycling and industry. Preferentially adopt more coordinated measures in the formulation process, and then formulate a recycling policy suitable for the region based on actual conditions and combined with the policies that have been issued.

6.2 Fully Consider the Interests of Enterprises and Improve the Operability of Uncoordinated Measures

When formulating policies, the government did not fully consider the interests of real estate, construction, and resource enterprises, making the policies stay on the surface of the text, and enterprises do not have a good implementation environment. Therefore, it is necessary to consider political, economic, and social benefits when formulating a construction waste recycling policy. While taking into account the interests of the enterprise, also solving construction waste disposal, classification, taxation, management, and price issues. Adjust the corresponding financial subsidies to increase the enthusiasm of enterprises to participate in the recycling of construction waste, reduce the difficulty of policy implementation, and reduce the corresponding implementation procedures, so that enterprises do not exclude policy constraints and enjoy it,) so that enterprises do not exclude policy constraints and enjoy it. Strengthen publicity, increase the public's awareness and recognition of recycling products, and enable construction waste to form a virtuous cycle of production-recycling-utilization, So as to fundamentally increase the resource utilization rate of construction waste.

The research results obtained the coordination degree of the current construction waste recycling policy by different stakeholders such as government, universities, and enterprises (real estate, construction, resource utilization). The main reason for the different coordination degree is that the government and enterprises have different opinions. This paper provides reference for researchers interested in construction waste, it can helps the government improve waste management policies, and provides construction companies with clearer ideas for construction waste management.

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Determinants of Regional Economic Resilience in the Context of Global Depression: A Case Study of the Pearl River Delta, China

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Abstract As economic globalization is deepened, the Pearl River Delta region is facing increasingly complex internal and external disturbance. In the context of global depression, this paper introduces the concept of "economic resilience" in order to understand the capability of the leading regions in the economic development of China to withstand the impacts of uncertainty. In this paper, it conducts quantitative analysis and qualitative explanation to the determinations of economic resilience of the Pearl River Delta region by using the fixed effects regression model. The results show that: ① The stronger unrelated variety and higher levels of regional innovation that a region has, the easier it will be to reduce or even eliminate the losses caused by the economic crisis; ② The regions with strong related variety, large scale of export base, a high proportion of regional fiscal expenditures, and a high ratio of SMEs have lower capabilities to resist economic risks and are more susceptible to crisis interference. Therefore, the government should focus on diversified industrial development and promote industrial transformation and upgrading; encourage innovation and increase investment in scientific research and development; optimize the structure of fiscal expenditures and improve the incentive mechanism of consumption to expand domestic demands; increase support for SMEs and avoid the losses caused by the economic crisis to SMEs.

Keywords Regional economic resilience · Related variety · Unrelated variety · Pearl River Delta

1 Introduction

With the constant development of the economic globalization, the external risks faced by a country or region are also increasing. Once a region is interfered by the impacts of economic recession, its economic growth path will be severely impacted or even destroyed [1]. Since the 1980s, increasingly frequent economic crises have had a great

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impact on regional economy, and there are obvious gaps in the capability of different regions to respond to and recover from economic crises. Therefore, how a region responds to the uncertainty of external environment and adapts to new environment has become a focus of scholars regarding the issue of regional resilience [2].

The Pearl River Delta (PRD) is located in the south-central part of Guangdong Province, covering nine cities including Guangzhou, Foshan, Zhaoqing, Shenzhen, Dongguan, Huizhou, Zhuhai, Zhongshan and Jiangmen. With convenient land and sea transportation, the Pearl River Delta is a world-renowned manufacturing and export base with a high level of export-oriented economy. In 2008, the US subprime mortgage crisis exerted a huge impact on the economy of all countries in the world. The global financial crisis had a more seriously negative impact on the PRD than that on the western regions in China [3]. Recently, the deepened Sino-US trade war has caused great pressure on the enterprises in the PRD, which aroused concerns about that regional economy would encounter crises and even have decline. Therefore, it is necessary to study the resilience characteristics of the PRD in response to the economic crisis.

In view of this, this paper uses the panel data of the Pearl River Delta region from 2009 to 2018 to conduct empirical estimations on the variables such as regional economic resilience and economic structure, then uses the fixed effects model to conduct qualitative explain on the explanatory factors of regional economic resilience in order to makes up the deficiency of theoretical research and empirical analysis in the domain of regional economic resilience, and provides basis for improving regions' capacity to respond to economic crisis.

2 Review

The term "resilience" was first introduced into the study of ecosystem carrying capacity by Holling, which refers to the capacity of an ecosystem to recover to its original level after being disturbed [4]. Subsequently, economic geographers introduced resilience into the study of regional economic and proposed the concept of "regional resilience" [5]. With the continuous improvement of the connotation of regional resilience, Martin used regional economic resilience to measure a region's economic robustness against shocks and capability to achieve long-term transformation and development [6].

Currently, the empirical studies on regional economic resilience can be divided into two categories: one is the measurement of regional economic resilience while the other is the analysis of determinations on regional economic resilience [7]. Scholars have conducted a lot of research on the influence factors on resilience, but no consensus has been reached. Existing literature generally regards economic structure as the most important factor influencing regional economic resilience. Frenken [8] believed that economic structure is closely related to regional resilience, and related variety helps strengthen economic resilience. Martin [1] believed that diversified industrial structure can reduce and alleviate the impacts of the crisis on regions.

Once the leading industries in a region with single industrial structure are impacted, industrial transformation cannot be realized in the short term, and the economy would be prone to a sharp decline. Sun [9] found that related variety has a significantly promoting effect on regional economic growth and stability. Guo [10] used the panel threshold model to analyze the influence mechanism of related variety on regional economic resilience in the different levels of regional innovation. On this basis, this paper puts forward the following hypotheses:

H_1: *Unrelated variety is directly proportional to regional economic resilience while related variety is inversely proportional to regional economic resilience.*

Clark [11] made statistics on the patent data in the United States and Europe and found that the gathering place of small companies with a high number of granted patents can improve the adaptability of regional economy. Williams et al. [12] analyzed the relationship between regional resilience and the economic structure, entrepreneurship, institutional innovation, labor resources, etc. of regions. Bristow et al. [13] conducted an empirical analysis on the relationship between regional innovation capacity and crisis response capacity of European regions, and found that the regions leading in innovations are more likely to recover quickly from the crisis. Based on this, this paper proposes the hypothesis 2 as follows:

H_2: *Innovation level is directly proportional to regional economic resilience.*

Giannakis et al. [14] analyzed the determinants in European regions' resistance against the economic crisis and found that the regions with a high degree of economic openness and large scales of export base will likely be more susceptible to external economic shocks. As a result, the hypothesis 3 is put forward as follows:

H_3: *The scale of export base is inversely proportional to regional economic resilience.*

Many researchers mentioned that government management behaviors play an important role in enhancing regional economic resilience [1, 15]. Tan et al. [3] analyzed the determinants on China's regional economic resilience from the following five aspects: regional development foundation, industrial structure, labor status, financial support capacity, and government management capacity. The study found that the regional development foundation and government management capacity have a greater impact on the regional economy's response to the economic crisis. Therefore, hypothesis 4 is put forward as follows:

H_4: *The proportion of regional fiscal expenditure is directly proportional to regional economic resilience.*

Xu et al. [16] took the Zhejiang and Jiangsu Province as a case study to analyze the impacts that regional innovation level, government expenditures, foreign trade and industrial structure have on regional economic resilience. The study found that the regions with a large proportion of small and medium-sized enterprises have looser entrepreneurial environment, which can promote the emergence of new enterprises and enhance regional economic resilience. Based on this, the hypothesis 5 is put forward as follows:

> H_5: *The proportion of small and medium-sized enterprises (SMEs) is directly proportional to regional economic resilience.*

According to the relevant research achievements, this paper analyzes the determinants on economic resilience of the PRD region from the following five aspects: economic structure, innovation level, scale of export base, government expenditure and industrial structure.

3 Methodology and Data Source

3.1 Definitions of Concepts

3.1.1 Regional Economic Resilience

Regional economic resilience is the adaptability of regional economies to respond to the impacts of external crisis, and its measurement methods include sensitivity coefficient method and index system method. Among them, the measurement method proposed by Martin is relatively objective, namely use the sensitivity index b of each region in each period for measurement, and the calculation formula is as follows [17]:

$$b_r = (\Delta E_r/E_r)/(\Delta E_N/E_N) \tag{1}$$

in which b_r is the sensitivity index of the researched region, $\Delta E_r/E_r$ is the rate of change of the regional Gross Domestic Product (GDP), $\Delta E_N/E_N$ is the rate of change of the national GDP in economic recession.

3.1.2 Related Variety and Unrelated Variety

The economist Frenken first defined the concepts of unrelated variety and related variety, and used the entropy index method to decompose unrelated variety and related variety index [8]. Unrelated variety is an industrial pattern that the industries without obvious technical and economic connections, the size of which is represented with the entropy of the two-digit industry code in the industrial sector. The formula of unrelated variety uv is as follows:

$$UV_{i,t} = \sum_{j=1}^{m} P_{i,j}\log_2\left(\frac{1}{P_{i,j}}\right) \tag{2}$$

in which $P_{i,j}$ is the proportion of the number of all employees in a certain major category department j in city i to the number of employees in the region in year t, m is all major category departments in the region, $UV_{i,t}$ is the unrelated variety of city i in year t.

Related variety is the industrial pattern that a series of industries with strong economic and technological connections, which is represented by the entropy weight of the three-digit industry code in each two-digit industrial category. The formula of the related variety rv is as follows:

$$H_{i,j} = \sum_{k=1}^{n} \frac{P_{j,k}}{P_{i,j}} \log_2\left(\frac{1}{P_{j,k}/P_{i,j}}\right) \tag{3}$$

$$RV_{i,t} = \sum_{j=1}^{m} P_{i,j} H_{i,j} \tag{4}$$

in which $P_{i,k}$ is the proportion of the number of all employees in the sub-category department k of a certain major category department j in city i to the number of regional employees in year t, $P_{i,j}$ is the proportion of the number of all employees in a certain major category department j in city i to the number of regional employees in year t, n is all sub-category departments in the region, m is all major category departments in the region, $RV_{i,t}$ is the related variety of city i in year t.

Before calculating the unrelated variety and related variety index, it is necessary to identify the standards at different levels of industrial classification. On the basis of Frenken and by drawing on the ideas of Sun and Chai [9], this paper takes 19 industries in the *China City Statistical Year Book* as the sub-category departments for measurement. The division of major category departments is based on the three industries, and the service industry is divided into four categories: producer service, consumer service, circulative service and social service.

3.2 Exploring the Determinants of Economic Resilience

Based on the theoretical analysis discussed above, this paper verifies the factors on regional economic resilience from the following five dimensions: economic structure, level of regional innovation, the scale of export base, the ratio of regional fiscal expenditure, and the proportion of SMEs. The measurement model is constructed as follows:

$$b = \beta_0 + \beta_1 rv + \beta_2 uv + \beta_3 innova + \beta_4 open + \beta_5 gov + \beta_6 indus + \lambda_i + \mu_{it} \tag{5}$$

in which t is the period, i is the city, and the explained variable b is the sensitivity index; the explanatory variables are *rv, uv, innova, gov, indus*, which respectively represent related variety, unrelated variety, level of regional innovation, scale of export base, ratio of regional fiscal expenditure, proportion of SMEs. $\beta_1 - \beta_6$ is the estimated coefficient of the explanatory variable, which is the core estimated coefficient of the measurement model.

This paper takes the regional economic resilience as the dependent variable, and analyzes the factors, such as economic structure, innovation level, scale of export base, government expenditure and industrial structure, on regional economic resilience. In the regression analysis, these factors are respectively represented by related variety and unrelated variety, the proportion of regional granted patents, the proportion of total import and export, the proportion of regional fiscal expenditure and the proportion of SMEs from 2009 to 2018. Table 1 lists the description of the variables.

The data sources of this paper mainly include: ① The regional Statistical Yearbook and China Statistical Yearbook, the data from which is used to understand the regional GDP, total import and export, the number of granted patents, the number of employed people and the number of SMEs, etc. ② China City Statistical Yearbook, the data from which is mainly used to calculate the related variety and unrelated variety index with the number of employees in different industries.

Table 1 Variable description

Variable		Abbreviation	Description
Regional economic resilience	"Sensitivity" indices	b	The lower the sensitivity index, the stronger the economic resilience
Economic structure	Related variety	rv	The degree of correlation between industries that have common or complementary capabilities
	Unrelated variety	uv	The degree of correlation of the companies that have no obvious technical and economic ties with each other
Innovation level	The proportion of regional granted patents	innova	The proportion of the number of regional granted patent applications to the number of national granted
Scale of export base	The proportion of total import and export	open	The proportion of total regional import and export to the regional GDP
Government expenditure	The proportion of regional fiscal expenditure	gov	The proportion of regional fiscal expenditures to regional GDP
Industrial structure	The proportion of SMEs	indus	Ratio of SMEs to all enterprises in a region

4 Results

4.1 Panel Regression Analysis

In this paper, it first examines the influence of each independent variable on the dependent variable of regional economic resilience, respectively estimates the partial least squares (PLS) model, the fixed effects model (FEM) and the random effects model (REM). Table 2 lists the basic regression results of 9 cities in the PRD region. Model (1) to model (3) respectively show the results of PLS, FEM and REM. It can be known through the F test and the Hausman test that FEM is superior to PLS and REM. Therefore, the estimation results of the variables are mainly explained according to the model (2) FEM.

The regression results show that: ① The regional innovation level is significant and positive in the 90% confidence level, which means that the regions with relatively high innovation level are more inclined to show relatively strong adaptability in the face of economic crisis; ② The proportion of regional fiscal expenditure is significant and negative under 90% confidence level, indicating that the higher proportion of fiscal expenditure that a region has, the worse it will perform in economic impacts; ③ The

Table 2 Panel regression results

Dependent variable	b	Model(1)	Model(2)	Model(3)
		PLS	FEM	REM
Explanatory variable	rv	− 0.261	0.287	− 0.260
		(− 0.700)	(0.660)	(− 0.820)
	uv	0.213	− 0.375	0.212
		(0.680)	(− 0.850)	(0.620)
	innova	1.266	− 21.627*	1.266
		(0.420)	(− 2.810)	(0.390)
	open	− 0.104*	0.062	− 0.104*
		(− 1.730)	(0.520)	(− 2.320)
	gov	0.832*	3.439*	0.832
		(1.75)	(2.230)	(1.440)
	indus	− 3.238	0.895	− 3.238*
		(− 1.55)	(0.430)	(− 2.480)
	R^2	0.088	0.120	0.088
	P (F test)	0.197	0.000	0.197
	n	9	9	9
	N	90	90	90

Notes: 1. “n” is the number of sections, “N” is the number of samples. 2. The number in parentheses is the “t” value of the estimated coefficient. 3. *, ** and *** mean significant at the test level of 10%, 5% and 1% respectively unrelated variety (uv), related variety (rv), the scale of export base, and the proportion of SMEs have no significant relationship with regional economic resilience. The regression results show that the hypothesis H_2 proposed in the above section is verified, the hypothesis H_1 and H_3 are partially supported, and the hypothesis H_4 and H_5 are falsified.

4.2 *Determinants of Economic Resilience in the PRD*

4.2.1 Related Variety and Unrelated Variety

The results of this paper show that there is a positive correlation between unrelated variety and regional economic resilience, and a negative correlation between related variety and regional economic resilience, but these two variables have no significant impact on resilience. Sun found that if the macroeconomic situation is promising, the industrial development brought about by related variety can promote the increase of employment, and it would play a greater role in economic stabilization; if the macroeconomic situation is grim, as market demand is shrunk, unrelated variety would begin to perform its function in economic stabilization [9]. Therefore, in the global financial crisis cycle after 2008, the economic growth rate of the PRD region was slowed down, and the unrelated variety would have a positive impact on the capability of regional economy to resist risks.

4.2.2 Regional Innovation Level Has Significant Affects on Regional Economic Resilience

From the results of the model, the variable coefficient of innovation level is significant and positive, indicating that regions with higher innovation level perform better in the face of economic impacts. It is found that many regions are inclined to the path-dependent effect in the face of economic crisis whereas negative path dependence is the "barrier" of regional economic resilience, which is easy to lead regional economy to gradually go on the declining path after being impacted externally. Innovation can help regional industries break the negative path dependence, and promote industrial transformation and upgrading so as to enable regional economy to have good capabilities to respond to economic crises. The *China Regional Innovation Capability Evaluation Report 2019* shows that Guangdong's innovation capability in 2019 ranked the first place in the country. The PRD urban agglomeration is superior in its innovation capability, which is helpful for the regional economy to withstand risks.

4.2.3 The Scale of Export Base Negatively Affects Regional Economic Resilience

The results of the model show that the scale of export base has a negative impact on the risk adaptability of regional economy. The degree of opening-up of a region highlights the ability of the region to absorb the risks in the face of external fluctuations. The larger the scale of export base is and the stronger the correlation with the external environment is, the more likely that economy will be affected by external environment and have fluctuations consequently. Many export-oriented industries in the PRD rely on the American and European markets. Consequently, the further expansion of the Sino-U.S. trade war severely shrunk the consumer markets in the developed countries such as the U.S., greatly impacted coastal areas and private listed companies, which consequently resulted in economic recession.

4.2.4 The Significant Effect of the Proportion of Regional Fiscal Expenditure on Regional Economic Resilience

It is researched that regional fiscal expenditures have significant effects on regional economic resilience, namely the higher proportion of fiscal expenditures that a region has, the lower capability that it will have in adapting to external economic risks. Each regional government has to provide financial assistance when the region is in the face of external fluctuations and impacts. Although this assistance can help the recovery of the industries in crises to a certain extent, it will likely lead to the policy dependence of the regional production subjects in the long run, weakens their viability in crises, and even reduces their investment in research and development, which is unfavorable for their transformation. The excessively high proportion of administrative service expenditure will inevitably lead to the rigidity of fiscal expenditure structure, which leads other public expenditures to fail to be guaranteed and seriously affects the performance of the financial function.

4.2.5 The Proportion of SMEs Negatively Affects Regional Economic Resilience

Viewed from the results of model, the proportion of SMEs has a negative impact on regional economic resilience. Because of their small scale, low technical content, weak strengths, and low adaptability to risks and crises, economic crises can easily lead to the bankruptcy of SMEs, which will consequently lower the capacity of regional economy to resist risks. The yearbook data shows that the proportion of SMEs in PRD is up to more than 90%. In the background of the financial crisis, domestic foreign trade and exports have been severely impacted. In addition, SMEs, as the main providers of jobs, led the employment problem to become more serious, which consequently resulted in the lower regional capacity to resist the negative impacts of the economic crisis.

5 Conclusion

Based on the PRD as a case study, this paper analyzes the factors influencing regional economic resilience through the fixed effects model. The research shows that the regional innovation level and the proportion of regional fiscal expenditure have a significant influence on regional economic resilience. Specifically, regions with strong unrelated variety and high level of innovation performed well in the economic crisis; to contrast, the regions with strong related variety, a large scale of export base, a high ratio of regional fiscal expenditures, and a high proportion of SMEs showed poor adaptability to economic impacts. Based on the above research, the following suggestions are proposed for the development of regional economic resilience:

(1) Increase funding for scientific research and educational activities, and encourage the innovation-driven acceleration of industrial transformation and upgrading. At the same time, focus on the diversified development of industries and avoid low production efficiency caused by industrial simplification..
(2) Change the mode of economic growth, put the focus of economic development on domestic demand, appropriately increase investment, strive to improve the living standards of urban and rural residents, and perfect consumption incentive policies and enhance the consumption levels in domestic market to increase domestic demands.
(3) Further optimize the structure of fiscal expenditures, and appropriately increase the proportion of fiscal expenditures in social security in order to maintain the regional employment rate during the financial crisis and make sure the full performance of government financial function.
(4) Increase the support for SMEs, such as reducing the taxation of SMEs, reduce the losses of SMEs caused by the economic crisis and increase the level of employment. In addition, enterprises should increase their awareness of crisis prevention and establish perfect alarming mechanism and systems against economic crisis so that they can swiftly make correct decisions and avoid economic risks to a maximum extent in the emergence of economic crisis.

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Accessing Australia-China Supply Chains by Australian Home Builders

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Abstract Along with the development of international trade and the increasing benefits of global sourcing, the Australian construction industry has started sourcing more products overseas, especially from China. The potential of sourcing from China has been recognised since the middle 1980s and trade between China and Australia has increased significantly. This study aims to examine the trade in building products between China and Australia. The objectives are to identify the specific products that are imported from China for use in the residential building sector in Australia. Building products such as steel, windows, tiles, joinery and sanitary wares are often procured in large quantities from China for the residential sector. Using data from 4 case studies, we determine that the main motivation for Australian builders to purchase increasing quantities of products is the lower prices that can be obtained from suppliers in China leading to both higher profits for these builders and lower building costs for home buyers. We will also discuss the risks for offshore supply especially in light of the increasing trade tensions and the recent disruptions cause by the pandemic.

Keywords Australia · Building products · International trade · Outsourcing

1 Introduction

In the last three decades, global trade flows and investment have accelerated dramatically, which have created enormous economic value. As a result, cross-border trade

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and financial flows have increased tenfold in between 1980 and 2007 [12]. Accordingly, numerous benefits and risks of global sourcing have been identified. For example, benefits include global lower prices and technical expertise, while risks include the increased instability in supply chain [11].

According to the Australian Trade and Investment Commission [1], Australia has maintained its 28th year of uninterrupted annual economic growth. Australia economic growth has maintained an average increase of more than 3% since 1992. This makes Australia the only major developed economy having the record of no annual recessions from 1992 to 2018. Australian robust economy is sustained by solid policy frameworks, profitable investment environment, resilient institutions and profound trade ties with the Asian region. Additionally, Australia's two-way trade in goods and services totalled AUD763 billion, accounting for more than 40% of the nominal gross domestic product (GDP) in 2017. The Asian region made up around two-thirds of Australia's total trade and China became Australia's largest trading market in 2017. In addition to the trade in final goods, there is considerable import of intermediate goods for inclusion into final assembly in Australia. An example of this is the import of construction materials and products by builders or their subcontractors for inclusion into buildings here in Australia. The construction industry, which represents 8% of Australia's GDP, is the largest non-service-related industry that contributes AUD134.2 billion to economy [2]. There are reports that imports into the construction sector are expected to reach 20% of total construction value by 2023.

The aim of this project was to examine the benefits and challenges for Australian residential builders in sourcing from China. The objectives are to understand the benefits of sourcing these products from China and the associated risks or challenges involved. We carried out an empirical study to determine what building materials are currently being sourced from China by residential builders, the cost of these materials and the associated transportation costs.

2 International Trade and Global Supply Chains

With growing international trade, global supply chains are becoming increasingly important for many national economies. However, within the construction sector, there is little theoretical or empirical research on the response of these enterprises to adopt global supply chains. In fact, research on construction supply chains only emerged in the mid-1990s. Research into construction supply chains need to consider the fundamental structure of project-based work, economic and organizational nature of the sector [9]. In the 1990s, the Hawk-Keating government abolished import tariffs and floated the Australian dollar, allowing Australian importers to source products from overseas with higher quality and lower prices [7]. The Australian construction industry has already sourced around 11% of all construction materials from overseas in 2011–2012 [15] and it is expected this to increase to 20% by 2023 representing more than AUD30 billion of imports [3].

Moreover, since the mid-1980s, the potential of outsourcing to China had been recognized, as global companies procure goods and services from lower labour costs economies and improved control of product quality [6]. China became a member of the World Trade Organization in October 2001, which indicates the Chinese economic development and manufacturing capacity had been recognized in the world. China has become the world's leading manufacturing centre producing different types of products for the Western markets [8].

Price Waterhouse Coopers [13] reported that global construction and engineering firms found that 10% of engineering and construction products can be sourced with lower cost from manufacturing hubs in Eastern Europe, Latin America, China and India. These firms can save around 30–38% by sourcing overseas, which leads to a competitive advantage compared with the domestic sourcing. Building products that were suitable for low-cost sourcing were electrical wiring, flooring, sanitary wares, furniture, and doors and windows.

In a survey of 35 Australian manufacturers that procure materials from China, Xie et al. [16] observed that the most important consideration was economic benefit, to achieve cost reduction, cost savings and capital investment reduction. Most of these manufacturers expected at least 25% cost savings but reported that savings were less than anticipated when they realized that logistics, administration and operation costs were significantly higher than predicted. Their study reported that the quality of products produced in China was not a concern whereas a later study by Crossley and Tomson [4] found significant problems with products that do not comply with Australian standards. Difficulties highlighted by Xie et al. [16] include understanding and adjusting to social and cultural practices, business culture in China. Considering the balance of risks and benefits of global sourcing, these firms were still committed to their sourcing practices from China. These Australian firms were more likely to adopt formal construction mechanisms to address the difficulties faced in sourcing from China while Chinese firms are more amenable for social mechanisms [16]. Other researchers focused on developing other tools to ensure alignment of motivations such as e-procurement and global sourcing techniques [10], or responsible sourcing practices to ensure that these purchasing decisions address a range of environmental and social considerations [5].

3 Research Method and Data Collection

Many previous studies that have analyzed the motivations of companies sourcing their products from China were qualitative surveys on manufacturers or builders. There is a need for more detailed examination of these motivations and challenges to provide quantitative evidence of these savings, hidden costs and difficulties. Therefore, the research method adopted in this study was to examine 4 case studies of current projects being handled by a local domestic builder in Melbourne, Australia. This builder is the employer of the first author and permission was sought from the managers to disclose the quotes and costing sheets to the research team. To maintain

Table 1 Details of the four case study projects

Location	Description	Height	GFA (each, m^2)	Site area (m^2)
Mitcham	12 townhouses	3 storeys	146.0–165.3	2102.0
Doncaster east	3 townhouses	2 storeys	174.2–205.5	842.0
Paterson lakes	2 townhouses	3 storeys	355.1–362.5	576.6
Croydon	4 townhouses	2×1 storey, 2×2 storeys	182.0–221.0	1509.0

confidentiality of these costs, the results are reported either as an aggregate or as a percentage of the total cost.

The details of the projects in these 4 case studies are shown in Table 1. All these projects are in the suburbs of Melbourne and are on-going projects reflecting prices and challenges during the January–July 2020 period.

Subcontract rates were obtained for all the trades including preliminaries and contingencies for these four projects. The subcontractors were instructed to price their packages in three parts: materials, labour and transportation as separate items and to indicate the lead times for their respective packages. Suppliers that only supply construction materials were requested to identify the place of manufacturer for these materials, and to also indicate the lead times for order, manufacture and deliveries. During the research, we identified a group of distributors that act as agents of suppliers from China. These distributors procure building materials from overseas, primarily from China, and hold stock in local warehouses eliminating supply and transport risk. We foresee that builders will pay a premium for these products compared to direct sourcing from China. Shipping and transport rates were obtained either directly from suppliers overseas (CIF basis) or from logistics companies in Melbourne (FOB Basis). As the COVID-19 pandemic spread across the world, there were reduced frequency of ships sailing from ports in China to Australian, and reports of shipping companies in financial distress led to uncertainties and price increases.

4 Results

In an attempt to stimulate the local manufacturing sector and to protect jobs in Victoria, the state government has enacted the Local Jobs First policy that ensures that all public construction projects above a certain value or deemed to be strategic by the Minister must source at least 90% of their contract value from domestic suppliers. The Industry Capability Network (ICN, https://icn.org.au/) provides a list of contestable construction products to contractors and encourages the local manufacturers to bid for these items. The relevant *contestable* items in this study are windows, light steel framing, joinery, steel beams, timber flooring, and sanitary fixtures.

The first task for the builder was to determine a competitive price for these projects based on domestically source building materials and local labour. This will form the base cost for all four projects. The second task was to obtain quotes for these same

Table 2 Price ratios for contestable building materials and products

Trades	M-local	M-dist	M-import	T-import
Steelwork	1.000	0.661	0.446	0.160
Flooring	1.000	0.675	0.500	0.077
Joinery	1.000	0.600	0.400	0.053
Windows	1.000	0.465	0.314	0.088
Tiling, non-resilient	1.000	0.700	0.500	0.155
Sanitary fixtures	1.000	0.426	0.333	0.298

trades from both suppliers in China and distributors in Melbourne. It should be noted that these quotes are generally for material supply only as labour to install will remain firmly in the hands of the local installers. With the strict employment laws and licensing of building trades in Australia, all labour at these project sites are local. Subcontract prices for the supply and install of these materials and products were averaged across 4 projects and discussed as an aggregated project in Tables 2 and 3.

4.1 Benefits and Cost Savings

Table 2 shows a comparison for contestable materials sourced from three types of suppliers: local manufacturer, local distributors of Chinese manufactured products, and manufacturers in China. The data is presented as a ratio of the local manufacturer's material price. The supply of imported windows was only 31% of the locally sourced windows leading to a substantial saving for the builder. Similarly, products manufactured in China, but supplied through a local distributor attracts a premium of about 11%. Note that for all these cases, the installation costs of these building products are similar as these are installed by local installers. Transportation and logistics costs for direct imports are reported in the final column.

Table 3 shows an aggregate residential project divided into 34 items or trades further split into materials, labour and transport. The term 'share' in column 3 represents the proportion of an item or trade in the total cost. It must be pointed out that the cost items listed here are all builder's cost and do not include the builder's margin nor the contingency sum. An estimate of the builder's margin is in the range of 8–15% depending on market conditions and the number of projects that the builder has in hand. For these four projects, the material-labour-transport split was estimated at 59%–40%–1%, respectively, reflecting the high labour cost in Australia. Obviously, the contestable portion is solely on the material supply which accounts for 59% of the total cost of the project. Global sourcing of materials (see the last row of Table 3) reduces the material proportion to 49% resulting in a total project cost of 91% of the total for Case A or a saving of 9% of the total project cost. Transport and logistics cost increased from 0.8 to 2.5%. Procuring these materials from local distributors will increase the cost marginally but still provide a 7% savings on overall project

Table 3 Cost ratios for typical residential building based on local, distributor and import prices

	Item	Share	C/NC	Base case A—local				Case B—distributor				Case C—import			
				M	L	T	Sum	M	L	T	Sum	M	L	T	Sum
1	Demolition	0.015	NC	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
2	Site preparation	0.020	NC	0.628	0.356	0.016	1.000	0.628	0.356	0.016	1.000	0.628	0.356	0.016	1.000
3	Excavation/site cut	0.008	NC	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000
4	Termite control	0.003	NC	0.750	0.250	0.000	1.000	0.750	0.250	0.000	1.000	0.750	0.250	0.000	1.000
5	Driveway and footpath	0.027	NC	0.600	0.386	0.014	1.000	0.600	0.386	0.014	1.000	0.600	0.386	0.014	1.000
6	Fencing and retaining wall	0.012	NC	0.850	0.125	0.025	1.000	0.850	0.125	0.025	1.000	0.850	0.125	0.025	1.000
7	Plumbing works	0.035	NC	0.637	0.351	0.012	1.000	0.637	0.351	0.012	1.000	0.637	0.351	0.012	1.000
8	Concrete works—footings	0.083	NC	0.600	0.391	0.009	1.000	0.600	0.391	0.009	1.000	0.600	0.391	0.009	1.000
9	Brickwork and blockwork	0.083	NC	0.467	0.524	0.009	1.000	0.467	0.524	0.009	1.000	0.467	0.524	0.009	1.000
10	Cladding, rendering external wall	0.015	NC	0.600	0.400	0.000	1.000	0.600	0.400	0.000	1.000	0.600	0.400	0.000	1.000
11	Moulding	0.008	NC	0.736	0.250	0.014	1.000	0.736	0.250	0.014	1.000	0.736	0.250	0.014	1.000
12	Steelwork	0.033	C	0.690	0.293	0.016	1.000	0.462	0.293	0.016	0.772	0.308	0.293	0.112	0.713
13	Timber frame	0.122	NC	0.638	0.356	0.006	1.000	0.638	0.356	0.006	1.000	0.638	0.356	0.006	1.000
14	Insulation	0.014	NC	0.667	0.333	0.000	1.000	0.667	0.333	0.000	1.000	0.667	0.333	0.000	1.000
15	Flooring	0.038	C	0.818	0.182	0.000	1.000	0.552	0.182	0.000	0.734	0.409	0.182	0.063	0.655

(continued)

Table 3 (continued)

	Item	Share	C/NC	Base case A—local				Case B—distributor				Case C—import			
				M	L	T	Sum	M	L	T	Sum	M	L	T	Sum
16	Staircases	0.005	NC	0.620	0.365	0.015	1.000	0.620	0.365	0.015	1.000	0.620	0.365	0.015	1.000
17	Skirting and architrave	0.009	NC	0.389	0.611	0.000	1.000	0.389	0.611	0.000	1.000	0.389	0.611	0.000	1.000
18	Joinery	0.061	C	0.751	0.242	0.007	1.000	0.450	0.242	0.007	0.700	0.300	0.242	0.040	0.583
19	Stone	0.012	NC	0.640	0.346	0.014	1.000	0.640	0.346	0.014	1.000	0.640	0.346	0.014	1.000
20	Windows	0.059	C	0.889	0.104	0.007	1.000	0.414	0.104	0.007	0.525	0.276	0.104	0.078	0.457
21	Doors	0.025	NC	0.675	0.308	0.017	1.000	0.675	0.308	0.017	1.000	0.675	0.308	0.017	1.000
22	Roofing tiles	0.031	NC	0.759	0.227	0.013	1.000	0.759	0.227	0.013	1.000	0.759	0.227	0.013	1.000
23	Roof plumbing	0.030	NC	0.773	0.227	0.000	1.000	0.773	0.227	0.000	1.000	0.773	0.227	0.000	1.000
24	Plasterboard	0.046	NC	0.451	0.540	0.009	1.000	0.451	0.540	0.009	1.000	0.451	0.540	0.009	1.000
25	Tiling, non-resilient	0.029	C	0.291	0.709	0.000	1.000	0.204	0.709	0.000	0.913	0.145	0.709	0.045	0.900
26	Tiles for alfresco and porch	0.012	NC	0.468	0.498	0.034	1.000	0.468	0.498	0.034	1.000	0.468	0.498	0.034	1.000
27	Resilient finishes	0.009	NC	0.597	0.398	0.005	1.000	0.597	0.398	0.005	1.000	0.597	0.398	0.005	1.000
28	Glazing	0.011	NC	0.857	0.103	0.040	1.000	0.857	0.103	0.040	1.000	0.857	0.103	0.040	1.000
29	Painting	0.031	NC	0.123	0.877	0.000	1.000	0.123	0.877	0.000	1.000	0.123	0.877	0.000	1.000
30	Sanitary fixtures	0.032	C	0.417	0.583	0.000	1.000	0.326	0.583	0.000	0.910	0.139	0.583	0.124	0.846
31	Kitchen appliances	0.013	NC	0.804	0.183	0.013	1.000	0.804	0.183	0.013	1.000	0.804	0.183	0.013	1.000

(continued)

Table 3 (continued)

	Item	Share	C/NC	Base case A—local				Case B—distributor				Case C—import			
				M	L	T	Sum	M	L	T	Sum	M	L	T	Sum
32	Electrical services	0.031	NC	0.300	0.700	0.000	1.000	0.300	0.700	0.000	1.000	0.300	0.700	0.000	1.000
33	Mechanical services	0.030	NC	0.711	0.266	0.023	1.000	0.711	0.266	0.023	1.000	0.711	0.266	0.023	1.000
34	Miscellaneous	0.009	NC	0.298	0.702	0.000	1.000	0.298	0.702	0.000	1.000	0.298	0.702	0.000	1.000
	Total	1.000		0.593	0.398	0.008	1.000	0.524	0.398	0.008	0.931	0.489	0.398	0.025	0.912

C contestable, *NC* not contestable, *M* material, *L* labour, *T* transport cost. These savings, either from direct imports or via a local distributor are significant when compared to the potential profit for the builder and is expected to act the main motivating factor for their continued commitment to source from China. The economic benefits of lower material costs more than offsets the 1.7% increase in overall transport costs.

4.2 Risks and Disadvantages

Despite these potential economic benefits, the research also uncovered several risks. The most obvious disadvantage is the longer procurement period as the manufacturer is now located offshore and requires additional effort to organize if products are customized or bespoke. For example, windows, that are made to order will require a 4-month manufacturing period and an additional 40-day shipping compared to a 1-month manufacturing period and 7-day delivery, if ordered locally. The outbreak of the pandemic initially resulted in factory closures in China but soon led to more significant delays in shipping and transportation when the infection spread to Australia and resulted in extensive lockdowns. Shipping companies, facing a reduction in sea freight, reduced the frequency of their vessels and increased shipping costs. Although the building industry was not shut down, travel restrictions, work from home and social distancing rules in Melbourne resulted in delays for material deliveries and lower site productivities.

With US-China trade tensions on the rise, the Chinese yuan weakened significantly against the Australian dollar since January 2020 sparking concern amongst suppliers in China. A strengthening of the yuan would have put Australian builders in a difficult position. Currency fluctuation poses an obvious risk to global trade.

Another challenge for global procurement is the differences in work practices and building standards. The builder reported that major differences in practices and standards have resulted in extensive consultations between the designers in Australia and manufacturers in China. They attributed this to a lack of familiarity between the estimating team and their suppliers in China; and expect this process to be improved as the relationship develops into the future. Despite engaging native Chinese speakers in the company, the builder was also reporting issues communicating with their suppliers in China. The supplier in China has little experience in suppling internationally and are not familiar with Australian requirements.

5 Discussion

This study has now provided concrete evidence of significant cost savings for both direct and indirect procurement of building materials from China. These benefits are substantial when compared to the total material cost of residential buildings and are only slightly reduced when transportation and logistics costs are added. The economic benefits previously described in the literature [13, 16] are therefore confirmed and explicitly quantified for residential building projects.

There was no issue with non-conforming building products as the builder was constantly in communication with their Chinese suppliers to adhere to Australian standards. Other risks such as delivery and shipping times remain a challenge especially during this pandemic. One obvious mode of risk mitigation was to procure building materials from local distributors of Chinese suppliers who hold stock locally. However, this only applies to common building materials and not for bespoke items such as joinery or windows. This mode of global sourcing has not been investigated previously and possibly ignored by manufacturers who prefer to go directly to the suppliers in China. Builders on the other hand may not have the resources or network to directly access suppliers overseas.

Challenges in communication, coordination and business practices remain for the builder, potentially because the quantities procured are generally small. The longer time lag as a result of the distance is well understood and not seen to be an issue for this builder. Many of these disadvantages were previously identified in the manufacturing sector and can be successfully addressed by building up core competencies targeted at operating in a globally integrated supply chain [14].

6 Conclusions

This research clearly illustrates the significant cost advantage in procuring building materials from a lower cost producer such as China. While a direct comparison of material costs indicate savings of up to 70% the inclusion of shipping costs, taxes and insurances will reduce this cost advantage marginally. As the material-labour-transport split in Australian residential building sector is approximately 59%–40%–1%, the maximum quantity of imported materials in a project is limited to 59% of the builder's cost. Given that items such as concrete, bricks, roof tiles and other bulky items are not contestable, an upper limit of 25% of the total project cost is more representative.

While labour is obviously not contestable, the significant wage differential between Australia and lower wage countries may drive Chinese manufacturers to pre-assemble kitchen cabinets and windows; and ship these assemblies for quick installation in Australia. Utilizing this approach, lower cost labour can be embodied into imported products thus reducing the need for more expensive labour on the project site in Australia.

This study provides a practical evidence of the significant cost saving from global sourcing. Therefore, it is important for Australia to broadly participate in the global economy to achieve mutual benefits with other countries. However, the challenges of global procurement for building materials are not unsurprising. These include difficulties in communications, difference in work practices and standards, and exposure to delays in manufacturing and transportation.

This research is limited to four case studies in the Melbourne metropolitan area and may not be representative of the broader residential building sector in Australia. Nevertheless, it provides hard evidence of the immediate advantages and disadvantages of global supply between China and Australia; and lays the foundation for future work either to improve the management practices of the construction and manufacturing supply chain in China or to deepen the understanding of global procurement practices in Australia.

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A Review of the Research on the Life Cycle Energy of Buildings Using Science Mapping

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Abstract Building energy consumption is the main contributor to the total energy consumption, which has an increasing impact on the environment. A systematic and comprehensive life cycle perspective assessment of building energy is crucial to maintaining project sustainability. Building energy analysis from life cycle perspective has been increasingly favoured by scholars. However, contents and links of many literatures have not been summarized, and there is a lack of systematic literature research. This review-based study adopted a three-step workflow consisting of bibliometric literature search, science mapping (keywords analysis), and systematic discussion to mining the recent decade's research of life cycle energy of buildings (LCE-B). Keywords analysis revealed the emerging research topics, such as Environmental impact, BIM, nZEBs and passive houses. A follow-up systematic discussion summarised mainstream research topics (e.g. trade-off between operating energy and embodied energy), discusses existing research gaps (e.g. stakeholder factors) and identified future research directions. This study helps scholars obtain an in-depth understanding of state-of-the-art LCE-B research, providing a comprehensive knowledge framework and allowing linkages on the current research field to future research trends.

Keywords Life cycle energy · Building energy · Review · Bibliometric analysis · Keywords analysis · Science mapping

1 Introduction

Construction industry is a major contributor to socio-economic development. It also consumes a large amount of energy and natural resources. Building energy accounts for more than 40% of global energy use, and greenhouse-gas (GHG) emissions account for 40%–50% of the world's energy, thus making it a key player in energy,

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facing increasing economic challenges and environmental responsibility. Environmental problems include global warming and acid rain, atmospheric suspended particles, photochemical pollution, solid waste pollution and natural ecological damage. Meanwhile, sustainable social, economic and environmental indicators have gradually become the focus of construction industry in developed and developing countries. Many academic studies have analysed building energy from the aspects of building types, building materials and building functions. Hong et al. [1] established an intelligent system that can automatically manage dust emission and energy consumption in construction sites for real-time monitoring and evaluation for reducing dust emissions and energy consumption.

A construction project is characterised by long duration, complex resources, uncertain factors and systematicness. Therefore, the application of life cycle concept for buildings has become crucial, and the research methods of life cycle assessment and analysis of building energy have become increasingly popular amongst scholars. A literature review is an expedient approach to obtain an in-depth understanding of a research domain [2] and provides a good summary of research directions. Through literature review, researchers can avoid duplication of work, further explore the research direction, understand the research status, and gain a broader academic vision in order to establish a specific work [3]. The number of academic studies on the combination of building energy and life cycle concepts has increased in recent years. The number of academic studies on the combination of building energy and life cycle concepts has increased in recent years. Many scholars have reviewed the study of LCE-B from different perspectives. For example, a summary of research methods [4], a summary of single-stage energy [5], a summary of life-cycle energy for a particular building or structural type [6], and case studies to review the characteristics and changes of LCE [7]. However, the relationship and content of these studies have not been explored, and there is a lack of systematic review. However, some reviews used subjective judgment when selecting data, which could lead to bias or even misleading results [8]. For example, Yuan and Shen [9] obtained literature data by selecting authoritative journals, or several other studies included only limited samples [10]. The bibliometric analysis method was introduced to minimise the potential subjectivity of literature reviews. Text mining and science mapping can be used to analyse articles in specific research fields in a highly objective and visual manner [11].

Therefore, the present study applies text mining (science mapping) and systematic analysis to the research field of LCE-B and conducts keywords and content analyses of LCE-B articles published from 2009 to 2019 (up to the end of November). The detailed objectives of this study are to:

(1) use science mapping approach to analyse keywords in the domain of LCE-B;
(2) summarise the mainstream research topics on LCE-B;
(3) discuss the gaps of existing research in the LCE-B domain and provide a framework to inference potential research directions.

2 Research Methodology

In the first stage, bibliometric search is used to obtain literature samples; in the second stage, science mapping is used to conduct keyword analysis to preliminarily explore research topics; in the last stage, systematic analysis is adopted to summarize mainstream research topics, discuss existing research gaps and determine future research directions.

2.1 Bibliometric Search

Bibliometric analysis is a useful method to obtain a comprehensive understanding of a given research field, and it provides further insights into topics that have not been previously fully understood or evaluated [12]. The bibliometric search of LCE-B publications was performed in Web of Science, one of the main search engines for academic outputs. Web of Science encompasses a large number of authoritative journals. The search query used for data extraction from the Web of Science database was as follows: TS = ((“life cycle energy” OR “LC energy”) AND building*) AND LANGUGE: (English) AND DOCUMENT TYPES: (Article or Review); Timespan = 2009–2019; Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, ESCI, CCR-EXPANDED, IC.

The initial search yielded 348 documents. Conference papers were excluded because the information and theoretical framework they provide are not as comprehensive as those provided by journal articles [13]. After initial screening, 288 articles remained in the literature sample. Further refinement of the remaining 288 articles was conducted by using articles’ titles, abstracts and keywords.

Firstly, researchers screened out articles with inconsistent research objects. For examples, Natarajan et al. [14] performed an LCE analysis but focus on gardens as objects. Hence, these studies were removed from the literature sample. Secondly, research scope of remaining articles was verified. Only studies that focused on LCE-B were retained. Several studies were excluded, including those of Ren et al. [15] and Vats and Vaish [16] who limited their research to building materials but did not apply the results to building itself. Other studies, such as Hoxha et al. [17] mentioned LCE-B but were aimed at other macro evaluation questions. After the final round of screening, ultimately 248 articles were selected as the literature samples for the follow-up analysis. Figure 1 shows the overall trend of research outputs in LCE-B in the past decade. Excluding the incomplete data for 2019, during the period of 2009–2018, the studies on LCE-B increased annually.

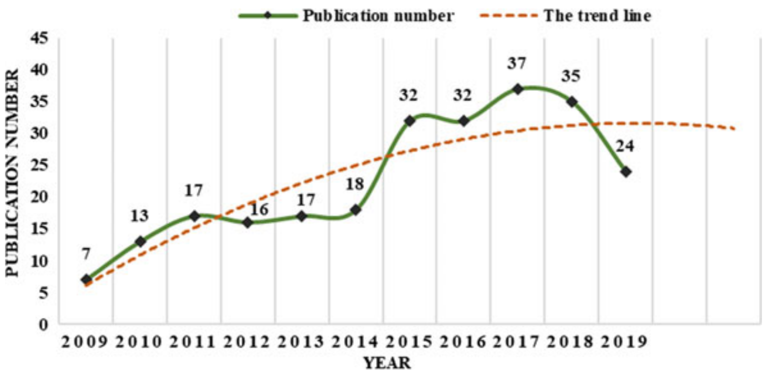

Fig. 1 Annual publication of related papers

2.2 Science Mapping

This study used science mapping for analysing and visualising keywords networks. Science mapping consists of knowledge mining and visualisation, mining of useful information to display knowledge or social evolution in the field of research and examination of trends or outliers from the constructed visual network. VOSViewer version 1.6.11 was used in this study to conduct the science mapping because it is suitable for visualising larger networks with special text-mining features [18].

2.3 Systematic Analysis

Systematic analysis is the last step that provides an in-depth analysis and discussions of the content of LCE-B literature. A systematic analysis was conducted based on the contents of literature samples and findings of keywords to summarise main research topics of the existing studies. On this basis, a comprehensive knowledge framework that links existing research topics to future directions was proposed for scholars to continue the research work on LCE-B.

3 Research Topics Based on Keyword Analysis

3.1 Analysis of Keywords by Science Mapping

Keywords are the condensed content of a research article. Analysis of keywords by visualising their co-occurrence represents the interrelationships of knowledge and the intellectual organisation of research topics. Therefore, a co-occurrence network of keywords was mapped using VOSViewer, in which the node size represents the number of occurrences, the distance represents the strength of the relationship between two keywords and the different colours represent different clusters of research topics.

By using 'Author Keywords' and 'Fractionalisation', the minimum number of occurrences was set to 3; initially, 64 of the 719 keywords satisfied the threshold. General keywords, such as building, construction or energy, were removed. Furthermore, keywords with the same semantic meanings, such as 'energy saving' versus 'energy savings' and 'lca' versus 'life cycle assessment', were integrated. Finally, 40 keywords were created from the science mapping shown in Fig. 2. Figure 2 shows that the most frequent keywords used in previous research on LCE-B included 'embodied energy', 'life cycle assessment', 'residential building', 'life cycle energy analysis' and 'operational energy'. Operational energy, life cycle energy analysis and embodied energy are strongly related to one another within the same cluster.

Additional quantitative measurements of the highly influential keywords are presented in Table 1. The keywords with the highest occurrence do not necessarily have the highest average citations or average normal citation [19]. According to their average normal citation listed in Table 1, the keywords that receive high scores

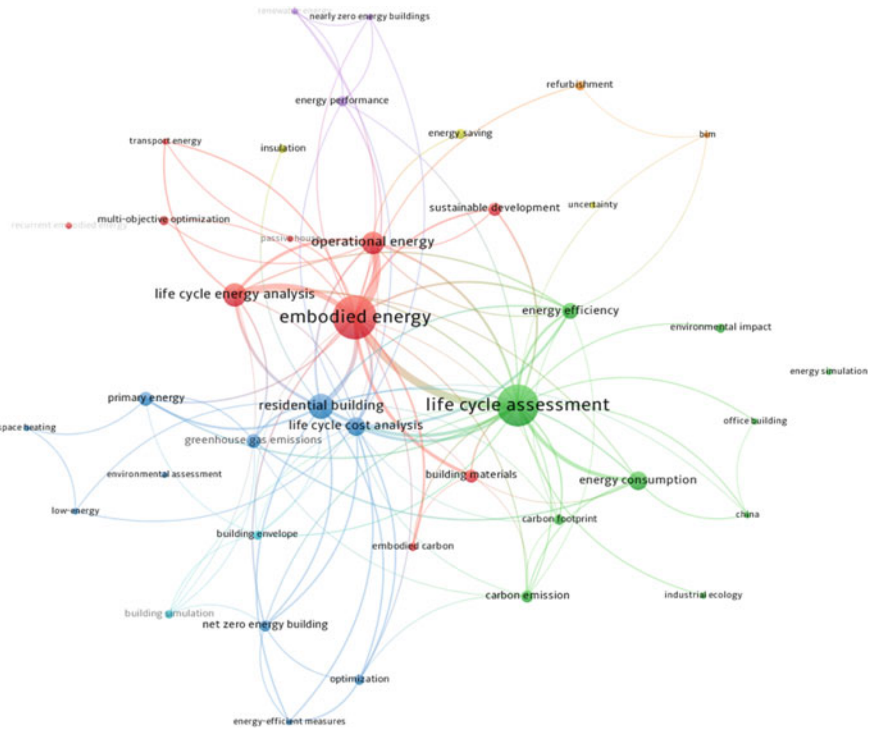

Fig. 2 Mapping of keywords in the LCE-B domain (2009–2019)

Table 1 Quantitative analysis of keywords in LCE-B research

Keywords	Code	Occurrences	Avg. citations	Avg. norm. citations[a]	Avg. pub. year[b]
Nearly zero energy buildings	K-1	3	32.33	5.80	2017
Renewable energy	K-2	3	34.67	2.64	2017
Sustainable development	K-3	10	41.00	2.06	2014
China	K-4	3	62.67	1.78	2013
Recurrent embodied energy	K-5	3	28.33	1.72	2016
Passive house	K-6	3	49.00	1.56	2014
BIM	K-7	3	14.67	1.55	2018
Office building	K-8	3	64.67	1.47	2013
Energy simulation	K-9	3	11.67	1.24	2017
Energy performance	K-10	6	19.17	1.19	2016
Energy efficiency	K-11	13	30.15	1.18	2015
Energy-efficient measures	K-12	3	35.33	1.15	2015
Residential building	K-13	31	35.77	1.12	2015
Life cycle assessment	K-14	76	42.37	1.12	2015
Building materials	K-15	9	14.67	1.11	2017
Greenhouse gas emissions	K-16	11	15.64	1.10	2016
Building simulation	K-17	4	8.00	1.05	2017
Primary energy	K-18	11	57.91	1.04	2014
Life cycle cost analysis	K-19	18	27.83	1.03	2016
Life cycle energy analysis	K-20	27	32.26	1.02	2015
Net zero energy building	K-21	7	16.57	1.01	2016
Uncertainty	K-22	3	14.00	1.00	2017
Multi-objective optimisation	K-23	5	7.20	0.97	2018
Operational energy	K-24	25	40.68	0.96	2015
Transport energy	K-25	3	49.67	0.94	2013

(continued)

Table 1 (continued)

Keywords	Code	Occurrences	Avg. citations	Avg. norm. citations[a]	Avg. pub. year[b]
Embodied energy	K-26	83	29.73	0.94	2014
Low energy	K-27	3	75.67	0.88	2016
Optimisation	K-28	6	25.83	0.85	2015
Industrial ecology	K-29	3	41.00	0.85	2012
Insulation	K-30	4	29.50	0.83	2014
Space heating	K-31	3	87.67	0.83	2014
Embodied carbon	K-32	4	9.00	0.78	2015
Energy consumption	K-33	17	17.29	0.78	2016
Carbon footprint	K-34	6	25.33	0.77	2013
Carbon emission	K-35	8	17.38	0.75	2015
Building envelope	K-36	5	12.80	0.65	2015
Energy saving	K-37	6	17.00	0.52	2016
Environmental impact	K-38	5	10.60	0.46	2015
Environmental assessment	K-39	3	6.33	0.36	2016
Refurbishment	K-40	5	5.20	0.35	2017

[a] Avg. norm. citation represents the normalised citation per article. It is calculated by dividing norm citations by the number of articles
[b] Avg. pub. year represents the average publication year of articles published in the journal [34].

include nearly zero energy buildings (nZEBs), renewable energy and sustainable development. It is implied that studies focus on investigating the application and development prospects of nZEBs [20], analysing the impact of renewable energy on LCE-B [21] and achieving sustainable development of buildings [22].

According to Table 1, studies related to BIM, multi-objective optimisation, nZEBs, simulation, refurbishment, renewable energy and uncertainty were published around 2017/2018, showing that these emerging keywords received scholars' interest and became the hot topic in recent years. For example, keyword 'optimisation' in 2015 has shifted to 'multi-objective optimisation', which indicates the analysis of building energy from multiple perspectives in 2018.

3.2 Research Topics

Keywords from different clusters, such as building materials and life cycle assessment, may have strong links. Co-occurrence networks can provide high frequency and influential keywords, but the classification of research topics is not detailed enough.

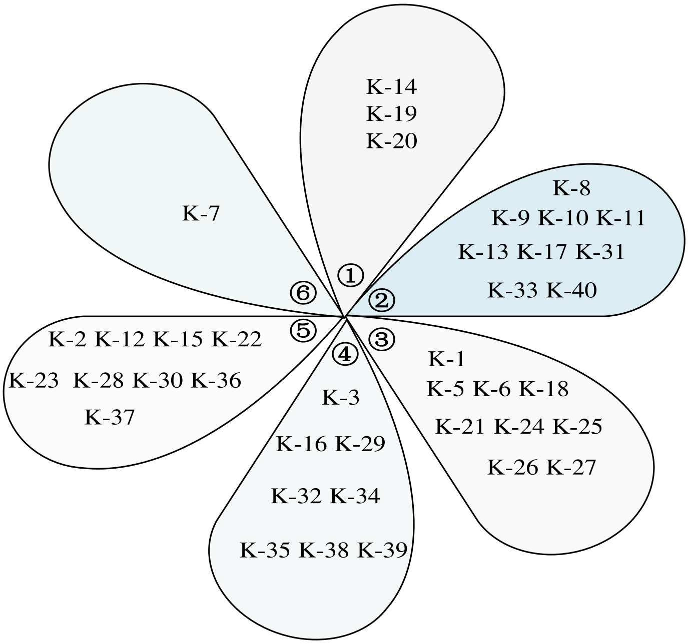

Fig. 3 Keywords clusters of the research topics (K–X represents the keyword code, ⊗ represents a certain type of research topic)

Therefore, according to Fig. 2 and Table 1, combined with the literature content, this paper redivides the keywords into 6 clusters, as shown in Fig. 3. The following is the main research topic of LCE-B according to the classification of keywords and specific contents.

3.2.1 Research Method of LCE-B

Related LCE-B research methods have been widely combined with life cycle assessment (LCA), life cycle energy analysis (LCEA), life cycle cost analysis (LCCA), and even life cycle carbon analysis (LCCO(2)A). The four methods are the mainstream methods in the LCE-B domain, but they have different problems and perspectives. Figure 2 also shows that these methods are divided clusters of different colors. LCA focuses on the evaluation of life cycle energy and environmental performance [23]. LCEA focuses on the assessment and calculation of all energy inputs in LCE-B [24]. LCCA focuses on cost analysis and performance evaluation of energy use and environmental impact from an economic perspective [25]. Case study is another main research methodology to further simulate and quantify the life cycle energy features of buildings. Table 1 shows that case study focuses more on residential buildings comparing to office buildings. Residential buildings consume large amounts of energy and thus play a major role in reducing energy requirements and GHG emissions in many countries [26].

3.2.2 Life Cycle Energy Consumption and Performance Evaluation

Many articles analysis of individual building life cycle energy, such as residential, office buildings, exhibition halls and warehouses. Atmaca et al. [27] conducted LCEA and LCCO(2)A on the life cycle energy (LCE) and carbon emissions of two residential buildings in Turkey. In addition to quantifying a single building LCE, scholars have gradually expanded their research scope by focusing on the regional study of building energy. The high integration and complex interaction between buildings, human behaviour and the regional environment to understand the regional building energy performance, which can assist in relevant decision-making. With the reform of the construction industry towards industrialization, prefabricated buildings have become an important means to realise industrialisation and improve the environment, and research on the energy performance of modular prefabricated parts has become a hot topic [6].

3.2.3 Passive Buildings, Low-Energy Buildings and nZEBs and Balance Between OE and EE

The results of the keyword analysis indicated that embodied energy (EE) and operational energy (EE) were mainly studied because they account for a large proportion and exert a serious influence on LCE-B with the decline of OE, low material efficiency and improvement of laws and regulations, the focus has gradually shifted to EE [28]. Dixit et al. committed to the study of the EE problem and obtained many research outputs. They developed a comprehensive system boundary model in 2013, defining system boundaries and quantifying the EE of buildings [29]. To achieve the minimum of LCE, OE and EE must reach a certain balance in the life cycle of buildings. Gervasio et al. [30] balanced OE and EE and analysed the influence of various insulating materials on OE and EE balance in the life cycle.

Buildings are divided into passive buildings, low-energy buildings and nZEBs according to energy efficiency. The definition of the three types of energy buildings depends on the energy regulations and measurement standards. Therefore, to a certain extent, these types of energy buildings can be converted through EEM and energy transformation. Ramesh et al. [31] pointed out that excessive use of passive and active functions in buildings may backfire. In the context of life cycle, the performance of low-energy buildings is better than that of nZEB. Colclough and McGrath [32] realised nZEBs by adding a combined energy system to low-energy buildings.

3.2.4 Environmental Impact

Environmental impact has been widely studied in the research theme of sustainable development. The analysis of LCE-B in existing research is related to the impact on the environment; it mainly comes from the GHG emitted by construction industry, such as tracking carbon footprints [33] and carbon dioxide emissions [34], to assess the impact on construction environment.

3.2.5 Design Scheme Selection and Optimisation

Decisions at the project design and planning stages have identified key impacts on the building's energy and environmental performance. Dawood et al. [21] considered active and passive renewable energy technologies to improve LCE performance in the energy design of buildings. Kneifel [35] used the integrated design approach to estimate the cost-effectiveness of LCE-saving, carbon emission reduction and energy-saving measures in new commercial buildings. Sequential search techniques [36, 37] and methods combining LCA with target value design (TVD) [38, 39] have been commonly used to generate and optimise sustainable architectural designs. Optimising the energy consumption and efficiency of buildings is a crucial issue. The selected research mainly focused on the optimisation of LCE-B from the aspects of enclosure components [40], building structure [41], thermal system [42] and energy design scheme [43].

3.2.6 Newly Emerging Technology

With the progress of science and technology, emerging technologies and computer algorithms have also become active in the research field of LCE-B. Building information modelling (BIM) has been displaying its function in building design, construction and information management. Existing research has used BIM to optimise the design process, strengthen information circulation, weigh EE and OE and provide improved design decisions [44, 45]. Eleftheriadis et al. [46] integrated LCA and BIM to investigate the latest development of energy efficiency of structural systems.

4 Discussions and Future Directions

4.1 Current Research Gaps

4.1.1 Systematic Framework for Quantifying LCE-B

The research scale of LCE-B spans different levels, including certain components, systems, individual buildings and regional buildings. At the research level of individual buildings, Thomas et al. [47] developed a system simulation framework to analyse the LCE consumption of a single building by combining various dynamic events in the life cycle.

A certain connection exists between architecture planning and regional planning. Huang et al. [48] further evaluated LCE-B from a system perspective, explored the interaction between buildings, the surrounding environment and user behaviour in urban areas and proposed a region-level system boundary definition and integration model. The energy assessment framework is extremely complicated and the definition among different levels is unclear due to the heterogeneity and complexity of the project. At present, the boundary of different levels should be defined, and the assessment of different levels should be systematically integrated for further developing a robust building energy assessment framework suitable for various locations and levels.

4.1.2 Human/Stakeholders Factors in the LCE-B Domain

Human/stakeholder factors include expectations, perceptions, attitudes and behaviours, etc. However, LCE analysis of buildings often ignores the expected level and behaviour consciousness of users or stakeholders. The energy consumption and energy efficiency indicators at each stage of building design, construction and operation are inseparable from the decisions and behaviour of stakeholders. Hernandez and Kenny [49] proposed a method that combined life cycle energy analysis and comfort expectations with building energy assessment to study the potential contribution of occupant preferences. Hu [50] focused on the common benefits of building energy efficiency and assess the impact of buildings on energy, the environment, water and human health. Currently, studies on the impact of human/stakeholder factors on LCE-B are limited, the concepts of human and subjective influence are lacking, and analysis of stakeholders corresponding to each stage of the building life cycle has not been conducted.

4.1.3 Emerging Technologies in the LCE-B Domain

As an emerging digital technology, BIM is mainly used for the design and planning stages of building energy. Currently, BIM has not been fully applied to the control and optimisation of various stages of the building life cycle and has not been fully integrated with other big data technologies. In addition, applications of other emerging technologies are limited and still in the initial stage. Therefore, multiple technologies can be combined to strengthen the research on LCE-B.

4.1.4 Energy-Saving Building Types

Energy efficiency and sustainability are becoming serious concerns, and a shift towards building nZEBs and net ZEBs has been observed. As the target of building energy, nZEBs has become a focus of research. LCE analysis of nZEBs is conducted from the perspectives of energy and cost, energy balance, envelope structure and design strategy. The concept of net ZEBs originated from United States; compared with nZEBs, smart grid, distributed energy and other concepts were added. Berggren et al. [51] pointed out that when moving from low-energy buildings to net ZEB, OE decreases and EE increases to a certain extent.

For developing countries, further technical and economic efforts are required to achieve nZEBs. For example, Liu et al. [22] highlighted China's further research work on nZEBs, including meteorological parameter changes, intelligent building operations management (IBOM) systems, energy storage systems and social policy issues. Currently, a gap exists between the acceptance and research of nZEB in developed and developing countries. A systematic comparative analysis of the social, economic, environmental and managerial aspects of nZEBs or net ZEBs in practice will facilitate the achievement of energy consumption targets to identify technical and managerial solutions appropriate for nZEBs or net ZEBs in a particular area.

4.1.5 Calculation and Evaluation of EE

With the emergence of numerous low-energy buildings and nZEBs, accurate assessment of EE has become particularly important. Compared with measuring OE, quantifying EE is additionally complicated and consumes more resources, and the calculation is inaccurate and incomplete. Dixit et al. [7] determined the parameters leading to EE data problems and identified unresolved problems in the LCA standard according to literature. They determined the key parameters affecting REE and evaluated REE and IEE at the same time to help simplifying the calculation of EE [5]. Miller and Doh [52] pointed out that the normative calculation program and systematic approach of the EE database for building materials are crucial for sustainable structural design. Different methods and parameters for quantifying EE can lead to large differences in reported EE data. Currently, a complete, accurate, specific EE database, calculations for EE and relevant guidelines to regulate EE evaluation parameters are lacking.

4.2 Future Research Directions

Based on the keyword analysis, systematic discussion of the mainstream research domain within LCE-B and gap analysis, a research framework suggesting future directions is proposed, as shown in Fig. 4. The existing research can be deduced to the possible research trends. A few directions for future research in the LCE-B domain are provided as follows:

- A comprehensive quantitative system should be developed to accurately analyse the LCE of buildings at all levels. At the same time, various conditions, including but not limited to the type of building structure, geographical location, regional characteristics and uncertainty factors, should be considered. A quantitative framework and benchmark that link micro and macro relationships should be developed. In addition, additional studies on the environment, economy, society and management are required to strengthen sustainable development.
- Energy consumption in building operation phase is closely related to human factors. However, at each stage, certain subjective factors are mainly influenced

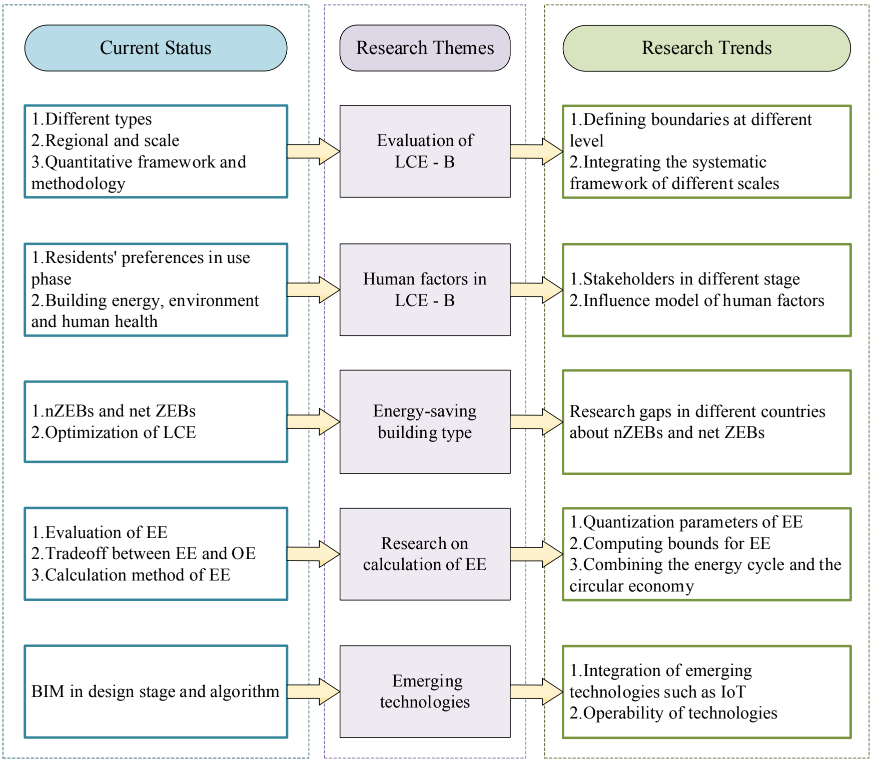

Fig. 4 Research framework linking the current status of LCE-B to future directions

by human will, such as the expectation level in the planning stage, decision-making attitude in the design stage and work behaviour in the construction stage. It is necessary to develop a model that combines stakeholder behaviour factors at different stages of a building's LCE.
- System boundary of EE should be clarified, computing functional unit should be specified [53], uncertainty factors affecting EE should be further determined [5] and quantification criteria of corresponding material database should be standardised. Energy cycle analysis of LCE-B can be combined with circular economics.
- Studies integrating the methodological techniques in different research domains could generate greater responses and lead to significant contributions to the research community. In addition to BIM, combined application with other information technologies, such as Internet of Things (real-time collection, processing and exchange of data), blockchain, AI and GIS, should be strengthened, and the operability of various methods and tools should be improved.

5 Conclusions

In this study, a combination of qualitative and quantitative methods is adopted. 248 journal articles published from 2009 to 2019 (up to the end of November) are selected as literature samples to analyze the frontier research and existing gaps in the domain of LCE-B and explore the research direction.

According to the number of papers published each year, it is confirmed that the research in the field of LCE-B is on the rise. On the basis of the keywords analysis, a follow-up systematic analysis was performed to summarise the mainstream research topics of LCE-B, identify the research gaps and propose future research directions. This holistic review further contributes to the direction in the LCE-B domain for near-future research, including:

- Defining the boundaries of different levels and integrating different scales to establish a systematic quantisation framework and quantitative analysis of irregular buildings, such as industrial and prefabricated buildings.
- Developing an influence model of human factors on LCE-B from the perspective of stakeholders at different stages.
- Integration of technologies and methods in different areas and improving operability amongst technologies (e.g. BIM, IoT, blockchain, AI and GIS).
- Analysis of research gaps in different countries regarding nZEBs and net ZEBs.
- Determining the computing boundary and parameters of EE and combination with life cycle energy cycle and cyclic economics to analyse EE.

These proposed directions for future work could benefit the academic community and industry practitioners for enhancing energy performance and generating new thinkings. Notably, this study was limited to the selected literature sample. The sample is published in the Web of Science and includes only English journal articles, the study only used journal articles and excluded other types of publications (trade journals or conference proceedings); it focused more on the academic research movement of LCE-B. Further identification of the uncertainties and differences between the latest academic research and industry practice is necessary.

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Research on the Competitive Mechanism Between Long-Term Rental Apartment and Traditional House Rental from the Perspective of Game Theory

Hui Liu

Abstract After our country has repeatedly issued favorable policies on housing rental, long-term rental apartments have emerged at the current development of sharing economy. Long-term rental apartments have so many advantages traditional housing rental does not have that it is favored by the young generation. Although the permeability of long-term rental apartments is still relatively low compared with traditional house rental in the market, to a certain extent, the former affects the interests of the latter. The industry is increasingly divided. The emergence of "oligopoly" with strong comprehensive strength has become a new trend in the industry. Therefore, the emergence and development of long-term rental apartments will occupy the traditional housing rental market share. Based on the comparative analysis of their business models and rental prices, this paper establishes the dynamic game model of both in the long rent real estate market and the return equilibrium solution of the game is obtained by inverse induction. In this theory, this paper puts forward the competitive strategy of long-term rental apartments in the future real estate storage quantity market to make an effective balance between the steady operation of leasing and scale expansion.

Keywords Long-term rental apartment · Traditional house rental · Competition mechanism · Game theory

1 Introduction

According to the forecast of the Lianjia Research Institute, the scale of our country's real estate rental market will reach 1.6 trillion yuan in 2020, further increase to 2.9 trillion yuan in 2025 and exceed 4.6 trillion yuan by 2030 [1], which shows that the future housing rental market space is huge. In the report of the 19th CPC (the Communist Party of China) National Congress, it was proposed to speed up the establishment of a "housing system for both renting and purchasing" and fully

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implement the policy of "houses are for the living, not for speculation", so that the whole people have a house to live. At the end of 2019, the Central Economic Working Conference also established "vigorously develop rental housing" as one of the key tasks in 2020. With the support of policies, long rental apartments have gradually become a hot topic in the housing market. According to the "Summary of China's Migrant Population Report for 2018" issued by the National Health Commission of the People's Republic of China, by the end of 2017, the number of floating population in China was up to 244 million [2]. Among the new generation of floating population, the proportion of those born in the 80s and 90s is relatively large. With the economic development of urban agglomeration areas, more and more people will gather in cities, which also means that the scale of population mobility is bound to aggravate the housing tensions. Meanwhile, in some developed areas, the purchasing power of commercial housing is not what ordinary people can afford. Contradictions are becoming increasingly obvious. As a result, the housing rental market will also face new opportunities and challenges. The emergence and development of long-term rental apartments will inevitably bring competition threats to traditional house leasing. It is also bound to seize the traditional house rental in the market share. Therefore, the research on the competition mechanism between them is a topic worthy of attention. Based on the comparative analysis of long-term rental apartments and traditional house rental, this paper establishes a dynamic game model of both to provide theoretical support for the future development of long-term rental apartments.

2 Literature Review

Long-term rental apartment is an emerging industry derived from the housing rental market. The houses are usually leased for professional decoration and renovation, with the help of brand premiums and mobile Internet, to provide single rooms or complete sets to tenants in need. Generally, the rental term is for several months or more than one year. Regarding the research on the development status of long-term rental apartments, Shenghuan Liu et al. pointed out that huge demand, policy support, investment, and service advantages are the main reasons for the rapid development of the long-term rental apartment industry. They also put forward four issues in the industry, namely profit model issues, financing issues, competition issues, and housing quality issues [3]. Based on the development experience of the foreign apartment market, Qinghua Wang, while affirming the prospects of long-term rental apartments, rationally pointed out that there are still problems such as market extensive expansion, difficult profitability under heavy assets, and rising financing difficulties [4]. Yujia Wang claimed the financial problems faced by long-term rental apartments, including the high land cost in first- and second-tier cities, the large consumption of batch housing design, decoration and renovation, and the difficulty of achieving large-scale profitability in the short term. He also proposed that REITs financing methods can solve the current situation [5]. Therefore, under the bright prospect of long-term rental apartments, it will stimulate the development pressure of the traditional housing rental industry to a certain extent. It has a greater impact on the market share of long-term rental apartment companies.

Research on the business model of long-term rental apartments, after analyzing the development constraints of long-term rental apartments, Xiaobin Ye et al. concluded that the rate of return on rent was too low to cover expenditure [6]. For heavy assets, high-priced financing can be obtained by reducing the cost of acquiring land and housing, improving apartment brand operations, and asset securitization; for light assets, the profit model requires companies to strictly control costs and increase revenue. Xue Bi discussed the three types of long-term rental apartment assets securitization models in the current market, including ABS, CMBS, and quasi-REITs. By analyzing the transaction structure, legal substance, and product defects of each model, he compared the advantages and disadvantages of each product and minimized the financial burden caused by high cost [7]. In general, it can be found from the existing literature that the focus of future control is cost management for the long-term rental apartment business model.

Research on the traditional housing rental market, since the reform of the housing system, our country's housing rental and sales market has developed unevenly, and the housing rental market has been in a backward state. In response to this problem, Yanfen Huang et al. proposed specific measures to use "same right to rent and purchase" as a breakthrough to promote "simultaneous rent and sale", thereby establishing a long-term mechanism for the development of the housing rental market [8]. The slow development of the housing rental market in our country has become a key factor restricting the healthy and balanced development of the real estate market. China's housing leasing market has emerged from scratch and has formed a large scale. However, the development of the housing leasing market has problems such as insufficient resource utilization, unbalanced supply and demand structure, irregular market operation, unfair competition, and lack of management. Zeng Guoan, etc. have found that these problems are caused by low rent levels, high concentration of demand for rental housing, commercial housing development and business models that only sell but not rent, insufficient adjustments to the stock housing structure, imperfect leasing market management regulations, and imperfect content [9]. Some scholars have found that there is a gap between buying and renting a house through research. The difference will affect the residents' choice of housing rental purchase [10]. These factors hinder the development of the traditional housing leasing market, which in turn will bring a series of difficulties and challenges to the traditional housing leasing industry.

In the existing literature on long-term rental apartments and traditional house leasing, it elaborates on the development status and policy support of long-term rental apartments, as well as the research on the business development model of long-term rental apartments, and analyzes the development challenges faced by traditional house leasing. However, there is no analysis of the competitive strategy of long-term rental apartments and traditional house rentals in the long-term real estate rental market. Based on the comparative analysis of long-term rental apartments and traditional housing rental business models, this paper establishes a dynamic game model between the both in the real estate long rental market and provides a theoretical reference value for the development of long-term rental apartments.

3 Comparative Analysis of Long-Term Rental Apartment and Traditional House Rental Operation Mode

3.1 Comparative Analysis of the Business Model

There are obvious differences between the business model of long-term rental apartments and traditional house rental. In the real estate storage quantity market, long-term rental apartments can be divided into centralized long-term rental apartments and decentralized long-term rental apartments according to asset distribution. From the perspective of the overall business model in Fig. 1, the development of centralized long-term rental apartments is usually invested and constructed by state-owned enterprises and developers with relatively strong self-owned assets. They often hold property rights, and the distribution of property assets is relatively concentrated. The decentralized long-term rental apartments are mainly operated through entrusted management, and generally do not hold property rights. It is a light asset model. The distribution of property assets is also relatively scattered.

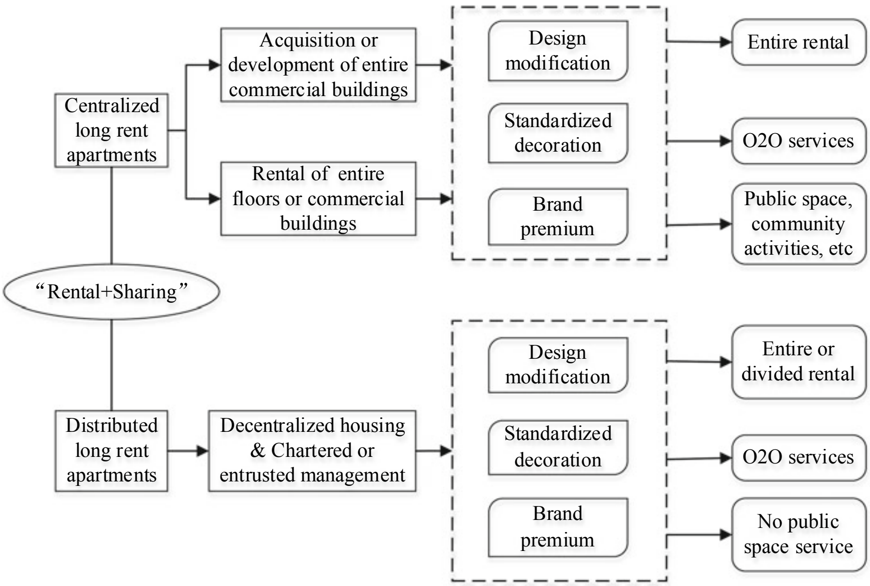

Fig. 1 Long-term rental apartment business model

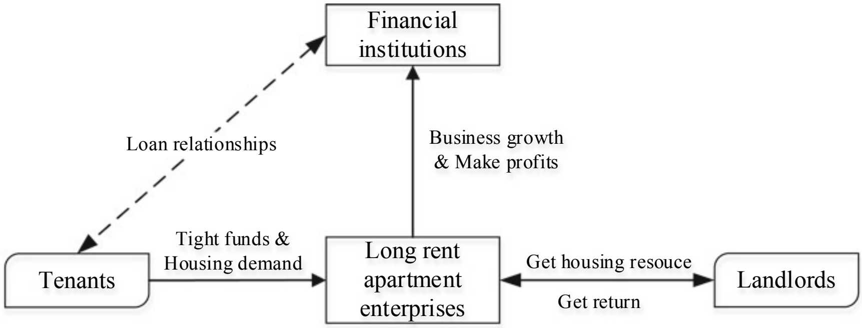

Fig. 2 "Finance + long-term rental apartment" transaction model

Judging from international experience, a variety of "long-term rental apartment + finance" business models have emerged in China, which mainly include REITs, trust products, ABS, etc. These financing methods can not only obtain more housing resources to achieve scale expansion but also use financial tools to enhance the liquidity of long-term rental apartment assets. In the long run, this will inevitably be the development trend of the future long-term rental apartment industry. It can be seen from Fig. 2 that such a transaction model has certain advantages for all parties involved: First, for the tenant, it can reduce the financial pressure of "bet one pay three" in the traditional rental model, at the same time, it can get high-quality housing for selection; second, for long-term rental apartment companies, it can diversify the way of earning income and accelerate the input and output of cash flow, which is conducive to the continuous expansion of scale, to realize the brand's premium; third, for landlords, while earning high rental income, they can also avoid the self-management trouble; fourth, for financial institutions, they can get more business and provide more financial products for tenants to obtain profit.

The business model of traditional house rental is relatively simple, which is mainly divided into two models: private rental and intermediary rental. The private rental model is that the landlord directly provides housing to the tenant. After both are satisfied with each other, they directly sign the contract. The tenant only needs to pay the rent. The intermediary rental model is that the real estate intermediary releases the housing resource to the Internet and other commercial platforms. In the back of finding a suitable house, the tenant will contact the agent for on-site inspections. When the two parties are satisfied, the rental contract will be signed. The tenant pays agent fees and rent. The transaction is completed (Fig. 3).

According to the comparison of business models, it is found that the centralized type is easier to industrialize than the decentralized type in the long-term rental apartment market, which has a greater impact on the competition of the traditional house rental model; in the traditional house rental model, the intermediary rental is easier to industrialize in the market than the private rental. It poses a greater threat to competition for long-term rental apartments.

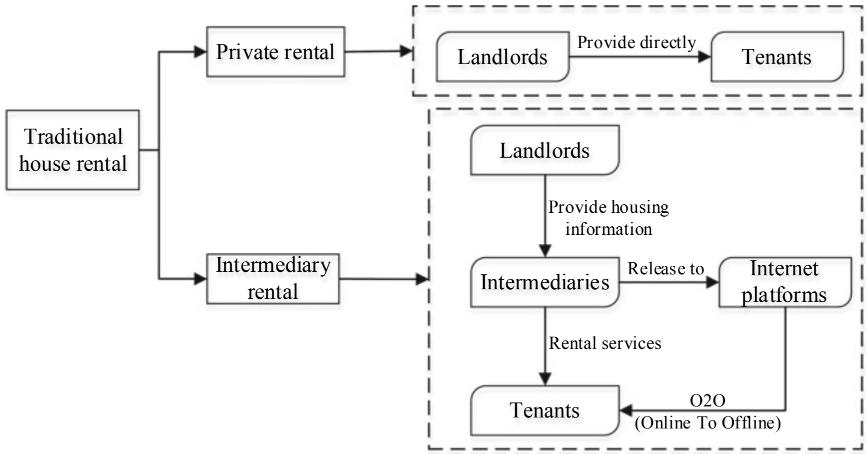

Fig. 3 Traditional house rental business model

3.2 Market Operation Analysis

It can be seen from the business model that the initial investment costs of long-term rental apartments are relatively high, and the investment recovery period is too short. This article selects the most representative 6 long-term rental apartments and 4 housing rental intermediary companies to conduct market operation analysis. Relevant data on the operation of the company are crawled from the Internet. The results of statistical analysis of the data are shown in Tables 1 and 2.

By comparing the data in Tables 1 and 2, it is found that in terms of deposit payment methods, both are "bet one pay one" and "bet one pay three". However, long-term rental apartments provide some preferential support for the payment behavior of "bet one pay three". Since most of the long-term rental apartments are mainly operated by long-term rentals, combined with their brand characteristics, long-term rental apartments divide the long-term rental market of traditional house rental with professional apartment management methods. In terms of rental prices, the price selection space of traditional house leasing is more flexible than that of long-term rental apartments, and there is a wider market in the face of different consumer groups. In the aspect of the number of housing leases, traditional intermediary rental housing accounts for significantly more and more extensive housing in the market than long-term rental apartments, but this also shows that it is difficult to centralize management. In terms of target customers, long-term rental apartments are more targeted, but it will inevitably lose more potential customers. This is both an advantage and a disadvantage.

Table 1 Long-term apartment operation table

Brands	Type	Number of stores	Monthly rent range (yuan/month)	Term of lease	Main deposit method	Target customers
MoFang apartment	Centralized	32	1188–6567	Lease from 1 month, long-term lease for more than 6 months	Bet one pay one /bet one pay three (several companies will have preferential means)	Urban white-collar workers
Warm+	Centralized	17	994–12,608			Young white-collar workers
YOU+ international youth community	Centralized	4	1699–3450			Young white-collar workers and entrepreneurs
Port apartment	Centralized	147	235–11,999			Young white-collar workers
Goyoo	Centralized	24	454–5700			Youth community
China young professionals apartments	Centralized	1	1399–4599			Urban white-collar workers

Data source Company official website, public information, the data collection time is Dec 26, 2020

Table 2 Traditional housing rental operation table

Brands	Rental way	Number of house	Monthly rent range (yuan/month)	Term of lease	Main deposit method
Lianjia	Entire rental; joint rental	13,076	1600–6200	Short-term rent/monthly rent/annual rent	Bet one pay one /bet one pay three
Centaline		20,538	400–15,000		
Fang		6960	430–15,000		
Q Fang		45,412	267–15,000		

Data source Company official website, public information, the data collection time is Dec 26, 2020

3.3 Consumer Demand Analysis

The long-term rental apartment industry is an emerging industry that has developed in recent years. The consumer groups it faces are also diverse. Traditional intermediary rental houses have many shortcomings and loopholes in the development process, mainly including the following points: first, the delivery process is cumbersome, some intermediaries ignore the housing quality and conceal their real housing to complete the transaction as soon as possible; second, Some tenants need to purchase furniture and electrical appliances by themselves after obtaining housing; third, the intermediary management service is inefficiency and the quality is not guaranteed; fourth, in the long-term development of the market, some landlords and intermediaries have some false frauds. The deposit is difficult to withdraw and the rent is increased at any time. Compared with traditional house rental, the advantages of long-term rental apartments are particularly prominent. The price is transparent, standard decoration, complete equipment, professional after-sales service guarantee, and even some companies have introduced a credit-free deposit policy, which is in line with the living consumption concept of modern young people. As a result, young white-collar and college students have become potential customers in the long-term rental apartment market. To better understand the factors influencing the demand of young people for long-term rental apartments, Wenbo Fan analyzed the consumption characteristics of young people and found that the facilities and decoration design for house leasing is relatively high-level demand, and the supporting services for house leasing also shows diversified characteristics [11]. Therefore, long-term rental apartments must balance cost control and tenants' willingness. It has to set up diversification for different residential needs for tenants to choose, which is another major competitive advantage of long-term rental apartments.

4 Game Model Analysis

Based on the above comparative analysis of long-term rental apartments and traditional housing rental models, it is found that although long-term rental apartments occupy a small share in the housing rental market, they have diversified competitive advantages compared with traditional housing leasing; traditional housing leasing covers a wide range in the market and the transaction process is relatively simple, but there will inevitably be some drawbacks. Therefore, this article studies the competition mechanism between the two parties in the long-term rental market from the perspective of game theory, and analyzes the development strategies of both by establishing and solving a dynamic game model.

4.1 Model Basic Assumptions

Game theory is usually divided into "static game", "dynamic game" and "repetitive game" according to the difference of the game sequence or repeated strategies. Furthermore, on the basis of the information mastery of the players, "dynamic game" is divided into complete information dynamic game and incomplete information dynamic game [12]. Based on the characteristics of this paper, the game type we choose is the complete information dynamic game model. The basic assumptions are as follows:

Table 3 Correlation parameter conventions

Symbol	Representation
C_1	The price paid by traditional house rental to develop long-term rental apartments
C_1'	The price paid by traditional house rental to choose not to develop long-term rental apartments
I_1	The income from traditional house rental chooses to develop long-term rental apartment
C_2	The competition price paid by long-term rental apartment
I_2	The income from long-term rental apartment chooses to competition
d_1	The decrease in income after traditional house rental chooses to develop long-term rental apartments
d_2	The decrease in income after long-term rental apartment chooses to competition
S	Government subsidies to housing rental companies
M	Percentage of long-term rental apartment companies receiving government subsidies
I_0	Long-term rental apartments take advantage of the profits made by financial institutions

Assumption 1: Assume that the participants are long-term rental apartments and traditional house rental, and the two subjects are limited rational people. They both aim at maximizing their interests;
Assumption 2: Assume that the information is complete, that is, the information of both parties is interoperable;
Assumption 3: Assume that the rental term is more than 6 months;
Assumption 4: Assume that the main body of long-term rental apartments is centralized, and the main body of traditional house rental is the intermediary rental.

Correlation parameter conventions are shown in Table 3.

4.2 Model Building

The probability that the traditional house rental chooses to develop the long-term rental apartment model is P_1, so the probability that it chooses not to develop the long-term rental apartment model is $1 - P_1$; the probability that the long-term rental apartment chooses to compete with traditional house rental is P_2, so the probability that it chooses not to compete with the traditional house rental is $1 - P_2$. The income matrix of long-term rental apartments and traditional house rental is as follows (*Note*: the first item in the income matrix is the income of traditional house rental, the second item is the income of long-term rental apartments, and all parameter values are positive):

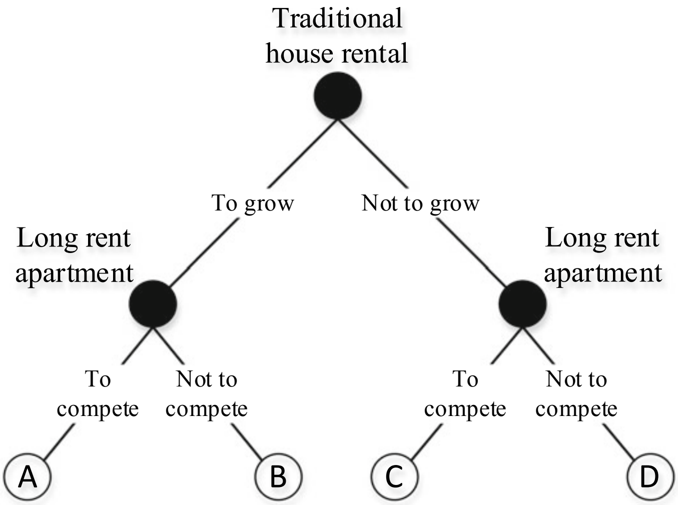

Fig. 4 Extensive form dynamic game tree

$$
\begin{aligned}
&\mathrm{A}: (\mathrm{I}_1 - \mathrm{d}_1 - \mathrm{C}_1,\ \mathrm{I}_2 + \mu\mathrm{S} + \mathrm{I}_0 - \mathrm{d}_2 - \mathrm{C}_2) \\
&\mathrm{B}: (\mathrm{I}_1 - \mathrm{C}_1,\ \mu\mathrm{S} + \mathrm{I}_0) \\
&\mathrm{C}: \left(-\mathrm{C}_1',\ \mathrm{I}_2 + \mu\mathrm{S} + \mathrm{I}_0 - \mathrm{C}_2\right) \\
&\mathrm{D}: \left(-\mathrm{C}_1',\ \mu\mathrm{S} + \mathrm{I}_0\right)
\end{aligned}
$$

The order of strategic actions is: firstly, whether the traditional house rental options develop into the long-term rental apartment, and then, the long-term rental apartment decides whether to compete with the traditional house rental actions, as shown in Fig. 4.

4.3 Solution and Analysis of the Model

In this paper, backward induction is used to solve the dynamic game equilibrium problem. The specific analysis process is as follows:

(1) Nash equilibrium solution of expected return on the long-term rental apartment.

Income function:

$$
\begin{aligned}
\pi_2 = {} & \mathrm{P}_1\mathrm{P}_2(\mathrm{I}_2 + \mu\mathrm{S} + \mathrm{I}_0 - \mathrm{d}_2 - \mathrm{C}_2) + \mathrm{P}_1(1 - \mathrm{P}_2)(\mu\mathrm{S} + \mathrm{I}_0) \\
& + \mathrm{P}_2(1 - \mathrm{P}_1)(\mathrm{I}_2 + \mu\mathrm{S} + \mathrm{I}_0 - \mathrm{C}_2) + (1 - \mathrm{P}_1)(1 - \mathrm{P}_2)(\mu\mathrm{S} + \mathrm{I}_0)
\end{aligned} \tag{1}
$$

Take the first derivative of the income function π_2 and set it equal to 0, we can get:

$$\frac{d\pi_2}{dP_2} = -P_1 d_2 + I_2 - C_2 = 0 \quad (2)$$

That is when the expected return on the long-term rental apartment is highest, we can get:

$$P_1 = \frac{I_2 - C_2}{d_2} \quad (3)$$

It can be seen from the above formula (3) that the probability P_1 that the traditional house rental chooses to develop long-term rental apartment is proportional to the net income $(I_2 - C_2)$ obtained after the long-term rental apartment chooses to competition, and is inversely proportional to d_2, the decrease in income after long-term rental apartment chooses to competition. The main reason is that the traditional house rental maintains a wait-and-see attitude on whether to develop long-term rental apartments. It is also necessary to conduct specific calculations on the demand and revenue of the long-term rental apartment market. If long-term rental apartment companies choose the asset-heavy model to compete with them, traditional housing rental companies will not choose to develop long-term rental apartments. This is mainly because compared with the traditional rental housing industry, long-term rental apartments have higher upfront cost investment and longer payback periods. Long-term capital investment may easily lead to the break of the company's capital chain. But if long-term rental apartment companies choose to compete, they can still get a net income greater than 0. It also shows that the long-term rental apartment market is in large demand. The development prospects are relatively optimistic. Traditional housing rental will choose to develop into long-term rental apartments.

(2) Nash equilibrium solution of expected return on traditional house rental.

Income function:

$$\begin{aligned}\pi_1 = {} & P_1P_2(I_1 - d_1 - C_1) + P_1(1 - P_2)(I_1 - C_1) \\ & + P_2(1 - P_1)\left(-C_1'\right) + (1 - P_1)(1 - P_2)\left(-C_1'\right)\end{aligned} \quad (4)$$

Take the first derivative of the income function π_1 and set it equal to 0, we can get:

$$\frac{d\pi_1}{dP_1} = -P_2 d_1 + I_1 - C_1 + C_1' = 0 \quad (5)$$

That is when the expected return on traditional house rental is the highest, we can get:

$$P_2 = \frac{I_1 - C_1 + C_1'}{d_1} \tag{6}$$

It can be seen from the above formula (6) that the probability P_2 that the long-term rental apartment chooses to compete with the traditional house rental is proportional to the net income $(I_1 - C_1)$ that traditional house rental chooses to develop long-term rental apartments, and is inversely proportional to d_1, the decrease in income after traditional house rental chooses to develop long-term rental apartments. The main reason is that long-term rental apartment companies are optimistic about the entire long-term rental market. If traditional house rental chooses to develop long-term rental apartments, the income I_1 obtained is greater than the competition cost, which also means that the entire long-term rental apartment market is in high demand. Traditional house rental will seize the market share of long-term rental apartments. Long-term rental apartment companies are more likely to choose to compete with them. The competitive advantage of long-term rental apartments will attract consumers' attention and improve their consumption idea. It leads to higher vacancy rates and more store operation management costs in traditional housing rental.

(3) Nash equilibrium income of long-term rental apartments.

Substituting the Nash equilibrium solutions of P_1 and P_2 into the income function π_2, after simplification, we can get:

$$\pi_2 = \mu S + I_0 \tag{7}$$

It can be seen from the above formula (7) that $\mu S + I_0$ is the game equilibrium income after the long-term rental apartment chooses to compete with the traditional house rental, and the income π_2 has a linear relationship with government subsidies and financial institutions' income. Hence, government policy support and financial institutions' income are the two main factors for long rental apartments to participate in the competition.

(4) Nash equilibrium income of traditional house rental.

Substituting the Nash equilibrium solutions of P_1 and P_2 into the income function π_1, after simplification, we can get:

$$\pi_1 = C_1' \tag{8}$$

It can be seen from the above formula (8) that C_1' is the game equilibrium income from the development of traditional house rental into long-term rental apartments, which means that the development of the long-term rental apartment can reduce the vacancy rate, thereby reducing the costs caused when houses are vacant.

Based on the above analysis, the development of traditional house rental into long-term rental apartments can reduce the cost of vacant housing. Long-term rental apartments choose to compete because they can get government subsidies and financial institutions' income. Therefore, both sides will compete.

5 Case Study

In order to clearly show the game analysis process, the above game model is analyzed with specific numerical examples. The leasing conditions of MoFang Apartment and Lianjia in Shenzhen are selected respectively, and both adopt the form of "bet one pay one". According to the current rent price, the MoFang Apartment selects (1188 + 6567) $\div$ 2 = 3877.50 yuan/month as its pricing standard. With a 6-month lease period, the income I_1 is 3877.50 $\times$ 6 = 23,265 yuan and the rent cost is based on the standard of 3000 yuan/month. The rent cost C_1 is 3000 $\times$ 6 = 18,000 yuan. Assuming that the financial institution makes a profit of I_0 = (23,265 – 18,000) $\times$ 1% = 52.65 yuan. The vacant housing and store management cost C_1' is 3000 yuan. The number of rental houses is the same. The government subsidy S takes the values 0 and 10,000, $\mu \in (0, 1)$. Calculate the change value of π_1 and π_2 when S and μ take different values. The calculation results are shown in Table 4.

From Table 4, it can be seen that the income from the development of traditional house rental into long-term rental apartments is not associated with the government subsidy S and the ratio μ of government subsidies, while the income of long-term rental apartments could be affected by government subsidies and cooperation with financial institutions. It is also consistent with the point mentioned above.

Table 4 Simulated income variation values of traditional house rental and long-term rental apartments

S	μ	$\pi_1 = C_1'$	$\pi_2 = \mu S + I_0$
0	/	3000	52.65
10,000	0	3000	52.65
	0.1	3000	1052.65
	0.2	3000	2052.65
	0.3	3000	3052.65
	0.4	3000	4052.65
	0.5	3000	5052.65
	0.6	3000	6052.65
	0.7	3000	7052.65
	0.8	3000	8052.65
	0.9	3000	9052.65
	1	3000	10,052.65

6 Conclusion and Recommendation

By establishing a dynamic game model between long-term rental apartments and traditional house rental, this paper obtains the solution of the Nash equilibrium. After analysis, the main conclusions are as follows:

(1) Traditional house rental maintains a wait-and-see attitude on whether to decide to develop long-term rental apartments. Since the development of long-term rental apartments can reduce the cost of vacant houses, some houses may be selected to develop into long-term rental apartments and participate in the competition.
(2) Long-term rental apartment companies remain optimistic about the entire long-term rental market. They may choose to participate in the competition because they are considering whether to get government subsidies and financial institution benefits.
(3) The greater the proportion μ of long-term rental apartment companies receiving government subsidies, the more benefits they can obtain from cooperation with financial institutions, and the more intense the competition with traditional housing rental companies.

Based on the above conclusions, this paper proposes a "government + financial institutions" cooperation mechanism. The specific recommendations are as follows:

1. The government should provide more policy support for the long-term rental market while strengthening government supervision. In terms of policies, one is that the government can regulate the decoration costs and land acquisition costs of long-term rental apartments; the second is to encourage college students and youth to obtain employment rental subsidies. The purpose is to stimulate housing consumption; the third is to enhance infrastructure construction and develop traffic and commerce near the housing as appropriate. Regarding market supervision, the government should regulate market behavior, set reasonable subsidy policies, and avoid fraud. Related regulations should also be set for transaction management in the rental market to safeguard the legitimate rights and interests of buyers and sellers.
2. Long-term rental apartment companies need to communicate with financial institutions to maximize their benefits without harming consumers' rights and interests. Long-term rental apartment companies can develop financing models such as credit loans and securitization to reduce consumers' payment pressure. At the same time, it also can shorten the project's investment payback period and improve product transaction efficiency. For financial institutions, this is also a long-term business to increase corporate profits.
3. For long-term rental apartment companies, it is necessary to intensify cost control. Starting from the life-cycle cost control model, some scholars specifically analyzed the key links and nodes of cost control at each stage of long-term rental apartments life-cycle, such as reducing the cost of housing acquisition

in the early stage, strengthening corporate cooperation to achieve standardized decoration, and refined management to achieve scale expansion and other measures [13].

4. Long-term rental apartment companies and traditional house rental companies need to cooperate to achieve a reasonable allocation of resources. Traditional house rental occupies a certain share in the market and is an indispensable part. It should grow together with long-term rental apartments and make full use of the resources in the real estate storage quantity market. Some houses can be developed into long-term rental apartments. It has the platform and technical advantages to meet the diverse needs of consumers. Keep the dynamic balance of the long-term rental market to obtain more corporate profits.

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Scientific Mapping Analysis of Environmental Impacts of Construction and Demolition Waste

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Abstract The environmental impacts of construction and demolition waste (C&D waste) has become a serious problem all over the world. As a result, researches related with the environmental impacts of C&D waste have been significant increased during the past decades. However, a systematic review on the research trend of environmental impacts in the domain of C&D waste is lacking. Based on a selection of 111 articles related to the environmental impacts of C&D waste, this review-based study adopted scientific mapping methods to evaluating the recent decade's C&D waste environmental impacts research. Through a three-step workflow of bibliometric literature search, scientometric analysis and qualitative discussion, this review identified the most influential journals, authors, articles, and countries in C&D waste environmental impacts studies from 2010 to 2019. Keywords analysis revealed the most concerned research topics of existing scholars, e.g. LCA, recycled aggregates, recycling. This paper provides the overall situation of C&D waste environmental impacts research in 2010–2019, and provides multi-disciplinary guidance for practitioners and researchers to link current research fields with future trends.

Keywords Construction and demolition waste · Environmental impacts · Science mapping · Scientometric analysis · Literature review

1 Introduction

Every year, more than 10 billion tons of C&D waste will be generated in the construction, renovation and demolition of buildings and infrastructure in the world, including about 700 million tons in the United States [1], and over 800 million tons in the European Union [2], and about 3 billion tons in China due to the acceleration of urbanization and large-scale urban renewal plan [3]. C&D waste accounts for 30–40% of urban solid waste [4]. At the same time, the environmental impacts of C&D waste

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(including land occupation, raw material consumption, water pollution, air pollution and energy consumption) has become a major problem faced by many countries [5]. For example, a large number of C&D waste landfills may have landslide risk. In 2015, a landfill landslide occurred in Guangming New District, Shenzhen City, Guangdong Province, with a volume of about 2.73 million m^3, killing 77 people and destroying 33 houses [6]. Secondly, due to the existence of C&D waste leachate, illegal dumping may bring potential risks to groundwater and surface water [7]. In addition, demolition activities not only waste a large number of building materials with residual value, but also the use of transport vehicles and machinery during demolition may have a negative impact on the air, e.g. dust, gas emissions and noise pollution [8]. Currently, C&D waste landfill rather than recycling is still the main disposal method in many parts of the world [9]. The large output of C&D waste and the negative impact on the environment are very serious. Therefore, there is an urgent need to reduce the environmental impacts of C&D waste.

Based on extensive research on C&D waste management, some research scholars have reviewed the main research status and future trends, covering different research topics. These reviews can generally be divided into two categories. The first one is to identify the main topics and research trends related to C&D waste management [10–13]. The second type focuses on specific aspects. For example, Wu et al. [14] summarized the main methods to evaluate the performance of C&D waste management, and proposed an integrated framework with procedures to better evaluate the performance of C&D waste management. Abanda et al. [15] proposed a framework to develop a comprehensive model for forecasting energy, greenhouse gases, waste production, time and cost. Wu et al. [16] systematically combed and summarized the existing prediction and estimation methods of C&D waste production, and pointed out the specific scope of each quantification method. Other scholars have conducted in-depth reviews of the recycling of C&D waste [17, 18], which provide valuable insights into C&D waste research by presenting a complete picture of the discipline or addressing specific topics. Although C&D waste environmental impacts has received more and more attention and with the rapid development of architecture research, emerging technologies, e.g. BIM [4, 19], GIS [19], big data and emerging concepts of circular economy have been applied in C&D waste environmental impacts research [20]. However, the current review of C&D waste environmental impacts research is missing, and a comprehensive review of C&D waste environmental impacts research will help to provide a holistic picture to practitioners, researchers and stakeholders. Hence, it is necessary to clarify the current hot issues of C&D waste environmental impacts research, research methods adopted for different issues, research stages, application of emerging technologies in C&D waste environmental impacts, research gaps and recent research trends.

Literature review is a method of in-depth study of a certain field. This study adopted science mapping to try to comprehensively review the research on the environmental impacts of C&D waste from 2010 to 2019. Firstly, through sample selection, the article with the highest correlation degree of C&D waste environmental impacts was found. Secondly, scientometric analysis was adopted to determine the most active and influential journals, authors, publications, countries and mainstream keywords in the current research of C&D waste environmental impacts, so as to clarify the current research status of C&D waste environmental impacts. Thus, a more comprehensive method was adopted to evaluate the environmental impacts of C&D waste in recent ten years.

2 Methodology

This review-based study adopts a holistic approach to evaluating environmental impacts of C&D waste. The entire workflow is shown in Fig. 1, which includes biblimetric literature search and scientometric analysis.

The biblimetric literature search on C&D waste environmental impacts research publications was conducted on the Web of Science (WoS), which has been widely used in Bibliometrics research [21, 22]. Compared with other databases (e.g. PubMed, Scopus and Google Scholar), WoS has a wider coverage in science, technology, social sciences, arts and humanities [23], and core and authoritative journals related to C&D waste are included in the WoS database [11]. As shown in Fig. 1, bibliometrics performs a total of three sub-steps to screen articles that were out of scope or not focused on the C&D waste environment impact. First of all, the input keywords included: "construction and demolition waste" OR "C&D waste" OR "C&D wastes" OR "C&D waste" OR "construction waste" OR "demolition waste" AND "carbon*" OR "environment*" OR "embodied energy". It is worth noting that

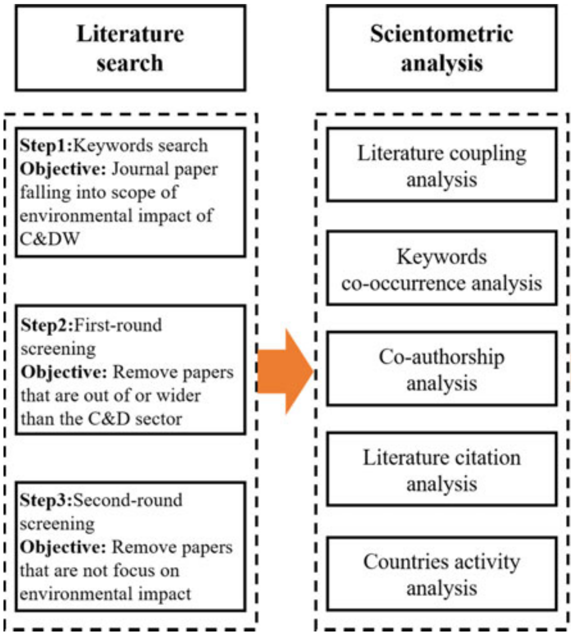

Fig. 1 Workflow for reviewing the environmental impacts of C&DW literature

this study identified the relevant journal articles published in English from 2010 to 2019 through keywords search. Conference papers were excluded due to the fact that the information they provided was far lower than that of journal articles, and there was little gain in including these papers, while the analysis would add extra complexity [24]. At the same time, the existing review articles were usually based on the literature published in the past 10 years, because they could better reflect the research status of the field [10, 12, 16].

Secondly, the researchers screened 765 journal articles generated by keyword-based bibliometric search in the first round, and selected the articles that were not in the C&D waste field or extended to the C&D waste field. For example, Wang et al. [25] studied the environmental impacts of abandoned lead-acid battery factories, Kao et al. [26] involved debris dumping, but none of these studies focused on the C&D industry. Other studies such as Hu et al. [27] focused on reverse logistics management of post-disaster debris, Chan et al. [28] targeted the impact of sediments on the marine environment, Iroba et al. [29] targeted municipal solid waste, which covered the C&D waste but was not limited to it. Therefore, these studies were removed from the literature sample. Finally, the second round of screening validated the research goals of the remaining articles, and only retained articles focused on the environmental impacts of C&D waste. For example, [30] aimed to increase the reuse potential of C&D waste, Vural et al. [31] optimized the vertical transportation and recycling of high-rise building construction waste, Moreno-Perez et al. [32] characterized recycled aggregate from C&D waste, but these studies did not involve environmental impacts. Although Bjegovic et al. [33] mentioned the use of construction waste recycled materials to save natural resources, but was designed to study the durability of materials. These studies were also removed from the literature sample. Ultimately, 111 articles were included in the review.

On this basis, this study conducted a scientometric analysis of 111 finalized journal articles. Existing studies have shown that science mapping can minimize subjectivity and prejudice when conducting review-based research [34], which has been adopted and applied by existing literature review studies [10–12]. At the same time, as a component of science mapping, scientometric analysis may comprehensively understand a specific research field and effectively provide further insights beyond what has been fully mastered or evaluated in previous studies [35], and it has been well applied in existing studies. In addition, VOSViewer not only provides visual analysis of distance-based bibliometrics network, but also has special text mining function [36], which has been adopted and applied by literature review research in C&D waste management field [10].

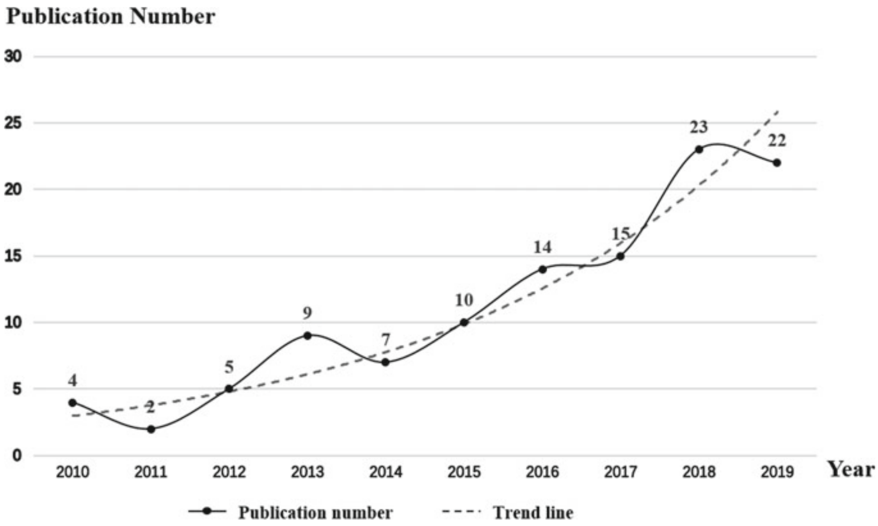

Fig. 2 Number of papers published in 2010–2019

3 Results of Scientometric Analysis

3.1 An Overview of the Literature Sample

Figure 2 shows the number of papers published each year for the period 2010–2019 in the selected literature sample. From the above data, it can be seen that the overall trend of research results on environmental impacts of C&D waste has been rising in recent ten years. Although the environmental impacts of C&D waste has gradually attracted attention, the number of research results is relatively small and there is a lack of relevant research in this area.

3.2 Literature Coupling Analysis

In this study, journals of selected C&D waste environmental impacts articles were identified, visualized and evaluated. The results are shown in Fig. 3 and Table 1. The minimum number of papers published and the minimum number of citations were set at 2 and 20, respectively, in VOSViewer. In total 11 out of 41 journals met the threshold. Figure 3 displays the clusters of journal sources and their interrelationships through connection lines. Note that journal names may not be shown fully in VOSViewer. The missing information can be seen in Table 1.

In Fig. 3, the size of fonts and nodes in the literature coupling network represents the number of publications from the given journals. The larger the fonts and nodes,

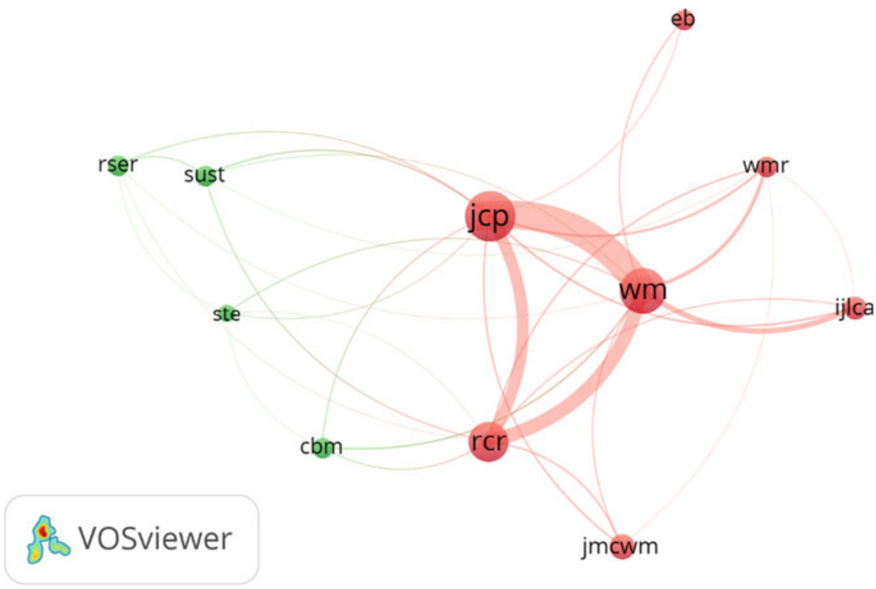

Fig. 3 Science mapping of mainstream journals in the field of C&D waste environmental impacts

the larger the number of publications, and vice versa. At the same time, different colors represent the journal categories to which each literature belongs after clustering the literature coupling network by the clustering algorithm, and different link lines indicate the closeness of different journals in terms of mutual citations. The number of citations is one of the important indicators to measure the influence of academic works. The use of direct citations is a common indicator for determining influential research in a certain field. It can be seen that the journals Waste Management, Journal of Cleaner Production, Resources Conservation and Recycling have made significant contributions to the field of C&DW environmental impacts research. Table 1 summarizes the quantitative measures of the impact of more journals. It lists four indicators, including number of publications, total citations received, average citations per publication, and average normalized citation quantify the influence of journals in the field of C&D waste environmental impacts. Figure 3 and Table 1 consistently show the most productive journals: Journal of Cleaner Production, Waste Management, and Resources Conservation and Recycling. They are also the journals receiving the highest total citations, indicating that they have the highest impact in terms of production and research. Construction and Building Materials is not only the journal with the largest average annual influence, but total citations are also high, but its annual production is not high.

Table 1 Quantitative measurements of journals publishing C&D waste environmental impacts research

Acronym in VOSViewer	Source	Number of publications	Total citations	Average citations	Ave. norm. citation
JCP	Journal of Cleaner Production	23	472	21	1.1
WM	Waste Management	19	763	40	1.2
RCR	Resources Conservation and Recycling	14	245	18	1.5
JMCWM	Journal of Material Cycles and Waste Management	5	45	9	0.5
CBM	Construction and Building Materials	3	72	24	2.3
RSER	Renewable and Sustainable Energy Reviews	3	110	37	1.1
IJLCA	International Journal of Life Cycle Assessment	4	40	10	0.5
WMR	Waste Management and Research	3	126	42	1.2
EB	Energy and Buildings	3	125	42	1.2
Sust	Sustainability	3	22	7	0.4
STE	Science of the Total Environment	2	30	15	0.9

3.3 Keywords Co-occurrence Analysis

Keywords represent the main contents of existing researches and describe topics of interest in a given field [37]. The keywords co-occurrence network shows the knowledge among their relationships and intellectual organization of research themes. This study used "Author Keywords" and "Fractional Counting" in VOSViewer analysis. The minimum occurrence of a keyword was set at 3. Initially 24 out of 285 keywords met the threshold, from which some general items were removed, e.g. "construction and demolition waste", "C&D waste", "construction waste", "demolition waste" and

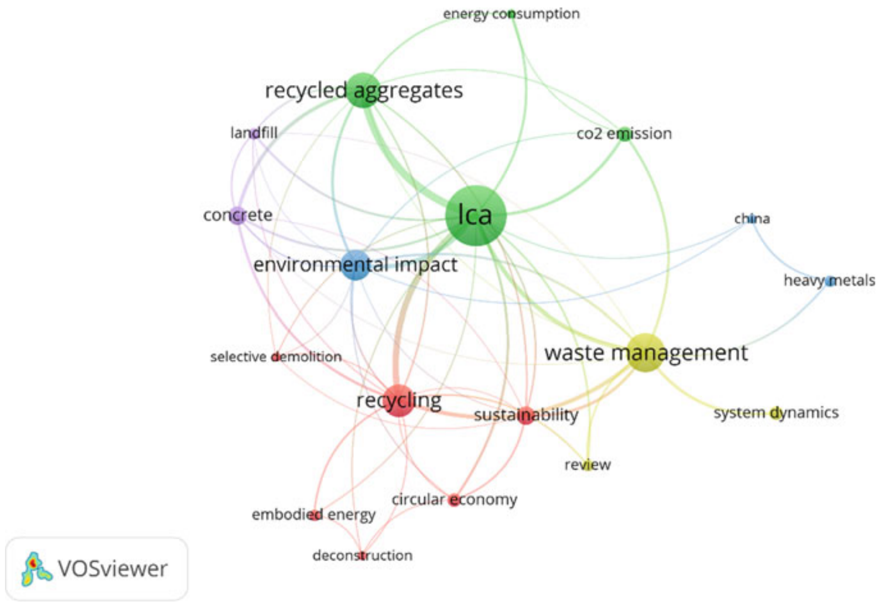

Fig. 4 Science mapping of keywords co-occurrence analysis in C&D waste environmental impacts

"waste". In the second round of keywords co-occurrence analysis, replace keywords with the same meaning. Finally, a total of 18 keywords were selected for analysis (Fig. 4).

In the keywords co-occurrence analysis network, the size of the nodes, the distance between the nodes and the connection lines represent the research popularity of the keywords. The node colors divide the keywords into different clusters, e.g. LCA, recycled aggregates and CO_2 emission in the same cluster have a strong correlation. At the same time, there may also be strong links between different clusters, e.g. recycling and LCA. Table 2 summarizes four methods for identifying keywords in quantitative measurements, including occurrence, average year published, average citations, and average normalized citation. Among them, LCA has the highest number of occurrences. In terms of average citations, sustainability, recycled aggregates, selective demolition and China have attracted widespread attention in the field of C&D waste environmental impacts. The average year of publication indicates the novelty of a given keywords in the field. For example, the research around LCA has been a research hotspot in the field of C&D waste in recent years, and research on environmental impacts and recycled aggregates were largely published around 2017. At the same time, studies on energy consumption, landfill, circular economy and concrete were published in recent years, indicating that the environmental impacts of C&D waste was highly valued by researchers and may become the main research direction in the future C&D waste field. In addition, in terms of average normalized citation, recycled aggregates, sustainability, and circular economy all have a high annual average influence, especially the highest selective demolition of average normalized

Table 2 Summaries of main keywords in C&DW environmental impacts research

Keywords in environmental impacts of C&D waste research	Occurrence	Average year published	Average citations	Ave. norm. citations
LCA	43	2017	20	1.0
Waste management	23	2016	19	0.9
Recycled aggregates	20	2017	25	1.1
Recycling	18	2017	17	0.8
Environmental impact	16	2017	19	1.0
Concrete	8	2018	6	0.5
Sustainability	8	2016	30	1.1
CO_2 emission	6	2015	23	0.7
Circular economy	5	2018	10	1.1
System dynamics	5	2016	18	0.9
Embodied energy	4	2015	11	0.4
Heavy metals	4	2016	11	0.4
Landfill	4	2018	9	0.7
Review	4	2018	14	0.8
China	3	2015	24	1.0
Deconstruction	3	2017	12	0.6
Energy consumption	3	2018	6	0.5
Selective demolition	3	2016	26	1.6

citation, which indicates that it has attracted high attention in the field of C&D waste environmental impacts.

3.4 Co-authorship Analysis

In academic research, collaborations between scholars can increase productivity while reducing isolation. In VOSViewer, the minimum number of articles published and the minimum citations of an author were set as 3 and 25. Totally 16 out of 352 authors from the literature sample met the selection criteria. These most influential authors are shown in Fig. 5 and Table 3.

The density visualization results mainly include five clusters, each cluster represents the co-authorship between different authors, the depth of the color represents

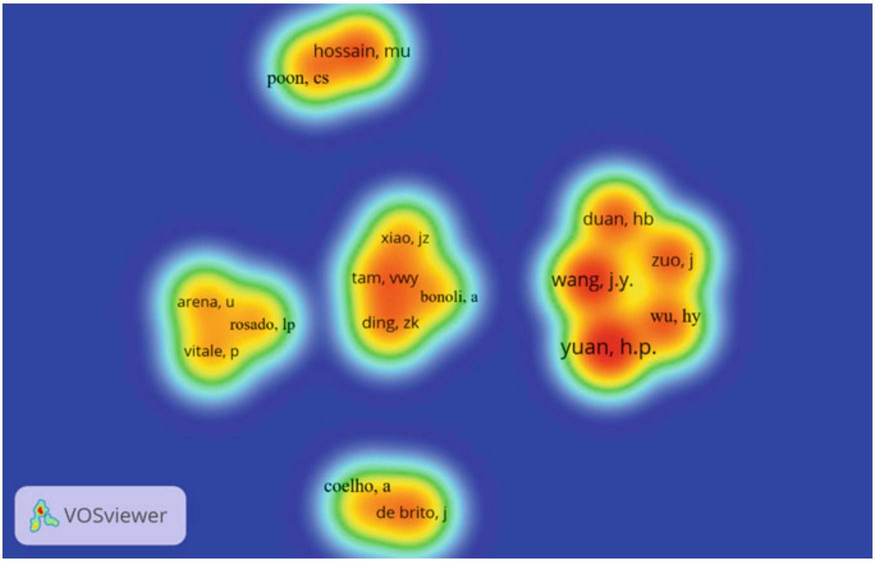

Fig. 5 Science mapping of co-authorship analysis in C&D waste environmental impacts. *Note* Only the first author of each article is displayed in VOSViewer, more details of each article can be found in Table 3

the number of published articles by the author and the strength of the connection, the stronger the relationship between the strength of the author's collaboration, the closer the color of the point is to red. The connections in the co-authorship network represent the strength of the author's collaboration. As can be seen in Fig. 5, these authors are divided into five categories, representing the co-authorship networks of five types of C&D waste environmental impacts research scholars, e.g. H. B. Duan, J. Y. Wang, H. P. Yuan, H. Y. Wu and J. Zuo. Table 3 lists five methods for quantitative measurement of these scholars, including number of articles published, total citations, the average year of publication, average citations per article, and average normalized citation. Among them, number of articles published and total citations reflect the production of research outputs and the influence of authors in the research community. As can be seen from Table 3, H. P. Yuan and J. Y. Wang are the most productive scholars in the field of C&D waste environmental impacts, and de Brito, J. has the highest total citations. At the same time, in terms of average citations, A Coelho is much higher than others in the table, indicating that A Coelho is an influential scholar in this field. H. Y. Wu and J. Zuo also make significant contributions to the research community. As shown in Fig. 5, they have very close academic collaborations with H. B. Duan and others. The average publication year indicates the degree of novelty of scholars in the field of C&D waste environmental impacts. Average normalized citation analysis shows the average annual influence of scholars. V. W. Y. Tam is the scholar with the largest average influence in this field.

Table 3 Quantitative measurements of scholars in C&D waste environmental impacts research

Scholar	Affiliation	Number of articles published	Total citations	Average publication year	Average citations	Ave. norm. citations
Yuan, H. P.	Southwest Jiaotong University	8	102	2017	13	1.5
Wang, J. Y.	Shenzhen University	7	83	2018	12	0.8
Hossain, M. U.	Hong Kong Polytech University	5	112	2017	22	1.6
Duan, H. B.	Shenzhen University	5	69	2016	14	0.7
Wu, H. Y.	University of Adelaide	5	29	2018	6	0.5
Zuo, J.	University of Adelaide	5	26	2018	5	0.4
de Brito, J.	University of Lisbon	4	175	2014	44	1.4
Tam, V. W. Y.	Western Sydney University	4	149	2017	37	2.2
Poon, C. S.	Hong Kong Polytech University	4	106	2017	27	1.4
Ding, Z. K.	Shenzhen University	4	86	2017	22	1.1
Coelho, A.	University of Lisbon	3	150	2013	50	1.3
Arena, U.	University of Naples Federico II	3	63	2018	21	1.5
Vitale, P.	University of Naples Federico II	3	63	2018	21	1.5
Bonoli, A.	University of Bologna	3	58	2015	19	0.6
Rosado, L. P.	University of Campinas	3	48	2017	16	1.1
Xiao, J. Z.	Tongji University	3	41	2018	14	1.3

3.5 Literature Citation Analysis

The most influential journal publications in the past dacade were also investigated in VOSViewer, with the minimum citations set at 40. This resulted in a total of 17 out of 111 articles being selected. Figure 6 visualizes citations that measure the most influential articles (Table 4).

In the citation analysis of VOSViewer, the correlation between articles is determined by the number of citations [53]. In the visualization results of the citation analysis, the color of the nodes also represents clustering analysis, and the size of the nodes indicates the number of citation relationships. The larger the node, the greater the number of citation relationships. The most citation article in the past ten years was [38], which comparatively analyzed the environmental impacts of producing recycled products [46, 49]. Blengini et al. [39] obtained the second highest citation rate. From the perspective of sustainable planning and waste management, it sorted out the key issues of C&D waste research and put forward future development trends, including a detailed study of recycling plants and the impact of land use into the LCA method requires further improvement. Yeheyis et al. [40] was the third highest cited article, which proposed an LCA-based C&D waste management framework that incorporates 3rs into the planning, design, construction, transformation, and demolition stages of the construction project life cycle. Other highly citation article topics include: (1) Environmental impacts of sorting, landfilling, recycling and incineration [41, 42, 50]; (2) Energy use of materials and life cycle environmental impacts [47, 51]; (3) C&D waste management environmental impacts evaluation model [43,

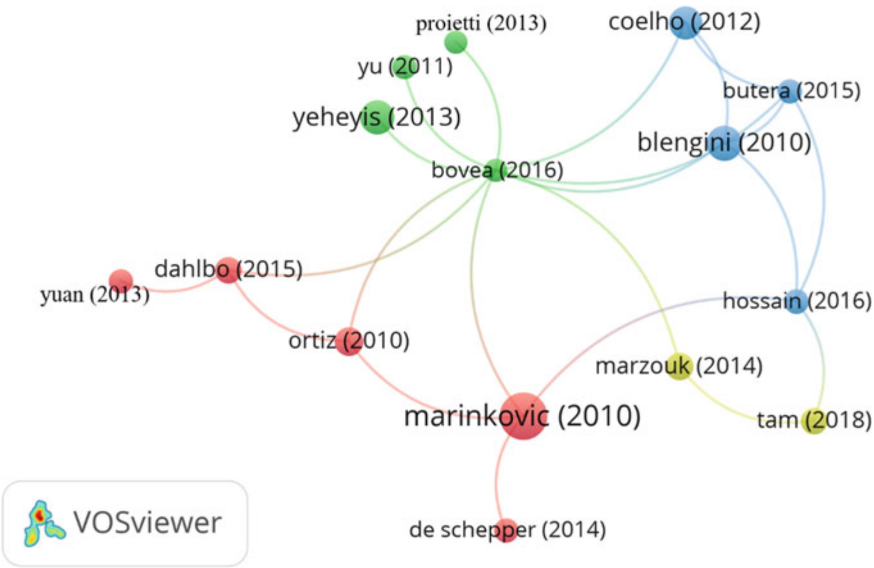

Fig. 6 Science mapping of most influential publications in C&D waste environmental impacts

Table 4 List of publications with the highest impact in C&D waste environmental impacts research

Article	Title	Number of citations	Norm. citations
Marinkovic [38]	Comparative environmental assessment of natural and recycled aggregate concrete	196	2.0
Blengini [39]	Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix	103	1.1
Yeheyis [40]	An overview of construction and demolition waste management in Canada: a lifecycle analysis approach to sustainability	101	2.3
Coelho [41]	Influence of construction and demolition waste management on the environmental impacts of buildings	90	2.5
Ortiz [42]	Environmental performance of construction waste: comparing three scenarios from a case study in Catalonia, Spain	71	0.7
Marzouk [43]	Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics	64	2.3
Dahlbo [44]	Construction and demolition waste management—a holistic evaluation of environmental performance	58	2.4
Tam [45]	A review of recycled aggregate in concrete applications (2000–2017)	56	4.0
Hossain [46]	Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA	50	2.2
Yu [47]	A future bamboo-structure residential building prototype in China: life cycle assessment of energy use and carbon emission	50	1.2
Butera [48]	Life cycle assessment of construction and demolition waste management	48	2.0
De Schepper [49]	Life cycle assessment of completely recyclable concrete	47	1.7
Yuan [50]	The evolution of construction waste sorting on-site	47	1.1
Proietti [51]	Life cycle assessment of a passive house in a seismic temperate zone	45	1.0

(continued)

Table 4 (continued)

Article	Title	Number of citations	Norm. citations
Bovea [52]	Developments in life cycle assessment applied to evaluate the environmental performance of construction and demolition wastes	43	1.9

48]; (4) Bovea et al. [52] summarized the application of LCA to evaluate the environmental performance of C&D waste management systems. In terms of average normalized citation rates, Tam et al. [45] reviewed the recycling and application of recycled aggregates and received the highest annual attention in academia.

3.6 Countries Activity Analysis

Figure 7 and Table 5 present the survey results of countries that have been actively engaged in C&D waste environmental impacts research in the past decade. These countries include developing and advanced economies, e.g. China and Australia. This study used VOSViewer to evaluate the contribution of these countries to this research area. The minimum number of documents and citations of a country set at 3 and 30. This resulted in totally 11 out of 34 countries short-listed.

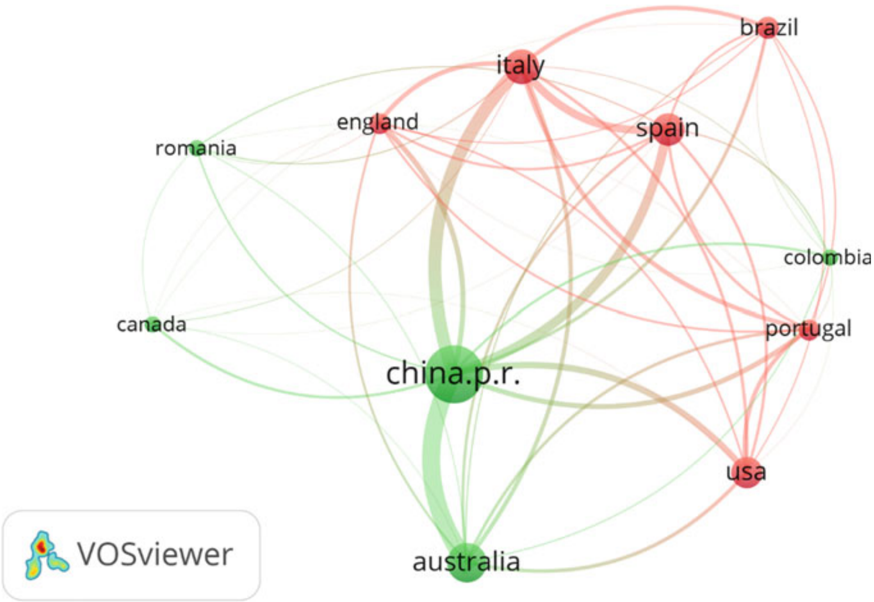

Fig. 7 Science mapping of countries activity in C&D waste environmental impacts research

Table 5 Countries activity in C&D waste environmental impacts research

Country	Number of publications	Total citations	Average citation	Ave. norm. citation
China.P.R.	42	782	19	1.2
Australia	19	327	17	1.1
Italy	15	379	25	1.0
Spain	13	261	20	0.8
USA	12	122	10	1.1
Brazil	6	105	18	1.3
Portugal	5	213	43	1.6
England	5	135	27	2.8
Canada	3	151	50	1.5
Colombia	3	80	27	0.6
Romania	3	57	19	0.4

The connection lines in Fig. 7 represent the mutual citations of studies among different countries, which can be further measured by the total link strength. According to the size of the country or region nodes and the connecting lines between the countries, it can be seen that China, Italy, Australia, Spain and USA have been contributing to the research community. Table 5 lists four methods for quantitative measurement of these countries, including number of publications, total citations, average citations and average normalized citation. Scholars from China have the highest number of publications and total citations, followed by Australia and Italy. China is faced with low recycling rate and serious shortage of landfill space in the disposal of C&D waste [54]. At the same time, the composition of C&D waste varies widely, so it is necessary to evaluate the environmental impacts of C&D waste [5]. Some countries and regions have run out of raw materials and urgently need to make secondary use of C&D waste [46]. More and more countries have begun to try to evaluate the sustainability of C&D waste from multiple perspectives. Average normalized citation shows England, Portugal and Canada create higher annual impact in research.

4 Conclusion

This review-based study in C&D waste environmental impacts adopted a holistic approach incorporating bibiometric literature search, scientometric analysis, and qualitative discussion. A total of 111 journal articles published in 2010–2019 were selected as sample literature. The annual C&D waste environmental impacts studies showed an upward trend in the number of publications. The scientometric analysis revealed the following findings:

- Influential journals that have been publishing research results on environmental impacts of C&D waste include Journal of cleaner production, waste management and resources conservation and recycling.
- Keywords analysis determined the main themes of existing research. For example, waste management, environmental impacts (e.g. energy consumption, CO_2 emission), environmental impacts evaluation methods (e.g. LCA, system dynamics), waste disposal methods (e.g. recycling, selective removal) and environmental performance of recycled products.
- Co-author analysis identified productive and influential analysis of scholars in the research community of C&D waste environmental impacts. Yuan, H. P. was considered to be the scholar with the largest number of publications and the highest number of citations per capita. V. W. Y. Tam was the scholar with the largest average annual influence in this field.
- The article with the highest number of citations since 2010 was determined, and the main research topics of these influential articles were discussed, such as compared the environmental impacts of the production of natural aggregate concrete and recycled aggregate concrete.
- The countries actively engaged in environmental impacts research of C&D waste were identified and discussed. China, Australia, Italy, Spain and USA and other countries have paid more attention to the research of C&D waste environmental impacts.

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A Review on the Driving Factors of Green Building Development Based on Subjective Attitude

Shenghan Li and Yulin Wu

Abstract In recent years, green buildings have gradually become popular to minimize the negative impact of the construction industry on the environment, economy and society. In order to encourage the widespread adoption of green buildings, it is necessary to have a better understanding of the driving factors for achieving GB. And more and more studies have shown that people's subjective attitudes play a vital role in the development of green buildings. Through a systematic review of existing literature, the driving factors that influence the development of green buildings based on subjective attitudes are comprehensively sorted out. Based on the identified sources, we divide these driving factors into two categories: external driving factors and internal driving factors. The external driving factors include stakeholder wishes, GB reputation, GB ecological value, GB economic value, etc., and internal driving factors include moral responsibility and reputation image. Based on the summary of the existing research results, the future research direction is proposed. The research results can provide beneficial reference for researchers to fully understand the current research work and provide convenience for further research in this field. Discussion of GB drivers will also allow governments and developers to better understand and implement THE GB project, thereby reducing the difficulty of implementation.

Keywords Green building · Driving factors · Subjective attitude · Review

1 Introduction

The construction industry has a negative impact on the natural environment, economy and society. Globally, the construction industry consumes 40% of total energy production, 12–16% of all available water, 32% of non-renewable and renewable

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resources, 25% of all wood, and 40% of all raw materials, produce all energy 30–40% of solid waste and 35–40% of CO_2 emissions [1, 2]. In order to reduce the negative impact of buildings and promote the concept of sustainable development, green buildings have emerged as the times require and become the life concept advocated in the construction field. Green building refers to the maximum saving of resources during the whole life cycle of the building, including energy saving, land saving, water resource saving, material saving, etc., which can protect the environment and reduce pollution, and provide people with healthy, comfortable and efficient Use space and which also can live in harmony with nature. Therefore, the implementation of green buildings provides several environmental, economic and social benefits to the construction industry. For example, the development of green buildings can improve the ecological environment to a certain extent, realize sustainable land use, protect the ecosystem, increase material reuse and recycling rate, and increase Energy efficiency, reduction of solid waste and CO_2 emissions [3]; The development of green buildings is inseparable from the active participation of stakeholders (governments, developers, technical constructors, and consumers); the key to promoting the development of green buildings is economy, Social and ecological benefits (environment); these basic conclusions indicate that the ecological, social, and economic behaviors of stakeholders may be the key to driving the development of green buildings [4].

In this study, the term "driver" refers to the motivation that encourages the adoption of GB practices, and it is defined to include both the potential benefits of GB and the decisions that motivate people to participate beyond the benefits of green implementation. An overall understanding of these drivers is critical to making GB more popular and successful.

As a new type of building, green building is not easy to be accepted in a short time due to the immature market development environment and green construction technology, long payback period of investment and insufficient public recognition of its value. These facts reflect the key issues in the current research on green building development. And more and more studies have shown that people's subjective attitudes play a vital role in the development of green buildings. Therefore, systematic analysis of the driving mechanism of green building development based on subjective attitudes and identification of key driving factors have become an urgent problem to be solved.

2 Research Method

This research is based on a systematic literature review and focusing on relevant empirical research on the driving factors for implementing GB practices in the past. Based on the definition of the development of green buildings, a highly recognized database containing "Web of Science" and "ScienceDirect" was used to search relevant literature with "green building", "Green building and influence", "Green building and Drive", "Green building and subjective attitude" as keywords.

Through systematic literature research, based on the analysis of subjective attitudes, the collection papers were analyzed according to GB drivers, and various drivers in the literature were identified according to these drivers (Table 1) and classified (Fig. 1).

Through in-depth and systematic analysis, the external and internal drivers are shown in Table 2, which are the focus of the research on the driving mechanism of green building development based on subjective attitudes.

Table 1 Summary of drivers found in the literature

No.	Factor	Reference	Frequency
1	Energy saving	[3–15]	14
2	Water saving	[3–5, 9–12, 16]	8
3	Material saving	[3–5, 10, 11, 13]	6
4	Land saving	[3–5, 10, 11, 13]	6
5	Protect environment	[3–5, 10, 12, 13, 17]	7
6	Indoor comfort	[3–5, 10, 13, 18–20]	8
7	Improve operation management	[3–5, 19]	4
8	Green building certification	[3–5, 21–25]	8
9	Improve work efficiency	[26–30]	5
10	Living healthy	[26–30]	5
11	Moral responsibility	[24, 26, 27, 31–33]	6
12	Reputation image	[26, 31–33]	4
13	The market demand	[4, 26, 27, 31, 32]	5
14	Public perception	[14, 24, 26–28, 31, 34–36]	9
15	Green building premium	[4, 5, 12, 23, 31, 37, 38]	7
16	Incentives method	[3, 4, 23, 24, 26, 31, 39]	7
17	Life cycle cost	[4, 10, 17, 30, 40–42]	7
18	Government regulations and policies	[3, 4, 12, 21–24, 26, 31, 37, 39, 43]	12
19	Public attitudes	[12, 26, 27, 31, 33, 37, 44–47]	9
20	Green building advertising	[26, 34, 35]	3
21	Marketing tool	[15, 26, 31, 32]	4
22	The enterprise culture	[23, 26, 31, 32, 48]	5

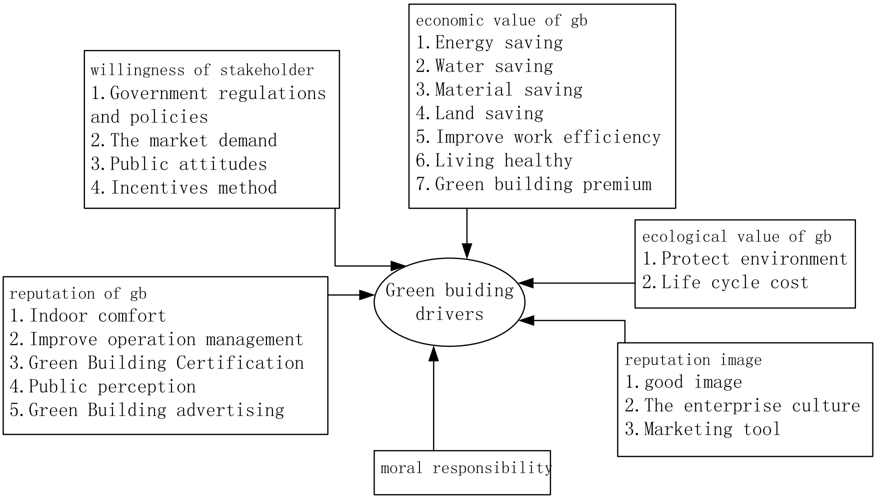

Fig. 1 Classification of CB drivers

Table 2 GB drivers identified from the literature based on the analysis of subjective attitudes

Category	Serial	Factor
External driver	1	Willingness of stakeholder
	2	Reputation of GB
	3	Ecological value of GB
	4	Economic value of GB
Internal driver	1	Moral responsibility
	2	Reputation image

3 Review GB Drivers

3.1 External Driving Factor

The external driving factors for the development of green buildings are mainly divided into the willingness of stakeholders, GB reputation, GB ecological value and GB economic value. Stakeholders can be defined as individuals or groups who are interested or concerned about specific issues [26]. The adoption and development of GB involves many stakeholders. Although these stakeholders and their relationships are different, their coordination, leadership and sense of responsibility have a vital impact on the development of GB. Research shows that the stakeholders most affected by GB's driving factors are architects, developers, consumers, construction units, government and green material suppliers. The establishment of GB reputation is mainly determined by GB's green mark recognition, GB's living experience and GB popularity. GB's green mark recognition can be regarded as the recognition of

GB rating system. In addition, GB ecological value and GB economic value are obvious external driving factors that cannot be ignored.

3.1.1 Willingness of Stakeholder

Architects are important stakeholders in GB development because they are the key decision makers in determining the type of materials to be used [24]. They develop the design of the green project, make specifications and drawings, and ensure that the project is implemented within the scope of time, cost and quality control [34]. In addition, architects play a key role in educating customers and recommending green materials to customers [35]. The construction company is also responsible for converting the green design into GB, ensuring safety and quality, and minimizing resource consumption during the construction process to protect the environment [35]. The extent of achieving this goal directly affects the quality of GB products. The main factors affecting the willingness of architects and construction units are their environmental awareness, social responsibility and self-identity [49, 50].

As suppliers do not want to invest in green material innovation and new product development, we are faced with a lack of green materials when implementing green building projects. However, studies have shown that the cooperation between developers and green material suppliers can ensure the quality and performance of construction products, and provide discounted prices to purchase materials and increase the possibility of innovative materials. According to the report, some leading developers in China have begun to cooperate with suppliers forming strategic partnerships, and found good benefits from such cooperation. According to the list of green suppliers released by developers Franshion and Vanke, green material suppliers can provide them with more alternatives and meet their needs in terms of quantity and quality [51]. In addition, the government's requirements for suppliers to comply with relevant carbon emissions and environmental policies also have a great impact on their willingness [52].

Developers have full decision-making power to select appropriate green building technologies and materials according to cost, quality and schedule [40]. Although green building development is closely related to social, economic development and environmental issues, cost and economic benefits are at the core of developers' decision-making.

A large amount of literature has studied the government's policies aimed at developers to expand the green building development market.

The government has an important influence and leadership role in promoting the development of green buildings [32, 53]. For example, in China, the government is adopting multiple policies and specific plans to build green buildings [54]. However, the initial cost is an obstacle preventing developers from developing green buildings [27, 41]. In the current macroeconomic environment, most developers need a payback period of 7–20 years [39, 54], and it is difficult for developers to invest additional funds [3]. The argument that green building premiums can offset its high initial cost is still under debate and is still inconclusive [38]. Therefore, to reduce cost barriers, the government provides incentives, such as subsidies or incentives, to overcome economic barriers [55].

However, the government also uses stricter orders when incentives are neither sufficient nor effective. As Gordon [56] has observed, green practices are becoming a mandatory way for all construction projects rather than an option. Because green buildings are becoming the only construction method accepted by the government [57]. Therefore, it is expected that in the short term, government incentives will only be provided to willing green building developers in the future. And those developers who are backward and resistant will face the negative consequences of regulations and violations [58], and the construction industry will generate a real green structure in the government's mandatory and incentive policies [39].

And more and more studies have shown that market demand and consumer willingness play a vital role in the development of green buildings.

Through case studies and semi-structured interviews, Arif et al. investigated the main driving factors and challenges of implementing waste management in construction projects, indicating that consumer demand and regulations are the most important driving factors [59]. In addition, in a British study, most architects believe that the first driving factor for sustainable construction is customer demand, and customer demand ultimately determines the degree of green building development [49].

The needs and willingness of customers ultimately determine the extent of GB development. Customer needs are closely related to issues such as knowledge, supply, value, and cost [60]. To increase the market demand for green buildings, we must first understand consumer expectations and preferences for green buildings.

Hu et al. used the discrete choice model to evaluate the willingness to pay for green houses of different social groups in Nanjing, and the results showed that the socioeconomic status of house buyers determines their purchasing power and willingness to pay for green houses, and only consumers with good economic conditions are more willing to buy Green houses to improve their living comfort [44].

Zhao et al. studied the public's acceptance and support for green buildings through questionnaire surveys, and proposed that green buildings should not only be oriented toward energy efficiency improvement, but also be people-oriented. This means that humane care for users should be considered in the concept of green building, planning and design, operation and maintenance, etc., in order to improve the happiness and productivity of users [33].

Some scholars pointed out that because of the information asymmetry in the green building market, if more product information is provided to the public to make the public better understand the overall concept of green buildings, it may increase the acceptance of green buildings. Therefore, publicity and education of the public on green buildings will become an important force to increase market demand [61].

Research by Zhang et al. found that consumers' sources of information about green buildings mainly come from developers' publicity and government official information (certification of the green building evaluation standard system), but about 90% of the respondents know little about the green building certification system. The main source of information comes from the developer's advertising [28].

Due to the information asymmetry between developers and consumers, this uncertainty will reduce the willingness of buyers to pay for green buildings. Therefore, official information plays an important role in overcoming market information asymmetry and promoting the development of green buildings.

Zheng et al. used Google search to create an index model to evaluate the green marketing strategy of real estate projects in Beijing, and found that the premium obtained by green real estate projects in the pre-sale period will be greatly reduced when they resell or sublet, which is due to the asymmetry of market information [62].

On the one hand, consumers may overestimate the energy saving performance of green buildings during the pre-sale period, and the actual energy saving after living is lower than expected. On the other hand, it may be because developers only take green publicity as the marketing strategy, but do not adopt the actual green building technology, leading to more energy consumption in the later period. Wong pointed out that in order to effectively improve the market penetration of green buildings, it is necessary to increase the environmental awareness and understanding of green buildings among green building stakeholders [63].

The main stakeholders and conclusions are shown in Table 3.

3.1.2 Reputation of GB

In practice, GB certification is usually completed through the GB rating system, which provides guidance for the measurement of sustainability levels and strengthens the commitment to best practice experience [64]. The GB rating system incorporates sustainability principles into construction practices. Its main role is to use a set of universal and verifiable standards and targets to achieve higher environmental quality for building owners and designers, in order to "comprehensively evaluate the environmental characteristics of buildings" [13].

A systematic and complete green building evaluation system includes evaluation content, evaluation methods and evaluation systems. In terms of evaluation content, the green building evaluation system has similarities. They all take environmental sustainability as the main evaluation content. More and more scholars have proposed that the green building evaluation system should consider economic and social sustainability. Social sustainability means that all stakeholders (such as construction personnel, users, and operators) should be considered in the construction process, and a healthy and safe environment should be provided for them.

Valdes-Vasquez and Klot believe that the content of social sustainable development indicators includes end-user stakeholders, evaluation of the social impact of construction projects and local communities [65].

Sarkis puts forward a sustainability-oriented framework for contractor selection and evaluation by embedding relevant indicators of social sustainability into the LEED framework [66].

Table 3 Research summary of willingness of Stakeholder

Stakeholder	Conclusion	References
Architectural designer	Architects' controlled items in a green building project account for 36% of all architectural designs, and their willingness are mainly influenced by self-identification and social responsibility	[24, 34, 35, 50]
Developers	Developers' willingness is the main driving force of GB market development, which is mainly affected by policies and costs	[3, 27, 28, 38, 40, 41, 56–58]
Construction unit	In the construction process, the construction units minimize resource consumption to protect the environment, and their willingness is mainly affected by social responsibility and commitment	[35, 49, 50]
GB materials supplier	Suppliers do not want to invest in green material innovation and new product development, but cooperation with developers and government policies can promote their wishes	[52]
Consumers	The demand and willingness of customers ultimately determine the development level of GB. The green building market is characterized by information asymmetry, and this uncertainty will reduce consumers' willingness to pay for green building	[28, 33, 44, 49, 59–63]
Government	It plays a key role in guiding the spread of green buildings through the use of mandatory laws and incentive economic policies	[3, 32, 52–58]

Berardi pointed out that green buildings need to meet the standards of social and economic sustainability, including education, ability to pay, economic value, indoor health, cultural perception, etc. [2].

In terms of assessment methods, since 1990, Life Cycle Assessment (LCA) has been widely used in the environmental impact assessment of green buildings. The whole life cycle assessment method can be applied to the entire building or individual components or materials to assess the impact of the building on the environment, thereby improving the architectural design [42].

Some scholars have conducted empirical research on green building evaluation using the whole life cycle assessment method.

Mahlia et al. carried out a full life cycle cost estimation in a university lighting renovation project in Malaysia, and the study found that the lighting renovation project helped to reduce energy consumption by 17–40% [67].

Regarding the green building certification system, some scholars believe that the certification process of the green building evaluation system takes a lot of cost and time. Therefore, the green building evaluation system needs a transparent, fair and open certification system, as well as professional certification personnel and detailed certification guidance [68]. The US Green Building Evaluation System (LEED) adopts third-party certification and is operated by well-trained professionals. Evaluators actively cooperate with stakeholders to optimize the certification process of green buildings.

Jang et al. conducted experiments based on vignette to study the impact of building green building certification on the willingness of potential tenants to rent. The results show that green building certification increases the willingness of potential tenants to rent; however, a higher certification level does not further increase the willingness of potential tenants to rent, which shows that considering the cost of improving the building to obtain a higher certification level, a lower level is obtained May be a good strategy [25].

A very important aspect of GB's living experience is the indoor environment quality of GB. How to ensure a good living experience in buildings while meeting sustainable development and saving energy is an important issue. The indoor environment indicators include indoor air quality, thermal environment, light environment and acoustic environment under the ISO classification framework of sustainability indicators.

Lu et al. used 12 high-star green buildings in cold areas, taking hot summer and warm winter areas (HSWW areas) as the research objects to evaluate their indoor thermal comfort. The results showed that the indoor temperature and humidity of most buildings did not reach the standard, and the degree of deviation was different, but users were generally satisfied with the indoor environment. A modified model of human subjective thermal sensation in air-conditioned rooms of green buildings in China is proposed to make the objective indicators of PMV better reflect the real subjective sensations. Helps improve local standards for indoor temperature and humidity ranges [18].

The study by Du et al. showed that in terms of indoor environmental quality and occupants' environmental satisfaction, green shopping malls are superior to ordinary shopping malls. Objective measurement results show that the green shopping center building is superior to the traditional shopping center building in terms of relative humidity, illuminance, carbon dioxide concentration and sound level (especially indoor illuminance) [19].

Lee et al. concluded that residents in buildings with green signs are more satisfied with indoor environmental quality than ordinary buildings, especially air quality, temperature, lighting level, indoor environment and humidity. And residents in buildings with green signs are at significantly lower risk of experiencing building-related acute health symptoms (such as skin irritation, abnormal fatigue, and headaches) than residents in ordinary buildings [20].

In response to few studies verifying that POE based on one-time data collection is still effective in modern buildings, Joon-HoChoi conducted four different POE studies in two commercial office buildings in Southern California, USA: Choose between two buildings 189 independent workstations, repeated environmental satisfaction surveys and on-site measurements in 4 seasons, taking into account seasonal and daily factors [69]. The study found that human factors such as gender and age lead to inconsistent environmental perception, depending on the season or month, which requires multiple data collections to provide powerful environmental design solutions and improve the environmental comfort of building occupants degree.

Wongbumru et al. used the post-evaluation method of questionnaires to analyze 740 questionnaire responses from Klong Chan Fla (old project) and Buengkum Baan Eur Arthron (new project) to understand residents' satisfaction with existing conditions. The research results show that residents' satisfaction with new projects is higher than that of old projects. The information provided by the results of this questionnaire will help improve future housing projects, or will enable stakeholders (such as the National Housing Administration) to determine ways to improve the quality of life of residents and the sustainability of new housing development [70].

3.1.3 Ecological Value of GB

GB ecological value mainly refers to the ecological benefits brought by green building entities, such as the ratio of energy saving per unit area (CO_2 emission reduction), water saving ratio, land saving ratio, material saving ratio, domestic waste reduction ratio, and indoor environment health and comfort etc. The effective embodiment of the ecological value of green buildings is the key to driving the development of green buildings.

Construction activities have an irreversible impact on the natural environment. According to statistics, during the entire life cycle, the construction sector contributes about 50% of global final energy consumption and 42% of global greenhouse gas emissions [17]. People are beginning to pay attention to the greening of the construction industry, hoping that the construction industry will reduce its impact on the environment.

Research by Chau C.-K. et al. shows that both green residents and regular residents have strong preferences and are willing to pay more for improving the environmental performance of all aspects of green housing development. They found that they are willing to pay more for energy conservation, improve indoor air quality, reduce noise levels, expand landscape area or save water. There are no significant differences in preferences between green residents and traditional residents in terms of energy saving, indoor air quality improvement, indoor noise reduction or water saving. However, it is found that green residents are willing to pay significantly more than ordinary residents to expand energy savings [45].

Park M. et al. used two methods: conjoint analysis and ranking method to determine preferences for environmental factors of residential buildings. Attempt to determine the monetary value of consumers in terms of environmental performance by testing consumers' marginal willingness to pay (MWTP). A survey was conducted in Seoul, South Korea to clarify the preferences and monetary value of four selected attributes representing environmental performance. These attributes include reducing energy costs, reducing CO_2 emissions, reducing volatile organic compound emissions, and the application of information technology facilities. The results show that the MWTP emissions of 1% CO_2 reduction are estimated to be about US$377, which is twice as much as the reduction of VOC emissions, which is almost the same as reducing energy costs. In the ranking, energy costs are the highest priority, and IT facilities are ranked last [46].

Devine and Kok compared and analyzed the difference in residential satisfaction of tenants in green buildings and non-green buildings, and found that the satisfaction of tenants in green buildings was 4% higher than that in non-green buildings [36]. For owners of green commercial buildings, this means less tenant turnover, lower vacancy rates and sustained investment returns.

3.1.4 Economic Value of GB

Economic value mainly refers to the economic benefits brought by green building entities. By improving investment efficiency, reducing the incremental investment and vacancy rate of green buildings, shortening the investment payback period, reducing the cost of the whole life cycle, fully reflecting the economic value of green buildings, and promoting regional economic development.

Compared with traditional buildings, green buildings have greater market demand, higher consumer willingness to pay and lease value. For developers who focus on profitability, the market prospects of green buildings are quite attractive. Green labels can differentiate their products and achieve market premiums, helping to bring developers more profit.

Kahn and Kok studied the impact of providing building energy efficiency information on consumers' choice of sustainable housing, and found that houses with green labels have a market premium over other houses without green labels. From the perspective of the developer, more energy-efficient houses in the same area may generate economies of scale [71].

Cathy Turner et al. studied the operating energy consumption of 121 LEED-NC certified buildings (based on office buildings). The results showed that only 30% of the buildings' energy savings exceeded expectations, while 25% of the energy savings were lower than expected, and the energy consumption of some buildings was even higher than the standard reference value. There is no significant difference in energy consumption between buildings of different levels of LEED certification [14].

Researchers from the Canadian New Building Association selected 121 new LEED buildings that can provide energy consumption data for more than one year, and evaluated the energy efficiency of the buildings from the following three aspects: energy efficiency comparison between LEED buildings and ordinary buildings, energy EnergyStar scores, design models and benchmark models of LEED buildings. The research conclusions include that LEED-certified buildings have basically achieved the expected environmental protection and energy-saving effects; the same performance indicators of different buildings are widely distributed, and it is necessary to propose improvement suggestions for buildings with problems; LEED's benchmark building energy efficiency standards are not applicable to the energy efficiency standards expected by the industry; LEED certification standards need to be further improved.

In addition to the economic value of building energy and building prices, green buildings also have an impact on improving labor productivity.

Edwards inspected the green office spaces of the British government and enterprises and found that such buildings can increase labor productivity and enhance the competitiveness of enterprises. For example, when the productivity of corporate employees in the green office of a large company increases by 3%, the increased benefits can cover the annual energy costs of building lighting and heating [29].

Ries et al. proposed that the economic benefits of green buildings in improving productivity and reducing absenteeism should not be ignored. They found that when employees move from conventional buildings to green buildings, productivity will increase by 25% and absenteeism will be significantly reduced [30].

Due to the positive impact of green buildings on human aspects such as health and productivity, project owners are inherently or internally encouraged to develop green buildings.

3.2 Internal Driving Factors

3.2.1 Moral Responsibility

An inherent motivation for promoting the development of green buildings is the concept of pro-environmental behavior based on altruism or personal ethics and values [47].

Aliagha et al. believe that the development of green buildings by construction project owners may not be entirely due to the benefits of energy saving and cost savings, but due to an altruistic belief. That is, climate change and its impact on humans and the environment are real, and they can take actions to reduce the impact on the environment [72].

Olanipekun conducted a survey of 150 green certified experts (GSAPs) to study the motivation of developers to build green building projects and found that in addition to the economic or non-economic incentives provided by the government, and external driving factors such as market attractiveness, for green building developers, internal driving factors are often more important, including developers' values, environmentalism, and advocacy of sustainable development methods. Therefore, the formulation and implementation of government policies should focus on stimulating developers' environmental awareness to increase developers' motivation to participate in green building practices [73].

Mulligan and others pointed out that enterprises, non-profit organizations and educational institutions are the leaders in the promotion of sustainable development in the market. Their vision is to reduce carbon emissions and improve energy efficiency, and increase public awareness of sustainable building technologies and practices [74].That is to say, the stakeholders of green building projects must not only bear the responsibility of protecting the environment, but also cannot ignore the social and economic impacts [75].

3.2.2 Reputation Image

Gaining a sense of identity and improving reputation in society is another intrinsic driving factor for green building practices. The competitive and complex business environment has affected the way companies operate, and establishing a good image and reputation has become a necessary condition for companies to survive in the industry. With the continuous improvement of the level of technological progress, information about abuse of power and irresponsible behavior can easily be disseminated, making companies pay more attention to their own reputation and image.

Zhang et al. conducted a case study on green housing projects in my country and found that developers believe that the development of green housing can reduce construction and operating costs, obtain favorable land prices and more financing channels, and improve the reputation of corporate green brands [76].

Li et al. used qualitative analysis methods to conduct a comprehensive analysis of media articles on 24 green buildings approved by the Australian Green Building Council (2004–2011). It is found that "the lofty image among competitors" is the core driving force of Australian university decision makers to implement green building projects [15].

Andelin et al. investigated the driving factors of tenants and investors in the Nordic countries for accepting sustainable buildings, and found that the most significant driving factors for these two stakeholder groups are real estate corporate image and culture [48].

A recent study in South Africa showed that a good public image is the most important driving factor for construction companies to implement green construction projects [77]. By promoting their green image, real estate companies can be more competitive in the market, gain greater product demand and higher profit potential.

Green building can be further embodied as a company's commitment to social responsibility. By assuming this social responsibility, real estate companies can enhance their image. Social responsibility is an important factor that affects the competitiveness and image of real estate companies. More and more real estate companies are beginning to attach importance to social responsibility, trying to build their own reputation and maintain the competitiveness of the industry. Many leading real estate companies actively disseminate and practice the concept of green and low-carbon real estate, which enables them to obtain a large amount of media publicity, thereby shaping a good corporate brand and realizing corporate differentiated value [78].

The implementation of green building practices can not only help real estate companies achieve high-level environmental performance standards, but also help achieve sustainable social development and enhance their attractiveness to customers. Therefore, the social responsibility of real estate companies has become a key driving force for companies to develop green buildings [79].

4 Conclusion

Through systematic review and collation of relevant research literature, this paper establishes an analytical framework from both external and internal dimensions, and carries out a literature review on relevant research from six aspects: stakeholders' will, GB public praise, GB ecological value, GB economic value, GB moral responsibility and reputation image. Through analysis, it was found that:

- Among the stakeholders, architects are important stakeholders driving the development of GB because they are the front end of the construction industry. In a typical green building design, the controllable items of the architect account for 36% of all building designs. The market demand and consumer will play a vital role in the development of green buildings. The needs and wishes of customers ultimately determine the extent of GB development. There is information asymmetry between developers and consumers, and this uncertainty will reduce the willingness of buyers to pay for green buildings. The main stakeholders of green building are interrelated and interact with each other. A government-led green building market has been formed, and the relationship between them is shown in Fig. 2
- The establishment of GB reputation is mainly determined by the recognition of GB rating system, the living experience of GB and the popularity of GB. Regarding the green building certification system, the certification process takes a lot of cost and time. In terms of indoor environmental quality and occupants' environmental satisfaction, certified buildings are superior to ordinary buildings.
- People are willing to pay more for improving the environmental performance in all aspects of green housing development. For the ecological value, people pay more attention to energy conservation. The economic value of green buildings is mainly reflected in: (i) The differentiation of green labels and non-greens has achieved a market premium; (ii) Energy saving; (iii) Reduced vacancy rate; (iv) Impact on improving labor productivity.
- The internal driving factor is mainly the unconstrained behavior of the stakeholder groups out of their own will. The environmental-friendly concept of construction companies promotes the construction and supply of green buildings, and establishes a good brand image through green building products at the same time, it provides people with a healthy and comfortable environment to improve the health of residents and the productivity of employees.

In addition, the following suggestions and future research directions are put forward:

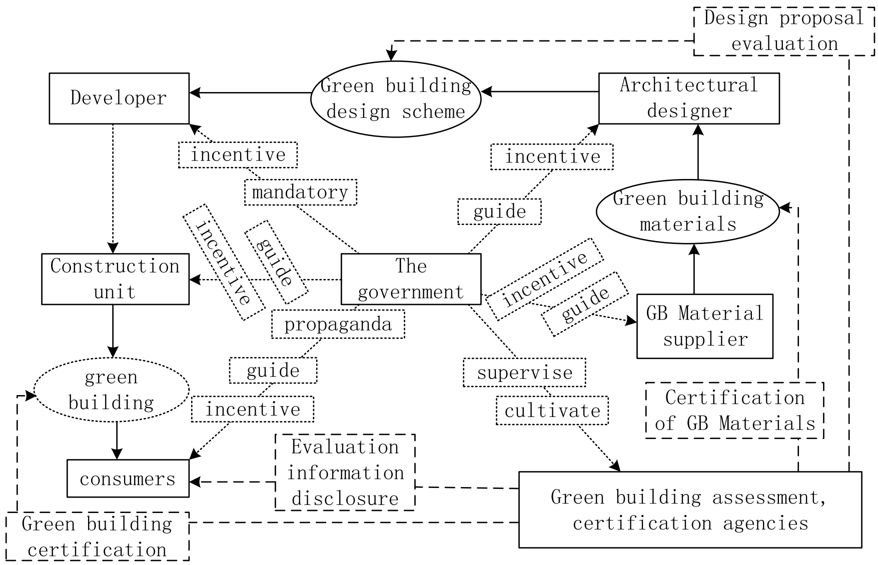

Fig. 2 Stakeholder relationships

- The government can help establish a trust mechanism in the green housing market, so that consumers can identify real green real estate and purchase them. More profits will also promote relevant development by developers. Thereby, the healthy development of the green housing market will be realized.
- The green building evaluation system needs a transparent, fair and open certification system, as well as professional certification personnel and detailed certification guidance.
- The research on green building driving factors in this article does not limit specific countries or regions, but due to differences in their respective economies, culture, society, etc., the driving factors and their degree of influence of green buildings in different countries or regions are different. Further research is needed.
- The external and internal driving factors of green buildings are related, and how to promote the further development of green buildings through the interaction of external and internal driving factors needs to be studied in depth.

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A Holistic Review of the Emerging Advanced Technologies in Prefabricated Construction Management

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Abstract Emerging advanced technologies (EAT) have been regarded as significant technological innovation which will greatly help transform the construction industry and they have been adopted widely in the prefabricated construction. As the research on emerging advanced technologies in the management of prefabricated construction (MPC) has not been involved, various researchers require a state-of-the-art summary of EAT research and implementation in the MPC field. The purpose of this paper is to provide an objective and systematic summary of advance EAT by analyzing published EAT research in 10 leading journals during period from 2009 to 2019 in terms of the annual number of EAT papers, contributions of authors and countries, and research interest. Through a thorough review of selected papers from the state-of-the-art academic journals in the construction industry, the EAT research in the MPC field is reviewed and summarized. This study is of value in offering useful and original insights to summarize the advance status quo of EAT knowledge, helping researchers in related fields gain an in-depth understanding of underlying structure of EAT in the MPC and allow them to continue from the findings of studies.

Keywords Emerging advanced technologies · Prefabricated construction · Construction management · Literature review

1 Introduction

EAT refers to a series of cutting-edge technologies developed in the twenty-first century, characterized by technological convergence, in which previously different technologies gradually share resources to accomplish similar tasks, such as the interaction of original voice, data and video technologies to create more efficient new technologies. Prefabricated construction is the current characteristic and future development trend of the construction industry. As there are multiple 'information islands' among construction project participants, the efficiency and level of prefabricated

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construction management are low. The core function of EAT is to provide users with the ability to integrate, analyze, exchange and share a great deal of information in the MPC. Previous research had involved the terms and acronyms of various innovative technologies related to prefabricated construction management, including BIM, RFID, Internet of Things (IoT), Big Data, Blockchain, and modular construction technology, to name a few. By take advantage of EAT, the design, production, transportation, and installation of components will become more real-time, dynamic, efficient, and intelligent, greatly saving labor, time, and funds, and ultimately improving the benefits of prefabricated construction projects, and it is technically possible to exchange and share a large amount of information in the process of the MPC in real time, accurately and efficiently, which improves the level and efficiency of the MPC and promotes the traditional MPC to the transformation of industrialization and informatization. EAT as a series of innovative management technologies that promotes the transformation of prefabricated construction management from traditional, outdated and inefficient to advanced, intelligent and efficient, has attracted great attention from many countries over the past decade. However, the content analysis and research of the existing literature appear to be inadequate, preventing researchers from grasping the overall evolution of research in this field. A systematic visual scientometrics analysis of previous publications related to EAT research in the MPC can greatly contribute to a comprehensive understanding of the topic and stimulate subsequent research into the EAT in the MPC.

Despite the significance of the research review, no such work has been carried out in the MPC field of EAT. Furthermore, a critical review and knowledge map of the existing literature can improve our understanding of the application and development of EAT in the MPC. Therefore, this article has carried out a series of content analysis on academic papers published from 2009 to 2019, including an investigation of the current research status and a forecast of future research trends. To facilitate the development and implementation of EAT in the MPC discipline, the objectives of this study are to: (1) identify which authors, and countries are major contributors to EAT research in the MPC; (2) explore keywords knowledge domains; (3) analyze the current research status of this field; (4) provide a framework for exploring the future research direction in this field.

By systematically reviewing and summarizing the emerging technologies used in the existing MPC, this literature review can provide advanced knowledge for the EAT discipline in the MPC and identify the general research direction of the discipline in the future, helping the researchers to a great extent.

2 Research Method

This research is conducted as a systematic review, which is a repeatable process that documents all existing MPC research related to the EAT thematic area or specific research issues related to the EAT discipline. To the objectivity and systematization of the review, this research is conducted mainly by the following methods.

2.1 Selecting Mainstream Academic Journals and Papers

The authors of this research used the Web of Science (WoS) search engine frequently used by researchers, especially new researchers to identify major journals and papers on EAT research related to the MPC that had been published between 2009 and 2019. Furthermore, for storing information about the author, title, source publication, year of publication, abstract, and so on of all articles, Endnote, a bibliographic management tool, was used to save search results from the database, as well as remove duplicates and irrelevant articles. The workflow of the literature search for this study is shown in Fig. 1.

As shown in Fig. 1, the workflow of the literature search takes five steps to achieve the goal of each corresponding step. By sorting and summarizing the selected articles, it is found that ten journals, namely, *Automation in Construction* (*AIC*), *Procedia Engineering* (*PE*), *Journals of Clear Production* (*JCP*), *Sustainability*,

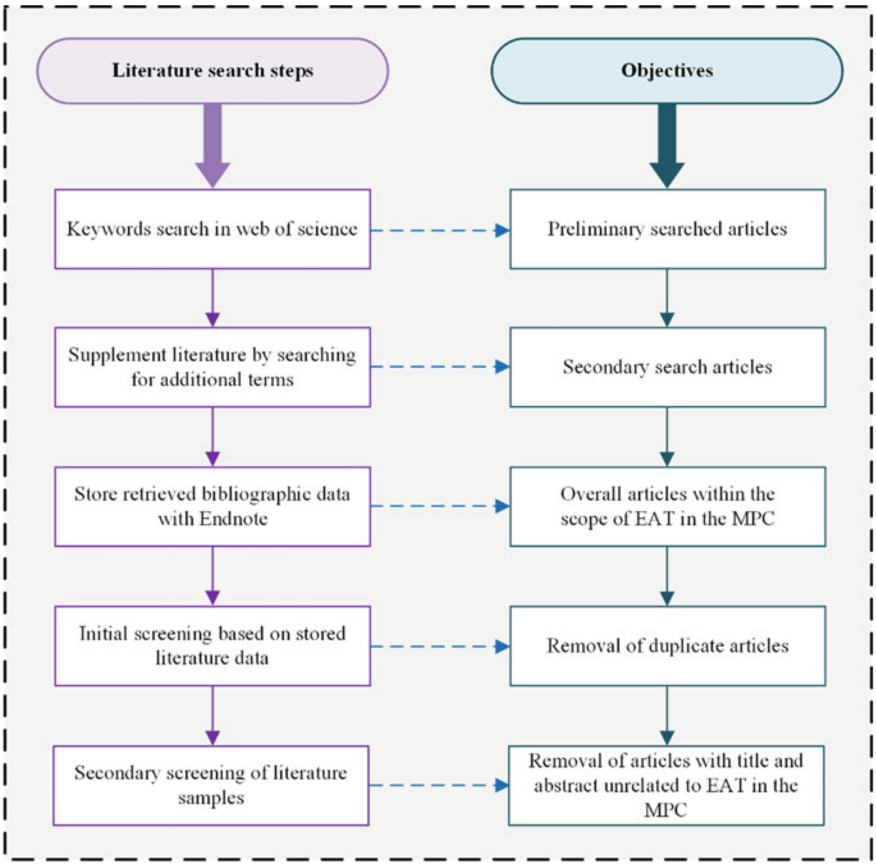

Fig. 1 The workflow of the literature search for this study. Adapted from [1]

Journals of Construction Engineering and Management (*JCEM*), *Energy Procedia* (*EP*), *Energy and Buildings* (*EB*), *Buildings*, *Construction and Building Materials* (*CBM*), and *Energy* have published at least three articles related to EAT research in the MPC from 2009 to 2019. Furthermore, seven of the ten journals, that is, *AIC*, *PE*, *JCP*, *Sustainability*, *JCEM*, *EP*, and *EB* were widely considered by the research community as the top core journals in the field of civil construction, guaranteeing the rigor and authority of EAT research in the MPC.

2.2 Comprehensive Data Analysis of Literature Samples and Selected Journals

To gain an in-depth understanding of the major research points and analyze future research directions and trends in this domain, an overview of the literature sample (including, distribution of papers published on EAT related to the MPC per year from 2009 to 2019, distribution of publications published in 10 leading journals.), co-occurrence of keywords, co-authorship analysis, and countries actively engaged in EAT research related to the MPC were quantitatively assessed and analyzed by adopting the approach of [1, 2]. In the first section, the method of bibliometric analysis is mainly used to collect data for quantitative analysis. For the remaining three sections, VOSviewer is used to perform scientific mapping and export data for analysis.

These methods can determine the current research status of EAT research in the MPC and which countries and authors are the main contributors in this field, assisting subsequent researchers in advancing the research in this field.

3 Results and Analyses

Based on the above narrative and analysis, the chapter is divided into five sections. The basic framework of this chapter is shown in Fig. 2.

3.1 An Overview of the Literature Sample

This section mainly studied and analyzed the annual publication distribution of EAT research in the MPC from 2009 to 2019, the publication quantity of leading journals.

Distribution of publications per year during the period from 2009 to 2019 are shown in Fig. 3, and publications published in leading journals are displayed in Table 1.

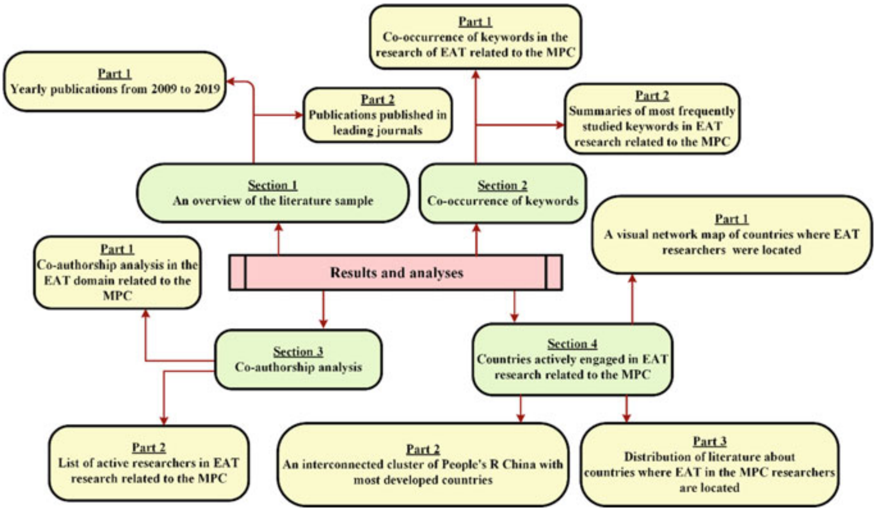

Fig. 2 The framework of results and analyses

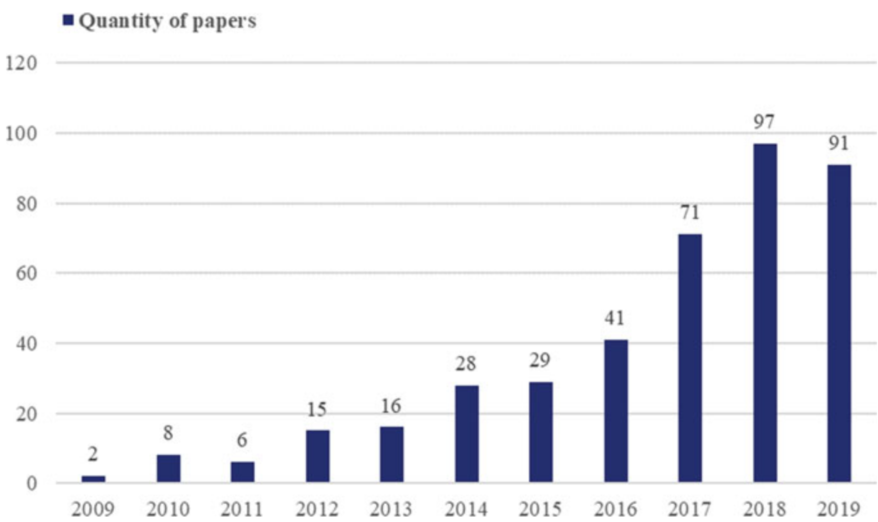

Fig. 3 Yearly publications from 2009 to 2019

Figure 3 shows the overall growth trend of publications from 2009 to 2019. According to Fig. 3, the past decade can be further divided into three periods: (1) from 2009 to 2013, the number of EAT publications in the MPC was still low with less than 20 journal articles published annually in Web of Science; (2) 2014 to 2016 when the number of publications had been significantly increased compared to previous years with more than 20 papers; (3) the yearly number of academic publications has been

Table 1 Publications published in leading journals

No.	Leading journal	Quantity	Total cited time	Time per paper
1	Automation in Construction (AIC)	130	3498	26.91
2	Procedia Engineering (PE)	39	150	3.85
3	Journal of Cleaner Production (JCP)	21	336	16.00
4	Sustainability	21	121	5.76
5	Journal of Construction Engineering and Management (JCEM)	20	175	8.75
6	Energy Procedia (EP)	17	201	11.82
7	Energy and Buildings (EB)	15	487	32.47
8	Buildings	10	188	18.80
9	Construction and Building Materials (CBM)	10	100	10.00
10	Energy	7	155	22.14

soaring to 71 or more since 2017. As a consequence, based on this current trend, it is expected that the research output of EAT in the MPC would continue to grow in the next few years. After the above analysis, the authors collected data on the number of publications and citation status of the selected leading journals and obtained the following Table 1.

As shown in Table 1, the top-ranked journals in terms of the quantity of publications include: *AIC* (130), *PE* (39), *JCP* (21), *Sustainability* (21) and *JCEM* (20), indicating that *AIC* is the journal with the largest output of publications in EAT research related to the MPC. Furthermore, according to the total cited time, *AIC* was the most frequently referred journals, reaching a maximum of 3,498 times, followed by *EB* (487 referrals), *JCP* (336 referrals) and *EP* (201 referrals). However, the average cited time per paper is generally regarded as an important indicator to evaluate the influence per publication. Therefore, regarding article citations, the articles in *EB* were the most cited (32.47 times per paper), whereas those in *AIC*, *Energy*, *Buildings*, *JCP*, *EP*, *CBM* had been cited 26.91, 22.14, 18.80, 16.00, 11.82 and 10.00 times, respectively.

3.2 Co-occurrence of Keywords

'Keywords represent the key contents of existing research and depict the areas studied within the boundaries of a domain. A network of keywords shows the knowledge in terms of relationships, patterns, and intellectual organization of research themes' [1]. In the output, initially 50 out of 1489 met the threshold. Within these 50 keywords, some keywords with semantically consistent meaning were combined, for example, "Off-site construction" and "OSC", "BIM" and "Building Information Modeling", "Construction" and "Building" and so on. Finally, a total of 37 main keywords were shortlisted and visualized in Fig. 4.

It can be found from Fig. 4 that there are eight clusters in total and prefabrication was the most frequently mentioned research keyword. Other keywords that most frequently co-occur prefabrication with include modular construction, BIM, construction, sustainability, innovation, internet of things, Hong Kong, and China, etc. The clusters and connecting lines between keyword nodes in Fig. 5 show these main research areas in EAT related to the MPC: (1) EAT in the MPC has often being linked to BIM, which is in the same cluster with digital construction, Hong Kong, Internet of Things, literature review, prefabrication, RFID; (2) EAT in the MPC does not simply refer to modular construction [3, 4], but involves China, off-site construction [5], supply chain management [6], project planning and design [7], and automation [8]; (3) EAT in the MPC is also widely used in prefabricated construction for construction management [9], quality control [10], simulation [11], and lean construction [12]; (4) point cloud [13], machine learning [14], are used in the construction progress monitoring [15], and quality control [16] of prefabricated construction; (5) literature review has been one of the main research methods in investigating EAT related to the MPC; (6) several countries or regions have been active in researching EAT related to the MPC, including Hong Kong (China), and China. Quantitative measurements of keywords are further summarized in Table 2.

As keywords are related to the core content of the publication, keyword analysis can help to identify key research topics in EAT research related to the MPC. It can

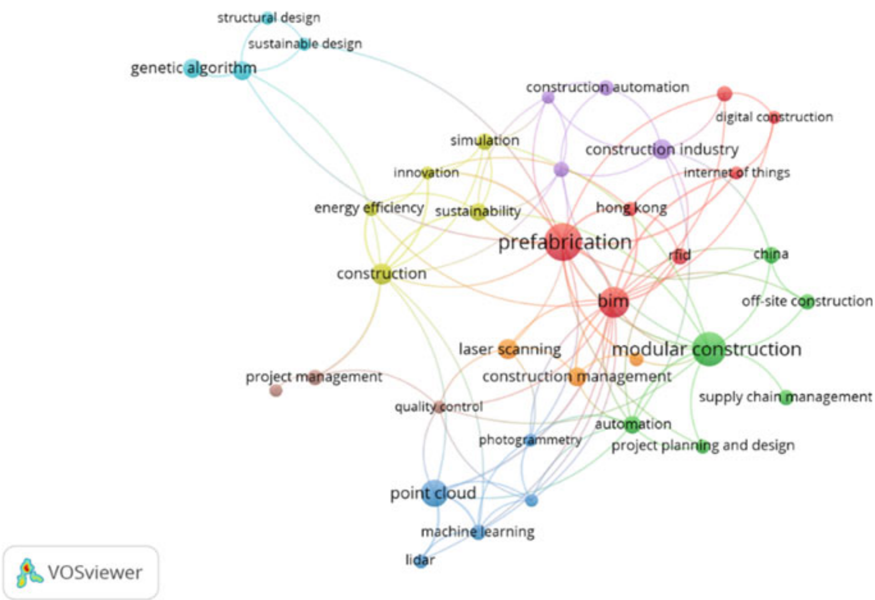

Fig. 4 Co-occurrence of keywords in the research of EAT related to the MPC

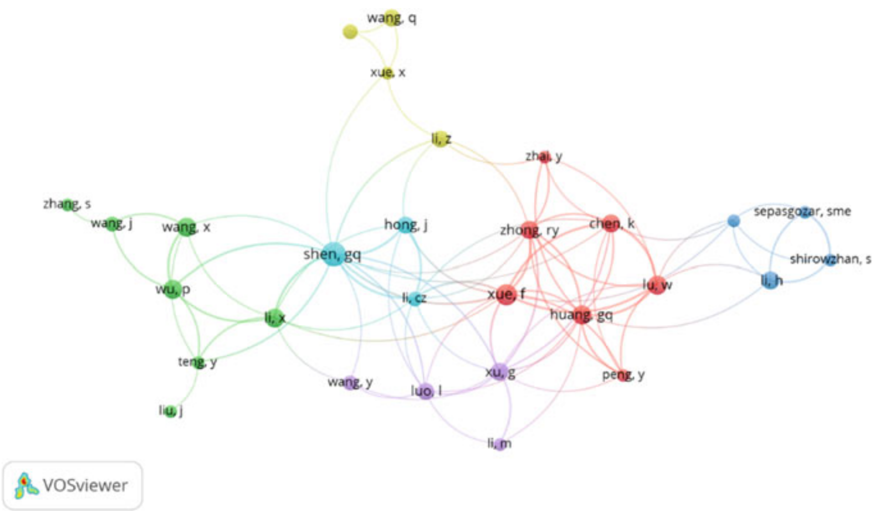

Fig. 5 Co-authorship analysis in the EAT domain related to the MPC

be seen in Table 2, besides prefabrication, other most frequently studied keywords in EAT include modular construction, BIM, point cloud, followed by construction, construction industry and laser scanning of 28, 22, 18, 11, 10, and 10 occurrences, respectively. Multiple studies have been focusing on the movement of EAT in Hong Kong, addressing various issues such as information sharing and supply chain risk [17], Visualization and traceability of construction progress [18], and the demand for lower energy consumption [19]. However, the lack of research on EAT related to the MPC by current researchers leads to a large number of knowledge gaps in this field, which also indirectly affects the development of prefabricated construction, providing a new research direction for future researchers.

3.3 Co-authorship Analysis

'Knowledge of the existing collaborations in a research field enhances the access to funds and expertise, improves productivity and prevents researchers from isolation' [1]. To gain an in-depth understanding of existing collaborations among researchers in the field of EAT research related to the MPC, a co-authorship analysis was conducted by using the VOSviewer tool. Figure 5 shows some of the main research collaborations among authors in the EAT domain related to the MPC.

As can be seen in Fig. 5, some authors and clusters have been both productive and collaborative from 2009 to 2019 and a total of six clusters, including the group consisting of Shen G. Q., Hong J., Li C. Z., and the cluster of Huang G. Q., Xue F., Chen K., Lu W., Peng Y., Zhai Y., Zhong R. Y., the cluster of Wang X., Wu P.,

Table 2 Summaries of most frequently studied keywords in EAT research related to the MPC

No.	Keywords	Occurrences	Total link strength
1	3D printing	4	6
2	Automation	8	10
3	BIM	22	26
4	China	7	5
5	Construction	11	14
6	Construction automation	6	3
7	Construction industry	10	7
8	Construction management	9	5
9	Construction progress monitoring	4	6
10	Digital construction	4	3
11	Digital fabrication	6	7
12	Energy efficiency	5	5
13	Genetic algorithm	9	2
14	Hong Kong	5	7
15	Innovation	4	7
16	Integration	4	1
17	Internet of things	4	6
18	Laser scanning	10	5
19	Lean construction	5	4
20	Lidar	5	4
21	Literature review	6	4
22	Machine learning	6	7
23	Modular construction	28	14
24	Off-site construction	6	3
25	Optimisation	9	6
26	Photogrammetry	4	6
27	Point cloud	18	10
28	Prefabrication	33	23
29	Project management	6	4
30	Project planning and design	5	3
31	Quality control	4	6
32	RFID	7	5
33	Simulation	7	5
34	Structural design	4	2
35	Supply chain management	6	1
36	Sustainability	8	9
37	Sustainable design	4	3

Li X., Liu J., Teng Y., Wang J., Zhang S., the cluster of Li H., Sepasgozar, Sme., Shirowzhan S., Tang P., the research cluster of Li X., Wang L., Wang Q., Xue X., as well as the collaboration among Xu G., Li M., Luo L., Wang Y.. Quantitative summary of authors is showed in Table 3.

A total of 29 productive authors are listed in Table 3. As a result, there was no significant correlation between the number of papers published and total citations each other. The correlation analysis showed that the number of papers published

Table 3 List of active researchers in EAT research related to the MPC

No.	Author	Total link strength	Number of articles	Total citations	Average citations
1	Chen K.	20	6	125	20.83
2	Hong J.	12	5	134	26.80
3	Huang G. Q.	21	7	225	32.14
4	Li C. Z.	15	4	106	26.50
5	Li H.	7	6	171	28.50
6	Li M.	4	3	29	9.67
7	Li X.	14	7	119	17.00
8	Li Z.	6	5	170	34.00
9	Liu J.	1	3	15	5.00
10	Lu W.	21	7	228	32.57
11	Luo L.	10	5	118	23.60
12	Peng Y.	11	3	123	41.00
13	Sepasgozar Sme.	6	3	14	4.67
14	Shen G. Q.	31	11	347	31.55
15	Shirowzhan S.	6	3	14	4.67
16	Tang P.	6	3	353	117.67
17	Teng Y.	8	3	67	22.33
18	Wang J.	5	4	194	48.50
19	Wang L.	2	4	27	6.75
20	Wang Q.	2	5	57	11.40
21	Wang X.	9	7	207	29.57
22	Wang Y.	4	4	20	5.00
23	Wu P.	14	7	248	35.43
24	Xu G.	20	6	80	13.33
25	Xue F.	30	8	183	22.88
26	Xue X.	4	3	118	39.33
27	Zhai Y.	7	3	20	6.67
28	Zhang S.	1	3	55	18.33
29	Zhong R. Y.	21	6	118	19.67

by authors is not the same as the authors' contribution to the field of EAT research related to the MPC (namely, there was no significant linear correlation between the two indicators) which is measured by total link strength, total citation and the average citation per paper. According to Table 3, most productive authors in the decade from 2009 to 2019 are Shen G. Q., Xue F., Huang G. Q., Li X., Lu W., Wang X., and Wu P., who have published 11, 8, 7, 7, 7, 7, 7 and 7 articles respectively. However, in terms of the average citation metric per paper (that is, considering the research significance of per paper), the top-ranked authors are also slightly different: Tang P., Wang J., Peng Y., Xue F., Wu P., Li Z., Lu W., Huang G. Q., Shen G. Q. These scholars have made great contributions to the EAT research in the MPC, for example, Tang P systematically reviewed the potential application, research progress and technical deficiencies of the automation technology based on laser scanning point cloud in BIM model construction [20], Wang J. studied the feasibility of using point cloud technology to enhance construction safety [21], Peng Y. and Xue F. studied the feasibility of using the Internet of Things and cloud technology to strengthen transportation timeliness and information communication [22], Wu P. systematically reviewed and summarized the application advantages and potential feasibility of 3D printing technology in the construction industry [23], etc., which will greatly help subsequent researchers to deepen their understanding of this field.

3.4 Countries Actively Engaged in EAT Research Related to the MPC

In order to explore the countries where EAT research in the MPC is usually conducted, a knowledge network visualization analysis was carried out for the country where the publication author is located. Figure 6 visualizes these research-active countries in EAT research related to the MPC.

It can be seen in Fig. 6 that scholars from countries with geographically closer, stronger economic strength and greater regional influence are more likely to influence each other or to cite each other's articles, and except for Brazil, Egypt, India, Iran, the remaining 21 countries have a higher overall economic development level, and a total of eight clusters, including, scholars from the group consisting of People's R. China (the world's second largest economy), New Zealand, Singapore, and Japan, those from the cluster of Australia, and Taiwan (China), the cluster of Netherlands, and Ireland, the cluster of England, and Italy, the cluster of Germany, South Korea, Sweden, Norway, Israel, and India, the cluster of USA, Egypt, and Switzerland, the cluster of Canada, and Iran, as well as the cluster of Spain, Finland, Brazil, and Scotland. Both developed and developing countries have been active in the research of EAT related to the MPC, such as Australia, People's R. China. In general, most of the countries where EAT research in the MPC was carried out were developed countries. However, although People's R. China is a developing country, it has a high number of publications in the EAT research field related to the MPC and is the only

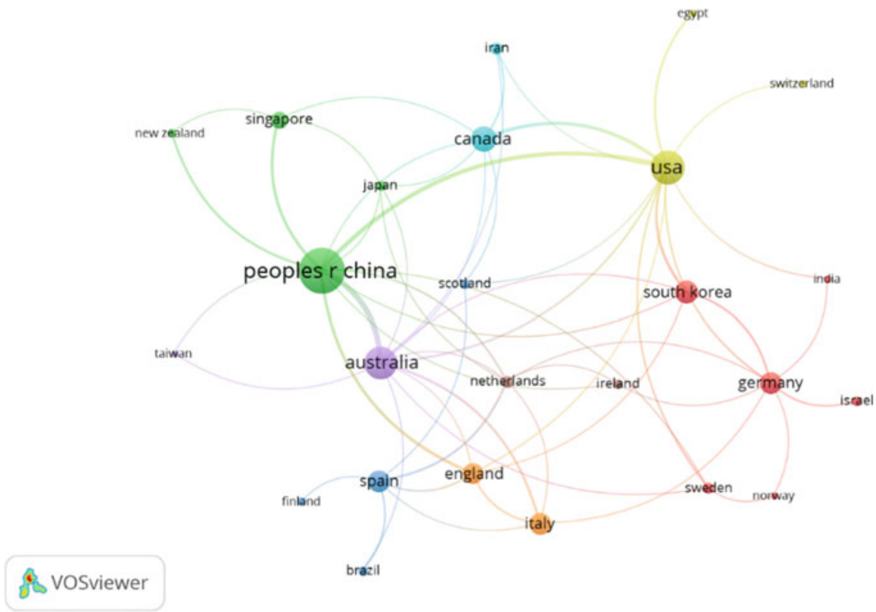

Fig. 6 A visual network map of countries where EAT in the MPC researchers were located

cluster (the cluster is displayed in Fig. 7) that has the highest correlation with most developed countries in this field (e.g., the United States, Australia, South Korea, and Canada, etc.). The quantitative indicators of countries are shown in Table 4.

As can be seen from Table 4, scholars from People's R. China, USA, and Australia are among the top in terms of the number of publications, ranking first, second and third respectively. In addition, People's R. China is also the country with the highest total link strength in EAT research related to the MPC. In terms of influence and mutual citations, these countries (i.e., USA, People's R. China, Germany, Australia, and Canada.) have been playing a significant leading role in advancing the research direction of EAT in the MPC. However, on the whole, People's R. China is at the core of leadership in EAT research related to the MPC.

4 Discussion

Following the scientometric analysis of the literature sample, keywords, scholars, countries and institutions involved in the research community of EAT related to the MPC, qualitative analysis was carried out to summarize the main research topics, to identify current research gaps, and to provide recommendations for future research directions.

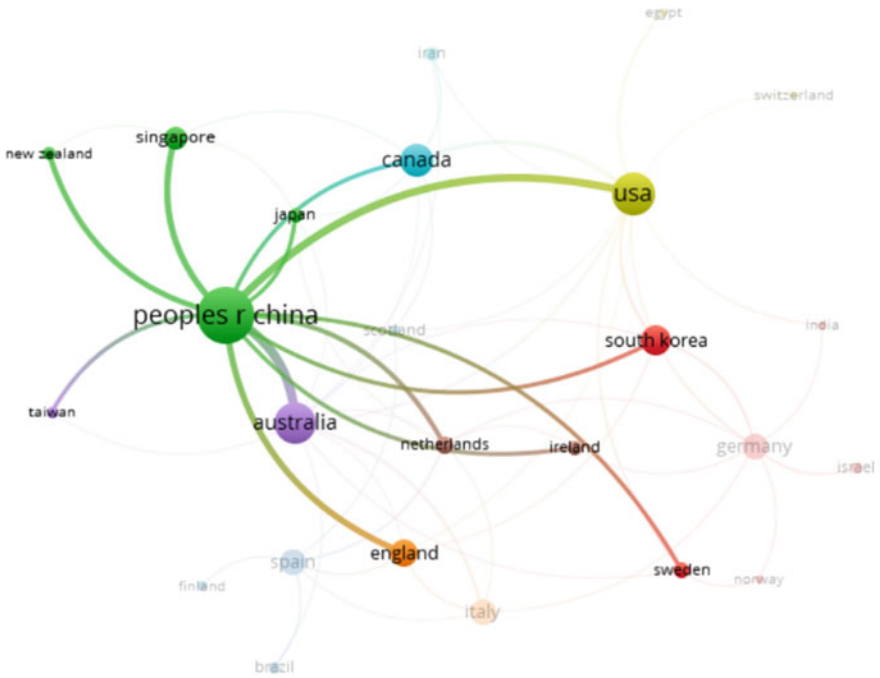

Fig. 7 An interconnected cluster of People's R. China with most developed countries

4.1 Research Topics Within EAT in the MPC

4.1.1 Prefabrication

Prefabrication has been a mainstream topic of EAT related to the MPC in both academic research and practice. Prefabrication is widely promoted due to its potential benefits in construction, such as reducing construction time and improving quality. In the MPC field, the design, production, transportation and assembly of prefabricated components is a lean and rigorous process, and any mistake in any link may greatly affect the quality and efficiency of the subsequent stages. To promote lean construction and solve the existing problems of prefabricated construction, more and more researchers are incorporating EAT in prefabricated construction, which has also made prefabrication a mainstream research topic in EAT research related to the MPC.

4.1.2 Modular Construction

As an environmentally friendly and sustainable construction method, modular construction is increasingly being widely recognized in the construction industry.

Table 4 Distribution of literature about countries where EAT in the MPC researchers are located

No.	Country	Total link strength	Quantity of papers	Total citations	Average citations
1	Australia	37	59	944	16
2	Brazil	3	5	63	13
3	Canada	15	34	572	17
4	Egypt	3	3	13	4
5	England	13	23	432	19
6	Finland	1	4	53	13
7	Germany	12	26	1100	42
8	India	2	3	41	14
9	Iran	4	9	98	11
10	Ireland	3	5	49	10
11	Israel	2	5	49	10
12	Italy	9	27	188	7
13	Japan	5	6	20	3
14	Netherlands	10	8	60	8
15	New Zealand	5	4	80	20
16	Norway	2	3	137	46
17	People's Republic of China	57	115	1438	13
18	Scotland	3	5	168	34
19	Singapore	9	16	84	5
20	South Korea	11	28	423	15
21	Spain	10	26	310	12
22	Sweden	5	7	269	38
23	Switzerland	1	3	53	18
24	Taiwan (China)	2	3	35	12
25	USA	40	64	1760	28

A large number of scholars have shown great interest in the research of modular construction and have achieved some research outputs. With the gradual research, development and application of modular construction, the requirements on construction quality, cost and efficiency are getting higher and higher, prompting researchers to integrate EAT into modular construction to meet the development needs of the current construction industry, which makes modular construction a research hotspot in EAT research related to the MPC.

4.1.3 Technical Research and Application in EAT Discipline Related to the MPC

With the gradually development of prefabricated construction, accompanied by also appeared many problems, for example, extensive construction mode, low degree of information, poor information communication, lack of coordination and cooperation among all parties, etc. In addition, all parties involved in the construction also put forward higher requirements for the cost, quality and efficiency management of construction projects. Therefore, in the MPC field, many researchers seek technical research and try to apply technical research results to the prefabricated construction process, which has become a new research hotspot.

4.2 Current Research Gaps

4.2.1 A Systematic Summary of EAT Research and Application in the MPC

In the MPC discipline, although a large number of research outputs and contributions in the advanced technologies have been produced by researchers before, a great many research results are messy, scattered and not effectively integrated. In addition, the EAT discipline has not been systematically summarized by researchers, and no systematic theoretical system has been formed in this discipline, which provides a new research direction for subsequent researchers.

4.2.2 In-Depth Research on Technologies Integration from the Perspective of Project Life Cycle

Although many technologies have been studied and applied in prefabricated construction, and some cases of technologies integration have also been studied, these studies are based on a certain activity link in the process of prefabricated construction. The research on technologies integration from the full life cycle process of the construction project has not been involved at present.

4.2.3 Holistic Performance Evaluation on Technologies Application

Based on the need to save time, resources and costs, and protect the environment, performance appraisal is increasingly becoming a consensus theme in the construction industry. Li et al. [2] pointed out that performance evaluation has become a key research direction in the future of MPC discipline. With the gradual research and application of advanced technologies in MPC discipline, performance evaluation in the EAT field has also received increasing attention. However, since the research results could vary among studies, the performance of EAT needs to be placed in the context of a particular country or region. Therefore, in order to further analyze the benefits and obstacles of cost changes caused by the application of advanced technologies in the MPC field, the performance evaluation research of EAT discipline still needs to be further studied by subsequent researchers.

4.3 Future Research Directions for EAT in the MPC

Based on the qualitative analysis of current research topic within EAT and research gaps, the framework that links the existing studies to future directions is initiated in Fig. 8.

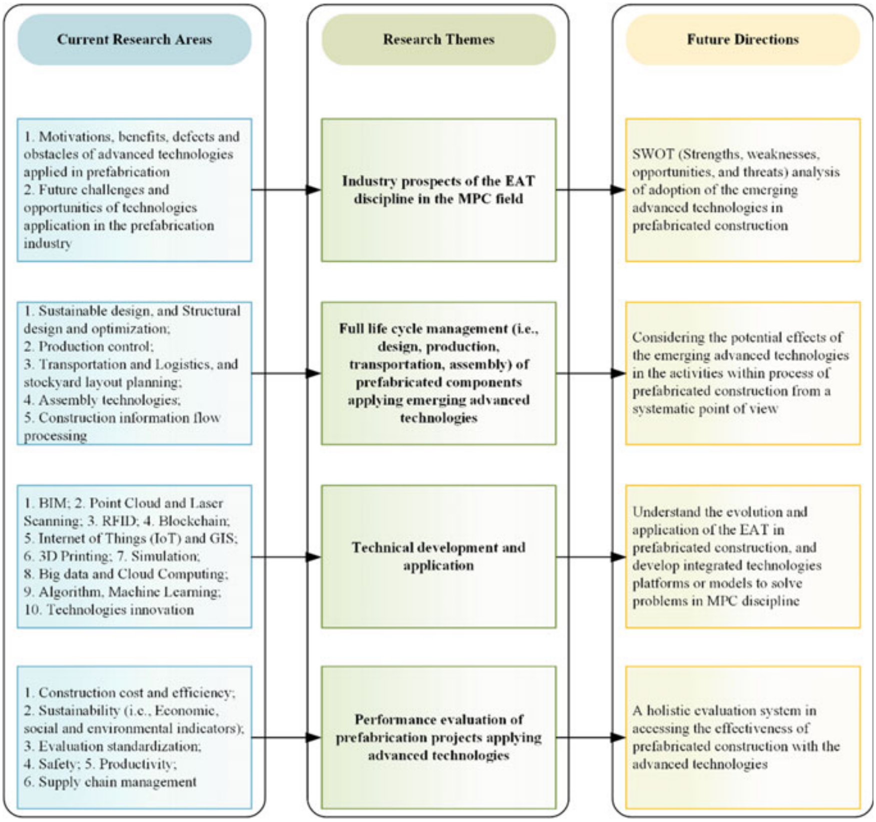

Fig. 8 A framework linking the current research field with the future research direction in the EAT field of MPC discipline

Industry prospects. The literature on industry prospects mainly focuses on the factors that promote or inhibit the adoption of the emerging advanced technologies in prefabrication. Through a comprehensive literature research, the authors found that "better real-time supervision and dynamic management", "lower overall construction costs", "shorter construction time", and "higher construction quality and efficiency" were the most essential advantages of adopting EAT in prefabricated construction. Through literature analysis and research, the authors found that "low knowledge level of technical management personnel", "lack of policy promotion", and "low technology maturity" are the main constraints for EAT to be widely used in the MPC field. Moreover, it is found that in some developing countries, such as China, due to rapid economic growth and urbanization, there is a great demand for sustainable buildings. Therefore, a similar SWOT (strengths, weaknesses, opportunities and threats) analysis of EAT research in MPC field has become a consensus in the construction industry.

Full life cycle management of prefabricated components under EAT application. It is widely recognized that the monitoring and control of the precast construction process and their variables are of strategic importance in responding to the dynamics of the construction industry [2]. However, many studies on the process of prefabricated construction only focus on one link in the full life cycle of the construction project (e.g., transportation and logistics) and many monitoring processes focus on controlling time and cost. As the whole management process of precast construction is highly complex, it is necessary to comprehensively consider and study in depth the potential effects of EAT in each link of prefabricated construction from the perspective of full life cycle.

Technical development and application. Although there have been many technical studies in the MPC field (for example, BIM, RFID, Internet of things, etc.), due to the immature application of technologies and the lack of in-depth integration between technologies, the application of construction and management technologies in the prefabricated construction field are still relatively traditional and backward. Therefore, it is necessary for subsequent researchers to further understand and study the evolution and development of technologies in the prefabricated construction field and further strengthen the research on technologies integration in the field of MPC.

Performance evaluation. In the field of prefabricated construction, the benefits of adopting various advanced technologies have been confirmed by many researchers, including: more efficient transportation efficiency of prefabricated components; shorter construction period; less labor demands; better control and management of construction schedule and quality; a greater potential of digitalization, automation, informatization, intelligent management systems; safer on-site construction, etc. However, the promotion and application of EAT in the field of prefabricated construction can be successfully promoted only when various stakeholders gain practical benefits. Therefore, in the future further study of EAT, it is necessary to study and build a comprehensive performance evaluation system to better evaluate the feasibility and rationality of various advanced technologies applied in the field of prefabricated construction.

5 Conclusion

EAT is becoming increasingly popular in prefabricated construction due to its potential in sustainable construction, lean construction, intelligent construction and information management, etc. By collecting research literature, overview of the literature sample, keyword co-occurrence, co-analysis and active countries are analyzed, and then research topics, research gaps and future research frameworks are identified and proposed.

This study provides a critical overview of the EAT research development in MPC discipline, which provides a valuable reference for both scholars and industry practitioners. This research helps scholars have a deep understanding of the current status of EAT research in MPC discipline and allows them to continue from the findings of previous studies. This study can also benefit industry practitioners by providing them with the results of effective technologies research and application in the MPC field. Since no previous research in the EAT field of the MPC discipline has been involved, this study may have some deficiencies in the actual research, which needs to be supplemented and improved by subsequent researchers.

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A Review on Indoor Thermal Comfort Research in Transportation Buildings

Zhenxiong Wen and Shenghan Li

Abstract Public transportation has become the most practical choice for people for reducing and controlling air pollution and greenhouse gas emissions caused by traffic congestion. However, the high density of people and the poor thermal environment in transportation buildings may affect passenger comfort, travel efficiency, and health. Accordingly, it is recommended to be considered in both building design and planning projects. This paper provides a very careful review of existing thermal comfort research on different types of transport station buildings. Firstly, a wide range of combined keywords in different accredited academic databases were searched. Then, the methods of thermal comfort assessment in transportation buildings, relevant influencing factors and improving solutions were scrutinized. Finally, the shortcomings were discussed and a few useful recommendations for future work are presented for greater improvement.

Keywords Thermal comfort · Transportation buildings · Transition · Passengers · Public transport

1 Introduction

Over the past century, global temperatures have been rising as a result of a sharp increase in carbon dioxide and other greenhouse gases emitted by humans in production and living [1]. In 2010, the transport sector accounted for 13.5% of total human greenhouse gas emissions [2]. In order to reduce and control air pollution and greenhouse gas emissions caused by traffic congestion, public transportation has become the most practical choice for people [3]. In addition, with economic and technological progress and transportation innovation, the transportation industry, mainly

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represented by aircraft and railway, has become the core of the modern social system [4].

The transportation building is the public building that serves transportation. Compared with other types of buildings, transportation buildings usually have a high space, high density of heat (i.e., habitant and electrical equipment), and variable passenger residence time (i.e. passengers are usually brief stay in transportation buildings and the density of inhabitants can change dramatically in a day, every day in a building, from one to another) [5, 6]. In today's life, everyone commutes to and from work for a variety of purposes, such as work, personal or social [7]. They can usually gather in transportation buildings in a relatively short period of time. This can lead to thermal discomfort in crowded enclosed areas even when climatic conditions are favorable [8]. In addition, in the wake of COVID-19 and other pandemics, people have increasingly shown a desire for a comfortable, healthy, and hygienic environment in which to arrive at a station or wait for a train [9].

The thermal comfort defined in ASHRAE standard 55 is "the mental state of expressing satisfaction with the thermal environment". Human environmental health is closely related to people's productivity and travel efficiency [10]. In recent years, railway stations, airports, subway stations, and other transportation buildings have accumulated a lot of valuable knowledge about indoor thermal comfort. But the different methods and models used to obtain, analyze, and interpret data to make indoor thermal comfort a complex problem. At the same time, the number of research on the thermal comfort of transportation buildings is also increasing. Therefore, in order to provide timely information for further study, a rigorous review is necessary to comprehensively and systematically summarize the current methods, models and influencing factors in the study of indoor thermal comfort.

This review aims to collate, classify, arrange and integrate existing information on thermal comfort in transportation buildings, while highlighting recent findings and proposing future research directions and hotspots. The study of thermal comfort in the field of transportation architecture is of great significance to the future development of transportation architecture.

2 Methods

This study focuses on buildings such as transportation buildings, in order to cover as many studies and cases as possible, while maintaining consistency of data. A wide range of combination keywords are used, which are related to transportation buildings and thermal comfort studies, as shown in Table 1. It represents the most common transportation facilities that provide public services for social production and residents' life, which is a summary of the literature results.

This study first searched articles on the Web of Science, Google Scholar and ScienceDirect databases using the relevant keywords in the title or abstract. The search dates were restricted from 2000 to 2020 in order to find articles published over the past 20 years. The search results are carefully examined and collated.

Table 1 The list of keywords used to select the literature

Category	Type of transportation buildings	Related to thermal comfort
Rail transport	Subway, metro, underground railway station	Thermal comfort, thermal environment, predicted mean vote, thermal perception
	Train station, railway station, high-speed railway station	
Air transport	Airport terminals	
Land transport	Bus terminals	
Sea transport	Cruise terminals	

The following inclusion criteria was considered: (i) study the thermal comfort of the indoor environment of transportation buildings; (ii) Articles published in English; (iii) Papers published in peer-reviewed papers and proceedings of scientific conferences; (iv) A clear description of the results and results of the study. Studies that do not meet the definition criteria are excluded from the review. Subsequently, the information provided in the study was rigorously examined, selected and integrated.

3 Indoor Thermal Comfort Research in Transportation Buildings

The research is summarized in Table 2. Further details of each study are provided in the subsequent sections.

3.1 The Studies on Subway

A number of different benchmarks have been provided in the literature to assess whether the thermal comfort of the interior space has been achieved. Subjective judgments of thermal comfort, thermal preference, thermal comfort and thermal acceptability are important indicators of thermal comfort. Ordódy et al. [11] evaluated the thermal environment of the passenger area of the Budapest metro by monitoring the environmental parameters. Similarly, Abbaspour et al. [15] evaluated the thermal comfort of subway station through on-site measurement. Although these studies used different models of thermal comfort, many of them measured the basic parameters for thermal comfort, including T_a, RH and V_a. Then, Han et al. [22] evaluated the thermal environment and passenger comfort of subway stations by combining field measurement and subjective questionnaires methods and analyzed the results using the SET*. The results showed that the comfort range of passenger flow is 16.1–31.2 SET* C, and the comfort range of platform is 15.9–31.5 SET* C, which is broader than that of other countries.

Table 2 Summary of characteristics of thermal comfort studies

References	City	Method[a]	Study area[b]	Measurement[c]	Indices used[c]
Subways					
Ordódy [11]	Budapest	M	A_{PS}, P	T_a, RH, V_a	PMV-PPD
Ke et al. [12]	Taipei	Mo	H, P	N/A	N/A
Hu et al. [13]	Taipei	Mo	H, P	N/A	N/A
Fukuyo [14]	N/A	Mo	H, P	N/A	N/A
Abbaspour et al. [15]	Tehran	M	E, H, P, C	T_a, RH, V_a, $F_{ac}\%$	RWI
Ye et al. [16]	Shanghai	Q + M	Not specified	T_a, T_{rad}, RH	T_{op}
Liu et al. [17]	N/A	Mo	P	N/A	N/A
Jenkins et al. [18]	London	Mo	P	N/A	N/A
Marzouk et al. [19]	N/A	Mo	P	N/A	N/A
Adibi et al. [20]	N/A	Mo	P	N/A	N/A
Mortada et al. [21]	N/A	Mo	P	N/A	N/A
Han et al. [22]	Seoul	Q + M	H, P	T_a, RH, V_a	SET*
Katavoutas et al. [23]	Athens	M	H, P	T_a, RH, V_a	PMV-PPD
Wang et al. [24]	N/A	Mo	P	N/A	RWI
Zhang et al. [25]	Shenyang	Mo	P	N/A	N/A
Assimakopoulos et al. [26]	Athens	Q + M	C, P	T_a, P_v, T_{op}	PMV-PPD
Liu et al. [27]	N/A	Mo	P	N/A	N/A
Wang et al. [28]	Beijing	Mo	P	N/A	N/A
Zhou et al. [29]	Beijing	Q + M	H, C, P, A_C	T_a, RH, V_a	T_{rm}, ET
Ma et al. [30]	N/A	Mo	P	N/A	N/A
Zhang et al. [31]	N/A	Mo	P	N/A	N/A
Li et al. [32]	N/A	Mo	P	N/A	N/A
Liu et al. [33]	Qingdao	Q + M	A_C, E, H	T_a, V_a, T_s	T_a
Park et al. [34]	N/A	M	H, P	T_a, RH, V_a	T_a
Tao et al. [35]	N/A	M	H, P	T_a, RH, V_a	T_a
Tian et al. [36]	Beijing	M	E, A_T, H, P	T_a, RH, V_a	T_a
Hu et al. [37]	N/A	M	H, P	T_a, RH, V_a	T_a
Song [38]	Beijing	Q + M	E, H, P	T_a, RH, V_a	PPD
Sinha et al. [39]	New Delhi	Q + M	H, P	T_a, RH, V_a	RWI
Wu et al. [40]	Beijing	Q + M	C	T_a, RH, V_a	RWI
Railway stations					

(continued)

Table 2 (continued)

References	City	Method[a]	Study area[b]	Measurement[c]	Indices used[c]
Misawa et al. [41]	Tokyo	Q + M	H	T_a, RH, V_a, D_a, S_r	SET*
Li et al. [42]	N/A	M	W	T_a, RH, V_a	T_a
Deb et al. [43]	Chennai	Q + M	W	T_a, T_g, RH, V_a, T_s	PET
Liu et al. [44]	Cold Region of China	Q + M	W	T_a, RH, V_a, T_{rad}	PMV-PPD
Liu et al. [45]	Cangzhou and Dezhou	Q + M	W	T_a, RH, V_a, T_g	PMV
Meng et al. [46]	Harbin	Q + M	W	T_a, RH, V_a	T_a
Yu et al. [47]	Changsha	Q + M + O	Not specified	T_a, RH, V_a, T_g	PMV, SET
Du [48]	Beijing and Tianjin	Q + M	W	T_a, RH, V_a, T_{rad}	PMV-PDD
Airport terminals					
Tsutsumi et al. [49]	Okinawa	Q + M	H	T_a, RH, V_a,	T_a
Liu et al. [50]	Chengdu	Q + M	A_C, DL	T_a, RH, V_a, T_g, T_s	PMV-PPD
Kim et al. [51]	N/A	M	H	T_a, RH, V_a,	T_a
Kotopouleas et al. [52]	London	Q + M	A_C, A_S, DL, BR	T_a, RH, V_a, T_g	PMV
Zhao et al. [53]	Xi'an	M	H	T_a, RH, V_a,	T_a
Liu et al. [54]	N/A	M	H	T_a, RH, V_a,	T_a
Wang et al. [55]	China	Q + M	A_C, DL, BR, H	T_a, RH, V_a, T_{sa}, T_g	T_a
Kotopouleas et al. [56]	London	Q + M	A_C, H, DL, W, BR	T_a, RH, V_a, T_g	T_a
Kotopouleas et al. [57]	London	Q + M	Not specified	T_a, RH, V_a, T_g	T_a
Pichatwatana et al. [58]	N/A	Q + M	W	T_a, RH, V_a	T_a
Akyuz et al. [59]	Dalaman	M	A_C, H, DL, W, BR	T_a, RH, V_a	PMV-PPD
Zhao et al. [60]	Shanxi and Zhejiang	M	A_C, H, W	T_a, RH, V_a	T_a
Bus terminals					
Cardoso et al. [61]	Porto	Q + M	W	T_a, RH, V_a, T_{rad}	PMV, aPMV, PET, SET*
Cruise terminals					

(continued)

Table 2 (continued)

References	City	Method[a]	Study area[b]	Measurement[c]	Indices used[c]
Cardoso et al. [62]	Porto	Q + M	Not specified	T_a, RH, V_a, T_{rad}	PMV

Abbreviation
[a] *Q* questionnaire, *M* measurement, *Mo* modeling, *O* observation
[b] *E* entrance, *H* hall, *P* platform, *C* carriage, *W* waiting area, A_{PS} passenger sorting area, A_C check area, A_S sitting area, A_T transit areas, *DL* departure lounge, *BR* baggage reclaims
[c] T_a air temperature (°C), *RH* relative humidity (%), V_a wind speed (m/s), T_g globe temperature (°C), T_S surface temperature (°C), T_{sa} supply air temperature, T_{rad} mean radiant temperature (°C), T_{rm} moving average temperature, T_{op} operation temperature, S_r solar radiation (W/m^2), *PMV* predicted mean vote, *PPD* predicted percentage dissatisfied, *RWI* relative warmth index, *SET* standard effective temperature, *SET** new standard effective temperature, *PET* physiological equivalent temperature, *aPMV* adaptive predicted mean vote, *ET* effective temperature

Passengers enter the station hall from the outdoors, through a series of processes such as buying a ticket, entering the gate, taking the elevator or taking the stairs to arrive at the platform floor, taking a ride, etc., the environment and behavior state are different in different positions, and thermal comfort is also different. Some studies have found that the PMV-PPD model is not suitable for evaluating dynamic thermal comfort. Zhou et al. [18] focused on the thermal changes that occur when different spaces move within the subway, in conjunction with the concept of transition space. The areas measured in the study include entrances, transit areas, halls and platforms. The results showed that the transient change of ambient temperature causes an abrupt change of sensation and affects the thermal sensation voting.

Several factors with potential effects on the thermal environment were identified. Table 3 summarizes these studies and compares their characteristics. In a field study carried out in Shanghai metro stations, Ye et al. [16] found that gender differences in thermal comfort in metro stations were small as the neutral temperature was 1 °C T_{op} higher for males than for females. Ventilation was the focus of many researchers in past studies. It was demonstrated that air curtain ventilation presented an appropriate

Table 3 The influencing factors of thermal comfort in subway stations found in the review

Type of building	Dimension	Factor(s)	Ref
Subway	Personal	Gender	[16]
	Building characteristics and service	HVAC systems	[14, 17, 20, 27]
		Spatial depth	[22, 23, 26]
	Environmental factors	Low outer tunnel temperature	[21]
		Climate change	[18]
		Nature ventilation	[33]
		Thermal shift	[29]
		Piston wind	[31, 33]

velocity and temperature distribution, which provides a healthy and comfortable environment. It is indicated that the highest velocities and the lowest temperatures were both achieved at the height of 0.2 m above the floor [27]. Differences in the thermal comfort conditions on the platforms are shown to be associated with the depth and the design characteristics of the stations. The average PMV at the station with a small depth is 0.9 scale points higher than that of the station with great depth [40]. There is a great mobility of people in the subway station, and the passenger density of different areas in the public area (entrance, station hall, platform) and carriages varies, and the passenger density of each area also changes over time. A large amount of heat and piston wind is generated during the train brake. The piston wind will be heated by the braking energy simultaneously, which has a significant influence on the air temperature and the flow field of subway stations and tunnels [25].

Some studies have shown that part of the problem with thermal discomfort can be avoided or alleviated through proper selection and operation of HVAC equipment. In an experiment to study the thermal environment of subway stations, Liu et al. [33] proposed to improve the thermal environment by installing a warm air curtain at the entrance of the ceiling and a method of recovering waste heat to reduce the influence of natural ventilation and piston wind of the pump station on the thermal environment of the station. Similarly, Zhang et al. [25] put forward one passive approach and three active approaches to improve the utilization of braking energy.

3.2 *The Studies on Railway Stations*

In most cases, the air distribution in the waiting hall is simulated under steady-state conditions, or it is carried out by means of subjective questionnaires combined with objective field tests. Yu et al. [47] who collected some supplementary materials by recording unobtrusive observations of naturally occurring behavior, such as unlocking coat buttons and passenger density. In the research of thermal comfort in railway station, the waiting room [43–48] and lobby [41] were mainly studied as most of the time passengers stay here. For analytical purposes, most studies used linear regression analysis between thermal indices and mean thermal sensation votes to derive the neutral range of thermal indices. This neutral thermal index range reveals the thermal comfort range in different cities and study sites. Deb et al. [43] studied the thermal comfort of a large railway station in southern India in the summer months of June. The neutral temperature obtained through the questionnaire is 31.93 °C.

The waiting hall of railway station is a special public place, which has the characteristics of large human flow, great mobility and complex situation of building users. The applicability of thermal comfort model has also aroused people's concern. Liu et al. [44] conducted questionnaires and physical measurements at two typical high-speed railway stations in cold regions of China. The results showed that there was a big difference between the measured thermal sensation value and the predicted average voting value of most high-speed railway waiting rooms, indicating that the

Table 4 The influencing factors of thermal comfort in railway stations found in the review

Type of building	Dimension	Factor(s)	Ref
Railway stations	Personal	Acclimatization	[46, 48]
		Gender	[48]
		Age	[46, 48]
		Active state	[47]
		Staying time	[44, 47, 48]
	Building characteristics and service	HVAC systems	[42]
	Environmental factors	Air movement	[43]

PMV calculation method was not applicable to the air-conditioning waiting rooms of high-speed railway.

Several factors with potential effects on the thermal environment were identified. Table 4 summarizes these studies and compares their characteristics. In addition to the six main factors, the thermal comfort of waiting room is also related to station grade and passenger stay time. Passengers waiting in the waiting hall come from all over the country. There are great differences in age, clothing and physical condition, etc. Everyone's feeling of thermal comfort also varies to some extent. Liu et al. [44] found that the length of time a respondent stay in the waiting hall also had an effect on the rule of the thermal comfort. For people with a waiting time greater than or equal to 30 min, their thermal comfort model was more similar to PMV thermal comfort model. On the other hand, people who spent less than 30 min in the waiting room were better able to withstand different environments.

3.3 The Studies on Airport Terminals

Terminal buildings are mainly characterized by large space and strong streamline, which is also determined by the functional characteristics of terminal buildings. Liu et al. [28] studied, measured and simulated the indoor thermal environment of the airport terminal using the computational fluid dynamics program. Kotopouleas et al. conducted a field survey of the thermal comfort of three airport terminals and found that people's preferences for thermal environments were different from the thermal environments they experienced, and that there was thermal neutrality at temperatures lower than those they experienced, indicating overheating in winter.

Several factors with potential effects on the thermal environment were identified. Table 5 summarizes these studies and compares their characteristics. Tsutsumi et al. [49] explored the relationship between thermal climate change and thermal comfort of visitors to subtropical Okinawa from mainland Japan. They found that previous heat histories affected the heat-sensing vote. There are some relationships between these sensations in the male subjects, but the relationships are not clear in the female subjects. Liu et al. [50] reported that high ceilings and upper-walls in the present

Table 5 The influencing factors of thermal comfort in airport terminals found in the review

Type of building	Dimension	Factor(s)	Refs.
Airport terminals	Personal	Acclimatization	[49]
		Gender	[49]
	Building characteristics and service	HVAC systems	[51]
		Building height	[50]
	Environmental factors	Vertical temperature distributions	[50]
		Solar radiation	[50]

building resulted in the use of a large quantities of supply air, and large amounts of heat in upper zones radiate lots of thermal, which is harmful to human health.

General researchers improve indoor thermal conditions by improving airflow design. Liu [54] took an airport terminal as the research object and used computational fluid dynamics method to study the indoor thermal environment under different working conditions. The results showed that the upper opening should be used effectively to improve the thermal environment of airport terminal building design.

3.4 Other Studies

The PMV model has important limitations in the application of typology in bus terminals and cruise terminals. Cardoso et al. evaluated a free-running bus terminal in a temperate country by using field measurements and surveys. The results showed that the PMV-PPD and aPMV models overestimated the cooling sensation. Although ASHRAE 55 and EN 15251 adaptive methods were more relaxed, they still did not completely conform to the thermal sensation of the interviewees.

Acclimatization is related to thermal perception. Cardoso et al. [62] found that the environment of tropical climate primitive was significantly colder, while the MTS scale of temperate climate primitive was warmer. In terms of thermal environment improvement, ventilation is usually an important concern of researchers.

4 Discussion

The research on these different spaces showed different levels of development. Although most thermal comfort models were used to evaluate the indoor thermal comfort of offices, educational buildings, commercial buildings, etc. They were also used to evaluate the thermal comfort of transportation building spaces. However, the application of thermal comfort models in these types of studies requires careful calibration.

The research on these different spaces showed different levels of development. Although most thermal comfort models were used to evaluate the indoor thermal comfort of offices, educational buildings, commercial buildings, etc. [63], they were also used to evaluate the thermal comfort of transportation building spaces. However, the application of thermal comfort models in these types of studies requires careful calibration. Cardoso et al. pointed out that although ASHRAE 55 and EN 15251 adaptive methods were more relaxed, they still did not completely conform to the thermal sensation of interviewees [61].

The average residence time of various transportation buildings and the areas involved also vary, indicating that the use of the relevant areas within the transport station conforms to the context of the transition space [64], which adds a layer of complexity to the study, as the user's behavior deviates from the typical sedentary behavior observed in offices and homes [65]. Besides, the time spent in the environment can affect the user's thermal comfort. This is very relevant because exposure at different times over time leads to different environmental perceptions as adaptation takes place [66].

In different spaces, in addition to individual differences, the focus of influencing factors is not the same, which is mainly due to the different spatial characteristics of each transportation buildings. For example, more attention was paid to piston effects [31, 33] and ventilation systems in subway [14] while solar radiation [50] were the main factors in airport terminals. However, ventilation was still the main consideration to improve the thermal comfort of the transportation building [67].

In previous thermal comfort studies, researchers have often used a constant metabolic rate and rarely evaluated the effects of variable activities on heat perception. It has been mentioned in the literature that in transportation buildings, thermal overregulation caused by metabolic rate will affect passengers' thermal comfort [47]. Relevant research should pay more attention to the human body's heat regulation mechanism. Also, most previous studies have focused on waiting areas, where the thermal environment of transitional space is often overlooked, although people often stay there. But due to the special mechanism of subways, a dynamic thermal comfort evaluation method should be adopted to evaluate a dynamic thermal perception process of passengers. In addition, Fig. 1 summarizes the missing pieces of the current study.

5 Conclusion

This paper reviews the indoor thermal comfort of transportation buildings. The transportation buildings included in the review represent the most common transport engineering facilities to provide public services for social production and residents' lives. The key point is to understand the research progress of the thermal comfort of the transportation station building and answer the important questions in order to find out the important research direction in the future. The research results of this review are as follows:

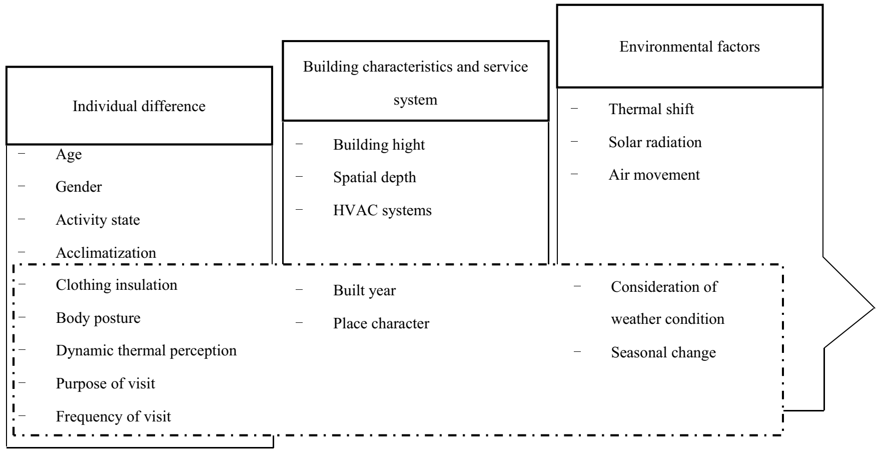

Fig. 1 The influencing factors and missing parts found in the review

(1) Most studies focus on subways, railway stations and terminals. Relatively few studies have focused on bus terminals and cruise terminals.
(2) Most thermal comfort models used for residential and office buildings were also used to evaluate the thermal comfort of transportation building spaces, but their adaption has not been well investigated.
(3) Individual differences, spatial characteristics, service systems, and environment are the main influencing factors on thermal comfort. The research emphasises influencing factors in different types of transportation buildings are different, which is mainly influenced by spatial characteristics.
(4) The use of transport station related areas is consistent with the transition space profile, but relatively few studies adopt dynamic thermal comfort evaluation model.
(5) The lack of research focuses on the thermal regulation mechanism of the human body.

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Research on the Differentiation Mechanism of Commodity Residential Prices in Shenzhen

Zhuoyuan Chen and Botong Song

Abstract Urban house prices and their spatial variation are hot issues of continuous interest to urban geographers in the twenty-first century. Taking each residential district in Shenzhen as the object of the study, using the data of house price points in the community and the data of points of interest related to the living environment, we reveal the specific influence and spatial differences of the living environment on the house price through the quantitative analysis of geographically weighted regression from the two aspects of house price differences and their influencing factors. The results show that the house prices in Shenzhen are gradually decreasing in the east–west direction from Nanshan District and Futian District to the east, and in the north–south direction from Nanshan District and Futian District to the north; the average price of the ordinary residential community in Shenzhen shows obvious spatial differences, and high house prices are mainly distributed in the city center, near subway stations and high-grade closed communities. The spatial differentiation of housing prices is a structural manifestation and market-oriented response to the socio-spatial differentiation of cities, as well as a comprehensive reflection of the differences in the ability of cities to dispose of resources.

Keywords House prices · POI · Shenzhen · Spatial heterogeneity · Geographically weighted regression

1 Introduction

Urban residential differentiation has both spatial and social properties, with spatial differences in housing type, environment, and supporting facilities, and social disparities in economic status, education level, and lifestyles of social groups occupying different living spaces [1].

Residential space differentiation in Chinese cities began as an independent research object in the late 1980s [2]. Since then, it has gradually become a hotspot

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of attention in geographic research in China. The current academic research on residential space differentiation mainly focuses on analyzing the current situation, the evolution process, and countermeasure suggestions [3–8]. At present, China is in the stage of social transformation, where the internal reconstruction and external expansion of the city are advancing rapidly at the same time, and the unfair distribution of social resources brought about by the differentiation of living space is continuously aggravated [1, 3]. In the process of urban renewal and expansion, the unevenness of spatial reconstruction and resource allocation has been highlighted, causing more and more significant temporal and spatial heterogeneity in housing prices, while new influencing factors such as school district, subway, landscape, property management, technology, etc. complicate the mechanism of house price differentiation [9]. In recent years, intra-city house price differences and influencing factors have received more attention in the field of urban geography in China [10, 11]. In different cities, due to varying levels of economic development and industrial layout patterns, there are significant differences in the residential space differentiation pattern [12]. Simultaneously, within the same city, there are differences in spatial differentiation at different scales, such as neighborhoods, streets, and counties [13, 14].

From the perspective of urban socio-geography, the significance of urban house prices is reflected in the dialectical relationship between house prices and the reshaping of urban social space [15, 16]. The space of housing price is social space, and the spatial differentiation of housing price is not only the structural manifestation and market reaction of the differentiation of urban social space but also an important driving mechanism to promote the redifferentiation of social space [17]. The spatial differentiation of urban house prices and its evolution can reflect the overall pattern and evolution trend of the residential space differentiation, and house prices will become an important data source and analysis tool in the study of urban social space [9].

With the development of information technology, location-based open data sources have become popular in research, improving the accuracy and timeliness of data analysis and reflecting more adequately the spatial and temporal information of geographic entities. Some studies have applied POI big data to the study of urban spatial structure, analyzing the influences of housing prices in old industrial areas [18], and the effect of shopping centers, public service facilities, and urban parks and green spaces on housing prices [19–21], and the quantitative study of the spatial correlation between urban housing and its prices combined with point-of-interest data is an important research content of urban economic geography in the future.

Based on the above background, this paper takes Shenzhen city as an example and uses a web crawler to crawl the house price point data and the living environment-related interest point data in Shenzhen city to investigate the house price differentiation and its influencing factors. The structure of this paper is as follows: firstly, an exploratory analysis of house price data and an analysis of the regional trends of house prices to study the degree of spatial differentiation and characteristics of each region; secondly, a geographically weighted regression model is constructed to explore the quantitative relationship between the house price level and living environment elements and reveal the specific influence and spatial differences of the living environment on the house price level.

2 Study Area and Data Sources

2.1 Regional Presentations

Shenzhen is the first special economic zone established since China's reform and opening up and is located in the southern part of China's Guangdong Province. It has an area of 1996.85 km^2 and a population of 13,438,800 people as of 2019. According to the National Bureau of Statistics, Shenzhen is one of the cities in China with the largest increase in housing prices and has received widespread attention from the government, enterprises, residents, and scholars. Therefore, this study chooses Shenzhen as the study area, with 10 administrative regions (including one new region), including four districts (Futian, Luohu, Nanshan, and Yantian) within the former Special Administrative Region (SAR), and six districts (Bao'an, Guangming, Longhua, Longgang, Pingshan, and Dapeng) outside the former SAR.

2.2 Data Sources

The data used in this paper consists of two parts. The first is the second-hand housing transaction data in Shenzhen in 2019 crawled from lianjia.com by using big data technology, and since this study takes the second-hand general residential neighborhoods as the object of research rather than specific houses, a total of 1464 neighborhood samples are obtained after screening. The other one is the POI (Point of Interests) data of Shenzhen City, which is obtained from Gaode Map. In view of the diversity and complexity of the causes of house price differentiation, this paper synthesizes the findings of existing studies and the situation in Shenzhen, and selects the location characteristics, transportation accessibility characteristics, natural environment characteristics, and public facilities characteristics related to housing prices to analyze their impact on house prices. At the same time, considering the availability and accuracy of the data, seven types of indicators were selected: hospitals, subway stations, major roads, lakes, finance, shopping, and entertainment. Finally, the spatial matching of the two was performed in ArcGIS software to obtain the location characteristics of each house price data, and the spatial information database of house prices in Shenzhen was established.

3 Methodology

3.1 Analysis of Space Trends

Spatial trend surface analysis is the process of using mathematical models to simulate and analyze the spatial distribution patterns and regional trends of geographical elements [22]. It is a smooth mathematical surface that is an approximation of a real surface [23]. The actual surface is decomposed into a trend surface, which reflects regional patterns and is controlled by a wide range of systematic factors, and a residual surface, which reflects local characteristics and is controlled by local and random factors [24].

3.2 Kriging Spatial Interpolation

Kriging interpolation, also known as spatial autocovariance optimal interpolation, is an unbiased optimal estimation method for regionalized variables in a finite region based on spatial autocorrelation, using a semi-variance function, taking into account the distance between samples and sample clustering. This interpolation method can reflect the spatial distribution and continuity of variables [25]. Some scholars have proved that Kriging spatial interpolation is significantly better than several other interpolation methods [26].

3.3 Geographically Weighted Regression

Professor Fotheringham from the University of St. Andrews, UK, formally proposed the geographically weighted regression (GWR) model in 1996 [27]. The geographically weighted regression (GWR) model is an extension of the simple linear regression model, which adds the spatial location information of the observation points to the regression analysis, and uses spatial relationships as weights in the calculation to achieve a local regression that follows the first law of geography [28], and obtains coefficient results for each local region regression, which applies to spatial non-stationarity data.

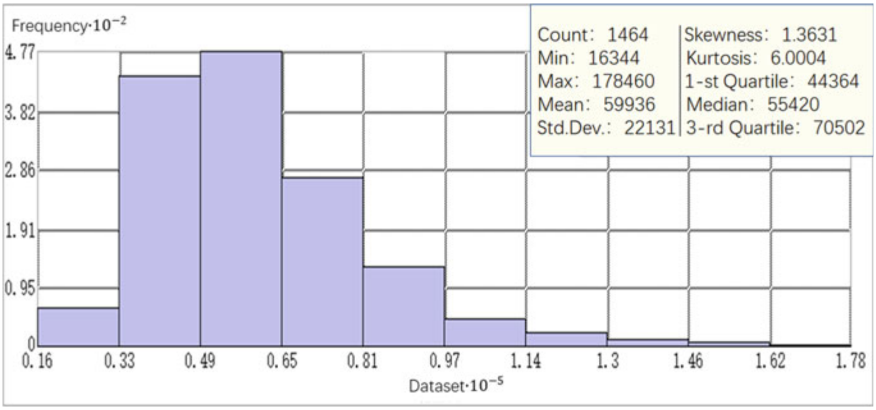

Fig. 1 Histogram of house price statistics for Shenzhen neighborhoods, 2019

4 Analysis of the Spatial Characteristics of House Prices in Shenzhen

4.1 Statistical Histogram Analysis

The statistical histogram generated by the ArcGIS data analysis tool (Fig. 1) shows that the average price of the 1464 residential neighborhoods in Shenzhen in 2019 was 59,936 (RMB/m^2), which is greater than the median of 55,420 (RMB/m^2), with a positively skewed frequency distribution. It can be inferred that the economic level of the majority of residents in Shenzhen matches the housing price level of the middle and lower price levels, and the divergence between the high housing purchasing power group and the low housing purchasing power group is more significant.

According to the Shenzhen 2019 statistics, it can be seen that the per capita disposable income of residents is 62,522.40 yuan, then the annual per capita disposable income of households is 125,044.8 yuan. If we make the purchase of 80 m^2 of housing as an example, the housing income ratio in Shenzhen 2019 reached 38.3, far higher than the reasonable house price income ratio range of 3–6, which is a popular international term. It can be seen that the housing purchase burden of residents is generally high.

4.2 Exploratory Analysis

The histogram of the plot average transaction price data is plotted (Fig. 1), with a skewness of 1.3631, and the distribution of plot average prices is close to a normal bias distribution. After the log transformation, the skewness was 0.16649, which was more relative to the normal distribution (Fig. 2). The closer the data is to a

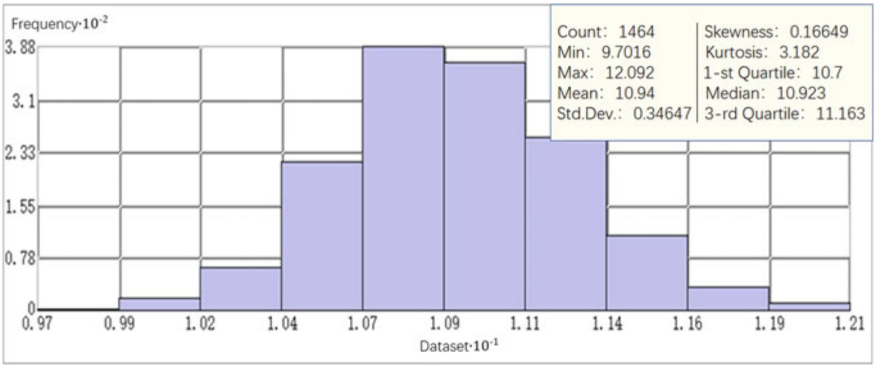

Fig. 2 Log-transformed histogram of the average transaction price for neighborhoods

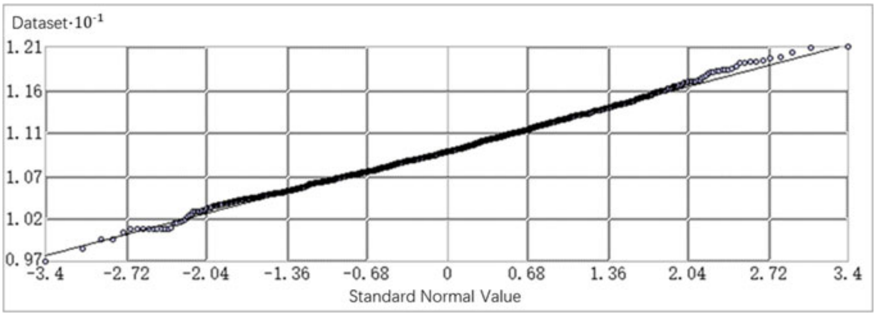

Fig. 3 Log-transformed QQPIot distribution map of average transaction price for neighborhoods

straight line, the closer it is to a normal distribution. The scatter image of the average transaction price data after the log transformation is close to a straight line, that is, the data after the log transformation is close to a normal distribution (Fig. 3).

4.3 Analysis of Space Trends

Spatial trend analysis is used to project the average transaction price data of the district onto the XZ and YZ planes, with the Z-axis being the unit price, and a three-dimensional image is used to show the trend of the data distribution on a global scale (Fig. 4).

The green arc is the projected trend of house prices in the longitude direction, and it can be seen that house prices are gradually decreasing along the positive X-axis (east longitude), which is consistent with the unique geographic division of Shenzhen. The highest house prices are in the west of Shenzhen in the Nanshan district, then eastward in the Futian district where prices are slightly lower than in the Nanshan

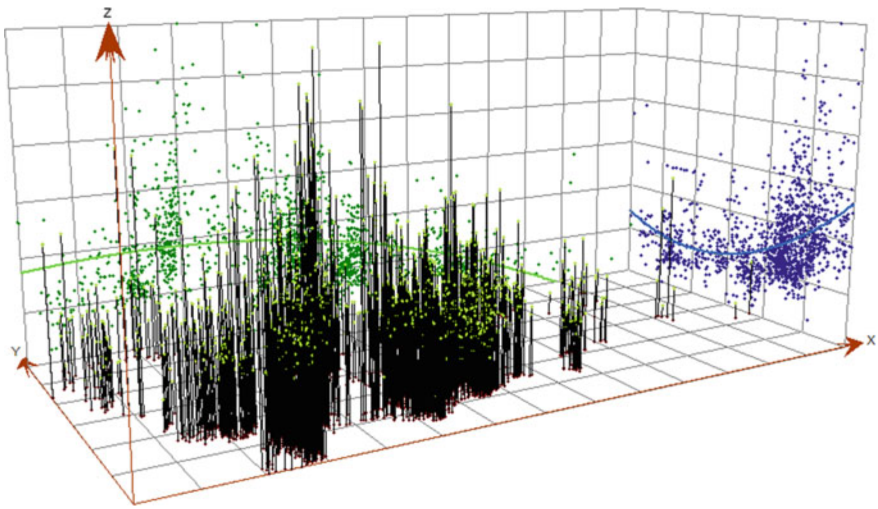

Fig. 4 Trend analysis of average transaction prices for neighborhoods

district, then in the Luohu and Yantian districts where prices gradually decrease to the east.

Along the Y-axis direction, that is, the direction of latitude, you can see the blue projection trend line to the south increasing, the northern part of Shenzhen is mostly less developed areas of traffic, such as Guangming New District, Pingshan District, etc., to the south is central Bao'an, Longhua District, Longgang District, housing prices gradually increase, the southernmost is Nanshan District, Futian District, Luohu District and Yantian District, so the trend line of housing prices in the southernmost part of the city reached the highest.

In summary, you can get the overall distribution of housing prices in Shenzhen, east–west housing prices from Nanshan District, Futian District to the east gradually decreasing, north–south direction, housing prices from Nanshan, Futian first line to the north decreasing progressively.

4.4 Spatially Interpolated Analysis of House Price Data

In this paper, the data are sampled for ordinary residential neighborhood transaction data, which exist in the form of discrete points in space, and spatial interpolation can be used to obtain possible prices in areas that are not sampled and to fill in data gaps.

After histogram and normal QQPIot distribution chart analysis shows that the original neighborhood transaction average price data is close to the normal skewed distribution, while the price data after log transformation obey the normal distribution in general, to carry out Kriging interpolation, it is necessary to carry out log transformation of the original data. The interpolation results using ordinary Kriging

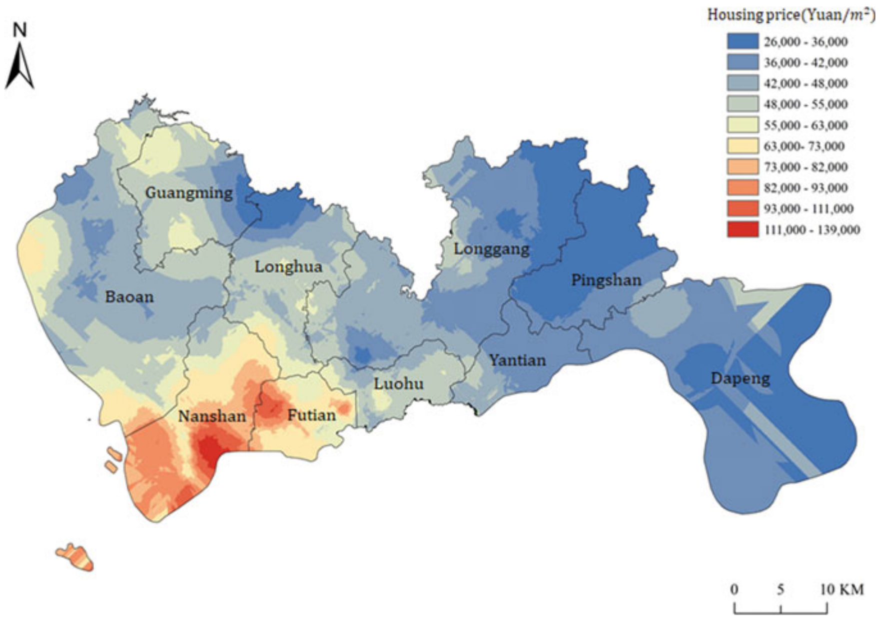

Fig. 5 Spatial interpolation results of house prices for neighborhoods in Shenzhen

interpolation are shown in Fig. 5, the average price of ordinary residential neighborhoods in Shenzhen shows obvious spatial differences in general, with prices in Nanshan and Futian regions in the southwest being particularly prominent, which is closely related to the educational resources and geographical advantages of the region; Pingshan and Dapeng regions in the east of Shenzhen have lower prices due to transportation and other factors.

5 Empirical Analysis of Spatial Differentiation of House Prices Based on the GWR Model

5.1 Explanatory Model Construction

In this study, a total of seven indicators such as medical, transportation, nature, and public facilities were selected as explanatory variables of the model. The proximity analysis tool is used to analyze the data of hospitals, subway stations, finance, major roads, and lakes to obtain the distance indicators; the density tool is used to analyze the data of residential facilities and leisure and entertainment to get the density indicators. This paper establishes a geographically weighted regression model for the average price in Shenzhen based on the above variables.

The model has two key indicators to be selected, namely the weight function and the bandwidth calculation method. The weight function, also known as the kernel type in ArcGIS software, has 2 choices, fixed and adaptive. For the bandwidth determination, there are also 2 methods, the AIC method and the CV method. So there will be a total of 4 combinations of 2×2 methods for model parameter setting. It should be noted that the bandwidth value returned by the fixed type is the distance threshold in meters, while the bandwidth returned by the adaptive type is the number of neighboring points. In this paper, the 4 combinations were verified separately, and the model effects are shown in Table 1.

R2 is a measure of model fit, and its value varies from 0 to 1, and the larger, the better; AICc is a measure of model performance, and if the difference between the AICc values of different models is greater than 3, the lower value of the model performs better.

From Table 1, comparing models 1, 2, or 3 and 4, it can be found that the adaptive model R2 is significantly improved, and the AICc is smaller. Thus, the adaptive model is better than the fixed model. Then the two adaptive models, 2 and 4, were compared to see which of the two methods, AIC or CV, was more appropriate. Observing Table 1, it is found that the R2 and AICc values of model 2 using the AIC method are better than those of model 4 using the CV method, so the AIC method is used to calculate the bandwidth in this paper.

In summary, the models using adaptive and AIC methods work best.

5.2 Interpretation of Model Results

In this paper, the GWR model with adaptive and AIC methods was selected for the empirical study in Shenzhen, and the regression model was run using ArcGIS software. The coefficients of the regression results for the 1464 cell sample points in Shenzhen are shown in Table 2.

(1) The effect of distance to the hospital on house prices. As can be seen from Table 2, the coefficient of influence of distance to the hospital on house prices is distributed between − 9.02 and 3.26, and the proportion of negative values is more than 3/4, which means that the farther the distance to the nearest hospital, the lower the price of residential property. The common feature of Luohu District, Nanshan District, and Longhua District are that there are more key hospitals, such as tertiary hospitals, and the demand factor of residents for hospitals is greater than the exclusion factor, so the distance to hospitals is negatively correlated with house prices in space.

(2) The impact of distance to the subway station on house prices. From Table 2, we can see that the regression coefficient of the influence factor of the subway station is between − 21.98 and − 1.33, which is significantly negatively correlated, which means that the farther away from the nearest subway station, the lower the residential prices. The most obvious effect of the metro on the

Table 1 Comparison table of the effect of different parameters of the model

	1 Fixed-AIC	2 Adaptive-AIC	3 Fixed-CV	4 Adaptive-CV
Bandwidth/neighbors	8071.06	429	8234.84	432
Residual squares	393,716,079,530.61	372,831,334,489.91	395,226,649,900.71	373,649,850,588.42
Effective number	76.94	78.82	74.87	78.24
Sigma	16,847.82	16,405.99	16,867.54	16,420.59
AICc	32,695.46	32,623.33	32,697.51	32,625.53
R2	0.4505	0.4797	0.4484	0.4785
R2 adjusted	0.4204	0.4504	0.4191	0.4495

Table 2 GWR model regression coefficients by quartile statistics

	Minimum	Lower quantile	Median	Upper quantile	Maximum
Intercept	43,771.4034	67,934.5580	87,208.9160	107,145.3980	121,614.6659
Hospital	− 9.0283	− 3.0924	− 2.0547	− 0.5118	3.2657
Metro station	− 21.9872	− 13.0436	− 6.6094	− 4.6522	− 1.3347
Main roads	− 21.4387	0.0715	4.0088	10.5016	19.2209
Lake	− 17.3379	− 9.9333	− 3.8345	1.2782	9.2208
Banking	− 8.4136	− 5.5765	− 3.5443	− 0.5911	3.4139
Shopping	− 12,273.2463	− 3540.3814	− 1059.4851	1698.0791	3823.1297
Entertainment	− 6288.8121	− 4296.9575	− 2270.6502	1014.0131	3310.0374

promotion of surrounding house prices is in the south of Bao'an District and the west of Futian District, where residents of these areas rely heavily on the metro for travel, so the positive influence of the metro on house prices is also the strongest. For areas outside the former Special Administrative Region, the distance to the nearest subway station has a weakening effect on house prices.

(3) The effect of distance to major roads on house prices. From Table 2, we can see that the coefficient of influence of major roads on house prices is distributed between − 21.43 and 19.22, with the proportion of positive values exceeding 3/4, which means that the farther the distance to major roads, the higher the house prices. The most obvious influence is in Futian and Nanshan, where residents in this area live and work closer to each other, have a less strong preference for transportation, and attach more importance to the suitability of the living environment.

(4) The influence of the distance to the lake on house prices. From Table 2 can be seen, the lake influence factor regression coefficient distribution between − 17.33 and 9.22, the proportion of negative value more than 50%, the closer the distance to the lake, the higher the price of the region is mainly Nanshan, the south of Baoan and Futian.

(5) To the financial distance to the influence of house prices. From Table 2, we can see that the regression coefficients of financial influence factors are distributed between -— 8.41 and 3.41, and the proportion of negative values is more than 3/4, which means that the closer to the nearest financial point, the higher the house price. Due to the high house price level, the supporting facilities are generally more perfect, and the reasonable layout of high-grade financial institutions and various service centers can meet the living needs of residents more efficiently.

(6) The influence of shopping density on house prices. As we can see from Table 2, the influence coefficient of shopping density on house prices is distributed between − 12,273.24 and 3823.12, the negative value of the coefficient of more than 50%, house prices with the increase in shopping density and increase in the region is mainly distributed in Nanshan, while the north of Bao'an,

Longhua District, Guangming District house prices with the increase in shopping density and decrease, the reasons for this phenomenon is more complex, maybe with Nanshan District in High-end business districts are related, and commercial areas bring more positive externalities than other areas that are relatively underdeveloped.

(7) Influence of entertainment density on house prices. From Table 2, it can be seen that the coefficient of the impact of entertainment density on house prices is distributed between − 6288.81 and 3310.03, and the proportion of negative coefficients is more than 50%; Nanshan and Futian house prices decreased with the increase of entertainment density, followed by Longgang, mainly due to a certain degree of noise pollution and traffic congestion, which reduces the living experience of nearby residents.

Summing up the above findings, among the explanatory variables, subway stations, hospitals, and financial institutions have a positive incentive effect on house prices, that is to say, house prices are higher the closer they are to these influences, which is mainly related to the convenience of travel and positive externalities from commercial areas. Conversely, house prices are higher in areas that are farther away from major roads, with the most pronounced effect in Futian and Nanshan, where residents live and work closer to each other and therefore value the living environment's suitability more. Besides, among the explanatory variables, lakes, shopping, and recreation affect house prices in different directions in different regions and do not have a dominant effect, which may be related to the differences in shopping and recreation venues and the added value they bring.

6 Conclusions and Discussion

In this paper, several environmental factors influencing house prices are selected as explanatory variables, crawling the transaction records of ordinary residential neighborhoods in Shenzhen in 2019 on Chain.com, and obtaining the data of the main categories of interest in Shenzhen through the Gaode Map API, on ArcGIS software, through nearest neighbor analysis as well as density analysis. Finally, geographically weighted regression was used to reveal the spatial heterogeneity of the role of each influencing factor on house prices, and the following conclusions were obtained: (1) The overall house prices in Shenzhen show a gradually decreasing trend in the east–west direction from Nanshan District and Futian District to the east, and in the north–south direction from Nanshan District and Futian first line to the north. (2) There are obvious spatial differences in the average price of ordinary residential areas in Shenzhen, in which the house prices in Nanshan and Futian areas in the southwest are particularly prominent, which is closely related to the educational resources and the degree of economic development in these areas; in Pingshan and Dapeng areas in the east of Shenzhen, the house prices are lower due to traffic and other factors. (3) The influence of explanatory variables on house prices mainly has 2 kinds of distribution status. The first one is the general consistency of the direction of influence in each region, factors such as subway stations, hospitals, financial institutions, and so on generally have a positive incentive effect on house prices in space, that is, the closer to the influencing factors house prices are higher, on the contrary, the farther away from the main road region house prices are higher. The second is that the variables have different directions of influence on house prices in other regions and do not form a dominant direction of action, distance to the lake, shopping density, and entertainment density belong to this distribution of characteristics.

Guided by the concept of public value, proper planning of public social resources such as medical care, transportation, education, and basic supporting facilities, which can be directly planned and allocated, can effectively alleviate the problem of uneven distribution of social resources brought about by the differentiation of living space, thus improving the living level of residents and guiding the practice of living space justice. In the former Special Administrative Region, public supporting facilities are relatively more complete, but at the same time, problems such as the separation of urban jobs and housing caused by the concentration of office buildings should be avoided; in the former less developed areas outside the Special Administrative Region, public resources should be rationally allocated according to the characteristics of the region's industries, location advantages and the features of the spatial distribution of residence and employment.

The weakness of this paper is that, for the sake of data availability and accuracy, only some typical factors of location characteristics, transportation accessibility characteristics, natural environment characteristics, and public facilities characteristics related to house prices are selected as influencing factors, failure to include other possible influences such as education, natural landscapes, and bus stops, etc. Subsequent studies could be conducted to explore one impact factor in more depth. In addition, the study of house prices in this paper only considers the overall situation in the same time period, but does not study the law of change over time. The law of change over time of urban house prices has great significance for the formulation of policies and the guidance of market transactions, so we can further discuss the spatial differentiation and influencing factors of house price combined with time factors in the future.

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Characterizing the Generation of Building Interior Decoration Waste: A Case Study in Guangzhou City

Jiajia Wang and Huabo Duan

Abstract China has been striving to urbanize in recent years. Accordingly, decoration waste is triggering an enormous challenge to green development if effective management hardly adopted. Authentic statistics or accurate estimation of decoration waste generation can play crucial roles in handle this problem. This study takes Guangzhou city as an example, is designed to understand the generation and flows of decoration waste. The results show that a total of approximately 1.6 million metric tons of decoration waste generated from newly built residential and public buildings in Guangzhou city over the past two decades, and this amount has kept fast growth. Concrete waste and brick account for 78% of the total decoration waste. Moreover, the study found that the total recovery rate of newly-built decoration waste in Guangzhou in 2018 is only 8.6%. Increasing the recovery rate of decoration waste and decreasing the landfill rate can increase the potential economic value of recycling and significantly reduce the land use and potential environmental impact.

Keywords Decoration waste · Generation · Estimate and prediction · Guangzhou city

1 Introduction

With the rapid urbanization of China, increasingly more researchers pay attention to the management of construction and demolition waste (C&D Waste). Large areas of demolition, new construction projects produced a large number of C&D Waste [1]. It has caused a series of environmental and social problems [2]. In 2017, the study concluded that about 2.36 billion tons of C&D waste were generated in China annually, were generated every year in the world [3]. Remarkably, its growth rate has

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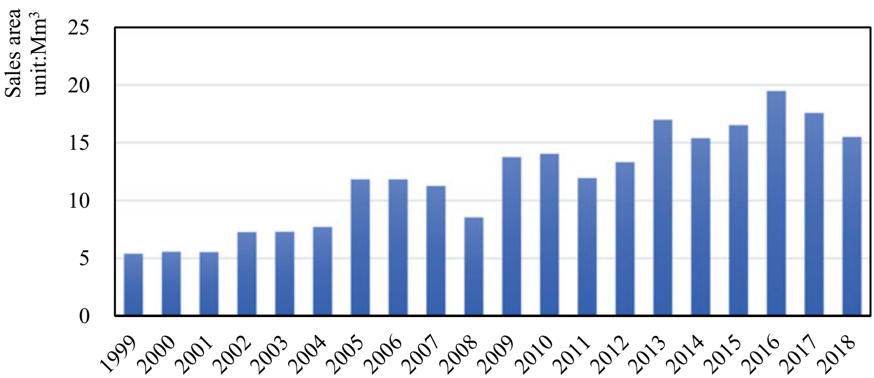
continued to grow, with the rapid development of China's economy and the acceleration of urban renewal, a large number of new construction and demolition activities have resulted in an increasing amount of construction waste. China's construction industry has boomed in the past few decades [4]. It has brought about tremendous improvements in economic growth and people's lives; however, the adverse effects are not to be underestimated. The construction waste not only brings a significant challenge to the environment but also endangers the public's life and property safety.

With the concept of green development and sustainable development, the generation and disposal of construction waste have attracted a lot of attention and research [5]. Due to more advanced researches, there have been many results on the characteristics and flow direction of the new buildings and the demolition stage [6]. However, the study on the waste generation and environmental impact in the decoration stage is seldom carried out. There is no doubt that the amount of waste produced during the demolition phase is enormous, though the quantity of waste that in decorates phase is relatively small on numerical value, it does not mean this part can be ignored. As shown in Fig. 1, the transaction area of new commercial housing in Guangzhou showed a linear growth trend from 1999 to 2018. During the last two decades, the trading area has been overgrowing, and most new-house will be decorated after the transaction. Subsequently, the generation of decoration waste will meet its increase. These data reflect the problems that decorate cast-off indirectly are becoming increasingly severe.

At present, the whole country does not have any clear definition of decoration waste, and there is no unified standard in management. In the related research on construction waste, the decoration part of the research is often accounted for a small portion and seldom being the centre of the research. The scope of this study is limited to the interior decoration stage of new commercial housing. The inert materials and



Data source: Statistical Bureau of Guangdong Province (SBGZ), 2018. Guangdong Statistical Yearbook.

Fig. 1 Floor space of buildings actually sold in Guangzhou city. Data *Source* Statistical Bureau of Guangdong Province (SBGZ), 2018. Guangdong Statistical Yearbook non-inert materials in the decoration waste are mixed, like the inert materials such as concrete, brick stone, etc., its mass volume occupies a relatively large part in the demolition phase, this part of the material is a relatively small impact on the environment, but improper disposal will occupy the land, waste space resources. On the other hand, this kind of waste possesses vital recycling potential and good prospects of circular economy [7]. Rather than inert materials such as gypsum, paint materials and other toxic, this kind of material has great direct and potential harm to the environment.

Until now, there are no relevant laws and regulations to constrain and manage the waste generated in the decoration process. At the same time, there is no management control of the decoration link; this also leads to the decoration of the construction site, and the owner ignored the environmental impact and waste of this link. At present, most of the waste generated in the process of new decoration is not properly and effectively managed. They are just randomly buried, dumped and piled; such treatment will severely occupy land and wasteland resources [3]. Secondly, the volatile infiltration of non-inert materials will lead to air, soil and underground water pollution. They have had a significant impact on human activities and even endanger people's life and health. Therefore, it is essential to strengthening the study on the waste of the decoration link. This study estimated the consumption and predicted the environmental impact of newly built decoration waste in Guangzhou in the future through the existing data and research.

1.1 Existing Researches on Decoration Waste

Referring to the literature review, some of the existing studies on newly built housing waste include studies on the decoration stage. In this study, using literature collection, the existing quantification methods of waste in the decoration stage are sorted out and summarized. There are three quantification methods commonly used:

Empirical estimation method: As shown in the calculation of decoration waste in the article of the current situation analysis of construction waste in Xi'an [8]. According to the statistical data of Shanghai, the decoration waste accounted for about 10% of the total construction waste. Because of city differences, the study adjusted the ratio to 15% based on experience. The paper estimates the output of decoration waste in Xi'an from 2008 to 2012 by using this method to estimate the output of decoration waste, the total amount of construction waste in the year can be obtained by reading literature and consulting statistical yearbook. At the same time, according to experience through literature or expert interviews to determine the rate of production of decoration waste. This method can be used to calculate the quantify without field investigation. However, subjective factors have a significant influence on the accuracy of the data. Using this method to carry on the quantification to the decoration waste should add the deviation analysis again on the basis to improve the accuracy of the calculation.

Unit cost waste quantity calculation method applied the unit cost of waste production and decoration cost. In the government released on the Luoyang city construction waste calculation label [9], it stipulates the unit cost and output of office buildings, store and other public buildings decoration waste. Therefore, the total amount of decoration waste of public buildings in a given year can be calculated based on the data given in this standard and the total cost of public buildings in this city. In the present study, this method is mainly used in regional research. Because of the difference in economic development and decorate complexity, there are obvious differences between different cities. As a result, there is a gap in the output of decoration waste at unit cost. Considering the impact of GDP and other related factors on its data, when the research scope is a large area such as province or country, the research should be carried out in a sub-region. At present, there are few official statistics on the interior decoration cost of residential and public buildings. Still, it needs to pass the method of questionnaire investigation, and spot investigation to statistic decorate total cost.

Waste yield per unit area calculation method. The method is calculated by using the output of decoration waste and decoration area produced per unit area. In the calculation of waste output per unit area method, the data published by the government can be used to calculate the amount of construction garbage issued by Luoyang to the city [9]. The waste output per unit area of the house is given, by using this data and statistical data, the regional output of decoration waste can be obtained by calculating the residential decoration area of this city in a year. In addition to the official release of data, unit waste production can also be obtained through field research. In the regional research, due to the regional differences in decoration and the incomplete official data, the decoration situation of the research area can be counted by questionnaire and field survey. According to the statistical data for data processing and induction, the calculation of the unit decoration garbage production realized. In research on decoration waste in Haikou [10], the method of on-site investigation and questionnaire survey was used to obtain unit production volume for calculation. The area of decoration can be counted through official statistics, and the statistical yearbook of each province and city has a transaction area about a new commodity house.

This study adopts the method of waste quantity calculation per unit area to calculate the amount of garbage produced in the decoration of newly-built commercial houses in Guangzhou considering the precision of the research and the complexity of the research method. The production amount of interior decoration waste varies significantly among different types; therefore, when adopting this method for calculating two different types of buildings should be classified.

In this study, relevant literature was sorted out, and some field research data were analyzed and revised. Previously, a field survey [11] was conducted on the waste rate of decoration waste in Shenzhen in 2018. Guangzhou and Shenzhen are located in the Guangdong-Hong Kong-Macao greater bay area, both of which are megacity cities in China. Therefore, the results of this literature study were used to carry out a quantitative study on decoration waste in Guangzhou. This study will carry out error analysis considering the accuracy of data sources. Besides, the output of waste per unit area in the decoration of residential and public buildings was calculated. In order to calculate the consistency and convenience, this study assumes that the newly built houses proceed with immediate decoration activities in its transaction year. The sales area of new commercial houses in Guangzhou statistical yearbook [12] can be used as the decoration area of new commercial houses in Guangzhou in that year.

2 Methods

2.1 *Scope of the Study*

The scope of this study is limited to the interior decoration waste of newly built commercial houses. Composition materials include concrete, masonry, metal, gypsum, wood, glass, paint, ceramic tile, paper, and so on. The main life cycle stages of decoration activities include decoration materials production, decorate activity. In the production stage, materials are produced and transported to the renovation site. Diverse categories of decorative materials are utilized in residential decoration, which is known as the waste generation stage. Furthermore, every material meets its particular production process. This study is based on the data of Guangzhou city, because of the availability of data from 1999 to 2018.

2.2 *Estimate and Projection Methods for Decoration Waste Generation*

The quantity of construction waste can be predicted by qualitative and quantitative methods. Quantitative prediction can predict the production of construction waste in the future using mathematical modelling. Exponential smoothing prediction model, time series prediction model, differential equation prediction model and grey theory prediction model are commonly used. When the prediction is calculated, the calculation process and precision of different models are different. The yield of construction waste is affected by many factors, but the prediction accuracy of the grey model theory is within the acceptable range, and the calculation amount is not huge, which is suitable for this study. It can meet the requirements of this study that the distribution rule of typical data is not required and the demand for sample selection is not great.

Grey system theory refers to the prediction of uncertain processes related to time series in a certain range of changes. That is, the development of eigenvalues in the system is predicted. The raw data shows messiness in the system process, but there is an underlying pattern. On this basis, the grey prediction model is established to predict the grey system, so as to predict the future development trend caused by the uncertain factors in the special field. According to the estimation trend of waste

Table 1 Model accuracy evaluation

Model accuracy level	Mean–variance ratio (C)	Small error probability (P)
Excellent	< 0.35	0.95–1
Good	0.35–0.5	0.8–0.95
Secondary	0.5–0.65	0.7–0.8
Unqualified	> 0.65	< 0.7

production from 1999 to 2018, the grey model was selected for prediction, and MATLAB software was used for calculation.

Testing the accuracy of the model is the basis for the next step of prediction. The test methods of model prediction accuracy mainly include relative error test, correlation test and posterior error test. In this paper, as Table 1 shows, the posterior error test method will be used to test the constructed prediction model. When the posterior difference method is employed to test the accuracy of the model, it can be determined by two parameters: mean square error ratio C and small error probability P. The classification of model precision is shown in the table.

2.3 Calculation Method

In this study, the method of unit buildings area estimation was used to estimate the amount of waste produced in a given year in Guangzhou. The method of estimating the amount of waste produced by buildings area was subject Eqs. 1–3:

$$W = Wr + Wp \tag{1}$$

where W represents the amount of decoration waste produced by new commercial houses in a given year; The Wr represents the total amount of waste generated from the decoration of new houses in a given year. Wp means the total amount of waste generated by the decoration of new public buildings in a given year.

$$Wr = Ar * Gr \tag{2}$$

where Wr represents the total amount of waste generated by the decoration of new houses in a given year. Ar represents the total area of residential decoration in a given year; Gr refers to the amount of decoration waste produced per unit area of residential buildings.

$$Wp = Ap * Gp \tag{3}$$

where Wp represents the total amount of waste generated by the decoration of public buildings in a given year; Ap means the total area of public buildings decoration in a given year; Gp stands for the amount of decoration garbage produced per unit area of public buildings.

2.4 Data Inventory

The data needed to estimate the output of decoration waste in this study are shown in the table. The sales area of newly-built residential buildings and public buildings can be obtained in Guangzhou statistical yearbook (SBGZ). The output of waste per unit produced can be referred to as literature data. Recycling and landfill related data were obtained from the literature (Table 2).

Through the literature summary, nine kinds of waste products generated in the decoration process: brick, concrete, wood chips, paint, paper, plastic, gypsum board, glass, metal, ceramic tile. The literature data revealed that the waste generation of residential buildings decoration is about 7.26 kg/m^2. The production of brick and concrete were namely 4.19 and 1.69 kg/m^2, accounting for 58% and 23% respectively. The production condition of public buildings is 3.06 kg/m^2. The concrete production was 1.07 kg/m^2, and brick production was 0.87 kg/m^2, the proportion of them were 35 and 28%. Ceramic tile produces quantity to account for a proportion of 13%; sawdust produces quantity to account for a proportion of about 12%. From the perspective of unit production (Fig. 2), different types of waste generated by different buildings types have different proportions. The inert waste still accounts for the majority, and the non-inert wastes generated by residential buildings account for a larger proportion than those generated by public buildings.

3 Results and Discussion

This research studies the decoration waste of newly-built commercial houses in Guangzhou, and the research scope is limited to the interior decoration of newly-built

Table 2 Key parameters and data source for quantification of decoration waste

Calculated index	Data Source	Definition
Ar	Guangzhou Statistical Yearbook	Floor space of residential buildings Sold
Ap	Guangzhou Statistical Yearbook	Floor space of public buildings sold
Gr	literature data	The output of waste per unit of residential buildings
Gp	literature data	The output of waste per unit of public buildings

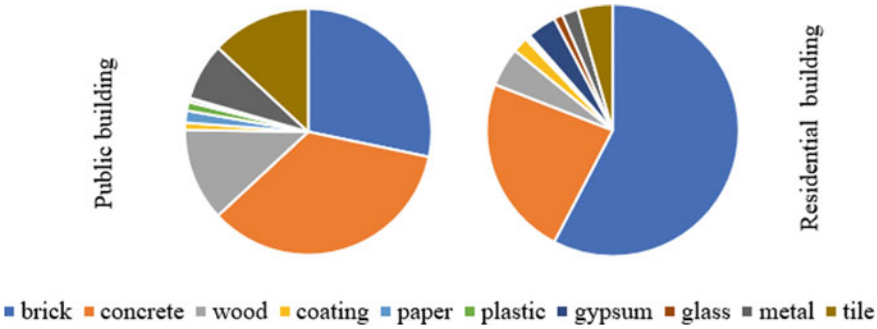


Fig. 2 Waste generation rate of decoration waste in different building types

buildings. Decoration activities have its particularity, unlike the waste generated in the construction process, the non-inert waste generated in the decoration process poses more serious harm to the environment. During the decoration process, most of these non-inert materials are disposed of together with household waste, which is dragged to the landfill or illegally dumped. Therefore, it is urgent to study the quantitative classification of decoration garbage according to materials. Employing quantification and prediction of future production, the waste generated in the decoration process can be studied, and the future management of decoration waste can be pointed out, which can also attract the attention of the government and relevant departments. By improving the control of the decoration process, the impact of such wastes on the environment can be reduced. Guangzhou, the capital of Guangdong province, has a huge economy, according to the statistics of Guangzhou statistics bureau, in 2018, the permanent population of Guangzhou reached 14.9 million and the transaction area of commercial housing reached 15.5 million square meters. A large number of people will bring a large number of decoration activities, which should capture individuals' attention to the environmental impact.

3.1 Estimation of Decoration Waste Generation

There are many smaller units in the waste generated in the decoration process, and a lot of powdered garbage exist in them. The amount of this kind of waste is small, but the pollution to the environment is non-negligible, so it is necessary to increase the study of the waste generated in the decoration link and classify and quantify its production. This study selects the decoration waste of newly-built commercial houses in Guangzhou city as an example and conducts a quantitative study on decoration waste. In this paper, through statistical yearbook and literature reading, the author quantified the commercial buildings into two types: residential buildings and public buildings. Residential buildings decoration unit area is small. This type of decoration

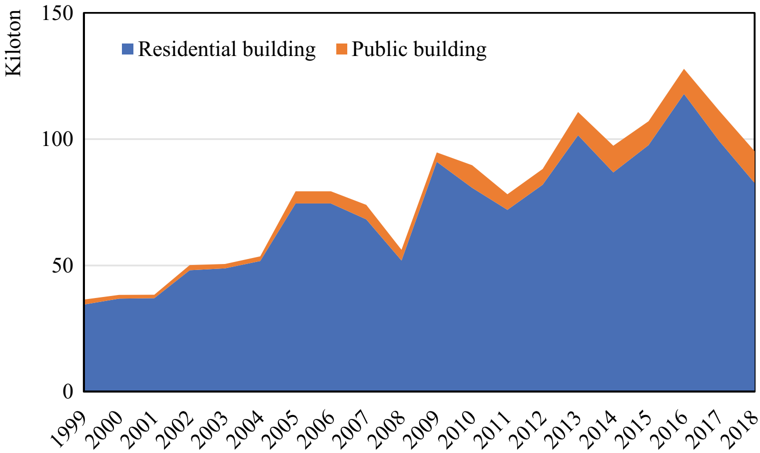


Fig. 3 Estimation of decoration waste in Guangzhou city

waste is more easily ignored. However, the large trading area of residential buildings leads to the large output of decoration wastes generated by such buildings.

In Fig. 3, the output of construction waste generated by the decoration of newly built commercial buildings in Guangzhou in the recent two decades. From 1999 to 2018, the output of decoration waste increased rapidly; additionally, continued growth poses a great threat to environmental governance. Residential buildings produce more decoration waste than public buildings, so more attention should be captured to the decoration management of residential buildings. The research reveals that the waste generated by public buildings decoration increases rapidly with time; similarly, public buildings produced about six times as much waste in 2018 as they did in 1999. With the development of economy and society, the construction of public buildings will increase accordingly. The decoration waste caused by public buildings decoration also ought to be controlled timely. The amount of decoration waste is less than the amount of demolition waste, but the total amount of the last two decades is not to be ignored.

The output of waste per unit area involved in this paper is the data cited in the literature, so it is necessary to conduct an uncertain analysis to estimate the total amount of decoration waste in the recent two decades. In this paper, the crystal ball software is used to carry out a Monte Carlo simulation experiment on the total amount of decoration waste estimated in the paper. The area data and unit production data were put into the crystal ball software, and through nearly 10,000 experiments, the estimates ranged from 1.45 million tons to 1.66 million tons. About 1.55 million tons of wastes, if directly released into the environment, will cause great harm to the soil and atmosphere. If effective and reasonable utilization of resources is carried out, it will not only reduce pollution but also bring economic benefits.

3.2 Composition of Decoration Waste

In order to identify the metabolic pathways of various kinds of waste in the process of material metabolic output in Guangzhou decoration activities, this study collected the flow direction of decoration waste through literature collection. A large amount of decoration waste is disposed of with nearby dumping sites. However, wasted materials (e.g. wasted, metals, paper, plastic, and wood) with higher economic value can possess higher recycling rates, whereas low economic value materials (e.g. brick and concrete) cannot be treated appropriately for future construction. Figure 4 shows the direction of different types of decoration waste, and it is found that the total recovery rate of newly-built decoration waste in Guangzhou in 2018 is only 8.6%. Such a large amount of landfill disposal can create a significant negative environmental impact.

The percentages of various materials in the composition of decoration waste in different types of buildings, in Guangzhou city in 2018, was estimated in this study, as shown in Fig. 5. From the perspective of total volume, due to the high transaction volume and complex decoration of residential buildings, the decoration waste of residential buildings exceeds that of public buildings. The production of wood, paper, plastics and metals in public buildings is relatively high, which the recovery rate of these substances is higher than that of other substances. The amount of brick and coating used in public buildings is relatively smaller than those used in residential buildings because residence buildings need to achieve the particular requirements of space division. Among these, indicating more supervision should be given to the decoration activities of residential buildings.

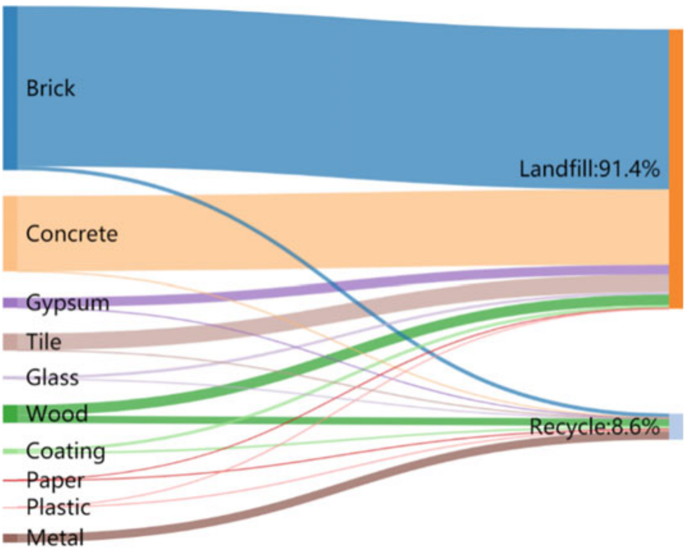


Fig. 4 Materials flowed of decoration waste in Guangzhou city in 2018

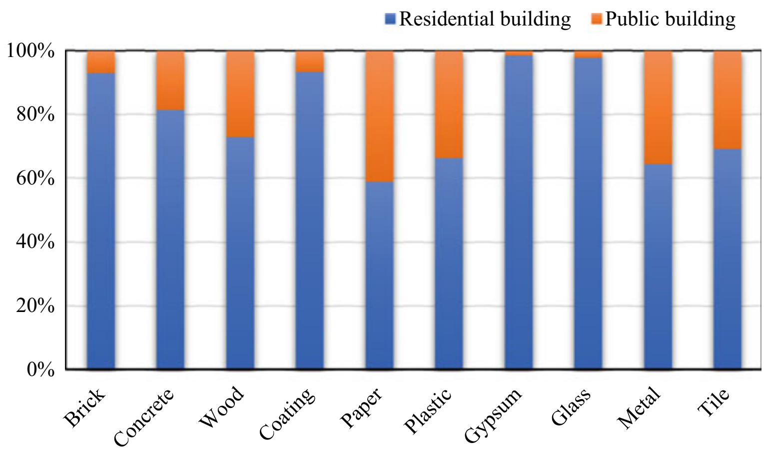


Fig. 5 Generation of scrap materials for residential and public buildings (in 2018)

3.3 Projection of Decoration Waste Generation

As for the quantitative estimation, based on the estimated value of new decoration waste production in Guangzhou from 1999 to 2018, the grey model was used to predict construction waste production. From the comparison of predicted value and estimated value, the predicted value of waste production is close to the estimated value, and the specific value is plotted in the figure. From 1999 to 2018, the average annual growth rate of new commercial housing decoration waste in Guangzhou reached 8%, and through forecast research, the next five years decoration waste will continue to grow. Besides, the average growth rate will increase to 12%, which is remarkable. If there is no future decoration waste policy and management intervention, the resulting environmental impact and social impact is unpredictable.

$GM(1, 1)$ the model was used to predict and test the output of construction waste. Model test C = 0.25611, P = 1. From the results obtained, it can be seen that the P and C tests are good and belong to the first level. The table is the forecast for the output of decoration waste from 2019 to 2023. According to Eq. 4:

$$\hat{X}^{(0)}(k+1) = \left(1 - e^{a}\right)\left(x^{(0)}(1) - \frac{b}{a}\right)e^{-ak} \tag{4}$$

Through the forecast, undoubtedly, Guangzhou's new commercial housing decoration waste production situation presents a trend of continuous growth in the future (Table 3). Although the amount of decoration waste compared with the demolition phase of the waste is small, considering the characteristics of decoration waste, such as strong toxic, large harm scope, the society has to seriously treat the seriousness of its harm. Therefore, the government should timely issue corresponding management measures and policies to predict and deal with such pollution faster.

Table 3 Forecast quantity of decoration waste

Year	Predicted value(10^3t)
2019	122.8
2020	134.2
2021	141.1
2022	148.3
2023	155.8

3.4 Suggestions for Soundly Managing Decoration Waste

The disposal and resource utilization of decoration waste can be started from the two aspects of reducing output and increasing resource utilization rate. Reduce that is, control from the source, by reducing the amount of waste generated in the decoration process to achieve reasonable control. For the decoration of residential buildings, the management mode can be changed, and the decoration of one family can be transformed into the prefabricated decoration of the whole buildings or the whole community to realize the efficient utilization of resources. The prefabricated parts of the assembly decoration can reduce the waste of materials, and planning the number of materials can also reduce unnecessary waste. The unified decoration management not only controls the output from the source but also carries on the unified management to the waste that has produced. Until now, decoration waste management caused a certain degree of damage to the environment; hence, the orderly disposal of this type of waste should be poured attention. The assembly decoration is still in the exploration stage, in the future, it can further deepen the research of assembled decoration, and explore its rationality in economic respect as well as the feasibility on decorating quality. Plus, through the whole life cycle theory to explore whether the assembly decoration has enough advantages is a subject worthy of study.

Moreover, most of the technical equipment for the resource-based utilization of construction waste in China is imported from abroad, and there is a lack of technical equipment with independent intellectual property rights. Therefore, it is suggested that the government should encourage universities, scientific research institutes and enterprises to adopt a cooperative approach to focus on the research and development of common key technologies (such as construction waste disposal technology, production technology of recycled products) and advanced production equipment manufacturing. In this way, the technical level, industrial production level and added value of recycled products can be continuously improved.

Following the principle of “who produces, who bears the responsibility for the disposal”, the disposal fee system of construction waste shall be studied and developed as soon as possible. Meanwhile, in combination with the relevant national and provincial documents and regulations, it is indispensable to explore the policies such as tax reduction and exemption of renewable construction waste products, preferential treatment of relevant factory land, a tax refund of value-added product tax, etc. Thus, to study the feasibility and operability of the application proportion of renewable products in the public welfare projects invested by the government could promote the application of renewable products. Furthermore, it is also one of the significant measures to actively introduce social capital to participate in the resource utilization of construction waste.

4 Conclusion

In this paper, the area of the building prediction method is adopted to estimate and analyze the waste products of newly-built commercial house decoration in Guangzhou; simultaneously, the grey model is employed to predict the waste products in the future. The main conclusions are as follows:

According to the estimation of waste production per unit area, in recent years, the accumulative production of newly built commercial housing decoration waste in Guangzhou has exceeded 1.6 million tons. In the absence of a regulatory policy, illegal dumping and landfill have resulted in serious pollution and impacts. It is urgent to promote the recycling of construction waste in the province. Besides, it is suggested to strengthen the construction waste treatment and resource utilization in the aspects of planning standards, pilot demonstration, technological innovation and policy support.

Despite its benefits, the limitations of the research should highlight. As a result, the estimation accuracy of the results needs further examine. Plus, it is suggested to improve the research method of estimating the yield of construction waste, and a better method could develop for calculation standard of production volume according to the actual situation of the region. The grey model is effective for short term prediction, but hardly fulfil its accuracy for medium and long-term prediction. In order to further modify the prediction accuracy, the combined weight method can be used for short-term prediction, that is, two or more different single models can be hybrid used for prediction, respectively.

From this research, intensive study of decoration waste is highlighted. In the future, the research scope will be expanded, not only the expansion of the research area but also the second-hand housing decoration part of the decoration waste research. Mainly speaking, the impact of decoration waste on the environment was from the particularity of decoration materials used, such as gypsum, paint, both are non-inert materials. Because the material characteristics will bring great harm to the environment; consequently, the research on the environmental impact of waste from such materials will be expanded in the future.

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A Systematic Design Approach for the Innovation of Supply Chain Resilience of Prefabrication

Clyde Zhengdao Li, Zhe Chen, Yiyu Zhao, and Xulu Lai

Abstract Prefabrication has been widely deployed as an integral part in the intelligent construction, of which prefabrication supply chain resilience (SCR) will play a significant role. However, when an emergency [e.g., the outbreak of the novel coronavirus disease (COVID-19)] occurs, prefabrication's life-cycle management will be seriously threatened. Besides, there exists efficiency and interaction challenges such as schedule delays, invisible progress, and fragmented information transmission. This article aims at developing an intelligent platform based on inclusive technologies, incorporating blockchain, building information modeling (BIM), and Internet of Things (IoT) to facilitate the real-time management of prefabrication supply chain. Specifically, from the perspective of stakeholders, this platform not only shares real-time interactive information management and control but also provides reliable support for decision making. As far as potential security issues are concerned, a blockchain framework is proposed to reveal how it helps to guarantee the reliability and authenticity of the entire supply chain. Under this platform, a case study in Shenzhen is presented to demonstrate the feasibility of the platform. With the guarantee of interactive efficiency and data reliability, the prefabrication supply chain is considered to be more resilient to disruptions.

Keywords Prefabrication · Supply chain resilience · Blockchain · Internet of Things

1 Introduction

Prefabrication, with its widely recognized benefits, has become a trend in the construction industry [1]. However, the conventional prefabrication faces several

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challenges, including low productivity, environmental pollution, high safety risks, and emergency events. prefabrication relies on the stable operations of supply chains, which mainly include building design, prefabricated components (PC) production, logistics, and prefabrication assembly [2]. As a result, in supply chain management (SCM), how to build resilient supply networks becomes increasing more significant. Supply chain resilience (SCR) is the ability of a preexisting network of demand and supply to deploy surviving capacity, and/or introduce new capacity, under severe duress. Given the prefabrication has diverse construction sites, long construction cycles, large industrial chains, and vulnerability to various uncertainties, even disruptions in a small node of the supply chain may cause the serious consequences [3].

As supply chain become more complex, the ability to quantify and mitigate supply chain risks is paramount. Shareholders need to identify the critical risks so as to minimize disruption and help ensure supply chain operational efficiency, financial flows and data security [4]. The prefabrication's resilience is determined by its ability to continue working even when important portions of the network are no longer operating [5]. As all supply chain components can impact prefabrication SCR, it is indispensable to employ emerging technologies to realize the enhancement of resilience. The extant Internet of Things (IoT) systems are built on a centralized server/client model that requires all equipment and information to go through a set center, whereas this model is unable to meet the demand for outspreading IoT in the future [6].

With the development of IoT, security and privacy concerns have become main barriers to its implementation [7], in which data may be communicated under low-power and lossy environments. Therefore, in the prefabrication supply chain, the security of information interaction has become one of the major concerns for stakeholders. Blockchain, as one key solution to these problems, is a distributed database of records that stores all transactions in a distributed ledger and verifies them with the consent of the participants in the network. Blockchain technologies send instantaneous updates to each stakeholder in the supply chain by using peer-to-peer networks for information sharing, thereby guaranteeing information security [6]. In addition, the decentralized model of the blockchain can handle large amounts of data collected by the IoT, which thereby greatly reduces the costs associated with the installation and maintenance of large centralized data centers [8]. Supply chain has the advantages of integrity, meanwhile, it also faces the risks once the supply chain is interrupted. Supply chain interruption refers to events with high degree of uncertainty which incurs the value and utility of existing resources ambiguous. SCR, based on the basic assumption that not all risks can be prevented, is the ability to self-rebuild an interrupted or broken supply chain which even stronger than before. In the overview of SCR, four principles of supply chain were proposed, including (1) supply chain reorganization, (2) collaboration, (3) agility, (4) supply chain risk management culture. Most studies have emphasized the critical role of resilience assessment in considering the risk of damage.

Previous research on prefabrication SCR often adopts the risk management perspective and focuses on single stage of prefabrication SCM [9]. However, the construction supply chain is a network of cross-echelon organizations that are connected by information, material, services, product flows, and capital flows among stakeholders [10]. The core strategies of the prefabrication SCM are embodied in five aspects, namely, collecting, integrating, coordinating, sharing, and securing [11], however, little research following this direction can be found in the existing literature [12]. Therefore, to address the limitations related to cooperation, information interaction and security, by using lightweight building information modeling (BIM) as basic underlying infrastructure [13], an IoT-integrated and blockchain-enabled platform is developed in this paper. At the same time, relevant schemes have been configured in its core links to enhance resilience, so that the negative impact caused by the interruption could be mitigated, and the supply chain system could recover from the impact of disruptions.

2 Structure of Systematic Design Approach

The platform involves many professional fields, multiple levels of users, data information diversity, strong professional characteristics, thus the platform of the overall solution architecture design should not only contain the project construction of hardware and software system but also consider how to make the project implementation achieve its desired results. The whole system structure includes the technical support part, the data processing part, the system business part and other different levels of support and application parts. In addition, it also has security systems, standard systems, and data exchange service systems etc.

2.1 Platform Operation Structure

The traditional prefabrication management system uses a temporary project department for project construction management, thus, the management of each phase of the project can be readily separated, and unified. However, coordinated management will be more difficult to achieve. Consequently, information islands will be generated easily. Given that the construction units of project progress, quality, risk, and fund-tracking are difficult to control, prefabrication projects need to be combined to build a new digital management system [14–17]. prefabrication project information management systems are based on computer technology, communication technology and other edge digital technology, coordinated with the construction project information management systems and its structure as well as organizational levels to achieve its management function. By adopting the idea of system management, the platform can be divided into four levels, namely, the sensing layer, intelligence layer, big data processing layer, and application layer.

2.1.1 Sensing Layer

An information center is set up on the site, and each link of the prefabricated building collects data on the daily operation level of project management by automatically or manually operating information-reading devices (e.g., sensors, cameras, and RFID) during the construction of the prefabricated building project. In the process of system management and control, this layer will conduct comprehensive data collection and management on project safety, project quality, project schedule and other aspects.

2.1.2 Intelligence Layer

The intelligence layer embodies the core value of the platform, is mainly supported by IoT and blockchain technologies, and serves as the bridge between the interface and data access layers. If we aim to manage the information network and data platform of a prefabricated building project, each system requires a reliable infrastructure to manage, which is the key in ensuring the normal operation of the digital core infrastructure of a prefabricated building project and supports the coordinated operation of various information collection, transmission, communication, and network systems, maintains the relationship among all parties, and provides a reliable basis for synergy.

The intelligence layer implements the business logic and focuses on the formulation of business rules, implementation of business processes, and other business requirements related to system design. This layer provides support for the subsequent implementation of the system structure, including the system function modules, data access storage data interface, data security inspection mechanism, user authentication and permission control, and security detection system, to prevent illegal intrusion and security control.

2.1.3 Big Data Processing Layer

The big data processing layer deals with databases, including data addition, deletion, changes, and checks. The data stored in the database are submitted to the business layer, whereas the data processed by the business layer are saved in the database. The operations of the data access layer are based on those of other layers. User needs are reflected to the application layer and are subsequently forwarded to the intelligent layer and then to the data layer. The data layer carries out data operations and then returns these data one by one to the specific users, thus realizing a centralized and orderly management of data in the system. This layer involves basic document data, BIM information and 3D geographic information systems, monitoring data, and information generated by management processes.

2.1.4 Application Layer

The application layer involves the application of relevant data for business management by different stakeholders. In the user interaction interface, this layer receives the data input by the user and then displays the data required by the user after processing. The user groups involved in the management system are defined. The system then offers different access interfaces and assigns corresponding functions and data permissions according to the levels and user identity. The user groups involved in the system include owner (such as the government), design, production, transportation, and construction units. The application layer is also mainly responsible for the timely, accurate, and comprehensive management of the engineering process, receiving timely engineering instructions from the upper layer, and offering timely feedback to ensure the convenient application of services for the system users.

2.2 Platform Safety Structure

System and Internet security are important aspects of the intelligent platform. System security requirements [18], including data security requirements (e.g., confidentiality, integrity, availability, and network security requirements) and application security requirements (e.g., identity authentication and access control), ensure the safe operation of the system. Each stage of prefabrication involves many shareholders and generates a huge amount of data. Therefore, the system adopts certain security measures, such as blockchain and advanced computer encryption technologies, to ensure the privacy and security of data in the system.

2.2.1 Data Security

To ensure data security, smart systems use blockchains to implement a strict data encryption. Encryption algorithms are generally classified into symmetric and asymmetric encryption and integrate encryption technology into blockchains to fulfill security and ownership verification requirements. Asymmetric encryption often uses two asymmetric ciphers, namely, public and private keys, during the encryption and decryption processes. Asymmetric key pairs have two characteristics. On the one hand, after encrypting information with one of the keys (either public or private), only the other corresponding key can be unlocked [19]. On the other hand, the public key can be disclosed to others, while the private key should be kept secret. Other people cannot calculate the corresponding private key through the public key. The intelligent system also records the activities of the computer network system users. This system not only identifies the objects that are accessing the system but also indicates how the system is being used.

Data transmissions traditionally adopt an intelligent system. Specifically, based on the algorithm used in the encryption of confidential data, the encrypted data are transmitted to the Internet and then are sent to the client. Data are encrypted at every upload and download stage, and they cannot be changed unless all the relevant personnel agree to modify the data. The stakeholders in each stage upload encrypted data after completing the data collection and processing, and secure data transmissions are conducted in the blockchains. All parties are unable to modify or delete the uploaded data but can view and use these data within their respective authorities, thereby enhancing the security of all types of construction data.

2.2.2 Application Security

To ensure the security of the user operating system, only registered users with the system administrator are given access. Each user is given server access, database access, form and view access, section and field access, document access control, and application system operation privileges by the system administrator, and each prefabricated building owner party and design, production, transportation, and installation party is given different control permissions. System control users can only operate within their scope of authorization and cannot exceed their authority over the operation. The system has a timeout validation function to prevent users from leaving for a long time after their entry. Specifically, when a threshold interval exceeded, the user needs to log in again to continue operating the system.

The construction data and component information of each stage are also traceable. The blockchain used by smart systems is a decentralized database where nodes store the data, and these data are scattered across the network of linked computers instead of being controlled by a centralized server. Given that the data stored in the blockchain are secure, the data in the blockchain can be tracked. Any data generated by the prefabrication process are unique and can be recorded by blockchains. In other words, these data can be searched and traced, thereby clarifying the rights and responsibilities of users and ensuring the authenticity of the construction data.

3 Practical Application of the Intelligent Platform

3.1 Description of the Case Study

As the first EPC project in Longgang District, Shenzhen City, the Baolan Community is a government-funded indemnificatory housing project. This project is selected in this research as a practical case. To collect relevant information, the research team has arranged a series of site visits and meetings with the government personnel who are responsible for the housing production in the district, the managers of PC manufacturers and logistics companies, the relevant engineers, and the managers of contractors. Various project stakeholders, including owners, manufacturers, transportation personnel, engineers, and workers, are also invited to test the intelligent platform.

The project BIM models are automatically analyzed and uploaded to the intelligent platform after lightweight processing, and the project data are automatically gathered and uploaded in real time.

3.2 Functional Operation of the Platform

3.2.1 Project Management Service

The project participants use their respective enterprise accounts and passwords to log into the platform. The login roles of the intelligent platform are divided into the owner, design, component production, transportation, and construction units, with each unit having a unique set of system operation rights. After different roles log into the system, the following application operations are carried out:

(1) the owner performs model audit, production progress follow-up, logistics and transportation progress tracking, construction progress follow-up, quality and safety control, cost direction, completion acceptance, and operations and maintenance management;
(2) the design unit evaluates the model design and layout and uploads the BIM model files of the project;
(3) the production unit evaluates the model layout, sets up the component production plans, and produces the components;
(4) the transportation unit is responsible for the transportation and positioning management of the components; and
(5) the construction unit is responsible for the component inspection and site installation.

After generating the data according to the operations of different roles in the system, the platform carries out the subsequent operation according to the business process in order to realize an accurate flow of data among the project participants and to achieve the goals of information sharing and collaborative work. The management cockpit generates statistics on the component distribution, plan implementation, and investment status in each stage. The data penetration function is used to generate a real-time components data statistical chart to simplify the operation interface and ensure the richness of the data. Clicking the previous part of the plan execution diagram will generate a corresponding list, whereas clicking the "Details" button will present the details of the components.

In the project management function of the platform, taking the project as the main line and maintaining the basic project information, project data, other data, and information of each project stage in series can realize an efficient management of the entire project process. With the help of the system, each stakeholder can view real-time information about the components from their design to their installation and receive visual assistance for the subsequent process control, operation, and maintenance. The system also provides solutions for managers in each stage and allows them to check information related to the project progress and cost control that can help them further understand the manufacturing and construction details.

3.2.2 BIM Model Management Service

The BIM model has a huge data volume. For instance, a model of a civil structure curtain wall with a floor area of 300,000 m^2 consumes 1.7 Gb. In this case, if direct transmission and processing are performed in the system, having a large amount of data corresponds to a poor efficiency and high hardware equipment and network bandwidth requirements. Therefore, a lightweight BIM model must be built by technical means, such as targeted data compression and reduction technologies. In the joint development of a lightweight model and algorithm, targeted data compression and reduction techniques can reduce the original model size by approximately 85%. This technique also allows the BIM model to move from traditional desktop software to web and mobile terminals without being affected by the computing power and memory limitations of the browser. The combination of BIM technology and Internet of things technology transfers the needs of owners, designers, component manufacturers, transportation and logistics parties and construction parties from offline to online applications. In this way, BIM technology application and service can be provided conveniently through the Internet to maximize the advantages of BIM. After developing a lightweight model, the computer performance requirements are reduced, and the data can be processed efficiently and quickly.

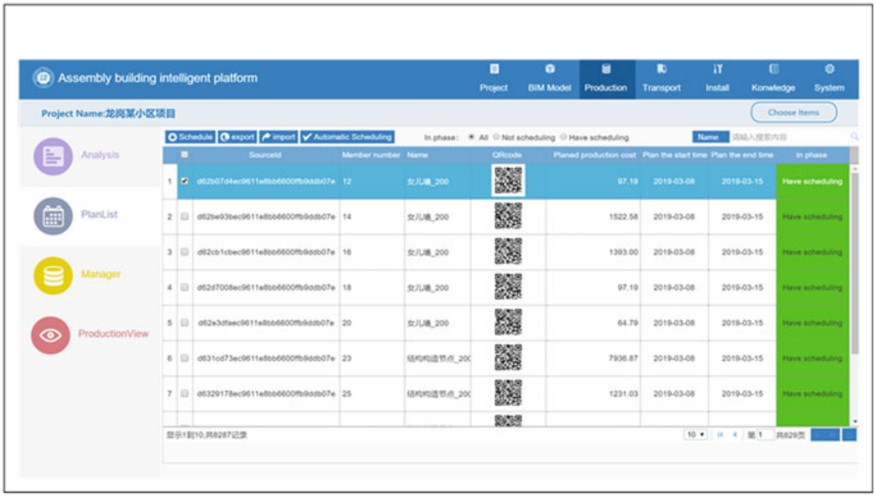
After receiving basic project information, the design unit starts to design and typeset the model before uploading the model files into the system. After lightening the model, the system automatically reads the contents of the files and sends them to the stakeholders in the other stages for subsequent works. In the model management service of the platform, the BIM model can be browsed by single building, floor, component type, component multi-level, and multi-perspective using Internet Explorer and a mobile app. At the same time, viewing the model of the project can visualize and monitor the real-time progress of the construction. Different colors represent the various states of each component. For instance, transparency indicates that the component is assembled, whereas red color indicates that the component has not been produced. In the real-time visualization of project progress, when a user clicks a floor in the BIM model, s/he can obtain detailed information about its components, including design, status, schedule, and cost.

3.2.3 Production Management Service

Production management service generates statistics on four dimensions, namely, production component state, production schedule, production execution, and production investment. In the proposed platform, the bill of quantities and BIM model of PCs can be obtained to ensure a smooth production process. Components manufacturers can also directly input the start and end times of PC production through this platform. Cost is an extremely important factor in PC production management. As shown in Fig. 1, the planned and actual investments are reviewed in each phase of the project, and the implementation cost management and control of the project can be realized through a statistical analysis of the cost management function. Clicking the cost statistics line graph of a node at a certain period displays detailed information, including the current sub-item investment proportion and total funds used.

After receiving information on the design unit model and components, the manufacturer starts to arrange the components production plan, views and downloads the list of PCs, and imports the costs, schedules, and other plans of the production unit to manage the project components through the platform. After the manufacturer produces the components, the platform generates QR codes, and each component

Production statistics



QR codes and status of components

Fig. 1 Production statistics and components status associated with these QR codes can be uniquely identified. The QR code logo of the project is used for production, logistics, transportation, installation guidance, mobile app, and other business function modules. The production progress of components can be visually displayed by using BIM technology, the production of components is tracked and managed by using QR codes, and the production information, current status (unscheduled, to be produced, in production, and completed) of components are recorded, thereby providing solutions for the production department. After entering the production plan page, the user can also set the exact schedule, select multiple components, click on "schedule," and set the start and end times of the plan.

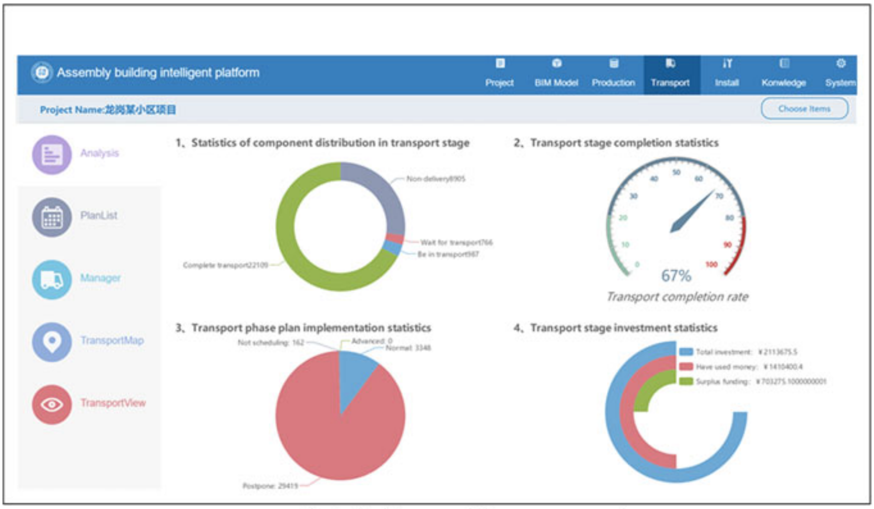
3.2.4 Transportation Management Service

As shown in Fig. 2, the platform also generates statistics on the distribution of components, mission completion, plan execution, and transportation cost in the transportation phase. In this way, the relevant staff and decision makers can make the appropriate adjustments.

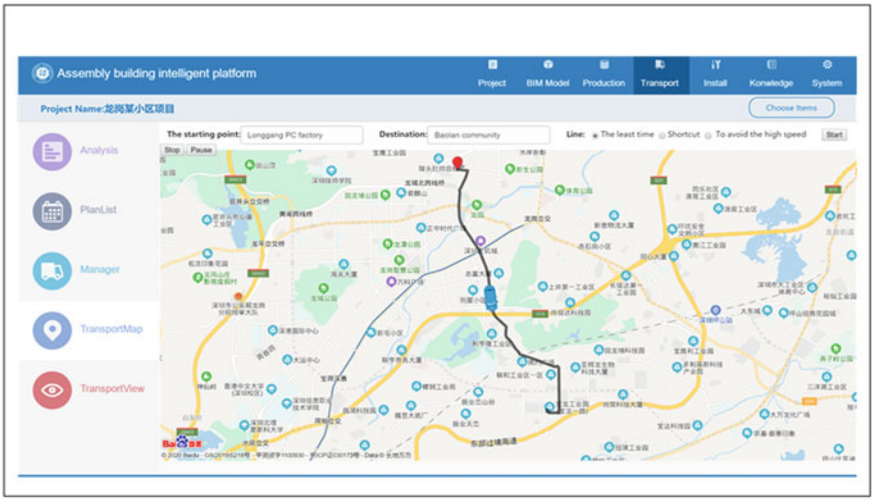
(1) Checking the real-time transportation cost
The platform can produce real-time statistics on the investment in the transportation stage and visualize the transportation costs. If the funds used do not match the progress of transportation components, then component transportation enterprises and owners can use this function to check whether the use of transportation vehicles is reasonable and when the selection of transportation lines is optimal.

(2) Components intelligent management
Components manufacturers can send production instructions from the construction site to the component prefabrication factory and then adjust their logistics transportation plans. By understanding the component transportation plan of the transportation unit, the site assembly manager can make predictions regarding the incoming vehicles, the loaded prefabricated components, and the entry time of these components. Additionally, the unloading of machinery, movement of vehicles within and outside of the route, and location of the stacking site can be planned in advance to avoid vehicle congestion and other problems.

(3) Quality information management
During their transportation, the quality of components can be damaged due to the bumping of vehicles and other operation errors in loading and unloading processes. The platform stores information and images related to the transportation stage, such as the quality of components before delivery, driver information, delivery time, vehicle license plate, and transportation route. When a quality problem emerges, the cause of such problem and the person responsible can be traced through the system.



Cockpit of transportation management



Simulation of real-time transportation

Fig. 2 Transportation management

(4) Simulation of real-time transportation
A real-time positioning and simulation planning of transportation lines is carried out based on GPS. The QR codes technology is used to store and extract the component logistics information and to realize a visual intelligent scheduling of component transportation. Transportation managers can use a mobile app to obtain the factory information of the prefabricated components. An intelligent and visual transportation environment can also be established by combining the basic factory information and transportation information of

the components. Each project participant can link the transportation vehicles to their components. The information communication platform can be used to update and locate the transported PCs, ensure an efficient data collection and real-time logistics information transmission, and realize information sharing, all of which can help the participants rationally plan and control those problems that emerge during the transportation phase.

3.2.5 On-Site Assembly Management Service

The on-site assembly management service of the platform is mainly used to guide construction personnel in installing PCs. The system can assist workers in determining the real-time assembly progress of components and the corresponding state of PCs in the assembly phase. Clicking on a specific component reveals detailed information that can facilitate its assembly. On-site construction managers can also log into the mobile app for real-time information query and feedback. QR codes can also be scanned by the mobile app to obtain component installation information and guide the on-site operation. The component installation progress is displayed in real time in the BIM model, and the rationality of the construction process is automatically verified. The system can assist in the installation, positioning, and lifting of auxiliary components, thereby improving the on-site installation efficiency of workers and avoiding rework due to installation errors.

As shown in Fig. 3, when the components are transported to the construction site, the on-site material manager launches the QR codes scanning function of the PC storage to complete the PC storage operation. When uploading warehousing information to the cloud platform, other personnel can check the status of PCs through the platform and mobile app. After installing the PCs, the on-site construction supervisor activates the QR codes scanning function of the component installation and uses the input operation of the installed component to confirm its installation. By moving the app and clicking on the up, down, left, right, front, and back buttons, the camera is adjusted to scan the QR code, verify the position of components, and generate the corresponding results. Component calibration produces two types of results, namely,

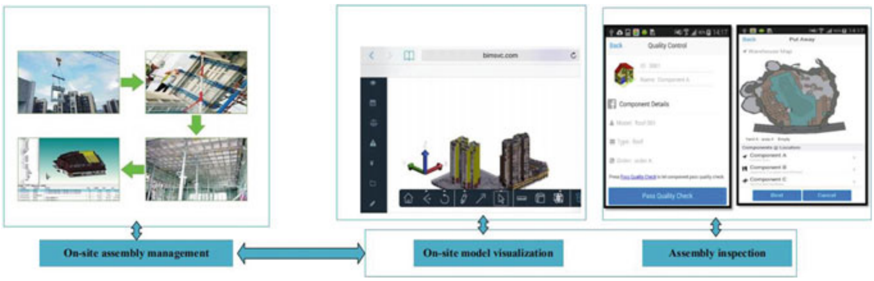


Fig. 3 On-site assembly management

correct matching of the components and failure of component matching. If a failure alarm is sent out, then the errors in installation can be corrected in time.

4 Conclusion

Over the years, prefabrication has played a significant role in the construction of public houses in China, but its benefits cannot be realized without overcoming its inherent drawbacks related to data fragmentation, processes discontinuity, poor interoperability among enterprise information systems, and poor visibility and traceability of real-time information. Reviewing practical implementations in case study, main benefits of proposed platform can be summarized as: (1) resilience enhancement, where the platform can be seamlessly integrated with PHC supply chain to enable the sharing and synchronization of information throughout the lifecycle. Specifically, no matter which phase encounter unexpected interruptions, the platform is committed to alleviating the effects of disruptions and avoiding long-term failures. (2) Lean construction, by utilizing blockchain, in addition to the realization of traceability of PCs, it performs authority classification and security-assurance based on smart contract. (3) Timely interaction and convenient access, with the real-time feedback and visualization achieved in the platform, real-time costs in every stage can be visualized to facilitate the relevant staff making the appropriate modifications. Furthermore, it is feasible to identify any current or potential barriers such as schedule delay, labor shortage, and incorrect installation.

Despite its benefits, the limitations of the proposed platform warrant consideration. Still in its research stage, this platform may be unable to be operated by some stakeholders. This platform also requires relevant professionals from each participating unit, thereby hindering its full implementation. This problem can be mitigated to a certain extent by customizing the operation manual for operators in different stages. Additional case studies should also be conducted to validate its effectiveness, and the user interface of web systems and apps should be refined to make the platform suitable for the operation habits of site workers. Despite these limitations, this research not only pioneers the development of a platform for on-site assembly services of prefabricated construction by integrating blockchain and IoT technologies but also serves as a solid basis for further research. Future studies may also investigate other prefabrication concerns with the help of the proposed intelligent platform.

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Performance Assessments of Clustering-Based Methods for Smart Data-Driven Building Energy Anomaly Diagnosis

Yan Yu, Cheng Fan, and Jiayuan Wang

Abstract The wide adoption of building automation system has collected massive amounts of building operational data, which are of great value to facilitate the decision-making of building professionals. In the past few years, many data-driven approaches have been proposed for building energy anomaly diagnosis. Existing studies mainly utilized clustering analysis as the analytical tool as it can be applied with little prior knowledge. One of the most challenging problems is the performance assessment of clustering-based methods for building energy anomaly diagnosis, as there is no ground truth for validations. This study aims to quantitatively assess the effectiveness of different clustering algorithms in building energy anomaly diagnosis. To ensure the research validity and generalization performance, building energy data from 10 primary schools have been adopted for analysis. Manual labeling has been conducted to provide ground truths on building energy anomalies. A number of data-driven methods have been proposed for identifying daily energy anomalies using different feature extraction and clustering methods. The method effectiveness has been tested using the manually labeled data. This study helps to quantify the value of clustering-based methods in building energy anomaly diagnosis. The research outcomes are beneficial for the development of data-driven methods for smart building energy management.

Keywords Building energy management · Anomaly diagnosis · Data-driven · Clustering analysis · Performance assessment

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1 Introduction

Buildings are responsible for the majority of global energy consumptions. The energy efficiency of buildings has essential impacts on sustainable development. Meanwhile, the wide adoption of building automation system has collected massive amounts of building operational data, which are of great value to facilitate the decision-making of building professionals. The main challenge in both academia and industry is to develop suitable data analytics to extract useful insights from building operational data for energy efficiency management.

In the past few years, many data-driven approaches have been proposed for the in-time detection of building energy anomalies. The anomaly diagnosis methods can be broadly classified into two groups, i.e. supervised and unsupervised methods. Alfonso Capozzoli et al. used statistical pattern recognition technology, artificial neural integrated network and outlier detection method to conduct anomaly detection [1]. Li et al. developed a two-stage data-driven fault detection and diagnosis strategy, which could detect and diagnose faults in the first stage and identify fault severity levels in the second stage. The method was verified by the ASHRAE Research Project 1043 [2]. The above methods are supervised methods, requiring the data to be labeled either by expert knowledge or manual inspections. Unlike supervised learning, unsupervised methods do not require the data to be labeled and therefore, is more convenient for practical applications. Clustering analysis is one of the most widely used unsupervised learning techniques. Panapakidis et al. applied the K-means and Self-Organizing Map algorithms to the power consumptions of different buildings to study building energy behaviors [3]. To analyze the abnormal pattern of the variable refrigerant flow system, Chen et al. firstly used correlation analysis to select key factors. The density-based spatial clustering of applications with noise method was then used to remove transient data and outliers, based on which Support Vector Regression algorithm was adopted for power prediction and anomaly detection [4]. Fan et al. proposed a data mining framework for analyzing building operational data based on Association Rule Mining. The frameworks showed powerful capacity in detecting abnormal building operations and faults [5]. Madhikermi et al. proposed a process history-based method by adopting nominal efficiency of air handling units to detect heat recovery failure using Principle Component Analysis (PCA) and Logistic Regression [6].

Clustering methods have been implemented for a variety of purposes related to building energy consumptions, such as patterns recognition and energy demand characterization [7–9], demand side management [3, 10], building energy consumption forecasting [7–9]. One of the most challenging problems is the performance assessment of clustering analysis, as there is no ground truth or labels to justify the clustering results. To tackle this challenge, manual labeling has been adopted in this study to provide ground truths on building energy anomalies. To ensure the research validity and generalization performance, building energy data from 10 primary schools have been adopted for analysis. A number of clustering-based methods have been proposed for detecting building energy anomalies, each varies in terms of the feature extraction and clustering algorithm used. An anomaly index was proposed to quantify the effectiveness of different clustering-based method for anomaly detection. The paper is organized as follows. The proposed data-driven methods are introduced in Sect. 2. The methodology has been tested using measurements retrieved from 10 primary schools and research results are presented in Sect. 3. Conclusions are drawn in Sect. 4.

2 Research Methodology

2.1 Research Outline

The research methodology is shown in Fig. 1. Data cleaning is performed to handle missing values and data partitioning is used to partition the time-series data into daily subsequences for clustering analysis. PCA and statistical methods are adopted for feature extraction. The aim is to reduce the computation burden and improve the detection performance. The clustering algorithms adopted are K-means and Agglomerative Hierarchical Clustering. After that, an anomaly index is proposed based on Euclidean distance, based on which abnormal energy consumption profiles

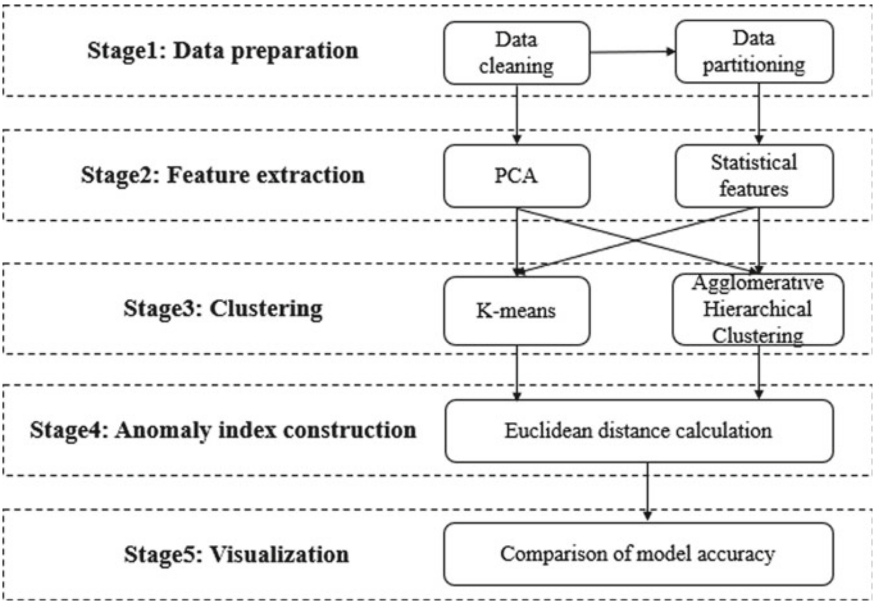

Fig. 1 Research outline

are detected. Performance evaluation is conducted to quantify the effectiveness of different clustering-based methods for building energy anomaly detection.

2.2 Feature Extraction

In the process of data mining, not all variables have great impacts on analysis results. Sometimes, there may be a large number of variables which are noisy and highly correlated. The direct application of such data may lead to high computational costs and poor analysis results. Feature engineering is often used with the aim of information preservation and complexity reduction. There are two general feature engineering methods, i.e., feature selection and feature extraction. Feature selection aims to select data variables that are most influential to data analysis. By contrast, feature extraction aims to create new features based on linear or nonlinear transformation of the original data variables [11].

In this research, two feature extraction methods have been adopted for feature engineering. The first is based on statistical methods. More specifically, a time series is partitioned into several non-overlapping temporal segments, based on which the mean and variance of each segment are extracted as features. The second is based on PCA, which in essence performs linear transformations of original data variables for feature extraction. As a result, a set of principal components, which are uncorrelated or orthogonal to each other, are created as features.

2.3 Clustering Analysis

Clustering algorithms can be roughly divided into three categories: partition-based, density-based and hierarchical clustering algorithms. In this study, two representative algorithms, i.e., K-means and Agglomerative Hierarchical Clustering, are used for performance assessment.

Due to the high computational efficiency and scalability, the K-means clustering algorithm has been widely adopted in various fields. The algorithm requires the users to specify the number of underlying clusters, i.e., k. The algorithm divides the data into k clusters in an iterative manner according to a certain distance metric. At each iteration, K-means assigns each data sample to its nearest cluster. Afterwards, the clustering centers are updated according to current memberships. The clustering process is repeated until a termination condition is met.

At the beginning of hierarchical clustering, each data sample forms a separate cluster. Afterwards, two clusters are unified according to their data similarities. The unification process continues until all clusters are grouped into a single cluster.

In practice, the most challenging problem is to determine the optimal number of clusters, especially when there is little prior knowledge on the data set. In this study, the optimal cluster number is determined using 26 Cluster Validation Indexes [12].

Each index is computed to assess the optimal number of clusters for each cluster. A majority rule is used to select the results: the final optimal number of clusters are designated by the highest number of Cluster Validation Index indicating the same results. When there comes to more than one optimal cluster number, we determine the number by domain knowledge.

2.4 Anomaly Index

Anomaly detection is typically done based on data distribution, distance, migration and density. Distribution-based anomaly detection methods require data to satisfy a certain probability distribution. The definition of variation function of deviation-based anomaly detection methods is typically of high complexity and the resulting performance may not be satisfactory for different data sets. In this study, a distance-based method has been proposed to quantify the abnormality of each data sample. The details of the method are summarized as below:

(1) Determine the position of each cluster center;
(2) For each data sample, calculate its Euclidean distances to different cluster centers and selected the smallest distance as anomaly index. In such a case, the larger the anomaly index, the more abnormal the building energy consumption is, as it is relatively far from any cluster center.

The Euclidean distance formula is shown as follows:

$$d_i = \sqrt{\sum_{k=1}^{n} \left(x_{ik} - x_{jk}\right)^2}$$

3 Case Study

3.1 Description of Building Operational Data

In this study, ten office buildings located in London have been used for analysis. The data were collected with a time interval of one-hour and each has one-year data [13]. The data analysis was performed using the R programming language.

3.2 Data Preparation

The raw energy consumption data are provided in a single column format, with each row corresponding to a certain time step. Data transformation was performed to extract daily energy consumption data. For each building, the daily energy consumption data are stored in a two-dimensional data table with 365 rows (i.e., one-year data) and 24 columns (i.e., 24 h power consumptions).

Data cleaning was performed to identify low-quality data including missing data and data collection failures. Considering the continuity of the time series data, the missing data will be deleted in rows. In other words, if there is one missing data in a day, the whole daily data will be removed from analysis for simplicity. Energy consumption data often fluctuate over time. For example, during working hours, the energy consumptions are higher due to the presence of building occupants and the operation of various services systems. By contrast, energy consumptions during midnight are much lower. In this study, daily subsequences were segmented into two time periods for the accurate identification of building operations patterns: (1) Period 1: unoccupied period from 00:00 to 07:59 and 20:00 to 23:59, during which the building energy systems are mostly turned OFF; (2) Period 2: occupied period from 08:00 to 19:59, during which the building energy systems are mostly turned ON.

3.3 Feature Extraction on Daily Energy Consumptions

In the data pre-processing stage, the time series data were partitioned into two periods. The mean and variance were calculated as features for each period, resulting in 4 features per daily subsequence. The statistic feature extraction process is shown in Table 1. To ensure the result comparability, the number of features extracted by PCA were set consistent with the number of statistical features. Consequently, the top four principal components extracted from raw data after data cleaning were used as features for each day.

Table 1 Statistic feature extraction process of building 1

	Period 1										Period 2					
	1	2	…	7	19	20	…	24	M1	V1	8	9	…	18	M2	V2
2014.12.03	0.5	0.4	…	0.7	2.0	0.5	…	0.5	0.6	0.18	0.9	2.7	…	2.8	4.04	2.53
2014.12.06	0.4	0.4	…	0.3	0.4	0.3	…	0.3	0.39	0.01	0.4	0.4	…	0.4	0.38	0.00
2014.12.07	0.4	0.3	…	0.4	0.4	0.4	…	0.4	0.38	0.01	0.6	0.6	…	0.6	0.61	0.00
2014.12.08	0.5	0.4	…	0.6	2.3	0.5	…	0.4	0.64	0.25	1.9	1.7	…	2.9	3.94	2.02
…					…									…		

3.4 Clustering Analysis on Daily Energy Consumptions

K-means and Agglomerative Hierarchical Clustering algorithms were applied to cluster daily energy consumption data., so each building has carried out four clustering analysis. For the sake of clarity, the K-means clustering analysis method taking the four PCA features as the model input is denoted as *PCA_K-means*. The K-means clustering analysis method taking the statistical features as the model input is denoted as *STA_K-means*. The hierarchical clustering method taking the PCA features as the model input is denoted as *PCA_HCL*. The hierarchical clustering analysis method taking the statistical features as the model input is denoted as *ST_HCL*. As an example, cluster results of building 1 are shown in Fig. 2. Nine clustering validity indices proposed three as the optimal cluster number of *STA_K-means*. One thing worth noting is that two clusters were obtained by *PCA_K-means*, which seems to be reasonable based on domain knowledge. Comparative results are summarized in Table 2.

It should be noted that clustering analysis using *PCA_K-means* mainly groups the data into two categories, and *STA_K-means* groups the data into three categories. The clustering results are different using different algorithms. The quality of clustering results can be manually assessed by observing energy consumption curves. For example, the clustering results of *STA_K-means* for building 1 are shown in the Fig. 3. Cluster 1 represents the pattern with low energy consumption, and groups

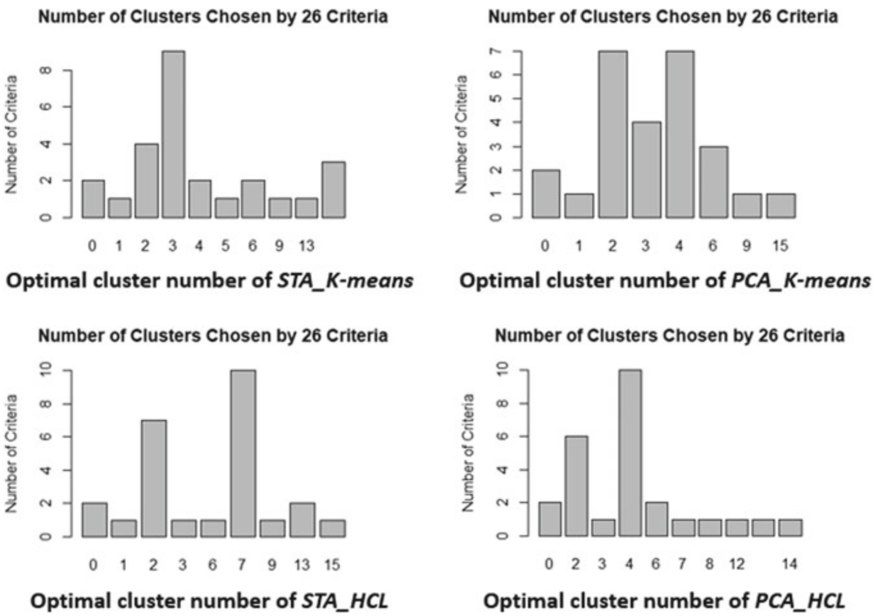

Fig. 2 Cluster results of building 1

Table 2 Comparative clustering results for ten buildings

	K-means		Agglomerative hierarchical clustering	
	STA	PCA	STA	PCA
Building1	3	2	7	4
Building2	2	2	2	5
Building3	3	2	6	2
Building4	3	2	2	2
Building5	3	2	6	2
Building6	4	2	4	4
Building7	3	3	7	2
Building8	3	2	6	6
Building9	2	2	5	3
Building10	3	2	6	4

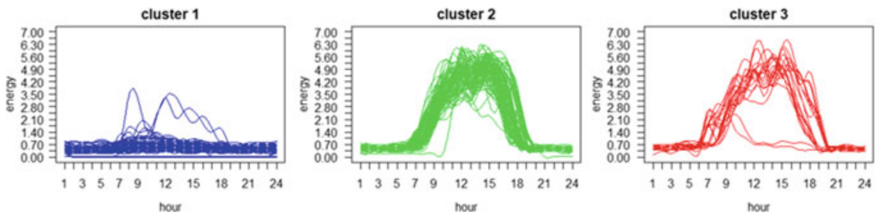

Fig. 3 Clustering results of *STA_K-means* for building 1

the weekends, cluster 2 represents the pattern with much more regular consumption than cluster 3, and groups Mondays to Thursday. Cluster 3 groups Fridays.

3.5 Anomaly Index Calculation

Euclidean distance is used to measure the distance of the clustering methods in this study. the larger the distance between groups and the smaller the distance within the group, indicating that the better the effect of clustering. Therefore, we calculate the distance between each point and the corresponding cluster center after each clustering, from which we can get one distance list after *PCA_K-means* clustering analysis, one distance list after *STA_K-means* clustering analysis. The same thing happens in hierarchical clustering analysis.

In order to scale these distance values between 0 and 1, we normalized the value, the normalization formula is shown as follows:

$$I = \frac{x_i - \min(mean_i)}{\max(mean_i) - \min(mean_i)}$$

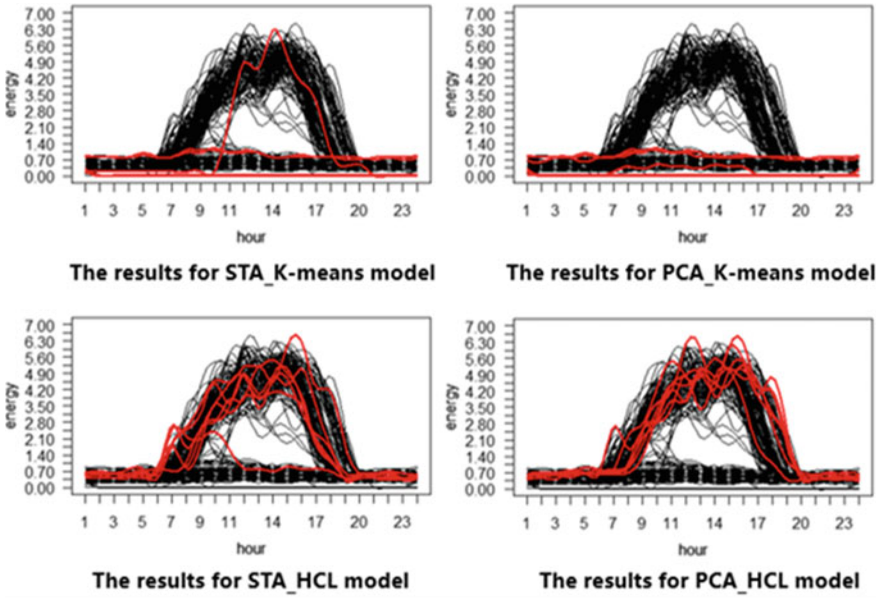

Fig. 4 Example results of Building 1

Then we get the anomaly index *I*. The larger the *I* is, the more abnormal the energy consumption profile is.

In the current research, there are a variety of evaluation criteria for anomaly diagnosis, such as the 3-sigma method which takes values that deviate from the standard value by 3 times or more as abnormal data, and the factor method which uses influence factor, distance factor or level factor to judge abnormality. In this paper, the data corresponding to the top 2% I value are regarded as anomalies (i.e., represented by red lines). The number of the anomalies obtained by clustering analysis is consistent with manually labeled abnormal days except for building 6, as it is difficult to find more than three abnormal days in building 6 during the manual labeling process. The identification results of building1 are shown in Fig. 4. It is worth noting that *PCA_K-means* and *STA_K-means* can both detect patterns without fluctuation at the bottom.

3.6 Anomaly Detection Rate

In total, there are 59 manually labeled abnormal days for ten buildings, out of which 35, 37, 5 and 11 were successfully detected using the *PCA_K-means*, *STA_K-means*, *PCA_HCL* and *STA_HCL* methods respectively. The resulting detection rate is shown in Fig. 5. In terms of the clustering algorithms, K-means tends to have better performance than Agglomerative Hierarchical Clustering algorithm. In terms of the feature

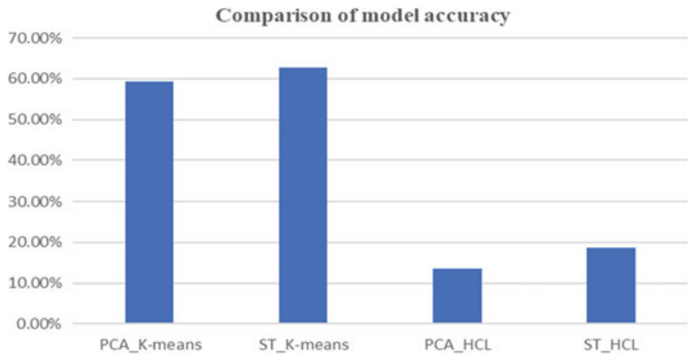

Fig. 5 Comparison of model accuracy

extraction methods, the results suggest that statistical features are more valuable for detecting anomalies in daily energy consumptions.

4 Conclusions

In this research, four data-driven methods have been proposed for identifying daily energy anomalies considering different feature extraction (PCA and statistical features) and clustering methods (K-means and Agglomerative Hierarchical Clustering). An anomaly index has been proposed to quantify and evaluate the abnormality of each daily energy consumption profile. To ensure the research validity and generalization performance, building energy data from 10 primary schools have been adopted for analysis. Manual labeling has been conducted to provide ground truths on building energy anomalies. The results show that compared with hierarchical clustering, the performance of K-means clustering is better. In addition, statistical features present higher values for identifying anomalies in daily energy consumptions. The best performance can be achieved using statistical features and K-means algorithm. Future studies will be carried out to address potential limitations of this study:

(1) This study only compares the detection accuracy of conventional feature extraction and clustering methods. Data experiments will be conducted to investigate the potential of advanced feature engineering and clustering methods.
(2) This study only adopts ten buildings for analysis. To ensure the reliability of analysis results, more buildings with manual labels will be used for further analysis.

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A Deep Recurrent Neural Network-Based Method for Automated Building System Fault Diagnosis

Yichen Liu, Xinghua Wang, Cheng Fan, Bufu Huang, and Jiayuan Wang

Abstract Faults in building system operations typically result in building functionality degradations and considerable energy wastes. Conventional approaches mainly rely on domain expertise and engineering experiences for decision makings, which are neither efficient and effective considering the great varieties in individual building system configurations and operating conditions. The wide existence of building operational data has provided ideal platform to develop data-driven approaches for building system fault diagnosis. Such approaches are capable of conducting accurate, automated and in-time controls over building systems and therefore, has drawn increasing attentions from both academia and building professionals. Existing studies mainly treated building operational data as cross-sectional data for developing fault diagnosis methods, while ignoring the temporal dependencies among building variables. To enhance the fault diagnosis performance, it is essential to explore the intrinsic temporal relationships in building operational data. Therefore, this study proposes a deep recurrent neural network-based methodology for building system fault diagnosis. The methodology has been validated using experimental data on building chiller systems. The results indicate that deep recurrent models can achieve an accuracy of at least 95% for seven typical faults in chiller systems. The research outcomes are helpful for enriching analytic tools for building system fault diagnosis.

Keywords Fault detection and diagnosis · Deep learning · Recurrent models · Long short-term memory (LSTM) · Building systems

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1 Introduction

Building operations account for 80–90% of the energy consumption in building life cycle. The energy saving potential in building operations can be very large considering the wide existence of system operation faults and improper control strategies [1]. Therefore, the main task in building energy management is to develop accurate methods for building system fault diagnosis and thereby, achieving energy savings.

Conventional approaches mainly rely on domain expertise and engineering experiences for decision makings, which are neither efficient nor effective for large-scale applications [2, 3]. For instance, the heating, ventilation and air-conditioning (HVAC) system accounts for the largest energy consumptions in building operations and may consists of hundreds of components which are interconnected for daily operations [4]. Chillers are the core component in the HVAC system to provide cooling energy. It is a large-scale system which have many types of operating faults. The chiller operating faults generally lead to large amounts of energy wastes. In practice, it can be very challenging to achieve accurate and in-time chiller fault diagnosis considering complicated dynamics between system variables. In addition, each building has its own HVAC system configurations and working conditions, making it very difficult to come up with universal rules for chiller fault diagnosis.

Modern buildings are being equipped with advanced monitoring hardware for building operational data collection. It is becoming increasingly popular to develop data-driven approaches for building system fault diagnosis due to their potentials in achieving accurate and automated controls over building services systems [5]. Xia used a kernel entropy component analysis to detect faults in chillers. The fault detection performance was reported to be better than traditional principal component analysis method [2]. Yan used unsupervised learning for fault detection and diagnosis. The generative adversarial network (i.e., GAN) was used to tackle the data shortage problem [3]. Han adopted least squares support vector machine for chiller fault detection and diagnosis. The method could achieve over 90% classification accuracy and was computational efficient compared with other machine learning methods [6]. Based on literature review, it is found that existing studies mainly treated building operational data as cross-sectional data for system fault diagnosis. In such a case, the intrinsic temporal relationships among building variables are neglected, which may not result in optimal performance for fault diagnosis. Therefore, this study adopts deep recurrent networks as tools to capture complicated temporal relationships in building operational data. Compared with conventional methods, the proposed Long Short-Term Memory (LSTM) methods cannot only capture dynamic information, but also deal with gradient explosion and gradient descent which can't be processed by traditional Recurrent Neural Network (RNN) methods. It is therefore expected that LSTM models can achieve more accurate fault diagnosis performance.

The reminder of this paper is structured as follow. The theoretical backgrounds are introduced in Sect. 2. Section 3 describes the research methodology. Section 4 presents data analysis results using experimental data on chiller operations. Conclusions are drawn in Sect. 5.

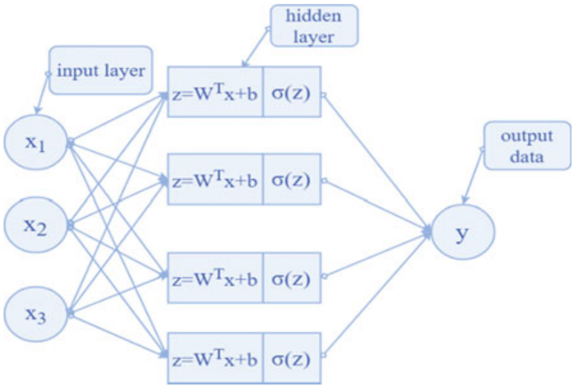


Fig. 1 Structure of the fully-connected neural networks

2 Theoretical Background

2.1 Fully-Connected Neural Networks

Fully-connected neural networks are the basic version of deep learning models. As shown in Fig. 1, the neurons between adjacent layers are connected to each layer. The model has three components, i.e., input, hidden and output layers. The neuron numbers in the input and output layers equal to the numbers of input and output variables respectively. The mode is trained in an iterative approach by forward passing and back-propagation. Nonlinearity is introduced by using different activation functions, such as the sigmoid function, the tangent hyperbolic function and the rectified linear units [7].

2.2 Convolutional Neural Networks

Convolutional neural networks are designed to analyze data with special structures, such as the one-dimensional sequential data and two-dimensional image data. Compared with fully-connected neural networks, the neurons between adjacent layers are only partially connected, leading to higher computational efficiency. Convolutional layers have proved to be especially useful in extracting features from sequential data, which in turns enhance the model performance. Multiple convolutional layers can be stacked to gradually develop high-level features from low-level features [8].

2.3 Recurrent Neural Networks

Conventional neural networks typically do not present capabilities in capturing relationships in sequential data. The recurrent neural network (RNN) has been proposed to solve such problem [7, 9]. RNN is especially useful in analyzing time sequence data. In such a case, the output at each time step is determined by values at previous time steps [10]. The basic structure of RNN is shown in Fig. 2.

One drawback of conventional RNN operations is that they cannot efficiently capture temporal relationships in long sequence data, especially given the problem of gradient exploding or vanishing. The Long Short-Term Memory (LSTM) was proposed by Hochreiter and Schmidhuber in 1997 to solve such problems [11]. The structure of LSTM is shown in Fig. 3. The main idea is to adopt three gates (i.e., input gate, forget gate and output gate) for controlling the information flow and thereby, reducing potential risks of gradient vanishing or exploding. The output value of each gate is set between 0 and 1 using sigmoid function. We direct interested readers to

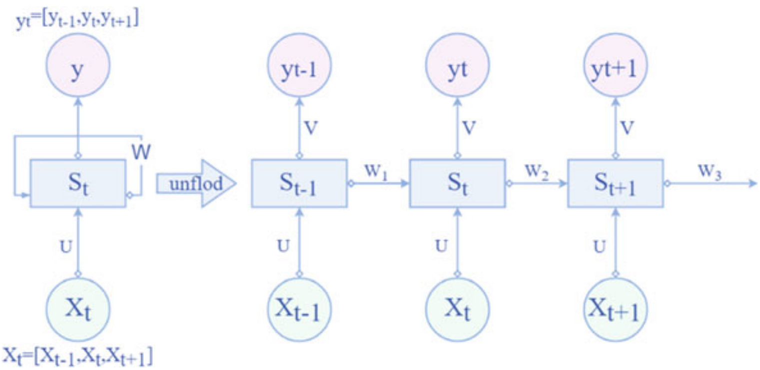
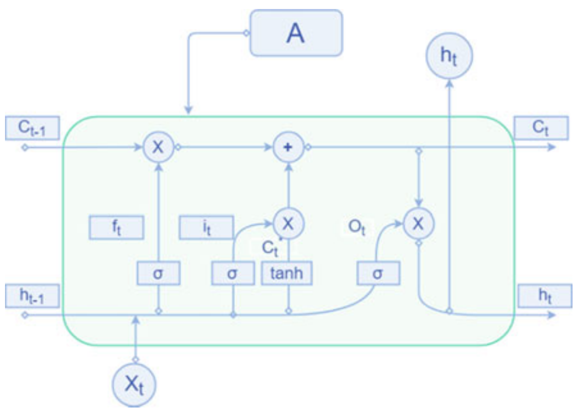


Fig. 2 Structure of the recurrent neural network

Fig. 3 Structure of long short-term memory



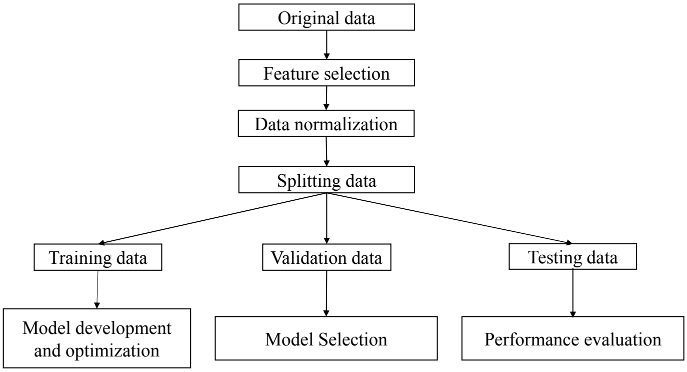


Fig. 4 Research outline

Ref. [11] for more details on LSTM. Other RNN variations do exist, such as the gated recurrent units (i.e., GRU) [12]. Previous studies have shown the LSTM do have performance advantages on fault detection and diagnosis in the other domains [13, 14] and therefore, is adopted for model development in this study.

3 Research Methodology

3.1 Research Outline

The research outline is shown in Fig. 4. Research outline divided into three sections, data preprocessing, model development and model evaluation. Data preprocessing contained feature selection, data normalization and splitting data. Model development contained model building and optimized parameters. Performance evaluation contains computing several different evaluating indexes.

3.2 Data Preprocessing

Firstly, feature selection is performed to select input for predictive modeling. It helps to speed up the model training process while ensuring the prediction performance. Secondly, data normalization is used to transform input variables into similar ranges using max–min normalization, which is shown in Eq. 1. Thirdly, to ensure the result validity, the data set is randomly divided into three parts, i.e., training, validation and testing with proportions of 70%, 15% and 15% respectively. Training and validation data are used for model training and parameter optimization, while the testing data are used to quantify the model generalization performance.

Table 1 Optimization parameter

Parameters	Value
The number of LSTM layers	1; 2
The units of LSTM	32; 64
Dropout	0; 0.3

$$X^{*} = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \tag{1}$$

3.3 Model Development

The recurrent model is to be developed using LSTM layers. Parameters should be optimized to ensure the generalization performance. In this study, three parameters are optimized, including the number of LSTM layers, the number of hidden neurons and the dropout values. As shown in Table 1, several candidate values are prepared for optimization for each parameter. The combination with the best accuracy on validation data will be used as the optimal model architecture. The parameters to be optimized and optional values as shown in the follow Table 1.

3.4 Model Evaluation

Classification accuracy is typically used for performance evaluation. For multi-classification problems, using accuracy may not fully reflect the model performance, especially given imbalanced data. For example, when there are 9900 positive samples and 100 negative samples, a naïve model which always output positive will result in an accuracy of 99%. However, such model is not useful at all. In this study, three other accuracy metrics have been used to provide a comprehensive description on model performance, i.e., Recall, Precision and F1. The equations are shown in Eqs. 2–5, where TP means true positive, TN means true negative, FP and FN mean false positive and false negative respectively. The Precision presents the proportion of actual positive samples among all predicted positive samples. The Recall indicates the proportion of true positive in true positive and false negative. The F1 value is the harmonic mean of the exact value and recall rate.

$$Accuracy = \frac{|TP| + |TN|}{|TP| + |TN| + |FP| + |FN|} \tag{2}$$

$$Recall = \frac{|TP|}{|\mathrm{TP}| + |\mathrm{FN}|} \tag{3}$$

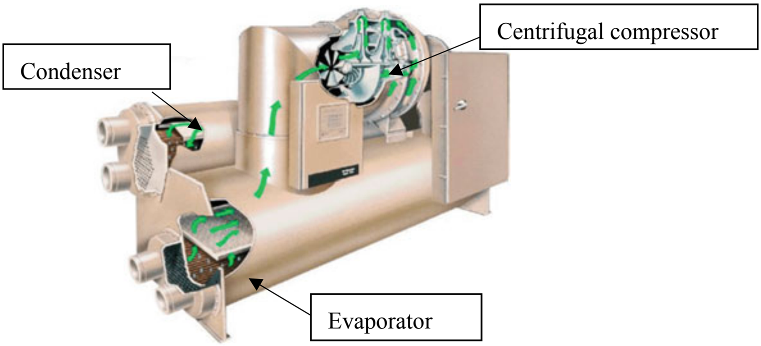


Fig. 5 An example of centrifugal chillers

$$Precision = \frac{|\mathrm{TP}|}{|\mathrm{TP}|+|\mathrm{FP}|} \tag{4}$$

$$F1 = \frac{2 * Recall * Precision}{(Recall + Precision)} \tag{5}$$

4 Applications on Chiller Fault Diagnosis

4.1 Data Description

The ASHRAE RP-1043 data set was used for analysis [15]. The data describe operating conditions of a 316KW centrifugal chiller. As shown in Fig. 5, a chiller mainly consists of a condenser, evaporator and centrifugal compressor [16]. As summarized in Table 2, seven typical faults in chiller operations each with four severity levels, were introduced during experiments. In this study, the measurements at 2 min collection interval are adopted for analysis. The total data has 23,040 data samples and 64 variables.

4.2 Data Preparation

The raw data was divided into different groups according to four faulty severity levels. The raw data were normalized using max–min normalization to unify data. Afterwards, the raw data were transformed into temporal subsequences for model development using a time window of 16 [17]. The subsequence data were split into training, validation and test sets with proportions of 70%, 15% and 15% respectively.

Table 2 Description on fault severity levels

Types of fault	Description	Normal	Level 1 (%)	Level 2 (%)	Level 3 (%)	Level 4 (%)
FWC	Reduced condenser water flow	270 gmp	− 10	− 20	− 30	− 40
FWE	Reduced evaporator water flow	216 gmp	− 10	− 20	− 30	− 40
RL	Refrigerant	300 lbs	− 10	− 20	− 30	− 40
RO	Excess oil	300 lbs	+ 10	+ 20	+ 30	+ 40
EO	Refrigerant overcharge	22 lbs	− 14	− 32	− 50	− 68
CF	Condenser fouling	164 tubes	− 12	− 20	− 30	− 45
NC	Non-condensable in refrigerant	No nitrogen	1	1.8	2.4	5.6

Table 3 A summary of input variables

Number	Description	Label
1	Temperature of condenser water in	TCI
2	Temperature of the evaporator	TEO
3	Evaporator approach temperature	TEA
4	Condenser approach temperature	TCA
5	Temperature of condenser water out	TCO
6	Temperature of oil in sump	TO_sump
7	Liquid-line refrigerant subcooling from condenser	TRC_sub
8	Refrigerant discharge temperature	TR_dis

For each severity level, the training, validation and testing data sets contain 2341, 502 and 501 data samples respectively. 8 temperature variables, which are easy to obtain in practice, were selected as model inputs. The input variables data are shown in Table 3.

4.3 Development and Optimization of Fault Diagnosis Models

The recurrent model was developed and optimized considering different numbers of LSTM layers, hidden unit and dropouts. Considering the relatively small training data amount, the model was set with more concise architectures to avoid the overfitting problem. Each parameter has two candidate values and optimization has been performed to determine the best combination. Indicating that the best model architecture is the M5 which has 1 LSTM layer, 64 hidden units and 0 dropout. The number

Table 4 Optimization parameters

Model	TNL	TUPL	Dropout	Accuracy (%)
M1	1	32	0	92.23
M2	1	32	0	91.24
M3	1	64	0	96.22
M4	1	64	0	90.04
M5	2	32	0.3	13.55
M6	2	32	0.3	17.53
M7	2	64	0.3	13.94
M8	2	64	0.3	11.95

of LSTM is named TNL. The units of per LSTM is named TUPL. The accuracy on validation set is shown in Table 4.

4.4 Evaluation on Fault Diagnosis Performance

The confusion matrix is used to present the fault diagnosis performance at different fault severity levels, where predictions and actual values are represented in rows and columns respectively. Row is the LSTM model prediction. The confusion matrices for each of the four severity levels are shown as Tables 5, 6, 7 and 8 respectively. It is observed that the higher the fault severity level, the higher the classification accuracy. This is expected as the increase in fault severity levels typically leads to more discrepancies in building variables, making it easier for fault classification. The overall classification accuracies are 97.2%, 97.0%, 99.8% and 100% for fault severity level 1–4 respectively.

The fault diagnosis performance in different accuracy metrics is summarized in Tables 5, 6, 7 and 8. At severity level 4, all predictions are correct, resulting in perfect

Table 5 The confusion matrix for fault diagnosis at severity level 1

Category	Normal	CF	EO	NC	FWC	FWE	RL	RO	Recall	Precision	F1
Normal	59	0	0	0	1	0	0	3	0.95	0.94	0.94
CF	0	54	0	0	1	0	1	0	1	0.96	0.98
EO	0	0	66	0	0	0	0	0	1	1	1
NC	0	0	0	67	0	0	0	0	1	1	1
FWC	0	0	0	0	55	0	1	1	0.94	0.96	0.96
FEW	0	0	0	0	0	58	0	0	1	1	1
RL	3	0	0	0	0	0	64	0	0.97	0.92	0.95
RO	0	0	0	0	1	0	0	64	0.91	0.98	0.95

Table 6 The confusion matrix for fault diagnosis at severity level 2

Category	Normal	CF	EO	NC	FWC	FWE	RL	RO	Recall	Precision	F1
Normal	59	0	0	1	0	1	0	1	1	0.98	0.99
CF	0	58	0	1	0	0	0	2	0.90	0.95	0.92
EO	0	0	53	0	1	0	0	0	1	1	1
NC	0	0	0	59	0	0	0	0	0.95	1	0.97
FWC	0	0	0	0	71	0	1	1	1	0.97	0.98
FEW	0	0	0	0	0	57	0	0	1	1	1
RL	0	3	0	0	0	0	68	0	0.97	0.944	0.95
RO	0	3	0	1	0	0	1	61	0.93	0.92	0.93

Table 7 The confusion matrix for fault diagnosis at severity level 3

Category	Normal	CF	EO	NC	FWC	FWE	RL	RO	Recall	Precision	F1
Normal	62	0	0	0	0	0	0	0	1	1	1
CF	0	73	0	0	0	0	1	0	1	0.99	0.99
EO	0	0	64	0	0	0	0	0	1	1	1
NC	0	0	0	62	0	0	0	0	1	1	1
FWC	0	0	0	0	65	0	0	0	1	1	1
FEW	0	0	0	0	0	56	0	0	1	1	1
RL	3	0	0	0	0	0	60	0	0.98	1	0.99
RO	0	0	0	0	0	0	0	58	1	1	1

Table 8 The confusion matrix for fault diagnosis at severity level 4

Category	Normal	CF	EO	NC	FWC	FWE	RL	RO	Recall	Precision	F1
Normal	63	0	0	0	0	0	0	0	1	1	1
CF	0	57	0	0	0	0	0	0	1	1	1
EO	0	0	63	0	0	0	0	0	1	1	1
NC	0	0	0	65	0	0	0	0	1	1	1
FWC	0	0	0	0	67	0	0	0	1	1	1
FEW	0	0	0	0	0	61	0	0	1	1	1
RL	0	0	0	0	0	0	63	0	1	1	1
RO	0	0	0	0	0	0	0	62	1	1	1

scores in Recall, Precision and F1. The fault diagnosis performance is nearly perfect at the third severity level. By contrast, the classification accuracy is lower at the first two severity levels. Nevertheless, the resulting metrics are still high enough for practical applications. The F1 scores for each label across four severity levels are summed up and shown in Table 9. It can be seen EO and FWE have the highest

Table 9 The sums of F1 for typical chiller faults

	Level 1	Level 2	Level 3	Level 4	Sum
CF	0.98	0.93	0.99	1	3.9
EO	1	1	1	1	4
NC	1	0.98	1	1	3.98
FWC	0.96	0.99	1	1	3.95
FEW	1	1	1	1	4
RL	0.95	0.95	0.99	1	3.89
RO	0.95	0.93	1	1	3.88

F-1 scores, indicating that the model is best in identifying these two faults in chiller operations. By contrast, CF and RO results in the lowest F1 scores. It indicates that these two faults are the most challenging for accurate diagnosis. The result indicated LSTM is good at fault detection and diagnosis. It is capable to extract useful temporal knowledge in chiller operation data for fault detection and diagnosis.

5 Conclusions

Conventional data-driven methods typically neglect temporal data dependencies and therefore, may not be capable of identifying complicated faults in chiller operations. This study adopted deep recurrent neural networks for developing data-driven models for building system fault diagnosis. The method has been designed to capture temporal dependencies among building variables and thereby, enhancing the performance in fault diagnosis. The methodology has been tested using experimental data on chiller operations. The results show that deep recurrent models can successfully identify typical faults in chiller operations with different severity levels. More specifically, the model can achieve 100% accuracy given the highest severity level for all seven typical faults. Even at the lowest severity level, the model can achieve satisfactory results with a minimal F1 score of 0.95. The results indicate that faults in excessive oil and reduced evaporator water flow are relatively easy to diagnose, while the condenser fouling and refrigerant overcharge are more challenging for accurate fault diagnosis. The proposed method can effectively identify chiller faults and thereby, improving the energy efficiency while extending the service life of chiller systems. The insights obtained are helpful for the development of advanced data analytics for building system management.

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Automated Evaluation of Indoor Dimensional Tolerance Compliance Using the TLS Data and BIM

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Abstract As commercial residential building prices are getting increasingly expensive, whether the dimensions of building components to be delivered conforms to the design codes is significantly important to the owner. However, the current dimension assessment is still manually conducted with field measurement, which is error-prone and time-consuming. To improve the assessment efficiency and accuracy, this study presents an automated geometric quality assessment technique which measures the dimensions of indoor components by means of the terrestrial laser scanning (TLS). The point cloud data obtained by the TLS is reversely reconstructed into a three-dimensional model, representing as-built model of the building. Building information model (BIM) stores rich geometric information, which represents as-designed model of the building. Then, "Scan-vs-BIM" systems, which are based on comparing the as-built point cloud model with as-designed BIM models, can effectively detect the dimension discrepancy of indoor components and provide decision-making basis for the local detection. Experiments using the commercial residential building are conducted and the result that the presented method can effectively and accurately evaluate the building dimensional tolerance compliance.

Keywords BIM · Commercial residential building · Indoor geometric quality assessment · Point cloud · Tolerance compliance · Terrestrial laser scanning

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1 Introduction

As-built dimensions of commercial residential building often differ from the dimensions originally specified in as-designed plans. Geometric quality evaluation verifies that commercial residential buildings are constructed in compliance with the designed dimensional tolerances. For instance, when carrying out the formwork support project of the floor and beams, checking whether the dimensional tolerances of all formworks conform to the design codes ensures the connection performance between the beams. Especially in the construction industry, if the dimension of the building does not meet the design codes or the requirements of the contract after handing over the to the owner, it will cause default and increase in costs.

At present, the geometric quality evaluation of commercial residential buildings relies heavily on the manual inspection with traditional measuring tools such as steel ruler and laser rangefinder. However, it is time-consuming, labor-intensive, hazardous and tedious to detect large-scale buildings manually on the site. There are a lot of manpower in the inspection, so the quality evaluation results are subjective and error-prone to some extent. Although electronic measuring instruments such as construction engineering detectors and electronic rangefinders are widely used in the geometric quality inspection of buildings and other civil infrastructures, it is unable to provide accurate and rapid inspection results for large and complex construction environment during unfavorable weather conditions [1].

In recent years, three-dimensional (3D) laser scanning technology obtaining the as-built 3D point cloud model of target object is becoming popular in the architecture, engineering, and construction (AEC) industry. Laser scanners have two commonly used range measurement principles, time of flight (TOF) and amplitude-modulated continuous-wave (AMCW). The point cloud data in this study was collected with Trimble X7 adopting the TOF technology, which calculates the distance from the scanner to the target object by transmitting the laser beam and detecting the reflected signal of the target. A simple time flight system is shown in Fig. 1, the distance (D) between the scanner (P) and the target object (R) can be measured by calculating the time to emit and recover the beam. Considering 3D visualization model of complex

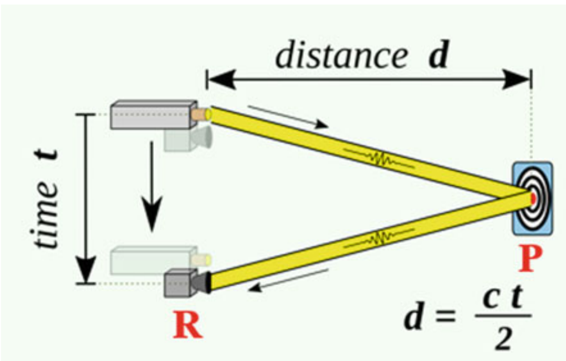

Fig. 1 Simple time flight system

and irregular scene can be built effectively, 3D laser scanning is applied in various fields, such as as-built model reconstruction [2, 3], surveying and mapping engineering [4, 5], structural health monitoring [6, 7], and construction progress control [8, 9]. While the point cloud data obtained from TLS represents the as-built conditions of objects, the corresponding as-designed objects are usually stored in BIM models, which represent a digital representation of physical and functional characteristics of a facility.

To address the problems of long inspection time and large error in results, this paper proposes a technique for automatically evaluating the geometric quality of commercial residential buildings. This technique attempts to use the advantages of the 3D laser point cloud to solve the shortcomings of the previous manual dimension inspection of the geometric quality, such as time-consuming and low accuracy. The point cloud data obtained by TLS is automatically registered in *Realwork* software to obtain a complete as-built building model. Then, as-designed point cloud data is generated from BIM, which can present the as-designed stage of the commercial residential buildings. Next, the as-built point cloud data is compared with the as-designed point cloud data from BIM by means of registration. Finally, the deviation of registered point cloud data is calculated.

The rest of this paper is organized as follows. Section 2 provides research review on two aspects of quality evaluation: geometric quality evaluation and Scan-vs-BIM system. The proposed method of comparing the point cloud generated from BIM with the as-built point cloud data is described in Sect. 3. Section 4 uses an illustrated example to validate the presented method and discusses the experimental results. Finally, Sect. 5 concludes this study.

2 Literature Review

The proposed method involves indoor geometric quality evaluation, as well as comparing the as-built point cloud model with the as-designed BIM. Generally, the process can be divided into two parts: (1) geometric quality evaluation and control, (2) Scan-vs-BIM, as illustrated in Sects. 2.1–2.2, respectively. Existing related research studies are reviewed in the following sections.

2.1 Geometric Quality Evaluation and Control

In recent years, numerous methods have been proposed for geometry quality assurance and control in the AEC industry. For example, Wang et al. used the terrestrial laser scanning to automatically assess the quality of precast concrete elements with geometry irregularities [10]. Kim et al. developed a quality assurance method for full-scale precast concrete elements using laser scanning and BIM [11]. Anil et al. presented a method for assessing the quality of as-is BIM generated from point cloud data by analyzing the patterns of geometric deviations between the model and the point cloud data [12]. Ghahremani et al. proposed a method using 3D point clouds obtained with the aid of a handheld 3D laser scanner for the quality assurance of high-frequency mechanical impact (HFMI) treatment [13]. The evaluation technologies based on point cloud processing have not involved the geometric quality of indoor buildings. The complexity of interior architecture promotes the indoor geometric quality evaluation technology.

Machine vision-based evaluation technologies have also been wildly adopted for geometric quality control, especially the geometric quality of large components before installation on site. For example, Fox et al. developed a time-lapse thermography technology on the building [14], which can enhance the differentiation among environmental conditions, actual behavior, and construction defects. Malpica et al. proposed a method of applying the support vector machine (SVM) classification algorithm to a joint data set composed of satellite images and laser scanner data [15], which can detect the most of the urban developments and changes. Vetrivel et al. identified the damage in buildings based on gaps in 3D point clouds from very high resolution oblique airborne images [16]. Park et al. proposed a displacement measurement method based on machine vision technology to monitor the displacement of high-rise building structures using the partitioning approach and the verification experiments were conducted on a flexible steel column [17]. Xu et al. adopted digital image processing technology to the monitoring of building crack [18]. Huang et al. proposed a deep learning-based algorithm called ABCDHIDL [19], which can automatically detect the building changes from multi-temporal HRRS images. Due to the lack of illumination and noise, the geometric quality evaluation technology based on image processing is not suitable for indoor dimension evaluation.

Some researchers have also developed several techniques for quality assessment of building facilities using laser scan data. Sun et al. used the region growing algorithm to reconstruct the roof model from the point cloud obtained by airborne radar [20]. However, some noises such as trees and telegraph pole will affect the accuracy of building model detection. Li et al. proposed a straight-line-segment feature-extraction method for the building-facade point cloud data based on slicing to improve the existing method of detecting and extracting the straight-line-segment features from the building-facade point-cloud data [21], but the straight line segment that forms a certain angle with the ground in the building cannot be extracted effectively. Ahmed et al. presented a practical and cost-effective approach based on the Hough transform and judicious use of domain constraints [22], which can automatically search, detect, and reconstruct 3D pipes within point cloud data obtained from airborne laser scanning (ALS). Although previous work has utilized point clouds or image processing for quality evaluation and applied their methods into the AEC industry, the geometric information extraction of complex buildings composed of two and more faces has not been well studied. Therefore, this study presents a method to automatically evaluate geometric quality of complex commercial building.

2.2 Scan-vs-BIM

The Scan-vs-BIM principle matching each point to the corresponding object in the BIM stems from Bosche [23], which refers to the comparison between the as-built model based on scanned point cloud data and as-designed BIM model by the calculation of deviation. The systems of “Scan-vs-BIM” have been applied in construction progress and building quality control in quite a few studies. For example, Pucko et al. identified the differences between both models and thus the discrepancy from the time schedule by means of the comparison of the 4D as-built BIM and the 4D as-designed BIM [9]. Frias et al. presented an automatic method aimed to determinate the optimal scan positions and the optimal route based on the use of BIM and considering data completeness as stopping criteria [24]. Turkan et al. proposed a technique of using the “Scans-vs-BIM” target identification system to detect secondary and temporary objects of concrete structures with the TLS point cloud [25], which can help enhance the performance of progress estimation and tracking. Bosché et al. combined Scan-to-BIM and Scan-vs-BIM [26], which can automatically compare as-built and as-designed cylindrical MEP projects robustly, thus providing automatic measurement of planned percentage completion, and assisting in the delivery of designed as-is BIM models from as-designed ones. Above all, the comparison between as-designed BIM and as-built point cloud model has been adopted to the construction process tracking and geometric quality evaluation of structural components.

In order to promote further data processing, Guo et al. uses coarse and fine registration to unify the coordinate system of the point cloud model generated from BIM and the laser scanning model, and compares them [27]. Wang et al. calculated the completeness of degree (DOC) and matching of degree (DOM) by aligning the as-designed rebar model and as-built scanning model, which can be used to detect the standard of model segmentation [28]. Although the previous research efforts have studied some basic primitives, the geometric quality inspection of complex indoors has not been well studied. Therefore, this study presented technique for automatically evaluating the indoor geometric dimensions.

3 Methodology

This section introduces the presented technique for geometric quality evaluation of indoor based on laser scan data and BIM. Figure 2 shows the overview of the proposed building dimensional tolerance compliance evaluation technique with three steps: (1) the preprocessing as-built point cloud data, the extraction of point cloud data from as-designed BIM, (2) the comparison between the as-built point cloud model, and (3) the as-designed BIMs and the calculation of the RMSE. In the Sect. 3.1, as-built point cloud data is collected and preprocessed via mosaic [29], down-sampling, and the segmentation. Then, the algorithms are developed and implemented in MATLAB to extract the point from as-designed BIM in the Sect. 3.2. Finally, as-designed BIM and

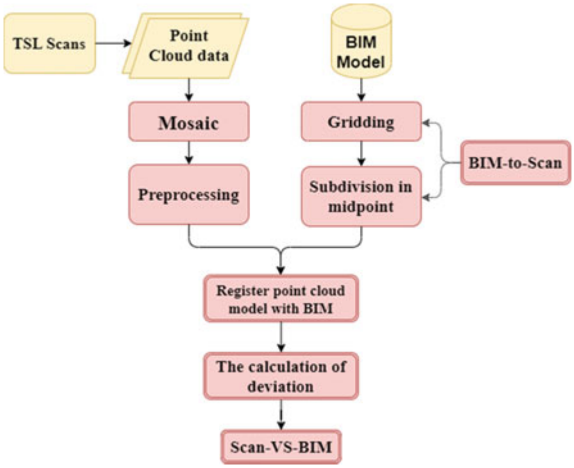

Fig. 2 Summary of the proposed building dimensional estimation technique

as-built point cloud model are compared and the deviation is calculated for geometric quality assessment in the Sect. 3.3.

3.1 Data Acquisition and Preprocessing

Since commercial residences usually consist of several individual rooms with different sizes, TLS cannot obtain all point cloud data directly. Therefore, a complete 3D model can only be obtained by registering the point clouds collected from several stations. The as-built 3D model registration process is completed in *Realworks* software of Trimble. Target ball-based registration method is applied to stitch the point cloud, which needs to select the short distance and accuracy high plane and ball target after extracting the target center of each station. Indirect adjustment method is adopted to extract the center of the spherical target [30]. Figure 3 shows the registered point cloud model with noise, which caused by the storage of some construction materials indoors and the movement of people during the scanning process. Before comparing point cloud model with BIM models, it is necessary to process the point cloud after registration. The registration process of this study is conducted in inter(R) Core™ i7-6700 CPU @ 3.40 GHz.

Point cloud preprocessing mainly includes point cloud down-sampling, denoising and segmentation. The number of commercial housing point clouds collected from TLS reached 250 million, which can result in great computational pressure and time cost. Point cloud down-sampling can reduce the number of point clouds without changing the basic characteristics of the entire model. One of the commonly used point cloud downs-sampling methods is grid filtering down-sampling [31].

The common noise in the point cloud is generally due to the movement of people during the scanning process and the presence of some impurities unrelated to the

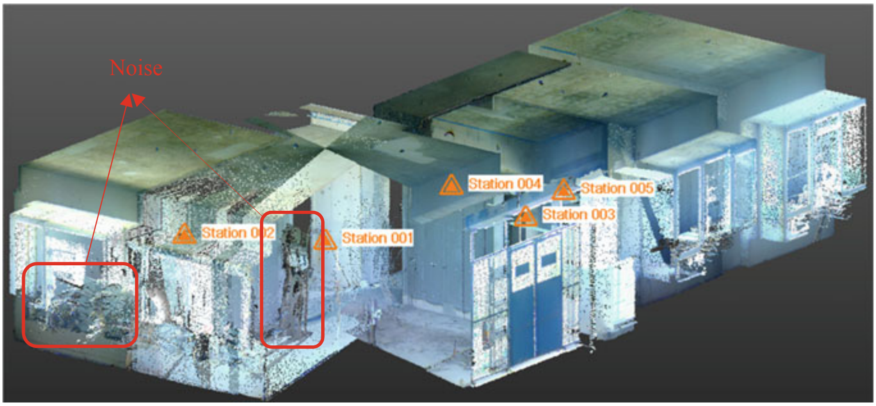

Fig. 3 Point cloud model with noise

target object in the scanning environment. A mixed pixel filter combined geometric and color information from point cloud data is applied to remove noise, which can classify valid data and mixed pixels from the scanned data.

3.2 *Generation of Point Cloud from BIM Model*

BIM models with rich geometric information are widely applied into a building's life cycle, including design, construction, and facility operation and management phases, which may vary significantly from the as-built phase of the facility [32]. Obtaining as-designed point cloud data from the BIM models mainly takes two steps: (1) BIM model gridding; (2) Mesh subdivision via edge midpoint and iteration.

3.2.1 BIM Model Gridding

Designed BIM models are converted into signifying standard template library (STL) format in computer-aided design (CAD), which comprises adjacent triangular faces. Since BIM models are basically composed of regular and few polygons, the BIM models have few vertices. If the point cloud is extracted directly from BIM, the points are generally the existing vertices of the BIM model. However, the number of point clouds obtained from TLS reaches hundreds of thousands, so the points extracted directly from the BIM model cannot meet the comparison with the as-built point cloud model. One of the ways is to increase the vertices or faces of the BIM model.

Spatial region growth algorithm based on Delaunay is applied to the meshing of 3D model, which selects a sample triangle as the initial surface, expands the boundary of the surface, and finally forms a complete triangular mesh surface [33]. The simple

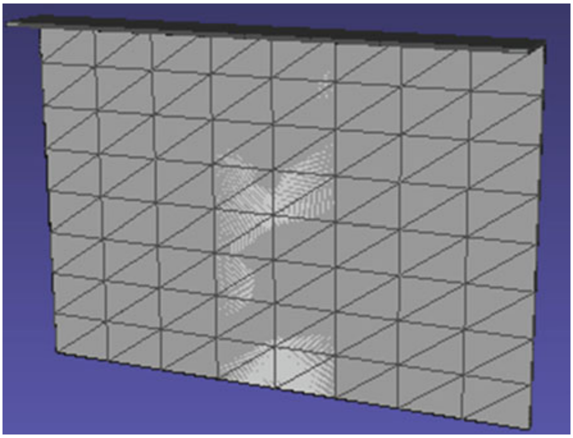

Fig. 4 The gridding of the wall BIM

gridding of BIM model of the wall is shown in Fig. 4, which just contains 420 vertices and 836 faces.

3.2.2 Mesh Subdivision Via Edge Midpoint and Iteration

To be able to match the as-designed point cloud model, the subdivision surface method is applied to get more points from the BIM model without changing the shape of the BIM model, which refers to the generation of a series of meshes by means of repeatedly refining the initial polygon mesh [34]. The focus of subdivision surface method is the subdivision rules, which includes Butterfly Subdivision, Catmull-Clark, LS3 Loop, Doo-Sabin, and Midpoint subdivision surfaces. Doo-Sabin-based subdivision surfaces method is utilized in the study, which can directly obtain the vertex and face connected with the edges through any edge of the geometric model in the case of 2-manifold [35]. Doo-Sabin Subdivision surface algorithm mainly includes three steps: (1) generating a new point inside the face for each vertex of the original face, (2) connecting newly generated points and removing duplicated edges and points, (3) performing chamfer operation on each original edge and vertex.

As shown in the Fig. 5, the center of all vertices is face point, and the center of each edge is edge point. The average value of two edges and the edge points connected with each vertex are the newly generated vertex position. The pointer of original vertex will be retained to ensure that the subsequent algorithm is effective for newly generated vertices.

Since all the points generated inside face are related to the vertices of face, according to the loop direction of the face, a new loop can be constructed to connect the newly created points inside, and the newly created loop can be stored in the face structure corresponding to the original loop. Therefore, the head node is the original

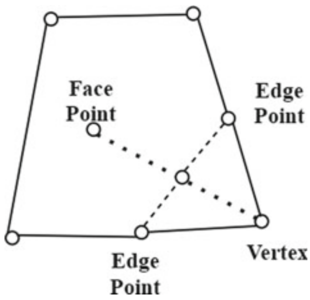

Fig. 5 The generation of vertex

loop, and the second node is the newly generated loop in the loop linked list of face structure [34].

As shown in Fig. 6, performing chamfering operation mainly include three steps: (1) a new face and ring are created for each vertex V of the original model, (2) all edges that are originally connected to vertex V are obtained (e.g., the blue edge in the figure), then two faces adjacent to the blue edge are obtained, (3) the search of the vertices whose original vertices are V (the two green points in the figure) for the left and right faces respectively, and then connection of the two vertices in the order of the faces. After the corresponding surface subdivision rules are selected, a certain number of point clouds can be output after iterations, which is the vertex after the surface subdivision. The point cloud model of as-designed BIM after subdivision surface iteration is shown in Fig. 7a. As-built 3D point cloud model is shown in Fig. 7b.

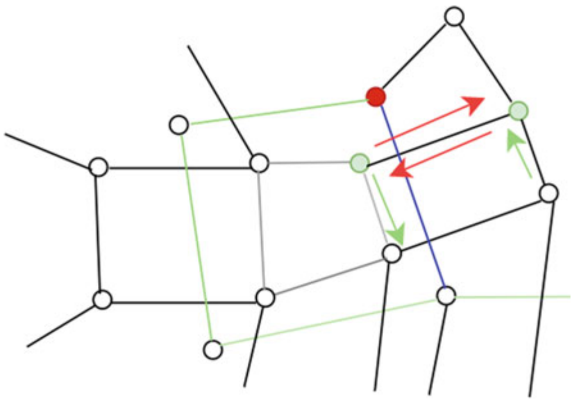

Fig. 6 Chamfering operation

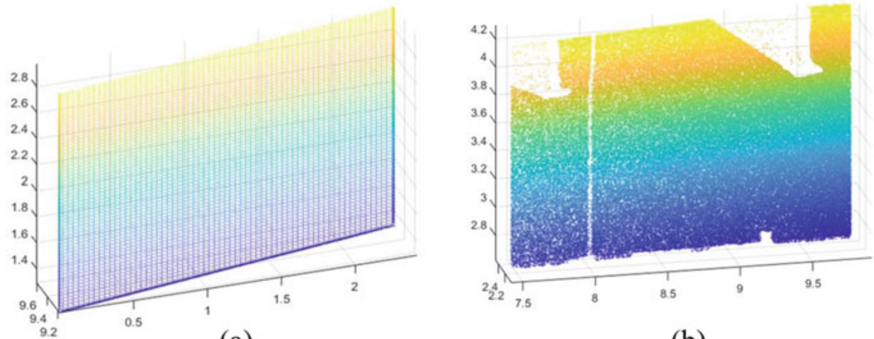

Fig. 7 Point cloud model: **a** the point cloud of as-designed wall BIM model and **b** the point cloud of as-built wall

3.3 Registration

To obtain sufficient building coverage, the scanner is placed in various locations throughout and around the facility, and the point clouds from each location are combined in a common coordinate system known as registration. Iterative closest point (ICP) algorithm is the most commonly used registration method [36], but various enhanced registration algorithms matching the BIM with point cloud data have been widely applied in the AEC industry. For instance, Besl et al. presented a semi-automated plane-based registration algorithm for coarse registration of laser scanned 3D point clouds with project 3D models [37]. Bueno et al. proposed an automatic coarse registration algorithm based 4 Points Congruent Set' algorithm [38], which can accurately register scanned point cloud data with 3D (BIM) models. However, the registration process still takes a long time.

For the ICP algorithm, there are four key steps: (1) minimizing objective function f (R, T), (2) researching the corresponding point, (3) optimizing of translation parameter (T) and rotation parameters, (4) fitting.

$$f(R, T) = \frac{1}{N_P}\sum_{i=1}^{N_P}\left|p_t^i - R \cdot p_s^i - T\right|^2 \tag{1}$$

where the $f(R, T)$ is the objective function value, the p_t^i and the p_s^i devote the corresponding points and the N_P represents the number of point cloud. In this study, KD-tree and singular value decomposition (SVD)-based ICP algorithm is adopted to match the as-built point cloud model with the as-designed BIM models [39]. First, two sets of matching point cloud data weighting centers are calculated. Then, corresponding point set is searched and created via the KDtree, which can realize fast query in high latitude data. Finally, rotation matrix and translation vector are

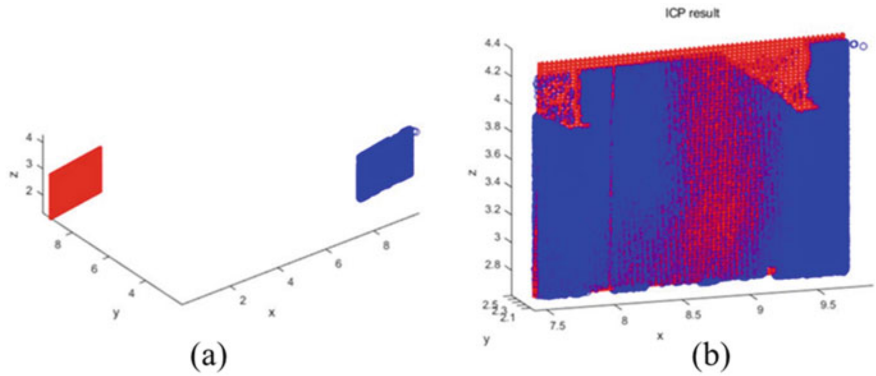

Fig. 8 Registration: **a** as-built point cloud model and as-designed BIM model and **b** the model after registration

calculated by means of SVD decomposing the matrix. Assuming that our matrix A is an m × n matrix, the SVD of matrix A is defined as:

$$A = U\Sigma V^{T} \tag{2}$$

where U and V are both unitary matrices, which means UTU = I, VTV = I. Σ is singular value.

The 3D point cloud model and BIM mode are compared to analyze the geometric quality, are shown in Fig. 8a. RMSE is used as an evaluation index for the registration results of the two models, which was defined as expected value of the square of the difference between the estimated value of the parameter and the true value of the parameter.

$$RMSE = \sqrt{\sum (w - r)^2 / length(w)} \tag{3}$$

where the (w-r) is the deviation of measured value from true value, the length (w) is the number of measurements.

As-built point cloud model and as-designed BIM model have been registered as shown in Fig. 8b. The point cloud model and the BIM model can be matched very well. The root mean square error graph is shown in Fig. 9. According to the RMSE and comparison results, the proposed technique can be used as an overall evaluation method, which provides help to determine whether the local inspection is necessary.

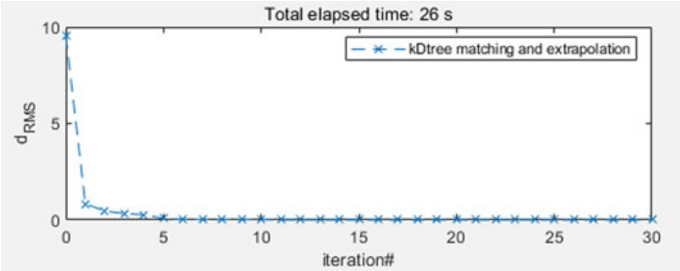

Fig. 9 Root mean square error chart

4 Experiment Validation

To validate the effectiveness of the proposed technology for automated evaluation of indoor dimensional tolerance compliance using the TLS data and BIM, experiments were conducted on a room of commercial residential building, which is shown in Fig. 10. A Trimble 3D terrestrial laser scanner was used for acquisition of point cloud data of building, which had a ranging accuracy of ± 5 mm within 20 m. To acquire sufficient scan data for the BIM, the highest angular resolution of 0.009° was used, providing a spatial resolution (spacing between two adjacent scan points) of 1.25 mm and a data density of 500,000 points/m^2. One scan was conducted for each of the room and the total point cloud data acquisition time was around 15 min. The as-built point cloud model of the selected room is shown in the Fig. 11a.

The point cloud data of BIM is extracted from the selected room of BIM model based on subdivision surface. The point cloud model of as-designed BIM is shown in the Fig. 11b. The 3D point cloud small room model and as-design BIM are shown in Fig. 12. As-built point cloud model and as-designed BIM after the comparison are

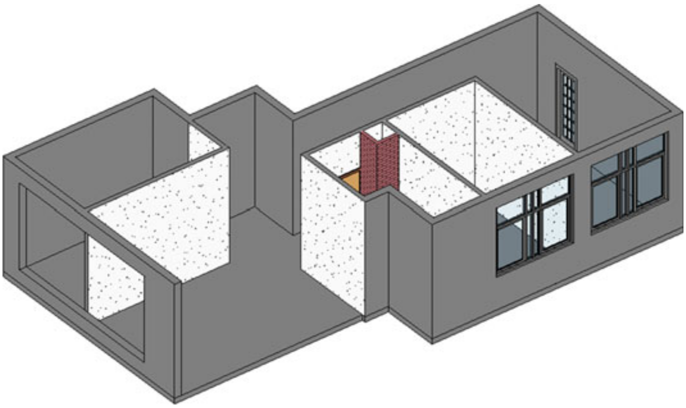

Fig. 10 Target-validated commercial residential BIM

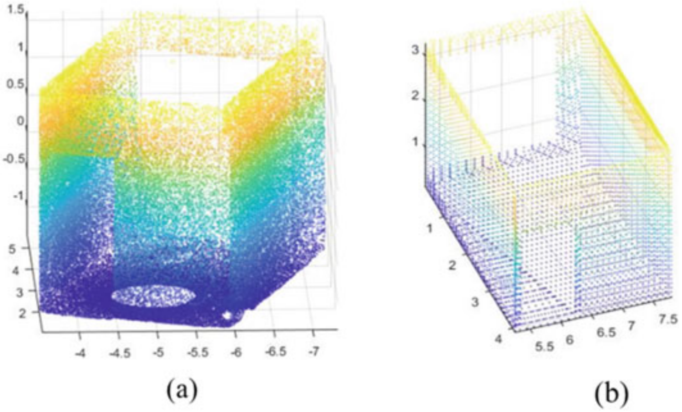

Fig. 11 Point cloud model: **a** as-built room model and **b** as-designed room model

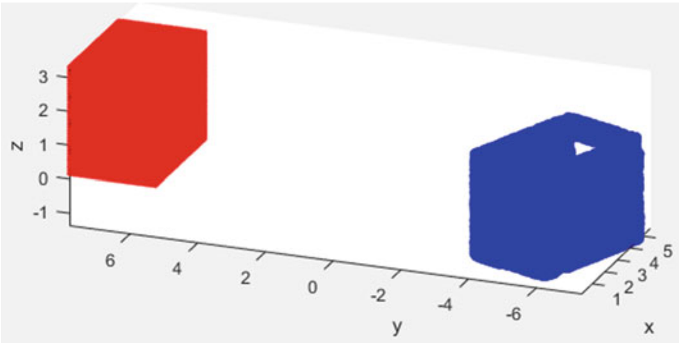

Fig. 12 As-built point cloud model and as-designed BIM

shown in Fig. 13, the root mean square error chart is shown in Fig. 14. The registration time of as-is point cloud model and as-designed BIM is 2 s, and the RMSE is the 5.3%, the reason of high RMSE may be due to the noise in the process of rescanning from the perspective of as-built point cloud data acquisition. The larger RMSE may be caused by the thickness of the wall, from the perspective of extracting point clouds from the as-designed BIM.

From the above comparisons, recommendations are made as follows: (1) In the process of collecting scanning data, the target ball placed in advance cannot be moved until the end of a site scan, otherwise it will lead to incomplete point cloud data or incomplete registration. (2) In the subdivision surface process of BIM, the point cloud data output is incomplete when there are edges with multiple adjacent surfaces or significantly distorted surfaces.

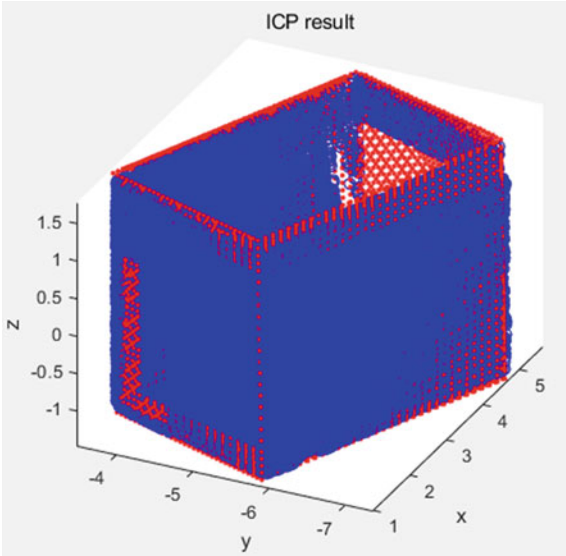

Fig. 13 The room model after registration

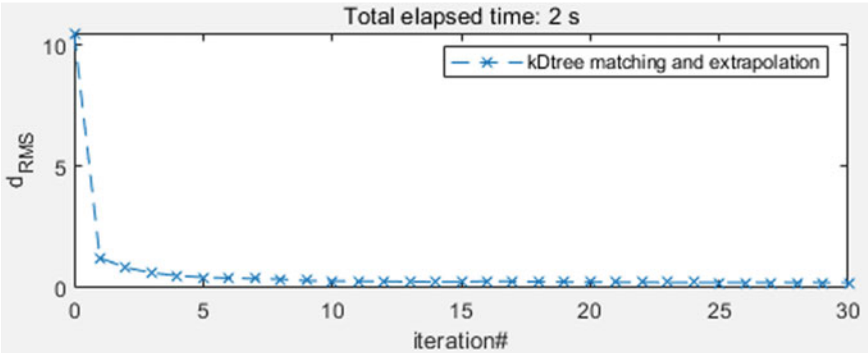

Fig. 14 Root mean square error chart

5 Discussion

The RMSE value of the registration process after 30 iterations is 0.053, which is relatively high compared with other component inspections. The reasons may be as follows. (1) The density of the point cloud model generated from BIM is not consistent with the scanning model, which will lead to the inconsistency of the feature points in the registration. (2) The quality of the collected point cloud data is not the best, which may be caused by occlusion during scanning. (3) The registration algorithm cannot recognize all the feature points. From the above discussions, recommendations are made as follows. (1) Before data collection, an efficient scan planning should be made to reduce occlusion. (2) Coarse registration and fine registration will be applied to match BIM models and point cloud models to reduce false matches.

6 Conclusions

In this study, an automated building dimensional evaluation technique based on 3D laser scanning and BIM is developed. The technique first extracts point cloud data from the BIM models via the subdivision surface. Experiment shows that the extraction of point cloud data from BIM has a better performance. Next, as-built point cloud data is preprocessed by the mosaic, down-sampling and segmentation. Subsequently, as-built point cloud model is compared with the as-designed BIM based on enhanced ICP algorithm. The RMSE value compared by as-built point cloud model and as-designed BIM model provides a decision basis for the local detection.

To validate the effectiveness and accuracy of the developed technique, experiments were conducted on a room of commercial building. The developed technique applied to the geometric quality of the building was compared to those obtained by manual inspection. The comparison shows that the developed technology is more accurate and faster than manual inspection. The results indicate that the developed technique can successfully provide overall geometric quality evaluation of buildings.

Besides, this study still has a few limitations. First, when registering the point cloud model and the BIM model, due to a great number of point clouds, the registration calculation is large, and the computer performance requirements are high. The future work is to propose a registration algorithm with a faster speed and less demanding on the computer. Second, the developed technique is unable to detect other quality problems of indoor, such as flatness and verticality. In the future, more efforts are expected to take to identify other indoor geometric quality issues using laser scan data and BIM.

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A Review of the Application of CNN-Based Computer Vision in Civil Infrastructure Maintenance

Ruying Cai, Jingru Li, Geng Li, Dongdong Tang, and Yi Tan

Abstract Computer-vision and deep-learning techniques are being increasingly applied to the maintenance of civil infrastructure, such as inspecting, monitoring, and assessing infrastructure conditions, which overcome time-consuming and laborious compared with traditional technology. In this paper, the research progress of deep learning, the developments of convolutional neural network (CNN)-based computer vision in improving accuracy, reliability and generalized object detection capability and its application in civil infrastructure maintenance are reviewed. The main objectives are as follows: (1) clarify the application of deep learning in computer vision to help researchers systematically understand deep learning; (2) review the application of computer vision in civil infrastructure maintenance to help researchers pay more attention to its advantages; (3) encourage relevant personnel to use this research as a reference, take deep learning as an important method at the forefront of engineering management, generate more innovations in the construction field, and promote the development of the construction industry.

Keywords Civil infrastructure · Computer vision · Convolutional neural networks · Deep learning

1 Introduction

Civil infrastructure can provide good services to the citizens as the operation and management activities. If maintenance is not carried out in time, it will not only cause potential hazards and hidden dangers to the civil infrastructure and its ancillary facilities, but also threaten citizen lives. Therefore, it's essential for real-time monitoring the condition of the infrastructure, so that necessary repairs and maintenance work can be carried out proactively and timely before it becomes too dangerous and

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expensive. Conventional manual monitoring is extensively time-consuming, laborious, expensive and has healthy and safety problems, particularly for the aerial working environment where detection is difficult to conduct [1].

In the past years, deep learning techniques, especially convolutional neural network (CNN), have been shown to outperform previous state-of-the-art machine learning techniques in several fields, with computer vision being one of the most prominent cases [2]. Computer vision is changing processes of the construction management as it enables the automatic acquisition, processing, analysis of digital images, and the extraction of high-dimensional data from the real world to produce useful information to improve managerial decision-making [3].

Deep learning has obtained promising performance in various computer vision tasks such as image classification [4], object detection [5] and object segmentation [6]. These three tasks are not only related to each other, but also progressive. The connection is that they are all based on the basic idea of CNN. The progressive relationship increases difficulties of three tasks. Both object detection and segmentation use some basic network models from image classification. The CNN-based image classification algorithm provides many new ideas for object detection and segmentation, and has achieved good results. This paper will briefly describe these three tasks and make a general comparison. From the beginning, these tasks have been applied to the industrial field, until now, they have been applied to many other fields and made great achievements, and have great application prospects in civil infrastructure maintenance. The application of deep learning based on CNN in the automatic detection and location of defects in civil infrastructures [7], such as bridges [8], roads [9] and sewage pipes [6], can solve these problems.

The remainder of this paper is organized as follows. Figure 1 is the structure of this review work. In Sect. 2, the research progress of deep learning, including the structure of deep learning, is described. Section 3 described the use of deep learning methods to address key tasks in computer vision, such as image classification, object

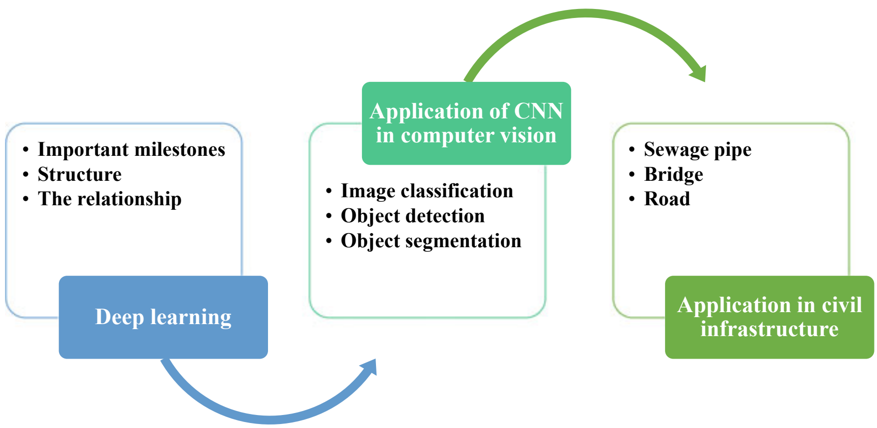

Fig. 1 Review structure

detection, and object segmentation. In Sect. 4, the application of deep learning-based computer vision in civil infrastructure maintenance are reviewed.

2 Research Progress of Deep Learning

2.1 Important Milestones of Deep Learning

Deep learning methods usually addresses rich and complex data from different sources, and they have performed better than previous technologies in multiple tasks, attracting increasing attention. Where does it start? How does it determine whether a particular deep learning model is suitable for their problem? How to train and deploy them? With these questions, the important milestones leading up to the era of deep learning [2] are firstly summarized in Table 1. The MCP model and Neocognitron are the beginning of the artificial neural networks (ANN) and CNN, respectively. However, AlexNet [10] won the ImageNet contest in 2012 with an absolute advantage of 10.9 percentage points over the second place. Since then, deep learning and

Table 1 Important milestones

Year	Contributor	Milestone
1943	McCulloch and Pitts	MCP model, considered to be the ancestor of ANN
1949	Hebb	Hebbian learning rule
1958	Rosenblatt	First perceptron
1974	Werbos	Backpropagation
1980	Fukushima	Neocognitron, considered to be the ancestor of the CNN
1985	Ackley, Hinton and Sejnowski	Boltzmann Machine
1986	Smolensky	Restricted Boltzmann Machine (initially known as Harmonium)
1986	Jordan	Recurrent Neural Network
1986	Rumelhart, Hinton and Williams	Autoencoders
1987	Ballard	
1990	LeCun	LeNet, starting the era of Convolutional Neural Networks
1997	Hochreiter and Schmidhuber	LSTM
2006	Hinton	Deep BeliefNetwork, ushering the "age of deep learning"
2009	2009	Deep Boltzmann Machine
2012	Krizhevsky, Sutskever, and Hinton	AlexNet, starting the age of CNN used for ImageNet classification

convolutional neural networks rose to prominence with AlexNet. An overview of deep learning structure based on CNN is presented next.

2.2 Deep Learning Structure Based on CNN

CNNs were inspired by the visual system's structure, in particular by its proposed models [11]. A CNN consists of three main types of layers, namely, convolutional layers, pooling layers and fully connected layers. Each type of layers has a different task. Figure 2 shows a general CNN architecture for an image classification task. In addition, CNN also has activation function, Batch Normalization and Regularization.

(i) Convolutional layers
In the convolutional layers, various kernels are used to convolve the input data to generate feature maps. The convolution operation is to cover the entire image step by step with the convolution kernel according to the step size, and the value of the filter is multiplied by the pixel value of the corresponding position of the image and then summed. The value obtained is the value of the target pixel in the output image.

(ii) Pooling layers
The pooling layer reduces the spatial size (width × height) of the input volume of the next convolutional layer through maximum pooling or average pooling, but does not affect its depth. This operation can reduce the number of parameters in the network, reduce the consumption of computing resources, and can also effectively control overfitting. The operation process of the pooling layer is to first slide the input data through the spatial window, and select the maximum or average value as the output result, and then continue to slide the window until the entire input data is covered, and finally the output results of each sliding are in order arrange to obtain the final complete output data. In the whole process, reduce the spatial size of the input data. The size of

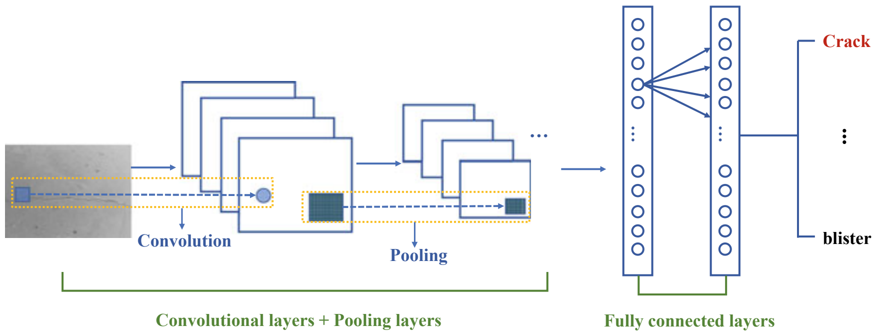

Fig. 2 The general CNN architecture

the sliding window and the sliding step size will affect the output data, so it is necessary to use the appropriate size and step size for the accuracy of the results.

(iii) Fully connected layers
Following several convolutional and pooling layers, the high-level reasoning in the neural network is performed via fully connected layers. Fully connected layers play the role of classifier in the entire CNN.

(iv) Activation function
The emergence of the activation function Rectified Linear Units (ReLU) solves the problem that sigmoid and tanh are prone to disappearing gradients, which is currently the most commonly used activation function. Generally, the activation function is used after each convolution.

(v) Batch Normalization and Regularization
Batch Normalization is to force the distribution of the input value back to a standard normal distribution with a mean of 0 and a variance of 1, to avoid the problem of vanishing gradients. Dropout is a convenient but powerful regularization method, which randomly deletes some nodes in each iteration, and only train the remaining nodes to suppress overfitting.

2.3 The Relationship Between Machine Learning, Deep Learning, CNN, Computer Vision and Civil Infrastructure

Understanding the relationship between machine learning, deep learning, CNN, computer vision and civil infrastructure can help researchers understand this paper. For machine learning, the way to solve the problem is to find out the mapping relationship between X and Y through the model, among which the available models are logistic regression, linear regression, support vector machine (SVM) and others. While, using the type of neural network model is called deep learning, which including convolutional neural networks. The application of convolutional neural network to computer vision mainly has three major tasks, including Image classification, Object detection, Object segmentation. Then, these three tasks are applied to civil infrastructure, as can be seen from Fig. 3.

3 Application of CNN in Computer Vision

Deep learning has been widely adopted in various directions of computer vision, such as image classification, object detection and segmentation, which are key tasks for image understanding. The differences among the three tasks can be seen intuitively from Fig. 4, taking crack images of sewage pipes [12] as an example. In this part, the

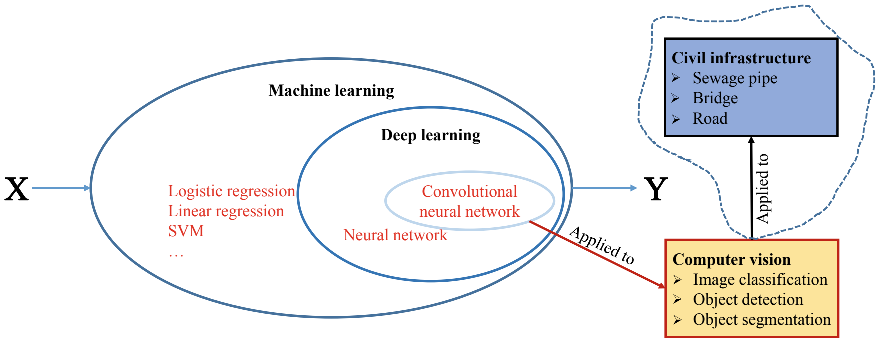

Fig. 3 The relationship between machine learning, deep learning, CNN, computer vision and civil infrastructure

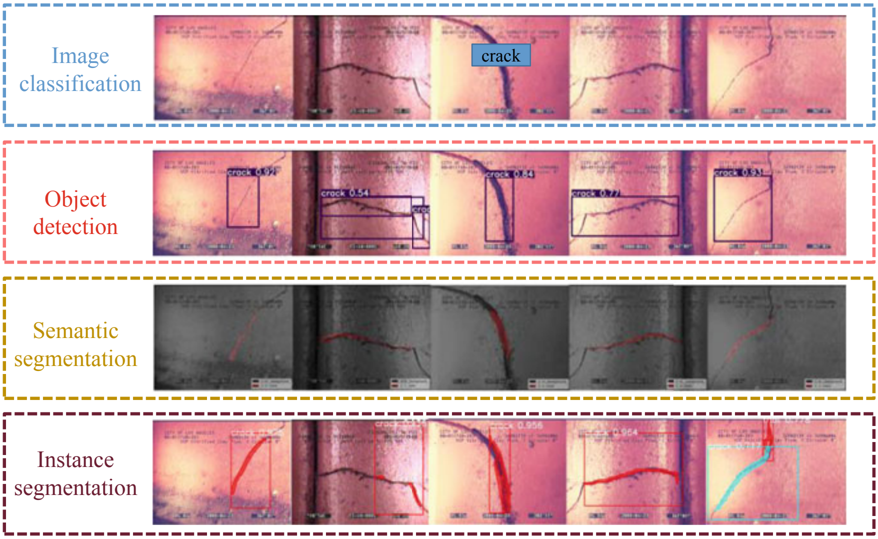

Fig. 4 Example of crack images of sewage pipes in three tasks

developments of deep learning in above-mentioned three tasks, especially the CNN-based algorithms, will be briefly summarized.

3.1 Image Classification

The image classification task means that image is labeled with a probability of the presence of a particular visual object class [13], which is the simplest and most basic image understanding task. The task of the deep learning model is to achieve the first breakthrough and realize large-scale application.

In general, CNN is the most advanced compared to classical algorithms [14]. Through the continuous research and improvement of its structure, a series of network models have been formed and successfully applied in a wide range of practical applications, such as AlexNet, VGGNet [15], GoogleNet [16] and ResNet [17] as shown in Table 2. It can be seen from the table that more and more optimizations are applied to network design, such as Dropout, Local response normalization (LRN), and Batch normalization. The state-of-the-art results of the top-5 error rate tested by ImageNet since 2012 are also presented in Fig. 5. The model CNN-based is also used in the cracks of civil infrastructures, for example, Zhou and Song developed

Table 2 Structure of typical convolutional neural networks models

Model	AlexNet	VGGNet	GoogleNet	ResNet
1st release time	2012	2014	2014	2015
layers	8	19	22	152
Data Augmentation	+	+	+	+
Inception	−	−	+	−
Convolutional layers	5	16	21	151
Convolutional kernel size	11, 5, 3	3	7, 1, 3, 5	7, 1, 3, 5
Full connected layers	3	3	1	1
Full connected layers size	4096, 4096, 1000	4096, 4096, 1000	1000	1000
Dropout	+	+	+	+
Local response normalization	+	−	+	−
Batch normalization	−	−	+	+

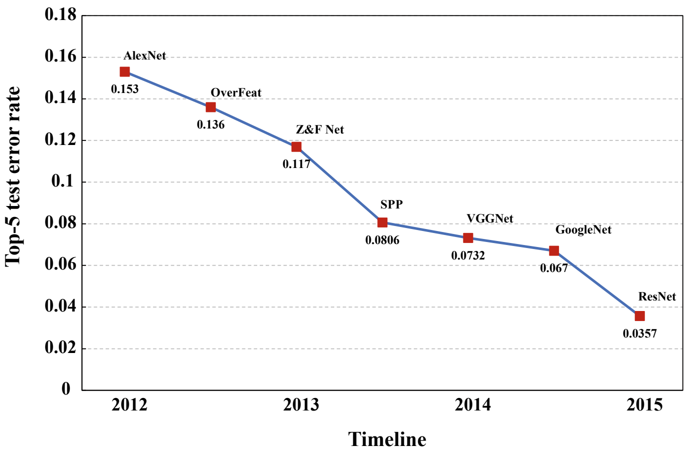

Fig. 5 The top-5 error rate results of typical model

Deep CNN structures with different layouts for fracture classification based on laser scanning range images [4], Wang et al. proposed a CNN-based damage classification technology for deep buildings targeting masonry historical structures [18].

3.2 Object Detection

Image classification is the basis of computer vision, but only classification is not enough. Object detection is different from but closely related to the image classification task. Object recognition and segmentation are more difficult but meaningful. The classification task is only concerned with classification, while the detection task is not only focus on classification, but also required to obtain the location of the detected object.

Object detection research has been conducted for many years, and there are many methods that have been widely recognized and applied in the industry. Several typical detection models and their feature are introduced in Table 3. Object detection is usually divided into two categories, one category is one-stage network, such as You Only Look Once (YOLO) [19–21] series and Single Shot MultiBox Detector (SSD) [22], the other is two-stage network, such as Regions with CNN features (RCNN) series [23]. In general, one-stage is faster, two-stage is more precise. Some scholars have applied these two types of detection networks to sewage pipes and have reached a consistent conclusion [24]. In addition, these algorithms have attracted the attention of the researchers, for example, YOLO was applied in various kinds of defects automatic detection [25], YOLO have also been used in detecting multiple damage on the surface of the concrete bridge [26, 27], Faster RCNN was used to detect and preliminarily evaluate the damage caused by earthquake to buildings [28].

3.3 Object Segmentation

In addition to classification and object detection, it is also necessary to separate out all the pixels related to the object and give the categories even though it's more difficult, which is called object segmentation.

Object segmentation consists of semantic segmentation and instance segmentation. The former is an extension of the pre-background segmentation, requiring the separation of image parts with different semantics [29]. Figure 6 shows the scores of its typical model in the VOC2012 dataset. While the latter is an extension of the detection task, which requires the outline of the objects and more refined than the detection frame. The MASK R-CNN and FCIS [30] are the most significant research outcomes in recent years. Compared with semantic segmentation, instance segmentation can label different individuals of the same type of object on the image, which is a comprehensive task combining image classification, object detection, and semantic segmentation.

Table 3 Object detection model feature

Model	Features
RCNN	(a) Using the selective-search (SS) to extract 2000 region proposals (b) Computing feature for each region proposal with a large network (c) Classifying each region proposal using a linear support vector machines (SVMs) classifier (d) Regression analysis
Fast-RCNN	(a) Extracting features from the entire image with convolutional neural network to get the feature map (b) Getting the region of interests (RoIs) of the image through SS (c) The pooling layer extract a fixed-size feature factor for each RoIs (d) The RoIs are connected to the full connection layer. Separately evaluating k object classes and generating bounding box regressor
Faster-RCNN	(a) Getting the feature map with CNN (b) Using region proposal networks (RPN) to generate region proposal on the feature map (c) Using the classifier to determine whether a feature belongs to a specific class for the features extracted in the proposal frame (d) Regression using bounding box
YOLOv1	(a) Dividing the image into S × S grids (b) The grid is responsible for detecting the object if the center of the object falls into the grid
YOLOv2	(a) Adding Batch Normalization to make the network learn faster and better, avoid overfitting (b) Removing a pooling layer to increase the resolution of the convolution output (c) Using K-means clustering algorithm to automatically select the best initial boxes (d) Feature map of 26 × 26 × 512 turned into 13 × 13 × 2048 using fine-grained features
YOLOv3	(e) Logistic regression was used to predict confidence and classify (f) Retrained a new feature extractor-DarkNet-53 (g) Predicting the coordinates of bounding box on three scales
SSD	(a) Getting the feature map with CNN (b) Extracting the feature map of six layers, generating the default box on each point of the feature map (c) Collecting all the generated default boxes, throw them all into maximum value suppression (NMS), output the filtered default box

In general, Object segmentation is a pixel-level description of an image [14], which is suitable for scenes with high requirements for understanding. Such as the segmentation of roads and non-roads in auto pilot.

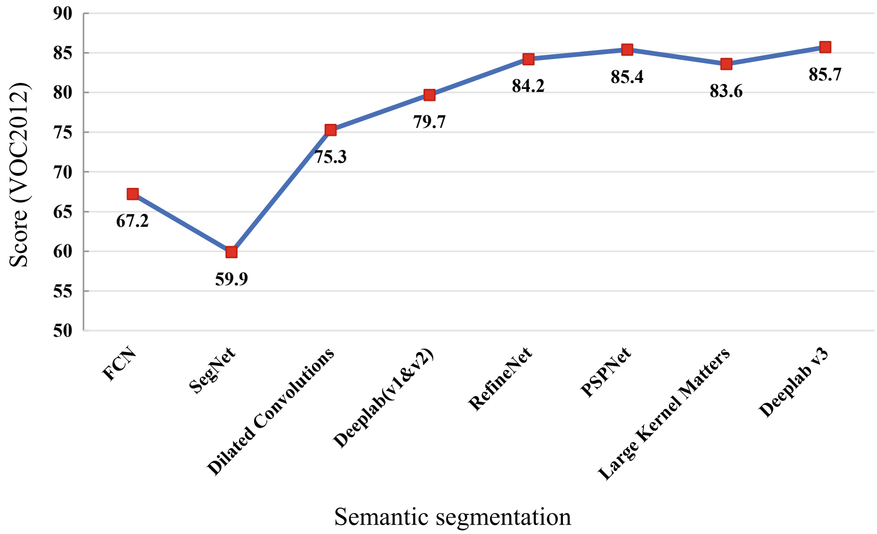

Fig. 6 The scores of typical semantic segmentation model

3.4 Typical Experimental Tools and Model Evaluation

Good tools such as datasets and computing platform, can make the research process more effective and successful. The development of deep learning is inseparable from the development of datasets. The typical datasets of image processing fields, including MNIST, PASCAL VOC, CIFAR, ImageNet, COCO, Open Image, and Youtube8M play an important role in the recent neural network researches in industry application, academic research and other fields. Programming tools that support deep learning are also very popular, such as TensorFlow, MXNet, PaddlePaddle, Caffe, Torch, and Theano, providing rich convenient interfaces for mathematical computation.

Deep learning is a branch of machine learning, and precision and recall are typical indicators for most machine learning. However, due to the uneven distribution of prior targets, traditional evaluation indicators are not suitable for multi-object detection models. Therefore, different types of classification errors should be considered when evaluating object detection models [5]. The performance of the model is summarized as two aspects: (1) accuracy. The precise recall, average accuracy (AP), mean AP and missing rate belong to accuracy; (2) calculating cost. Detection speed and training time belong to calculating cost.

4 Application in Civil Infrastructure

Civil infrastructures, including bridges, roads, tunnels, and underground utilities like sewage pipe, are becoming susceptible to losing their designed functions due to deterioration caused by use [7]. This inevitable situation means urgent maintenance is required. The condition monitoring of concrete surface plays a significant role in civil infrastructure management system [31]. Defects are the main threat to concrete surface of infrastructure. Traditional vision-based methods of crack detection lack accuracy and generalization when working on complicated infrastructural conditions [32]. At present, a number of computer vision-based crack detection techniques have been developed to enhance the efficiency, speed, and objectivity of inspection [33] and manage a large number of structures [34]. For example, as shown in Fig. 7, three computer vision tasks based on CNN, including image classification, object detection and object segmentation, are employed in three civil infrastructures, including sewage pipe, bridge and road, respectively.

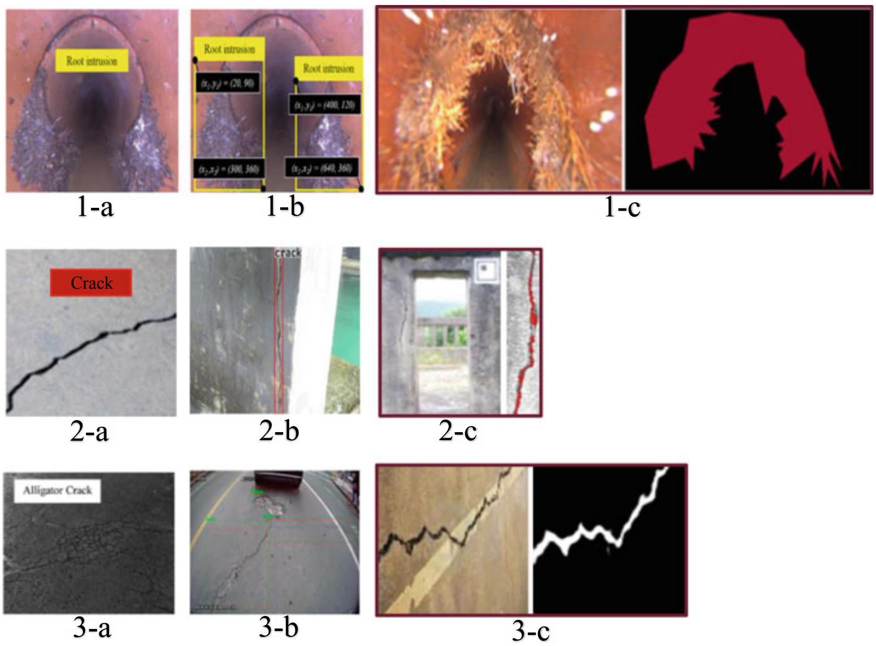

Fig. 7 Three kinds of civil infrastructure respectively use three kinds of computer vision tasks, where **a**, **b**, **c** is image classification, object detection and object segmentation respectively, and 1, 2, 3 is sewage pipe, bridge and road respectively

4.1 Sewage Pipe Inspection

As an important component of civil infrastructure, sanitary sewer systems are designed to collect and transport sanitary wastewater and stormwater. Sewer defect inspection is the key in identifying both the type and location of pipe defects to maintain the normal sewer operations [5] for maintenance of urban underground infrastructure [35].

For sewage pipe defect inspection, a CNN was initially used to detect and characterize cracks on an autonomous sewer inspection robot [36]. Currently, closed-circuit television (CCTV) and other visual inspection technologies have been widely used in the inspection of underground sewage pipelines. However, it's time-consuming and the results are subjective [37] when relying on manual interpretation of the images or videos. However, the deep learning-based approach can automatically extract image features and improve the accuracy and efficiency, and it does not require much for image preprocessing. Therefore, several studies of deep learning-based approach exploration have been performed. For example, the method of image classification is applied to sewage pipe detection with a sufficiently large dataset (over 2 million CCTV images) by Dirk Meijer [38]. A deep learning-based approach is developed for sewer pipe defect detection using faster region-based convolutional neural network (Faster R-CNN) [12]. With the development of deep learning techniques, Yin et al. employ a state-of-the art convolutional neural network (CNN) based object detector, namely YOLOv3 network, for detection system of sewer pipes [39]. A unified neural network, namely DilaSeg-CRF, is proposed by fully integrating a deep convolutional neural network (CNN) with dense conditional random field (CRF) and applied to sewer pipe [6].

4.2 Bridge Inspection

Bridges play an important role in civil infrastructure. Periodic bridge inspections are very important to maintain the functionality, safety and reliability of the bridge structure. It's essential for the continuous monitoring and maintenance of bridges. As bridges become obsolete, the number of bridges that need to be inspected increases, which requires a lot of maintenance costs. If postponing the cost of bridge maintenance, more costs will be required in the near future [40].

Traditional bridge detection methods rely on human visual inspection [41], which remains the most adopted approach among all nondestructive evaluation techniques that can be used to identify and monitor defects [42]. This method has limitations that the performance is highly related to the experience of the inspector, time consumption and accessible areas [40]. In this case, detection technology based on computer vision [43] and the idea of images obtained from drones [44] are proposed.

Zhang et al. use the applicability of the state-of-the-art single-stage detector YOLOv3 to identify various types of defects in concrete bridges and improve its performance in terms of detection accuracy [42]. Some researchers also use other deep learning-based methods to detect bridge damage and achieve better results, such as CNN [45–48], region with convolutional neural networks (R-CNN)-based transfer learning [40] when the dataset is not enough.

4.3 Road Inspection

With the rapid development of road traffic, road surface cracks not only affect the transportation efficiency but also pose a potential threat to vehicle safety. The importance of road maintenance has attracted increasing attention. It is crucial to repair the roads in time when potholes are appeared to prevent accidents in advance [49]. In reality, however, due to limited human resources, it is difficult to detect and repair potholes in time. A lot of research has focused on road damage detection, and there are three main methods: vibration sensor-based, laser scanning-based, and computer vision-based methods [50].

With the advent of CNN [51], image processing technology has made significant progress recently, and computer vision-based methods are widely utilized to research road defects. Image processing algorithms [52] mainly include threshold segmentation [53], edge detection [54] and region growth methods [55] for image processing and crack feature recognition. CNN algorithm is applied to concrete pavement crack detection [56, 57]. Chun et al. proposed Fully CNN-based road surface damage detection with semi-supervised learning to detect road damage [49]. Hybrid deep CNN is applied to the detection and location of moisture damage in asphalt pavements, including ResNet50 network for feature extraction, YOLOv2 network for identification, and detection and location of moisture damage [9].

4.4 Other Civil Infrastructures Inspection

In addition to the civil infrastructure mentioned above, other infrastructures also applied deep learning methods to detect damage. Structural health monitoring (SHM) is used to manage and maintain civil infrastructure, which generated a large amount of data. Traditional detection technology cannot effectively analyze these data, and it is time-consuming, laborious, and inefficient. Therefore, how to effectively monitor, mine and use the data requires in-depth research, which considers the introduction of deep learning-based methods for detection. Deep learning-based method is also used to detect crack from concrete surface [58–63], structure [64, 65], buildings [66, 67]. In addition, deep learning is also used to identify unsafe behavior from two-dimensional images that appear on construction site [68, 69]. Their experimental results show that the method has a significant improvement in accuracy and efficiency. In summary, deep learning has good application prospects in the field of construction.

Through the review, we found that although many people apply cutting-edge technologies such as computer vision to civilian infrastructure, they have not been implemented in practice and have not achieved real-time detection technology.

5 Conclusions

Computer vision has attracted the increasing attention of researchers and practitioners. This paper gives a brief review of the application of deep learning-based computer vision in civil infrastructure maintenance. Firstly, the research progress of deep learning was reviewed, including the important milestones and deep learning architectures. Deep learning is widely used in the three major directions of computer vision, image classification, object detection, and object segmentation. Secondly, the models used in these three aspects are summarized. Finally, the applications of deep learning-based computer vision for damage detection in the maintenance phase of civil infrastructure, including sewage pipes, bridges and roads, were reviewed.

Through the review, we can find that more and more people are paying attention to automation and intelligence. The application of cutting-edge technology to the construction industry is a measure that conforms to the times. Moving to the forefront of technology is a necessary condition for the development of automation and intelligence in the construction industry. Prosperous application prospects in other aspects of the construction industry. In recent years, these reviewed models have become new hotspots for deep learning and CNN to effectively applied in computer vision, multi-object classification and related fields. They are considered effective methods and tool by the industry and academia. Applying deep learning-based computer vision technology to the construction management field can achieve greater and more innovation and promote the transformation and development of the construction industry. However, we found that although many people apply cutting-edge technologies such as computer vision to civil infrastructure, the implementation is limited in practice, and the real-time detection is also still limited.

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The Uses of Social Network Analysis in the Field of Engineering Construction Management: A Review of the Literature

Qingshan Hao

Abstract A bibliometric analysis of related publications on the uses of social network analysis in the field of engineering construction management is reported in this study in order to depict existing research activities and to identify future directions in this research field. These publications were retrieved from China National Knowledge Infrastructure databases. There is a notable growth associated with the body of knowledge on he uses of social network analysis in the field of engineering construction management. From the 513 retrieved literatures, 98 related literatures related to the uses of social network analysis in the field of engineering construction management were selected through reading abstracts for research and analysis. Through the comprehensive analysis of key words and related literature, it can be found that the application of social network analysis in the field of engineering construction management is mainly studied from the perspectives of stakeholders, construction projects and workers. The content of these publications mainly focuses on relationship among stakeholders, project risk research, information sharing among organizations, multi-agent collaborative management, information sharing and knowledge exchange among workers. These findings help to identify hotspots in the uses of social network analysis in the field of engineering construction management research. In addition, this study also puts forward the future research direction of the uses of social network analysis in the field of engineering construction management in order to provide reference for the research in the field of engineering construction management.

Keywords Social network analysis · Bibliometric analysis · Stakeholders · Construction projects

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1 Introduction

The use of social network analysis (SNA) in many social science disciplines has increased exponentially over the past one decade. Although documented applications of social network analysis in the field of engineering construction management are still rare, instances of its use in management, psychology, anthropology and political science are increasingly common. Social network analysis themselves have addressed network analysis more widely available in the social sciences and increasingly in management science. As interest in the potential uses of social network analysis grows rapidly, it is both appropriate and timely to review its applications and potential in the field of engineering construction management.

Social network analysis is a sociological research method developed to meet the needs of the study of social relations and social structure. Specifically, it refers to an analytical method that comprehensively applies graph theory and sociometry to study multiple actors, social networks in which actors are located and the relationships among multiple social networks [1]. As a clear sociological research method, the formation and application of social network analysis are only recent years, especially in the field of engineering construction management. According to the study, social network analysis research has grown exponentially from 2005 to 2019. However, in the research field of western sociology, the idea of social network analysis has existed for 60 or 70 years, which can be traced back to the research of psychology, anthropology and sociology in the 1930s. There are three main aspects to the early development of social network analysis [2].

i. The sociometry school of social psychology, whose contributions to the analysis of social networks are mainly reflected in the application of graph theory.
ii. The Harvard School in the 1930s, whose contributions to the analysis of social networks are mainly reflected in the study of interpersonal relationships and the forms of factions.
iii. The Humanist School of The University of Manchester, who contributed to the analysis of social networks, developed a structure based on the "community" relationship between rural society and tribes. By the 1970s, with the emergence of the new Harvard School, social network analysis had matured. In the 1990s, social network analysis entered an era of rapid development.

In recent years, social network analysis has attracted more and more attention from scholars in the field of engineering construction management. However, no scholars have systematically sorted out the application status of social network analysis in the field of engineering construction management. Therefore, this paper aims to summarize the development status, research progress and research directions of social network analysis in the field of engineering construction management, so as to provide theories and references for subsequent studies.

2 Methodology

2.1 Bibliometric Analysis

Bibliometric analysis is a systematic approach to the quantitative analysis of scientific publications in order to identify specific research phenomena. The application of bibliometric analysis has been expanded from the initial field of library and information science to the measurement of scientific progress in various fields [3]. Mathematical statistics technology is applied to literature econometric analysis, aiming at investigating and studying the distribution structure, mathematical law, change pattern and quantitative management of information, and then analyzing the structure, characteristics and patterns of underlying science and technology. Compared to other methods, bibliometric analysis has the following advantages: (1) mathematical evaluation of a specific research field in a certain period of time; (2) to provide a scientific evaluation method to identify the knowledge generation nature of the system [3, 4].

2.2 Content Analysis

Word frequency analysis is a useful and effective method for content analysis. It is a common method to take the core words representing the core content of literature as the research object [5]. Therefore, the author's keywords reflect the research focus within a certain area which may suggest future science directions. This study analyzed the relevance of co-occurrence keywords in publications to identify word clusters, combined with quantitative analysis of keywords, and investigated the context and relevance of hot research [4, 5].

2.3 Data Source

This study selects the CNKI Chinese periodical database as the data source, with "subject = (social network analysis)" is a retrieval model, set up the document classification catalogue for the building science and engineering in the engineering technology II album, time selection from 2000.1.1 to 2020.4.30, search to 513 publications. Of 513 retrieved publications, 149 were Chinese articles and 364 were English articles. In order to ensure the reliability of the research data, the title and abstract of the collected literature were reviewed, and the literature of academic research was manually screened. In the end, 77 Chinese literatures and 21 English literatures were retained for further analysis in this study.

3 Results

3.1 Analysis of Literature Volume and Its Development Trend

Figure 1 describes the main performance of the literatures published during the period of 2000.1.1–2020.4.30 on the application of social network analysis in the field of engineering construction management. Results show.

As shown in Fig. 1, the volume of literature on the application of social network analysis in the field of engineering construction management has gone through four stages from 2000 to 2019, showing an overall upward trend. From 2000 to 2010, social network analysis has not attracted the attention of most scholars in the field of engineering construction management, and only a few scholars have applied social network analysis in the field of engineering construction management. From 2010 to 2013, the application of social network analysis in the field of engineering construction management began to develop and grow steadily, indicating that scholars in this field began to attach importance to the application research of social network analysis in this field. From 2013 to 2017, the application of social network analysis in the field of engineering construction management showed exponential growth. 2017–present is the rapid development stage of the application of social network analysis in the field of engineering construction management. It is expected that the application research of social network analysis in the field of engineering construction management will continue to grow in the next few years.

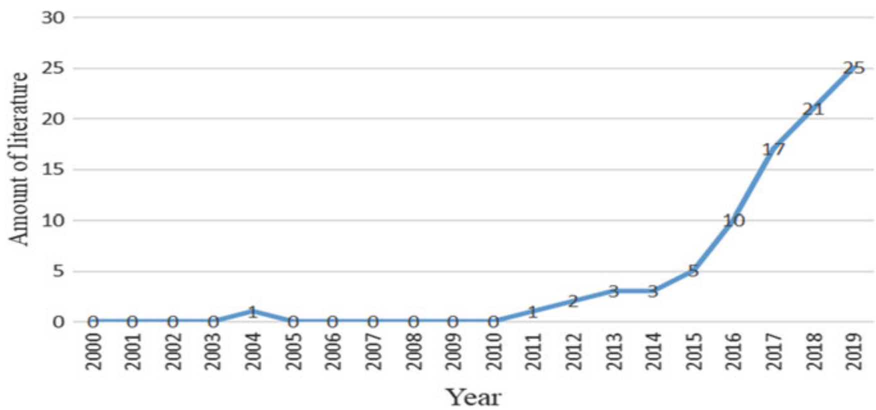

Fig. 1 Literature growth trend of social network analysis in engineering construction management

3.2 Main Research Fields and Future Research Directions

In this study, the application of social network analysis in the field of engineering construction management related publications keywords are analyzed, because keywords can determine the research focus of one paper. Of the 99 publications analyzed, the average number of keywords in each publication range from 4 to 5. Considering that some keywords have very slight differences, such as "social network analysis" and "social network", "stakeholder" and "stakeholders", "construction project" and "the project", "workers" and "construction workers", these similar keywords are unified in a standard form for further study. With such a treatment, a total of 451 individual keywords were obtained for further analysis. Most of these keywords were not used frequently, about 72.94% of keywords were used only once or twice, while keywords used more than 10 times accounted for less than 1.00%. Table 1 presents the frequency of some keywords appearing in publications related to the application of social network analysis in engineering construction management from 2000.1.1 to 2020.4.30. The frequency of keywords listed in the

Table 1 High frequency keywords ranking

Number	Keywords	Frequency
1	Social network analysis	92
2	Stakeholder	21
3	Construction project	19
4	Building information model	16
5	Prefabricated building	13
6	Green building	13
7	Construction companies	8
8	Risk analysis	7
9	Organization relationship	6
10	Influential factors	6
11	Risk factors	5
12	Risk network	4
13	Industrialization of architecture	4
14	Construction management	4
15	Unsafe behavior	4
16	Project management	4
17	workers	4
18	Collaborative innovation	3
19	Sustainability	3
20	Communication	3
21	Social risk	3
22	Effect of detection	3

Table 1 in this study, to some extent, it reflects the hotspots of the application of social network analysis in the field of engineering construction management.

As shown in Table 1, social network analysis is the most used keyword (92 times), which may be related to the subject being searched. The followed by stakeholders (21 times), construction projects (19 times). A further analysis indicates that in addition to social network analysis, stakeholders is the most frequently used keyword in relevant studies. This reflects that social network analysis is often used by scholars in the field of engineering construction to analyze the relationship between stakeholders. In addition, since stakeholders are linked together by various relationships, and the purpose of social network analysis is to study how the relationship structure among stakeholders affects behavior [6]. Construction projects are also frequently used keyword in relevant literature. The theory of social network analysis views a construction project as a systematic environment, which is interwoven by various relationships, and this theory is concerned with the structure and patterning of those relationships and tries to identify both their causes and effects [7]. In the future, it is still a research hotspot to apply social network analysis theory to construction projects and stakeholders.

In order to better understand the application of social network analysis in the field of engineering construction management research hotspots, this paper conducts keyword clustering analysis on relevant literatures and forms a knowledge map with keywords as the core and collinear relationship as the connecting line, as shown in Fig. 2.

As shown in Fig. 2, the Social network analysis occupies the central position of the whole keyword collinear network, and closely related to social network analysis are stakeholders, construction projects, building information models, prefabricated buildings, and green buildings. It shows that these five key words are the research

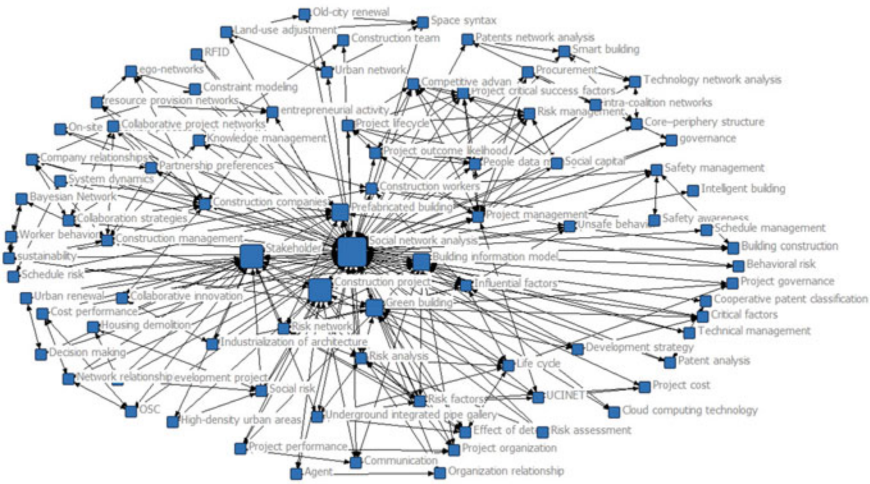

Fig. 2 Keywords network diagram

hotspots of social network analysis in the field of engineering construction management, and they are in the core position in this field. At the same time, it can be seen that there is no isolated point in the network diagram, and the keywords between each part are closely connected.

In Fig. 2, the application research hotspots of social network analysis in the field of engineering construction management are mainly studied from three subjects. Firstly, based on social network analysis, research from the perspective of stakeholders. The main research content is centered on the stakeholder nodes, and the risk as the research object, mainly including risk analysis, risk factors, risk network and so on. Secondly, based on social network analysis, research from the perspective of construction projects. The main research content is centered on the project node, and the project organization relationship as the research object, mainly including prefabricated building, green building and building information model and so on. Thirdly, based on social network analysis, research from the perspective of construction workers. The main research content is centered on the node of construction workers and the research object, mainly including workers' safety behavior, unsafe behavior, knowledge management, communication and so on.

3.2.1 Research from the Perspective of Stakeholders

The relationship between stakeholders is complex and not easy to be identified, while the purpose of social network analysis is to study how relationships affect behavior, especially to highlight the importance of different stakeholders. Therefore, many scholars use social network analysis method to study the relationship between stakeholders. The main content of the study is the management of stakeholders and the study of risk issues from the perspective of stakeholders.

In the research on stakeholder management, firstly, Qiao and Liu [7] through the literature research on green building project stakeholders, screening to identify green building projects at different stages of the entire life cycle of key stakeholders, secondly, using social network analysis to measure the green building project key stakeholders network organization relations, analyzes the mutual influence between key stakeholders, finally, combining with the results of social network analysis, the governance of key stakeholders is realized. In order to solve the problem of static cooperation among stakeholders, some studies use the social network analysis method to analyze the dynamic changes of stakeholders and their relationships, assist the management of stakeholders, and put forward a systematic research framework. Xue et al. [8] developed the main framework of off-site construction collaborative project management through social network analysis to explore the evolution of collaboration among stakeholders. All the above studies have studied the dynamics of the relationship between stakeholders through the social network analysis method, but few have studied the dynamic characteristics of the relationship between stakeholders in the whole life cycle of the project, which will be a direction of future research.

Most of the research on stakeholders and risks focuses on a certain stage of the project. In order to identify and manage the risks in the design and construction of green building projects, Yang et al. [6] proposed a stakeholder related risk analysis model of green building projects based on social network perspective. The model overcomes the limitations of traditional linear risk analysis and improves the effectiveness and accuracy of stakeholder and risk analysis. Yu et al. [9] studied the social risks of house demolition from the perspective of stakeholders and identified the key risks and their corresponding stakeholders by using social network analysis. Yuan et al. [10] used social network analysis to establish a theoretical model of social risk network analysis that considered the relationship between stakeholders and risks. This model analyzed the relationship between 16 social risk factors and 8 stakeholders. There are many studies on risks and stakeholders, but most of them regard risk factors as isolated points and focus on the independent analysis of risk factors and stakeholders. There is a lack of research on risks from the perspective of building life cycle and stakeholders, and a lack of systematic combing of the corresponding combination of stakeholders and risks. In order to solve these problems, from the perspective of the whole life cycle of prefabricated construction and stakeholders, Huang and Zhang [11] combed the risk factors of green supply chain of prefabricated buildings and the combination of stakeholders, and uses social network analysis method to build a risk network analysis model to identify key risks and key relationships. Finally, the results are analyzed and targeted risk mitigation strategies are proposed. Based on the analysis of the above literature, it is found that most of the existing literature studies the relationship between risk and stakeholders from one or several stages of the project. Few literatures have studied the relationship between stakeholders and risks from the perspective of the whole life cycle of a project, and few have considered that conflicts between different stakeholders have become the main source of project risks. Therefore, from the whole life cycle of the project and the conflict between different stakeholders has become the main source of project risk, which will be the future research direction.

3.2.2 Research from the Perspective of Construction Projects

Construction project has obvious social characteristics, which not only includes material operation activities, but also includes a large number of social activities such as complex personnel cooperation and cooperation [12]. Social network theory regards construction project as a system environment, which is connected by various relationships. The greatest advantage of social network analysis is that it can clearly understand the social relationship between actors and the group structure within the actor faction. Therefore, many scholars in the field of engineering construction management use the theory of social network analysis to study the relationship between project organizations. With the help of social network analysis method, Yang [13] constructs the organization network model and finds the quantitative way of key indicators of project organization, through the construction of the model, it can be concluded that social network theory is an effective theoretical method to study the organizational relationship of engineering projects. In order to improve the current situation of knowledge sharing among large-scale engineering project organizations, Feng et al. [14] constructed a reciprocal knowledge sharing network model by using social network analysis method. Based on social network analysis, Liu et al. [15] studied the organizational relationship of EPC general contracting projects. Taking the engineering organization as the research object, Yang et al. [16] used the social network analysis method to quantitatively analyze the influencing factors and their mutual relations of BIM adoption within the organizations. Wang et al. [17] used the social network analysis method to identify the core risks and key relationships in the risk network of prefab construction projects, and proposed targeted risk countermeasures in order to control risks from the source and improve the risk management level of prefab construction projects. Based on the social network analysis method, Liu et al. [18] attempted to analyze the behavioral risk of multiple subjects in prefabricated building projects from the perspective of the internal connection of risk factors, so as to explore the key factors and mechanism of the behavioral risk of prefabricated building project subjects.

Based on the above literature analysis, it can be found that social network analysis is widely used in project management, risk management, collaborative innovation, social risk and other aspects. In particular, it provides a new perspective and method for the study of project management organization, organizational learning, information exchange and knowledge management. Because the construction project is a complex and systematic project, it has the characteristics of large investment scale, long construction period, many risk factors and complex interest relationship of the project subject. Moreover, the information asymmetry, complexity of relationship, uncertainty and multi-directional interests further aggravate the complexity and variability of construction project risk [19]. In addition, the application of social network analysis in the risk management of construction projects is rare. Therefore, the risk management of construction projects will be a research direction in the future.

3.2.3 Research from the Perspective of Workers

Social network analysis can effectively analyze the social interaction between people and reveal the potential mechanism and dynamics that make this connection possible in complex systems. Compared with other methods, social network analysis has the advantages of analyzing communication structure and generating indicators, which can be used as indicators of network performance [20]. For instance, Heo et al. [21]. used the social network analysis method to study the online interaction among employees, so as to analyze the influencing factors of information sharing among employees. Dang-Pham et al. [22] used the method of social network analysis to explore the reasons why employees are willing to share information security suggestions, and investigated the structure mode of the sharing network. In another study, Li et al. [23] used social network analysis to conduct a central analysis on the indicators of workers' safety literacy model, determined 16 core indicators of the safety literacy model, and constructed the index system of safety literacy. There are also some studies that use social network analysis to build the relationship model of unsafe behavior of construction workers. For instance, Li et al. [24] used social network analysis method to construct the relationship network model among unsafe behaviors of construction workers, and studied their structural characteristics, node attributes, influence and clustering levels. Wang et al. [25] analyzed the characteristics of the propagation path of unsafe behaviors among construction workers in groups from the perspective of groups, and constructed the network propagation model of unsafe behaviors among construction workers using the theory of social network analysis.

As noted above, from the perspective of workers, scholars in the field of construction management use social network analysis to study the relationship between individuals, including information sharing, communication, propagation of individual behavior and so on. Social network analysis is also a quantitative analysis method to study the social interaction between different groups. Therefore, future research will focus more on the use of social networks to analyze the relationship between individuals and organizations and the relationship between different organizations.

4 Conclusions

Via the bibliometric methods, 98 publications related to the uses of social network analysis in the field of engineering construction management were retrieved China National Knowledge Infrastructure databases. The analysis reveals that literatures on the uses of social network analysis in the field of engineering construction management have gained a rapid growth. This study has the following findings:

(1) From the perspective of development trend, the number of literatures related to the applied research of social network analysis in the field of engineering construction management shows a trend of gradual increase. It can be seen that the social network analysis method has been widely concerned by scholars in the field of engineering construction management.
(2) Through the knowledge map of keywords, it can be found that in addition to the subject word "social network analysis", the keywords "stakeholders" and "construction project" appear most frequently. This reveals the research focus of social network analysis in the field of engineering construction management. By analyzing other keywords, it is found that some keywords are studied from the perspective of workers. Therefore, the application of social network analysis in the field of engineering construction management is mainly studied from the perspectives of stakeholders, construction projects and workers.

In general, social network analysis has attracted increasing attention from researchers in the field of engineering construction management at the present stage, and at the same time, abundant research results have been obtained. But it should also be noted that there are still many defects and deficiencies in social network analysis itself. For example, social network analysis focuses on static analysis and ignores dynamic analysis. Researchers in the future research should foster strengths and circumvent weaknesses, will be the perspective of social network analysis as a cut, rather than the only tools or methods to research on treatment, only in this way can make the research and analysis of problems in the field of engineering construction management have a better solution, can we truly prompt development and progress in research of project management.

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Research on Environmental Benefits of Prefabricated Buildings—A Literature Review Method

Zikui Yuan and Jiayuan Wang

Abstract Taking the topics related to prefabricated buildings in the core collection of Web of Science as the document source, the literature data of prefabricated buildings is exported through Web of Science, and Citespace analysis software is used to measure and visualize the literature data. Meanwhile, literature research on environmental benefits of prefabricated buildings is carried out. This paper summarizes the general trend of prefabricated buildings research in the past 10 years, and analyzes the early and recent concerns of prefabricated buildings. On this basis, combined with the relevant research literature on environmental benefits of prefabricated buildings in recent years, this paper summarizes the specific impact of prefabricated buildings on the environment, the energy conservation and emission reduction schemes of prefabricated buildings and the research methods of environmental benefits of prefabricated buildings, and analyzes the key research directions in this field in the future.

Keywords Prefabricated buildings · Environmental benefits · Literature review · Citespace software

1 Introduction

With the vigorous development of the global construction industry, people's living environment and living standard have been significantly improved, but it has also caused a series of environmental problems. The construction industry is a major consumer of energy and materials and an important producer of wastes [1]. Evidence showed that the construction industry accounts for 39% of global greenhouse gas emissions and 36% of global energy consumption [2]. Therefore, the construction industry should actively seek solutions to realize the industrialization of construction [2].

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Due to the increasing demand for construction, the increasingly serious environmental problems have caused the global construction industry to pay extensive attention to prefabricated buildings [3]. The concept of prefabricated building comes from the manufacturing industry. It refers to a building that is manufactured in a prefabricated component factory and then transported to the construction site for assembly [2]. Relevant data showed that prefabricated buildings can reduce construction waste emissions by 65% and save timber by 224 tons [4]. With the spread of prefabricated buildings, it has brought many positive effects on the global environment. Many scholars have done a lot of research on the environmental benefits of prefabricated buildings, but there is still a lack of systematic analysis.

This paper adopts quantitative and qualitative research methods. First, in terms of quantitative research, this paper uses Citespace software to study and analyze the literature related to prefabricated buildings. Then, in terms of qualitative research, this paper uses the method of literature review to explore the specific impact of prefabricated buildings on the environment, the energy conservation and emission reduction scheme of prefabricated buildings and the research method of environmental benefits. Meanwhile, this study also analyzes the main research directions in this field in the future.

2 Research Methods and Data Sources

2.1 Research Methods

This article uses a combination of quantitative and qualitative research. CiteSpace is one of the most popular software for visualizing and analyzing trends and patterns in the scientific literature [5]. Therefore, in terms of quantitative research, this article uses Citespace software to analyze all literatures related to prefabricated buildings downloaded from Web of Science, and makes statistics according to countries, keywords and cited literatures [6], and performs visual analysis. In terms of qualitative research, through reading the classic literature of prefabricated buildings compiled by Citespace software and the literature on the environmental benefits research of prefabricated buildings selected manually in the Web of Science, this article analyzes the specific environmental impact of prefabricated buildings, the energy conservation and emission reduction scheme of prefabricated buildings and the research method of environmental benefits, and discusses the future research direction of prefabricated buildings based on the research status of environmental benefits of prefabricated buildings.

2.2 Literature Selection

The literature search started from inputting the following in Web of Science: database = "the core collection of Web of Science", subject = "prefabricated building", time span = "from 2010 to 2019". After manually sorting out and removing non-academic papers, 1191 literatures from 2010 to 2019 were retrieved. Then, these 1191 literatures were input into Citespace software for quantitative and visual analysis. In addition, the literature on the environmental benefits research of prefabricated buildings was manually screened in the Web of Science.

3 Research Status of Prefabricated Buildings

In order to understand the research status of prefabricated buildings, and grasp the research situation of prefabricated buildings in general, this paper adopts a quantitative method to research and analyze the literature of prefabricated buildings from 2010 to 2019, and elaborates the prefabricated building literature in three aspects: the country, the literature number trend, and the citation.

3.1 Country Cooperation Network Analysis

Country cooperation network analysis can reflect the research strength and influence of a country in a certain research field, as well as the mutual cooperation relationship between countries. This article enters the literature samples obtained from Web of Science into the Citespace software, selects the "Country" function, and obtains the diagram of the country cooperation network, as shown in Fig. 1.

The detailed information of the national cooperative network was exported into tabular data. Two key pieces of information, count and centrality, were selected and sorted into Table 1 according to the top six ranked by count.

It can be seen from Fig. 1 that "China" has the largest node, indicating that China has the largest amount of literature on prefabricated building research during the decade from 2010 to 2019. It can be seen from Table 1 that the literatures published in the United States have the highest centrality, indicating that American scholars have the closest connection with scholars from other countries in the research of prefabricated buildings, and can play a better role as a bridge between scholars from various countries. Therefore, the influence of the American literature on prefabricated building research in various countries is correspondingly higher.

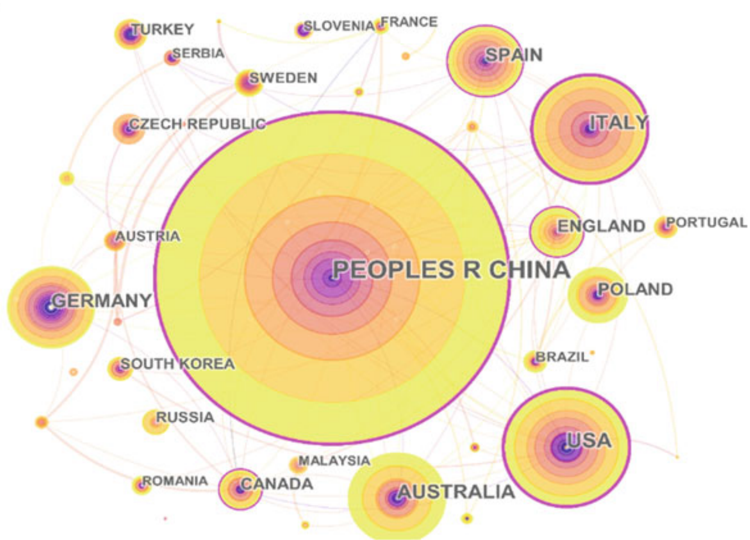

Fig. 1 The country cooperation network in prefabricated buildings

Table 1 The top six countries in the circulation of prefabricated buildings literature

Number	Count	Centrality	Country
1	260	0.24	China
2	94	0.31	USA
3	85	0.21	Italy
4	77	0.07	Australia
5	67	0.05	Germany
6	57	0.17	Spain

3.2 Literature Number Trend Analysis

The change in the number of academic papers in each year is an important indicator to evaluate the development trend of a certain discipline. In this paper, the literature samples obtained from Web of Science are counted according to the chronological order from 2010 to 2019, so as to grasp the research trend of prefabricated buildings on the whole, as shown in Fig. 2.

It can be seen from Fig. 2, the publication number on prefabricated buildings from 2010 to 2014 was relatively stable, and there was a certain increase in 2015. Since 2016, the publication number on prefabricated buildings has increased significantly, and the amount of literatures reached its peak in 2019, ushering in a research upsurge of prefabricated buildings. Compared with previous years, the number of literatures has increased by multiples after 2016.

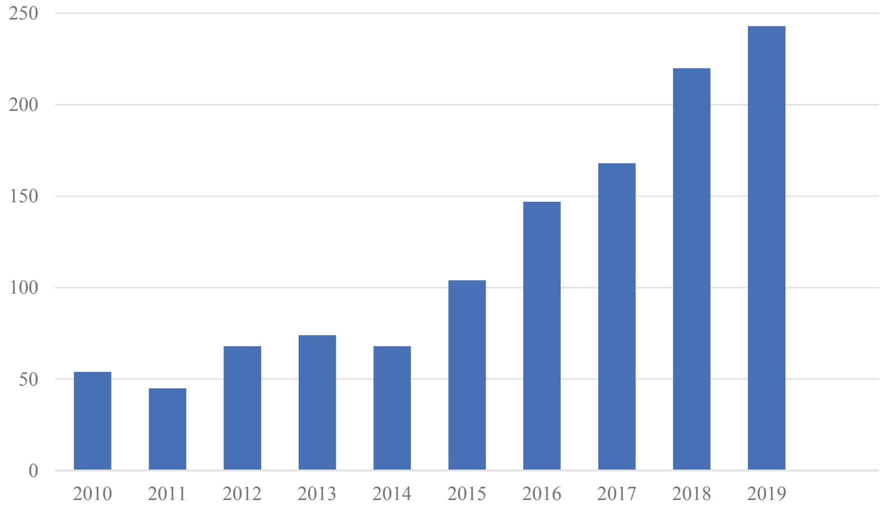

Fig. 2 Annual publication number from 2010 to 2019

3.3 Literature Co-citation Analysis

Document co-citation analysis is to show people's current focus of attention by analyzing the citations of previously published papers, that is, to analyze important literatures in a research field. The time-zone diagram of literature co-citation analysis can intuitively identify the evolution path of the classic literature and core theory in the field. This article enters the literature samples obtained from Web of Science into the Citespace software, selects the "Reference" function and selects the "Timezone View" function to display, and finally obtains the literature co-citation analysis time-zone map. Its module value: Q = 0.8298, which means that the divided structure is significant, as shown in Fig. 3.

In order to have a deeper understanding of the key node literature in the research of prefabricated buildings, the top 5 high-frequency cited literatures are analyzed in detail, as shown in Table 2.

It can be seen from Table 2 that these high-frequency cited literatures in the field of prefabricated buildings have conducted detailed studies on the impact of prefabricated buildings on the environment and construction quality management. Among them, the environmental benefit research is more prominent, mainly including the four aspects of resources consumption, energy consumption, greenhouse gas emissions and construction waste emissions.

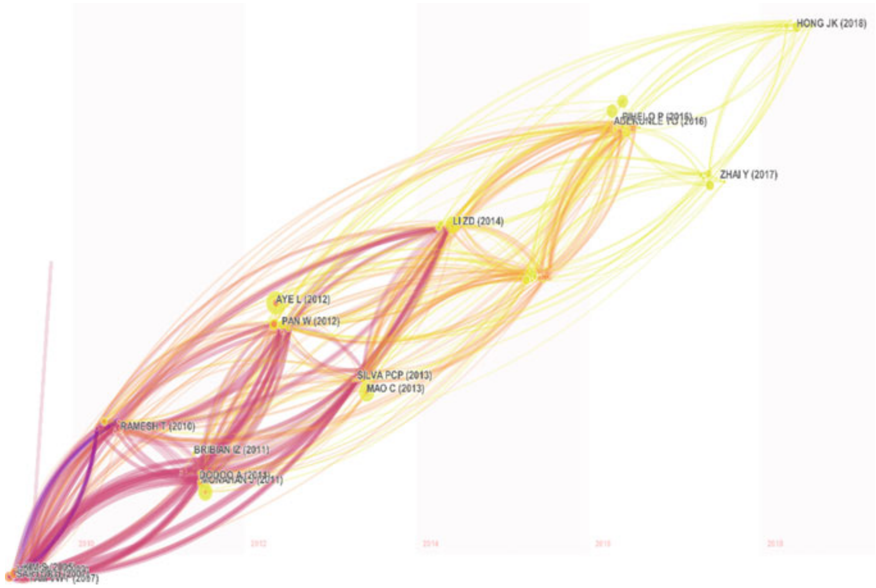

Fig. 3 The diagram of literature co-citation analysis in prefabricated buildings

4 Research Hotspots of Prefabricated Buildings

This section aims to gain an in-depth understanding of the current research hotspots of prefabricated buildings. Therefore, a quantitative method is adopted to analyze the literature of prefabricated buildings in the recent ten years according to the situation of keywords.

4.1 Keywords Co-occurrence Network Analysis

Keywords are words condensed and extracted from the core content of the article, which can effectively summarize the research purpose, objects, methods and results of the article. If a certain keyword appears repeatedly in the literature of its field in a certain period, it can reflect that the research topic represented by the keyword is a research hotspot in this period and field. This article imports the literature data into the Citespace software, selects the "keyword" function, and obtains the keywords co-occurrence network, as shown in Fig. 4.

The detailed information of the keywords co-occurrence network is exported into tabular data, and the two key information about quantity and centrality is selected and sorted into Table 3 according to the top 15 of quantity ranking.

It can be seen from Fig. 4 and Table 3 that the "prefabrication" appears most frequently in literature data. While the keyword with the greatest centrality is the

Table 2 Research content of the top 5 cited literatures in prefabricated buildings

Number	Research problem	Research content
1	Environmental benefits (greenhouse gas emissions and energy analysis throughout the life cycle)	The inherent energy of modular prefabricated steel and wood multi-story residential buildings is quantified to determine whether this form of building has better environmental performance than traditional concrete construction methods [7]
2	Environmental benefits (emission of greenhouse gases)	A quantitative model is established to determine the difference in greenhouse gas emissions between prefabricated and conventional construction methods [8]
3	Environmental impact Quality research	The construction technology of prefabricated schools is analyzed from a technical and sustainable perspective in order to propose new optimization techniques to determine how to improve the quality of these buildings and reduce their environmental impact [9]
4	Review of construction management research	An analysis of construction management research published in 10 leading journals from 2000 to 2013 is conducted to examine the latest research trends, institutional contributions, data collection and processing methods used and research interests in the discipline, starting with the annual number of papers on prefabrication construction management [10]
5	Environmental impact (resources and energy consumption, construction waste emissions)	The model based on life cycle assessment is used to analyze and compare the environmental performance of prefabricated houses and traditional houses [11]

"performance", which indicates that performance is a research hotspot in prefabricated buildings in the past decade and appears most frequently in the same literature with other keywords.

4.2 *Keywords Annual Trend Analysis*

The change of keywords can reflect the change of research topics in a certain field. The keywords year trend chart shows the year when each keyword first appeared and the connection with other keywords. This article selects the "Timezone View" function for the keywords co-occurrence network to get the annual trend chart of the

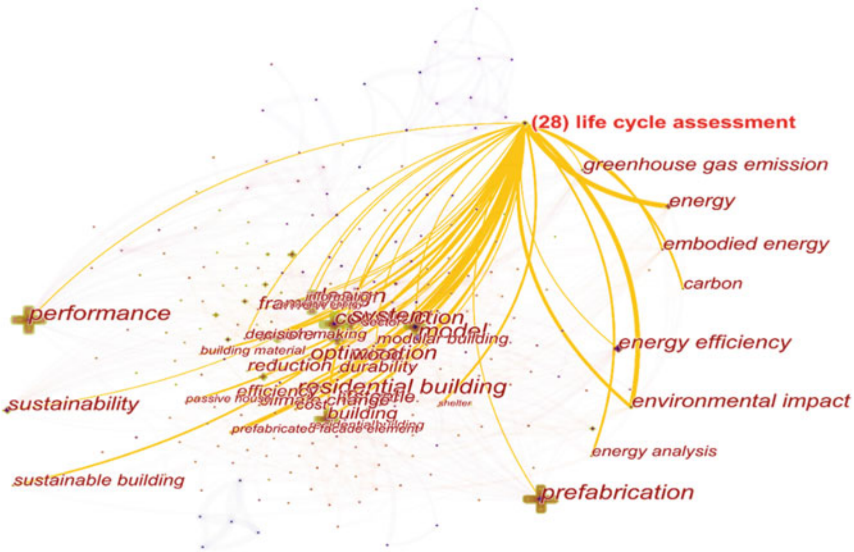

Fig. 4 The keywords co-occurrence network in prefabricated buildings

Table 3 The top 15 keywords by count

Number	Count	Centrality	Keyword
1	90	0.12	Prefabrication
2	89	0.17	Performance
3	74	0.14	Design
4	72	0.06	Construction
5	61	0.11	System
6	60	0.02	Building
7	57	0.09	Behavior
8	40	0.1	Concrete
9	30	0.12	Model
10	29	0.08	Sustainability
11	28	0.05	Life cycle assessment
12	27	0.09	Management
13	26	0.08	Energy efficiency
14	25	0.1	Simulation
15	25	0.01	Hong Kong

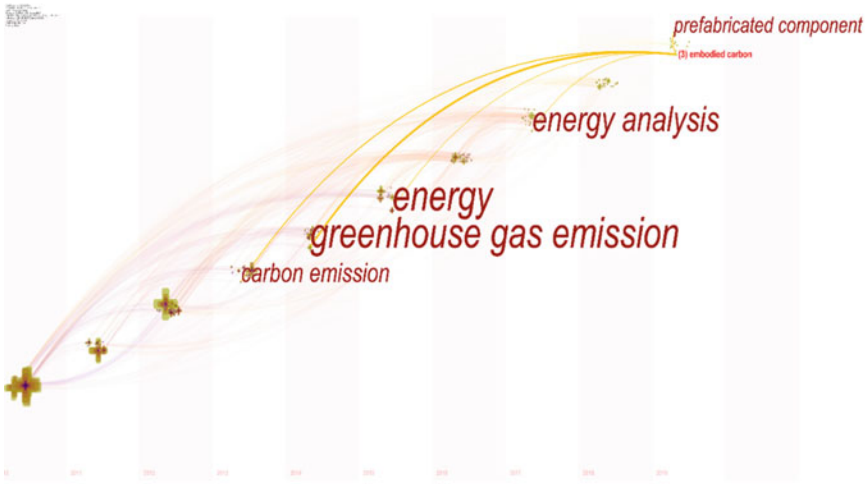

Fig. 5 Annual trend chart of keywords

keywords, as shown in Fig. 5, which can get the research hotspots and the evolution of research hotspots in the field of prefabricated buildings in the past decade.

It can be seen from Fig. 5 that in the past ten years, the early stage of research on prefabricated buildings has mainly focused on the technical implementation of structure, design, construction and models. With the deepening of research and development, scholars from various countries have begun to explore in many aspects, especially the performance aspects of life cycle assessment, management of prefabricated buildings and environmental impact, such as energy analysis, greenhouse gas emissions and waste emissions.

5 Research on Environmental Benefits of Prefabricated Buildings

According to the different nature of benefits, the benefits of prefabricated buildings can be divided into economic benefits, environmental benefits and social benefits [12]. Environmental benefits are also called ecological benefits. With the rapid development of economy, people only paid attention to economic benefits at the beginning, but now they begin to pay more and more attention to the impact of projects on the ecology. People's awareness of environmental protection is constantly increasing, and they pay more attention to improving and protecting the ecological environment [13]. From the microscopic point of view, environmental benefits mean that it is necessary to reduce the loss of raw materials as much as possible, to reduce the emission of pollutants, to increase the utilization rate of resources and to achieve the best environmental benefits on the basis of achieving economic goals in the production process. The environmental benefits of prefabricated buildings are the basis of economic and social benefits, and economic and social benefits are the consequences of environmental benefits. The three benefits are mutually conditional and influencing each other [14]. Fundamentally speaking, environmental benefits are one of the most basic benefits. Therefore, improving environmental benefits plays a vital role in human life.

The contents of environmental benefits are very rich, but what is closely related to human life and production are mainly the “four saving” —water saving, material saving, land saving and energy saving [15]. According to the analysis of the prefabricated building literature, it can be found that many scholars have carried out the research on the environmental benefits of prefabricated building. The research mainly focuses on the three aspects of energy consumption, greenhouse gas emissions and waste emissions. Therefore, the following describes in detail the environmental impact brought by prefabricated buildings and the energy-saving and emission reduction programs proposed for prefabricated buildings from these three aspects. In addition, this article also elaborates on the specific application of research methods of environmental benefits of prefabricated buildings, reviews the research content and results of domestic and foreign scholars, and analyzes the future research directions in this field.

5.1 Literature Review

5.1.1 Environmental Impact of Prefabricated Buildings

The construction industry consumes a lot of resources and energy, and due to the current global population growth trend, this situation is expected to worsen in the near future. The energy consumed by buildings accounts for about 40% of the total global energy [16]. As an energy-intensive industry, the construction industry has great potential in reducing energy demand and environmental pollution [17]. Environmental issues related to buildings have attracted global attention, and prefabricated buildings have obvious advantages in energy conservation and environmental protection. Therefore, scholars at home and abroad began to pay attention to the research on the environmental impact of prefabricated buildings.

In terms of energy consumption, Cao et al. compared two typical residential buildings constructed with prefabricated technology and traditional cast-in-situ technology, and found that the example prefabricated residential building had higher energy use efficiency and reduced total energy consumption by 20.49% [11]. Kneifel et al. found that by improving energy efficiency, smaller and cheaper heating, ventilation and air conditioning (HVAC) equipment can be installed. This improvement not only reduced the carbon emissions of buildings by an average of 16%, but also saved energy [18].

In terms of greenhouse gas emissions, Teng et al. achieved a 15.6% carbon emission reduction and contributed to reduce the embodied carbon in high-rise buildings through the use of prefabrication [19, 20]. Mao et al. used the method of checking the greenhouse gas emissions of semi-prefabricated projects during the construction phase and found that compared with traditional buildings, semi-prefabricated methods produced less greenhouse gas emissions per square meter, which were 368 kg/m^2 and 336 kg/m^2 respectively [8]. Liu et al. found that the advantage of prefabrication to reduce greenhouse gas emissions also lay in the reduction of labor. As workers' living facilities (i.e. living areas, water and electricity consumption) were reduced, so were their greenhouse gas emissions [21].

In terms of waste emissions, Jaillon et al. proposed that compared with traditional buildings, the use of prefabricated buildings can reduce construction waste, which is one of the main benefits. The average waste reduction level was about 52%, indicating that the widespread use of prefabricated buildings can greatly reduce the generation of construction waste and can reduce the burden related to its management [4]. Based on a case study, Jaillon and Poon showed the advantages of using prefabricated components, such as reducing waste, improving quality control, and reducing material usage [22].

5.1.2 Energy-Saving and Emission Reduction Programs of Prefabricated Buildings

Buildings are the main consumers of energy and materials, as well as important producers of waste and emissions. The appearance of prefabrication provides an opportunity to reduce the impact on the construction industry [1]. So far, a series of comprehensive strategies, technologies and evaluation methods have been implemented in the construction field to improve the life cycle environmental benefits of buildings. The prefabricated building is one of the effective solutions. In the whole construction industry, the prefabricated building has become more and more important [23]. Therefore, domestic and foreign scholars have begun to carry out further research on energy saving and emission reduction programs for prefabricated buildings from various perspectives.

In terms of energy consumption, Silva et al. proposed a new prefabricated modification module solution for the exterior walls of existing buildings to minimize the energy consumption and greenhouse gas emissions of buildings [17]. Matic et al. found that implementing measures to improve energy efficiency can reduce the energy load of buildings [24]. Eckelman et al. used a structural design clamping prefabricated composite floor system to replace cast-in-place flooring, and found that although it would cause higher initial energy consumption and environmental impact, if it was used at least once, it would have less environmental impact than the traditional design. If it was reused three times according to the design requirements, the environmental impact could be reduced by 60–70% on average [25]. Hong et al.

found that in addition to reusability, the energy consumption of prefabricated buildings can be saved through waste reduction and high-quality control. This strategy can save 4–14% of the life cycle energy consumption [23].

In terms of greenhouse gas emissions, Teng and Pan found that an effective measure to reduce the embodied carbon of prefabricated high-rise public houses was to use low-carbon concrete, increase the prefabrication rate and reduce wall thickness [20]. Jaillon et al. adopted deconstructive design principles and flexible disassembly building systems to minimize carbon emissions through effective use of resources [22]. Li et al. found that enhancing the environmental performance of cement production and increasing the recycling rate of scrap steel in steel production were important factors in reducing the total carbon emissions of residential buildings in China [26]. In order to strengthen the monitoring of carbon emissions of prefabricated buildings and prevent them from causing excessive impact on the environment, Liu et al. proposed a real-time carbon emission monitoring (CEM) system for the entire industry chain of prefabricated buildings. This system can successfully conduct real-time carbon emission monitoring and analysis, which was helpful to strengthen carbon emission management and control and prevent additional emissions [27].

In terms of waste emissions, Ding et al. proposed that the implementation of waste reduction management in the design and construction stages can effectively reduce construction waste and bring obvious environmental benefits [28]. Pons et al. found that energy consumption and carbon dioxide emissions can be reduced by optimizing production. They also found that the use of recyclable materials [9] and the implementation of closed-loop material recycling methods when fabricated components were used [22] can reduce waste generation. It should be noted that, due to the late popularity of prefabricated buildings and the long service life of buildings, most of the research on waste emissions of prefabricated buildings is in the theoretical research stage, and empirical research is relatively lacking.

5.1.3 Research Methods of Environmental Benefits of Prefabricated Buildings

As a new construction mode, prefabricated buildings have made significant improvements in energy conservation and emission reduction. Many scholars have adopted a variety of methods to carry out research on the environmental benefits of prefabricated buildings, including life cycle assessment, BIM technology, model building and other methods. The following discusses the specific applications of these methods in the environmental benefits of prefabricated buildings.

In terms of life cycle assessment, Wang et al. used a hybrid model to evaluate the environmental impact of prefabricated buildings and traditional cast-in-place buildings throughout the life cycle of the building, and concluded that the total energy consumption of the prefabricated buildings throughout the life cycle was 7.54% and the carbon emission was 7.17%, which was lower than traditional cast-in-place buildings. As the assembly rate increased, the carbon emission would decrease, but it would bottom out when the assembly rate was 60%, and then it would show an upward trend again as the assembly rate increased [29]. Balasbaneh et al. used the life cycle assessment method to compare the environmental impact of prefabricated steel and concrete structures throughout the life cycle, and the results showed that prefabricated steel structures performed better in terms of environment, excluding greenhouse gas emissions [30].

In terms of BIM technology, based on building information modeling (BIM) and carbon emission measurement model, Ding et al. developed a carbon emission measurement system for prefabricated residential buildings during the materialization phase. The measurement system can accurately predict the carbon emissions of prefabricated residential buildings in the project planning and preliminary design stage, identify key areas of carbon emissions pre-control, and facilitate the implementation of dynamic management of carbon emission reduction in the materialization stage [31]. From the environmental point of view, Ji et al. conducted a comparative environmental analysis of conventional and prefabricated construction technologies through BIM-based simulations, and the results showed that prefabricated buildings have good environmental performance and the environmental impact also can be further reduced by increasing the proportion of the prefabricated area in the project [32]. Combining the case of a hotel apartment building in a commercial plaza in Shanghai, Xi conducted a comprehensive analysis of the environmental benefits of prefabricated buildings using BIM technology, and obtained its incremental benefits [33].

In terms of model establishment, on the basis of interview data and literature review, Ding et al. used Vensim software to construct a two-stage system dynamic model of environmental benefit assessment, including the subsystem of construction waste reduction management, the subsystem of waste generation and disposal, and the subsystem of environmental benefit assessment. The dynamic model can effectively evaluate the environmental benefits of construction waste reduction in the design and construction phase [28]. Zheng et al. used eQuest software to build models of prefabricated building and comparative building, and obtained the contribution rate of energy saving and carbon dioxide emission reduction of prefabricated buildings through comparison [34]. Feng et al. established an environmental benefit analysis model based on an example of a residential project in Jiangxi Province, and carried out a quantitative analysis in terms of carbon emissions and the "four saving" [15].

In other aspects, for example, the market value method uses the current market price as the price standard, and compares the same or similar resource market price with the assessed object to determine the value of the assessed resource. Yang Yan et al. used this method to calculate the environmental benefits and mainly analyzed the energy conservation benefits [14].

5.2 Future Research

According to the review of research literature on environmental benefits of prefabricated buildings, it is found that:

(1) Existing research on the environmental benefits of prefabricated buildings mainly focuses on residential buildings, and future research can be further spread to other fields, such as schools, factories, and subways.
(2) Existing research on the environmental benefits of prefabricated buildings mainly focuses on high-rise residential buildings, and low-rise residential buildings can be studied in the future. For example, low-rise residential buildings can be taken as an example to study the environmental benefits generated in each stage of its life cycle or specific energy conservation and emission reduction programs.
(3) For prefabricated buildings, the impact related to the transportation process is very significant. Prefabricated buildings cannot save a lot of energy. One important reason is that it consumes more energy in other forms such as long-distance transportation [35]. Current research lacks a comprehensive assessment of the impacts related to the transportation of prefabricated buildings. Therefore, future research can focus more on the transportation phase.
(4) The current research on the environmental benefits of prefabricated buildings mainly focuses on energy consumption, greenhouse gas emissions and waste emissions. Future research can consider the environmental impact of prefabricated buildings as much as possible from the perspective of the entire construction industry.

6 Conclusion

Based on the above metrological and visual analysis of prefabricated building literature in the past ten years and the literature research on the environmental benefits of prefabricated buildings, the following conclusions can be drawn:

(1) China is the country that publishes the most literatures on the research of prefabricated buildings, and the United States is the country that has the closest connection with scholars from other countries in the research of prefabricated buildings.
(2) Judging from the total number of prefabricated building literature published each year, the publication number on prefabricated buildings was relatively stable from 2010 to 2014, and there was a certain increase in 2015. Starting in 2016, the publication number has increased significantly, and the amount of literature reached its highest peak in 2018.
(3) Through the analysis of the top five high-frequency cited literatures in the field of prefabricated buildings, it is found that they mainly carry out detailed research on the impact of prefabricated buildings on the environment and

construction quality management. Among them, the research on environmental benefits is more prominent. It mainly includes four aspects: resource consumption, energy consumption, greenhouse gas emissions and construction waste emissions.

(4) Through the analysis of keywords in the prefabricated building literature, it is found that the "prefabrication" has the highest frequency, meanwhile the "performance" and other keywords appear in a literature at the same time the most. In addition, the research on prefabricated buildings has gradually changed from the previous technology and implementation to performance and evaluation.

(5) According to the analysis of literature data, the research on environmental benefits of prefabricated buildings has been very mature. It mainly discusses the environmental impact and energy saving and emission reduction programs from three aspects: energy consumption, greenhouse gas emissions and waste emissions. And it uses a variety of research methods of environmental benefit such as the life cycle assessment, BIM technology, and model building.

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Influencing Factors of Farmers' Risk Perception on Returning Their Lands: Evidence from Chongqing, China

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Abstract The purpose of this paper is to explore the risk perception and its influencing factors of farmers to return their lands in China. We use Ordered Probit Model to examine this topic based on primary data in Chongqing. Our finding indicates that (1) From the risk perception of homestead return: famers' age, whether major family members settle in city, expectation of life quality after returning lands, trust of land-returning policy have a significant and negative impact on risk perception of famers' returning. Meanwhile, stable residence lost after returning lands, unable to have enough compensation after returning lands have a significant and positive impact on the risk perception of farmers' returning homestead (2) From the risk conception of contracted farmlands return: farmers, whether the family has a stable non-agricultural income, whether major family members have the new rural social pension insurance, expectation of life quality after returning lands, trust of land-returning policy have a significant and negative impact on the risk perception of farmers returning contracted farmlands. Meanwhile, variables unable to have stable employment for livelihood after returning lands, unable to have expenditure for pension and medical treatment after returning lands, unable to have enough compensation after returning lands have a significant and positive impact on the dependent variable the risk perception of farmers returning contracted farmlands.

Keywords Land return · Risk perception · Influencing factors · Chongqing

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1 Introduction

For a long time, *Hukou* system in China plays an important and supporting role in fields such as social public service, employment and consumer goods supply [7, 8, 22]. In the background of urban–rural integration development, *Hukou* weakens the economic elements exchange between urban and rural areas, slows the process of the urbanization and brings systematic obstacles to agriculture industrialization and the transfer of agricultural population [28]. In the 1980's, central government of China put forward a series of policies to promote the reform of household register system.

At present, there exits two approaches to reform *Hukou* system in China: One is to reform Hukou system and land management system synchronously, meanwhile, the local governments use urban residence registration and its appendiculated urban public service and compensations to entice farmers to return their contracted farmlands and homestead [21, 23, 26]. The other is to increase the farmers' public service and to decrease the gaps in welfare and public service between urban and rural residence, to make the *Hukou* only have the function of population registration [10, 16].

Current *Hukou* system reform in China is a top-down compulsory institutional change started by local governments [12, 27]. The difference between compulsory institutional change and induced institutional change is whether to consider the willingness of individual during the system change. However, the main influencing factors of the farmers' willingness are the estimation results of their risk perception and risk aversion ability in the system reform. For a long time, rural lands in China have economic and social security function for farmers. It is very risky for them to return their lands, especially, in the condition that Chinese urban and rural social security systems are not completely matched. As a result, this paper chooses first approach of *Hukou* system reform to explore risk perception and its influencing factors of farmers to return their lands:

Through the literature review, it is found that farmers' risks involve four parts: (1) Risks in agricultural production, Lu et al. [15] analyzed farmers reacting to the agricultural risks applying MOTAD model in aspects of agricultural operations scale, cropping system, agricultural income proportion. (2) Risks in agricultural industrialized operation and management, [2] considers that farmers in "company + farmers" business model are faced with risks in aspects of nature, market, reputation and management. (3) Risks in land circulation and scale operation, Huang et al. [9] analyzed the natural, social and economic risks that farmers encountered during land circulation and scale operation. (4) Risks in livelihood of farmers, Chen et al. [3] divided economic risks of farmers into three types and analyzed their aversion strategies, separately.

In addition, the current researches on lands return only focus on how to build and ameliorate land-returning system and how to respect farmers' land-returning willingness. The former as Zhang et al. [29] analyzed the house site returning mechanism from the aspects of rural infrastructure investment, farmers' employment model, farmers' dependence on lands, arrangements of collective land property rights. The latter as Wu et al. [25] used the Binary Probit Model to analyze the influencing factors of farmers' land-returning willingness. Consequently, few researches focus on risk perception of farmers' returning lands. As a matter of fact, avoiding the risks of returning lands is of great importance for local government to promote this work.

2 Data Sources

Chongqing is the main area of rural labor force export in China. With the decrease of the rural population, more and more lands are idle and abandoned. Chongqing started to reform household registration system and land management system, synchronously, guiding farmers to return their lands, voluntary and orderly in 2011. In order to understand this topic, we designed and did a random questionnaire survey about farmers' returning their lands in 132 administrative village of One-Hour Economic Circle and Northeast and Southeast of Chongqing using Participatory Rural Appraisal (PRA) and Contingent Valuation Method (CVM) from September, 2010 to April, 2011 (Table1). We launched 2050 questionnaires and received 1960 of them, and ultimately acquired 1829 efficient questionnaires.

The contents of questionnaire mainly includes: (1) Basic information of farmers such as the name of districts and towns, the name of villages, the name of farmers, contact information and date of survey, etc. (2) Basic features of farmers' family such as age, gender, education level of the head of household; income, social security, non-agricultural employment and breeding operation of farmers' family, etc. (3) Condition of land use and operation such as area of contracted farmland and homestead, condition of land use and circulation, etc. (4) Farmers' attitude towards returning their lands such as land-returning willingness, land-returning risk perception and risk aversion ability, etc. (5) Primary motivations and obstacles of farmers returning lands such as pension, medical treatment, employment and children's education, etc. (6) Policy perception of farmers returning lands such as understanding level, sources and appraisement of policy, etc. (Table 1).

3 Methodology

3.1 Variables

This paper sets risk perception of farmers returning homestead and contracted farmland as dependent variables respectively, referring Huang et al. [9], Wu et al. [25] and Wang et al. [23], then sets 23 indicators as independent variables including family features factors, land-returning information factors, land-returning expectant risk factors, social psychology factors and location conditions factors. The statistical description of variables is shown in Table 2.

Table 1 Sample distribution in Chongqing

Region		Number of towns	Number of villages	Number of samples
One-hour economic circle	Jiangbei District	2	6	120
	Jiulongpo District	2	5	132
	Beibei District	3	8	118
	Hechuan District	3	7	95
	Fuling District	4	10	78
	Yongchuan District	5	15	80
Northeast of Chongqing	Liangping County	3	9	152
	Yunyang County	2	6	133
	Fengdu County	5	11	146
	Kai County	3	7	127
Southeast of Chongqing	Pengshui County	2	6	130
	Youyang County	4	8	142
	Xiushan County	4	9	145
	Wulong County	5	12	126
	Shizhu County	6	13	105
Total		53	132	1829

3.2 *Ordered Probit Model*

Ordered Probit Model in this paper are used to examine farmers' land-returning risk perception due to the discrete dependent variables (Y = 1, 2, 3). So we set a multiple ordered choice model as follows:

$$prob.(Y = Y_i|X_i, \beta) = prob.(Y = Y_i|X_0, X_1, X_2, \cdots, X_k)$$

where Y_i has three choices (1, 2, 3). In order to analyze the multiple ordered choice model, we introduce an unobservable latent variable Y_i^*, $Y_i^* = X_i'\beta + \varepsilon_i^*$, where β is a parameter, ε_i^* is a random disturbance term. Further, we assume that there exits two demarcation points $c_1,\ c_2(c_1 < c_2)$, which represent unknown critical values of evaluation ranks of land-retuning risk perception. And the value of Y_i and the latent

Table 2 Explanation and statistical description of sample variables

Name and code of the variables	Scope of assignment	Definition and acquisition of variables	Mean	Std. Dev
Dependent variables (Y)				
A. How do you think of the risk of homestead return? (Y_A)	1, 2, 3	Higher = 3; medium = 2; lower = 1	2.43	0.62
B. How do you think of the risk of contracted farmlands return? (Y_B)	1, 2, 3	Higher = 3; medium = 2; lower = 1	2.61	0.71
Independent variables (X)				
1. Family features factors				
Age of the head of households (X_1)	–	Actual observations (years old)	43.75	9.93
Gender of the head of households (X_2)	0, 1	Male = 1; female = 0	0.94	0.24
Education level of the head of households (X_3)	1, 2, 3, 4	Primary school and lower = 1; junior high school = 2; senior high school = 3; junior college and higher = 4	2.01	0.92
Whether the head of households has a part-time non-agricultural job (X_4)	0, 1	Yes = 1; No = 0	0.75	0.44
Whether the head of households is a village cadre (X_5)	0, 1	Yes = 1; No = 0	0.04	0.20
Family annual income (X_6)	–	Actual observations(ten thousand Yuan)	1.48	0.91
Whether the family has a stable non-agricultural income (X_7)	0, 1	Yes = 1; No = 0	0.23	0.42
Whether major family members settled in city (X_8)	0, 1	Yes = 1; No = 0	0.17	0.38
Whether major family members have the new rural social pension insurance (X_9)	0, 1	Yes = 1; No = 0	0.11	0.31
2. Land-returning information factors				

(continued)

Table 2 (continued)

Name and code of the variables	Scope of assignment	Definition and acquisition of variables	Mean	Std. Dev
Understanding level of land-returning information (X_{10})	1, 2, 3	Know a lot = 3; know a little = 2; unknown = 1	2.13	0.74
Learning of land-returning information from propaganda of villages and towns (X_{11})	0, 1	Yes = 1; No = 0	0.90	0.30
Learning of land-returning information from media propaganda (X_{12})	0, 1	Yes = 1; No = 0	0.54	0.50
Learning of land-returning information from relatives and friends (X_{13})	0, 1	Yes = 1; No = 0	0.79	0.41
3. Land-returning expectant risk factors				
Stable residence lost after returning lands (X_{14})	0, 1	Yes = 1; No = 0	0.26	0.35
Unable to have stable employment for livelihood after returning lands (X_{15})	0, 1	Yes = 1; No = 0	0.41	0.41
Unable to have expenditure for pension and medical treatment after returning lands (X_{16})	0, 1	Yes = 1; No = 0	0.44	0.48
Unable to have enough compensation after returning lands (X_{17})	0, 1	Yes = 1; No = 0	0.58	0.50
Unable to have enough money for children's education after returning lands (X_{18})	0, 1	Yes = 1; No = 0	0.15	0.36
Unable to change lifestyle and to adapt to city life (X_{19})	0, 1	Yes = 1; No = 0	0.02	0.14
4. Land-returning social psychology factors				

(continued)

Table 2 (continued)

Name and code of the variables	Scope of assignment	Definition and acquisition of variables	Mean	Std. Dev
Expectation of life quality after returning lands (X_{20})	1, 2, 3	Improved = 3; equal = 2; declined = 1	1.66	0.88
Trust extent of land-returning policy (X_{21})	1, 2, 3	Trustworthy = 3; likely to be trustworthy = 2; untrustworthy = 1	2.04	0.77
Concern level of land-returning propaganda (X_{22})	1, 2, 3	Concerned = 3; likely to be concerned = 2; unconcerned = 1	2.27	0.70
5. Location factors				
"One-Hour Economic Circle, Northeast or Southeast of Chongqing" (X_{23})	0, 1	"One-Hour Economic Circle" = 1;" Northeast or Southeast of Chongqing" = 0	0.43	0.50

Notes Due to paper length limited, we only did a comprehensive statistical description in Table 2. The formula of the comprehensive value of independent variables of land-returning risk perception is: [Mean (Std. Dev) of variables of homestead + Mean (Std. Dev) of variables of contracted farmland]/2

variable Y_i^* have a corresponding relationship as follows:

$$Y_i = \begin{cases} 1, \ Y_i^* \leq c_1 \\ 2, \ c_1 < Y_i^* \leq c_2 \\ 3, \ c_2 < Y_i^* \end{cases}$$

If the normal distribution function of ε_i^* is $F(X)$ and $Y_i = 1, 2, 3$, we can get the probability of dependent variable Y, as follows:

$$\begin{aligned} prob.(Y = 1) &= F(c_1 - X'\beta) \\ prob.(Y = 2) &= F(c_2 - X'\beta) - F(c_1 - X'\beta) \\ prob.(Y = 3) &= 1 - F(c_2 - X'\beta) \end{aligned}$$

Further,

$$\begin{aligned} \frac{\partial prob.(Y = 1)}{\partial X_i} &= -f(c_1 - X_i^{'}\beta)\beta; \\ \frac{\partial prob.(Y = 3)}{\partial X_i} &= f(c_2 - X_i^{'}\beta)\beta \end{aligned}$$

where $f(x)$ denote density function of ε_i^*. So the change direction of $prob.(Y = 1)$ influenced by X_i is opposite with the symbol of β. But the change direction of

$prob.(Y = 3)$ influenced by X_i is the same with the symbol of β. However, we can't make sure the relationship between the changes of probability of medium values and X_i. As the Binary Probit Model, the parameter of Ordered Probit Model also can be estimated by maximum likelihood method. The basic model of this paper is set as follows:

Risk perception of farmers' returning lands = F(family features factors, land-returning information factors, land-returning expectant risk factors, land-returning social psychology factors, location factors) + random disturbance terms.

$$Y_{risk\ perception} = \begin{cases} Y_{A(house\ sites)} = F_A(X_1, X_2, X_3, \cdots, X_{23}) + \varepsilon_A \\ Y_{B(contracted\ farmerlands)} = F_B(X_1, X_2, X_3, \cdots, X_{23}) + \varepsilon_B \end{cases}$$

4 Results and Discussions

4.1 Results of Sample Analysis

1. **Risk perception of farmers' returning their lands**

Risk perception is usually divided into two or three levels: risky and risk-free or risky, unknown and risk-free [13, 17]. But in the pre-survey of questionnaire, we found that farmers in China have a strong traditional land attachment. Farmers clearly know what it means, if they lost lands. They only have great difference in risk extent of land return [1, 12]. Consequently, we designed the questions as "How do you think of the risk to return your contracted farmlands or homestead?" to understand farmers' risk perception on returning their contracted farmlands or homestead in the questionnaire. The results are shown in Table 3.

As it shows in Table 3, sample farmers who consider returning contracted farmlands as a lower risk are less than those who consider returning homestead as a lower risk. However, sample farmers who consider returning contracted farmlands as a higher risk are more than those who house site as a higher risk. Overall, farmers consider lands return as a higher risk. They are more worried about returning contracted farmlands than that of homestead, so they prefer to returning homestead.

Table 3 Risk perception of farmers' returning their lands

Items	Risk perception of farmers' returning their homestead		Risk perception of farmers' returning their contracted farmlands	
	Number of samples	Percentage (%)	Number of samples	Percentage (%)
Higher	1041	56.92	1265	69.16
Medium	532	29.08	417	22.80
Lower	256	14.00	147	8.04

2. **Primary risk factors of farmers' returning their lands**

From the homestead, first, more than half of sample farmers think that the primary risk is no houses to live after returning homestead. So it's clear that homestead have a significant function of housing security in rural China. Second, sample farmers are more worried about the compensation after returning homestead, including whether the compensation is paid timely and fully, and how to distribute it when compensation is paid. Third, sample farmers think they will lose important family property after returning homestead. It shows that they have realized that homesteads are important property in rural China. Finally, some farmers think they can't depend on extra area of homestead to conduct sideline production after returning homestead (Table 4).

From contract farmlands, first, 65.28% of sample farmers consider unable to have a timely and stable employment affecting livelihood after returning contracted farmlands as primary risk. It indicates that contracted farmland operation is a basic

Table 4 Primary risk factors of farmers' returning their lands

Primary risk after returning homestead	Number of samples	Percentage (%)	Primary risk after returning contracted farmlands	Number of samples	Percentage (%)
No houses to live after returning homestead	993	54.29	Unable to have a timely and stable employment affecting livelihood after returning contracted farmlands	1194	65.28
Worrying about the compensation after returning homestead	421	23.02	Unable to have a medical treatment and pension after returning contracted farmlands	382	20.89
Losing important family property after returning homestead	252	13.78	Worrying about compensation after returning contracted farmlands	164	8.97
Unable to conduct sideline production after returning homestead	118	6.45	Unable to predict the change of policy in the future	60	3.28
Others	45	2.46	Others	29	1.58

income source of farmers' family in rural China. Second, farmers worry that they are unable to have a medical treatment and pension after returning contracted farmlands. We can conclude that contracted farmland has a basic social security function in rural China. Third, farmers also worry about the compensation after returning contracted farmland, including whether the compensation is paid timely and fully, and how to distribute it when compensation is paid. Finally, some farmers consider unable to predict the change of policy in the future as the primary risk after returning contracted farmlands.

3. **Risk aversion ability of farmers' returning their lands**

There are some differences and connections between risk perception and risk aversion ability of farmers returning lands. Farmers who think risks are lower after returning lands often have the ability to avert risks, generally [6]. However, farmers who have the ability to avert risks after returning lands don't always regarding lands return as a lower risk. As a result, risk perception is the sufficient but not necessary condition for risk aversion ability, so there are some difference in sample statistic (Table 4). Taking homestead as an example, the 354 sample farmers who think they have the ability to avert risk are more than the 256 sample farmers who think the house site return risk is lower. It shows that some of farmers who consider house site return as a higher or medium risk also have the ability to avoid risk. So, we design the questions as "Do you think you have the ability to avert the risk of returning homestead or contracted farmlands?" in the questionnaires to study risk aversion ability of farmers returning their contracted farmlands or homestead. The results are shown in Table 5.

As it shows in Table 5, sample farmers who think they can avert the risk of homestead return are more than those of contracted farmlands return. However, sample farmers who think they can't avert the risk of contracted farmlands return are more than those of homestead return. Overall, sample farmers have a weak risk aversion ability of lands return. They have stronger ability to avert risks of homestead return than that of contracted farmlands return.

4. **Risk aversion strategies of farmers returning their lands**

In the further investigation of 354 farmers who have the ability to avert the risk of homestead return and 204 farmers who have the ability to avert the risk of contracted farmlands return, we found that risk aversion strategies of farmers returning homestead mainly includes: First, most farmers avert the risks by exchanging homestead

Table 5 Statistic of risk aversion ability of farmers returning their lands

Items	Risk aversion ability of farmers returning homestead		Risk aversion ability of farmers returning contracted farmland	
	Number of samples	Percentage (%)	Number of samples	Percentage (%)
Yes	354	19.35	204	11.15
Uncertain	487	26.63	376	20.56
NO	988	54.02	1249	68.29

for a new house; Second, most old people avert the risks by going to town to rely on their children. Third, the farmers whose major family members settled in city are prone to become urban residence. Fourth, the heads of households who are farmer workers apply for urban indemnificatory housing to avert risk. Finally, a few farmers who have stable non-agricultural income or stable non-agricultural career buy urban commercial housing to avert risk (Table 6).

Risk aversion strategies of farmers' returning contracted farmland mainly includes: First, most farmers have stable non-agricultural income in city to avert risks; Second, some old farmers get high-level urban social security by becoming urban residence registration on the spots to avert risks; Third, some farmers get stable non-agricultural work by employment training and aid provided by local government;

Table 6 Risk aversion strategies of farmers' returning their Lands

Risk aversion strategies of farmers returning homestead (multiple choices)	Number of samples	Percentage (%)	Risk aversion strategies of farmers returning contracted farmland (multiple choices)	Number of samples	Percentage (%)
Major family members settled in city	85	24.01	Getting high-level urban social security by becoming urban residence registration on the spots	65	31.86
Going to town to rely on their children	102	28.81	Having stable non-agricultural income in city	96	47.06
Exchanging homestead for a new house	148	41.81	Relying on their children settled in city and having urban social security	27	13.24
Buying commercial housing in city	28	7.91	Employment training and aid provided by local government	53	25.98
Applying for indemnificatory housing in city	77	21.75	Operating non-agricultural business by using family savings and land-returning compensation	18	8.82
Others	34	9.6	Others	14	6.86

Fourth, some old famers whose children settled in city tend to become urban residence and acquired urban social security to avert risks; Finally, a few sample farmers operate non- agricultural business by using family savings and land-returning compensation.

4.2 Regression Results

EViews6.0 software is used to conduct Ordered Probit regression based on the primary data of Chongqing. As shown in Table 7, we can know that the probability values of statistic *LR* in model *A* and model *B* are both very small. LIMIT_1: C (24) and LIMIT_1: C (25) in model *A* and model *B* have increasing tendency. Other statistics also show that two models that we established have statistical significance. The specific analysis of influencing factors of farmers returning land risk perception is shown as follows:

1. **Family features and farmers' land-returning risk perception**

Older farmers are more risk-averse than the younger ones, so it is more adventurous for the old to return their lands without considering the livelihood and pension in the future [14, 18, 24]. However, estimated results show that the independent variable X_1 has a significant and negative influence at the significance level of 1%. The reasons why older farmers consider returning the homestead and contracted farmland as a lower risk is that they prefer to returning their lands and acquiring urban residence registration in order to get high level urban social security or relying on their children settled in city with the decrease of their labor ability. Independent variables X_7 and X_8 have a significant and negative impact on the dependent variables Y_B and Y_A, respectively. Because contracted farmlands and homestead play a different roles in farmers' daily life, respectively. On one hand, farmers who have stable non-agricultural income can hardly depend on contracted farmlands operations, on the other hand, farmers who have stable residences can hardly depend on rural homestead, as well. In a word, having stable non-agricultural income and stable urban residence is an important premise for farmer's households to live in the city. Consequently, farmers who have stable non-agricultural income can reduce the risk of contracted farmlands return; Besides, farmers whose major family members settled in city can also reduce the risk of returning homestead return. The independent variable X_9 only has a significant and negative impact on the dependent variable Y_B at the significance level of 1%. It is because that the construction of rural social security system including new rural social pension insurance can weaken the social security function of contracted farmlands [19]. The major family members participating in new rural social pension can significantly reduce the risk of contracted farmlands return, and they will be more confident to break away from contracted farmlands operation.

Table 7 The estimated results by ordered probit model

Variables	Model A (homestead-returning Risk perception)				Model B (Contracted farmland-returning risk perception)			
	Coefficient	Std. Error	z-Statistic	Prob	Coefficient	Std. Error	z-Statistic	Prob
1. Family features factors								
X_1	−0.3918***	0.1197	−3.272	0.0011	−0.4842***	0.1712	−2.8283	0.0047
X_2	−0.0828	0.3139	−0.2637	0.7920	−0.0047	0.4331	−0.0108	0.9914
X_3	−0.4802	0.3296	−1.4568	0.1452	0.0090	0.0758	0.1183	0.9058
X_4	0.1154	0.1161	0.9943	0.3201	1.5764	1.0152	1.5529	0.1205
X_5	0.0330	0.2641	0.1251	0.9005	0.4308	0.2960	1.4552	0.1456
X_6	−0.3690	0.2308	−1.5989	0.1099	−0.0374	0.1847	−0.2023	0.8397
X_7	−0.1808	0.1158	−1.5615	0.1184	−3.8736***	1.1875	−3.2621	0.0011
X_8	−0.3242***	0.1162	−2.7901	0.0053	−0.1103	0.7228	−0.1526	0.8787
X_9	0.0483	0.2957	0.1633	0.8703	−0.7108***	0.2657	−2.6751	0.0075
2. Land−returning information factors								
X_{10}	−0.6967	0.5230	−1.3322	0.1828	0.0881	0.4802	0.1836	0.8544
X_{11}	−1.4429	11.5282	−0.1252	0.9004	0.1601	0.1345	1.1899	0.2341
X_{12}	−1.2961	0.8626	−1.5025	0.1330	0.6725	0.6269	1.0726	0.2834
X_{13}	0.2802	0.3231	0.8673	0.3858	−0.8054	0.8073	−0.9977	0.3184
3. Land−returning expectant risk factors								
X_{14}	0.2605*	0.1422	1.8316	0.0670	−0.0664	0.3316	−0.2002	0.8414
X_{15}	0.0142	0.1254	0.1129	0.9101	0.3659***	0.1144	3.1993	0.0014
X_{16}	0.1819	0.1123	1.6205	0.1051	0.2929**	0.1154	2.5381	0.0111
X_{17}	1.4016***	0.3029	4.6280	0.0000	0.2177**	0.1004	2.1682	0.0301

(continued)

Table 7 (continued)

Variables	Model A (homestead-returning Risk perception)				Model B (Contracted farmland-returning risk perception)			
	Coefficient	Std. Error	z-Statistic	Prob	Coefficient	Std. Error	z-Statistic	Prob
X_{18}	0.0041	0.1256	0.0327	0.9739	0.1139	0.1165	0.9779	0.3281
X_{19}	0.2718	0.3180	0.8546	0.3928	0.5380	0.4848	1.1098	0.2671
4. Land−returning social psychology factors								
X_{20}	−2.4329***	0.7333	−3.3175	0.0009	−1.7537***	0.5053	−3.4705	0.0005
X_{21}	−1.9026***	0.6954	−2.7360	0.0062	−1.3593***	0.2840	−4.7865	0.0000
X_{22}	−0.0425	0.0639	−0.6650	0.5060	−0.0267	0.1309	−0.2038	0.8385
5. Location factors								
X_{23}	−0.9065	0.8581	−1.0563	0.2908	−0.2896	0.8017	−0.3613	0.7179
LIMIT_1:C(24)	−33.1856	14.6903	−2.2590	0.0239	−9.2368	3.5383	−2.6105	0.0090
LIMIT_2:C(25)	−29.1177	14.0931	−2.0661	0.0388	−7.3750	3.4549	−2.1346	0.0328
Pseudo $-R^2$	0.8077				0.6827			
Log likelihood	−14.1141				−19.9165			
LR Statistic	118.5442				85.7095			
Probability (LR_{stat})	0				0			

Notes Significant at: *10, **5, ***1 percent levels

2. **Land-returning information and farmers' land-returning risk perception**

Generally speaking, people's risk perception can be affected by the understanding level and sources of information [4], however, estimated results show that independent variables land-returning information factors have insignificant impact on two dependent variables. It shows that the understanding level and sources of land-returning information of farmer's households don't have direct impact on its risk perception of lands return. It is because that farmers' land-returning risk perception is a kind of subjective comparison and judgment between marginal utility and marginal costs of land return basing on the deep understanding of land-returning information. When marginal utility is bigger than marginal costs, farmers consider lands return as lower risks, otherwise, as higher risks [20]. Obviously, although the understanding level and sources of land-returning information of farmer's households play a necessary role in land-returning risk perception, they are not crucial factors. And this is different from people's general risk perception about commodity or technology.

3. **Land-returning expectant risk and farmers' land-returning risk perception**

The independent variable X_{14} only has a significant and positive impact on the dependent variable Y_A at the significant level of 10%. Obviously, it is a higher risk for farmers to return their homestead without stable residence in city. The independent variables X_{15} and X_{16} only have significant and positive impacts on the dependent variable Y_B. It is because that contracted farmland operation can still have a function of stable basic income and pension for farmers in Chinese rural areas, at present. Consequently, it is a higher risk for farmers to return their contracted farmland without stable employment and expenditure for pension and medical treatment. The independent variable X_{17} has a significant and positive impact on both dependent variables. Land-returning compensation is an important capital source for farmers to conduct non-agricultural operations and buy new urban houses. As a result, farmers who predict that they can't get enough compensation after returning lands consider lands return as a higher risk. The independent variables X_{18} and X_{19} have insignificant impact on both dependent variables. It shows that famers who are unable to have enough money for children's education after returning lands and unable to change lifestyle and to adapt to city life are not influencing factors of risk perception of farmer's households returning lands.

4. **Social psychology and farmers' land-returning risk perception**

The independent variable X_{20} has a significant and negative impact on both dependent variables at the significance level of 1%. This is because that the purpose of farmers returning their lands is to acquire maximum land-returning utility. Obviously, acquiring higher life quality after returning lands can reduce the risks of homestead and contracted farmlands return. The independent variable X_{21} also has a significant and negative impact on both dependent variables at the significance level of 1%. This is because that farmers' trust in land-returning policy reflects their trust in government's credibility [5], Kang et al. [11]. The credibility can assure them of acquiring stable promises of land-returning policies to reduce the risks of homestead and contracted farmlands return and improve their enthusiasm to return their lands. On the contrary, provided that land-returning policies are instable, farmers as "risk averse" are likely to doubt about the government's credibility and reduce their enthusiasm to return their lands. At the beginning of the household registration system reform in Chongqing, some land-returning policies are amphibolous, such as land-returning compensation standard and whether rural lands should be kept after farmers became urban residences, which results in farmers full of worried about lands return and lowering their enthusiasm to return their lands. The independent variable X_{22} has insignificant impact on both dependent variables. It shows that farmers' concern level of land-returning propaganda is not a influencing factor of risk perception of farmers returning lands.

5. **Location factors and farmers' land-returning risk perception**

Generally speaking, farmers of "one-hour economic circle" area that is urban hinterland of Chongqing have broader employment channels and more stable non-agricultural income than those of relatively remote northeast or southeast areas of Chongqing. From this perspective, farmers of "one-hour economic circle" area are likely to have less dependence on contracted farmlands, which may have impact on their risk perception of contracted farmlands return. In addition, because urban housing price of "one-hour economic circle" area is higher than that of remote northeast or southeast areas of Chongqing, so farmers of "one-hour economic circle" area have greater dependence on homestead, which may have some impact on their risk perception of homestead return. However, the estimated results showed that location factors have insignificant impact on two dependent variables. This is because that farmers' land-returning risk perception is determined by comparison between marginal utility and marginal costs of individuals returning lands.

5 Conclusions

We used Ordered Probit Model to analyze the risk perception and its influencing factors of farmers returning their lands basing on the field survey of Chongqing. Our finding indicates that:

(1) From the risk perception of homestead return: The older farmers, whose major family members settled in the city, who have a higher expectation of life quality after returning homestead, who more trust in the policies after returning lands consider homestead return as a lower risk. Farmers who think they will lose stable residence, who think they will be unable to have enough compensation after returning lands think of returning homestead as a higher risk.

(2) From the risk conception of contracted farmlands return: The older farmers, whose families have stable non-agricultural income, whose major family

members have new rural social pension insurances, farmers who have a higher expectation of life quality after returning contracted farmlands, who more trust in the policies of lands return consider contracted farmlands return as a lower risk. However, farmers who think they will be unable to have stable employment for livelihood after returning lands, who think they will be unable to have expenditure for pension and medical treatment after returning land, who think they will be unable to have enough compensation after returning lands think of contracted farmlands return as a higher risk.

(3) In summary, factors that affect the risk perception of farmers returning homestead are less than that of returning contracted farmlands, it shows that farmers have more anxious about contracted farmlands return, and they prefer to returning their homestead. Moreover, the same factor may has different impact on the risk perception of homestead and contracted farmlands return, which is likely to be determined by the difference of security function that homestead and contracted farmlands carrying on.

We can also obtain some policy implications from the research including accelerating the construction of urban indemnificatory housing, lowering the threshold to applying indemnificatory housing for farmer workers, accelerating the construction of new villages in remote rural areas for farmers, broadening employment channels for farmers, establishing integrated urban–rural social security services system, increasing investment in related integrated facilities, improving the standard of land-returning compensation and keeping the land-returning policies stable.

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Review on Building Energy Performance Labeling: Whole Life-Cycle Perspective

Fenglian Yi and Jiayuan Wang

Abstract Building energy performance labeling is an important tool for countries around the world to carry out building energy conservation work. More attention should be paid to the development of building energy performance labeling for China, which has huge energy-saving potential. However, there is currently a lack of reflectiveness and summery on the research and development of building energy performance labeling. Therefore, a systematic literature review method and bibliometric statistical tool are used to analyze the current status, trends, and gaps. Through a review of 162 articles from 2007 to 2020, the focuses of the research on building energy performance labeling have been summarized from four perspectives: design, decision-making, evaluation, control and feedback. Future research directions and feasible improvement directions are also provided. Considering the environment, people, technology, and process management aspects, this paper generalized the reasons why the development of energy performance labeling in China is slow and proposed targeted solutions as references for further theoretical and practical research.

Keywords Whole life-cycle · Building energy performance labeling · Review

1 Introduction

With the development of society and the increase in population, energy demand is getting higher and higher. However, the green environment is under tremendous pressure due to the continuously increasing energy consumption. According to the calculated results of the International Energy Agency (IEA) on the global energy consumption in the building sector: the end-use energy related to building construction and building operation accounted for 35% of global energy consumption in 2018 [1]. Under the gradual transformation scenario, the growth rate of building energy consumption will exceed industrial energy consumption and transportation energy

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consumption [2]. It can be seen that building energy consumption will become the primary goal of energy-saving and emission reduction. A large number of studies have proved that building energy performance labeling, as a new management mechanism and technical means, is an important building energy-saving tool. Student et al. argue that building energy efficiency labeling can help change consumer attitudes, thereby affecting consumer housing needs and promoting building energy efficiency [3]. Ren et al. concluded that building energy efficiency labeling is one of the important means for the government to solve the failure of the energy-saving building market [4].

The development of building energy performance labeling is relatively mature abroad. Foreign researches have become hot in recent years. The domestic researches are developing slowly and most of them are concentrated in 2008 and 2009, which is related to Technical Guidelines for Marking the Energy performance of Civil Buildings. Through literature collection and integrated analysis, this paper found that a large number of domestic and foreign building energy conservation researches focus on energy-saving design, technology, envelope structure, energy consumption, etc. Among them, there is little research on building energy performance labeling. Roughly speaking, the research on building energy efficiency labeling mainly revolves around building energy efficiency evaluation, labeling system, etc., and there is a lack of research on the whole process of building energy performance labeling. The industry related to building energy performance labeling has a certain disconnection problem with academia.

To bridge these gaps, bibliometric statistical tools are used to conduct a systematic review to identify the current status, trends, priorities, and gaps in building energy performance labeling. Three problems in building energy efficiency labeling are analyzed in this article: (1) Key research topics of building energy performance labeling; (2) Research gap; (3) Further forming measures to promote the research and development of building energy performance labeling. Strengthening the practical application of technology and environmental regulations is the basis for promoting the implementation of building energy performance labeling. Human decision-making optimization and process management can further optimize performance. Therefore, based on the overview of building energy performance labeling, specific suggestions for its development from the environment, people, technology, and process management are put forward, which can promote the sustainable development of energy-saving buildings.

2 Definition

2.1 Energy Performance Labeling

The building energy performance labeling will reflect the thermal performance, energy efficiency grade index, and other related information of the energy consumption or energy efficiency of buildings or building materials, etc. in the form of labels [5]. By disclosing the information of building energy-saving, building energy performance labeling can solve the information asymmetry and make the relevant responsible subjects clarify their respective responsibilities and obligations. It is a market-based operating mechanism, which is an effective complement to mandatory energy efficiency standards and administrative supervision. Later, building energy performance labeling will be referred to as BEPL.

2.2 The Whole Life Cycle of Building Energy Performance Labeling

BEPL systems mostly target one stage in the building life cycle: design, construction, and operation. And most studies consider the life cycle of the building, not the BEPL. Through a comprehensive understanding of BEPL, the whole life cycle can be divided into five stages: design, decision-making, evaluation, control and feedback, as shown in Fig. 1. The design phase mainly includes the design of the subject, scope, level, frequency, third-party principles, and identification certificate. Decisions are based on consideration of the background environment and their economic interests. The evaluation stage refers to the use of evaluation tools or techniques by the evaluation agency to evaluate the energy efficiency of buildings. The control phase includes quality control of evaluation and labels supervision. Feedback can mainly be reflected by consumers' recognition of policies, technical conditions, and economic factors.

3 Method

The paper adopted the method of systematic literature review through the tool of bibliometric statistics, which can effectively avoid the common subjectivity and unreliability in the literature review [6]. The research framework is shown in Fig. 2.

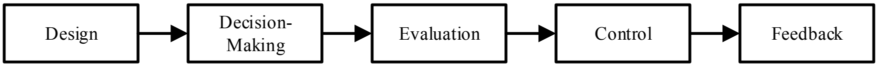

Fig. 1 The whole life cycle of building energy performance labeling

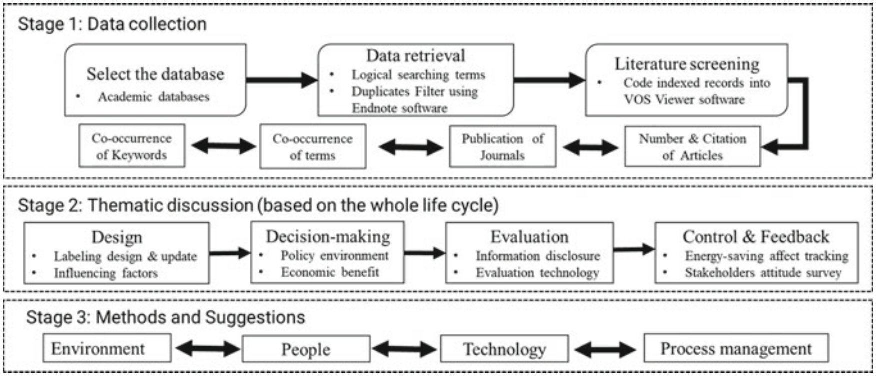

Fig. 2 The process of the review method

The first step is data collection, including the data collection process and descriptive statistics of the literature. The second step is the thematic discussion. According to the clustering results of the bibliometric software and the reading of the literature, the thematic literature is distinguished. Combining the whole life cycle view of BEPL, classify thematic literature. The third step is to explore solutions to the practical application from the four perspectives of the environment, people, technology, and process management.

4 Data Collection

4.1 Data Collection Process

Firstly, the web of science was selected as the main search database. To ensure the integrity of the search results, Elsevier, CNKI, etc. were used as additional databases. Secondly, the keyword "building energy efficiency label", "building energy performance label", "building energy efficiency certificate", "building energy performance certificate" et al. are entered in the "title/abstract/keyword" field. There are no restrictions on publications. Since the domestic BEPL research mainly started in 2007, the date range is set to "all years from 2007 to the present". The journal is selected. Then, after screening and supplementing documents and deleting duplicate records, journal documents that are related to the subject are left. A total of 162 qualified documents were obtained, which were cited 2499 times. The number of papers published per year is shown in Fig. 3 and the number of citations per year is shown in Fig. 4.

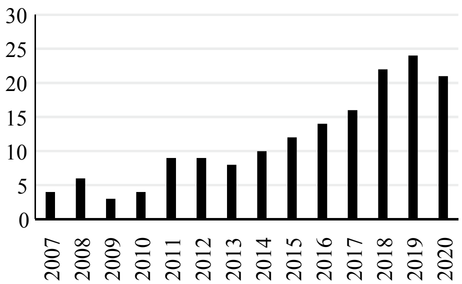

Fig. 3 The number of papers published

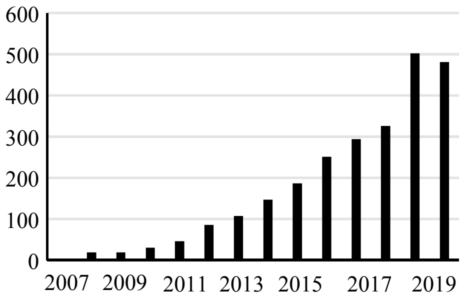

Fig. 4 The number of citations

4.2 Descriptive Statistics of the Reviewed Literature

VOSviewer was used to analyze the published journals. The number of articles published and cited journals of the main source journals is shown in Table 1. In terms of the number of publications, energy policy, energy and buildings, applied energy, sustainability, and journal of clean energy are the top five journals. In terms of total citations, energy policy, energy and buildings, applied energy, renewable and sustainable energy review and energy are the top five journals. In terms of Avg. Norm. Citations, renewable and sustainable energy review, energy, energy policy, energy and buildings are the top four journals. Judging from the publication year of the evaluation, most of the researches on BEPL was concentrated in 2014 and 2015.

VOSviewer shows that among the 4291 keywords in all documents, 54 of them meet the minimum connection strength of 12. The term co-occurrence map in the BEPL literature is generated as shown in Fig. 5. From the term co-occurrence map, “performance”, “efficiency”, “label”, “certificate”, “effect”, “cost”, and “difference” appear frequently. Among the 528 keywords, 31 keywords meet the setting condition of the minimum connection strength of three. The main body relationship network of BEPL research is shown in Fig. 6, which includes 30 nodes and 172 links. Judging from the keyword Keywords Co-Occurrence Experiment, the frequently-occurring keyword is “energy performance certificate”, “energy efficiency”, which closely surround the topic.

Table 1 Analysis of sources publishing building energy performance labeling research

Source	Number of articles	Total citations	Avg. Norm. citations	Avg. Pub. year
Energy policy	28	830	29.6	2013
Energy and buildings	25	630	25.2	2014
Applied energy	8	160	20.0	2014
Sustainability	8	15	1.9	2016
Journal of clean energy	6	29	4.8	2015
Bauphysik	5	12	2.4	2015
Renewable and sustainable energy review	4	131	32.8	2013
Energy	3	94	31.3	2014
Building research and information	3	46	15.3	2015
Energy efficiency	3	23	7.7	2015

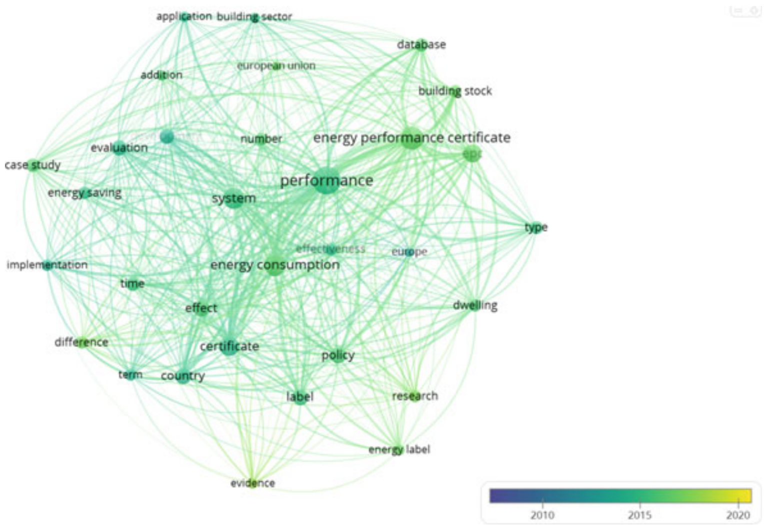

Fig. 5 The term co-occurrence map

Based on the commonness of the extracted keywords, combined with an accurate reading of the article, this article summarized the focus of research on BEPL at each stage of the life cycle. The design phase focuses on labeling design and its Influencing factors. The decision-making stage focuses on the policy environment for the implementation and the possible economic benefits. The evaluation phase

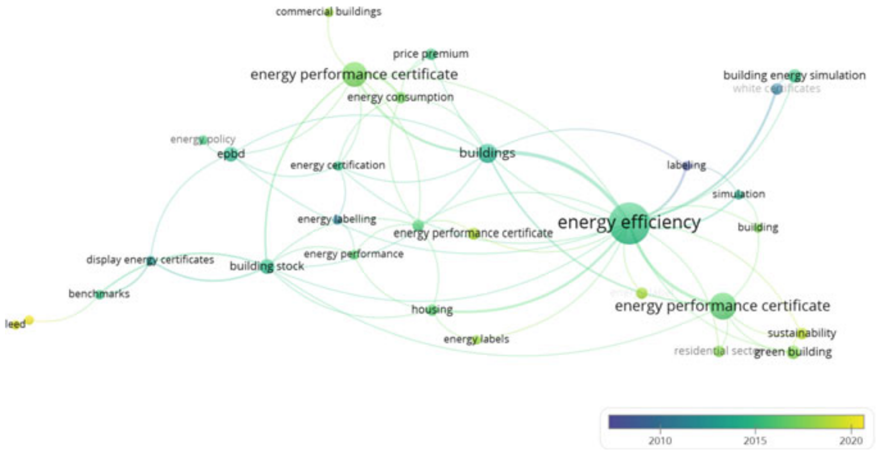

Fig. 6 The keywords co-occurrence map

focuses on the acquisition of energy consumption information and the development of evaluation technology. The quality control and feedback stage is mainly aimed at tracking energy-saving effects and investigating the recognition of stakeholders.

5 Thematic Discussion (Based on the Whole Life Cycle)

Given the focus of the research on the life cycle of the BEPL obtained above, this article summarized their research status and looked forward to the future.

5.1 Design

5.1.1 Labeling Design and Update

The careful design of the labeling program is very important [7]. Many scholars have considered the design of certificates from different directions. Fedorczak et al. demonstrated the certification method developed in dynamic simulation [8]. Vinagre et al. proposed the establishment of greenhouse gas-based energy efficiency eco-labels in buildings [9]. Zhang et al. introduced an interactive computer program for energy-saving certification of building envelopes [10]. Madrazo et al. added energy-related data to the energy performance certificate to support the building renovation decision [11]. Talajic et al. proposed to issue building energy certificates based on thermal image measurement and energy performance inspection of buildings [12].

Some scholars have updated the labeling system in response to the shortcomings of existing BEPL. Taranu et al. recalibrated the overly optimistic assessment of the energy performance of the F label [13]. Lopez et al. updated the energy performance certificate of the residential sector under the policy changes in the building technical code [14]. From the perspective of behavioral insights, Taranu et al. put forward some suggestions for the European Energy Performance Certificate to become an effective communication tool with residents [15].

5.1.2 Influencing Factors

Fujisawa et al. concluded that an energy label with a staircase score would have a negative impact [16]. Organ et al. discussed the main influencing factors of energy performance certificates and their impact on minimum energy efficiency standards [17]. Qiu et al. found that there is a significant correlation between the characteristics of commercial buildings (such as area, plot size, and construction years) and green certification [18]. Sanderford et al. concluded that the main predictors of the change in the proportion of Energy Star certified residences are public policy, climate, market attributes, industry characteristics, and energy prices [18]. Hjortling et al. also said that building codes have a certain impact on building energy performance and climate zones have less impact on energy consumption than building types [19]. Reis et al. insisted that the emission year, building direction, building type, and certification type affect the final energy label of the building [20].

5.1.3 Prospects

Regarding the design of BEPL, most studies considered macro-environmental aspects, such as public policies, climate, industry characteristics, buildings, etc., and there is little in-depth exploration of the properties. We mainly looked forward to the following aspects: (1) Regionality. Due to differences in climatic characteristics, architectural features, and human environments in different regions, it is necessary to adjust the BEPL to meet local characteristics after considering the uniformity index. How to reasonably display regionality and comprehensiveness of building energy efficiency labeling is the difficulty in future research. (2) Periodicity. Whether the BEPL is dedicated to the long-term or the short-term energy consumption effect is also a question, which is related to the validity period of the label. How to give full play to the subjective initiative of the owners, and encourage them is a problem. (3) Voluntary and mandatory. Mandatory policies can usually save a lot of energy, and the energy saved is easy to quantify and verify. However, mandatory policies can easily arouse the rebellious psychology of the executors, thus failing to achieve the expected results. Therefore, it is possible to explore the difference between mandatory and voluntary and the mechanism of action to appropriately select the attributes of the label.

5.2 Decision-Making

5.2.1 Policy Environment

Analysis of the operation mechanism of BEPL is the basis and prerequisite for establishing a building energy efficiency labeling system. Yin et al. and Fang et al. explored the operating mechanism of the energy efficiency evaluation and labeling system [21, 22]. In terms of policy formulation, Kang et al. proposed a fiscal and tax incentive policy plan to encourage energy-saving buildings, such as reducing consumer deed tax [23]. Kelly et al. also suggested that the content of the identification should match the policy to improve the reliability of the identification [24].

5.2.2 Economic Benefit

The main purpose of implementing BEPL is to increase economic benefits. Many scholars have researched the relationship between building energy efficiency labels and building price premiums. Most studies have proved that there is a significant relationship between energy efficiency labels and building price premiums. Kok et al. proved that public transportation and facilities provided in multi-functional office areas can realize the rent premium of a single-function office area [25]. Leskinen et al. used discounted cash flow to evaluate green building certificates and found that the brand value of the certificate can increase property rental income [26]. Using alternative modeling methods, McCord et al. believe that high energy performance will increase property prices more [27]. Porumb et al. surveyed that the price of green-certified office buildings was 19% higher than that of non-green certified office buildings [28]. Reichardt et al. argue that both Energy Star and LEED-certified buildings have significant rent premiums [29]. Zhang et al. surveyed that green-label residential projects attracted a 6.9% price premium over non-green-label residential projects [30]. Zhang et al. established a hedonic building energy efficiency certificate pricing model and found that the sales price premium of houses that obtained energy certificates was 11.7% [31].

However, some studies have shown that energy performance certificates cannot generate price premiums. Olaussen et al. argue that the introduction of the mandatory energy certification system does not affect the price premium [32]. Wilhelmsson et al. proved that the impact of energy performance certificates is not different in price distribution [33]. Holtermans et al. found that the rent growth of certified office buildings did not exceed those of uncertified office buildings [34].

5.2.3 Prospects

The current theoretical research on BEPL management is still not comprehensive and systematic. The issue of moral hazard as side effects in the operation mechanism has not been fully studied and resolved. The effectiveness of policy formulation and the supervision and management mechanism still need further discussion.

Most of the current research confirmed the direct relationship between energy performance certificates and price premiums. However, little research is discussing the reasons for the price premium and their differences. It is not only related to the methods and objects of their respective certifications but also closely related to the implementation and development of BEPL.

5.3 Energy Efficiency Evaluation

Building energy consumption evaluation is a necessary means for building energy efficiency design and energy consumption diagnosis, and it is also a basic condition for the application of building energy efficiency labeling. At present, domestic and foreign researches on energy efficiency evaluation are relatively hot. This article mainly summarized data acquisition and measurement technology.

5.3.1 Information Disclosure

The acquisition of energy efficiency data is a prerequisite for energy efficiency calculations. In response to the difficulty of data collection, the availability and effectiveness of building energy consumption data were explored from both technical and policy aspects. In terms of technology, Fan et al. proposed that unsupervised analysis can dig out more new knowledge in the complex big data structure with limited prior knowledge information [35]. In terms of the policy, Jin et al. proposed that public building owners and the government are the main stakeholders to promote the disclosure of public building energy consumption and energy efficiency information [36]. The availability and validity of future data deserve further exploration.

5.3.2 Evaluation Technology

There are various algorithms for energy efficiency measurement, among which common statistical calculation methods include parameter correction [37], linear regression [38]. Besides, there are more accurate machine learning methods, such as artificial neural networks [39], cluster analysis [40], support vector machines [41], deep learning [42], neuro-fuzzy inference [43], etc. Koo et al. used data mining technology and probability methods to develop a dynamic operation rating system for existing buildings [44]. Las et al. developed a revised algorithm for energy performance certificates to assess residential building stock [45].

Wei et al. used blind system identification and neural networks to predict the level of house use and energy consumption of office buildings. The results showed that compared with feedforward neural networks and integrated models, extreme learning machines have better prediction effects [46]. Melo et al. compared several statistical modeling techniques, including multiple linear regression, multiple adaptive regression splines, support vector machines, Gaussian processes, random forests, and artificial neural networks. Their results show that the artificial neural network method has the best performance [47].

5.3.3 Prospects

There are many types of energy efficiency measurement technologies, and the applicable objects of each technology are different. We believed that the energy efficiency measurement system can try to integrate a series of energy consumption calculation methods and choose different best solutions for different calculation and evaluation objects. The selection of the best solution needs further research. In the future, big data mining and driving will be a powerful tool in the field of building energy efficiency. The next generation of BEPL should rely on BIM technology and benefit from big data technology, which can better represent energy efficiency, the occupant's perceived comfort, and air quality.

Many experts and scholars believed that building energy consumption and indoor environment are largely affected by occupants' behavior and considered occupants' behavior factors in energy consumption calculations [48, 49]. However, in the evaluation stage of energy efficiency labeling, there is still a lack of consideration of human behavior. More in-depth research is needed to improve the establishment of random residential behavior detection models.

5.4 Control and Feedback

The energy consumption of buildings is not static. The long-term maintenance of BEPL must be regularly tested in time to guide subsequent energy-saving renovations. Besides, the attitude of the stakeholders reflects the effectiveness of the implementation BEPL to a certain extent, which can be a reference for later updates and improvement.

5.4.1 Energy-Saving Affect Tracking

Gao et al. found that the operating energy efficiency level of green buildings largely depends on the building's operation and management technology [50]. Asensio et al. tested the validity of BEPL in the United States and found that the energy-saving range was between 18 and 30% [51]. Cheng et al. found that public buildings and residential buildings are mainly one-star. Affected by policy and technical factors, there are more BEPL projects in hot summer and cold winter areas, but the number of high-star projects is small [52]. Cozza et al. concluded that by comparing the actual current consumption after the renovation with the expected theoretical consumption defined by the certificate, energy savings can be estimated fairly accurately [53]. Cozza et al. also found that the power consumption of buildings with low energy consumption levels is often significantly lower than expected, while the power consumption of buildings with high energy consumption levels is often slightly higher than expected [54]. Murphy et al. used pre-evaluation and post-evaluation data from BEPL to analyze the impact of energy performance [55]. Qiu et al. showed that both before and after certification, the energy consumption of Energy Star buildings is 8% lower than before gaining certification [56].

5.4.2 Stakeholders Attitude Survey

The BEPL score can be considered as an effective signal of overall facility satisfaction in the survey sample. Bozovic et al. concluded that the awareness of green lifestyles is related to the optimism of buildings to obtain green building ratings [57]. Jang et al. found that green building certification increased the willingness of potential tenants to rent, but higher certification levels did not further increase the willingness. Besides, potential tenants with a higher degree of eco-friendliness are more willing to rent buildings with green certification [58]. Lee et al. found that when relevant information is transmitted, the energy efficiency level of a given housing has a significant impact on consumers' housing choices [59]. Marmolejo et al. confirmed that the marginal willingness to pay for the "A" label instead of the "E" label is much higher than the energy cost savings [60]. Parkinson et al. found that the rental value only has a significant correlation with the beauty of the facility, but there is no evidence that residents' perceptions of the environmental impact of facilities affect the value of rent [61]. Schuitema et al. believed that trust is the key determinant of attitude towards energy performance certificates. High cognition involvement magnifies the effect of trust on attitude, while high emotional involvement inhibits the effect of trust on attitude [62].

5.4.3 Prospects

The improvement of the accuracy of building energy efficiency labeling needs to be pursued all the time, whether from the technical or management level. Aiming at the gap in energy performance, some studies have found the gap in energy performance, but there is a lack of discussion on the reasons for the gap and its mechanism. In particular, people are a special factor in building energy consumption. Future studies may consider the use of experimental design to assess consumers' actual concerns about building energy efficiency, or consumer characteristics to assess the impact of building energy efficiency labels.

6 Conclusion

Under the situation of an increasing energy shortage, building energy conservation is imperative. As an effective tool to promote building energy efficiency, BEPL should be used correctly and reasonably. This article reviews the current status, trends, and gaps in the research on BEPL, and put forward a future outlook. Search databases include WOS, Elsevier, and CNKI. First, 162 data closely related to BEPL were selected. Secondly, using VOSviewer software to analyze the number of papers published, citations, journals published, and co-occurrence of keywords. Based on the results of intensive reading of the literature and keyword clustering, the topics were reasonably divided from the perspective of the whole life cycle, and each topic was reviewed.

In view of the development of BEPL, the construction of the policy, market, and academic atmosphere for BEPL research need to increase in terms of the environment. In terms of decision-making, it is necessary to increase the training of professional certification personnel and improve the cooperation mechanism of stakeholders. In terms of technology, the goal should be to reduce the actual consumption of energy. Finding the reasons for the differences and striving to improve the accuracy, automation, and interpretability of the evaluation technology should always be needed. In terms of process management, it is necessary to simplify the certification process and strengthen the supervision of labeling to prevent moral hazards and ensure the effectiveness of building energy performance labeling.

The research results will help to acquire academic knowledge, research frontiers, and emerging trends of building energy performance labeling. At the same time, it can help solve the problems and difficulties faced by building energy performance labeling, further promoting its sustainable development.

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Research on Green Evaluation of Mountainous Highway Construction

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Abstract In the construction process of mountainous highways, it will exert greater pressure on the environment, consume resources, change the topography and landform, and bring about various pollutions, which are more and more valued and developed. The problem should be solved in the green evaluation of mountainous highway projects construction, which is how to discover the pollution in the construction process of mountainous highway projects and analyze them to further solve the pollution problems and effectively reduce resource consumption and environmental pollution. Scientific and objective evaluation of the construction system is an important part of the research on highway construction systems. In response to the above problems, people have introduced the concept of "green construction" in the construction field. As a result, this study aims to analyze the ecological environment of mountainous highways in the construction period and construct the highway green construction evaluation model. To obtain this goals, the concept and characteristics of green construction of mountainous highways is combined. Four impacts are analyzed including green construction environment, energy and resources conservation, construction technology management. Introducing self-organizing feature map (SOFM) neural network method, a highway green construction evaluation model is constructed. Lastly, a detailed case study was conducted to verify the empirical findings. The evaluation results are compared with the fuzzy comprehensiveness evaluation results, which show that green construction evaluation of mountain highway projects is good and consistent with the actual situation. The method provides a new way to objectively evaluate green construction evaluation of mountain highway projects. This study contributes to the body of knowledge by green evaluation of mountainous highway construction. In addition to that, the findings of this study can be used to improve construction management plans and select green construction technologies. The results can also provide a theoretical support for the mountainous highway construction green management.

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1 Introduction

In order to highlight the importance of sustainable development strategy and scientific outlook on development, the highway construction field has been comprehensively implemented in the management system of health, safety and environment, which has achieved gratifying results in many construction fields [1]. China's transportation infrastructure construction is developing rapidly, which is more obvious in remote mountainous areas and developed areas, and also has achieved good economic and social benefits. Vigorously developing transportation construction is the demand of national economic development and social progress development [2, 3]. China's highway construction developing rapidly, and the pressure on the ecological environment is also increasing. Therefore, people begin to pay more and more attention to the theory and practice of highway green construction evaluation and introduce the green concept into the construction field to promote the virtuous cycle of resources and ecological environment. Green construction refers to the realization of energy saving, land saving, water saving, material saving and environmental protection through scientific management and advanced technology under the premise of guaranteeing the basic requirements of quality and safety in the construction process. Therefore, evaluation research of the green construction for mountainous highways can improve the level of ecological environmental protection measures and promote the improvement of the utilization rate of ecological resources, so as to achieve the goal of strengthening the sustainable development of social economy and further promote the realization of the goal of ecological environment construction in China.

In recent years, a series of methods have been introduced into the green construction evaluation of mountain highway [4, 5], and some research work has been done on the green construction evaluation [6–8]. Wang et al. [9] built an index system based on information entropy, and established an evaluation model of road green construction based on the theory of negative entropy, and analyzed it with cases. Xiong et al. [10] introduced the fuzzy matter-element analysis method to establish the evaluation model of green construction of high-grade highway according to the characteristics of fuzzy incompatibility of indicators. Wang et al. [11] established the evaluation index system of green and low-carbon highways. Based on the combination of the analytic hierarchy process (AHP) and the multi-level fuzzy Comprehensiveness evaluation method, the green and low carbon grade of highway is determined and verified with an example. Although the existing evaluation methods have their own characteristics, but they are difficult to solve the weight problem and the calculation is tedious.

The aim of this paper is to enrich the knowledge on green evaluation of mountainous highway construction. First, the characteristics and management features of the mountain highway green engineering project are analyzed. Second, combining factor analysis method, evaluation index system for green construction of mountainous highways is established. Third, compared with fuzzy comprehensiveness evaluation method and SOFM neural network, performance model evaluation method for green building project is constructed. Results from the case study in the Nanjing-Hangzhou Expressway project in Zhejiang Province of China are presented to better understand the green construction management of engineering projects. This study can provide theoretical support to evaluate the green management for similar types of construction processes.

2 Characteristics and Measures for Green Construction of Mountainous Highway

2.1 Characteristics for Green Construction of Mountainous Highway

Green construction refers to utilizing, saving resources and reducing negative impact as much as possible on the environment in the construction process of engineering projects through innovative technologies and scientific management. All the aspects involved should run through the whole life cycle of highway construction and all reflect the requirements of sustainable development.

(1) High utilization rate. The mountainous highway project has a large consumption of land, energy and materials. Green construction ensures the quality of the project and reduces energy consumption and resource waste [12]. It has the characteristics of low energy consumption and low waste.
(2) Comprehensiveness. In addition to the processes required for traditional construction, green construction requires knowledge of energy, land, and environment. In addition, it needs to be further refined during the construction process to fully grasp the consumption of various resources during the construction process to maximize the utilization of resources. Therefore, the green construction coverage is larger and the Comprehensiveness is stronger.
(3) Good economy. Promote energy conservation and environmental protection under the premise of following the laws of natural ecology. The construction unit can cultivate and enhance the worker's concept of saving during the construction process, and avoid unnecessary waste of resources. At the same time, under the premise of ensuring quality and construction period, the cost is controlled, and finally the green construction of project value-added is realized. In addition, the green construction should reasonably carry out the organization and management of the staff on the premise of ensuring high-efficiency operation, which can significantly improve the construction efficiency.
(4) Systematic excellence. The construction system of a traditional engineering project basically consists of three parts: construction period, schedule and

quality. In addition, if the green construction can be extended in terms of ensuring the construction period, quality and progress, and at the same time in terms of energy conservation, coordination of people and materials, and protection of ecology, the construction process will be more scientific and the theoretical system will be systematic [13].

(5) Full of informationization. Due to the continuous deepening of engineering projects, various construction materials and equipment will change with the plan. Usually, subjective methods are often used in the selection. However, this method often causes excessive deviation, which makes the resources not fully utilized. In addition, it is difficult to make dynamic adjustments in the change of engineering quantity. Therefore, the realization of informationization in green construction can effectively supervise resources and energy, thereby realizing the full utilization of resources and energy.

2.2 Green Construction Measures for Green Construction of Mountainous Highway

(1) Without damaging the environment. During the construction of the project, it is bound to change the original ecological environment. Construction activities such as excavation of earth and stone and leveling the site will not only affect the local ecological environment, but also damage the local special resources. Therefore, it should not damaging the environment.

(2) Consider climate factors. The impact of climate factors on construction should not be underestimated. When constructing, considering the climatic factors in advance, and then taking corresponding measures, it can reduce many unnecessary resource consumption and reduce the construction cost.

(3) Water saving, electricity saving and materials saving. During the construction process, the builder Members often waste resources at will, and water, electricity, materials and resources do not know how to save. The period of road construction experience is long, so it will become a big consumption.

(4) Reduce environmental pollution and improve environmental quality. Construction activities will definitely pollute the environment and reduce environmental quality. Because a lot of noise, dust, construction waste, etc. are generated during the construction process, this not only affects the environmental quality but also harms people's health.

(5) Implement scientific and effective management. Green construction has a promoting effect on sustainable development. Adopting scientific and effective management in the construction process can improve the management level of the enterprise, and make the enterprise institutionalized and standardized, which not only increases the economic effect but also drives the contractor's enthusiasm in construction.

3 Construction of Evaluation Index System

3.1 Influencing Factors of Green Construction

The construction of mountain highway green evaluation index system is the basis of green evaluation. According to the scientific, systematic and operable principles of the construction of the index system, the impact of mountain highway construction on the surrounding ecological environment is considered, and the evaluation index of mountain highway green construction is analyzed from the perspective of construction management technology. According to the "Green Construction Guidelines", green construction refers to the use of advanced management methods and technologies in the construction process, to maximize the use of resources and less impact on the environment, to achieve energy saving, land saving, water saving, material saving and environmental protection. Therefore, based on the perspectives of load, resource utilization, resource conservation and energy saving, the evaluation index system of green highway construction in mountainous areas during the construction period is constructed.

3.1.1 Green Construction Environment Impact

(1) Noise pollution control

The noise is usually generated from the vibration of the on-site machinery. At the construction site, the machinery and equipment are easy to make loud noises. It is necessary to set the surrounding walls around the planned area of the construction plan. The walls should meet the sound insulation requirements for the construction site. Large-scale mechanical work will inevitably produce vibrations, such as excavators, concrete trucks, rotary pile drivers, etc., which will make a loud noise. Therefore, it is necessary to regularly inspect and maintain mechanical equipment. Construction work with large mechanical noise should not be operated at night to avoid affecting surrounding villages [13]. When loading formwork, scaffolding, aluminum alloys, etc., you need to handle them lightly to avoid unnecessary noise. Some relatively noisy mechanical equipment should be kept away from living areas and offices, and professional workers with mechanical knowledge should be assigned to detect and maintain the working machinery. Site construction sound insulation wall diagram can be seen by Fig. 1.

(2) Water pollution

The sewage generated in the living area of the Construction site shall not be discharged arbitrarily, and it shall be introduced into the sewage well and discharged into the sewage well. The car wash sewage from the car wash basin should be repeatedly flowed into the tertiary tank for precipitation and continued to be used. A rainwater collection pool is established to protect the concrete pavement, which needs

Fig. 1 Site construction sound insulation wall diagram

to be maintained with rainwater to reduce the use of municipal tap water. The water for mixing concrete on the construction site should be used after sedimentation. The sewage from the anchorage of the basement construction should be pumped to the designated area of the site and taken away by the sewage pump.

(3) Dust pollution

The earthwork excavated on site shall be covered with dust-proof net to prevent dust. The cement should be placed in a planned cement deposit or in a closed warehouse. Temporary stacking of cement on site should be covered with plastic film to prevent the dust caused by cement from drifting around with the wind. For the wood processing area, the sawdust should be cleaned in time, and the discarded wooden blocks should be cleaned up into the waste shed, and then transported separately. In the earthwork operation stage, the densely meshed net is used to cover the location where the excavation has been completed to reduce dust. The sprinkler measures are adopted for the area under construction [14].

(4) Light pollution

On-site steel cutting, welding should be carried out in the steel processing shed, and should not work in the open air.

3.1.2 Energy and Energy Conservation and Utilization

(1) Utilization of water resources

Prepare a detailed temporary water use plan for the construction site, establish a rainwater reservoir, and use rainwater to water the flowers and plants. Water-saving appliances are used in the office, living area and construction section. If using a water-saving faucet, the bathroom water switch adopts a pedaling method, and the bathroom is large and the urinal is self-cleaning. When road concrete is cured, it should be covered with water and covered with a cloth with high water content. The reduction of water consumption also reduces the difficulty of maintenance and reduces the number of watering.

(2) Use of land resources

According to the site, the planned land is reasonably arranged, and the site use situation is fully understood and recognized. There is a reasonable arrangement for the general flat land on the construction site. The site layout should be compact, reduce the abandoned land area, and strengthen the effective use of temporary machinery land. The land should follow the principles of science, practicality and rationality, reduce the waste of the site and respect the land use environment [15]. The temporary office uses a model room that is mobile, small in size, and reusable. The mixing station at the construction site, the material stacking area, the working area, the processing station, etc. should be placed close to the road to reduce the transportation distance. Excavation work should avoid destroying native vegetation and carry out earthwork work on the basis of protecting the original vegetation. If it is necessary to destroy the original vegetation, it should be filled in time when the earthwork is over, which avoid natural disasters such as soil erosion and landslides. The earthwork excavation project must compare multiple sets of plans and choose the most favorable plan for construction.

(3) Use of materials

For the use of materials, green and environmentally friendly materials should be used. If you can get the materials from the nearest place, you don't choose to transport them from other places, which can save the cost of transporting materials [14]. At the same time, the green construction materials are applied to the entire construction process. The number of squares of concrete should be reasonably estimated to avoid wasting resources by multiple calls. Rebar cutting should pay attention to the remaining tails to avoid unnecessary waste. The connection between the steel bars should be connected in a reasonable way to give full play to the utilization rate of steel bars, which optimize the template construction scheme. The template should be selected with the same length and length to avoid cutting and remaining waste. At the same time, the number of turnovers for the finished template is increased, the use of the template is reasonable and effective, and the usage rate of the template is improved.

3.1.3 Construction Technology Management

(1) Construction site management

The management of the construction site should follow the principle of optimization of construction site management, which mean for the principle of economic benefit, the principle of standardization and standardization, and the principle of scientific rationality. The awareness of all employees should be enhanced on the site's green construction and civilized construction. Implement various on-site management systems should be improved, and the quality control of the construction site should be strengthened.

(2) Environmental management mechanism

The construction site should set up a green construction environmental protection publicity sign. The signboard clearly indicates how to protect the environment, and strictly adhere to the norms and environmental protection awareness. At the same time, all construction units and individual class owners signed the "Promise for Environmental Protection Commitment". In the construction and construction, environmental awareness will be brought to practice, and everyone will actually implement the principle of green construction and protection of natural ecology.

(3) Safety and health management

Safety signs on the construction site, as well as entrances and exits, safety warning signs should be affixed on the closed fence. Safety warning signs should be placed at the foundation pits and dangerous sections. The mechanical equipment used on site should meet the requirements for safe use. The staff on site must wear helmets to work, which do not wear slippers for work and do not work after drinking. The security department should be equipped with a small medical kit, as well as a drug that can handle some wounds. In summer, the temperature is high, which is necessary to prevent heatstroke, with heat-reducing drugs and heat-resisting drinks [16].

Based on the above factors affecting the green construction of mountain roads and the scientific, systematic and operational principles of the indicator system [14], 3 first-level evaluation indexes and 10 s-level evaluation indexes are established, which are used as the evaluation index system for the green construction of mountain roads during the construction period. The evaluation index system of mountain highway green construction is shown in Table 1.The green evaluation and research diagram of highway construction in mountainous areas is shown in Fig. 2.

Table 1 Evaluation index system for green construction of mountainous highways

Green construction evaluation index	
Primary indicator	Secondary indicators
Green construction environment impact	Noise pollution control
	Water pollution
	Dust pollution
	Light pollution
Energy and resource conservation	Utilization of water resources
	Use of land resources
	Use of materials
Construction technology management	Construction site management
	Environmental management mechanism
	Safety and health management

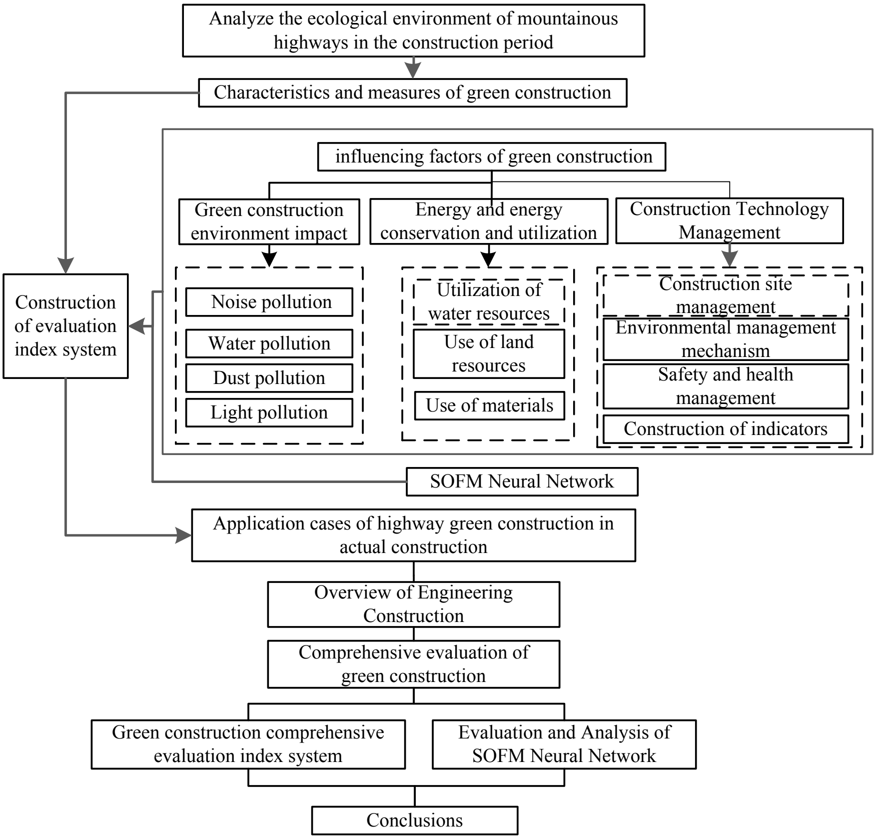

Fig. 2 Performance model evaluation method for green building project

4 Research on Green Evaluation of Mountain Expressway Based on SOFM Neural Network

Existing highway green evaluation studies are mostly USES the analytic hierarchy process (ahp) and fuzzy comprehensive evaluation method, through the analytic hierarchy process (ahp) to green road to quantify the weights of evaluation indexes, using fuzzy comprehensive evaluation method, comprehensive evaluation of green road, but the combination of the two methods used in the calculation of weight is too complex, and with the increase of sample size, the method of highway green evaluation accuracy is reduced, while the SOFM neural network to solve the problem, in improving accuracy but also reduces the amount of calculation, increase the effectiveness and feasibility of green building assessment. Therefore, this study used SOFM neural network and fuzzy comprehensive evaluation to evaluate green highway.

4.1 SOFM Neural Network

The method of neural network starts from simulating the image thinking of human brain, which has the characteristics of non-linear, parallel and strong generalization, and has a broad application prospect. At present, BP neural network is widely used, which are mostly only used for identification, not for grading. In order to improve the intelligence of evaluation, the basic algorithm foundation of self-organizing feature mapping neural network is introduced. On the basis of improving the convergence speed and performance of the algorithm, a self-organizing feature mapping (SOFM) neural network model for grade evaluation is established to open up a new way of thinking in the evaluation [17].

SOFM network is a kind of unsupervised learning network, which simulates the brain neural system and has the functions of self-adaptive, self-learning and association. The biggest advantage of SOFM network is that it can keep the topological structure of the original data and is widely used in the fields of data classification, knowledge acquisition, process monitoring and fault identification.

4.2 SOFM Network Topology

The learning process of the SOFM network can be described as: selecting the most suitable matching neurons in each input value or vector to adjust the neurons weight in the neuron domain (the field will decrease as the number of training increases), and then slowly form a learning mode of unorganized competition, through continuous training, and finally form a type of model representing the input network. SOFM network topology diagram is shown in Fig. 3. The training process is as follows:

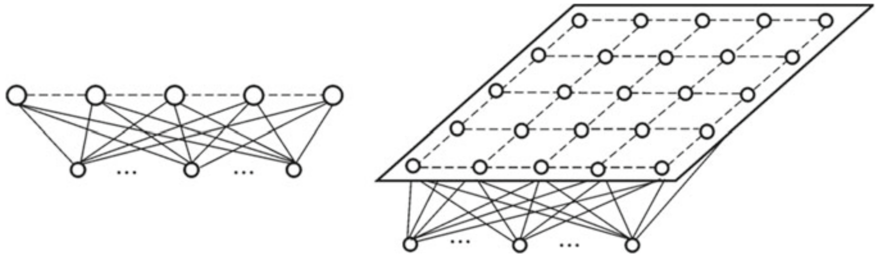

Fig. 3 SOFM network topology diagram

Network status initialization. A small random number is assigned to the output neural network, the initial learning rate is determined, and the domain (t) is determined, and the initial value of the learning rate is assigned [18].
Sample input. A random input mode is selected from the P input modes, and then a series of processes are performed to obtain P ∈ {1, 2, …, P}.
Find the winning neuron node r. Minimum standard by Euclidean distance:

$$\left\| \hat{X}^p - \hat{W}_j \right\| = \min_j \left\| \hat{X}^p - \hat{W}_j \right\|, \ j = 1, 2 \ldots, m \tag{1}$$

Adjust the connection rights. Correct the connection between the neurons in the neighborhood $N_r(t)$ and the input network:

$$\hat{W}_j(t+1) = \hat{W}_j(t) + \alpha(t) \left\| \hat{X}^p - \hat{W}_j \right\|, \ j \in N_r(t), \ 0 < \alpha(t) < 1 \tag{2}$$

Re-select a learning mode for the input layer, and then perform step (3) until P learning modes are processed to the neural network [19].
Renormalize the weights after learning:

$$\hat{W}_j(t+1) = \frac{W_j(\hat{t}+1)}{\left\| \hat{W}_j(t+1) \right\|}, \ j = 1, 2, \ldots, m \ \text{(Reattribute normalized values } \hat{W}_j(t+1)\text{)} \tag{3}$$

(7) Adjust the weight.
(8) Let t continue to increase by 1, and then perform step (2) until t = T.

5 Application Cases of Highway Green Construction in Actual Construction

5.1 Overview of Engineering Construction

The Nanjing-Hangzhou Expressway began construction in July 2000, and the first phase of the project was completed in 2003. It was completed and opened to traffic in the same year September. The construction was gradually carried out and finally completed in 2008. The geographical location along the Nanjing-Hangzhou Expressway is complex, and the topography and geomorphology are criss-crossed, but the ecological environment along the line is relatively good, rich in biological species, and has valuable forest resources and water resources [20].

The completion and opening of the Nanjing-Hangzhou Expressway will promote the new development of the Jiang Su Expressway, and promote the construction level of the Jiang su Expressway to be in line with the international. The design of Nanjing-Hangzhou Expressway is based on the premise of ecological and environmental protection. Under the premise of ensuring the satisfaction of construction work, it pays attention to the concept of ecological environment protection, integrates the expressway with the surrounding environment, and realizes the phenomenon that the construction project and the environment are harmonious and unified. It has improved some environmental problems brought about by the construction of highways in the past, improved the environmental quality and greening effect around the line, and brought people a different natural atmosphere.

The Nanjing-Hangzhou Expressway is located in the middle and lower reaches of the Yangtze River and belongs to the subtropical seasonal climate. The annual rainfall is relatively large, mainly concentrated in the summer. The Nanjing-Hangzhou Expressway passes through the Li shui section of the Jiangsu border, the Xiang yang section and Yixing County. The roads on these three routes have experienced more complicated topography.

The topography of the Lishui section is generally high in the east, low in the west, low in the mountains, and in the hills. The landscape in the Fu yang section is relatively low, the surface water system is developed, the rivers and ponds are interlaced, and there is a distribution pattern of the water network in the south of the Yangtze River. In Yixing County, there are many kinds of surface vegetation. A variety of species, rich and varied species, topographical fluctuations, distribution of plains, valleys.

There are different types of trees along the expressway, such as herbs and shrubs, and areas with lush vegetation. After excavation, other herbaceous plants have been grown. In areas where vegetation is weak, after excavation, the slopes are there is no regenerative vegetation [21].

5.2 Comprehensiveness Evaluation of Green Construction

5.2.1 Green Construction Comprehensiveness Evaluation Index System

In the green construction of mountainous highways, the main factors affecting green construction are divided into three categories. Evaluation Index System is shown by Table 2, including green construction environmental impact, energy and resource conservation and utilization, and construction technology management. Among them, the grading factors of green construction environment impact are: noise pollution control, water pollution, dust pollution, light pollution; energy and resource conservation and utilization index factors are: water resource utilization, land resource use, material use. The grading factors of construction technology management are as follows: construction site management technology, environmental management mechanism, and safety and health management. A total of 10 index indicators constitute a green construction evaluation index system. In this case, fuzzy Comprehensiveness evaluation and neural network method were used to evaluate and analyze.

That is, an indicator set is obtained. V = {v1, v2, v3, v4, v5, v6, v7, v8, v9, v10}.

In order to reflect the importance level of different indicators, corresponding weight values are assigned to different indicators V. The membership matrix was determined according to expert opinions, and the index weight was calculated by using the fuzzy comprehensive evaluation method. The weight of each index was shown in Table 3, and the final score of these indexes was obtained through the fuzzy comprehensive evaluation method [22], and finally the Comprehensiveness construction factors of mountainous highway construction, with the weight of the green construction environment, the energy and resources conservation, construction technology management, the three aspects of their respective weights [23].Calculating the results of all aspects of construction evaluation scores and combining all the indicators to finally obtain the evaluation results, the results are divided into excellent, good, general, poor, and poor grades. The weight ratio of each indicator is shown by Table 3.

Using the fuzzy Comprehensiveness evaluation method for evaluation, the following are the steps of the fuzzy Comprehensiveness evaluation:

Table 2 Evaluation index system table

Taking the Nanjing-Hangzhou Expressway as the evaluation object, 10 indicators were selected as reference factors	
v1: Noise pollution control	v2: Water pollution
v3: Dust pollution	v4: light pollution
v5: Utilization of water resources	v6: Use of land resources
v7: Use of materials	v8: Construction site management
v9: Environmental management mechanism	v10: Safety and health management

Table 3 Weights of indicators

Level 1 indicators and weights	Level 2 indicators and weights
Green construction environment impact (0.3)	Noise pollution control (0.25) Water pollution (0.25) Dust pollution (0.25) Light pollution (0.25)
Energy and resource conservation (0.45)	Utilization of water resources (1/3) Use of land resources (1/3) Use of materials (1/3)
Construction Technology Management (0.25)	Construction site management (1/3) Environmental Management Mechanism (1/3) Safety and health management (1/3)

(1) Determine the set of evaluation levels. U = {u1, u2, u3,… un} (where n is the number of levels), the green construction is divided into five levels: excellent, good, average, poor, and worst [23].

(2) Determine the membership matrix relationship. If there are n evaluation factors and there are m evaluation grades, the evaluation result can be: r_{ij} (i = 1, 2, 3 … n; j = 1, 2, 3 … m), The consultation expert is set to t, and the result of the evaluation object i for the expert x is … (x = 1, 2, 3 … a). That is, the membership matrix is:

$$r_{ij} = \sum_{x=1}^{a} p_{ij}^{x} \text{ (i = 1, 2, 3...n; j = 1, 2, 3...m)} \tag{4}$$

Among them, the evaluation result is indicated; a indicates the number of consulting experts; n indicates the number of evaluation objects; and m indicates the evaluation level.

Therefore, the matrix of the judgment level is:

$$\mathrm{R} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \dots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix} \tag{5}$$

(3) Conduct multi-level Comprehensiveness evaluation. The first-level fuzzy Comprehensiveness evaluation can only obtain low-level evaluation results. At this time, it is necessary to carry out the second-level fuzzy Comprehensiveness evaluation. Therefore, the single-layer evaluation of the first layer, the matrix Ri is:

$$\mathrm{R_i} = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_n \end{bmatrix} = \begin{bmatrix} A_1 R_1 \\ A_2 R_2 \\ \vdots \\ A_n R_n \end{bmatrix} \tag{6}$$

Then the first-level fuzzy Comprehensiveness evaluation level B of the second-level Comprehensiveness fuzzy evaluation is:

$$\mathrm{B} = \mathrm{AR_i} = \mathrm{A} \begin{bmatrix} \mathrm{A_1R_1} \\ \mathrm{A_2R_2} \\ \vdots \\ \mathrm{A}_n R_n \end{bmatrix} \tag{7}$$

Through multi-level fuzzy evaluation, and from the weight of green construction environment, energy and resource conservation and construction technology management, the construction evaluation results can be calculated, and the indicators at all levels are integrated according to the maximum degree of membership. The final green construction evaluation result of the Nanjing-Hangzhou Expressway can be obtained as "good".

5.2.2 Evaluation and Analysis of SOFM Neural Network

Using Matlab7.0 neural network tool SOFM neural network model, three different sample points were randomly collected in the construction section of the project for training verification. There are 300 sampling points, 600 sampling points and 1000 sampling points respectively, and 10 green construction evaluation grading factors of the sample points are input into the network. And the number of input layers is the number of grading index factors, and the output is. The number of neurons in the layer is the result, and the results are divided into several categories. The following learning methods were used to test the constructed SOFM neural network. The green construction evaluation scores were obtained through continuous training. The output results were divided into five grades: excellent, good, average, poor, and poor. The construction of the improved SOFM neural network and the running of the program are as follows (Table 4):

The above evaluation index is used as the input factor of SOFM neural network. Based on the classification scheme, the green construction evaluation is divided into 5 levels. The neurons in the network competition layer are defined as 5 × 1, and the initial network learning rate is 0.8. And the maximum number of iterations for 1000, the green evaluation index of the sample is input into the SOFM neural network. All above learning algorithm is used for continuous training to obtain the clustering

Table 4 How the SOFM neural network operates

The construction of SOFM neural network and the way the program runs	
P = H P = P′ Q = minmax (P) Net = newc (Q, 5, 0.8) Net = init(net) Net.trainparam.epochs = 300 et = train(net,p) A = sim(net,p) Ac = vec2ind(a) Y = Ac'	100% read input data that has been unified on the network 100% input data conversion 100% reading of the maximum value of p 100% neural network construction (5 is the fractional number, 0.8 is the rate) 100% initialization 100% set training data 100% network training 100% network simulation 100% conversion of data 100% percent reversal

result, and finally the output result is obtained. The results are shown in the following Tables 5, 6 and 7.

From the above Tables 5, 6 and 7, it can be seen that in the trained samples, the clustering results show that the percentage of the sample with a Comprehensiveness level of "good" is higher than that of the sample. And as the sample points increase, the evaluation of the clustering results tends to be "good". The result of the grade is more obvious, from 63 to 82% to 94.3%, which is consistent with the results obtained by the fuzzy Comprehensiveness evaluation method, and the clustering results are satisfactory.

Table 5 Comprehensiveness evaluation level table of 300 sampling points

Number of samples	Proportion (%)	Comprehensiveness level	Sample distance (km)
45	15	Excellent	1
189	63	Good	1
39	13	General	1
12	4	Poor	1
15	5	Worse	1

Table 6 Comprehensiveness evaluation level table of 600 sampling points

Number of samples	Proportion (%)	Comprehensiveness level	Sample distance (km)
42	7	Excellent	1
492	82	Good	1
30	5	General	1
24	4	Poor	1
12	2	Worse	1

Table7 Comprehensiveness evaluation level table of 1000 sampling points

Number of samples	Proportion (%)	Comprehensiveness level	Sample distance (km)
16	1.6	Excellent	1
943	94.3	Good	1
19	1.9	General	1
12	1.2	Poor	1
10	1	Worse	1

5.3 Discussion

Since the randomly selected test points are continuously trained, the judgment results are consistent with the level of the fuzzy Comprehensiveness evaluation method, thus verifying the feasibility of applying the SOFM neural network to the green construction evaluation of mountain highways. According to the SOFM neural network method, the green construction evaluation of the Nanjing-Hangzhou Expressway project generally conforms to the "good" rating.

The evaluation results of the two evaluation methods are consistent, but the SOFM neural network has good performance and has a stronger generalization ability, which can explain the green construction evaluation results more accurately and more specifically. With the increase of learning samples, the evaluation will tend to be more accurate and accurate. As the number of training samples increases, the prediction increase accuracy and the computational workload is greatly reduced. Therefore, it is effective and feasible to evaluate the green construction using the SOFM neural network.

6 Conclusion

Considering that environmental pollution during construction stages of mountainous highway are gaining interest from the industry, this study explored and quantified the green construction evaluation of mountainous highways. By conducting the activity characteristics and measures of green construction for mountainous highways, the SOFM neural network method was used to evaluate the green construction of the mountainous highway in the construction stage.

First, considering the impact of the construction of the mountain highway project on the surrounding ecological environment, combined with the concept and characteristics of the green construction of the mountainous highway, a green construction index evaluation system for the mountainous highway is established. Second, the evaluation model of mountain highway construction was established by using the SOFM neural network evaluation method. Finally, the model was used to evaluate the Nanjing-Hangzhou Expressway, and the evaluation results were compared with the fuzzy Comprehensiveness evaluation results. The results show that the evaluation model constructed in this paper is feasible and effective, which provides an effective tool for objectively evaluating the green construction level of expressway and also meets the requirements of the state to speed up the construction of resource-saving and environment-friendly highways.

Although the objectives of this study were achieved, some limitations were still present. Because of the limited scope of the survey and the limited data, and the different attention of the respondent to the questionnaire, the quality of the questionnaire will be affected to some extent. Nonetheless, the findings from this study are still valuable and contribute to the body of knowledge, as they are the first study to draws out the green construction evaluation of mountainous highways in the construction stage based on the SOFM neural network method. Furthermore, the findings of this study can provide a theoretical basis for enterprises to improve construction management and promote green construction technology. Additionally, the results can be used for pollution reduction policies and regulations for construction environment protect by governments and enterprises, ultimately helping them to achieve a better implementation of this method in the future. For future research, the model built in this paper should be fully investigated. In addition, the verification and revision of the model makes the evaluation results more realistic.

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Innovation Input–Output Decoupling and Efficiency in Urbanized Area: Evidence from 153 Counties in the Yangtze River Delta, China

Zihan Cui, Guijun Li, and Yulong Li

Abstract Innovation input and output and their relations in urbanized area plays an essential role in the improvement of national innovation capability. This paper explores the comprehensive level, decoupling type and relative efficiency of counties' innovation input–output (I-O) of 153 counties (county-level cities) in the Yangtze River Delta, where has achieved the highest level of urbanization in China. The results show that: (1) The comprehensive level of counties' innovation I-O presents a "pyramid" structure, which means few counties are at a high level while the majority counties stand in a low level. With regard to three provinces, Jiangsu is higher than Zhejiang than Anhui. (2) Over 80% of counties hold significant decoupling, in which nearly 40% belong to the negative decoupling type. They mainly distributed in Jiangsu, northern Zhejiang and northwestern Anhui, which the intensity of innovation output is relatively lower than the scale of input. (3) Around 20% of the counties' innovation I-O are SBM efficiency with positive decoupling areas show higher innovation efficiency.

Keywords Urbanization · Innovation · Decoupling · Efficiency

1 Introduction

Urbanization is one of the most important processes which has great impacts on human society and is closely related to regional modernization and economic growth. As the world largest developing country, China's urbanization has made remarkable achievements. From 1978 to 2019, the urbanization rate in China has increased from less than 20 to 60.6%, with an average annual growth by one percentage point. Compared with the average urbanization rate of 80% in developed countries, there is still a huge potential for the urban expansion in China.

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Currently, as the Chinese economy gradually shift to high-quality development stage, urbanization is not merely industrial expansion, but also affected by resource availability and environmental constraints. Under this circumstance, innovation have become the key driving force in reshaping our cities and accelerating the transition of urbanization from production factors-driven to technology innovation-driven [1]. This new type of pattern requires the cooperation between local governments and technical enterprises to increase the spatial effects of urban scale and aggregation. As the main driving force of innovation, technical enterprises can expand market scale, increase capital accumulation, create jobs and promote tertiary industry by integrating raw material resources, thereby improving the quality of urbanization. Meanwhile, Chinese government has recently issued many policies to promote enterprise innovation ability and regional integration development. Due to the differences in spatial distribution, industrial structure and innovation policy arrangement, the innovation output capabilities of enterprises may be varied greatly. Therefore, it is of great importance to explore the correlation among different kinds of innovation input and output across regions and identify their potential imbalance and spatial association.

The enterprises innovation has getting increasingly concerned among international scholars and research institutions. Yasmeen et al. took 30 Chinese provinces as example and pointed out the government should increase the investment in R&D and guide enterprises to expand financing channels for technological innovation [2]. Jin et al. found that the governance efficiency of the government where the enterprise is located determines the supply of innovation resources to corporate R&D activities [3]. Genin et al. investigated the restructuration conducted by state governance may limited the innovative performance of state-owned enterprises in emerging economies [4]. Monroe and Zook examined the effect of macro-institutional factors including form of government, economy type, cultural factors and model of civil society on the innovation ability of social enterprise [5]. Liang et al. emphasized the Open Government Data platform will expand scope of enterprise's application data and significantly affect the enterprise's innovation performance [6]. There are also some scholars study at county level. Li, L and Jin, T examined the impact of small and medium-sized enterprise cluster on the county-regional economic development and found the regional economic development with interaction effects of clustering [7]. Xiao Fan et al. found innovation and knowledge creation environments are critical positive factors in the location of high-tech enterprises at the provincial level through the spatiotemporal evolution of high-tech enterprise locations at county level [8]. Qu, L and Zhang, W suggested government should adopt different policies such as environmental technology innovation guidance and financing support for enterprises of different sizes based on a study county industrial enterprise [9].

It can be concluded that previous studies mainly focused on the enterprise innovation affected by government behavior, while ignoring the innovation activities conducted by enterprise itself. In addition, the county-level cities are the main component of urbanization, and they are also the basic unit for innovation governance. However, there are some limitations in existing county-level innovation research: (1) Most literature chooses county units within a single province, ignoring cross-regional innovation linkages. (2) The selection of innovation index mainly focuses on innovation output, especially the number of patents granted. The diversity and heterogeneity of index is poor. (3) The internal relationship between innovation input and output is separated. Although some scholars use DEA model to measure the input–output efficiency, the traditional DEA model cannot find the inefficient reason of it.

As the typical area with the highest urbanization rate in China, the Yangtze River Delta is an important intersection between the "Belt and Road" and the "21st-Century Maritime Silk Road". In 2019, its urbanization rate has reached 65.47% (Jiangsu province 70.61%, Zhejiang province 70.00%, Anhui province 55.81%) and well above the national average. The Yangtze River Delta also has an early start and rapid development of county economy, especially the county enterprises in this area have outstanding innovation capabilities and form a high degree of innovation resources concentration. At the same time, due to different levels of internal development in the Yangtze River Delta, there is a significant gap between counties. This phenomenon restricts the improvement of regional innovation service and the integration process of the Yangtze River Delta.

Based on the above, this paper takes 153 county units in the Yangtze River Delta as the analysis object, firstly uses Projection Pursuit (PP) to measure the comprehensive level of innovation input and output respectively. Then, the Expanded Decoupling Index is used to calculate the asymmetry degree between input and output, exploring whether and to what extent there is spatial imbalance in county innovation. Super SBM model is further introduced to identify and quantify the causes of decoupling and inefficiency. Based on the research results, this paper puts forward some suggestions for optimizing regional innovation input management, as well as policy arrangements for improving innovation governance in urbanized area.

2 Research Design

2.1 Projection Pursuit Model

The county-level innovation input and output index have multi-dimensional characteristics. Through dimension reduction, the comprehensive level can be obtained to measure the relationship between input and output. Projection Pursuit (PP), proposed by Kruskal, has unique advantages in processing non-linear and non-normal high-dimensional data [10]. Compared with traditional entropy method and principal component analysis method, PP does not need to set the index weight in advance, and has the characteristics of objectivity, robustness and accuracy. This paper firstly uses PP to measure the comprehensive level of county innovation input and output respectively. The theory and algorithm of PP are detailed in the literature [11].

2.2 Decoupling Index

Based on the innovation comprehensive level, decoupling index is introduced to measure whether there is asymmetry or disengagement between innovation input and output in county regions. Decoupling index is first applied in the field of economic and environmental relations research by OECD. Later, Tapio decoupling index is further developed in practical application [12]. Tapio model, also known as Elastic analysis which takes elasticity value as the judgment basis of decoupling status. The equation is as follows:

$$e(A, B) = (\Delta A/A)/(\Delta B/B)$$

where A represents environmental pressure, B represents economic development, and e (A, B) represents the relative relationship between environmental pressure and economic development in a certain period of time.

The traditional decoupling index is used to measure the synchronization degree of two variables between the end stage and the base stage. In order to reflect the innovation difference among counties, this paper redefines the decoupling index on the basis of ensuring relativity. The expanded decoupling index focuses on different counties' comparison on the same point in time. The calculation formula is as follows:

$$e(I_i, O_i) = [(I_i - I_0)/I_0]/[(O_i - O_0)/O_0]$$

where I_i and O_i are the enterprise innovation input and output of each county respectively, I_0 and O_0 are the mean values of enterprise innovation input and output of the whole county in the Yangtze river delta. The results calculated by this model can be divided into three categories: ① the input is lower than its average input while the output is higher than its average output, this is the desirable outcome and is defined as decoupling; ② the input is higher than its average input while the output is lower than its average output, this is the undesirable outcome and is defined as negative decoupling; ③ the transition between decoupling and negative decoupling is defined as connection.

Under the three basic types of decoupling, connection and negative decoupling, this paper further classifies 8 decoupling types by taking 0, 0.8 and 1.2 as threshold. They are namely strong decoupling, relatively strong decoupling, weak decoupling; positive connection, negative connection; strong negative decoupling, relatively strong negative decoupling, weak negative decoupling [13]. The details of decoupling classification are shown in Fig. 1.

Decoupling Type	Subtypes	$(A-A_0)/A_0$	$(B-B_0)/B_0$	e(A,B)	Code
decoupling	strong decoupling	-	+	e<0	⑧
	relatively strong decoupling	+	+	0<e<0.8	⑦
	weak decoupling	-	-	e>1.2	⑥
connection	positive connection	+	+	0.8<e<1.2	⑤
	negative connection	-	-	0.8<e<1.2	④
negative decoupling	weak negative decoupling	+	+	e>1.2	③
	relatively strong negative decoupling	-	-	0<e<0.8	②
	strong negative decoupling	+	-	e<0	①

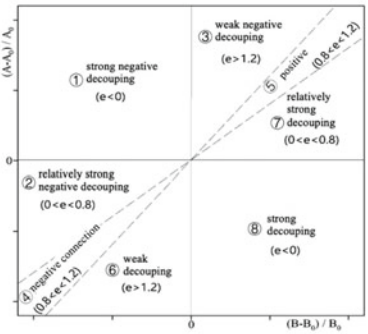

Fig. 1 Decoupling types and their classification basis

2.3 Super SBM Model

The decoupling type of innovation input and output can be used to judge the relative innovation performance of corresponding county regions. But it cannot reveal its distance to the best effective level and the quantity scale of input redundancy or output insufficiency. For this reason, this paper further adopts the non-radial and non-angular SBM (Slack Based Measure) model, which is proposed by Tone [14]. The advantage of SBM is that its input and output are dimensionless and the efficiency value decreases strictly monotonically with the change of the relaxation degree. Since SBM model still has multiple decision units of complete efficiency, Tone proposed the Super SBM model based on the modified relaxation variable, which solved the problem of evaluation and ordering of complete efficiency units. The detailed steps can be referred to references [15].

2.4 Index System

On the basis of referring to the previous research, this paper takes innovational enterprises as main evaluation object and constructs a multi-dimensional county innovation evaluation system. In addition, the input index takes into account the local science and technology expenditure, the output index takes into account the environmental benefits. Specific indicators and descriptions are shown in Table 1.

2.5 Data Source

The data used in this paper are from the *national monitoring report on innovation capacity of counties and cities* issued by the Ministry of Science and Technology

Table 1 The county-level innovation index system

Dimension layer	Index layer	Code	Mean value	Standard deviation
Input index	Governmental technology expenditure	I_1	1.91	2.53
	Enterprise R&D institutions	I_2	141.79	172.86
	Enterprise R&D expenditure	I_3	11.02	14.18
	Enterprise R&D employees	I_4	1.85	1.61
Output index	New product sales revenue	O_1	193.64	363.60
	High-tech enterprises income	O_2	211.04	446.68
	Enterprise patent applications	O_3	474.01	638.41
	Energy consumption per 10,000-yuan GDP	O_4	0.47	0.30

of China in 2018. It covers county statistical yearbook and reported data from local science and technology, taxation and other departments. This paper selects three provinces including Jiangsu, Zhejiang and Anhui as research object, a total of 153 county-level samples. Jiangsu, Zhejiang and Anhui have 41, 52 and 60 counties respectively.

3 Results

3.1 The Comprehensive Level of Innovation Input and Output

Projection Pursuit is first used to calculate the comprehensive level of innovation input and output in 153 counties in the Yangtze River Delta. The comprehensive level is arranged in descending order by province, as shown in Fig. 2.

Due to a few "extreme values" that increases the length of the vertical axis, most counties in the Yangtze River Delta are shown at low comprehensive level. The most prominent one is Kunshan, Jiangsu, where the innovation input and output levels reach 1.83 and 1.39 respectively. Whereas the overall average level of the Yangtze River Delta is only 0.25 and 0.15. In addition, the innovation input levels of Jiangyin, Changshu and Cixi in Jiangsu also exceed 1, reflecting that parts of southern Jiangsu and eastern Zhejiang have abundant high-tech capital and human resources. For example, Kunshan is home to a large number of foreign-funded scientific and technological enterprises, ranking first among the top 100 counties in China for many

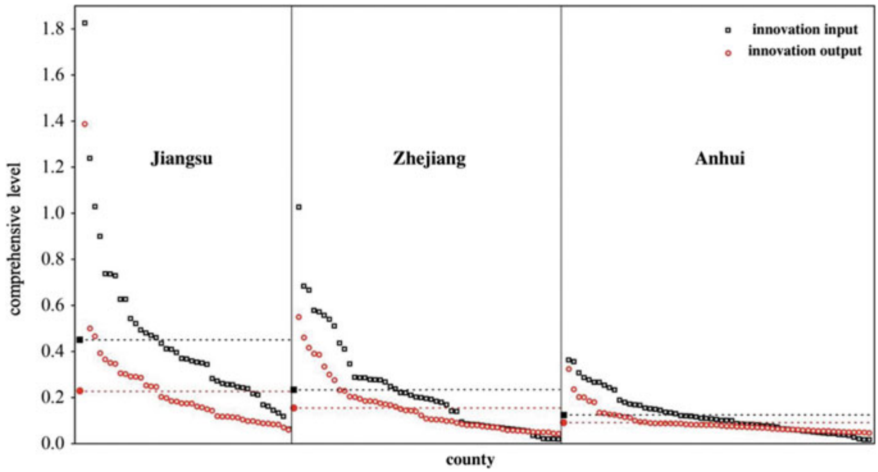

Fig. 2 The distribution of innovation input and output levels in 153 counties in the Yangtze River Delta

years. The township enterprises in Jiangyin and Changshu have been developing well and leading the transformation of manufacturing industry through technological innovation in recent years. Cixi is one of the most developed counties in Zhejiang, leading in the field of home appliance manufacturing.

Furthermore, this paper uses 0.2 as an interval to divide the comprehensive level (Table 2). It can be found that the number of high-level counties is relatively small except for a few scattered points exceeding 1. As the innovation comprehensive level declines, the number of county units gradually increases, showing a "pyramid" type of unbalanced structure. It means innovation activities mainly occur in a small number of county regions, and the share of innovation output in most counties is low. Moreover, such local innovation has a self-reinforcing trend. Counties with higher innovation output maintain a first-mover advantage due to cumulative causality.

From the perspective of overall province, the county innovation level in Jiangsu is higher than Zhejiang than Anhui. Among them, the average innovation input level in Jiangsu is 0.45, which is 1.93 and 3.65 times as much as Zhejiang and Anhui; the average innovation output level is 0.23, which is 1.48 and 2.5 times as much as Zhejiang and Anhui. This shows that there are significant regional differences in the innovation development of counties in the Yangtze River Delta, and the innovation gap between three provinces is large. The similarities include the county innovation

Table 2 The interval quantity distribution of county innovation input and output level in Yangtze River Delta

Interval	> 1	(0.8–1]	(0.6–0.8]	(0.4–0.6]	(0.2–0.4]	(0–0.2]
Innovation input level	4	1	7	17	42	82
Innovation output level	1	0	0	5	28	119

input level in the three provinces is higher than output. Jiangsu is the most obvious, Zhejiang, Anhui gradually reduces. Within each province, only one county in Jiangsu shows innovation output higher than input, while 15 in Zhejiang and 21 in Anhui respectively. The spatial imbalance between innovation input and output is prominent as well. Specifically, the calculation results show that the lower the level of counties, the more their innovation output tends to be greater than their innovation input. It indicates that for the backward areas of innovation development, input from finance and enterprises often has scale effect and is easier to obtain relatively high marginal output.

3.2 *The Spatial Distribution of Decoupling Index*

Considering the asymmetry and imbalance between innovation input and output in counties in the Yangtze River Delta, it is necessary to further discuss the specific disengagement degree of innovation output corresponding to input. Figure 3 shows the decoupling type distribution in the three provinces of the Yangtze River Delta.

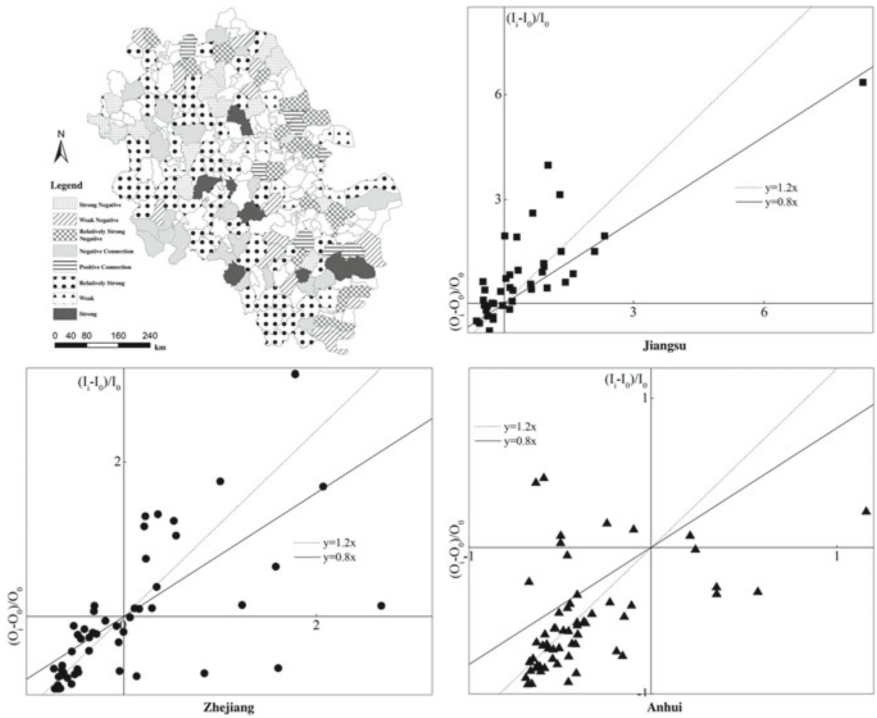

Fig. 3 The decoupling of innovation input–output in 153 counties in the Yangtze River Delta

There are 48 negative decoupling counties (①, ②, ③), which represent relatively poor innovation performance, accounting for 31.4% of the total. They are generally distributed in Jiangsu, northern Zhejiang and northwestern Anhui. Among them, 15 counties are strong negative decoupling type (①), indicating that the innovation input is higher while the output is lower than the regional average. They are concentrated in Taizhou-Yangzhou-Huaian-Suqian line in Jiangsu, as well as Hefei and Fuyang in Anhui. In these places, the absolute scale of input is quite limited, and there may be insufficient output due to weak efficiency transformation capabilities. 14 and 19 counties have relatively strong negative decoupling type (②) and weak negative decoupling type (③). The former indicates that the input and output are both below the average level but the output is relatively lower, while the latter means that the innovation input and output are both above the average level but the input is relatively higher. Weak negative decoupling regions are scattered in central Zhejiang and northern Jiangsu. These regions have fewer technology-based companies and belong to local blind areas of innovation, and they need to coordinate innovation resources from a macro perspective in the future. The negative decoupling of expansion is the opposite. Most of them are located in southern Jiangsu and northern Zhejiang around Shanghai. Although the governmental finances and enterprise resources have invested heavily in innovation, the excessive input does not lead to a synchronous increase in output but a phenomenon of input redundancy. In the future, these regions need to pay attention to optimizing the investment structure.

Seventy-five counties belong to decoupling type (⑥, ⑦, ⑧), accounting for 49% of the total. They are mainly in western Zhejiang and most of Anhui, which have relatively good performance in innovation. Among them, 51 counties show weak decoupling type (⑥), whose input and output are both below the average level but the input is relatively lower. Although governments and enterprises in these regions lack R&D resources, limited innovation investment brings higher production efficiency. The representative areas include Suzhou, Bengbu, Liuan, Chuzhou and Wanjiang in Anhui, Lishui and surrounding counties in Zhejiang. 14 counties are relatively strong decoupling type (⑦), with both innovation input and output above the average level but relatively lower input. They are mainly distributed in Nantong and Zhenjiang in Jiangsu, Huzhou and Jiaxing in Zhejiang. These places are close to the central cities of the Yangtze River Delta and are vulnerable to the impact of innovation industry radiation and technology spillover. 10 counties are strong decoupling type (⑧). The input of enterprise innovation is lower but the output is higher than the regional average. They are the most ideal type of innovation, including Taizhou and Jinhua in Zhejiang, Wuhu in Anhui. For positively decoupled regions, due to the increasing returns to scale, it is still possible to appropriately increase the innovative elements input in the future.

There are 30 counties located in the connection decoupling area (④, ⑤), accounting for 19.6% of the total. The innovation efficiency of these regions is at the ordinary level, that is, there is little difference between counties and the average level of regions. Among them, 22 counties are negative connection type (④). Both input and output of counties are lower than the average level at the same time. It is mainly distributed in the underdeveloped areas such as Huainan, Anqing in Anhui and central

Zhejiang. In addition, there are 8 positive connection type regions (⑤), Jiangsu and Zhejiang account for 5 and 3 respectively. All these connection regions may face constant rewards to scale and need to pay more attention to structural adjustment and release new driving forces.

To sum up, the local innovation input is largely determined by the level of county economic and social development. Especially the coastal and riverside counties which located in the center of the Yangtze River Delta have good innovational environment and input conditions. On the other hand, large-scale innovation input does not necessarily bring high innovation output. Some counties with low investment can achieve relatively high output. This indicates that there is a certain degree of asymmetry or disengagement between county innovation input and output within the Yangtze River Delta. The horizontal comparison of the decoupling index further confirms that more than 80% of the counties show obvious decoupling phenomenon. Nearly 40% of them are negative decoupling type, that is, the intensity of innovation output is relatively lower than the intensity of input. In other words, these regions have relatively serious input redundancy or output insufficiency.

3.3 Innovation Input–Output Efficiency Analysis

According to the decoupling result analysis, this paper further adopts the Super SBM model to quantify the input–output inefficiencies of counties in the Yangtze River Delta. The typical counties with SBM effective (Table 3) and input-redundancy and output-insufficiency in SBM non-effective areas (Table 4) are calculated.

According to Table 3, 31 counties in the Yangtze River Delta reach SBM effectiveness, accounting for 20.3% of the total. In terms of provinces, Jiangsu, Zhejiang and Anhui have 4, 10 and 17 counties as effective units, accounting for 9.8%, 19.2% and 28.3% respectively. It indicates the counties with smaller scale of innovation input and output have higher efficiency. At the same time, higher input–output efficiency area is more likely to show positive decoupling, which means to obtain relatively more innovation output with relatively less innovation input. The analysis of variance is performed on the two groups of county units that reach the SBM effectiveness,

Table 3 Counties with SBM effective input–output in Yangtze River Delta

Province	County (Efficiency)
Jiangsu	Lianshui (2.53), Kunshan (1.31), Pizhou (1), Donghai (1)
Zhejiang	Tiantai (1.39), Lanxi (1.12), Linhai (1.03), Sanmen (1.02), Chunan (1), Taishun (1), Kaihua (1), Qingtian (1), Songyang (1), Yunhe (1)
Anhui	Guzhen (1.51), Wuhe (1.36), Laian (1.27), TIanchang (1.21), Wuhu (1.09), Feixi (1.09), Fengyang (1.06), Yuexi (1.02), Taihe (1.01), Hanshan (1), Taihu (1), Xixian (1), Yingshang (1), Dangshan (1), Xiaoxian (1), Sixian (1), Shengde (1)

Table 4 Top 10 counties with input redundancy or output insufficiency in Yangtze River Delta

Input redundancy rate (%)								Output insufficiency rate (%)							
I_1		I_2		I_3		I_4		O_1		O_2		O_3		O_4	
Tongcheng ▲	58	Jurong ■	65	Susong ▲	56	Jurong ■	58	Changshan ●	40	Yixian ▲	40	Wuyi ●	37	Changxing ●	34
Huaiyuan ▲	55	Tongcheng ▲	54	Jurong ■	51	Changfeng ▲	49	Shengsi ●	40	Suichang ●	40	Jiande ●	37	Taicang ■	34
Huaining ▲	44	Huaining ▲	50	Huaining ▲	50	Huoqiu ▲	47	Linquan ▲	39	Jingxing ●	40	Xiangshui ■	36	Zhangjiagang ■	33
Shucheng ▲	35	Jinhu ■	43	Huoqiu ▲	48	Jinhu ■	37	Dingyuan ▲	31	Cixi ●	38	Tonglu ●	36	Zhuji ●	31
Jinzhai ▲	33	Jinzhai ▲	42	Fengtai ▲	32	Fengtai ▲	32	Guanyun ■	28	Xiangshan ●	36	Daishan ●	34	Liyang ■	31
Mengcheng ▲	31	Mengcheng ▲	33	Chaohu ▲	30	Danyang ■	28	Liubi ▲	22	Pujiang ●	36	Dongyang ●	33	Jieshou ▲	30
Xuyi ■	25	Huaiyuan ▲	29	Changfeng ▲	29	Gaoyou ■	26	Shitai ▲	20	Yuhuan ●	35	Ruia ●	33	Rudong ■	30
Langxi ▲	25	Gaoyou ■	29	Wuwei ▲	28	Qidong ■	19	Xinyi ■	11	Pingyang ●	34	Cangnan ●	33	Rugao ■	30
Gaoyou ■	23	Suining ■	27	Jinzhai ▲	26	Hexian ▲	19	Xiuning ▲	10	Wenling ●	33	Baoying ■	33	Dangtu ▲	29
Susong ▲	21	Xuyi ■	25	Xiuning ▲	25	Xinghua ■	17	Funan ▲	9	Yiwu ●	32	Qianshan ▲	32	Haian ■	28

■ represents Jiangsu province, ● represents Zhejiang province, ▲ represents Anhui province and it is found that they have significant differences in different decoupling types ($P = 0.048$).

In addition to focusing on county units that achieve innovation efficiency, counties in the non-effective state of SBM also need to be emphasized. It is related to how to optimize input arrangement and improve output target at the policy level in the future. Table 4 presents the top 10 counties with redundant input or insufficient output for each index. In terms of innovation input index, Jiangsu and Anhui have obvious input redundancy. Anhui has a high redundancy rate in governmental technology expenditure (I_1) and enterprise R&D expenditure (I_3). Some counties in Jiangsu have redundancies in enterprise R&D institutions (I_2) and enterprise R&D employees (I_4). Previous studies also believed that the reason may be the lack of scale and efficiency. For example, Jurong, Jinhu and Gaoyou all have about 200 enterprise R&D institutions and equipped with corresponding R&D teams, but their output benefits are not obvious for the time being. In terms of innovation output index, the calculation results show that Zhejiang still has relatively large output insufficiency in high-tech enterprises income (O_2) and enterprise patent applications (O_3). The main reason may be that Zhejiang is dominated by private processing and foreign trade enterprises, which is relatively weak in advanced technology and patent invention. It is necessary to adjust the input proportion according to the input redundancy rate, or to focus on increasing the output scale of corresponding indicators for the lack of output.

4 Conclusions and Discussions

In the process of regional urbanization and innovation governance, the allocation of innovation resources at county level has often been ignored. However, county level enterprise innovation is greatly associated with the sustainable development of high urbanized areas. In this context, more attention should be paid on the coordination between different stakeholders involved in the innovation governance and the synergies of cross-sectional and cross-regional innovation management. As one of the most urbanized area in China, the county innovation ability of Yangtze River Delta is related to the high-quality growth of regional economy. In the integration process of Yangtze River Delta, different provinces and counties face different geographical location, industrial structure and innovation policy environment. The innovation output brought by the same scale or intensity input also has great differences. In order to solve the asymmetric and unbalanced problems, it is of practical significance to explore the comprehensive level of innovation input and output and the relative disengagement between them. Furthermore, in-depth exploration of innovation efficiency and possible improvement space can help to optimize the direction of future county innovation input and output targets. In view of this, this paper first constructs a multi-dimensional county innovation index system, measures the innovation input and output levels of 153 counties in the Yangtze River Delta, and judges the decoupling types of innovation input and output in each county by expanding the traditional decoupling index. Considering that most counties have significant decoupling, the innovation efficiency is analyzed by Super SBM model, and the degree of input redundancy and output insufficiency in inefficient areas is calculated.

Through the analysis of the full text, the following conclusions can be drawn: ① The county innovation level of three provinces in the Yangtze River Delta shows a "pyramid" type of unbalanced structure. Jiangsu is significantly higher than Zhejiang, and Zhejiang is significantly higher than Anhui. The innovation input level in most counties is higher than the output level. As the innovation level gradually declines, the innovation output level tends to be greater than input. ② There is a relatively obvious asymmetric separation between innovation input and output in the counties of the Yangtze River Delta. More than 80% of the counties show significant decoupling. The negative decoupling regions are mainly distributed in Jiangsu, northern Zhejiang and northwest Anhui, while the decoupling regions are mostly located in western Zhejiang and most of Anhui, reflecting that underdeveloped regions tend to have better innovation performance. ③ Thirty-one counties reach SBM effective. Jiangsu, Zhejiang and Anhui provinces accounted for 4, 10 and 17 counties respectively. The smaller the scale of innovation input and output, the higher the efficiency of counties is, and the more likely they are to show decoupling states. ④ The inefficiency of county innovation in Jiangsu and Anhui provinces is prominently manifested in high input redundancy, while Zhejiang is due to the insufficiency of output.

According to the analysis results, this paper puts forward the following suggestions: ① Coordinate and allocate innovation resources from the Yangtze River Delta region and the provincial level. Pay attention to increase innovation resources in relatively backward counties and strive to improve their output level. Gradually narrow the overall innovation and development gap in counties and lay the foundation for an integrated and coordinated pattern of county development. ② Enhance the benefit transformation ability and efficiency of county innovation elements. Especially for "negative decoupling" or "non-efficiency" counties, the scale of innovation input should be adjusted and the structure of innovation output should be optimized according to local conditions, so as to reduce the input redundancy or output insufficiency to the greatest extent. ③ Focus on creating a number of innovation-driven development benchmarks at county level with outstanding innovation capabilities and strong radiation leadership. Then form a number of high-tech development cluster or innovation community through radiating and driving the surrounding counties. ④ Break down administrative barriers, accelerate the free and ordered flow of technology, talent, capital, information and other factors among counties. Build an open, inclusive and mutually reinforcing pattern of innovative development.

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Construction of an Engineering Construction Quality Traceability System Based on the Internet of Things and Block-chain

Tao Li, Xiaoli Yan, and Yingping Wu

Abstract Due to the urgent problems in the quality traceability of engineering construction, in this paper, we analyze the compatibility between the Internet of things technology, the Block-chain technology and engineering construction quality traceability requirements, and put forward the idea of constructing the whole process quality traceability system framework based on the Internet of things and Block-chain technology, design the overall system architecture, traceability process and query mechanism. Then, he effectiveness and usability of the system are evaluated by relevant professionals. Finally, the advantages of the system are analyzed by comparing with the traditional engineering management mode. The construction of engineering construction quality traceability system based on Internet of things and Block-chain technology can provide solutions for solving the whole process quality quality problem traceability, promote the solution of internal trust and supervision problems in engineering construction industry, and the innovation and development of engineering field.

Keywords Engineering construction · Quality · Internet of things · Block-chain · Traceability

1 Introduction

Engineering quality problems run through the whole life cycle of a construction project. Problems in any link will affect the project quality and even lead to serious engineering accidents [1]. In addition, there are problems in engineering quality management, for example, the project quality prevention is not rigorous in advance, the control is not in place, and the accountability is not accurate after the event [2, 3]. However, the old and extensive quality management mode is still used in the construction industry. The quality traceability relies on manual investigation [4], and

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quality control relies on the project quality responsibility system [5]. Quality control is very difficult at present. Therefore, it is urgent to change the current inefficient way of quality management and traceability, and establish a system that can truly find and trace quality problems, so as to realize the whole process quality management.

At present, a series of new technologies have penetrated into the construction field, subverting the inherent mode of the construction industry. Among them, the Internet of Things technology is an important part of the new generation of information technology, which is mainly manifested in comprehensive perception, reliable transmission and intelligent processing [6]. According to the characteristics of the Internet of things, some scholars proposed to embed it into the construction quality management, such as developing the engineering quality information collection system [7] to ensure the objective and true source of engineering information, constructing the construction site quality monitoring management system [8–10] and residential engineering quality life-cycle monitoring system [11] for real-time management, and using the Internet of things technology to trace the materials in the project [12].The information is objective and reliable, and the application of Internet of things technology improves the quality monitoring level and quality management effect of each link of project construction.

As a new distributed ledger database technology, the Block-chain deeply integrates P2P network technology, asymmetric encryption technology, consensus mechanism, chain script and other technologies, and has great advantages in information data management and traceability. At present, there have been fruitful achievements in the research field on the traceability system based on Block-chain, mainly in food [13–15] and medical [16], but few in the field of engineering. Initially, Li Li et al. established project quality traceability through two-dimensional code [17, 18]. With technological progress, Yang and others proposed to build a management platform with block-chain as a technical means to collect information in the whole process of project construction and ensure the traceability of information [19]. Li et al. built a framework of quality management and traceability system for engineering construction with authentic and unalterable data by introducing block-chain technology [20], and Zhang et al. have built an integrated framework of quality traceability system for prefabricated buildings based on block-chain [21], which provide direction for quality management.

According to the existing researches, it is found that the current engineering construction quality management and traceability only focus on solving the single problem of information source authenticity or storage security, but cannot really achieve the requirements of quality management and traceability: block-chain technology makes data unforgeable, but cannot prevent false information from entering into the block-chain from the source; while the Internet of things can ensure that the engineering data enter the network objectively and truly, but the security of data cannot be easily guaranteed, so it needs the unforgeable encryption and storage capacity of block-chain technology. Therefore, it is necessary to explore the combination of the Internet of things and block-chain in the field of project quality management and traceability.

On the basis of the above research, this paper, from the perspective of the whole process management of the project, combines the block-chain with Internet of things to build a quality traceability system for engineering construction. Firstly, in this paper, we analyze the compatibility of IOT and block-chain technology and engineering quality traceability, design the overall architecture, traceability process and query mechanism of the traceability system. Secondly the effectiveness and usability of the system are evaluated by relevant professionals; and finally the advantages of the system are analyzed by comparing with the traditional engineering management mode. The construction of this system can ensure the authenticity, reliability and traceability of engineering information on the chain under the premise of ensuring the objective and effective source data, and truly realize the effective supervision of engineering quality, so as to provide solutions for solving the industry pain point of difficult traceability of construction project quality problems.

2 The Fit Analysis of the Application of the Internet of Things and the Block Chain Technology in the Quality Traceability of Engineering Construction

2.1 Internet of Things Technology

The Internet of things refers to a kind of network that connects any object with the Internet through the information sensing equipment according to the agreed agreement for information exchange and communication, so as to realize intelligent identification, positioning, tracking, monitoring and management [22]. Perception is the basis of the Internet of things [23]. Perception technology collects events and data in the objective world through a variety of technologies, such as sensors, frequency identification, global positioning system, laser scanner, etc., so as to realize the perception and recognition of information in the external world. Recognition technology is the basis of realizing comprehensive perception. Based on two-dimensional code and frequency identification, it further integrates various existing sensors and identification methods to identify objects, locations and geography. However, there are security problems in data storage and data transmission.

2.2 Block-Chain Technology

Block-chain is a kind of distributed decentralized account book that can't be tampered with by cryptography, and can safely store the data that has been verified in the system [24]. The key technologies of block-chain mainly include linked data structure, asymmetric encryption technology, consensus mechanism and smart contract [25].

1. Chained data structure: The block-chain stores data through data blocks and chain structures. Each data block includes block header and block body, and has a unique hash value corresponding to it. The current block is connected with the previous block by storing the hash value of the previous block to form a chain structure [26]. Block-chain can be divided into public block-chain, private block-chain and alliance block-chain. The system chooses "alliance block-chain" as the organizational form, and its consensus process is managed by several main nodes. This form can not only ensure the efficiency of organization operation, but also take into account the characteristics of system security and members' common maintenance.
2. P2P technology: Through the Internet for point-to-point data transmission, all nodes have the same status, and there is no central node and hierarchical structure which occupies the core position, and realizes complete decentralization.
3. Consensus mechanism: According to the rules negotiated in advance, distributed nodes determine the ownership method of block bookkeeping right, so that different nodes can reach a consensus on transaction data, and ensure the consistency and authenticity of distributed ledger data. At present, the consensus mechanism mainly includes proof of work (POW), Proof of Stake (POS), Delegated Proof of Stake (DPOS), etc. The system uses POS consensus mechanism. The access of members is established by the leading unit, and then join the block-chain as a member node after approval. The access mechanism can carry the audit and management of enterprise qualification, and maintain the fairness and competition between the main bodies.
4. The smart contract: A smart contract is recognized by many parties, runs on the block-chain, and can automatically process transactions according to preset conditions.

2.3 The Fit Analysis of the Application of the Internet of Things and the Block Chain Technology to the Quality Traceability of Engineering Construction

The whole process of project construction involves many links, as shown in Fig. 1. Only through the information connection among these links can the quality of engineering construction be traceable. Therefore, the establishment of engineering construction quality traceability system has the following characteristics and requirements:

1. The amount of engineering data is large. The quality management of the whole process of engineering construction includes all the information of the whole life cycle of the project, involving economy, management, technology, etc.; at the same time, a large number of users participate in the quality management and accumulate a large number of transaction data.

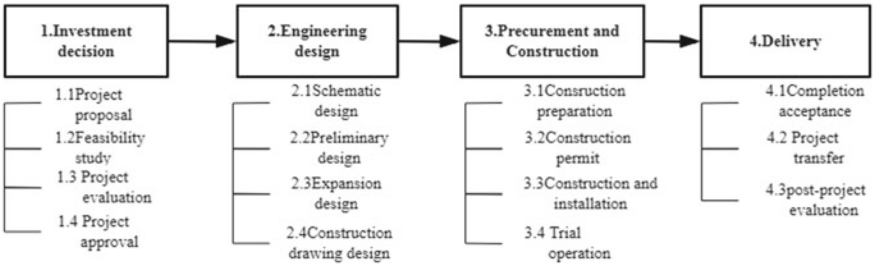

Fig. 1 Basic flowchart of project management

2. Information relevance management. The whole process quality management needs to analyze and manage the whole process construction information data, and ensure the clear relevance between the information.
3. An environment of trust where multiple parties participate. The construction process is carried out by multi parties, and multilateral information transmission can achieve information sharing. Good mechanisms are needed between participants to form a trustworthy cooperation environment.
4. An effective engineering construction quality traceability system has two prerequisites: ① Do a good job in the collection, storage and exchange of information throughout the entire process of engineering construction; ② Ensure that the information in the system cannot be forged or tampered with.

The combination of networking technology and block-chain technology can meet the above requirements for quality traceability of engineering construction:

The Internet of things connects the objective world with the Internet through a variety of information sensing devices to exchange information. Combined with the characteristics of the construction engineering, the comprehensive information collection, exchange, processing and analysis of the quality influencing factors in the whole process of the construction engineering are carried out through the information sensing equipment, so as to realize the intelligent identification, positioning, monitoring and control. The data collection is completely operated by the machine, avoiding human intervention and ensuring the reliable source of information.

The technical advantages of block-chain just ensure that the information cannot be tampered with, stored safely and traceable, forming a consensus, thus creating a trust environment: the data in the block-chain can only be stored after being verified by the consensus of the whole chain, which can guarantee the reliability of information. The unique distributed ledger can fully record a large amount of information, and the information transmission path is also marked by time stamp, which can break through the information transmission barriers between various links and ensure the integrity and traceability of information; moreover, consensus mechanism and smart contract can realize rapid response to information, promote the process automatically, and create an internal trust environment of the system.

The "Internet of Things and Block chain" realizes the reliable source of information, and the transmission process that is not tampered with, and creates a trusted collaborative working environment for the project construction process.

3 Design of an Engineering Construction Quality Traceability System Based on the Internet of Things and the Block Chain

3.1 Architecture Design of the Engineering Construction Quality Traceability System

With the increasingly mature technology of the Internet of things and the continuous reduction of its cost, it is becoming an important means of intelligent management; and the technologies of block-chain unforgeable and distributed storage provide solutions for engineering quality traceability. The architecture of the project construction quality traceability system of the Internet of things and block-chain is shown in Fig. 2.

The system perceives identifies and monitors the external environment through the Internet of things technology, such as two-dimensional bar code identification of building materials and mechanical equipment, real-time monitoring of Engineering entities with radio frequency identification technology and various embedded terminals, and supervision of personnel working conditions through cameras. Through network communication technology and embedded system technology, real-time collection, classification and transmission of information flow on each work node in

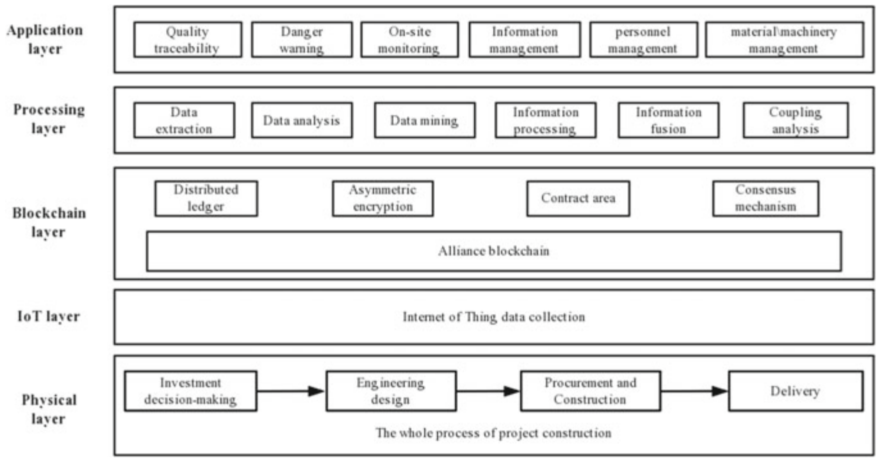

Fig. 2 The architecture of the engineering construction quality traceability system

the whole process of project construction are collected, classified and saved to the block-chain.

The block-chain layer chooses "alliance block-chain" as the organizational form, and its consensus process is managed by several main nodes. This form can not only ensure the system operation efficiency, but also take into account the characteristics of system security and member common maintenance. All the data follow the block-chain format, encryption and decryption algorithm and transmission mechanism, and are stored in the database of each node of the block-chain with time stamp. The distributed ledger registers the exchanged assets, transaction execution and data consensus with hash algorithm; the asymmetric encryption enables all nodes to maintain their own private and public key pairs, and it encrypts and decrypts the communication information between nodes in the block-chain network, and completes the trust transaction in the anonymous environment in this way. In the contract area, policies, legal provisions, industry standards, contracts and other contents are embedded in the block-chain in the form of smart contracts, so that the functions can be automatically and compulsorily executed along with the work flow. According to the smart contract, all links can automatically check the quality indicators, find problems in time, and avoid the occurrence of quality problems. The process is shown in Fig. 3. The consensus mechanism echoes the decision-making characteristics of the alliance block, and uses the access consensus mechanism of POS. The construction unit and government departments are the leading units to form the Alliance for the access of members, and other relevant government departments, enterprises and organizations join the block-chain as member nodes after being approved by the alliance.

Members of the chain include: material suppliers, design units, survey units, construction units, construction units, supervision units, property management units, government departments. Once the chain members are certified, they can add, update and query relevant information, and can strengthen the information exchange between other upstream and downstream units in the construction process.

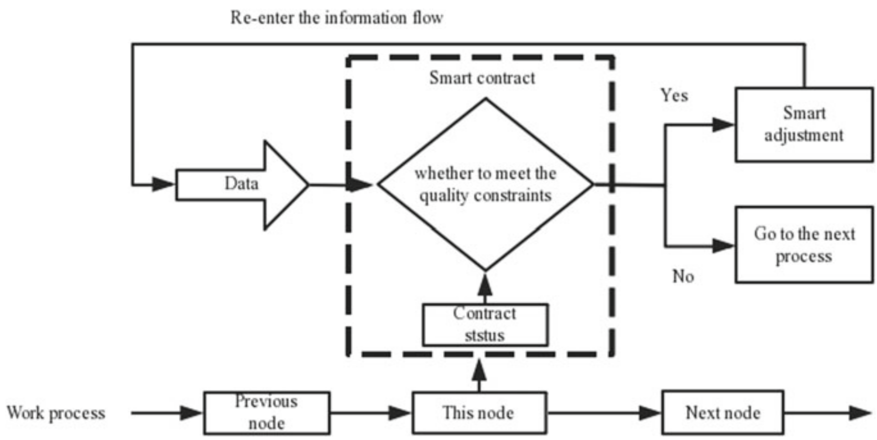

Fig. 3 Flowchart of quality indicators for intelligent contracts

Through the in-depth analysis and mining of data and information in the blockchain, it provides a variety of application functions for the members of the chain, including quality traceability, risk early warning, on-site monitoring, personnel management, etc., so that the construction unit and the construction unit can more accurately grasp the project dynamics; when the project quality problems occur, it can trace the source of the problem in time; and government regulatory agencies can improve work efficiency and strengthen quality supervision.

3.2 The Traceability Process Design of the Engineering Construction Quality Traceability System

Project quality traceability is divided into two processes: tracing and tracing. Tracing refers to tracing from upstream to downstream. Through tracking, the information flow direction can be understood, so as to evaluate the impact and eliminate irrelevant personnel. Traceability refers to the process from downstream to upstream when quality problems occur, which can find, locate the source of the problem and deal with it in time, and find the responsible subject. The processing flow of each link is as follows:

1. Investment decision-making stage: The construction unit will input the digital decision-making process into the system, share it with downstream enterprises, get preliminary risk assessment, and sign digital contracts with design units, survey units, construction units, etc.
2. Engineering design stage: The design unit enters the virtual building model design and detection analysis into the system, and dynamically adjusts the building information in the system, and shares engineering design ideas and key points with other members in real time. This provides an effective collaborative work and communication platform for all parties involved in the project, which can solve all design problems before construction, ensure the constructability of the design, reduce design and construction rework, and improve project quality.
3. Purchasing stage: Logistics providers and suppliers collect trade item identification code, commodity name and variety, number of logistics units, shipper information and other information from upstream; output batch number, receiving date, receiver information, and downstream delivery information at the same time, and monitor the status of building materials and machinery and environmental conditions through sensors in real time.
4. On-site construction stage: Construction site managers can access the circulation path of building materials and machinery from the manufacturer to the construction site by entering the system; Through the Internet of things technology, the construction materials and machinery can be identified, positioned, tracked, monitored and managed from the entry to the use and inspection, so as to ensure that the sources of the building materials and machinery are derived and

the construction use is recorded; real time monitoring and analysis of the identity information, working conditions and weather conditions of the personnel of various types of work are carried out. This system analyzes, forecasts and monitors the work nodes of the project construction, so as to realize the high efficiency of information feedback in the system, and uses the block-chain technology, so that all the information on the chain is verified, the quality is guaranteed and the information is traceable.

5. Supervision and acceptance: Strengthening the quality control at the completion acceptance stage is mainly to strictly implement the completion acceptance system and acceptance procedures. The construction in the system can self-check whether it meets the completion inspection or acceptance conditions; the relevant government departments can check the data files in the system at any time; and the on-site acceptance process is also directly entered into the system. To a large extent, this can prevent unfinished construction acceptance or unqualified construction acceptance, and ensure the full implementation of project construction quality.
6. Quality maintenance guarantee: Through the Internet of Things technology, different sensors are embedded in the building entity to collect, identify and monitor the state of the building, predict whether there will be quality problems, and provide timely warnings, and automatically schedule maintenance and inspections to ensure that the project is properly guaranteed.

The Internet of Things and Block-chain technology are used to monitor the entire life cycle of project construction from investment decision-making, design, construction to acceptance and operation, so that the source of materials can be checked, whereabouts can be traced, real-time monitoring of design and construction, and prevention of engineering quality accidents. If it happens, the quality problem can be traced and the responsibility can be investigated.

3.3 The Traceability Information Query Mechanism of the Engineering Construction Quality Traceability System

The engineering construction quality traceability system not only ensures the authenticity and reliability of data, traceability of quality problems, and clarifies the responsibility subject, but also provides efficient and accurate quality information query function for all members. In the project construction quality traceability system described in this paper, the engineering quality traceability platform established by the government department will be the interface for the system to query the traceability information externally, and the alliance chain will be the data source of this platform. As shown in Fig. 4, after user authentication, the user can log into the platform to initiate the query and traceability of engineering project quality problems, which will be processed by the alliance chain, and then the query and traceability

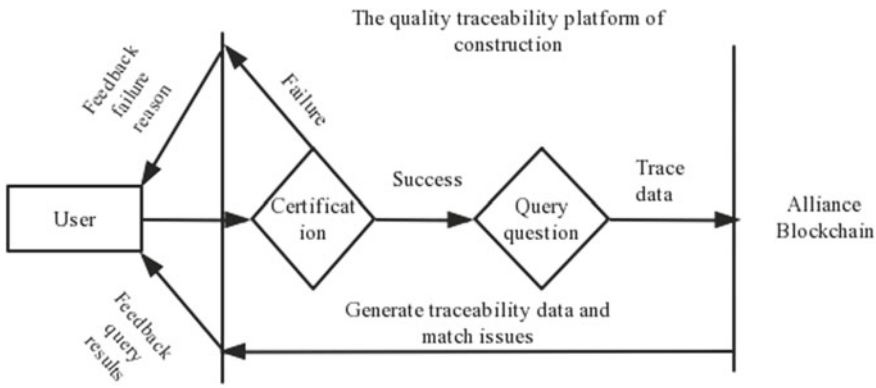

Fig. 4 Schematic diagram of engineering quality traceability information inquiry mechanism

results will be returned. The traceability platform will further match whether it is consistent with the user's problems, and then send the traceability results to the user.

4 Evaluation of Engineering Construction Quality Traceability System Based on Internet of Things and Block-Chain

In this paper, three professional panel are established to evaluate the effectiveness of the system framework. Group 1 is composed of experts with more than 5 years' experience in engineering construction management, and group 2 is composed of relevant information management experts who understand block-chain technology. Group 3 is composed of relevant technical experts connecting Internet of things technology. Each group has 5 members. Considering that some members may not understand the nonprofessional knowledge, we give a detailed description of all the objects evaluated in the system. Based on the system's setting of quality management in the whole process of engineering construction, each member were asked to check one of the four necessity levels: "must have", "should have", "nice to have", and "OK if missing" and check one of four difficulty levels for each object: "very difficult", "difficult", "not difficult", and "easy". Finally, a group discussion was conducted to reach a consensus. The evaluation results of the three groups are shown in Table 1.

First, experts affirmed the advantages of quality traceability system based on block-chain, especially dispersion, transparency, openness and traceability. Experts believe that the system is superior to the traditional traceability model in these aspects.

Experts with engineering management experience, Internet of things experts and block-chain experts have different opinions on the evaluation objects and functional modules of block-chain services. Experts in engineering management point out that

Table 1 Results of the evaluation of target objects in the system by three groups of members

Module	Composition, function, component	Necessity	Degree of difficulty achieved
Query interactions	Query information	Must have	Not difficult
	Query results set	Must have	Not difficult
	Information extraction ability	Should have	Not difficult
	Query interface	Must have	Easy
	Query frontend and backend server	Must have	Easy
Function	Quality traceability	Must have	Easy
	Danger warning	Nice to have	Difficult
	On-site monitoring	Must have	Difficult
	Information management	Must have	Not difficult
	Human resource, timber, machinery management	Must have	Not difficult
Block-chain	Data analysis	Must have	Very difficult
	Data fetch	Nice to have	Not difficult
	Data classification	OK if missing	Easy
	Computing services	Must have	Very difficult
	Alliance chain	Should have	Very difficult
	POS	Should have	Difficult
	Certification of smart contracts	Must have	Difficult
	Asymmetric encryption	Must have	Easy
	Distributed storage structure	Must have	Easy
Internet of things	Information sensing equipment	Must have	Not difficult
	Communication network	Must have	Easy
	Embedded system technology	Should have	Not difficult

it is less necessary to improve the performance of the system objects (i.e. data classification and data extraction), while expert group 2 believes that these measures are necessary to improve the performance of the block-chain. Data classification and extraction can speed up the operation of data analysis and reduce the requirements of computing services for data processing.

At the same time, with regard to the “information management (text data)” function, the experts of the group 2 and group 3 believe that this is easy to achieve. They agree that the data collected through online office and automatic collection is enough. However, the first group of experts pointed out that there are still some barriers in the management mode, and the complete online information management has not been realized.

In the second group, experts mentioned that the objects identified as “easy” in the evaluation objectives (such as query information, information management and data classification) are not very difficult to achieve. At present, the construction project also has the experience of “informatization”. For the technical means and application of the Internet of things (such as “information sensing equipment”, “on-site monitoring”, “human, material and machine management”), the expert of the group 3 thinks that there has been a precedent of application in the construction site, and there are examples for reference. Therefore, it was agreed that the implementation of these objectives was easier.

In contrast, for the objects used in other practical applications such as alliance block-chain architecture, data analysis and computing services, the experts of the group 2 gave a “very difficult” evaluation after discussion. The team explained that the complexity of participants in the whole life cycle of engineering construction and the multidimensional of data are more difficult to achieve. In addition, experts pointed out that some operations and components, such as computing services and data analysis, require too high quality and poor operability for massive data in the construction process, and it is difficult to instantiate them with existing technologies.

Among the 22 operations, functions and components, the expert group determined that 15 (68.18%) were “must have”, 4 (18.18%) were “should have”, 2 (9.09%) were “nice to have”, and 1 (4.55%) was “OK if missing”; 8 (36.36%) were “easy”, 7 (31.82%) were “not difficult”, 4 (18.18%) were “difficult”, and 3 (13.64%) were “very difficult”. These experts generally believe that block-chain technology can solve the limitations of traditional traceability, and the application of Internet of things technology will make traceability more efficient and reliable.

The evaluation results support the logic and construction of the framework of project construction quality traceability system based on Internet of things and block-chain, and constructive suggestions will be used for further research and improvement. According to the evaluation results, the traceability system framework is innovative and can meet the requirements of engineering construction quality management traceability. Experts affirmed the application prospect and importance of block-chain technology combined with Internet of things technology in the field of engineering quality traceability, which needs to be further developed and improved. They also believed that the system framework can be used as a specific reference for the future research on the implementation of the project construction quality traceability system, and the “must have” objects in the evaluation results can be applied first. For the components that are not necessary, we can choose whether to embed them into the system according to the resource conditions to improve the system performance.

5 The Advantages of the Quality Traceability System Based on the Internet of Things and Block-Chain

At present, the methods of project quality management and traceability are still relatively traditional in practice. Table 2 shows the comparison between the system based on block-chain and the Internet of Things and traditional management methods, reflecting the advantages of this system.

The engineering construction quality traceability system based on the Internet of Things and block-chain technology can record, analyze, supervise, and trace the entire process information, which is helpful to solve the internal development problems, trust problems, and supervision problems of the engineering construction industry.

Table 2 Comparison between this system and traditional management methods

Management system		The quality traceability system based on the Internet of Things and Block-chain	Other management approaches
The technology of engineering construction quality management and traceability	Data security	All information enters the system through the Internet of Things without manual intervention. And the data in the block-chain adopts distributed storage, which cannot be tampered with	Data is managed by personnel and stored in a central database. Once the password is leaked or the database is compromised, the data will be tampered with or lost
	Basis for accountability	The asymmetric encryption of the block-chain and the time stamp make the data authoritative and non-repudiation	The lifetime responsibility system for project quality was implemented. However, it is difficult to find the source of the problem when it is held accountable for major quality problems in the project
Management mode		Whole process, all information and comprehensive management	Information island and stage management
Management methods		Digital and intelligent	Human resources occupy a lot, low efficiency, slow response, lack of modern management methods

(1) The application of Internet of things technology realizes the monitoring and analysis of the whole process of engineering construction activities, breaks through the traditional mode of personnel monitoring, achieves the high integration of information space, construction site, building structure and management space, and ensures timely information, objective and true source, and lays a solid foundation for quality traceability.
(2) The project quality management traceability system using block-chain technology can solve the problem of large-scale application of Internet of Things technology in projects in a decentralized manner.
(3) The advantages of Internet of things technology and block-chain complement each other and learn from each other. From the perspective of the Internet of things, it protect the privacy of information providers through encryption technology, but the cost is high and the implementation is very difficult. Combined with the asymmetric encryption technology of block chain, the data is transmitted anonymously. At the same time, a shared database is formed.
(4) Block-chain, with the advantages of distributed ledger, collective maintenance and encryption algorithm, clarifies the operation trend of industrial chain, and establishes trust among users without trust foundation with low cost and high efficiency.
(5) The engineering quality management traceability system, due to the embedded Internet of Things technology and block-chain technology, makes information transparent and non-tamperable, which can promote two-way supervision between enterprises and government departments.
(6) The application of the Internet of Things and block-chain technology in engineering construction has promoted the informatization, unification and intelligence of industrial data.

6 Conclusion

Engineering construction quality traceability system plays an important role in blocking quality loopholes in decision-making, design, procurement, construction and supervision. In this paper, the Internet of things and block-chain technology are introduced into the whole process management of project quality, and the framework of project quality traceability system is constructed. The advantages of Internet of things technology are fully utilized. Combined with the characteristics of decentralization and tampered prevention of block-chain, the information of all links in the whole process of engineering construction is processed, which is linked to each other to ensure the accuracy and transparency of information. Once the problem is found, it can quickly locate the source of risk, truly realize the whole process quality traceability, and better guarantee the project quality.

It is of great significance to construct a project construction quality traceability system with a high degree of autonomy, collaborative supervision, and unforgeable information. It can solve two problems in the process of project construction management: the first is to provide solutions to the pain point of quality management and traceability in the process of engineering construction; the second is to explore the mechanism and significance of the Internet of things and block-chain technology in the quality management of engineering construction, which provides the possibility for the two technologies to be widely used in the construction field in the future.

At present, the engineering quality traceability system applying Internet of things and block-chain technology is still in the initial stage of exploration, and further analysis is needed in the combination with engineering practice. There are some problems of data standard unification in the integration of Internet of things technology and block-chain technology, but with the progress of technology, the details of the combination can be further refined. This paper only puts forward the system in theory, which has certain limitations. The implementation of this system requires the full cooperation of direct or indirect participants in the whole life cycle of engineering construction projects. Moreover, due to the lack of pilot projects, the implementation of the system is more difficult. The development of quality traceability system and case application analysis are still open problems and future exploration direction.

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The Impact of Industrial and Residential Land Supply Ratio on Economic Growth

Xu Yang and Rong-ping Hu

Abstract The purpose of this paper is to optimize and adjust the proportion of industrial and residential land supply to promote sustainable economic growth in China under the condition that the total scale of industrial and residential land supply remains the same. Research methods: In this paper, panel data of industrial and residential land from 2006 to 2016 in 282 prefecture-level cities in China were selected and the ratio of the two was incorporated into CD production function to establish a regression model. Firstly, OLS estimation was carried out without considering spatial autocorrelation to investigate the influence of the proportion of the two types of land on economic growth. Then, OLS estimation residues are tested for spatial correlation. If there is significant spatial autocorrelation, a spatial regression model with spatial correlation is needed for estimation. Finally, geographical weighted regression model is used to analyze the spatial and temporal differences of proportional effect. Research results: The proportion of industrial and residential land supply has significant temporal and spatial difference in promoting the economic growth; Under the condition that the total scale of industrial and residential land remains the same, increasing the proportion of industrial and residential land supply has a promoting effect on China's economic growth. However, the number of cities playing a promoting role is decreasing, while the number of cities playing a restraining role is increasing. Moreover, the degree of influence is becoming smaller and less significant.

Keywords Industrial and residential land · Supply structure · Economic growth · Cobb Douglas production function · Spatial regression model

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1 Introduction

From the existing literature, scholars choose different research samples, adopt different research models and methods, and carry out a wealth of research on the relationship between land input and economic growth. From the perspective of research issues, most scholars [1–3] focus on the impact of construction land on economic growth, Gao Huina and a few scholars [4, 5]began to research in industrial land level, such as its influence on economic growth, and direct impact on the economic growth of residence land of research is still rare. No scholars have yet regarded industrial and residential land as a system, and discussed the influence of supply structure of industrial and residential land on economic growth from the perspective of proportion under the condition of fixed total amount.

From the perspective of research methods, most scholars adopt CD production function and ignore spatial correlation to conduct OLS estimation directly, which may lead to deviation of regression results. Ma [6], Chen [7]and other scholars have empirically analyzed the impact of land investment on economic growth by using spatial error model and spatial lag model, but this model only includes random error term and spatial lag factor of dependent variable, and the consideration of spatial factors is not comprehensive enough. However, as for the generalized spatial regression model that contains spatial hysteresis factors of dependent variables and random error terms, no scholars have chosen it yet.

As for the discussion of spatial heterogeneity, scholars such as Chen and Rao [8–10] often divide the total samples artificially into eastern, central, western and other urban agglomerations according to spatial location, and analyze the spatial heterogeneity of influence effects by comparing the estimated parameters of urban agglomerations with different spatial locations. However, China has a vast territory, and this regional comparison is relatively rough. In this paper, the geographical weighted regression model can be used to estimate the influence effect of each sample point, which improves the accuracy and practicability of the research.

2 Model Building

2.1 Sample Selection and Data Sources

In this paper, data from 282 prefecture-level cities nationwide from 2006 to 2016 are selected as research samples. The data of industrial and residential land are from China Construction Statistical Yearbook from 2006 to 2016.Economic growth data, capital data and labor data are all from the China Urban Statistics Yearbook from 2006 to 2016.

2.2 *Variable Design*

2.2.1 Explained Variable

Economic growth indicators: Measured by the added value of the second and third generation of municipal districts, represented by the symbol "Y".

2.2.2 Explanatory Variables

1. Industrial land supply area: represented by the newly added industrial land area in the municipal district, represented by the symbol "gy".
2. Residential land supply area: represented by the newly added residential land area in the municipal district, represented by the symbol "jz".
3. The total supply scale of industrial and residential land: represented by the total area of newly added industrial and residential land in the municipal district, represented by the symbol "S", and represented by the quantitative relationship as follows:

$$\mathrm{S} = \mathrm{gy} + \mathrm{jz} \tag{1}$$

4. The proportion of industrial and residential land supply: represented by the proportion of newly added industrial and residential land supply in the municipal district, represented by the symbol "R", and represented by the quantitative relationship as follows:

$$R = gy \ / \ jz \tag{2}$$

2.2.3 Control Variables

1. Capital input volume: represented by the capital stock of municipal districts, represented by the symbol "K". In this paper, the more common perpetual inventory method is adopted to estimate the capital stock based on the total fixed asset investment. The calculation formula is as follows:

$$K_{i,t} = K_{i,t-1}(1 - \delta) + I_{i,t}/P_{i,t} \tag{3}$$

$K_{i,t}$ for the capital stock of the current year, $K_{i,t-1}$ capital stock for the previous year, δ for allowance for depreciation, $I_{i,t}$ for fixed assets investment this year, $P_{i,t}$ for as for the base period 2006 fixed assets price index. Is adopted in this paper, for the base year capital stock scholars Jones and Hall [11]when calculating the world 127 countries base capital estimation method, $K_{2006} = I_{2006}\left(g_i + \delta\right)$, g_i

in 2006–2016 for the national cities geometric growth of the total amount of investment in fixed assets, depreciation rate δ calculated at 9.6% [12].

2. Labor force: Represented by the number of people employed in the second and third industries of a municipal district at the end of the year, represented by the symbol "L".

2.3 Model Building

2.3.1 Cobb–Douglas Production Function Model

The Cobb–Douglas production function:

$$Y = A \times K^1 \times L^2 \times S^3 \times R^4 \quad (4)$$

In order to reduce heteroscasticity and increase comparability, logarithms are taken from both sides of the above equation to form an ordinary linear regression model:

$$lnY_{it} = \beta_0 + \beta_1 lnK_{it} + \beta_2 lnL_{it} + \beta_3 lnS_{it} + \beta_4 lnR_{it} + \varepsilon_{it} \quad (5)$$

Y represents economic output; K represents capital input; L represents labor input; S represents the total area of industrial and residential land supply; R represents the proportion of industrial and residential land supply. A is the original level of technology; t represents the time variable (2006 = 1…2016 = 11); β_1 represents the output elasticity coefficient of capital, β_2 represents the output elasticity coefficient of labor, β_3 represents the output elasticity coefficient of the total scale of the two types of land use, β_4 represents the production elasticity coefficient of the ratio of the two types of land, namely the percentage increase of economic output when the factor input is 1%; ε_{it} is the random error term, indicating other factors that are not included in the regression model but have an impact on Y.

2.3.2 Spatial Regression Model

$$1.\ SLM/SAR:\ \ln Y_{it} = \beta_0 + \rho \sum_{i=1}^{m} W_{ij} \ln Y_{it} + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln S_{it} + \beta_4 \ln R_{it} + \varepsilon_{it} \quad (6)$$

W_{ij} for m × m order space distance weighting matrix, ρ lag coefficient for the space.

$$2.\ SEM:\ \ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln S_{it} + \beta_4 \ln R_{it} + \mu_{it},\ \mu_{it} = \lambda W_{ij} \mu_{it} + \varepsilon_{it} \quad (7)$$

λ error coefficient for the space, said the random error term since the correlation in space.

$$3.\ SAC: \ln Y_{it} = \beta_0 + \rho \sum_{i=1}^{m} W_{ij} \ln Y_{it} + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \\ + \beta_3 \ln S_{it} + \beta_4 \ln R_{it} + \mu_{it}, \mu_{it} = \lambda W_{ij} + \mu_{it} + \varepsilon_{it} \quad (8)$$

$$4.\ SDM: \ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln S_{it} \\ + \beta_4 \ln R_{it} + \rho \sum_{i=1}^{m} W_{ij} \ln Y_{it} + \theta_1 \sum_{i=1}^{m} W_{ij} \ln K_{it} \\ + \theta_2 \sum_{i=1}^{m} W_{ij} \ln L_{it} + \theta_3 \sum_{i=1}^{m} W_{ij} \ln S_{it} + \theta_4 \sum_{i=1}^{m} W_{ij} \ln R_{it} + \varepsilon_{it} \quad (9)$$

θ_i is the spatial interaction term coefficient, which represents the spatial autocorrelation coefficient of independent variables.

2.3.3 Geographical Weighted Regression Model

$$lnY_{it} = \beta_0(u_i, v_i) + \beta_1(u_i, v_i)lnK_{it} + \beta_2(u_i, v_i)lnL_{it} \\ + \beta_3(u_i, v_i)lnS_{it} + \beta_4(u_i, v_i)lnR_{it} + \varepsilon_{it} \quad (10)$$

(u_i, v_i) is the geographic space coordinates of the sample point i city, $_j(u_i, v_i)$ is the regression estimation coefficient of the jth independent variable of the sample point i city, $_i$ is the random error term, and the other variables are explained in the same formula (5).

3 Empirical Analysis

3.1 Traditional Regression Model

3.1.1 OLS Regression Results Analysis

The Table 1 shows that labor, capital, industrial and residential land supply total scale, industrial and residential land supply ratio of four variables regression coefficients were significant under 1% level is positive, that in all the samples within the scope of labor, capital, industrial and residential land area, industrial and residential land supply ratio has significant promoting effect on urban economic growth.

Table 1 OLS estimation results

Variable	L	K	S	R	R^2	Log-L
Regression results	0.482***	0.643***	0.121***	0.159***	0.904	1328.87

*, **, and *** respectively represent the rejection of the null hypothesis of the existence of unit roots of sequences at the significance level of 10%, 5%, and 1%, the same below

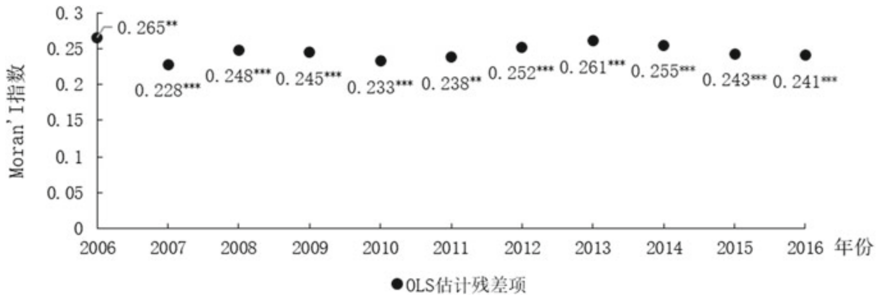

Fig. 1 Spatial correlation test for OLS estimation residuals

3.1.2 OLS Estimation Residual Spatial Correlation Test

According to Fig. 1, OLS residuals' Moran's I indexes are all positive at 5%, indicating that OLS residuals have significant spatial correlation. In order to improve the accuracy of regression results, it is necessary to establish a spatial regression model for empirical analysis by adding the influence of spatial correlation of various variables on the basis of traditional regression models.

3.2 Spatial Regression Model

3.2.1 Model Testing and Comparison Selection

1. Hausman test

According to Table 2, the absolute value of the statistics in the Hausman test of the four spatial econometric models is relatively large, and all of them pass the test

Table 2 Hausman test results of spatial econometric model

Model	T statistic	P values
SAR	−416.411***	0.000
SEM	−252.321***	0.000
SAC	−675.173***	0.000
SDM	−237.126***	0.000

Table 3 LM test results and Robust-LM test results

Test	T statistic	P values
LM spatial lag	477.695***	0.000
Robust LM spatial lag	42.986***	0.000
LM spatial error	677.558***	0.000
Robust LM spatial error	244.848***	0.000

Table 4 Wald test results and likelihood ratio LR test results

Test	T statistic	P values
Wald spatial lag	71.261***	0.000
LR spatial lag	64.598***	0.000

at the significance level of 1%. Therefore, the null hypothesis of the random effect is rejected, and the fixed effect model is selected for estimation.

2. LM test and Robust-LM test

According to Table 3, the statistics of Robust LM-lag and Robust LM-error both passed the test at a significant level of 1%, and they were also passed the test at a significant level of 1%, and the T statistics of Robust LM-error were significantly greater than those of Robust LM-lag. Therefore, according to the above judgment criteria, SEM model is better than SAR model.

3. Wald test and likelihood ratio LR test

According to Table 4, the statistics of Wald test and the likelihood ratio LR test both pass the test at the significance level of 1%, and the null hypothesis is rejected. Therefore, SDM model cannot be simplified as SEM or SAR model, that is, the effects of both spatial transmission mechanisms on urban economic growth need to be considered.

In summary, based on Hausman test, LM test, Robust LM test, Wald test and LR test, it can be concluded that the SDM model with fixed effects is the most reasonable among SAR, SEM and SDM models.

3.2.2 Empirical Results and Analysis

1. Spatial model estimation results (P.S.: C—coefficient; t—T statistic; P—P values.)

As can be seen from Table 5, the R-Sq and log-L of SDM model are the largest, and the number of regression coefficients is the most significant, indicating that SDM model has the best effect. Therefore, SDM estimation results are taken as the basis for empirical analysis in this paper.

Table 5 Model estimation results

Variable	OLS		SAR		SEM		SAC		SDM	
	C	t	C	P	C	P	C	P	C	P
r			0.390***	0.000			0.134***	0.000	0.402***	0.000
l					0.422***	0.000	0.286***	0.000		
L	0.482***	0.000	0.221***	0.000	0.212***	0.000	0.171***	0.000	0.205***	0.000
K	0.643***	0.000	0.293***	0.000	0.311***	0.000	0.256***	0.000	0.315***	0.000
S	0.121***	0.000	0.140***	0.000	0.149***	0.000	0.102***	0.000	0.137***	0.000
R	0.159***	0.000	0.031*	0.059	0.035**	0.035	0.043***	0.003	0.030***	0.001
w * L									0.087***	0.003
w * K									−0.099***	0.001
w * S									−-0.132**	0.027
w * R									−0.063*	0.071
R-sq	0.904		0.987		0.986		0.976		0.988	
Log-L	1326.454		1808.275		1799.413		1468.859		1823.690	

Table 6 Spatial Durbin model effect decomposition

Variable	Direct effect	P values	Indirect effect	P values	Total effect	P values
L	0.220***	0.000	0.269***	0.000	0.489***	0.000
K	0.317***	0.000	0.045	0.307	0.362***	0.000
S	0.111***	0.000	−0.097	0.239	0.014	0.898
R	0.026***	0.000	−0.080	0.153	−0.054	0.387

2. Spatial Durbin model effect decomposition

It can be seen from Table 6 that the direct effect of the total area of industrial and residential land and the proportion of industrial and residential land supply on economic growth is significantly positive at 1%, and the elasticity coefficient is 0.111 and 0.026, respectively.

3.3 Geographical Weighted Regression Model

In this section, the geographical weighted regression model is adopted, the adaptive quadratic form bandwidth is determined by AIC criterion, and the gaussian distance function is selected to construct the spatial weight matrix. GWR4 software is first used for the geographical weighted regression analysis of the cross-section data in 2006, 2011 and 2016, and ArcGIS10.5 software is also used for the visual analysis.

As can be seen from Fig. 2, on the whole, the regression coefficient of the proportion of industrial and residential land supply is not significant, and with the passage of time, the significance level drops significantly. This shows that when the total area of two types of land is determined, increasing the proportion of industrial land allocation has less and less significant impact on economic growth.

As can be seen from Fig. 3, on the whole, the proportion of industrial and residential land supply plays a promoting role in economic growth in most cities, but with the passage of time, the promoting role becomes less and less, and some cities have

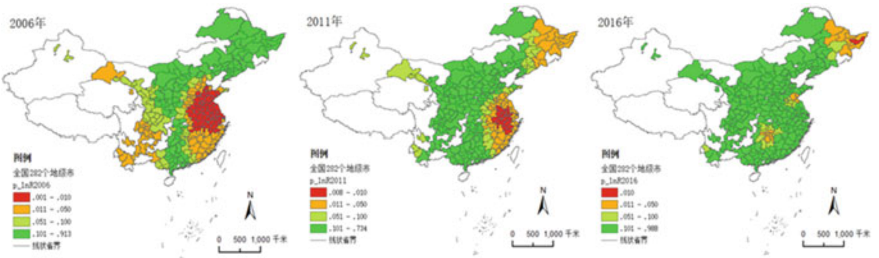

Fig. 2 Supply proportional regression coefficient P value spatial distribution *Note* Data in blank area is missing.

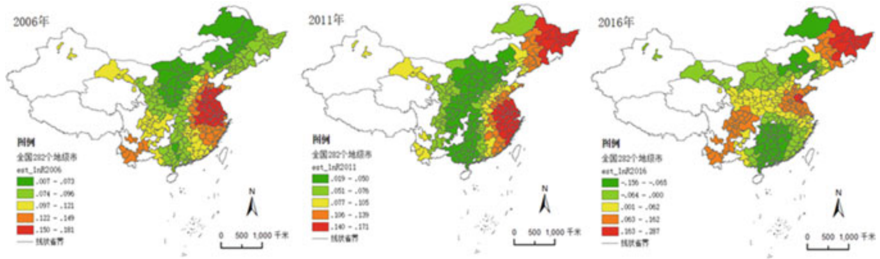

Fig. 3 Supply proportional regression coefficient spatial distribution *Note* Data in blank area is missing.

a restraining role. Year by year, the regression coefficients of all the sample cities in 2006 and 2011 were positive, indicating that the ratio of industrial and residential land supply in this region had a significant promoting effect on economic growth. In 2016, the regression coefficient of 46% of the sample cities in China was negative, indicating that the ratio of industrial and residential land in this region had a significant inhibitory effect on economic growth.

4 Conclusions and Suggestions

4.1 Conclusions

1. Without considering the spatial correlation, the elasticity coefficient of the supply ratio of the two types of land is 0.159, indicating that when the total scale of the two types of land is limited, the ratio of industrial land will increase by 1% and the urban economic output will increase by 0.159%. However, OLS residual estimates have significant spatial correlation, and the results of OLS regression using the traditional regression model cannot fully reflect the objective facts, so it is necessary to establish a spatial regression model for empirical analysis.
2. Considering the spatial correlation, when the total scale of industrial and residential land is limited, the direct effect of the two types of land is 0.026, which is significantly reduced compared with that without considering the spatial correlation.
3. When the total supply scale of the two types of land is limited, the promoting effect of increasing the ratio of industrial land on economic growth is gradually reduced, and the national average value of the three-year output elasticity coefficient is respectively 0.108, 0.087 and 0.016.

4.2 Suggestions

1. It is not a long-term plan for China's urban economic growth to rely on the expansion of industrial and residential land in the future. Instead, industrial and residential land should be used efficiently and intensively to promote their optimal allocation and improve the utilization efficiency and intensity of industrial and residential land.
2. As capital, labor force, industrial land and other factors of production have spatial correlation, urban economic growth is not only affected by the spatial effect of economic growth in other regions, but also affected by the spatial spillover effect of various factors of production. Therefore, it is necessary to consider not only the direct effect of production factors on economic growth, but also the indirect effect of production factors in the formulation of industrial and residential land supply policies.
3. We should give full consideration to the differences of technological and economic development level, resource endowment conditions and industrial structure in different regions, and formulate differentiated land supply policies according to local conditions.

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The Analysis of Second-Hand Housing Prices in Jiangmen City, Based on Semi-structured Interview and Hedonic Model

Jiajing Liao

Abstract The soaring housing prices in Chinese cities have aroused wide concern from all walks of life. The limited land resources for real estate development make the demand for second-hand housing increase day by day, and second-hand housing has gradually become an important part of the real estate market. First of all, through semi-structured interviews, this paper analyzes the relationship between the price of second-hand housing in Jiangmen and its micro-attributes from the perspective of consumers and real estate agents. Then, by integrating the open data of anjuke.com and Baidu map POI, this paper establishes a Hedonic model to further confirm that the architectural characteristics, location characteristics and neighborhood characteristics of second-hand housing have a significant impact on its price. Among these factors, the year of construction, the degree of decoration, whether there is an elevator, the proximity to the school, and the proximity to the business district have significant positive impact on the price of second-hand housing. The factors of floor and floor area have a significant negative impact on the price of second-hand housing.

Keywords Second-hand housing prices · Characteristic price theory · Open data · Semi-structured interview

1 Introduction

In recent years, the area of land available for development in cities has been decreasing year by year, but the housing price has been rising all the way. Therefore, the demand of buyers for second-hand housing market is also increasing. According to the China Real Estate Industry Association, the volume of second-hand housing transactions rose from 1.59 trillion yuan in 2012 to 6.53 trillion yuan in 2019.

At present, the research mainly starts from the supply and demand relationship, housing macro-control policy and other macro-influencing factors. However, most

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studies based on micro-factors such as the building characteristics, location characteristics and neighborhood characteristics of commercial housing only adopt quantitative research, which is difficult to explain. In view of this, it has become a hot and difficult point to reveal the micro factors and the degree of influence of commodity housing price, and to conduct qualitative and quantitative research on the commodity housing market. In addition, at present, most of the research on this issue is conducted in first-tier and second-tier cities in China, such as Beijing and Shanghai, while there is little research on other cities. Therefore, in order to fill the gap, Jiangmen, a third-tier city in China and one of the Guangdong-Hong Kong-Macao Greater Bay Area cities, is selected as the research area.

This study firstly adopts the semi-structured interview method to analyze the relationship between the price of second-hand housing and its micro attributes from the perspective of consumers and real estate agents. Then, based on the open data of anjuke.com and Baidu map, the Hedonic model was established to clarify the determinants of the second-hand housing market in Jiangmen city and the effect of the architectural characteristics, location characteristics and neighborhood characteristics of the commercial housing on its price. This paper attempts to answer the following questions: is there a positive correlation between the building characteristics, location characteristics and neighborhood characteristics of commercial housing and the local second-hand housing price? How sensitive are these relationships to housing prices? At the same time, this paper also examines how these factors affect the basic mechanism of Jiangmen housing price.

2 Literature Review

The micro features that affect the price of second-hand housing can be divided into three categories: building features, neighborhood features and location features [1]. Among them, building features are the features of the building itself, such as the building area and the year of construction. The neighborhood characteristics of housing mainly include socio-economic variables, public service facilities and external influences [2]. The location features of housing can be quantified through the accessibility of traffic [3].

In the past, some scholars have used a Hedonic model to study the effect of house prices. Concas [4] in 2013 added public transportation facilities, such as subway stations and bus routes, to a hedonic model in order to achieve a more accurate study of housing market prices. In addition, in 2018, Li et al. [5] analyzed the spatial pattern of apartment price in Shanghai and its relationship with characteristic attributes, and found that due to the centralized distribution of public transportation facilities and facilities, the housing market in Shanghai still has a single central structure. In 2019, Glumac et al. [6] studied the impact of surrounding plots and natural and built environment on urban land prices, and Tan et al. [7] studied the impact of adjacent subway stations on housing prices. They found that the opening of new subway stations makes the land around suburban stations more dynamic than the land around central station. Li et al. [8] argue that the value of single-family homes is influenced not only by structural attributes, but also by urban amenities and transport accessibility factors, such as air pollution, forest cover, the quality of public schools and commuting costs. Tajima [9] estimated the economic benefits of being near a park in Boston, Massachusetts, based on hedonic pricing. At the same time, they believe that proximity to urban open Spaces has a positive impact on real estate values, while proximity to highways has a negative impact on real estate prices. Risselada et al. [10] believe that the socioeconomic status of the community also affects the housing price, median household income, unemployment rate and education level and other variables are important factors for residents to choose housing. Kumar et al. [11] assessed the effect of proximity to light rail stations on the property value of residents in Buffalo, New York, and Hedonic model showed that for every foot in the study area, the average property value increased by \$2.31. Guan [12] believe that location, affordability and comfort have a positive impact on the value of a home. In addition, correlations between location, affordability and suitability are calculated.

Their research only uses quantitative modeling method, which is difficult to explain. In view of this, this paper combines semi-structured interview with Hedonic model, and studies the micro factors influencing commodity housing price and its degree of influence qualitatively and quantitatively.

3 Semi-structured Interview

Interviews are generally divided into three types: unstructured interview, semi-structured interview and structured interview. Among them, semi-structured interview is equivalent to the combination of unstructured interview and structured interview, that is, the questions set contain open questions and closed questions, but the questions can also be increased or decreased according to the actual situation at the time of interview. In this paper, semi-structured interviews are used to conduct in-depth interviews with consumers and real estate agents to understand the relationship between second-hand housing prices and their micro-attributes in their eyes in Jiangmen.

3.1 The Interview Process

As shown in Fig. 1, the interview process includes five steps, namely, determining the purpose of the interview, theoretical basis of the interview, determining the interviewees, formal interview and qualitative analysis. The detail of interview process are introduced as follow. The date of the interview is June 20, 2020. Due to the epidemic, this interview was conducted in the form of online video. Respondents 1: Miss Chen—age: 24—Bank staff with intention to buy a house (potential buyers).

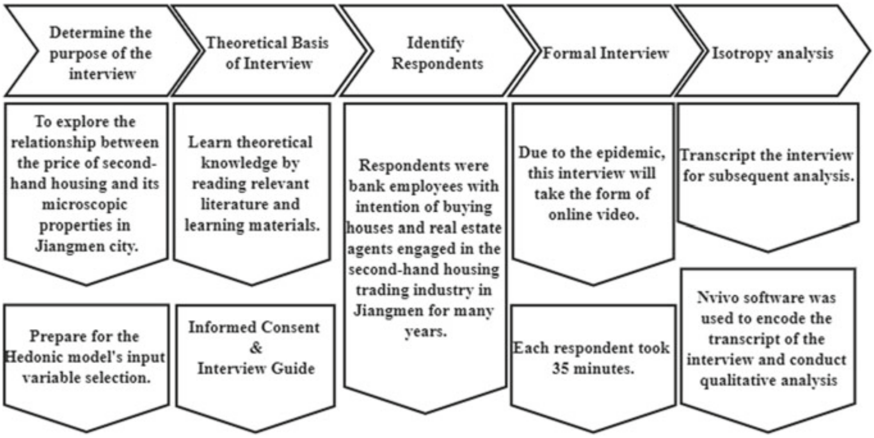

Fig. 1 Interview flow chart

Respondents 2: Ms. Lin—age: 50—Housing intermediary has worked for 15 years (intermediary). Each respondent took 35 min.

3.2 Analysis of Interview Results

Based on the interview Results, it can be seen that the interviewees mainly focus on the micro attributes related to the price of second-hand housing in Jiangmen, including: building features (floor area, degree of decoration, number of rooms, orientation, floor/total floor, year of construction, whether there is an elevator, floor area ratio); Neighborhood characteristics (distance from hospital, school, park); Location characteristics (distance from CBD, shopping mall and bus station). These variables can be used as input variables for the Hedonic model.

By analyzing the interview content, we find that both respondents believe that variables such as "degree of decoration, number of rooms, orientation, year of construction, whether there is an elevator, distance from school and park to CBD, shopping mall and bus station" have a positive impact on the price of second-hand housing in Jiangmen. The variables of "floor area, floor area ratio and floor" have a negative impact on the price of second-hand housing in Jiangmen; at the same time, both respondents believe that the distance between commercial housing and schools and the year of construction of commercial housing have a significant impact on the price of commercial housing. Believe that location, affordability and comfort have a positive impact on the value of a home. In addition, correlations between location, affordability and suitability are calculated.

However, the two interviewees differ in the impact of micro-factors such as the distance between commercial housing and hospitals, CBD and bus stations on the price of commercial housing, which may be caused by the differences in age and cognition of the two interviewees. How exactly do these micro factors affect the second-hand housing prices in Jiangmen City In the next chapter we will Hedonic model to continue this exploration.

4 Hedonic Pricing Model

In the previous section, we determined the Hedonic model's input variables through semi-structured interviews as building characteristics (area, degree of decoration, number of rooms, orientation, floor/total floor, year of construction, elevator presence, floor area ratio); Neighborhood characteristics (distance from hospital, school, park); Location characteristics (distance from CBD, shopping mall and bus station). First of all, this section will explain how to obtain the relevant data sets, and conduct preprocessing and relevant tests on the preliminarily obtained data sets. Next, the Hedonic model is established, and the model is tested and evaluated. Finally, the model results are analyzed.

4.1 Data Collection

With the development of social media and big data, obtaining a large number of open data sources through web crawlers has become an innovative means to study the micro-influencing factors of the real estate market. A web crawler is also known as a web spider or web robot. It is an automated computer program that recursively browses the web by tracking hyperlinks [13]. This study uses the Python SCRAPY module/Requests module/Selenium module to compile the crawler framework, and crawls the required data from anjuke.com website and Baidu map POI.

4.2 Preprocessing of Characteristic Variables

The data sets that are initially crawled have various data types, which are preprocessed by the following operations in this paper. Change the house type variable into three variables (be like: three rooms two hall two bath): room number, sitting room number, toilet number. The degree of decoration blank, simple decoration, fine decoration, luxury decoration quantified as 1, 2, 3, 4. Quantify whether the orientation is toward the south or not, 1 if the orientation is not toward the south and 2 if the orientation is toward the south. The existence of elevators is quantified. "no elevator" is quantified as 1 and "have elevator" is quantified as 2. The distance between the residential area of each second-hand commodity housing and schools, parks, shopping malls, business districts, hospitals and bus stations is obtained by crawling the POI coordinate information. Turn this distance into reciprocal, indicating the proximity between each residential area and each place where second-hand housing is located.

Due to the different dimensions and value range of each variable, when the level of each variable varies greatly, if the original variable value is directly used for analysis, the role of variables with higher numerical value will be highlighted in the comprehensive analysis, and the role of variables with lower numerical value will be relatively weakened [14]. Therefore, in order to ensure the reliability of the results, it is necessary to standardize the data.

4.3 Modeling

After pre-processing, 1718 pieces of data were obtained, 80% of which were taken as the training set of the model, and 20% of which were taken as the validation set of the model. In the characteristics of price model to house price as the dependent variable, build a year, the degree of construction area, elevator, decoration, room number, the number of the sitting room, toilet, building head, floor, plot ratio, communities and hospitals, schools, parks, business district, the bus station, shopping center distance as the independent variable for multiple linear regression, mathematical formula is as follows:

$$y = B_0 + B_1x_1 + B_2x_2 + \ldots + B_kx_k + \in$$

In this paper, SPSS software was used to establish the Hedonic Pricing Model, and multiple linear regression was carried out on the crawled data.

4.4 Test and Evaluate the Model

As shown in Table 1, R stands for goodness of fit, which is used to measure the degree of fitting of the estimated model to the observed values. The closer it is to 1, the better the model. The adjusted R squared is more accurate than the R squared. The final adjusted R squared in the figure is 0.780, indicating that the independent variables can explain 78% of the changes of dependent variables (Table 2).

It can be seen from the table of results of ANOVA that F = 136.499 and SIG = 0.000. F is the result of ANOVA and is a population test for the whole regression equation. It refers to whether the whole regression equation is useful or not (compared with random guessing), and if the corresponding SIG value of F is 0.000b < 0.05, the

Table 1 Model summary table

R	R squared	Adjusted R squared	Durbin-Watson
0.864	0.786	0.780	1.160

Table 2 The table of results of ANOVA

	Quadratic sum	DOF	Mean square	F	Significance
Regression	802.723	14	57.337	136.499	0.000
Residual error	571.277	1360	0.420	–	–

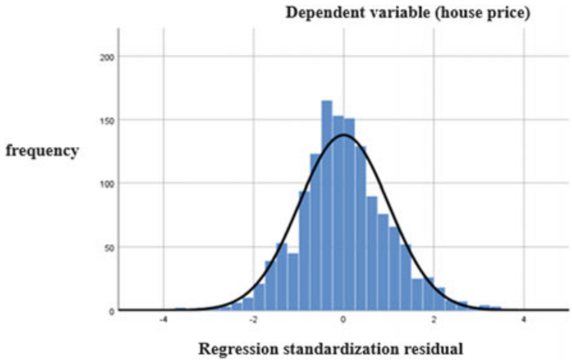

Fig. 2 Residual histogram of the model

regression equation can be considered useful. In addition, from the perspective of F value, the value of F is the significance test of the regression equation, indicating whether the linear relationship between the explained variables and all explanatory variables in the model is significant on the whole. If F is 136.499 > Fa(k,n – k − 1), the null hypothesis is rejected, that is, the combination of all explanatory variables included in the model has a significant impact on the explained variables.

It can be seen from the residual histogram of the model (Fig. 2) and the cumulative probability graph of the residual of the model (Fig. 3) that the histogram is consistent with the normal distribution curve and the scattered points are clustered near the diagonal, indicating that the residual is in line with the normal distribution.

4.5 Results and Discussion

As shown in Table 3, "degree of decoration, number of rooms, orientation, year of completion, whether there is an elevator, proximity to schools and parks, proximity to CBD, shopping malls and bus stations and plot ratio " have a positive impact on the price of second-hand housing in Jiangmen. Among them, the first significant positive impact is the " year of build " with a coefficient of 0.565, the second significant positive influence is " degree of decoration " with a coefficient of 0.249, the third significant positive influence is "whether to have the elevator" with a coefficient of 0.121, positive impact the fourth significant is "proximity to schools" with a coefficient of 0.105, the subsequent variable according to the positive significance is arranged in the order: The "proximity to the business district" with a coefficient of

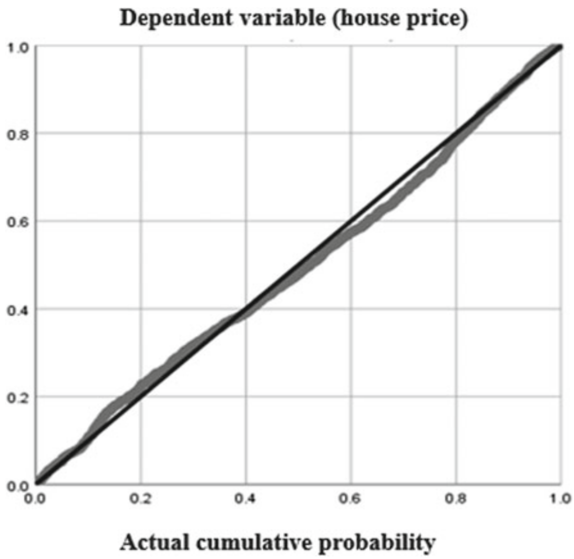

Fig. 3 Cumulative probability graph of model residuals

Table 3 Regression coefficient table of characteristic variables

Coefficient	B	Standard error
Constant	2.17E−14	0.017
Z-score (year of build)	0.565	0.033
Z-score (floor area)	−0.01	0.023
Z-score (elevator)	0.121	0.032
Z-score (degree of decoration)	0.249	0.02
Z-score (number of rooms)	0.007	0.025
Z-score (house orientation)	0.08	0.018
Z-score (the floor)	−0.134	0.018
Z-score (plot ratio)	0.018	0.018
Z-score (proximity to hospitals)	−0.004	0.018
Z-score (proximity to schools)	0.105	0.018
Z-score (proximity to parks)	0.004	0.018
Z-score (proximity to the business district)	0.083	0.018
Z-score (proximity to bus stations)	0.064	0.018
Z-score (the proximity to the shopping malls)	−0.001	0.018

0.083, the "house orientation" variable with a coefficient of 0.80, the "proximity to the bus stations" variable with a coefficient of 0.064, the "plot ratio" variable with a coefficient of 0.018, the "number of rooms" variable with a coefficient of 0.007, and the "proximity to the parks" variable with a coefficient of 0.004.

That is, according to the significance of their positive impact on the second-hand housing price in Jiangmen, the characteristic variables are ranked from large to small as follows: "year of build", "Decorate a degree", "whether to have the elevator", " proximity to schools ", " proximity to the business district ", " house orientation ", "proximity to bus stations", "plot ratio", "room number", " proximity to parks".

The variables of "the floor, the proximity to the hospital and shopping mall, and the floor area" have a negative impact on the price of second-hand housing in Jiangmen city. Among them, the first significant negative impact is "the floor" with a coefficient of −0.134, the second significant negative impact is the "construction area" with a coefficient of −0.010, the third significant negative effect is "proximity to hospital" with a coefficient of −0.004, and the fourth most significant negative effect is "proximity to shopping malls" with a coefficient of −0.001.

That is, according to the significance of their negative impact on the second-hand housing price in Jiangmen, the characteristic variables are ranked from the largest to the smallest as follows: "the floor", "the building area", "the proximity to the hospital", "the proximity to the shopping malls".

Among them, several conclusions are inconsistent with the results obtained by the interview method, which will be discussed in the following part.

First, the variable " plot ratio " in the model results has a positive impact on the second-hand housing price in Jiangmen city, while the interview results show that this variable has a negative impact on the housing price. It is speculated that the reasons leading to the difference in " plot ratio " are as follows: high volume rate of second-hand commercial housing due to factors such as location or a new house has a higher price, but the higher the volume rate of housing with the passage of time is bound to lead to a drop in the quality of living, along with the continuous development of city, residential plot ratio may be a critical value, that is to say, the factors influencing the housing price of other characteristics under the condition of stable, residential plot ratio of the marginal benefit as the value of zero, more than the rate of volume numerical residential overall livability will decline, and the determination of the threshold for experiment in future research.

Second, the variable "proximity to hospitals" in the model results has a negative impact on the price of second-hand housing in Jiangmen city, while the interview results show that this variable has a positive impact on the housing price. It is speculated that the reason for this difference is that in the sample data imported this time, there are many samples with a close distance between second-hand housing and hospitals. In the interview and research, the respondents believe that the greater the "proximity to hospitals" is outside a certain range of variables, the more convenient the access to medical services will be, which has a positive impact on the housing price. However, when the distance between second-hand housing and hospital is within a certain range, the greater the variable "proximity to hospital", which may have a negative impact on housing price due to feudal superstition.

Third, the variable "proximity to shopping malls" in the model results has a negative impact on the price of second-hand housing in Jiangmen, while the interview results show that this variable has a positive impact on the housing price. It is speculated that the reason for the difference is that the second-hand housing close to the shopping mall in the sample data has a lower pricing due to the bad location or the house is older. At the same time, the variable “proximity to shopping malls” has no significant negative impact on the price of second-hand housing in Jiangmen, which may be due to the rapid development of e-commerce, people can meet their shopping needs through the Internet without leaving home, so there is no excessive requirement on the distance between houses and businesses.

5 Conclusion

This study firstly adopts the semi-structured interview method to analyze the relationship between the price of second-hand housing and its micro attributes from the perspective of consumers and real estate agents. Then, based on the open data of anjuke.com and Baidu map, this thesis has conducted a study of the determinants of second-hand housing market in Jiangmen city and the influence of the architectural characteristics, location characteristics and neighborhood characteristics of commercial housing on its price through the establishment of a Hedonic model, and has drawn the following conclusions: Each feature variables according to its positive impact for Jiangmen second-hand commercial housing prices significantly from large to small is arranged respectively: “year of build”, “Decorate a degree”, “whether to have the elevator”, “ proximity to schools “, “ proximity to the business district “, “ house orientation “, “proximity to bus stations”, “plot ratio”, “room number”, “ proximity to parks". According to the significance of their negative impact on the housing price of second-hand goods in Jiangmen city, the characteristic variables are ranked from the largest to the smallest as follows: “the floor”, “the building area”, “the proximity to the hospital”, “the proximity to the shopping malls”.

With the development of social media and big data, a large number of open data sources provide innovative means for the study of micro influencing factors of the real estate market. This paper uses python crawler to crawl open data of second-hand housing information on Anjuke.com and Baidu map, which is more efficient, accurate and objective than traditional data acquisition methods. At the same time, this paper combined with the semi-structured interview results to explain the modeling results and analyze the reasons for the differences between the modeling results and the prepared conclusions.

In addition, this paper also has some limitations. Respondents in the semi-structured interview have different views on the impact of some characteristic factors on housing price, which may be caused by their different ages and demands. In future studies, scholars can interview more respondents of different ages and types, so as to make the research results representative and interpretable. In the meantime, multiple linear regression was used to construct the Hedonic Pricing Model in this study. It was assumed in advance that there was a linear relationship between various characteristic factors and the second-hand housing price, which was subjective to a certain extent. In the future, scholars could use neural network and other modeling methods to construct the Hedonic Pricing Model, so as to make the research results more objective and accurate.

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An Application Mechanism of Automated Construction Drawing Review on BIM-Based

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Abstract With the development of China's economy, the construction industry has become one of the important pillar industries supporting the national economy. In the process of industry development, construction drawing review is an important means to improve and guarantee the survey and design quality of construction projects, and to safeguard public interests and public safety. But now the drawing review work is still mainly done manually. The level and quality of drawing review personnel are uneven, and the understanding of the normative provisions cannot be completely consistent, resulting in inefficient omissions and human manipulation in the drawing review work. In order to adapt to the development of the times and realize the intelligent transformation of the industry, the use of Building Information Modelling (BIM) technology for automated drawing review is an extremely important development direction for future construction drawing review. Based on the introduction of a reasonable drawing review information database and the standard clauses of parametric design specifications, this paper standardizes the BIM model of design drawings and extracts information, and realizes the compliance review of the BIM model of design drawings. Further, a reasonable process for automated drawing review was formed, and a smart drawing review application mechanism based on BIM technology was finally constructed. Based on case studies, this paper analyzes the application mechanism of intelligent drawing review, and improves the comprehensiveness and precision of construction drawing review. It points out the direction for the development of smart drawing review and conforms to the development trend of smart construction in the construction industry.

Keywords Chinese construction drawing review · Automated drawing review · Building Information Modelling (BIM) · Application mechanism

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1 Introduction

In order to upgrade and ensure the quality of survey and design of construction projects, and maintain public interest and public safety, China has implemented a review system for construction drawings and design documents (construction drawings) of construction projects since 2000. By reducing the errors in the construction drawing design stage, the functionality and applicability of the building in the use, operation and maintenance stage can be ensured, and the loss of people's life and property caused by the lack of building function can be reduced. At present, the construction drawing review method in China is mainly manual review, which relies on experts with rich professional knowledge and engineering experience to review the construction drawing manually. During this period, the paper specifications, geological reports and manual calculation results are mainly used as the review basis. In the process of review, there are a series of problems caused by the traditional review method, such as incomplete management system, uneven level of experts, time-consuming and labor-consuming, and prone to review errors. First of all, the relevant design specifications contain a huge amount of data, which cannot be fully grasped by the human brain.. In practical works, multiple projects are often centralized for drawing review, and the drawing review time allocated to each project is very limited. Due to the high requirements of drawing review experts, they are usually reach an older age by the time they qualified, which result in the overburden of censors. Finally, there are many specifications such as related designs. For the same drawing review site, different specifications have different requirements [1]. Therefore, manual drawing review inevitably have some errors of drawing review points, and the quality of construction drawing review cannot be guaranteed. Meanwhile, Designers may have to obey the illogical demands of their employer for some commercial reasons, leading to deterioration of engineering design quality which may cause engineering accidents [2].

Automated drawing review is an effective means to solve these current problems. It can transform the traditional way of reviewing paper construction drawings into reviewing electronic models, reducing the transfer, mailing, and storage of a large number of paper documents. On the other hand, automated image review is much more refined compared with traditional checking process, which can significantly enhance the accuracy of the review process. In the future, automated image review will also play a unique role in more fields.

2 The Concept and Research Status of BIM-Based Automated Drawing Review

2.1 The Concept of BIM and BIM-Based Automated Review

BIM, short for "Building Information Modeling", can be deemed as one of the most influential technologies in architecture, engineering and the construction industry. Via integrating, collecting, and analyzing the digital information of various stages in the whole life cycle of construction projects, it can visualize these data in 3D by using 3D digital technology and automated. The way of model and digital report is to illustrate the digital model of all parties involved in the project, which has the characteristics of visibility, coordination, simulation, optimization, parameterization and so on. Based on this shared digital model, relevant personnel in all stages of project planning, design, operation and maintenance have access to obtain the data they need in their whole workflow. It provide a reliable basis for decision-making based on these continuous, instant, reliable and consistent data in the entire life cycle of the building.

BIM-based automated drawing review is a way to use BIM model as the review object to realize smart drawing review. That is, by analyzing the characteristics of IFC and semantic web description language, the semantic rule review environment is applied to the review of architectural drawings. The method in the article applies the knowledge base of specifications to the compliance review of drawings, and then evaluates the connectivity of the building by quantitative data and weights, and finally generates a report on the results of the drawing review automatically [3]. In addition, the value of automated drawing review in the BIM environment has the following points:

1. It can actualize multi-departmental BIM automated drawing review and make the details of the drawing review process more transparent, open and fair.
2. It liberates drawing reviewers and avoids the adverse effects of wastage, errors, and rework.
3. It could actualize the three-dimensional visualization of the results of the drawing review, and improve the efficiency of the designer's re-modification of the drawings.

There is no doubt that BIM-based automated drawing review has hit the pain points of current Chinese construction drawing review. Therefore, this research proposes a BIM-based implementation mechanism for digital image review and researches on its application, so as to carry out the informatization of the construction industry, conform to the development trend of technology application, and promote the technological progress of the construction industry.

2.2 Current Status of Research on BIM-Based Automated Drawing Review

According to the current development situation, a considerable number of scholars, research institutions and construction companies domestic and overseas have done a lot of research and attempts on the utilization of BIM technology in construction drawings, model inspection, and informatized drawing review. And they gain valuable basic research results and application results.

Domestically, He [4] and others discussed and put forward suggestions on how to cope with the main BIM-based practical obstacles in the construction industry. Wang [5] studied the BIM construction drawing review information delivery standard, and proposed the key technology of the BIM-based construction drawing review system. Jiang [2] introduced the classification method of the normative clauses, analyzed the normative clauses and established the corresponding Access database. Yu [6] et al. studied the partial automation review in fire protection design. Wang [7] studied fire protection planning and space planning safety inspection in architectural design.

In foreign countries, BIM model checking is realized by relying on some specific software, which mainly include Solibri Model Checker, ED Model Checker. The former is mainly used for collision and fire evacuation type code inspection, and the latter is used for implementing part of building code compliance inspection. In the application of BIM automated drawing review, Liebich, Wix and Forester provided one of the earliest successful cases of the implementation of the compliance inspection system. This research is dedicated to the Singapore building code, and the system developed is mainly focused on the industry standard data format (IFC) related rule processing [8], not the key issue of rule extraction from specification documents. Scholars such as Ding implemented the Australian Disability Access Code on the basis of the IFC model [9]. Their researches focus on integrating building codes with BIM/IFC and realizing automatic compliance checks.

In view of researches in this field, The main application of intelligent drawing examination is fire protection design in BIM models However, there are few researches on intelligent map review involving different professional fields of architecture. Therefore, the BIM-based automated drawing review proposed in this research can be applied to the compliance inspection of different architectural professions, breaking the barriers between different architectural majors, improving the efficiency of drawing review, and making the details of the drawing review process more transparent, open and fair.

2.3 The Necessity of Intelligent Drawing Review Based on BIM

In summary, compared with the traditional design information carrier (drawing/CAD), the application of BIM Technology has become the main focus in the field of construction drawing compliance review. In recent years, foreign scholars have been based on BIM architecture design compliance automatic review system and its key technologies, and gradually began to study the code review of a specific building field, considering the application of code review in a specific field in BIM to a certain extent, it can support the review of specific specifications, but the function of this kind of system support platform is still very limited at present. On the other hand, scholars at home and abroad have done a lot of research on BIM information expression, semantic rule design, review rule structure and so on, which can support the implementation of key technologies of automatic review platform. There are many and mature researches on automatic review management system, which can be used to support the electronic map review process and avoid the cumbersome data handover and information communication process between relevant departments. However, the specific review link is still the manual review with the participation of experts. The intelligent drawing review mechanism based on BIM improves the intelligent drawing review of BIM.

3 BIM-Based Automated Drawing Review Application Mechanism

In order to research the implementation mechanism of automated map review based on BIM environment, a teaching building project with basement in Shunde High-tech Zone was utilized as an example in this research.

The area of the basement floor is 6410.11 square meters in the teaching building. The basement floor is a frame structure system, and the above-ground building has six floors, with a height of 23.8 m. For the model of this case, the contents to be reviewed include five majors: architecture, structure, water supply and drainage, HVAC and electrical. Thereinto, we select the design of fire doors and evacuation doors in the case to show the whole process of automated construction drawings, which should be carried out in the following three aspects: analyzing the process of intelligent drawing examination under the BIM environment, optimizing each link of the process, realizing the overall inspection of the design construction drawing.

3.1 Automated Drawing Review Process

The process of automated drawing examination based on BIM environment mainly includes four aspects: the structure of normative provisions, the preparation of building models, the implementation of rules and the issuance of rules review reports. The specific process of drawing review is shown in Fig. 1.

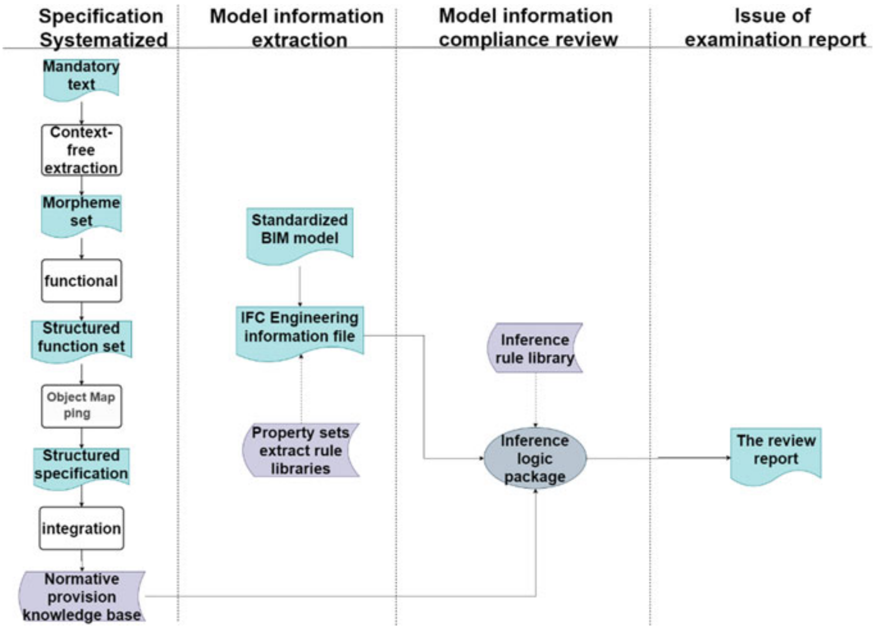

Fig. 1 Review of execution process

1. Specification systematized
   The systematized processing of specifications is a complicated process. First of all, the system sorts out and categorizes the mandatory regulations and provisions involved in related construction disciplines. Then, the system organized into a morpheme set after the morphemes extracted. At last, through object mapping and integration, a knowledge base of normative clauses is formed.
2. Model information extraction
   According to the property requirements of the review and the modeling depth standard, the list of review items needs to be compared before the formal rule reasoning review. It's the basis that direct attributes extracted from the model of BIM. After that, the form of the corresponding attribute sets are stored in file of the industry standard data format (IFC). The extraction process should be classified and extracted according to the attribute classification standard [3]. The main extraction methods include direct extraction, indirect extraction, spatial attribute extraction and simulation attribute extraction.
3. Compliance review
   During the model information compliance review phase, IFC format files for extracted project information are automatically compared with the striated structured functions.
4. Issue of examination report

After automatic comparison review of drawings, a specific review report should be generated. The function of the review report is to reflect the degree of compliance between the design documents and the specifications/regulations after reviewing the construction drawing design documents of a specific project. The construction drawing compliance review needs to perform reverse mapping from the rule review task and map to the original text description of the rule.

3.2 Selection of Database

A large amount of model data and specification provisions need to be matched and compared in the process of diagram review. Therefore, since information organization, storage and management, database needs to be introduced as a warehouse.

The database which required by the automated mapping system under the BIM environment can be divide into two types: one is the BIM model partition database, and the other is the specification provision knowledge database. The former is mainly utilized to store the geometric information of BIM model in partitions, while the latter is utilized to store the non-geometric information of BIM model and text storage such as design specifications and regulations. The establishment of database is the key to the realization of BIM-based drawing audit architecture. Choosing the right database can effectively accelerate the speed of the drawing audit process. Table 1 compares the strengths and weaknesses of databases about MySQL, Assess, and Oracle.

The databases about MySQL, Assess, and Oracle all meet the requirements of the BIM-based automated drawing review system. However, compared with other databases, MySQL database has the following unique characteristics: firstly, the database is small in size, fast and open source; Secondly, it can support multiple operating systems and multiple programming languages. Finally, a quick and stable thread-based memory allocation system that can provide users a operating environment to run continuously without worrying about its stability. Therefore, this system chooses MySQL database as the knowledge base of specification provisions and BIM model partitioned database.

3.3 Disposal of Normative Articles

The system of building design specification is huge and numerous, and the regulatory level is complex. The use of automated processing of normative provisions can effectively reduce the workload.

According to ***Code for fire protection design of buildings*****GB 50,016–2014** ***(2018 edition)***, the code provisions involved in this case are as follows:

Table 1 Database pros and cons comparison

Database	Strength	Weakness
MySQL	1. Open source database system, which is able to strictly follow THE GPL protocol, fully support SQL commands, and use C/C++ language to write data through the system's established procedures 2. MySQL software is widely used, which can run multiple system platforms such as Windows and Linux at the same time, and can maintain the consistency of basic functions such as data transmission, processing and storage 3. Fast data transmission speed and small volume	1. Do not fully support unfamiliar keywords 2. Lack of some stored program functions 3. Security systems are primarily complex but not standard, and change only when mysqladmin is called to reread user privileges
Assess	1. Easy to operate, do not need a database manager with professional level of ascending design, non-professional users can take it to create a database management system 2. It has an integrated environment that can process a variety of data information 3. Extensive support, easy to extend, more flexible	1. When the database is too large, the performance will start to decline when it reaches around 100 M 2. It is easy to appear various database problems caused by too fast database swiping frequency 3. Low database security
Oracle	1. With strong availability, scalability, data security and stability, it is the most widely used database management system in the world 2. It has a wealth of development tools covering all phases of the development cycle 3. It runs on all major platforms and fully support all industry standards 4. Adopting a fully open policy which enables customers to choose the most suitable solution	1. Oracle is a closed source product, so it is almost impossible to take Oracle as one's core technology. Management and maintenance are a bit more difficult 2. High demand for hardware and high price 3. The operation is complex and requires high technical content

1. section 6.4.3 Point 4: The door from the evacuation corridor to the front room and from the front room to the stairwell shall be a class B fire door;
2. section 6.4.10: Normally open class A fire doors shall be provided at fire zones;
3. section 6.4.5 point 5: evacuation doors should not be on the bench.

After the content of the design specification is determined, this case needs to conduct structural processing on the content of the specification. Collecting mandatory provisions in the architectural design specification via screening is the key process, and use Knowledge Graph technology to conduct automatic structural processing on the inherent text semantics of the specification, and finally store the structured provisions in the MySQL database.

For the above process, the application of Knowledge Graph technology is important. As a semantic network that reveals the relationship between entities, Knowledge Graph [10], with a strong semantic description ability, can systematize the rules to make the task of rule checking tractable and be compatible with different information model structures. These characteristics make it a key technology to realize the automatic structure processing of texts.

The application of knowledge mapping technology in this study is as follows:

1. At first, the LDA model text segmentation method [11] is used to locate the specific information in the compulsory provisions text, which refers to the values and judgment words in the text. The LDA model theory treats text as a random mix of specific words, using sampling algorithm to analyze the frequency of different words and assign the words to the corresponding types, at last determine the boundary estimation strategy complete text segmentation and for mapping specific vocabulary.
2. Since the computer cannot directly recognize the natural language text, it is convenient for the computer to understand the text vectorization of the positioned information. At the same time, word vectorization can make words of the same kind have similar vectors, make the probability of recognition of words of the same kind be similar, and retain the original meaning of the text.

The first step of word vectography is to classify and number the marked information, extract and convert the tagged information into corresponding word vectors, and finally sort out the corresponding relationship between the above text type number and word vectors into a data dictionary and input into a database.

1. By using the neural network model of machine deep learning to analyze the statement of text, the relationship between entity and attribute in text is extracted. Firstly, the syntactic dependency analysis is used to enumerate the word relations existing in the text, and then the classified vecondized words are introduced into the neural network model. Finally, the internal logic of entities, attributes, and relationships in the text is expressed by using the structured method of triples [10].Among them, the entity corresponds to the building component in the specification, the attribute corresponds to the geometric size, type, material, elevation and position deviation of the building component, and the relation corresponds to the spatial relationship between the building components and the attribute relationship of the building component itself, as shown in Fig. 2.
2. Finally, by organizing the structured text obtained from analysis and through the identification and entry of the database, the ontology is automatically constructed to acquire the normative knowledge used for the construction of construction drawing review rules and complete the automatic processing of the normative provisions.

According to the above method, the structured normative provisions in this case can be obtained, as shown in Table 2:

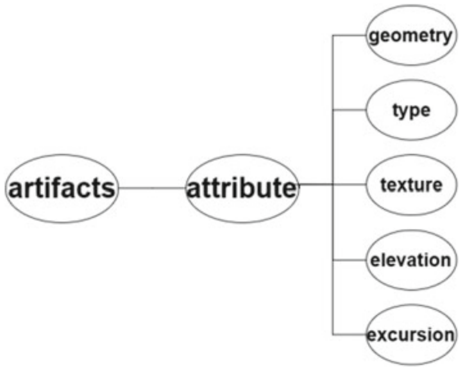

Fig. 2 Basic format for specification articles

Table 2 Structured specification provisions

Component	Attribute	Standard bar collection
Fire doors, evacuation doors	Geometry	None
	Type	The door of the evacuation corridor leading to the front room and the front room leading to the stairwell shall be a class B fire door; Usually open class fire doors should be set in fire zones
	Elevation	None
	Excursion	None

3.4 Standardization of BIM Model and Extraction of Information

In order to realize the extraction of design model information, this case carries out a standard specification for the object of drawing examination, namely BIM model, so that the object of model examination can match the information of specification provisions. Standardizing the model object under review requires not only the format structure of the model, but also the specification of the fineness of the model. In this way, information redundancy can be avoided, and the purpose of convenience and efficiency of later information extraction can be achieved. By referring to ***Hunan Province BIM Review System Model Delivery Standard***, some key model rules are sorted out as in Table 3.

According to the review attribute requirements and model design standards, different types of information should be obtained from the delivered model. The relevant attributes, however, required for the extraction of BIM model information can be divided into direct attributes, indirect attributes, spatial algorithm attributes, and simulation attribute information according to the process of extracting the basic attributes of components. Different types of review attributes have different extraction methods. The following is the specific extraction method (Table 4).

Table 3 Brief specification of model

Rule classification	Key requirements
General provisions	1. The model files delivered for review should be classified and sorted according to standards 2. The content of the delivery review model file should meet the review requirements and include the professional models submitted for review
File organization rules	The organization of model files should be organized in the way of project phases, professions, divisions, stratification, and divisions
Component naming rules	Professional code_system classification_location_component name_custom description
Component expression requirements	According to the review index standard information table, the component category, name, attribute name, attribute definition method and attribute definition format are described
Classification coding rules	Classify and code the delivered review model based on the "Building Information Model Classification and Coding Standard" GB/T5126. If it is not specified in the standard, it can be supplemented in accordance with the rules of the standard and should be stated in the model instruction manual
Review index requirements	The delivered building review single BIM model should include: building single information, building single component set, single space area, and floor information
Model expression rules	The same project model should be modeled with the same global far point and actual size

Table 4 BIM model information extraction requirements

Information classification	Extraction method	Information example
Direct attribute information	Obtained directly from IFC format file	Such as model entity attributes (such as height of doors and windows, materials used)
Indirect attribute information	Mathematical calculation	Using known direct attributes as independent variables, indirect attribute values (such as reinforcement ratio) are obtained through simple mathematical operations
Spatial algorithm attribute information [12]	Sub-model attempts to extract from spatial analysis	Spatial attributes such as passages for the disabled and fire passages
Simulation attribute information	Simulation analysis extraction	Such as building durability, fire performance, etc.

Table 5 BIM model data set

member	Attributes	Model data set
Fire doors, evacuation doors	Geometric size	1500 × 2100
	Types of	Class A fire door
	elevation	−2.5 m
	Offset	No

According to the above method, the location and size of the evacuation door and evacuation stairs can be confirmed through the case model. The standardized name of its components is: JZ-Building-#1 (250,1200,1)-fire door, evacuation door-Class A For evacuation doors, the extraction methods of model information mainly include IFC format file direct extraction method and sub-model attempted spatial analysis extraction method to obtain BIM model data set, as shown in Table 5.

3.5 Model Compliance Review

While reviewing the compliance of the model, the model shall be previewed to determine the integrity of the model information, and then compared with the structured provisions. Finally, the review report shall be issued, and the review mechanism shall be introduced in detail.

1. Preview of the model

Before a rule review, "syntax checked" to the model is essential which helps to determine whether the building model contains the required attributes, names, objects, or the part of the information used to complete the review task. In the preview stage of the building model, it is mainly to verify whether the precision of the BIM model meets the defined requirements according to the information requirements of the construction drawings, so as to ensure the completeness of the submitted BIM model information.

2. Model information versus compliance with structured terms

Two steps to comparing the compliance of model information and structured articles:

First, the building information required by structural provisions is accurately extracted from the BIM model.Secondly, the extracted BIM model information is examined for compliance, and the key point is the rule inference between the model information and the structured specification.The logical regulations applicable to models with different building types are different. For building models with some special places and facilities or meeting some special conditions, it is necessary to determine their types first, such as whether the building environment is a corrosive environment or a micro-corrosive environment. Then, the extracted BIM model data set is matched with the collection of structured specification bar, and the established inference rule base is used to judge whether it conforms to the specification. If it matches, the next item will continue to be matched, or the data and specification are recorded and the next matching is performed [13].

3. Issue of examination report

The review report is a document issued after a review of the construction drawing design documents for a particular project that reflects the degree of compliance of the design documents with the specifications/regulations. Reverse mapping needs to be performed from the rule review task to the original text description of the rule. Local instance parameters and definition of text violating the rule are the basis of the report. More detailed reports, specific text interpretation errors will be reported back, describing the parameters of the instance code associated with the rule, or possible corrective action instructions.

Above all, for this case, through the standard provision (Table 2) and review the model data (Table 3) and concluded that the degree of compliance, review tasks performed in the reverse mapping from the rules, the mapping to the rules of the original text description, examination results, as shown in Fig. 3, attributes—types of inspection results by highlighting “model”:

1. Use “blue” to screen class B fire doors (or evacuation doors) to verify whether the design conforms to specification clause 6.4.3;
2. Use “green” to screen class A fire door (or evacuation door) to verify whether the design conforms to specification clause 6.4.10.

As can be seen from the figure, the fire door and evacuation door of the design document conform to the standards and are class A fire doors.

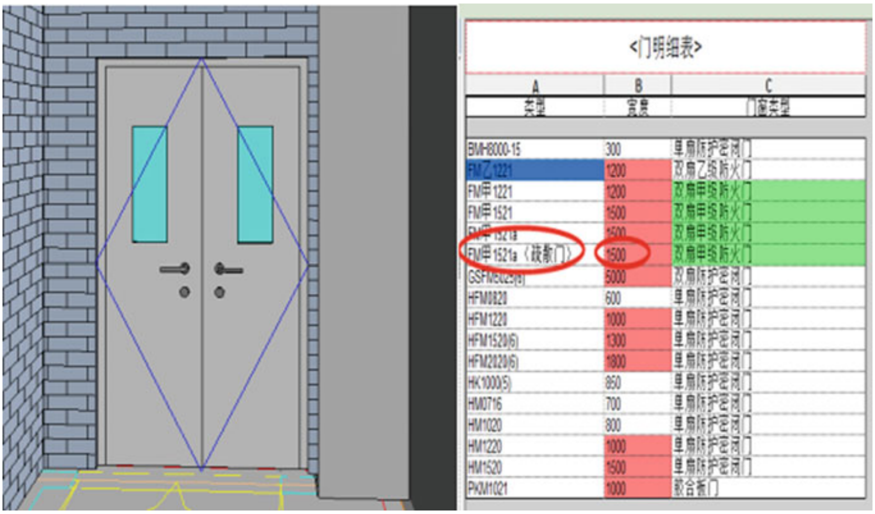

Fig. 3 Fire door (left) and door and window audit Table (right) in the model

3.6 Summary

This chapter demonstrates the feasibility of the BIM-based smart plan review application mechanism based on case studies. First of all, use the knowledge graph technology to structure the normative clauses to establish a normative knowledge base. Then, standardize the BIM model by referring to ***Hunan Province BIM Review System Model Delivery Standar***. According to the characteristics of the component, use the direct extraction method, indirect extraction method and other methods to extract the model information of the object under review. Finally, compare the normative knowledge base and the BIM information extraction database to check and analyze the compliance of the model. To sum up, the automated drawing review under the BIM environment studied in this paper solve various deficiencies and errors roundly in the traditional two-dimensional design, making the drawing review more objective and comprehensive.

4 Summary and Outlook

This paper constructs a BIM-based implementation mechanism for the review of automated architectural design drawings, which takes the advantages of Building Information Modelling (BIM) technology visualization and parametric to turn drawings from two-dimensional to three-dimensional. On the one hand, it not only deal with the problem of checking errors that are prone to traditional checking, but also extremely improves review efficiency. On the other hand, This review method realizes the visualization of information and improves the accuracy of data quantification. Meanwhile the review of architectural design drawings can be comprehensive and efficient, while achieving visibility and accuracy, which can reduce problems such as design changes in the subsequent construction phase.

In addition, the Knowledge Graph is a simple, flexible, and unified semantic network. It not only has powerful semantic description capabilities, can standardize semantic concepts in different professional fields, but also lays the foundation for the full professional design review of construction engineering on account of the characteristic of compatibility with different information model structures. While in the case mentioned above, the model compliance inspection of fire doors and evacuation doors was realized through the BIM automated drawing review method. The review results were efficient and accurate. Therefore, this approach has practical application value.

However, this automated image review mechanism still has certain limitations. When the model has a design change, it is necessary to import the new model again for construction drawing review, which cannot achieve real-time review, resulting in waste of resources and relatively low efficiency. Therefore, in the future, the platform can be linked to each other for model sharing, so that the model and review results can be updated simultaneously, and the efficiency of drawing review can be improved.

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Research on the Node Importance of Urban Rail Transit Network from the Perspective of Complex Network Theory

Min Luo, Liudan Jiao, Yinghan Zhu, Yu Zhang, and Xiangnan Song

Abstract With the rapid development of urban rail transit in China, how to make sure the safe operation of the urban rail transit system has been widely concerned. However, as a typical network structure, urban rail transit is composed of multiple stations. The importance of different sites on the whole network is also different. It is essential for the safe operation of the whole network by managing the significant stations. Therefore, this paper firstly uses the method of space L to establish the topological structure of the rail transit network. Secondly, based on the complex network theory, the five indicators—degree centrality, closeness centrality, betweenness centrality, passenger flow centrality and node property are used to evaluate the node importance of urban rail transit on the network. And then, an integrated model is used to identify the relative importance of nodes in urban rail transit. Finally, the case study is carried out in combination with China Chongqing Rail transit Line 3, which has important significance for the optimization of the urban rail transit network.

Keywords Urban rail transit · Complex network · Topological structure · Node importance · Integrated model

1 Introduction

With the rapid development of society and economy, China's urbanization rate has gradually increased, and the urban population is increasing rapidly. People's attention to the quality of life, the requirements for travel convenience, green travel, and the increasing awareness of environmental protection, have continuously promoted the development of Urban Rail Transit in China. More and more metropolises have formed a network of urban rail transit in China. It greatly eases the road traffic

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pressure, vehicle exhaust emissions and noise pollution, bus convenience, safety and other issues. However, the structure of urban rail transit system is becoming more and more complex. The increasing carrying capacity, system failure, human factors, natural disasters and other emergencies will pose a severe threat to the rail transit system. For examples: on June 27, 2017, a passenger at Babaoshan station of Beijing Metro Line 1 entered the mainline of operation track, resulting in the interruption of train operation. On July 28, 2017, affected by a rainstorm and strong wind, some foreign matters intruded into the track area of Liziba and Niujiaotuo section of rail line 2, resulting in partial outage of rail line 2 for 1 h. In late June 2019, Shanghai Rail Transit Line 1 broke down in the early peak period, and it took one hour to resume regular operation fully. The fault is that the middle section of the rail transit is stopped, resulting in a large number of passengers stranded. On August 11, 2019, due to a sudden fault between Dadongmen station and Qiupuhe Road Station of Hefei Rail Transit Line 1, the train could not run normally. Given the above problems, scholars have carried out a series of studies on the safe operation of rail transit. The research on the importance of urban rail transit station is more conducive to dealing with emergencies and reducing the potential risks of rail transit operation safety caused by the rapid increase of passenger flow.

At present, the research of complex network in various traffic networks has attracted extensive attention, such as railway [1], aviation [2–4], public transport [5, 6], subway [7], and rail transit [8, 9]. These studies show that a complex network is a useful tool to analyze the topology of the urban rail transit network. When the nodes in rail transit fail, the impact will rapidly extend to the whole network. Therefore, quantifying the importance of nodes in complex networks has essential theoretical and practical significance. In the aspect of node importance recognition, Meng et al. improved the traditional TOPSIS evaluation method from index weight and importance ranking, and then combined coefficient of variation method with improved TOPSIS to rank the importance of nodes on the network [8]. Yang et al. [9] through considered the three factors: the degree centrality, proximity centrality and betweenness centrality, and used the Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method to rank the importance of nodes. Some scholars have also started to include the passenger flow and node property into the research and analysis of the importance of the site. For example, based on the traditional complex network theory, Chen et al. explored the centrality of network passenger flow and identified the importance of stations [10]. Taking Beijing rail transit network as an example, Sun et al. (2017) used the L-space method to accurately analyze the relationship between rail passenger flow propagation path and its influence scope and the topological structure of rail transit network [11]. Wang et al. evaluated the site attributes from the two aspects of site size and site type to evaluate the importance of the site [21].

Based on the above discussion, most of the existing studies evaluated the importance of nodes from a single aspect. There is also few studies considered the factors of passenger flow and station operation or traffic function to analysis the importance of nodes in urban rail transit. Therefore, this paper will add these two factors to improve the diversity of node importance identification. Starting from urban rail transit, this paper constructs a topological structure model using Space-L and then analyzes the topology characteristics of the network based on the complex network theory, next on the basis of degree centrality [12], closeness centrality [13] and betweenness centrality [14], the passenger flow centrality and site attributes are added as the indexes to identify node importance.

2 Construction of the Urban Rail Transit Network Model

2.1 Basic Theory of Complex Networks

Complex network theory is to analyze the characteristics of network structure by calculating and counting the node degree and degree distribution, network diameter and average path length, clustering coefficient and overall efficiency. In the study of complex networks, Undirected rail transit network G (V, E) can be described to analyze the characteristics of the network, and any pair of stations (i, j) and (j, i) on the network correspond to the same line, where V is the set of nodes and E is the set of edges. The number of nodes in a complex network is represented by $N = |V|$, and the number of edges is represented by $M = |E|$.

2.1.1 Node Degree and Degree Distribution

Node degree k_i [15] refers to the number of points or edges connected to node i(i $\in N$), which reflects the connectivity between the node and its adjacent nodes. The average degree is the average value of all node degrees, expressed by $\overline{k}$.

BA model [16] is a scale-free complex network model. The degree distribution $P(k_i)$ [15] of scale-free network represents the proportion of nodes with moderate value k to the total number of nodes on the network, and its essence is the probability distribution function of node degree k_i. Its value is equal to the ratio of the number of nodes with node degree k_i to the number of all nodes on the network. The degree distribution $P(k_i)$ is defined as follows:

$$P(k_i) = \frac{n_{k_i}}{N}$$

where: $i = 1, 2, N$; N: the number of all nodes; n_{ki}: the number of nodes with degree k_i.

2.1.2 Network Diameter and Average Path Length

On the network, the minimum number of edges required for node i to node j is the shortest distance d_{ij}, and the maximum value of the shortest distance between nodes is the diameter of the network, which is recorded as D.

$D = \max_{i,j} d_{ij}$.

The average path length L [17] is the average value of the shortest path length required by a node to reach all other nodes in the rail network. The smaller the value is, the more convenient it is for the node to reach other nodes. The formula is as follows:

$$L = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij}$$

2.1.3 Clustering Coefficient

The clustering coefficient C_i [17] represents the closeness of the connection between nodes in rail transit network. If the k_i adjacent nodes of node$i$ have e_i edges connected with each other, then the clustering coefficient of node i is defined as the ratio of the number of edges between adjacent nodes e_i and the maximum number of connected edges. The formula is as follows:

$$C_i = \frac{2e_i}{k_i(k_i - 1)}$$

When all the k_i nodes connected by node i are connected by each other, then there are $\frac{k_i(k_i - 1)}{2}$ edges between these adjacent nodes. In this case, the number of network edges is the most, $C_i = 1$; when the degree of the node i is 1 or 0, $C_i = 0$; When there is no connection between k_i connection points of node i, $C_i = 0$.

The clustering coefficient C of the whole network of rail transit is the average of the clustering coefficients of all nodes or stations:

$$C = \frac{1}{N} \sum_{i=1}^{N} C_i.$$

2.1.4 Overall Efficiency

The connectivity efficiency E_{ij} [18] is the reciprocal of the shortest path length d_{ij} between two nodes. The shorter the shortest path length between two nodes is, the higher the connectivity efficiency of two nodes is.

$$E_{ij} = 1/d_{ij}$$

The network overall efficiency [12] is the average value of all effective connections on the network.

$$E = \frac{1}{N(N-1)} \sum_{i \neq j} E_{ij}$$

2.2 Urban Rail Transit Network Model

2.2.1 Topological Structure Model of Rail Transit Complex Network

Urban rail transit network has mainly three complex network models: Space L, Space R and Space P [19]. The Space L method regards the rail stations as nodes. If two stations are geographically adjacent and have the same train number passing through, then there is a connecting edge between the nodes. But the Space R model is to use nodes to represent track lines. If there are public stops between lines, there are connected edges. Space P method abstracts the stations in the urban rail transit network as nodes. If there is a direct rail line between the two stations, the two stations will be connected. In order to facilitate the analysis of the most basic characteristics of the rail network and the characteristics of the rail section, this paper constructs the complex network topology model of rail transit based on Space L model.

2.2.2 Node Importance Index of Rail Transit Network

The importance of stations on the network topology is reflected in different dimensions. In this study, the urban rail transit network is regarded as a complex network. Through considering the relevance of the station with other stations in the online network, the aggregation capacity of the station for passenger flow and the site's attributes, the five indicators—degree centrality, closeness centrality, betweenness centrality, passenger flow centrality and node property are used to evaluate the node importance of rail stations on the network.

1. Degree centrality
   Degree centrality [12] refers to the ratio between the number of intervals formed by the node connecting other nodes and the maximum number of possible intervals, which directly reflects the possibility of a direct connection between the node and other nodes on the network. The larger the value is, the more important the node is. The degree centrality of each node in the undirected network can be expressed as:

$$DC_i = \frac{k_i}{N-1}$$

where: k_i is the degree value of node i; N is the number of network nodes.

2. Closeness centrality

   Closeness centrality [13] reflects the proximity of a node to all other nodes on the network, which is expressed as the reciprocal of the average shortest path length from the node to other sites on the network multiplied by the number of other nodes:

$$CC_i = (N-1)(\sum_{j=1}^{N} d_{ij})^{-1}$$

   where: d_{ij} is the shortest path length between i and j.

   The higher the centrality value of a node is, the greater the degree of its being in the center of the network is, which reflects the convenience of the node to connect with other nodes.

3. Betweenness centrality

   Betweenness centrality [14] refers to the proportion of the number of shortest paths passing through the node in the total number of shortest paths on the network:

$$B_i = \sum_{j,k \in N, j \neq k} \frac{d_{jk}(i)}{d_{jk}}$$

   where $d_{jk}(i)$ is the number of the shortest paths connecting points j and k passing through points i; d_{jk} is the number of the shortest paths between points j and k. The control ability of a node to transmit information according to the shortest path is described. The higher the value is, the greater the importance of the node is. After removing these nodes, the impact on network transmission is greater.

4. Passenger flow centrality

   In order to truly reflect the actual station status of urban rail transit network operation, the passenger flow centrality [10] is proposed. On the basis of a single network topology index, further considering the influence of passenger flow factors, it is defined as the percentage of passenger flow passing through a station in the whole network in a certain period of time.

$$PFC_i = {}^{f_i}\!/_{F}$$

   where: f_i refers to all passenger flows passing through nodes in a certain period of time, and F refers to the total number of passengers using rail transit network in the same period. When all passenger flow is monopolized by one station, the index is equal to 1; when all stations have the same scale, the index is equal to ${}^{1}\!/_{n}$, so the larger the value is, the higher the aggregation of the network is.

5. Node property

The classification methods of urban rail stations can be divided into node oriented and place oriented [20]. In order to reflect the traffic function of the station, according to the node-oriented station classification method, the node property NP_i of urban rail transit station are divided into ordinary station, transfer station, train transfer station, airport transfer station, public transport hub station, and passenger station. Assuming that the properties of each site are equally important, Each property is 1 point and the final score is the cumulative sum.

3 Case Study

Up to December 2017, Chongqing Rail Transit Line 3 is a straddle type monorail transit line with the highest transportation efficiency, the most extended single-track operation mileage and the most complex terrain conditions in the world. Therefore, this study takes Line 3 for case study. And the data is collected from Chongqing Rail Transit (Group) Co. LTD. Based on the station data of Chongqing Rail Transit Line 3 on December 28, 2017, the undirected and unweighted topology network of Chongqing rail transit is established by Space L model method. The node number and topology diagram of each node is shown in Fig. 1 by using the Pajek software.

It can be seen from Table 1 that there are 45 with 44 sides connected stations in Chongqing Rail Transit Line 3. The average degree is 2.2, meaning that on average

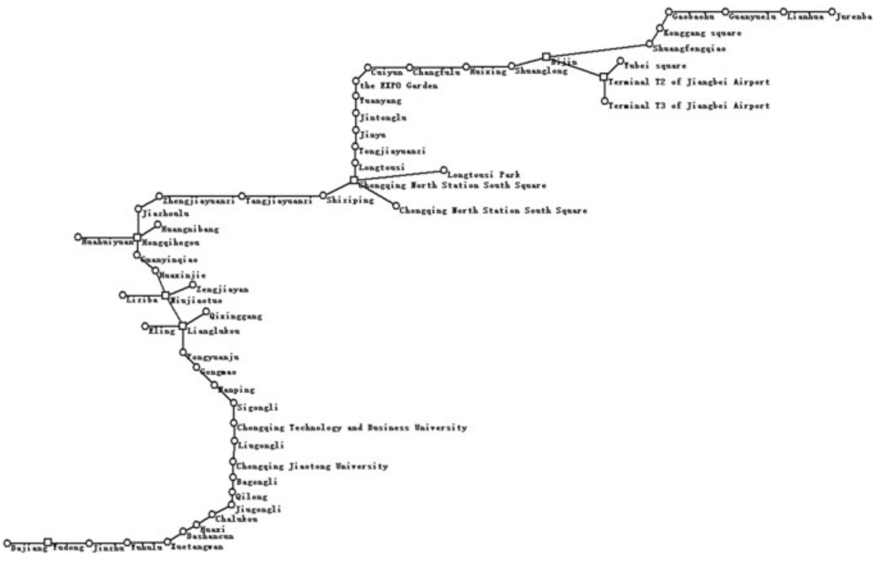

Fig. 1 Topology network of Chongqing Rail Transit Line 3

Table 1 Network characteristic index of Chongqing Rail Transit Line 3

Characteristic index	Number of nodes	Number of sides	Average degree	Average path length	Average clustering coefficient	Network betweenness	Network global efficiency
Line 3	45	44	2.2	15.08	0	0.30	0.15

one site is directly connected with 2.2 other sites; The average path length is 15.08, meaning that the shortest path length required for a site to reach all other sites is 15.08; And the aggregation coefficient is 0, the values of network betweenness and global efficiency are 0.30 and 0.15 respectively, indicating that there is a connection between adjacent stations, but there is not enough connection.

Take Yudong, the starting station of line 3, as an example. We can see in Fig. 1, Yudong is connected with two stations. So it's degree is 2 and there are 45 stations, we can get the value of degree centrality according to Formula 1: $DC_1 = \frac{k_1}{N-1} = \frac{2}{45 - 1} = 0.045$. In the same way, we can get closeness centrality and betweenness centrality. And then based on the passenger flow date of Chongqing Rail transit on December 28, 2017, we can get the daily total passenger flow of line 3 and the passenger flow of Yudong station. By calculation, we can get the passenger flow centrality: $PFC_1 = \frac{f_1}{F} = \frac{10771}{540638} = 0.020$. At last, Yudong station is not only an ordinary station but a rail transfer station, so it's node property is 2. Similarly, we can get values of the remaining 44 stations in Table 2.

By comparing the centrality index of Table 2. For degree centrality, the highest value is the four stations including Lianglukou, Niujiaotuo, Hongqihegou and Chongqing North Station South Square. The value of degree centrality is 0.091, indicating their relevance in line 3 is the best to remain the smooth flow of the network.

For closeness centrality, the highest value is 0.088 including three stations which are Jiazhoulu, Hongqihegou and Chongqing North Station South Square, indicating that the average shortest distance with all other nodes is the smallest, and the connection with other nodes is most convenient. They are in the central position of the network.

For betweenness centrality, Hongqihegou station is the maximum station with the value of 0.545, indicating that most of the shortest path of the network will pass through this station.Therefore, this station has a huge intermediate effect and good information control ability.

For passenger flow centrality, Guanyinqiao station is the maximum station with the value of 0.109, indicating that Guanyinqiao station has a strong aggregation capacity for passenger flow and large passenger flow.

For node property, the two stations Lianglukou and Chongqing North Station South Square are the largest with the value of 5, because they are not only ordinary stations, but also rail, train, public transport hub and passenger transfer stations. They play a significant role in the transfer and have comprehensive traffic functions.

We can clearly see the single importance index of the node in Table 2, but it is difficult to compare the importance of nodes. In order to better judge the relative

Table 2 Calculation results of central indicators

Station	*DCi*	*CCi*	*BCi*	*PFCi*	*NPi*	Station	*DCi*	*CCi*	*BCi*	*PFCi*	*NPi*
Yudong	0.045	0.045	0.036	0.020	2	Jiazhoulu	0.045	0.088	0.508	0.069	1
Jinzhu	0.045	0.047	0.071	0.011	1	Zhengjiayuanzi	0.045	0.088	0.505	0.020	1
Yuhulu	0.045	0.049	0.105	0.014	3	Tangjiayuanzi	0.045	0.087	0.501	0.014	1
Xuetangwan	0.045	0.051	0.137	0.016	1	Shiziping	0.045	0.086	0.496	0.027	1
Dashancun	0.045	0.053	0.168	0.007	1	Chongqing North Station South Square	0.091	0.085	0.516	0.022	5
Huaxi	0.045	0.056	0.198	0.012	1	Longtousi	0.045	0.084	0.461	0.020	1
Chalukou	0.045	0.058	0.226	0.007	1	Tongjiayuanzi	0.045	0.082	0.448	0.015	1
Jiugongli	0.045	0.061	0.253	0.023	1	Jinyu	0.045	0.080	0.435	0.016	1
Qilong	0.045	0.063	0.279	0.010	1	Jintonglu	0.045	0.078	0.420	0.032	1
Bagongli	0.045	0.066	0.303	0.008	1	Yuanyang	0.045	0.076	0.404	0.018	1
Chongqing Jiaotong University	0.045	0.068	0.326	0.012	1	the EXPO Garden	0.045	0.073	0.387	0.016	1
Liugongli	0.045	0.071	0.347	0.019	1	Cuiyun	0.045	0.071	0.368	0.007	1
Chongqing Technology and Business University	0.045	0.073	0.368	0.027	1	Changfulu	0.045	0.068	0.347	0.005	1
Sigongli	0.045	0.076	0.387	0.024	3	Huixing	0.045	0.066	0.326	0.024	1
Nanping	0.045	0.078	0.404	0.073	1	Shuanglong	0.045	0.063	0.303	0.016	1
Gongmao	0.045	0.080	0.420	0.046	2	Bijin	0.068	0.061	0.291	0.011	2
Tongyuanju	0.045	0.082	0.435	0.013	1	Terminal T2 of Jiangbei Airport	0.068	0.059	0.072	0.008	4
Lianglukou	0.091	0.084	0.496	0.059	5	Shuangfengqiao	0.045	0.058	0.168	0.003	3
Niujiaotuo	0.091	0.085	0.525	0.023	2	Konggang square	0.045	0.056	0.137	0.010	1
Huaxinjie	0.045	0.086	0.501	0.022	1	Gaobaohu	0.045	0.053	0.105	0.007	1

(continued)

Table 2 (continued)

Station	*DCi*	*CCi*	*BCi*	*PFCi*	*NPi*	Station	*DCi*	*CCi*	*BCi*	*PFCi*	*NPi*
Guanyinqiao	0.045	0.087	0.505	0.109	1	Guanyuelu	0.045	0.051	0.071	0.006	1
Hongqihegou	0.091	0.088	0.545	0.064	4	Lianhua	0.045	0.049	0.036	0.012	1
						Jurenba	0.023	0.047	0.000	0.002	1

importance of the above nodes, an integrated model will be established to better judge the relative importance of nodes:

Step 1: Establish a benchmark for these five index parameters. The maximum values of *DCi*, *CCi*, *BCi*, *PFCi*, and *NPi* (0.091, 0.088, 0.545, 0.109, and 5 in Table 2) are choose as the benchmark.

Step 2: Obtain the relative index of node centrality according to $DC_i' = DC_i \big/ DC_{i(\max)}$. $DC_{i(\max)}$ is the benchmark above. The relative calculation results of central indicators are shown in Table 3. In Table 3, the maximum value of parameters is 1, meaning that the site is the most important in this indicator.

Step 3: Use the integrated model and calculate the total score of each station by $(DC_i^{'} + CC_i^{'} + BC_i^{'} + PFC_i^{'} + NP_i^{'}) \times 0.2$ to determine the relative importance of five comprehensive indicators.

Based on the steps above, the relative importance of five comprehensive indicators of 45 stations on line 3 can be calculated. The results is shown in Table 4 that the top five stations are Lianglukou, Hongqihegou, Chongqing North Station South Square, Guanyinqiao and Niujiaotuo. Compared with the previous table, it can be seen that Lianglukou is the highest in total score, but it is not the highest in closeness centrality, betweenness centrality and passenger flow centrality, even in closeness centrality and betweeness centrality, it doesn't reach the top five, indicating that integrated model is more suitable for evaluating node importance.

4 Conclusion

Carrying on the concrete analysis combining with the case of Chongqing rail transit Line 3, this study establishes topological structure model of rail transit complex network and analyzes its structural features. Based on the complex network theory, the topological characteristic indexes such as average degree (2.22), network betweenness (0.3) and network global efficiency (0.15) of line 3 are obtained, reflecting the problems of insufficient connections between stations and the waste of topology structure, which can provide basis for further planning and adjustment of follow-up lines.

By analyzing the single importance index of the node in line 3, Lianglukou, Niujiaotuo, Hongqihegou and Chongqing North Station South Square have the most significant impact on network connectivity. Jiazhoulu, Hongqihegou and Zhengjiayuanyuan are located in the centre of the network, and the average shortest distance with all other nodes is the smallest; Hongqihegou is the node that passes the most times in the shortest path generation process and plays a robust intermediate role; Guanyinqiao has the most reliable passenger flow aggregation capacity; the Lianglukou and Chongqing North Station South Square have many transportation functions, taking on a large transport transfer role.

Table 3 Relative calculation results of central indicators

Station	DC_i'	CC_i'	BC_i'	PFC_i	NP_i'	Station	DC_i'	CC_i'	BC_i'	PFC_i	NP_i'
Yudong	0.50	0.508	0.067	0.183	0.4	Jiazhoulu	0.50	1.000	0.932	0.632	0.2
Jinzhu	0.50	0.531	0.131	0.101	0.2	Zhengjiayuanzi	0.50	0.998	0.927	0.182	0.2
Yuhulu	0.50	0.556	0.193	0.130	0.6	Tangjiayuanzi	0.50	0.992	0.920	0.126	0.2
Xuetangwan	0.50	0.581	0.252	0.150	0.2	Shiziping	0.50	0.982	0.910	0.248	0.2
Dashancun	0.50	0.607	0.309	0.064	0.2	Chongqing North Station South Square	1.00	0.969	0.948	0.199	1
Huaxi	0.50	0.634	0.363	0.114	0.2	Longtousi	0.50	0.952	0.845	0.185	0.2
Chalukou	0.50	0.661	0.415	0.068	0.2	Tongjiayuanzi	0.50	0.933	0.823	0.138	0.2
Jiugongli	0.50	0.690	0.465	0.215	0.2	Jinyu	0.50	0.911	0.799	0.150	0.2
Qilong	0.50	0.718	0.512	0.094	0.2	Jintonglu	0.50	0.887	0.771	0.292	0.2
Bagongli	0.50	0.747	0.556	0.070	0.2	Yuanyang	0.50	0.861	0.742	0.163	0.2
Chongqing Jiaotong University	0.50	0.776	0.598	0.114	0.2	the EXPO Garden	0.50	0.833	0.710	0.146	0.2
Liugongli	0.50	0.805	0.638	0.170	0.2	Cuiyun	0.50	0.805	0.675	0.068	0.2
Chongqing Technology and Business University	0.50	0.833	0.675	0.244	0.2	Changfulu	0.50	0.776	0.638	0.047	0.2
Sigongli	0.50	0.861	0.710	0.220	0.6	Huixing	0.50	0.747	0.598	0.220	0.2
Nanping	0.50	0.887	0.742	0.669	0.2	Shuanglong	0.50	0.718	0.556	0.148	0.2
Gongmao	0.50	0.911	0.771	0.421	0.4	Bijin	0.75	0.690	0.534	0.101	0.4
Tongyuanju	0.50	0.933	0.799	0.122	0.2	Terminal T2 of Jiangbei Airport	0.75	0.675	0.132	0.073	0.8
Lianglukou	1.00	0.952	0.911	0.543	1	Shuangfengqiao	0.50	0.661	0.309	0.023	0.6
Niujiaotuo	1.00	0.969	0.963	0.211	0.4	Konggang square	0.50	0.633	0.252	0.096	0.2
Huaxinjie	0.50	0.982	0.920	0.202	0.2	Gaobaohu	0.50	0.605	0.193	0.065	0.2
Guanyinqiao	0.50	0.992	0.927	1.000	0.2	Guanyuelu	0.50	0.579	0.131	0.057	0.2
Hongqihegou	1.00	0.998	1.000	0.585	0.8	Lianhua	0.50	0.553	0.067	0.108	0.2

(continued)

Table 3 (continued)

Station	$DC_i^{'}$	$CC_i^{'}$	$BC_i^{'}$	PFC_i	$NP_i^{'}$	Station	$DC_i^{'}$	$CC_i^{'}$	$BC_i^{'}$	PFC_i	$NP_i^{'}$
						Jurenba	0.25	0.529	0.000	0.020	0.2

Table 4 Calculation results of total score

Station	Total score $(DC_i^{'} + CC_i^{'} + BC_i^{'} + PFC_i^{'} + NP_i^{'}) \times 0.2$	Station	Total score $(DC_i^{'} + CC_i^{'} + BC_i^{'} + PFC_i^{'} + NP_i^{'}) \times 0.2$
Lianglukou	0.881	the EXPO Garden	0.478
Hongqihegou	0.877	Liugongli	0.463
Chongqing North Station South Square	0.823	Huixing	0.453
Guanyinqiao	0.724	Cuiyun	0.450
Niujiaotuo	0.709	Chongqing Jiaotong University	0.438
Jiazhoulu	0.653	Changfulu	0.432
Gongmao	0.601	Shuanglong	0.424
Nanping	0.600	Shuangfengqiao	0.419
Sigongli	0.578	Bagongli	0.415
Shiziping	0.568	Jiugongli	0.414
Zhengjiayuanzi	0.561	Qilong	0.405
Huaxinjie	0.561	Yuhulu	0.396
Tangjiayuanzi	0.548	Chalukou	0.369
Longtousi	0.537	Huaxi	0.362
Jintonglu	0.530	Xuetangwan	0.337
Tongjiayuanzi	0.519	Konggang square	0.336
Jinyu	0.512	Dashancun	0.336
Tongyuanju	0.511	Yudong	0.332
Bijin	0.495	Gaobaohu	0.313
Yuanyang	0.493	Guanyuelu	0.293
Chongqing Technology and Business University	0.490	Jinzhu	0.293
Terminal T2 of Jiangbei Airport	0.486	Lianhua	0.285
		Jurenba	0.200

But it's hard to tell which is the most important site on the network, so integrated model is used to evaluate and analyze. By calculation, Lianglukou, Hongqihegou, Chongqing North Station South Square, Guanyinqiao and Niujiaotuo stations are the top five important stations of line 3, which play an essential role in the regular operation of the network.

According to the evaluation results of rail transit stations, special attention should be paid to the resource allocation and reliability of these important nodes on the network in the daily management practice of rail transit to reduce the unstable factors as far as possible and ensure the smooth operation of the whole rail transit network.

And in this study, the research data is about one rail transit line in one day. In further, our research group will collect more research data to analyses the whole system.

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Community's Interest in Brownfield Development: A Case in Melbourne

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Abstract Brownfield developments may be theoretically and practically approached as the method and process to convert previous industrial land with environmental concern that mitigates problem occurs in the urbanisation processes. Given rapid urban growth and land supply constraint, urban brownfield is becoming attractive to developers and local government. Along with research focus on developer and planner's perspectives, this paper investigates local community's involvement in and its impact on brownfield developments. Local community suffers cost and risk associate with brownfield development which can be easily discounted or even ignored in development phases. It is important to understand community's concerns, involvement and impacts. A brownfield project from Melbourne is studied by questionnaire surveys and face-to-face interviews. The local community confirms their awareness of the project although their involvement is low because many claimed their lack of in-depth knowledge of project effects. Obstructions and lack of motivation at local community level in brownfield development impose policy challenge and social risk.

Keywords Brownfields development · Community involvement · Passive and active responses · Melbourne

1 Introduction

Brownfields development is recognised as a process to convert developed land that is obsolete and underused [1, 2]. Developing brownfields takes sustainable development as an opportunity (method) to control urban sprawl and preserve urban region

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and environmental protection strategy, while it contributes to growth and justice [3–12]. Brownfield enjoys existing infrastructure while it reduces congestion and retains density [3]. Its land use history suggests risk and cost may involve before benefit can be realised. Brownfield is described as underutilized, contaminated infill site with land use change relates to the legacy of Industrial Revolution that inner city was left for industrial [9]. This brings popular definition that "… *abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination*" [13–15]. It was later amended to: "*with certain legal exclusions and additions, 'brownfield site' means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant*" [13]. Its application is limited to policy and finance issues and it is hard to develop generic brownfield definition because states and countries differ in their context and challenge [15–18]. A definition relevant to this paper is: "*any land or premises which has previously been used or developed and is not currently fully in use, although it may be partially occupied or utilized. It may also be vacant, derelict or contaminated…brownfield site is not necessarily available for immediate use without intervention*" [19]. It implies stakeholder interest, emphasizing contextual aspect of brownfield cases.

Brownfield development often involves high risk as it may trigger high cost for remediation, infrastructure upgrade, legal liability, and local community resistance [1]. Negativity of potential land contamination raises uncertainty even community-wide stigma [13]. Not only is brownfields development risky to landowner and developer, it also concerns broader members of community [17]. It is important to ensure sufficient and effective land use process for brownfield development where local community's concern is satisfied so that risk could be controlled for better outcome to satisfy interests of the broader community.

Relative to research from the perspectives of project team, few has focused on community's impact and importance. Being a key group, community and its support has been mentioned as a contributor to promotion, identification and success of brownfield development [1, 9, 14, 17, 19]; though the literature focuses on the private sector with some focus on planning and political perspectives [20]. Local community does not often have strong financial and political incentive, albeit obstacle, to participate and this situation can worsen if affected local residents are immobile during or after the development. So it is important to gain them better understanding of project impact and that their concerns effectively communicated, while gaining the social support. It is useful to improve planning process for local community understanding and participation. Australia has developed its planning process with the opportunity for local community to participate in land redevelopment. This study aims for gaining detailed insights of community participation at the project level.

2 Community's Concern of Brownfields

Community's role in brownfield development is either broadly discussed in planning process or as a factor contributing to project success. Much is from policymaking and developer's perspectives of environmental contamination, financial risk and little on community wellbeing. Planning as a method to allocate public goods represents policy objective to balance community's diverse land use interests [21]. Participation of local community is recognised main contributor to planning and landscape design and actual needs [22]. Opinions exist on community need compared to other stakeholders due to diverse interests [2, 23] that leads to methods of community planning such as the outcome-led approach [23]. Large scale public involvement prevails when planning authority adopts it to frame the interest of small community groups. Opportunity or problem driven approach supports the necessary of community participation [23]. The concern of community participation is disconnected with brownfields development is not uncommon as similar situation can be found in research of community and social capital development [24]. This means that brownfield project influences wider-scale community welfare by linking it with community interactions.

Regarding community development associated perspectives, the brownfield literature has community's participation as contributor to the social success of brownfield reuse. For instance, the US Environmental Protection Agency identified key themes on sustainable brownfield projects by literature review where idea of community organization and community participation are defined as key feature of the sustainability of brownfields [2]. Community involvement and participation is costly and problematic even though community represents groups of people of varying need and interest. It is argued that community participation could not only "enhances a project's bottom line" but also contributes to design opinion and social support [2]. The study of brownfields program in Florida recognises community's role for responsible development through enhancing accessibility and participation of community [9]. Similar finding is found in nationwide survey in the U.S. that collects responses from brownfield development stakeholders such as developer and planner, where community's support is elected has strong factor of success [14]. Most parties involved in brownfields are aware of the important role of community and its participation.

Community participation may impose negative impact on brownfield development as one may argue community's involvement potentially increases risks because it may object on the project or demand more inputs from developer due to concern of contamination, cost for remediation, liability and so on [19]. It is the lack of information and communication results in negative and passive feeling in community [13]. Specifically, landlords may concern negative outcome of property information exposure involving loss in sales price, regulation change and decontamination cost that leads to information asymmetry and risk to involved parties [20]. Communication efficiency and effective community participation improves project's social performance, especially for greenfield or cleaned sites. Communication among all parties will benefit from plans facilitate community and private interests for communication and distribution purposes. Developer could benefit from having its development plan incorporating community's concern and interest for it to represent community support, so to save on time and effort in reducing objection and to gain planning approval [9]. Theoretically, among other indicators, multi-attribute decision-making process of brownfield developments allocates heavy weight on community support in anticipation that community participation will bring significant positive impact on brownfields project [19].

The literature recognises community's importance in brownfield process but few has analysed in detail. Considers risk involved in brownfield development, from planning and development perspectives, while the incentive to take risky project concern potential social and financial benefit of the development exceeds the its cost [2]. Much of its benefits could hardly be realised without firstly understanding the problems and opportunities that are associated with the local community, such as regeneration effect of brownfield on it [2]. Without deeper knowledge of community's role and importance, it will substantially limit the scope and depth of current research. This paper will focus on evidence of local community status, involvement and impact in a major brownfield residential development project in Melbourne.

3 Methodology and Design

This study investigates and analyses a case of brownfield residential development. Data was collected by qualitative method including questionnaire-based survey and interviews with the local community and developer of the subject brownfields development. As the earlier sections discussed, what is absent from the current research is detailed investigation and analysis of community's role and its participation in brownfield development. The investigation should be based on real-life example with detailed information and analysis. An in-depth understanding could be achieved by qualitative method. Although property-by-property research approach has been used frequently in brownfields developments related researches and contains some issues [2], larger-scale endeavour with greater research area or quantitative method could be considered after some detailed researches are done and some basic understandings are built. Qualitative method could provide detailed and coherent insights by bringing together heterogeneous data [25], which should benefit study of this nature. Mixed method, though, is popular in property related researches as it combines both the methods to minimise the methods' limitations and provide various perspectives, it is difficult to conduct without basic understanding of the research topic. Qualitative method is adopted in this research, supported by researches adopting same approach in this field [26].

3.1 Development of Alphington Paper Mill Site

The case study is known as Alphington Paper Mill Development (also known as the YarraBend Residential Development) in Melbourne, Australia. The project was selected for the following reasons. Firstly, for a long period Melbourne has developed and established comprehensive planning provision and regulations related to brownfield development activities. Melbourne as a former industrial city not only has large brownfields developments profile and sites but also develops detailed development regulatory framework and community participation procedures [17, 27]. The system allows specific planning scheme for each particular brownfield site based on local council management and practices, effectively and qualitatively expressed. Secondly, the Alphington Paper Mill Development (hereafter, APMD) is identified due to its condition, scale, significance and accessibility of data. The APMD site was used by the Alphington Paper Mill Factory, during which the site had been utilised that generated high level contamination. Contamination risk exists for it as residential development site. The site is over 16-hectare of land area, has long project timeline, high project complexity and significant private and social impacts. The local council, the City of Yarra, recognises the project as a major strategic redevelopment within its jurisdiction in the inner Melbourne, which adds the significance of the project. The Council generated specific development plan overlay scheme based on the APMD adding to its significance and community impact. The Council appointed a community reference group in addition to standard community consultation process, which makes the project a suitable case to examine the local community's responses and involvement. Figure 1 provides the location and some contextual information.

This study designed and conducted questionnaire survey of residents in the local community and face-to-face interviews with community member and developer. 51 individuals participated in the survey, with 29 males and 22 females. The age range is 18–65, and the education background of participants is Bachelor's degree or under. The results are divided under two categories for analysis, residential status as residents who live in Alphington as local resident and participants who live outside of Alphington as non-resident, and land tenure being property owner and renter. To bring out more in-depth insights, interviews were conducted with one local community club member and developer representatives. By, the it is expected that community involvement and corresponding impacts in the APMD case are revealed through analysing interactions with survey and interview results taking into account the case context and research limitations.

Fig. 1 The APMD's location map (*Source* APMD development map 2019)

4 Findings and Discussion

4.1 Huge Project and Little Difference in Response

Results suggest insignificant difference between local and non-local residents of Alphington. 16 out of 28 residents and 16 out of 23 non-residents indicate their early awareness of the APMD in 2015. This relates to the scope and exposure of the project. However, this high-level awareness did not translate into community's direct involvement. Almost half of the residents and non-residents believe their involvement as community member in the APMD is minimum. Of non-residents, it is clear that they have limited access to information and suffers from less direct project impact on their livelihood thus low-level involvement. However, of the local residents, they described their involvement at generally low, with little direct participation to the site's planning and development such as objection submission or being member of Community Reference Group. It is clear that the project is large-scale and complex that should trigger high level community awareness and attention. It appears there is something missing to explain people's being aware and direct involvement. The lower degree of involvement links to lower community impact level. Base on this finding, the paper makes further discussion about community involvement and corresponding impact, given the difference between their awareness and involvement.

4.2 Passive Versus Active Responses

We define awareness as passive response, while involvement as active response. Examples of actively response include making extra effort on self-research, making formal objection to express opinion, being a member of the Community Reference Group that requires regular meetings with councils and developers. Active response requires more time and efforts from the participants and potentially impacts other parties. One significant difference between passive and active response is how people response to project. The former requires less time and efforts from participants while the latter asks the participants to response actively and interact with other parties of the brownfields developments. The two different responses, active involvement and passive awareness, result in different degree of impacts to other parties' decision and brownfield development's outcomes. Actively responsive action shows higher possibility of direct contact between local community and other stakeholders, making it possible for them to understand and consider community's concern. For instance, submitting objection to council is one active response with effect on council and developer. Passive response tends to make small-scale impact. For example, discussing the project among the neighbours does not interact with or impact on other stakeholder's decision.

The community's impact on the project and other parties' decision involve active bargaining, as their concern will not be properly communicated and understood purely by their passive response. Awareness of the project is insufficient for local community's concern be heard and impact be exerted. Under Melbourne's planning system, limited approaches exist for community to express concern and raise question even by local community club. As an interviewee from a community club described: "[concerns raised by community clubs are] selected and monitored by appointed group… before it is discussed [by council and developers] … It's really up to the developer to create things that fit into the guidelines [made by council]." It states the fact that developer and council have different considerations from community. It is not easy for community's concerns to be expressed and considered.

4.3 Interactions with Survey Results

Two of the survey questions are designed to identify the potential reasons of people's differential response. People are asked to indicate factors they believe obstructed their participation in APMD, results are presented by categories, local residential status and property tenure. 41.2% of participants consider option, "lack of understanding of the project's impacts", is main factor that negatively affects their involvement. Under each sub-category, popular option slightly differs. Of non-residents, 69.6% of participants had low level of active involvement due to residential status. They are not prohibited from involving as non-resident of Alphington, as long as they can explain how the APMD affect them. Living in other suburbs implies relatively longer distance to the project hence lower direct influence. As for participants who are property renter, lack of understanding of project impact is clearly popular. While for participants who are property owner, lack of understanding of potential impacts, residential status and difficulty of expressing opinions are main factors obstruct their involvement. Compared to resident status, tenure does not significantly affect participant's involvement in the APMD.

Participants use the option "Others" to indicate their own factors. This includes lack of time, lack of faith and personal reasons. Participant involvement is negatively influenced by various factors other than their resident status. As the factors that encourage participant involvement, regardless resident status and property tenure, the option "the possible impacts of the development" attract over 60% of all participants. In contrast to the question where participant expresses concern about lacking information about development's impact, participants believed that acquiring information and knowledge of brownfield projects encourage their involvement. Thus, there is the struggle between passive response due to lack of information and active response based on known information. And the option "the responsibility as a community member" from non-residents is 53.6%, which shows how residential status influence community's involvement.

4.4 Missing Motivations and Existing Obstructions

It is found that the community responses passively to APMD due to some negative effects, and there are also positive effects encourage their active response. Specifically, the negative effects are obstructions that are existing to discourage participants to progress from being aware to being involved. Sorted by their influence intensity from survey results: (1) lack of understanding of the project's impact (the most influential); (2) residence status; (3) difficulty of accessing information; (4) personal issue (includes time and money); (5) difficulty of expressing opinions through planning process; (6) lack of incentive to involve; (7) project publicity (the least influential factor). While positive factors could encourage community's involvement are the motivations, where participants may response passively due to some of such motivation is missing. These motivations are: (1) possible impact of the project (the most influential factors); (2) responsibility as member of the community; (3) mandatory to be involved as community member. Summarising these motivations and obstructions that influence the community's responses, it is interesting to find that information of potential project impacts plays important role on both sides. As earlier mentioned, lacking information obstructs active response as participants do not know what and how to response actively. While knowing some information could push participants to step forward from passive response, as they know they are affected and need to let other parties know their concerns. However, the change in responding action normally takes time, effort, accessibility and other conditions for the participants to progress from lacking information to knowing of possible impact and estimate its intensity, and these conditions are included in the obstruction list as personal issues.

4.5 Developers' Perspective

Interview with representatives of the developer, a major stakeholder of the APMD, a different perspective is offered. In the APMD, the developer needs to deal with Council requirements such as parking requirement, facility construction, density so on. As said by one of the representatives: "I think it's important to know that we got requirements with council that we have to meet…we have to meet parking requirements, visitor parking as well…we have requirements for each lot, we have requirements on street parking and restrictions…we are required to do traffic management plans…" Developer is regulated and held responsible for meeting planning scheme and other council requirements on public good. In addition, new residents of APMD have their special concerns that need the developers to accommodate. Developers are responsible for what is required by council and its clients (buyer and investor) much more than the community, which means community's concern could not be taken into account in the development process if not agreed and enforced by the Council (and other policy and legal entities). Community's passive response could hardly deliver its concern to the Council, while it could interact with the Council and express concerns through active response. Under Melbourne's planning system and development control policy, it is difficult, probably infeasible, for developer to directly interact with community without the Council, based on concerns of safety, finance and efficiency so on. Therefore, it is important for the Council and community to identify the missing motivations and obstructions to help community's actively response to brownfield project, hence greater involvement and impacts are generated for better total benefits, as the existing literature has confirmed.

5 Conclusion

This research focuses on local community's role in brownfield development. It provides the following finds or conclusions on community involvement in and impact on brownfield development process: (1) large-scale brownfields development, in terms of its land size, project complexity and potential influence, could attract significant attention from local and surrounding places; (2) community awareness is passive response and it is active response that will exert clear impact; these two types of response are defined based on the different requirements of participants' time, effort, interaction with other stakeholders in brownfield projects; (3) based on participants' response, passive response usually remains small-scale impact while active response results in significant effects to brownfield development; (4) missing incentive and obstruction (or obstacle) can discourage participants to progress from passive to active response, including information of project impact, personal issue, residential status and so on; (5) Our survey shows increasing community's knowledge about project impact could reduce obstruction while encourage active response. These new insights could be studied in more detail through further research.

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An Investigation on Office-Based Workplace Modification During the COVID-19 Pandemic in the Netherlands

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Abstract This study sheds light on the office workplace environment and aims to investigate how organisations respond to the forces from the external environment (impact by COVID-19 pandemic) and how they modify their office workplace management strategically and operationally to suit the stakeholders' needs and future development in the post COVID-19 period. A desktop study was conducted to provide the framework for the in-depth interviews with five corporate real estate managers and three workplace consultants. Thematic analysis including coding technique was adopted to analyse the qualitative data. The findings show that, during COVID-19 pandemic, most of the intended and implemented office workplace modifications are mainly related to two types of risk control: administrative control and personal protection. The environment control approach, such as modifying the building systems or redesigning the office area, has rarely been adopted in office workplace management during the COVID-19 pandemic so far. At a strategic level, organisations react to the external force by re-modelling their business and working towards to re-orient their corporate real estate strategies, such as portfolio transformation, agile portfolio strategies and redesign of the office workplace, etc. It is foreseen that office workplace management will encounter other challenges due to the uncertainties of the COVID-19 pandemic. The findings of this study provide a practical lens to look at the future changes of office workplace environment.

Keywords Covid-19 pandemic · Office workplace modification · Risk control · Corporate business strategy · Strategic alignment · The Netherlands

1 Introduction

The COVID-19 pandemic has exerted an unpredictably negative impact on the world by causing damage to the international economy and drastic changes to all human

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being. The "work-from-home" requirement by local authorities affects the productivity which at the same time reduces the collaboration level among employees. "Social distancing" also creates challenges to work collaboration and community interaction. Organisations are committing in leveraging the work productivity up or back to the level prior to the outbreak of COVID-19 in both active and passive manners. The need for workplace upgrade and modification is compelled by the community or workplace measures published by local authorities to reduce the risk of the spread of COVID-19. The need for workplace upgrade and modification is compelled by the community or workplace measures published by local authorities to reduce the risk of the spread of COVID-19 [1]. It is foreseeable that organsiations will involve in different levels of workplace modification in the new normal, and many companies are committing in preparing for the modification plans.

Recognising the research gaps, we resorted to corporate real estate strategic alignment theory and used Haynes [2]'s 10 Ps framework to analyse the workplace changes brought by the COVID-19 pandemic. Six corporate real estate managers were interviewed for data collection. The interview questions were designed based on the investigation framework. Content analysis was adopted as the main analysis tool in this study. A coding structure was designed based on the investigation framework and the interview questions. The data was coded and categorised to identify the relationships among the codes. The findings of the study show companies have been suffered from Covid-19 pandemic at different degree. It is foreseen that long-term workplace modification plans will be further studied as the impacts of Covid-19 are still uncertain in a long run. In the long-term workplace strategies will further modified to suit activity-based workplace.

2 General Background of the Study

COVID-19 pandemic spreads globally with an unprecedented speed after its outbreak in January, 2020 [3]. It had been quickly proved that its risk of community transmission is very high and European Centre for Disease Prevention and Control (ECDPC) has urged to implement public measures to mitigatethe impact of the pandemic [4]. A document by European Centre for Disease Prevention and Control (ECDPC) [5] entitled "How to minimise the spread of COVID-19" suggests three measures in preventing the infection, including *environmental measures*, *personal protective measures* and *social distance measures.* Another document by ECDPC [4] entitled "Rapid risk assessment: Novel coronavirus disease 2019 (COVID-19) pandemic: increased transmission in the EU/EEA and the UK—sixth update" provides detailed information and update on the disease and suggests that measures that to be applied in the community should include: infection prevention and control, social distancing, travel-related and screenings of travellers. European Agency for Safety and Health at Work (EASHW) [6] published a guidance for workplace indicates that identification and risk assessment in both physical and psychosocial working environment shall be conducted for managing occupational safety and health under COVID-19 measures.

It suggests that the assessment of risk should consider long-term resilience at the workplace and workers should be involved in the process of risk assessment on an on-going basis. The assessment process should comply with the updated information shared by the local public authorities. The guidance provides instructions and examples regarding four workplace management operations: minimising exposure to Covid-19, resuming work after a period of closure, coping with a high rate of absence and managing workers working from home. International Labour Organisation (ILO) [7] provides detailed recommendation for employers to follow in order to mitigate the negative consequences at the workplace due to the Covid-19. Its recommendation provides insightful implication to be integrated into workplace policies.

During the pandemic lockdown, real estate consulting firms and professional associations leverage their expertise and resources to develop guidelines for workplace professionals to prepare for workplace re-entry and the operations in the new normal, including International Facility Management Association (IFMA), Chartered Institution of Building Services Engineers (CIBSE), JLL [9], CBRE, etc.

3 Theoretical Background of the Study

In the pre-COVID-19 pandemic period, the core objective of organizations is to obtain market competitiveness and the mission of CREM is to create added value to the organizations [11]. The added value is created through strategic alignment among different sectors within an organization [12]. From a CREM perspective, the business environment has influenced the corporate mission and business strategies, and thus affected the corporate real estate strategies [13]. The revolutionary realisation is that CREM shall react to the external forces while at the same time take a proactive role in strategic alignments: aligning external and internal needs, aligning corporate mission with environmental, economic and social sustainability, aligning corporate real estate resources with the business requirements, aligning CREM functions with business strategies, aligning operational decisions with strategic directions [14–21]. A number of studies shed light on interpreting the CREM practice and investigating management principles to develop CREM strategic alignment models [15]. Heywood [16] compared 10 models and identified 15 key strategic alignment components from the models, yet further found that none of the models include all 15 components. He suggested that all components should be included to form a comprehensive strategic alignment model.

The COVID-19 pandemic has changed the global business environment and it urges organisations to react rapidly to reduce the negative impacts. In turn, it calls for development of an updated strategic alignment model to prepare for the post-COVID-19 operation. Haynes et al. [22] develops an approach—PESTEL analysis, for CRE managers to evaluate the external factors to identify specific drivers that would impact on corporate real estate. PESTEL analysis approach proposes six external factors for corporate real estate managers to evaluate, which are political, economic, social, technological, environmental and legislative factors. The manifestation of the six factors have been changed significantly since the outbreak of COVID-19 and the changes are foreseen to be continued in the post-COVID-19 period. It calls for a comprehensive review on these factors and examine the current CREM alignment for modification.

As one of the important aspects of corporate real estate, workplace management has received increasing research attention in the past decade [22, 23]. In the past decade, workplace management strategies and practice have adapted to the changes of various business challenges, including globalisation, consolidation, downsizing, restructuring, streamlining, technological change [24]. From a CREM strategic alignment perspective, sound office environment supports the office occupiers in their work processes. Haynes et al. [22] suggest that "the alignment of the office environment (place) with the work processes provides increased workplace connectivity and productivity" and an efficient alignment to increase workplace productivity and employees' satisfaction is achieved by finding the best match between physical environment and behavioural environment. The physical environment shall embrace a high level of flexibility to suit the changes of business environment, human preference and environmental requirements on sustainability, safety and health. Workplace redesign is one of the important strategies in CREM to adjust the physical environment to adjust the needs of business, work processes and employees. Before the emergence of co-working space, physical space is the only element under one of the Ps (place) and the workplace efficiency is suggested to be achieved through "reducing space per employee through redesign, consolidating workspace, intensifying space use through non-territorial offices (such as hoteling) and making capital improvements that reduce the time and cost of churn when new product teams are put in place" [25]. As agile working style emerged and the advance of technology innovation, companies that provide co-working space were established to suit the trends [26]. Virtual space becomes another element under "place" in CREM. Aside from redesign, policies development and management service delivery are two important CREM approaches in workplace management. They focus on adjusting the behavioural environment at the workplace [22].

Haynes [13] proposed a 10 Ps' model—planet, position, purpose, procurement, place, paradigm, processes, people, productivity and performance - to evaluate corporates' alignments and adapt the alignments based on the changes of the Ps. As the COVID-19 significantly changed the external environment of an organisation, the 10 Ps are subjected to a series of changes driven by the community measures announced by international and local authorities. The measures require every organisation to respond to ensure a safe and healthy environment for sustainable organisation development, and the respondence lead to significant changes of workplace of every organisation. Figure 1 has identified the 9 Ps that are changed by the COVID-19, namely Planet, Place, Position, Purpose, Paradigm, People, Productivity, Performance, and Process. This study is triggered by the significant changes between community measures and office-based workplace. According to Haynes [13], community measures and office-based workplace represent "Planet and Place". The three major community measures—"social distancing", "environment control" and "personal protection", directly affect business environment, which

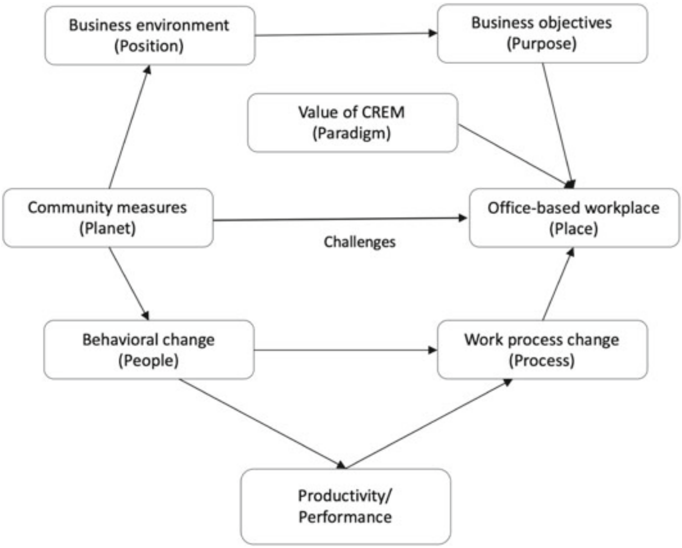

Fig. 1 The dynamic relationships among the 9 Ps (Adapted based on Haynes [13]'s 10 Ps model)

in turn requires organisations to adjust their business objectives. One of the major business objectives is regarding resource allocation, which involves relocating the resources in workplace management. Recognising the changes of the business environment and business objectives, CREM would proactively adapt to the changing situation and alter the workplace strategies and plans. On the operational level, community measures have severe impact on human behaviour.

4 Methodology

A qualitative approach was adopted in this study. In order to explore the workplace management practice under COVID-19 pandemics, in-depth interview was considered to be the most efficient way to obtain information from workplace management practitioners from different corporations. The targeted interviewees are corporate real estate managers or facilities managers from both in-house team or outsourced team in the Netherlands. Table 1 shows the background information of the eight interviewees, including their position, nature of the organisation that they are working or delivering service for, and their contractual relationship with the organisations.

Thematic analysis was adopted as the main analysis tool combined with coding technique to identify the structure of the interview results and relationships among the coded contents.

Table 1 Profile of the interviewees

Interviewee	Position	Nature of the organisation	Contractual relationship with the organisation
A	Consultant in real estate and facility services	Manufacturer	External consultant
B	Corporate real estate manager	Higher education institute	In-house management team
C	Managing consultant	Managing consultant corporate & public real estate	External consultant
D	Investment officer	Real estate investment company	External consultant
E	Facilities management specialist	Engineering consultancy company	In-house management team
F	Corporate real estate manager	Commercial bank	In-house management team
G	Corporate real estate and facilities manager	Management consulting	External consultant
H	Associate / facility and hospitality management lead	Real estate consulting firm	External consultant

5 Results and Discussion

A three-level coding hierarchy was developed based on the identified themes, as shown in Fig. 2. The first level includes three themes that were identified from the interview contents: impact (challenge) of Covid-19, workplace modification indicators and workplace modification implementation. The interviews are coded based on the three enquiries and the interview questions. The second level includes summative categories under each theme in level 1. The third level presents the specific issues that more than one interviewee shared in the interviews. An elaboration on the interview results by themes and frequently mentioned topics are presented as follows.

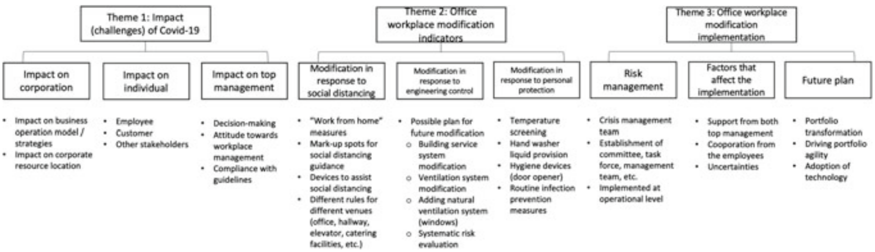

Fig. 2 Interview results by themes and frequently mentioned topics

5.1 Theme 1—Impact of Covid-19 Pandemic

Interviewees' responses regarding impacts of Covid-19 pandemic mainly focus on three themes, shown in Fig. 2. Under each theme, they further descripted specific management practice or examples on the manifestation of the impacts. According to the interviewees, corporations are affected by Covid-19 pandemic at different degrees. Manufacturing organizations seem to have severely suffered from the Covid-19 pandemic as the productivity has been significantly dropped due to the community measures. Workers were not allowed to attend work for a period of time and only a limited number of workers were permitted to work onsite in order to keep social distancing. Other companies whose core businesses are to provide consulting services seem to have suffered less from the Covid-19 pandemic. The Covid-19 pandemic may have interrupted their businesses, e.g. some of their business projects were forced to pause as the client companies weren't able to operate their businesses. In hind sight, the demand of other types of projects increased during the pandemic. The revenues from the core business have dropped at various levels for different companies. However, workplace operation cost on workplace management also dropped as most of the office areas were shut down. More than half of the interviewees suggested that "working from home" helps to save the workplace operation cost, especially on electricity cost.

Interviewees mentioned the impact on individual employees from their companies. They quoted a few comments from their colleagues during the interviews, such as "not used to the new working mode (working from home)", "lacking face-to-face communication", "missing the team working atmosphere", "looking forward to go back to the office" are mentioned among the interviewees when they described the comments from the employees of the organisation regarding "working from home" measures. They also expressed that the "working from home" measures does not affect employees' working quality and output to a significant level and regular surveys and interviews with employees have been conducted to understand employees' working conditions and personal emotion. "Work is not much affected during working from home", "get used to the new working mode", "workload is not reduced while it may be increased from time to time when working from home" are the sharing from the employees from the organisations. Aside from individual employees, top management decision-makers' attitude under Covid-19 pandemic was discussed in the interviews. Top management decision-makers' attitude towards the workplace strategies and management is positive and employee oriented.

5.2 Theme 2—Workplace Modification Indicators and Future Plans

Interviewees were asked in the second question to share how the CRE management team or facilities management team conduct workplace modification in corresponding to the three major community measures. Regarding workplace management practice, all companies are taking a proactive role in adapting to the community measures and an extra amount of expenditure has been committed in modification activities in response to "social distance" and "personal protection", according to eight interviewees. They suggested that many companies do not have a concrete plan for office redesign, but in the long run, office space is subject to further modification to suit the long-term safety and health requirements to prevent the spread of the Covid-19 pandemic. What is worth noting is that, more than half of the indicated that office space provision will be cut down as "working from home" becomes an alternative option for both companies and the employees. As less space may be needed in the future, office redesign may be constrained to soft renovation instead of major refurbishment projects, such as change of layout or configuration design, seating plan rearrangement, installing add-on facilities (e.g. signage to urge indoor personal protection); while refurbishment on building service system may not be conducted. Thus, the workplace management resources will more likely contributed to office renovation projects in the future. According to all the interviewees, corporate resources are allocated in four major workplace management practices at current time: (1) implementing activities to creating social distancing, such as putting mark-up between every 1.5-m distance as guidance, planning pathway logistic inside the office area, developing staff working plan to limit the number of staff at different functional space (elevator, canteen, hallway, office space, etc.; (2) monitoring workplace health and safety and delivering personal protection services, such as providing hand wash gel at the workplace, regular workplace cleaning services, etc. (3) providing support to employees who work from home, such as transporting working equipment to the employees' home; (4) developing human resources plan to comply with the "working from home" mode.

5.3 Theme 3—Factors that Affect the Workplace Management Implementation During Covid-19 Pandemic

Interviewees were asked to share their opinions on the factors that affect the workplace management implementation during the Covid-19 pandemic. Four interviewees stated that the risk management mechanism of a company plays an important role in coping with the Covid-19 pandemic. Based on the overall sharing by the interviewees, the general practice was that the facilities management team quickly took the responsibilities to implement the modification management activities by first, assessing the current operations and situation of the affected portfolio; second, relocating resources, including financial resources and human resources, to implement the changes and provide services; third, collecting users' feedback and making adjustment to the management activities.

Regarding the factors that affect the implementation of the workplace modification, interviewees explained that the implementation processes have been smooth. Support from the top management has been sufficient and most employees have been cooperative. The major concern from all interviewees is the uncertain future, such as how long the pandemic will last, whether an effective vaccine would be created, whether home office would become part of the new normal, etc. As for future plans for workplace management, three major trends are identified based on the interview results: portfolio transformation, driving the portfolio agility and technology adoption.

6 Conclusion

This study was initiated by noticing that a series of workplaces changes took place during Covid-19 and take the initiative to investigate the workplace modification combined with corporate real estate theory. Corporate real estate theory provides a lens to look into the dynamics of external and internal changes of an organisation and its impact on corporate real estate management strategies and activities. Covid-19 pandemic has exerted changes to all business and under this circumstances, this study explores the challenges by Covid-19 on companies from different industries and the manifestation of the challenges on their workplace modification and future management. The data were collected through in-depth interviews with experienced corporate real estate managers and facilities managers. The findings show that a certain degree of negative impacts were exerted by Covid-19 on companies while the degree of impacts vary by the industry nature of the companies. The workplace modification activities were standardised and implemented at the operational level. It is foreseen that long-term workplace modification plans will be further studied as the impacts of Covid-19 is still uncertain in a long run.

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The Coupling Coordination Research between Urban Competitiveness and Real Estate Industry in Shenzhen

Qi Gao

Abstract In this article, the comprehensive evaluation index of urban competitiveness and real estate development level of Shenzhen is constructed by combining principal component analysis and rank sum ratio comprehensive evaluation method. And then, the correlation between the two is analyzed through the linear regression model, and the coupling coordination model of the urban competitiveness and real estate development level of Shenzhen is built to analyze the coupling coordination evolution process of the two from 2009 to 2018. Based on the GM(1,1) grey prediction model, the coupling coordination relationship between the urban competitiveness and the development level of real estate industry is predicted in Shenzhen in 2019–2023. The research shows that the coupling between the development level of urban competitiveness and the development level of real estate industry in Shenzhen tends to be stable from 2009, and the coupling coordination degree of the two also increases gradually with the time going by, and the development level of urban competitiveness and the development level of the real estate industry in Shenzhen will develop towards high quality coupling coordination in 2019–2023.

Keywords Shenzhen · Urban competitiveness · Real estate industry · Coupling coordination studies

1 Introduction

With rapid advance of urbanization process in China, the improvement of urban competitiveness has brought huge development space for the development of real estate industry, and the development of real estate industry plays an irreplaceable role in enhancing urban competitiveness. Shenzhen, as the most prosperous and dynamic city in China, also takes the lead in the level of urbanization in China. However, the continuously high housing price leads to the real estate overheating, which has a significant impact on the urban competitiveness, urban economy and even

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the development of the macro economy. In this context, it is of great theoretical value and practical significance to accurately analyze the coordination between the urban competitiveness and the real estate industry of Shenzhen. And then establishing a long-term mechanism to promote the healthy development of the real estate industry, and making it be adapt to the overall long-term development strategy of the city, so as to continuously improve the urban competitiveness.

Therefore, an empirical analysis on the coupling coordination relationship between them is produced in this paper by constructing the horizontal coupling coordination model of urban competitiveness and real estate industry development in Shenzhen city. GM(1,1) model is used to predict the coupling coordination between the two in Shenzhen in 2019–2023. It is expected to analyze the specific evolution trend of the coordinated development types of the urban competitiveness and the real estate industry in Shenzhen, so as to provide the basis and reference for the government to formulate and coordinate the urban development planning and the development planning of the real estate industry in Shenzhen.

2 Literature Review

This article is reviewed in three aspects mainly from the city competitiveness research, the research of the development of the real estate industry and the coupling of the two studies. Researches on urban competitiveness mainly include the construction of urban competitiveness evaluation index and the analysis and comprehensive evaluation of urban competitiveness evolution characteristics.

Ning and Long [1] made a comprehensive evaluation of the competitiveness of 13 major cities in Jiangsu province through principal component analysis and concluded that that there were obvious regional differences in the urban competitiveness of major cities in Jiangsu Province, and the urban competitiveness of the cities in south was significantly better than that in north of Jiangsu province. Ni et al. [2] proposed the analysis framework of "factor system-industrial system-industrial value (FIV)" to explain the dynamic determination mechanism of urban competitiveness, constructed the measurement model and composition model of urban competitiveness, and evaluated the competitiveness level of 500 cities around the world. The research showed that the competitiveness of global cities was growing and changing on the whole, but there was an obvious trend of widening gap. Liu and Li [3] measured and compared the competitiveness level of 30 representative cities in China from 1990 to 2012, and concluded the evolution trend of the competitiveness of eastern and western cities. Jiang and Cui [4] selected 34 indicators to construct the urban competitiveness evaluation system, and conducted principal component analysis and cluster analysis of all indicators through R software to obtain the competitiveness evaluation results of cities in Guangdong Province. Wu et al. [5] constructed a model of urban competitiveness in urban agglomerations in the middle reaches of the Yangtze River, and the research showed that urban competitiveness was quite different and there was distinct hierarchy in urban agglomerations in the middle reaches of the Yangtze River. Wang and Shen [6] systematically compared the urban competitiveness of the Yangtze River Delta and the Pearl River Delta in China from 2000 to 2010, and concluded that the urban system of the Yangtze River Delta was more mature than that of the Pearl River Delta. Song and Xie [7] established a comprehensive model of urban competitiveness of Huai River Ecological economic belt, and used dynamic factor analysis method to analyze urban panel data.

The research on real estate development mainly includes the analysis on the development level of real estate industry and the policy regulation of real estate industry. Yang et al. [8] studied the regional sustainable development performance of the real estate industry in 30 provinces of China by using the data envelope analysis method. The study showed that after 2012, the efficiency of China's real estate industry would worsen and the development among provinces would be unbalanced. Hu [9] used principal component analysis and cluster analysis to explore the spatial variation characteristics of the development level of real estate economy in 17 cities in Shandong Province, and found that there was spatial interaction between the development of real estate economy in different cities. Guo [10] constructed the evaluation index system of real estate economic development level in Hebei Province through factor analysis and cluster analysis, and the research showed that there was a problem of unbalanced supply and demand in the development of real estate economy in Hebei Province. Liu et al. [11] conducted an empirical study on the real estate development status of 19 typical cities in China through DPSIR model, and concluded that there was strong sustainable development ability of real estate in Shenzhen and Xiamen. Leng [12] elaborated the content of real estate regulation policy of Shenzhen in 2016, analyzed the impact of regulation policy on real estate, and drew the conclusion that developers should improve the strength of housing development and strengthen capital management. Zhou and Wang [13] discussed the micro meaning of "destocking" policy in the real estate industry from the perspective of enterprise risk taking. Kong et al. [14] measured the supply structure of urban real estate in China from the product level and regional level, and found that the difference of the balance and sufficiency in the urban real estate supply structure reduced year by year, and the overall supply structure of urban real estate tended to be stable and healthy. By constructing DSGE model, Yang and Gu [15] studied the selection of macro-prudential policy rules to regulate the real estate market in the face of different exogenous shocks. The research showed that the loan-to-value rule of macro-prudential policy tools, which was aimed at the steady deviation of real estate price under the impact of housing preference, technology and cost, could effectively regulate the real estate market.

The research on the coupling coordination between urban competitiveness and real estate industry is mainly an empirical analysis from the perspective of time and space. Zhou [16, 17] studied the relationship between the urban competitiveness and the real estate industry of New York and Toronto, and concluded that the development of the real estate industry plays an irreplaceable role in enhancing the urban competitiveness. Zhang [18] analyzed the interaction between the urban competitiveness of Shanghai and the real estate market from a static perspective according to quantitative regression analysis, and the research showed that the urban economy and the real estate had a significant two-way effect. Zhang et al. [19] analyzed the correlation between urban competitiveness and real estate industry in the Pearl River Delta urban agglomeration and the spatio-temporal coupling coordination relationship by building linear regression model and coupling coordination degree model. It is found that the degree of coupling coordination between the two is increasing, and the degree of coupling coordination is centered on wide and deep, decreasing from the inside to the outside. Wang and Liu [20] analyzed urban competitiveness, comprehensive development level of real estate industry and coupled and coordinated development of 35 large and medium-sized cities in China from 2000 to 2015 from two dimensions of time and space. It is concluded that both the urban competitiveness and the comprehensive development level of the real estate industry rise in the fluctuation.

Existing researches on urban competitiveness and real estate industry coupling coordination is relatively less. The main evaluation methods used are principal component analysis, factor analysis, analytic hierarchy process, cluster analysis, and other classical evaluation methods. The innovation of this paper lies in the combination of principal component analysis and rank-sum ratio comprehensive evaluation method to construct the comprehensive evaluation index of urban competitiveness and development level of real estate industry. Among them, principal component analysis can transform multiple indicators into a few indicators (namely, principal component), and the information contained in each principal component is not repeated. Therefore, the data dimension reduction is realized and the correlation between evaluation indexes is eliminated at the same time. The rank-sum ratio comprehensive evaluation method is applicable to various evaluation objects, which strengthens the numerical relation of indexes in calculation and has good evaluation effect [21]. Moreover, the rank-sum ratio comprehensive evaluation method integrates the information of each evaluation indicator, which can indicate the comprehensive level of each evaluation indicator. The advantages of the two evaluation methods can be combined to make the evaluation result more objective and reliable. Furthermore, the coupling coordination degree of urban competitiveness and real estate industry in Shenzhen is obtained through the coupling coordination model.

The main contributions of this paper are mainly in two aspects. Firstly, the research on the coupling coordination between urban competitiveness and real estate development in Shenzhen enriches the existing empirical research system on the relationship between urban competitiveness and real estate development. Scholars at home and abroad have done a lot of researches on urban development and real estate industry, but most of them are about the real estate industry and economic growth, the bidirectional relationship between urban competitiveness and real estate price, or the relationship between real estate industry and urban competitiveness at a certain local level, such as urban economy, population structure and ecological environment. There are a few studies on the coupling coordination between urban competitiveness and real estate development. In addition, few scholars have made detailed analysis on the development and changes of the coupling coordination degree between urban competitiveness and real estate industry in Shenzhen in recent years. The research on this topic has important theoretical value and practical significance for improving the coordinated development level between the urban competitiveness and the real estate industry of Shenzhen. Secondly, in this paper, principal component analysis and rank-sum method are combined to evaluate the urban competitiveness and the development of real estate industry in Shenzhen. In the past, principal component analysis, factor analysis, analytic hierarchy process and entropy method were used to evaluate urban competitiveness and the development of real estate industry. Therefore, this paper combines principal component analysis and rank-sum ratio comprehensive evaluation method to improve the objectivity and accuracy of the comprehensive evaluation results of urban competitiveness and real estate industry to some extent.

3 Data Source and Index Selection

In view of data availability and comprehensiveness, the research data of this paper are mainly from Shenzhen Statistical Yearbook from 2009 to 2018 and the official website of Real Estate Industry Association, etc. It shows the development of urban competitiveness and real estate industry in Shenzhen in the past ten years.

Based on the comprehensive analysis of previous scholars such as Zhang et al. [19] and Wang [22] in the study of urban competitiveness and the development level of real estate industry, and combined with the development characteristics and ideas of Shenzhen, the index selection is carried out. The evaluation indexes of urban competitiveness subsystem and real estate subsystem are divided into four levels in this paper. The sub-system of urban competitiveness is divided into five categories, namely comprehensive economy, industrial structure, scientific and technological strength, ecological environment and opening to the outside world, and is subdivided into 15 four-level indicators. The sub-system of real estate is divided into three-level indicators, such as real estate input, real estate output and social contribution, and is subdivided into nine four-level indicators. The indicators and weights determined according to the existing literature are shown in Table 1 [19, 22].

4 Establishment of Coupling Coordination Model

Referring to the volumetric coupling system model in physics, a coupling function that can comprehensively reflect the degree of mutual influence between systems is constructed:

Set the variable $U_i(i = 1, 2, \ldots, m)$, $U_j(j = 1, 2, \ldots, m)$ represent the system respectively, and then the coupling degree model of multi-system interaction can be expressed as [19]:

$$\mathrm{A_n} = n\{(U_1 \times U_2 \times \cdots U_n)/\Pi(U_i + U_j)\}^{1/n} \tag{1}$$

Since there are only the urban competitiveness system and the real estate industry system, the coupling degree of urban competitiveness and the real estate industry

Table 1 Evaluation indexes of the coupling coordination research between urban competitiveness and real estate industry

Level 1 indicators	Level 2 indicators	Level 3 indicators	Level 4 indicators
Evaluation index of coupling coordination research between urban competitiveness and real estate industry	The urban competitiveness subsystem	Comprehensive economy	x_1: Gross regional product (100 million yuan)
			x_2: Balance of local and foreign currency deposits of financial institutions (100 million yuan)
			x_3: GDP per person (yuan)
		Industrial structure	x_4: The proportion of the added Value of the secondary industry in GDP (%)
			x_5: The proportion of the added Value of tertiary industry in GDP (%)
		Scientific and technological strength	x_6: Authorized invention patent every year (piece)
			x_7: R&D personnel equivalent to full time equivalent (personnel every year)
			x_8: Internal expenditure of R&D funds in industrial enterprises (ten thousand yuan)
		Ecological environment	x_9: Park Green Area Per capita (square meter)
			x_{10}: Total electricity consumption (10,000 kwh)
			x_{11}: Total industrial exhaust emissions per square kilometer (100 million cubic meters)
		Opening to the outside world	x_{12}: Total passenger transport (ten thousand people)

(continued)

Table 1 (continued)

Level 1 indicators	Level 2 indicators	Level 3 indicators	Level 4 indicators
			x_{13}: The total freight (ten thousand tons)
			x_{14}: Total imports and exports (100 million dollars)
			x_{15}: Actual utilization of foreign capital (100 million dollars)
	The real estate industry subsystem	Real estate input	x'_1: Total investment in real estate Development (100 million yuan)
		Real estate output	x'_2: Housing area under construction by real estate development enterprises (10,000 square meter)
			x'_3: Real estate development enterprises completed housing area (10,000 square meter)
			x'_4: Value of completed housing of real estate development enterprises (100 million yuan)
			x'_5: Commercial housing sales Area(10,000 square meters)
			x'_6: Commercial housing sales (100 million yuan)
			x'_7: Average selling price of commercial housing (yuan/square meter)
		Social contribution	x'_8: Number of Real estate Development enterprises (piece)
			x'_9: The Average annual Number of Real estate Employees (person)

can be defined by referring to Formula (1):

$$A_2 = 2\sqrt{(U_1 \times U_2)/(U_1 + U_2)^2} \tag{2}$$

U_1, U_2 represent the score of urban competitiveness and the score of the development level of real estate industry respectively. A represents the value of coupling degree, which is between 0 and 1. The closer the value of A is to 1, the greater the coupling degree of the two is, and the closer the mutual influence is. When A approaches 0, the coupling degree of the two systems is the smallest, indicating that the two systems have basically no influence on each other. In order to further avoid the correlation error between the two systems, improve the accuracy of the prediction, and further deepen the model, the comprehensive coordination model of the two systems can be obtained:

$$B = a \times U_1 + b \times U_2 \tag{3}$$

$$C = \sqrt{(A \times B)} \tag{4}$$

where, C represents the degree of coupling coordination, B represents the index of large system, *a* and *b* represents the importance degree of subsystem. The values can be assigned 0.6 and 0.4 respectively by referring to relevant scholars' research. Considering the synchronous development of the system, the reference standards are shown in Table 2 [19]:

Table 2 Evaluation criteria of coupling coordination

Coordinate interval	Coordination type	Coordination state
0–0.09	Extreme disorder decline	$U_1 > U_2$ is the lagging type of real estate industry
0.1–0.19	Severe disorder recession	
0.2–0.29	Moderate disorder decline	
0.3–0.39	Mild dysregulation recession	
0.4–0.49	On the verge of dislocation	
0.5–0.59	Grudging coordinated development	$U_1 = U_2$ is the synchronous type of urban competitiveness and real estate industry
0.6–0.69	Primary coordinated development	$U_1 < U_2$ is the lagging type of urban competitiveness
0.7–0.79	Intermediate coordinated development	
0.8–0.89	Well-coordinated development	
0.9–1.0	High-quality coordinated development	

5 Comprehensive Evaluation of Urban Competitiveness and the Development Level of Real Estate Industry in Shenzhen

5.1 *Measurement of Urban Competitiveness Development Level in Shenzhen*

According to Shenzhen Statistical Yearbook, and the official website of Real Estate Industry Association, the data of the above 15 indicators of urban competitiveness in Shenzhen are obtained. Dimensionality reduction is performed on the data according to the principal component analysis method, and the characteristic root and contribution rate of the correlation coefficient matrix are obtained by MATLAB, as shown in Table 3.

As can be seen from the above table, the cumulative contribution rate of the first three characteristics reaches above 96%, and the principal component analysis effect is very good. The first three principal components are selected below for comprehensive evaluation, which are as below:

$$y_1 = 0.294\tilde{x}_1 + 0.286\tilde{x}_2 - 0.218\tilde{x}_3 - 0.282\tilde{x}_4 - 0.281\tilde{x}_5 + \cdots - 0.295\tilde{x}_{15} \quad (5)$$

$$y_2 = 0.032\tilde{x}_1 - 0.012\tilde{x}_2 - 0.398\tilde{x}_3 - 0.030\tilde{x}_4 + 0.037\tilde{x}_5 + \cdots - 0.016\tilde{x}_{15} \quad (6)$$

$$y_3 = -0.071\tilde{x}_1 - 0.237\tilde{x}_2 + 0.244\tilde{x}_3 + 0.268\tilde{x}_4 - 0.278\tilde{x}_5 + \cdots - 0.038\tilde{x}_6 \quad (7)$$

The characteristic roots of the first three principal components are $\lambda_1 = 11.435$, $\lambda_2 = 2.030$, $\lambda_2 = 2.966$. Therefore, the variance contribution rates of the first three principal components F1, F2 and F3 (that is, the weight of F1, F2 and F3 in principal component F) are as below:

$$\mu_1 = \lambda_1/(\lambda_1 + \lambda_2 + \lambda_3) = 0.792 \quad (8)$$

Table 3 Results of principal component analysis

Serial number	Characteristic root	Contribution rate (%)	Cumulative contribution rate (%)
1	11.44	76.23	76.23
2	2.03	13.53	89.77
3	0.97	6.44	96.21
4	0.41	2.73	98.94
⋮	⋮	⋮	⋮
15	1.24e−17	8.25e−17	100

Table 4 Estimates of weighted rank sum ratio and the development level of urban competitiveness score

Year	f_i	cf_i	p_i	*Probit*	$WRSRfit_i$	The development level of urban competitiveness score
2009	1	1	0.100	3.718	0.206	0.206
2010	1	2	0.200	4.158	0.309	0.309
2011	1	3	0.300	4.476	0.382	0.382
2012	1	4	0.400	4.747	0.445	0.445
2013	1	5	0.500	5.000	0.504	0.504
2014	1	6	0.600	5.253	0.563	0.563
2015	1	7	0.700	5.524	0.626	0.626
2016	1	8	0.800	5.842	0.700	0.700
2017	1	9	0.900	6.282	0.803	0.803
2018	1	10	0.975	6.960	0.960	0.960

$$\mu_2 = \lambda_2/(\lambda_1 + \lambda_2 + \lambda_3) = 0.141 \tag{9}$$

$$\mu_3 = \lambda_3/(\lambda_1 + \lambda_2 + \lambda_3) = 0.067 \tag{10}$$

According to the principal component analysis of dimension reduction of urban competitiveness level index of Shenzhen, the three principal components and corresponding weights are obtained after dimension reduction, and then the obtained data are solved by rank-sum ratio comprehensive evaluation method with MATLAB.

The calculation results of each frequency f_i, cumulative frequency cf_i, cumulative percentage p_i, probit *Probit*($i = 1, 2, \ldots, 10$ corresponding to 2009, …, 2018) and the development level of urban competitiveness score are shown in Table 4. The last cumulative frequency rate is estimated at $1 - 1/(4n)$ [23].

According to the above table and the change of the urban competitiveness score in Shenzhen, it can be found that the urban competitiveness of Shenzhen is mainly reflected in four aspects: comprehensive economy, industrial structure, scientific and technological strength, and opening to the outside world. The urban competitiveness of Shenzhen also presents a rising trend.

5.2 *Measurement of the Development Level of Real Estate Industry in Shenzhen*

Similarly, by combining principal component analysis with the rank-sum ratio comprehensive evaluation method, the final rank-sum ratio and the comprehensive evaluation value of the development level of real estate industry in Shenzhen can be obtained, as shown in Table 5.

Table 5 Estimates of weighted rank sum ratio and the development level real estate industry score

Year	f_i	cf_i	p_i	*Probit*	$WRSRfit_i$	The development level real estate industry score
2009	1	5	0.500	5.000	0.511	0.511
2010	1	3	0.300	4.476	0.407	0.407
2011	1	2	0.200	4.158	0.343	0.343
2012	1	1	0.100	3.718	0.256	0.256
2013	1	6	0.600	5.253	0.561	0.561
2014	1	4	0.400	4.747	0.461	0.461
2015	1	9	0.900	6.282	0.766	0.766
2016	1	8	0.800	5.842	0.679	0.679
2017	1	7	0.700	5.524	0.615	0.615
2018	1	10	0.975	6.960	0.901	0.901

It can be found from the above changes in the score of the development level of the real estate industry in Shenzhen that the overall development of the real estate industry presents a fluctuating state. From 2009 to 2012, the development level of the real estate industry showed a downward trend, which was greatly improved in 2013 and presented a rapid growth trend from 2014 to 2015. However, from 2016 to 2017, the development level of the real estate industry gradually fell. On the whole, the development level of the real estate industry in Shenzhen is rising in the fluctuation.

6 An Empirical Analysis of the Coupling Coordination Between Urban Competitiveness and Real Estate Industry in Shenzhen

6.1 *Correlation Analysis of Urban Competitiveness and Real Estate Industry in Shenzhen*

Firstly, SPSS25 is used to test the correlation between the comprehensive score of the urban competitiveness U_1 and the comprehensive score of the real estate development level U_2 in Shenzhen. The correlation coefficients of Pearson, Kendall and Spearman are 0.753, 0.511 and 0.758 respectively, and their confidence (bilateral) is significant under the test of 0.05. Therefore, there is a significant correlation between the development level of the urban competitiveness and the development level of the real estate industry in Shenzhen.

And then, taking the score of the development level of the real estate industry as an independent variable and the score of the development level of the urban competitiveness as a dependent variable, the unary linear regression equation of the two was established through SPSS25, that is $y = 0.066 + 0.88x$.

According to SPSS25, the fitting R square is 0.567, with a good fitting degree, and the significance level of the model is less than 0.05, which has passed the test. Therefore, it can be seen that there is a positive relationship between the development level of the real estate industry and the urban competitiveness, and a reasonable improvement of the development level of the real estate industry can promote the improvement of the urban competitiveness. Similarly, the improvement of urban competitiveness can also promote the development level of real estate.

6.2 Coupling Coordination Analysis of Urban Competitiveness and Real Estate Industry in Shenzhen

According to the scores of the urban competitiveness and the real estate development in Shenzhen obtained above, and by substituting them into the corresponding coupling coordination formula (3) and (4), the comprehensive system index and coupling coordination value between the urban competitiveness and the real estate industry in Shenzhen can be calculated. The results are divided into different types according to Table 2. The larger the value is, the high coordinated level between the urban competitiveness and the development level of real estate industry in Shenzhen is. Conversely, the low coordinated level is. As is shown in Table 6.

As can be seen from the data in the above table, coupling degree A of the urban competitivity-the real estate industry system from 2009 to 2018 has been stable since 2009. The degree of coupling coordination increases with the increase of time, and the type of coupling coordination relationship develops from Grudging coordination at the beginning to high-quality coordination gradually.

According to the respective evaluation values of the urban competitiveness and the real estate industry in Shenzhen, it can be concluded that the urban competitiveness in Shenzhen presented a rising trend from 2009 to 2018, and the growth rate of the urban competitiveness from 2009 to 2016 was relatively slow, while the growth rate from 2016 to 2018 gradually improved. The real estate industry in Shenzhen as a whole in the fluctuating rise. According to the development trend in recent years, the development of the real estate industry lags behind the development of urban competitiveness in Shenzhen. Also, it can be seen from the development trend of the real estate industry in 2017–2018 that its growth rate keeps increasing and gradually approaches the development level of the urban competitiveness.

Table 6 Evaluation value of the urban competitiveness—The real estate industry system in Shenzhen

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Urban competitiveness U_1	0.206	0.309	0.382	0.445	0.504	0.563	0.626	0.700	0.803	0.960
Real estate industry U_2	0.511	0.407	0.343	0.256	0.561	0.461	0.766	0.679	0.615	0.901
The coupling value A	0.905	0.991	0.999	0.963	0.999	0.995	0.995	1.000	0.991	0.999
Composite system index B	0.328	0.348	0.367	0.370	0.527	0.522	0.682	0.692	0.728	0.937
Coupling coordination degree value C	0.545	0.587	0.605	0.597	0.726	0.721	0.824	0.832	0.849	0.968
Coupling coordination type	Grudging coordinated	Grudging coordinated	Primary coordinated	Grudging coordinated	Intermediate coordinated	Intermediate coordinate-d	Intermediate coordinated	Well-coordinated	Well-coordinated	High-quality coordinated

6.3 Prediction and Analysis of the Coupling Coordination Between the Urban Competitiveness and the Real Estate Industry in Shenzhen

According to the above coupling coordination value data of urban competitiveness and real estate industry in Shenzhen from 2009 to 2018, the corresponding time series is established as follows [23]:

$$\begin{aligned} x^{(0)} &= (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(10)) \\ &= (0.545, 0.587, 0.605, 0.597, 0.726, 0.721, 0.824, 0.832, 0.849, 0.968) \end{aligned} \tag{11}$$

Then, the stage ratio of the sequence is obtained as follows:

$$\begin{aligned} \lambda &= (\lambda(2), \lambda(3), \ldots, \lambda(10)) \\ &= (0.928, 0.970, 1.013, 0.822, 1.007, 0.875, 0.990, 0.877) \end{aligned} \tag{12}$$

And most of the $\lambda(k) \in [0.833, 1.199]$, $k = 2, \ldots, 7$, therefore, GM(1,1) can be modeled. A sum of the original data $x^{(0)}$ is:

$$x^{(1)} = (0.545, 1.1.32, 1.737, 2.334, 3.06, 3.781, 4.605, 5, 437, 6.286, 7.254) \tag{13}$$

By constructing data matrix B and data vector Y and calculating $\hat{u} = \begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = (B^T B)^{-1} B^T Y = \begin{bmatrix} -0.0635 \\ 0.5177 \end{bmatrix}$, it is concluded that $\hat{a} = -0.0635$, $\hat{b} = 0.5177$. According to the solution of differential equation, the prediction expression of GM(1,1) model can be written as follows: $\hat{x}^{(1)}(k+1) = 8.69543\mathrm{e}^{0.0635169\mathrm{t}} - 8.15043$. The predictive value of generated sequence $\hat{x}^{(1)}(k+1)$ and model reduction $\hat{x}^{(0)}(k+1)$ are obtained.

Each class ratio deviation of GM(1,1) model is less than 0.2 according to the calculating results. Therefore, the prediction accuracy of this model is verified to be high and accurate prediction can be made.

The final prediction results for 2019–2023 are as follows:

$$\hat{x}^{(0)} = (\hat{x}^{(0)}(11), \hat{x}^{(0)}(2), \ldots \hat{x}^{(0)}(15)) = (1.010, 1.076, 1.147, 1.222, 1.302) \tag{14}$$

From the prediction results, it can be seen that the coupling coordination value of the urban competitiveness and the real estate development level in Shenzhen will reach 1 by 2019. According to the description of the coupling coordination types mentioned above, it is in the stage of high-quality coupling coordination, and the coupling coordination degree will be further improved after 2019. At the same time, with the continuous development of Shenzhen, the urban competitiveness and the real estate industry will gradually achieve a high level of synchronous development.

7 Conclusion and Policy Suggestion

7.1 Conclusion

Based on the coupling coordination research between urban competitiveness system and real estate industry system in Shenzhen, the main conclusions are as follows:

1. On the whole, the coupling degree of the urban competitiveness and the real estate industry in Shenzhen is relatively high, and there is a significant correlation between them. The coupling between the development level of the urban competitiveness and the development level of the real estate industry in shenzhen has begun to stabilize in 2009, and the coupling coordination degree of the two gradually increases with the increase of time, and the type of coupling coordination relationship also gradually has developed from the grudging coordination at the beginning to the high-quality coordination.
2. The development level of the real estate industry in Shenzhen shows a rising trend in general. According to the analysis of the real estate development in Shenzhen in recent years, the development of the real estate industry lags behind the level of urban competitiveness in Shenzhen. From 2016 to 2017, the development level of the real estate industry has decreased because the influence of the government's macro-control. During the period of 2017–2018, the real estate development level has increased significantly, and the growth rate has accelerated, showing a high-quality coupling and coordination state with the development level of the urban competitiveness. This also shows that the development of real estate industry is also increasing in recent years. Therefore, further regulation and control policies are needed to avoid overheating of real estate and the emergence of real estate bubbles.
3. From 2019 to 2023, the coupling coordination between the urban competitiveness and the real estate industry in Shenzhen will be further improved, and will develop towards high-quality coupling and coordination. The comprehensive development level of urban competitiveness and the comprehensive development level of real estate industry in Shenzhen are constantly improving and approaching.

7.2 Policy Suggestion

According to the above conclusions, based on promoting the level of urban competitiveness and the development of real estate industry to achieve a benign interaction of quality development in Shenzhen, the following Suggestions are put forward.

Firstly, the development of urban competitiveness in Shenzhen needs to realize a reasonable development positioning of the real estate industry. The real estate industry is an important part of the economic development in Shenzhen. When making the long-term development plan of Shenzhen, it is necessary to define the orientation of the real estate industry in the urban development. The excessive dependence on the real estate industry which leads to the rise of house prices and the sharp warming of the development of real estate industry should be prevented [24]. In the long run, the overheated development of real estate, once it exceeds the level of urban development, will play a negative role in inhibiting the urban development. Therefore, the government needs to strengthen the regulation of the real estate market, promote the construction of affordable housing system, improve the land management mechanism, and formulate reasonable fiscal and tax policies. In this way, the reasonable positioning of real estate industry in the urban competitiveness of Shenzhen can be realized and a benign interactive mechanism can be formed between the urban competitiveness and the real estate industry in Shenzhen.

Secondly, the steady improvement of urban competitiveness in Shenzhen requires integrated development. The urban competitiveness of Shenzhen is mainly reflected in the four aspects of comprehensive economy, industrial structure, scientific and technological strength, and opening to the outside world. Therefore, when formulating the development strategy of Shenzhen according to local conditions, the government should first balance the competitiveness of these aspects, avoid excessive pursuit of economic strength and neglect the competitive advantages of other aspects, so as to realize the overall development of Shenzhen. In terms of the development of urban economy and industrial structure, the economic strength can be further enhanced by relying on the advantages of urban resources, promoting the upgrading and transformation of urban industrial structure and optimizing the efficiency of resource allocation. In terms of scientific and technological strength, innovation can drive the development of science and technology by further strengthening innovation, improving innovation output level and cultivating innovation industrial culture. In terms of opening to the outside world, the level of opening to the outside world can be further enhanced by actively participating in international business activities, seeking foreign cooperation, improving the urban social environment, and creating pluralistic culture and inclusive urban spirit.

Thirdly, the healthy and sustainable development of real estate industry in Shenzhen needs reasonable regulation and control policies. The policy regulation of the real estate industry in Shenzhen should aim at the goal of "no speculation in housing", achieve a balance between fairness and efficiency, standardize the commercialization of the real estate industry, and improve the housing security system, so as to ensure the coordinated and sustainable development of the real estate industry and national economy while promoting the maximization of social interests [25]. Due to the severe problem of more people and less land in Shenzhen, the supply of land needs to be expanded. On the one hand, the use of existing land needs to be more accurate, the efficiency of land use needs to be improved. On the other hand, it is necessary to realize land increment and bring more development space for real estate industry in Shenzhen through urban renewal and old city reconstruction. In addition, the government should implement differentiated tax policies and formulate different tax schemes for different income groups. For moderate and low-income people, when they have the need to buy a house, the government should implement the property tax reduction strategy when they buy their first house. For high-income people with multiple houses and speculative buyers, they should be required higher property taxes. In this way, the speculative activities of real estate can be reduced and the housing price can be returned to a reasonable range so as to promote the long-term sustainable development of Shenzhen real estate industry.

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A New Conceptual Framework for Analyzing the Social Capital of Construction Project Teams

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Abstract Team social capital plays a key role in positively affecting team performance. The construction project team is established temporarily to better achieve project targets, and the establishment and acquisition of its social capital became difficult in the process of construction because of the temporary characteristics. In the early stage of project construction, the construction project team often has a lot of implicit social capital which cannot be effectively utilized. Based on the Johari Window model in the cognitive psychology field, we propose a new model of construction project team's social capital and divide the dimensions of a construction team's social capital from a dynamic perspective, namely explicit social capital, private social capital, unknown social capital, and blind social capital. This paper explains the connotation of each type of social capital of the construction teams and discusses the strategies to transform the implicit social capital to explicit social capital, to provide the theoretical foundation and practical guidance for the establishment and cultivation of social capital in actual construction projects.

Keywords Conceptual framework · Social capital · Construction project teams · Johari Window · Lean construction

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1 Introduction

The construction project team is temporarily established to better achieve the project goals. It has clear job responsibilities and organizational structure, with the project manager as the top leader, and the realization of the construction project goals as the team task. The construction process is a social process. The human factor is key to the success of a construction project because the social relations among team members constitute the basic elements of the social structure, and these social relations involve the exchange of important information and resources [1, 2]. Understanding the interaction of team members and improving their working relationships can influence project performance and success [3]. According to Fonti and Maoret [4], organisations perform better not only because they have human capital and individual talent, but also because of the social capital they accumulate over time through stable employee working [4]. The actual or potential collection of resources in this relationship network is social capital [5]. The social capital of the construction project team exists and arises from the network of relationships between members within the team and with stakeholders outside the team [6]. Social capital is beneficial to organizations and an important potential source of enterprise value creation [7].

In the construction field, the benefits of social capital are also recognized. Senaratne et al. [8] found that through the equal interaction between project members, closer network ties were created, construction project knowledge sharing was promoted, and organizational performance and learning ability were improved [8]. Koh and Rowlinson [9] proposed that the impact of social capital on construction safety performance is mediated by organizational collaboration and adaptation [9]. However, because the construction industry is a special industry with typical characteristics, each building is a unique product, and the social capital characteristics of each project team are also unique. The establishment and acquisition of its social capital become difficult during the temporary formation of the construction project team. There is a large amount of undeveloped social capital in the construction project team, especially when the project team is just established.

This research focuses on those social capitals that have not yet been effectively utilized and analyzes their constituent characteristics. People are social, and the application and development of social capital are related to human cognition. At the individual level, social capital consists of a person's awareness of these norms and how much they interact with the community [10]. The appropriateness of social capital to project performance depends on the common perception of their relationships among team members [11]. The Johari window model [12] developed from the field of cognitive psychology is a method that helps people better understand their relationships with themselves and others. It was created by psychologists Luft and Ingham [12]. This study argues that the use of Johari window model is beneficial to explore the potential characteristics of social capital in construction project teams, because the two terms are related to cognition, reflect the relationship between individuals and others, and embody a dynamic characteristic. The Johari Window method is suitable for looking at things from multiple perspectives and different standpoints

[13], which also increases the feasibility of Johari window analysis of social capital in construction projects, because a construction project is a network composed of multiple stakeholders, and each stakeholder have their own different standpoints.

From the perspective of psychological self-cognition, a new social capital model for construction project teams is proposed based on Johari window method. To explore the characteristics and composition dimensions of social capital, especially for those social capitals that have not been directly used, it is important to note that social capital is not static, or a solidified one, but a dynamic evolution that can be transformed. In the past, social capital was more of a dimensional division of the cross-sectional nature, but there was less research on the process of longitudinal dynamic evolution. In the implementation phase of construction projects, more attention should be paid to cultivating social capital in project teams. Digging out the social capital that has not been used effectively can help achieve construction project delivery. This research aims to better understand the dynamic characteristics of social capital based on the Johari window method. The study sought to answer the following research questions:

1. What are the types of social capital of construction project teams divided from a dynamic perspective?
2. How to develop more available social capital in construction project teams?

2 Literature Review

2.1 Social Capital

Social capital is the actual or potential set of resources that exist and arise in the network of relationships between people and organizations [5, 14]. Scholars have a different emphasis on the concept of social capital. Loury [14] believes that social capital is a kind of social resource corresponding to physical capital and human capital [14]. Bourdieu [15] emphasizes the acquisition of individual interests [15], while Coleman [16] emphasizes the reciprocity and sharing of resources [16]. Putnam [17] believes that social capital is a certain characteristic of social organizations [17]. For the dimension of social capital, the structure, relationship and cognitive dimension proposed by Ghoshal and Nahapiet [5] were widely adopted. In this research, social capital is defined as the actual or potential set of resources embedded in the relation network [5].

2.2 Construction Project Team's Social Capital in Project Delivery

Team or group social capital is a special type of social capital. It can be defined as the resources which can be accessed through members' social relationships within the team's social structure and the broader formal and informal structure of the organization to which the team belongs [6, 18, 19]. Social relationships can promote a healthy team atmosphere, which is conducive to the formation of efficient teams [1]. In this regard, team social capital plays a key role in positively affecting team performance [6].

Construction projects are understood as social processes in multi-organizational settings and have complexity [20]. Due to the on-site construction characteristics, environmental complexity and multi-organizational characteristics in the construction industry, the construction project team is featured with uncertainty, temporary, and fragmentation [21]. Social capital transforms construction projects from loose associations of individuals into interwoven teams with common goals [11]. If a construction project can be viewed from the perspective of social collaboration, participants must values and trust, so that by sharing the same values and trust, participants can form an efficient team [3]. When project performance is appropriate, social capital creates "a sense of belonging" and the social cohesion makes project members feel connected. At that time, the sense of belonging encourages team members to make the project targets their own goals and help others to do the same. The process of "role socialization" integrates, shapes and constrains team members' behaviors in the social environment. This socialization requires team members to consciously cultivate appropriate forms of social capital in their relationships, however many people find this difficult [3, 11, 22]. To solve this problem, it is necessary to know what appropriate form of social capital is and, secondly, how to make social capital more explicit in a construction project team.

2.3 Explicit Social Capital and Implicit Social Capital

Because the social capital of a construction project team can be seen as a set of actual or potential resources in the relation network. According to the resource-based view, the resources of an organization are valuable, rare, unique and irreplaceable. Therefore, resource constellation is fixed to a certain extent [23]. Knowledge is also a kind of resources which can be classified as explicit and tacit [24]. Both knowledge and social capital have resource attributes. According to the categories of knowledge, we defined the social capital that can be directly obtained and utilized as explicit social capital, and the social capital that cannot be directly obtained is defined as implicit social capital.

2.4 Johari Window Model and Social Capital

The number of studies related to the Johari Window is very limited [25]. Johari Window, although simplistic in design, is generally regarded as an effective tool for developing self-awareness, an information processing tool or a structured method for effective communication [26–28]. The Johari window method has been applied to the fields of psychology [12], education [29], nursing [26], and disaster management [30]. In terms of research level, the Johari window was originally designed to encourage self-awareness at the individual level [13], and gradually the model was applied to group-level and organizational level [13, 31]. For example, Gapin [31] proposed organizatianal Johari to solve organizational communication problems [31].

Social capital and Johari Window both involve elements of mutual relations and trust. Trust is regarded a requirement to reach the goal of increasing self-awareness [26]. However, the application of Johari Windows to analyze social capital in construction field is still blank.

2.5 Identification of Research Gaps

Previous studies have divided the dimensions of social capital from a static perspective, such as the dimensions of structure, relationship and cognition. The social capital of construction project team accumulates with the progress of the project. However, the understanding of the form of social capital of construction project team from a dynamic perspective is still insufficient. The Johari Window model helps to place vague or unorganized phenomena into a logical structure, thus clearly focusing on them and providing a supporting template for users to think and act [28]. There have been studies using it to analyze the accumulation of knowledge from the perspectives of different groups of people, emphasizing the view that things seen from multiple standpoints may be different but equally important [13]. However, using the Johari Window to analyze the development of relational resources from the perspective of social connection is still blank. In addition, the use of Johari Windows to analyze problems at the team level is also very rare. In order to make up for these gaps, this research uses the Johari Window method to analyze social capital in the construction field, so as to provide a way to develop and cultivate more social capital that can be directly used in implementation of construction projects. Unlike the previous use of Johari window from the individual level, this article uses the Johari window method from the team level to discuss the social capital between the construction team and other stakeholders in a project.

3 Research Methodology

3.1 Critical Literature Review Method

A critical literature review method was adopted in this research. It is an analysis and conceptual innovation based on extensive research and quality evaluation of the literature [32]. The critical review method was used because it enables the study to provide a conceptual and theoretical contribution to social capital development of the construction project team. Daniel et al. [33] assert that a critical literature review allows a study to make conceptual and theoretical contributions to construction project management practice and theory because it provide useful literature for evaluation [33]. The critical literature review method was used to synthesis the current knowledge of the construction project team's social capital via Johari window model. Based on the Johari window model, a new conceptual model of social capital for construction project teams is proposed, and their dimensions are divided, the social capital transformation and cultivation strategies are discussed.

3.2 Johari Window Model Method

The Johari window model developed from the field of cognitive psychology. It is a method that helps people better understand their relationships with themselves and others. It was created by psychologists Luft and Ingham [12], and the window derives its name from them [12]. Johari window method is a technique of analyzing different parts of oneself by considering other peoples' perspectives. Through the different combinations of "others know", "others don't know", "oneself know", and "oneself don't know", the cognition of oneself is divided into four panes, as shown in Fig. 1a.

1. **Window 1**: Open or free areas

The part is known by oneself and also known by others, which is called "open or free area". It belongs to the part that is displayed by oneself and has nothing hidden to others. The degree of a person's self-exposure depends on the trust and relationship with others. The more a person shares, the more likely the relationship is mutually beneficial [26, 28, 31].

2. **Window 2**: Rivate or hidden area

The part that is known for oneself and not known by others is called "private or hidden area", which belongs to the secret part of the individual. Withholding information is believed to have a bad effect on the relationship between the two parties, which may be caused by the motivation of power and control [31, 34].

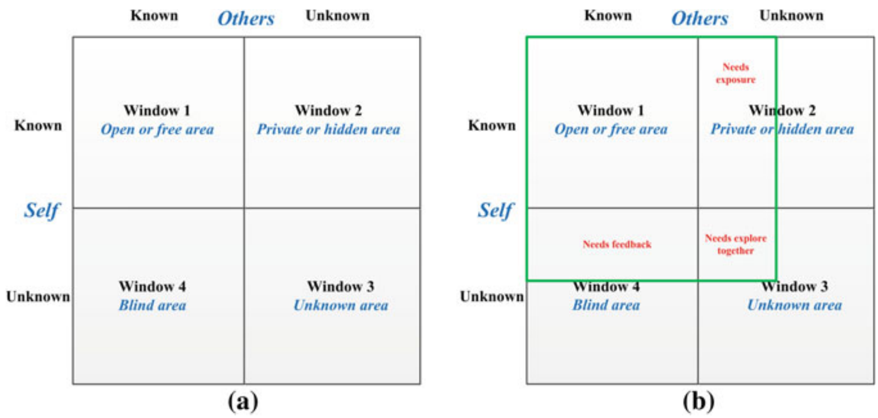

Fig. 1 Johari window model [12]

3. **Window 3**: Unknown area

The part is unknown by yourself and unknown by others, called the "unknown area", is the part that remains to be explored. This area is considered to have the most potential and creativity [31].

4. **Window 4**: Blind area

The part is unknown by oneself, but known by others, called "blind area". Just like a person's back, which is not seen by oneself, but can be seen by others very clearly. Blind spots are those traits that an individual is unaware of what he is disclosing publically to others but is perceived by others [26, 28].

Johari Windows are dynamic. A change in one quadrant can affect changes in the other three [12]. The Johari window is more used to solve the problem of communication barriers. The size of the four areas between "oneself" and "others" tends to change at different communication stages. With the deepening of the communication between the two parties, the open area will gradually become larger, while the other three areas will correspondingly become smaller. Methods to reduce hidden areas usually require self-exposure while effective methods to reduce blind areas require more feedback. The unknown area requires joint exploration by both parties, as shown in Fig. 1b. The application of Johari window theory to the analysis of social capital is rare in the field of construction.

The framework of the research methodology is shown in Fig. 2.

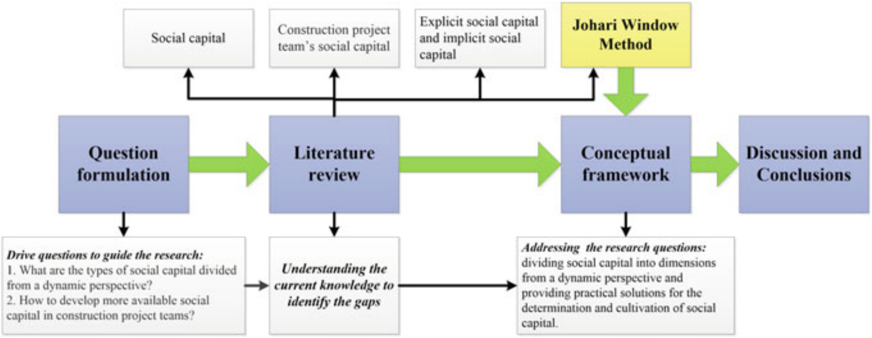

Fig. 2 Framework of the research methodology

4 Conceptual Framework

4.1 Application of Johari Window in the Analysis of Social Capital in the Construction Project Team

The construction project team is temporarily formed for project delivery. A network is established between the construction team and stakeholders outside the team. Because of the temporarily nature of construction project team, the explicit social capital and implicit social capital embedded in the network are constantly changing. The social capital of the construction team and stakeholders will continue to change as the project continues. Good trust and interaction will lead to the accumulation of directly usable social capital, thereby promoting the smooth progress of the project. This dynamic characteristic of team social capital is similar to the activity of Johari window to some extent. Johari window provides a method to discover the potential of the social capital exists in the project teams from a dynamic perspective to help improve the team performance.

4.2 Four Dimensions of Construction Project Team's Social Capital Based on Johari Window

The Johari Window model helps to place vague or unorganized phenomena into a logical structure, thus clearly focusing on them and providing a supporting template for users to think and act [28]. The Johari window also provides a way to understand interpersonal communication and how it is received and given [31]. Based on the Johari window model, the construction project team's social capital is divided into four dimensions. namely explicit social capital, private social capital, unknown social capital, and blind social capital, as shown in Fig. 3. The private, unknown, and blind

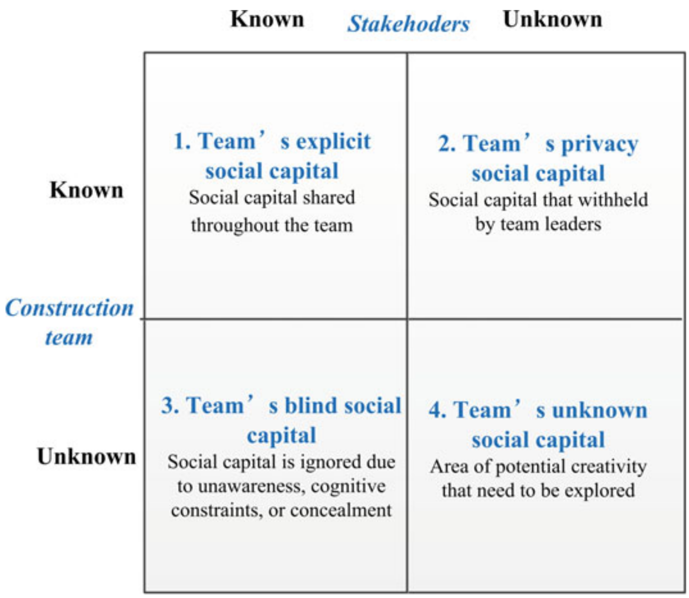

Fig. 3 The conceptual model of the construction team's social capital

social capital are all implicit social capital. It can be seen that according to the four quadrants, up to 75% of the construction project team's social capital may not be directly utilized, which needs to be developed, and the development difficulty of this implicit social capital is also differentiated.

A construction project network is composed of the construction project team and stakeholders such as the designers, suppliers, and project supervisors. According to the relationship between the construction project team and its stakeholders, the social capital of the construction project team divided based on the Johari window model is explained as follow.

1. **Window 1 (explicit social capital)**: explicit social capital shared thoughout the team can be directly acquired and used by any project stakeholders. Explicit social capital can be an open plan and official channel to identify partnerships and project resources. This kind of social capital is built on trust. The acquisition of these open social capital plays an important role in the success of the project. The explicit social capital also includes, for example, the explicit knowledge generated in construction projects [35], information which can be reused in the on-site construction process improvement and learning [36], and a recognized best process practice model in building construction [37]. Like clean air and safe streets, these forms of social capital are "collective goods" because they are not the private property of those who benefit from them [38]. This is especially true of internal, interconnected social capital; This use of social capital is non-competitive – one person's use of it does not reduce its availability to others

– but (unlike pure public goods) its use is exclusive – others can be excluded from a given network of relationships [18, 38].

2. **Window 2 (privacy social capital)**: it refers to the social capital that withheld by team leaders that cannot be accessed by other stakeholders. Construction project teams may be in a competitive relationship or involved in conflicts of demands among different stakeholders [39], which makes team members unwilling to share their social capital with participants outside the team. For example, the project target cost, quality, time limit, safety, environmental protection, each team has different perspectives, which prevent the sharing of social capital between teams; People's unwillingness to share their information is not simply because of their apathy, but their desire for control and power [31]. The concealment of the social capital of various stakeholders is for the control of the right in the project and the driving of interests.
3. **Window 3 (blind social capital)**: it is the social capital that unknown by the construction project team but known by others stakeholders. These types of social capital are the social relations that are ignored by the team or deliberately hidden by other stakeholders. A project itself has paradoxical nature of short-term and long-term interests. This kind of social capital stems from these paradoxical tensions. For example, a construction project team's leader may intend to establish project targets, best practices and gain resources to promote a good short-term performance. However, a long-term relationship with suppliers were ignored. Because the establishment or change of a relationship is considered not worth the time or will lead to a decrease in efficiency, this unconscious or cognitive limitation leads to a blind spot in social capital. In addition, the concealment of resources from the construction project team by other stakeholders in the project also led to a blind spot in the social capital of the construction project team.
4. **Window 4 (unknown social capital)**: it is the social capital that is unknown by the construction project team and unknown by other stakeholders, this part of social capital is very difficult to be discovered. The region needs to be explored by the team and other stakeholders together. It must be built on mutual trust and cooperation to develop those unknown social capital. The unknown area has the most potential for creativity [31].

4.3 A New Conceptual Framework for the Social Capital of Construction Project Teams

In order to achieve better project performance, trust and cooperation between the construction team and other stakeholders are needed, so as to realize the transformation of more implicit social capital into explicit social capital. Based on the structured approach provided by the Johari Window, a conceptual model is proposed to give cultivation strategies of a transformation of three kinds of implicit social capital

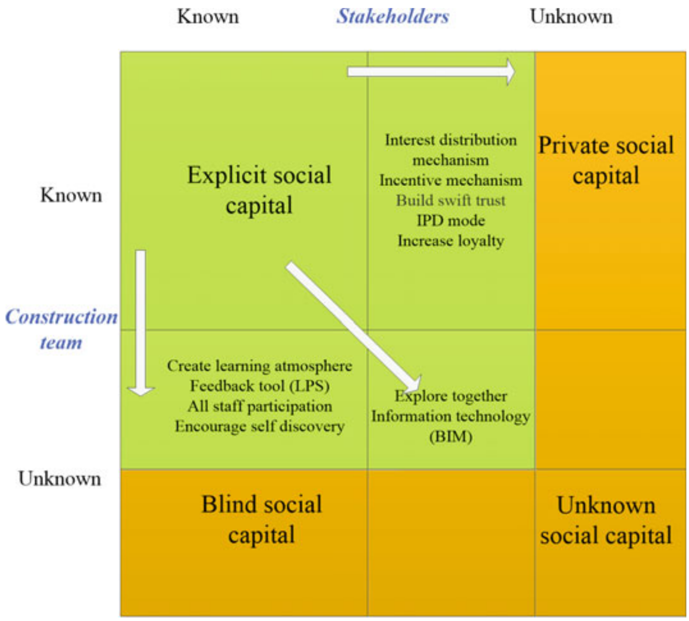

Fig. 4 The strategies to maximize the explicit social capital

into explicit social capital in a construction project team, as shown in Fig. 4. An explanation of the model will be provided in the discussion section.

5 Discussion

Based on the above model, specific strategies to achieve social capital transformation will be discussed below.

5.1 *The Transformation Strategies of Private Social Capital to Explicit Social Capital*

- **More reasonable interest distribution mechanism and incentive mechanism**. More reasonable interest distribution mechanism and incentive mechanism to make the team members willing to provide their private social capital. When the interests of team members personal and collective are not consistent, the team members cannot put overall interests first.
- **Build swift trust between project participants**. The trust-building process helps to mitigate the tensions between the individual and the collective [40]. Based on

trust, project stakeholders increase loyalty and willingness to disclose their private social capital.

- **Integrated project delivery (IPD)**. The model of Integrated Project Delivery (IPD) enables all parties involved in the project to work cooperatively and realize the integration of risks and benefits, to promote all parties involved in the project to take project benefits as the overall goal. The strategy can effectively promote private social capital to become public use.

5.2 The Transformation Strategies of Blind Social Capital to Explicit Social Capital

- **Create learning atmosphere**. Play the role of team leader and attach importance to the learning atmosphere of team open communication are good strategies. Managers and leaders can play an important role in facilitating feedback and disclosure among team members, as well as in reporting directly to individuals about their blind spots. Leaders also have a great responsibility to promote a culture and expectations that are open, honest, positive, helpful, constructive, and sensitive to communication and the sharing of knowledge throughout the organization. The best performing teams, departments, companies, and organizations tend to have a culture of open and positive communication, so encouraging everyone to actively develop "open spaces".
- **Use feedback tools, such as lean construction techniques**. The philosophy and methods of lean construction are conducive to the transformation of blind social capital to explicit social capital. Lean construction [41] was first proposed by Koskela [41]. It is the development of lean thinking in the field of construction. Lean construction focuses on reflection, full participation and continuous improvement. As a representative tool in the field of lean construction, the Last Planner System@ (LPS) tool advocates first-line managers to participate in the planning [42]. With the implementing of LPS, which can shorten the feedback cycle, and focus on learning and reflection. Feedback can reduce blind area, and learning can decrease unknown area, and make more social capital be utilized properly.
- **Encourage self-discovery**. In Toyota's Production System in Japan, undiscovered human potential is considered the eighth waste. By empowering employees and mobilizing them to participate in continuous improvement, people's potential can be brought into full play. It is widely accepted that most people in any organization work well within their potential at all times. Creating a culture, atmosphere, and expectations for self-discovery can help people realize more of their potential, thereby achieving more innovation and contributing more to organizational performance. An environment that encourages team members to explore the untapped opportunities can shrink the blind and unknown spot.

5.3 The Exploration of Unknown Social Capital

The construction project team and other stakeholders in the project working in partnership offers more than exploring their own and others' social capital. It provides the opportunity for new connection with a mount of social capital that neither group knew before. However, the unknown area has the greatest uncertainty. Because various changes will be encountered during the execution of the project. Every stakeholder will worry about the impact of these changes on them. This area also has the greatest potential and creativity and requires joint exploration by the construction team and stakeholders. Adequate communication is conducive to the openness and transparency of unknown social capital.

Implementing information technology can make resources visible and open. Such as using the Building Information Model (BIM), which can solve the problems caused by information asymmetries [43]; BIM is also considered to implement the construction industry to improve productivity, efficiency, shorten the delivery cycle, reduce life cycle costs, improve quality and sustainability [44], make information and resources integration and sharing, facilitate communication between the project participants, visualization and simulation function of BIM can diminish the unknown region, and make social capital explicit, to make the construction team's social capital be used more effectively.

Explicit social capital and unknown social capital are not adjacent to each other. However, as private social capital and blind social capital shrink, explicit social capital keeps increasing, while unknown social capital keeps decreasing. More unknown social capital can be further developed.

6 Conclusions

This research aims to better understand the dynamic characteristics of social capital and how to develop more available social capital based on the Johari window in construction project teams. The study found that because of the temporarily nature of construction project team, there are a lot of social capital in construction project team that cannot be effectively utilized. The social capital needs to be developed, and the development difficulty of the implicit social capital is also differentiated.

There are two main findings of this research. Firstly, types of social capital of construction project teams are understood and divided from a dynamic perspective based on Johari window model, namely explicit social capital, private social capital, blind social capital, and unknown social capital. In addition, a conceptual framework is proposed and put forward strategies on how to expand the implicit social capital of the construction project team in all dimensions to open areas.

The research has multiple contributions to social capital theory and managerial implications in the construction field. In previous studies, undeveloped social capital in the project was ignored. This research divides social capital into dimensions from a dynamic perspective for the first time and clarifies the dynamic composition of social capital with the help of the Johari window method. Besides, combining the four types of social capital with the actual situation faced by the construction project team, a new conceptual model was proposed. This model clarifies the conversion paths and strategies of social capital and provides practical solutions for the determination and cultivation of social capital in actual construction projects.

The evidence from this study can be promoted, although the research object of this study is the construction project team's social capital. It could be applied all kind of projects with temporary project team to achieve the project goals, rely on social relations, need to play to the role of the social capital between person and person, our conclusion is applicable. Since the construction industry is special, every building is a unique product, and the social capital characteristics of the project team are also unique. Temporarily formed teams need more sustained social capital to achieve project targets. Although the composition of social capital of each project team is different, the analysis method of the social capital can be copied. According to this method, the social capital of the construction project team is divided into these four dimensions and can excavate the implicit social capital, and promote the effective use of social capital.

The next focus of the authors is to apply the proposed framework in a real project to demonstrate how the social capital of the project team develops using case studies.

7 Disclosure Statement.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Making Sense of 'Project Management'—Chinese Contractors' Perspective

Beibei Qin

Abstract Despite the phenomenal growth of attention on project management in the Chinese construction sector, exploration of ground practices related project management is still lacking. The broader context is provided by introduction of marketization of the Chinese construction sector since 1978. What is notably absent in existing literature is understandings of practitioners' responses to the introduced project management policy. The reported research adopts a sensemaking perspective to understand how Chinese practising managers enact to project management, bridging the macro-level policy announcement and micro process of practising managers' enactment. Three contracting firms in Chongqing city region in South West China were selected as cases to study practising managers' enactment to project management. It has been found that Chinese contracting firms establish their organizational identity of 'general contractor' which resulted large scale of layoff and redefined the relationship between management staff and construction labours as subcontracting. 'Project manager' has been established as an important professional role in construction management practices, although decision making rights about selecting subcontractors and suppliers are decentred into headquarters of contracting firms. The findings illustrate how practitioners' enactment to 'project management' has resulted a complex plethora of hybrid practices, shaping and are shaped by the broader Chinese construction context.

Keywords Project management · Contracting firms · Manager · Sensemaking · Practices

1 Introduction

Since the foundation of China in 1949, the Chinese construction sector has experienced a series of significant transitions. The Open-Door policy issued in 1978

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marked a significant turning point from a centrally-planned economy towards the espoused 'social market'. Along with the rapidly growing economy and increasingly urbanization, construction demands increased dramatically. It is within this context that serials of reform polices relating to the Chinese construction sector were issued. Of particular importance is the introduction of 'project management' as a means to marketize the construction sector and improve efficiency. Although the importance of 'project management' is commonly acknowledged, related practices in the Chinese construction sector is significantly absent in existing literature. More importantly, the ways of practising managers responses to the announced policies in the marketization of Chinese construction sector is pronounced ignored. A sensemaking perspective is adopted to understand how Chinese practising managers enact to project management, bridging the macro-level policy announcement and micro process of practising managers' enactment.

This paper commences with the changing policies related to how to organize construction activities in the Chinese construction sector since 1949. Particular emphasis is given to how construction activities were organized before the Open-Door policy, which is essential to understand the Chinese construction industry today. Existing literature relating to project management in the Chinese construction sector is thereafter reviewed. The practice-based approach, particularly sensemaking perspective is hence justified. The research methods are then described which is followed by research findings and discussion. The broader implications are discussed and recommendations for future research are further made.

2 From Soviet Style Construction Towards 'Projects Management'

After the foundation of China, the Chinese government started to pay particular attention on economic growth and national defence. Part of soldiers relieved from the civil war were hence reassigned to join the production work and renamed as 'Engineering Army'. Divisions and corps from the PLA were hence reallocated to ministries to finish allocated construction tasks as building installation organizations. Commonly allocated construction tasks are planned heavy industry projects such as steel factories. For the convenience of centrally control, industrial projects were configured together in assigned cities. Construction activities were organised in a similar way to the manufacturing industry, with fixed factories and roles allocated by ministries. All specialist building installation organisations, which were allocated in the same construction base, were required to sign nominal 'subcontract agreements'. Productivity standards based on time and resources per unit of construction workload, duration quota and budget quota, were required so that national plans for constructing industrial projects could be supported through 'accurate' calculations. In order to encourage workers, the government provide welfare facilities such as schools, nurseries and hospitals for soldiers and their families in construction bases.

During this period, construction activities were organized in Soviet-style, the title of 'contractor' had not yet been established, nor the concept 'project'.

Since the 'Open Door' policy in 1978, the logic of 'learning from western countries' was formally announced. Construction activities hence began to be framed in terms of sectors, which was expected to 'increase revenue for the state'. The following reform agendas could be safely argued as a process of introducing market mechanisms and readjusting the degree of centralised planning. In order to develop construction market, 'engineering contracting firms' 'construction banks', 'designers' and 'suppliers' were introduced as the main actors in the sector. Building installation organisations were assigned different roles and renamed 'engineering contracting firms'. 'Improve the operational efficiency' became a key theme of reform policies about the Chinese construction sector. This is why Lubuge project attracted significant attention in 1980s. Taisei's success in Lubuge hydropower station became a shock for Chinese construction sector, which led to discussions on how best to organise and manage construction activities. 'Project way construction' is promoted, suggesting 'management and labour level separation'. Here, 'management level' refers to general manager, while 'labour level' refers to 'labour-only contractor', which were introduced by administrative business qualification certificate. The 'project way construction' policy also emphasises that construction production should be delivered through projects. Hence, projects were further suggested to be the central focus of Chinese construction enterprises. However, practitioners' responses to the announced project management policy are still unknown.

3 Project Management Literature Review

The project management research field has gain significantly increasing attention from worldwide since 1980s. In the first ten years (1983–1992), primary research interest was in developing and testing models for project planning and PRET, which was then commonly labelled as 'configuration perspective' (e.g. [8]). The underlying assumption is that project could be success as long as project managers adopt these tools, which is later be criticized underestimated the complexities faced by project practitioners. Recent years has witnessed increasing interest in actors involved in projects, particularly contracts, coordination and cooperation etc. Research interest has also expanded to topics of multi-projects and multi-firms. Söderlund [12] reviewed existing published research on projects and classifies them into four categories according to whether the research focus on one project or multi-projects and one firm or multi-firm. These four categories are project management which focus on success factors, planning; inter-firm projects that focus on transaction costs, contracts relationships; multi-project firms which focus on resource allocation, etc.; and project ecologies which focus of the sociology and economic geography of projects. In recent years, increasing attention has been given to the multi-project management (e.g. [7]), while the relationships between project and the environment is still lack of understandings [13].

The lack of understanding of relationships between project and the environment is particularly true in the Chinese construction project management research field. With reviewing research on project management in Chinese construction sector, it has been found that existing literature primarily focus on topics such as planning, risk management (e.g. [5], team management (e.g. [1, 2]), decision making. Existing literature primarily focus on critical factors that affect (the success of) 'project management'. For example, [3] attempted to explore 'project management practices' in the Chinese construction sector. Particular attention was given to key aspects, benefits and challenges of project management implementation highlighted by interviewed practitioners. However, the identified factorised aspects notably fails to engage with the material and discursive practices of construction practitioners [7]. There is seemingly little interest in the root-and-branch reorganization of organizations and the broader sector as part of the espoused project way management policies. Neither is there any recognition of know-how which is required to translate these factorised aspects into feasible actions. Hence, these research are inherently instrumental and static. It is notable that such normative models are not limited to research on project management in the Chinese construction sector, but also common on generic project management research field [7]. How practitioners respond to the introduction of 'project management' is still unknown, let along how this affects the actors' actions and interactions in the Chinese construction context. Hence, this paper intends to explore practices that Chinese practitioners developed in responding to the 'project management' policies.

4 Methodology

The reported research draws upon a practice-based research approach to explain how 'project management' happens in the dynamic, real life Chinese construction context. The practice-based approach ascribing a greater degree of agency to construction practitioners. Particularly, sensemaking perspective is adopted to understand how Chinese practitioners response to the introduction of 'project management' idea and the following impact on the Chinese construction sector. Sensemaking refers to the process by which individuals notice, interpret and react on changing environment. Through such process, the society is continuously made and unmade by individual's sensemaking practices [4]. Hence, sensemaking is seen to be a continuous activity through which individuals interact with the world around them. Adopting sensemaking perspective, practices are not only what people do, but also constructing meanings of terminologies and professional identities. Hence, this paper focuses on both material and discursive practices, positioning itself within the broad spectrum of practice-based research. More specifically, this research focus on both material and discursive practices related to 'project management' developed by practitioners in Chinese construction sector.

Despite an extensive literature relating to project management in the Chinese construction sector, there remains an absence of data relating to how Chinese contractor managers enact to ‘project management’. This research studies the ongoing sensemaking process of contractor managers, highlighting the ‘practice-turn’ in broader construction management and broader management research field. Organisational members’ sensemaking processes are seen to be embedded in material facts, artefacts and practices in their organizational context [9]. Hence, contracting firms are selected as cases to study how Chinese managers make sense of ‘project management’. Three state-owned contracting firms in Chongqing construction sector were selected as cases to study, which were anonymized as East Construction, South Construction and West Construction. The East Construction and West Construction are in large scale and annual outputs of these two firms are over 20 billion yuan. The South Construction was in middle scale, the annual output of which was around 0.8 billion yuan. For each case, multiple research methods were used to collect data in order to provide rich explanations of managers’ enactment to ‘project management’. Semi-structured interviews were conducted with 22, 14 and 8 senior and middle managers from three studied firms correspondingly. The selected managers are in key position in the firm and had worked many years in the firm. Managers were asked to interpret their past experience related to project management. All interviews were recorded and transcribed. Meanwhile, documents such as annual reports and historical records were also collected. For this research, data analysis focused on managers’ storylines related to project management.

5 Findings

The three case studies demonstrated that practitioners have absorbed terms such as ‘project’ and ‘project management’ into their lexicons. The notion of ‘project management’ was a key component of the managers’ accounts of how the construction process is organised. Nearly all interviewees highlighted the Lubuge project and the Ministry of Construction’s subsequent announcement of the ‘project way construction’ initiative and its following practices such as organising courses to promote this idea. Two key themes of managers’ storylines were identified.

5.1 Emergent Subcontracting

Interviewed managers in China commonly talk about separation of management and labour when they mobilising the notion ‘project management’. The phrase ‘management layer’ commonly refers to management staff and technicians, while the notion of ‘labour layer’ usually refers to people who conduct physical construction work. Many interviewees emphasized their professional role by repeating that ‘we are the management layer, we do project management only’. It seems that the introduction of the ‘project way construction’ policy have changed managers’ perception of labours. Labours then after started to be viewed as ‘burden for construction firms’, as firm had to provided salaries and welfare for them. The manager of the Department of Safety Monitoring in South Construction interpreted that:

> We have to focus on management only so that we can reduce the burden for the firm. No insurance and pensions need to pay for labours now, reducing costs for our firm. Before this, all labourers needed to be paid no matter whether they worked or not. Now we just pay for labourers that we subcontracted to work. Through this way, losses have been avoided. (Interviewee 42, Safety Monitoring Department manager)

What is notable is that the interviewee's account was constructed by grounded in his current perception of 'what the organisation should do'. Grounded in the perception of 'the firm should focus on management only', the interviewee interpreted laid off as 'reducing burdens'. It is clear that the interviewed manager adopted economy logics to further explain why labours were laid off. His argument is that labour subcontracting saved costs for the firm as the firms could avoid providing insurance and pensions for fixed labours. Floating workloads was also emphasized to further justify how cost could be saved by layoff. Both East Construction and South Construction witnessed layoff of manual workers, such as carpenters and steel benders. According to East Construction's annual reports, its number of employees decreased steadily during the 1990s and experienced a dramatic drop at the beginning of 2000s. Almost half of employees were laid off. Moreover, the term 'subcontracting' was introduced to redefine the relationship between the management layer and labour layer. Practices such as negotiation and contract were introduced to manage this redefined relationship.

5.2 *Redefining the Nature of Interactions Between the Firm and Project Management Teams*

Contractor's managers commonly argued that the 'project way construction' broke their then perception of the 'permanent work area' constructed in Soviet-style construction process. The word 'project' highlights the provision that project departments reorganise after the project is finished. Project manager became a new professional role which was given rights to manage aspects of construction activities. These include not only keep and disburse project funding at will, but also make decision on selecting sub-contractors and suppliers. Many interviewed managers remembered that fully-authorized project manager illegally took advantage of these rights, 'putting project money into their own private pocket'. An interviewed manager recalled the situation when she worked as an accountant for projects in the late 1990s, 'project managers commonly subcontracted work to those they had good guanxi and asked for kickback.' This seemingly further viewed as why the contracting firm was in loss, both company and project level in late 1990s. The need to redefine the relationship between the firm and project management teams were highlighted by almost all interviewed managers.

The phrase ‘centralized management and control’ was used by all interviewees to describe the following process of redefining the relationship between the firm and the project management team. The home office seemingly held back the rights to manage project funding and select subcontractors and material suppliers. Practices such as withdraw project managers’ rights to manage individual project bank accounts and introduce firm’s main bank accounts were adopted in East Construction and South Construction. Moreover, the home office achieved its control over project funding by checking and approving project managers’ expense. Practice of employ and assign accountants to individual projects seemingly secured the monitoring project managers during project process. In order to avoid project managers’ manipulation of subcontractor and suppliers selection, bid and tender practices were introduced. Both East Construction and South Construction developed their own Bid and Tender Centres in subsidiaries level, which were further centralized into home office level. All interviewees used the phrase ‘centralized bidding and purchasing’ to summarize these practices.

Moreover, functional departments in home office seemingly grabbed the right to make decisions gradually. Such process was labelled as ‘organizing into a matrix management system’ by the manager of Human Resource Department in South Construction. Functional departments include but not limited to accounting, human resource management, safety management, quality management, technology management and contract management. The phrase ‘managing every function line’ was commonly addressed, which refers to strengthening functional department control over project management decisions. Several practices taken to realize ‘managing every functional line’ were addressed by interviewees. For example, functional departments select project management staff. Particularly, only managers in leader group are entitled to nominate and approve project managers for individual projects. Deputy general managers and departments managers could nominate other project management members. By these practices, the right to appoint project management staff were maintained in home office. Moreover, home office makes plans for every individual project, including construction, construction sites, commercial and accounting, which further secured home office’s control over projects. Additionally, interviewees also highlighted that functional departments seemingly organize site inspection routinely to make sure the home office’s control over project. For many interviewees in South Construction, the role of project managers is progressively redefined as ‘executing agency’.

However, it is notable that the South Construction adopted different practices from the other two cases. Specifically, emphasis was seemingly given to South Construction’s inability to constrain project managers. Here, interviewees from the South Construction commonly admits that ‘South Construction can only manage projects in a very limited degree’. It is notable that interviewed managers commonly addressed that the project management norms introduced by the firm were ignored by project managers. It is notable that project management staff refuses to follow the firm’s requirements concerning standard budget planning. Another example of limited management over projects concerned difficulties in having project managers attend monthly production meetings. The contracting firm surely could not manage projects at ease if they could not obtain basic project information such as costs, quality and progress. Such different ways of interactions between South Construction and project managers are seemingly because that most projects in this firm are joint-operation projects. 'Joint-operation projects' means that projects that are run by both project manager and contracting firms, but primarily by the project manager. This is seemingly because that project managers of joint-operation project have personal guanxi with clients. The contracting firm such as South Construction was only involved as providing certificate of 'legal entity' to make sure bidding process is object to the law. According to China's Law of Construction, project bid procedures and contracts can only be signed by a registered contracting firm which has a corresponding level qualification certificate. Contracting firms normally sign an official contract with clients, although real deal is made by project manager and the client. Clearly, how managers in South Construction enact to the policy of 'project management' is embedded in their organizational context.

6 Discussion and Conclusion

The qualitative findings presented in this paper are persuasive in pointing towards an alternative research agenda. This research emphasises contractors' practices related to project management in a real-life, dynamic Chinese construction context, which has been long ignored in existing literature. The case study results further revealed that the term 'project management' was applied to how firms organise themselves, particularly in terms of their increased reliance on subcontractors. Thus, the notion of 'project management' relates to contractual arrangements through which projects are initiated and delivered, which are often taken for granted in the Western construction sector (e.g. [15]). Practising managers then began to construct their new role of 'we are management layer' and started to view labour-only subcontracting for granted. The increased reliance on subcontracting practices resonates with contractors' over-reliance on subcontracting to pursue 'structural flexibility' in the western construction sector (e.g. [15]). Green et al. [6] criticized that the apparent result of pursuit of structural flexibility led contractors to focus on 'contract trading' and reluctant to provide training for labours. This will harm the construction sector ultimately.

Moreover, Chinese contracting firms have redefined their interactions with project managers in the process of enacting to project management policy. During such process, the home office of contracting firm has been constructed as 'a centralized platform for controlling projects'. Meanwhile, project managers have been recast as a role to follow instructions only. This to certain degree resonates to [2] argument that project managers commonly view themselves as 'employees of the firm'. Differently, contractor-based project managers in western construction sectors tends to view themselves as 'independent manager of the project'. The 'home office' of western contracting firms seemingly exercising less control in this process than their Chinese counters. In conclusion, the Chinese construction practitioners have constructed the meanings of 'project management' through enacting to this idea. As Morris and

Geraldi [8] reminded, meanings of 'project management' in different context differ from each other in various ways.

Concurrent with the above was the progressive shift towards the projectification of the Chinese construction sector (e.g. [12]), otherwise phrased as the normalisation of the 'project' as the essential unit of production. The broader implication of this research lies in shifting existing research from 'single project-centric' towards to 'actor-centric', focusing on experiences and practices of embedded practitioners who involved in project management (e.g. [7]). This paper hence contributes to the black boxes of how interaction ways between project and their environment are constructed in particular context, which lacks understanding in exiting literature [13]. Phrase slightly differently, institutions are made and remade through practitioners' sensemaking practices [9, 16]. This research of course has its limitations as findings were generated from the three studied cases. But the described features of managers' sensemaking practice in the three studied firms are surely not unique. Findings could be taken by practising managers to rethink re-organizing process of their contracting firms. Moreover, findings could be tested quantitatively in future research.

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Building Materials Supply Process Reengineering Under the Background of Blockchain Technology

Liyan Qiao, Zhongyi Cheng, and Yuejun Liu

Abstract There is a good foundation in the field of blockchain research in China, and it is necessary to accelerate the development of blockchain technology and industrial innovation. In order to better complete the combined application of blockchain technology in the field of construction research, working from the perspective of building materials supply in the construction industrialization, after screening with the the method of "Classification Analysis" and "Comparative Analysis", the technologies that can be integrated with the traditional supply process under the background of blockchain technology are the "Supply Chain", "Smart Contract" and "Internet of things". During process reengineering, the first step is to complete the digital transformation of the supply process; the second step is to integrate the blockchain technology to update the data storage management mode and change the user transaction information interaction form in each stage of the process. Finally, through the application,the building materials supply process model under the background of blockchain technology is obtained, and the process reengineering is completed.

Keywords Building materials supply · Blockchain · Information storage · Process reengineering

1 Introduction

Blockchain technology is a newly emerging database technology, which can be organically combined with a variety of existing mature technologies to improve the management system or process system of various industries. It is a highly subversive and innovative technology. After more than a decade of development, blockchain technology has reshaped almost all modern industries [1]. At present, it has been formed to be a magnificent technological system and industrial ecology, and it is spreading from the field of digital currency to other fields, and promoting the innovative integration with all walks of life [2]. With the in-depth research and application

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of digitization, informationization, and intelligence, there is a good foundation in the field of blockchain research in China. It is not only applied in multiple fields, but also tested in the field of digital infrastructure. On October 25, 2019, General Secretary Xi Jinping stressed that the integrated application of blockchain technology plays an important role in the new technological innovation and industrial transformation, and it is necessary to accelerate the development of blockchain technology and industrial innovation. Comparing with the whole research field of blockchain technology application, the application examples of the blockchain technology in the construction industry are still very limited. Therefore, the exploration of application of blockchain technology in the construction industry can not be stopped. In order to better complete the application of blockchain technology in the field of construction research, the supply process should be reformed from the perspective of building materials supply chain of construction industrialization.

Chapter 2 is the part of literature review. Analyzed many Chinese and English literature such as SCI source journals, EI source journals, core journals, CSSCI and CSCD with method such as literature research method, classification analysis and comparative analysis, the following conclusions were obtained: a. The general trend of blockchain research is technology integration. It proves that the integration of building materials supply process and blockchain technology is a correct research idea; b. There is a prepared application system with many technology integration. It proves that a variety of related technologies under the background of blockchain technology can be the breakthrough point for the transformation of building materials supply process; c. The digital transformation of process provides the premise for the application of block chain. If the blockchain uses e-commerce platform as a carrier and manages effectively for the whole procedure of building materials supply on the flat, it is necessary to apply the blockchain technology to the whole procedure; d. The technologies such as "Supply Chain", "Smart Contract" and "Internet of things" are suitable to apply blockchain technology on the building materials supply procedure.

The Process Reengineering was accomplished under the background of blockchain in Chap. 3. The preliminary Process Reengineering was accomplished in Part 3.1. The information of building materials supply chain can be better carried in the e-commerce platform including the preliminary processed building materials to building materials suppliers provided by building materials manufacturers, the ordered materials provided by to contractors or construction units by building materials suppliers, along with the transportation process to the construction site after the construction materials are transported to the storage warehouse. All the information meets the demand of information transmission and supervision control to the building materials logistics supply. Therefore, in the process of process construction, the preliminary digital transformation of supply process is completed firstly, which is convenient for the management and supervision of new process on the e-commerce platform; secondly, the process is further updated by the introduction of blockchain technology in 3.2. Two major changes in the supply process are accomplished by using the three technologies selected in Chap. 2, the change of information interaction form and the update of data storage management mode: a. The change of information interaction form mainly transforms the digital integration of consumer groups into multiple nodes, and with the help of blockchain technology, these nodes are no longer fixed at a certain stage in the supply process of building materials, it can form a point-to-point network, and the interactive information in the whole process stage can be consulted and supervised by all participating nodes; b. The application of blockchain technology will update the data storage management mode. The corresponding three process stages of "Block header formation—Block body formation—Block package into chain" before, during and after the new process are described in details; Combined with the updated results in 3.2, a single building materials supply process reengineering in blocks is completed in 3.3. The new process can form blocks which form the building materials supply process in a macro clear way; finally, the reengineering process is further supplementary structured to solve the storage problems of "block" and "chain" in 3.4. The credit system derivation is completed.

In Chap. 4, through the application simulation, the building materials supply process model under the background of blockchain is obtained. As long as the hypothetical condition elements are available, the model is still feasible and process reengineering is successful.

In Chap. 5, the conclusion summarizes the changes, effects and advantages of process reengineering in theory and practice, and prospects for possible future research issues.

2 Literature Review

Analyzed many Chinese and English literature such as SCI source journals, EI source journals, core journals, CSSCI and CSCD with method such as literature research method, classification analysis and comparative analysis, the following conclusions were obtained:

(a) **The general trend of blockchain research is technology integration** [1, 3–6];

For example, Liang Wen and Si Junfang [6] draw a conclusion: the sharing economic model drives the development of shared logistics. "Blockchain + logistics" further promotes the pace of shared logistics. For example, according to the research of Abeyratne and Monfared [4], smart contracts should be implemented and embedded in the system to provide incentives to enable the blockchain to control the progress of business processes. Su Jian [1] mentioned that it is necessary to build a regulatory system suitable for the development of blockchain technology through multi-agent collaborative supervision [4].

(b) **The integration of many technologies owns a ready application system**;

For example, Betti et al. [7] explained that the blockchain technology and the technology of Internet of things which supports data collection can be automatic matched. The process from data collection to automatic matching fully conforms to the essence of physical network. This technology was first applied in hyperlink logistics. And the technology is ready. NIR Kshetri [8] sorted out the relevant knowledge of blockchain with literature research method, and elaborated the mechanism and strength based on the continuous development of blockchain technology, which is the application prospect of blockchain. Moreover, many references have expressed the intention of “joint use prospect” and “basic preparation of single technology". Therefore, combined use on this basis is a reliable blockchain application scheme, especially in the field of construction, Wang and others [9] also support this view: blockchain can solve the shortage of trusted information resources in prefabricated supply chain management. Because of the similarity between prefabricated supply chain and general logistics, it is feasible to manage prefabricated supply chain with blockchain [10].

(c) **The digital transformation of process provides the premise for the application of blockchain**;

On April 23, 2020, IPR daily, an authoritative intellectual property organization, released the latest G*lobal Blockchain Patent Lis*t, among which Chinese enterprises accounted for 60%, nearly three times that in the United States. Alibaba (Alipay), which focuses on e-commerce, ranks first with 1505 patents, while Tencent and China Ping’an Insurance rank second and third with 724 and 561 patents respectively. Therefore, e-commerce platform is a reliable carrier for the further application of blockchain technology. When the building materials supply process has been completed with the digital transformation and can be carried out on e-commerce platform, further process reengineering should be done combining with the relevant technologies of blockchain.

(d) **The technologies including the “Supply Chain”, “Smart Contract” and “Internet of things"are screened out to apply in building materials supply process under the background of blockchain technology**.

In order to screen out the keywords that cover and relate with “blockchain”, “construction” and “supply”, the subject of “blockchain” was searched from the data in the Chinese and English under the category of “basic science”, “engineering technology”, “information technology” and “economic and management science” such as CNKI.net, SCI source journals, EI source journals, core journals, CSSCI and CSCD from 2015 to 2020. Furthermore, focused on the “Technical research field related to blockchain applications”, 399 articles including the terms of “technology field” related to the blockchain are screened out for classification and statistics. Finally, the subject words with same meaning are merged into same category.The number and proportion of word frequency are shown in Table 1 and Chart 1.

Based on the above results, we searched “architecture” and got the topic word frequency of “architecture related research fields under the background of blockchain technology, in which “supply chain” ranks first with a total of 2 articles and “alliance chain” and “trade chain” ranks second with one article each. The proportion of word frequency is shown in Chart 2.

Based on the result of Chart 2, we searched “supply” and got keywords frequency of “Supply related fields in the background of blockchain” and merged the keywords

Table 1 (1015–2020) Words frequency related to blockchain applications in technology field

(1015–2020) Words frequency related to blockchain applications in technology field	
Subject words	Frequency
Smart contract	132
Digital currency	114
Internet of things	49
Supply chain	44
Chain alliance	33
Data sharing	14

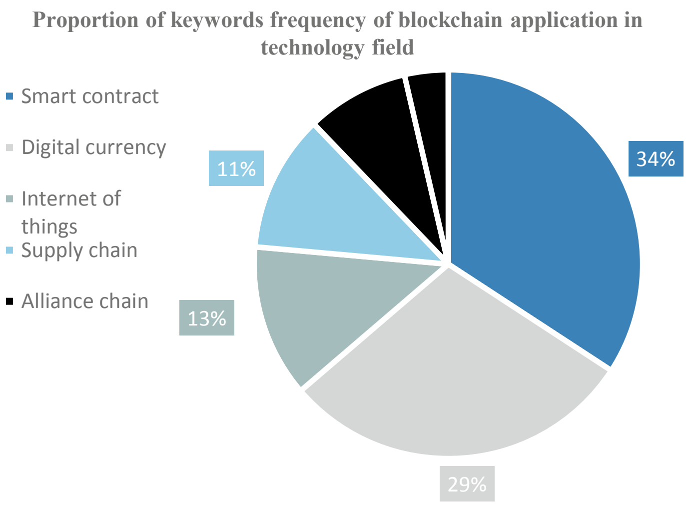

Chart 1 Proportion of keywords frequency related to blockchain application in technology field

with cross meanings into the same category. The number and proportion of word frequency are shown in Table 2 and Chart 3.

Comparing Charts 1 and 2, it is necessary to screen the subject words with the largest proportion of word frequency or the presence of “ ≥ 2” charts at the same time. After screening, it is concluded that the “smart contract” and “supply chain” rank first in the charts. The “Internet of things” exists in Charts 1 and 3 at the same time, and both rank the third, so the “Internet of things” is retained. In addition, although the “alliance chain” also exists in two charts, the subject word accounts less than 11% of the figure in Chart 1, and only one literature is involved in the search condition of Chart 2, the subject word is omitted. Finally, the technologies of “supply chain" [4, 11, 12] “Smart contract" [13] “Internet of things" [14] will be used for process reengineering.

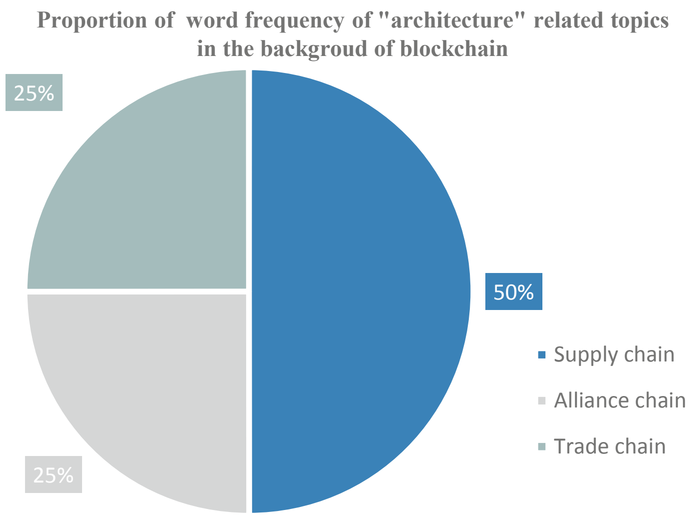

Chart 2 Proportion of word frequency of "architecture" related topics topics in the background of blockchain

Table 2 (1015–2020) Keywords frequency of "supply" related technical fields in the background of blockchain (2)

(1015–2020) Keywords frequency of "supply" related technical field in the background of blockchain	
Subject words	Frequency
Supply chain	35
Smart contract	7
Internet of things	3

3 Building Materials Supply Process Reengineering Under the Background of Blockchain Technology

The digital transformation of building materials supply process is the first step of process reengineering, which facilitates the real-time monitoring and management of information on the e-commerce platform, and creates preconditions for the introduction of blockchain technology. Secondly, the e-commerce platform is upgraded to the blockchain technology platform through technology integration, to complete the change of information interaction form and the update of data storage management mode. Finally, the framework of the whole reengineering process is further supplemented, and the data "blocks" and "chains" of multiple projects and multiple processes are coordinated to form a system.

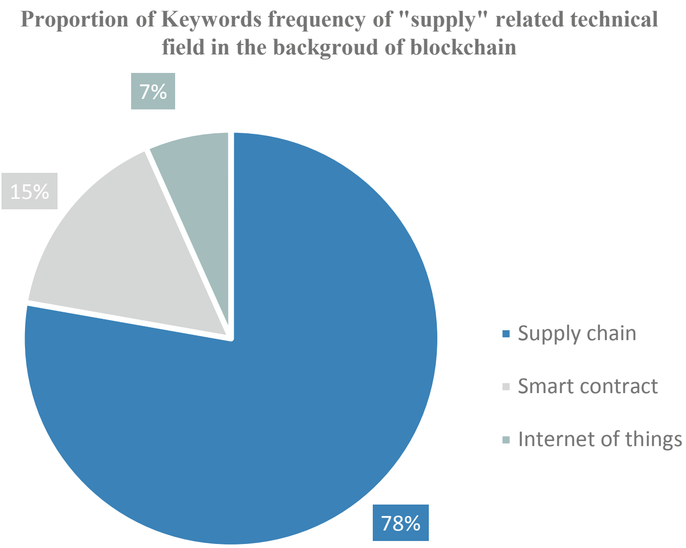

Chart 3 Proportion of keywords frequency of "supply" related technical field in the background of blockchain

3.1 Digital Transformation of Building Materials Supply Process

The e-commerce platform can realize the information transmission of building materials supply, and create preconditions for the introduction of blockchain technology. Combined with the reference to Liu Qin and Gong Fangheng [15], there are several factors such as specific projects, construction units, contractors, building materials suppliers and logistics service providers in the supply structure chart of traditional building materials for e-commerce upgrading. Through further analysis and integration of the role information of each stage in the process, the digital transformation of building materials supply process is completed, which is convenient for management on the e-commerce platform, as shown in Fig. 4.1.

"Consumer group", "building materials sales center" and "third party logistics" are connected from upstream to downstream. Hereby "Consumer group" refers to the digital integration of consumer role including parties in request(construction units/contractors). All building materials distributors and suppliers are integrated digitally in "building materials sales center" and all logistics providers are integrated digitally in "third party logistics". Then all consumer group will be matched along with the three time periods such as before, during, and after the supply process and stored in the e-commerce platform. Combined with the complexity of building materials logistics and other reasons, in order to balance the risk of process participants, the feedback process is added. After the initial digital transformation of supply process,

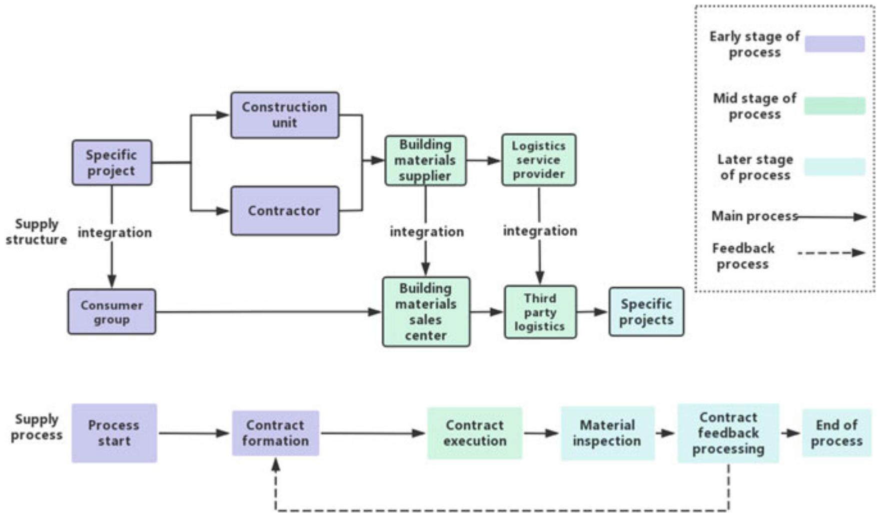

Fig. 1 Flow chart of initial building materials supply reengineering

the process information can only flow one-dimensional and one-way according to the actual operation time (Fig. 1).

3.2 *Process Update of the Blockchain Technology Introduction*

3.2.1 Changes of Information Interaction Form

After the initial digital transformation of the process, participating users from all the stages still can not achieve information interaction across the process links. If one of the stages breaks down, it is difficult for the role groups of the follow-up process to know the changes of the benefit relationship, which will not only complicate the feedback process, but also may be used for personal gain because of opaque information, which will lead to a vicious circle over time. The introduction of blockchain technology needs to convert all the participating roles in the group into node. The "consumer group" becomes the "demand user node", the "building materials sales center"becomes the "supply user node" and the "third party logistics" becomes "logistics user node". All the nodes include individual users and groups. Because blockchain is a technology supporting energy P2P transaction [16], after application, the information interaction structure of the whole supply process is changed. These nodes are no longer fixed in a certain stage of the building materials supply process, but form a point-to-point network. The interactive information of the whole process stage can be consulted and supervised by all participating nodes.

3.2.2 Update of Data Storage Management Mode

Blockchain technology is a new way of data storage and management. With the update of process information, the new information will be stored and managed in multiple blocks. After screening, e-commerce platform can be upgraded to blockchain platform by combining the technologies of supply chain, Internet of things and smart contract under the background of blockchain technology. The updated building materials supply process are described from three stages of the process such as early stage, mid stage and later stage as the following.

(a) **Block head formation (early stage of process)**

The formation of block head corresponds to the early stage of building materials supply process and is the part of block formation. The basic structure is shown in Fig. 4.

The Internet of things module is responsible for reading the information of building materials, which can be uploaded through the supplier's side by scanning the building materials and goods information. After obtaining the product information, the Internet of things module transmits the data to the supply chain module and the smart contract module for comparison and authentication, and finally uploads the data through the smart contract module.

Smart contract is a contract that uses computer language instead of legal language to record terms. It can be regarded as a automatic program deployed on the blockchain. It covers programming language, compiler, virtual machine, event, state machine, fault tolerance mechanism, etc. [17]. This research is a smart contract module under the background of blockchain, which is responsible for the interaction of management information, including contract generation and contract execution, which are jointly developed by the participating user nodes in the supply process. The contract generation is stored in the block header.

The supply chain module is a public query module for the competent departments and the participating users in the supply process. It mainly authenticates the formation of contracts in the block head itinerary, and immediately opens the monitoring and feedback mode of the process. It can receive the user feedback from each stage of the supply process, and act on the block formation together with the smart contract. The supply chain module can obtain information of feedback and contacts with public key for smart comparison authentication. participating user can check private data with private key and manually send a feedback request. The competent authority can also review and decide through this module.

Since block trades the transaction information in a transaction block through the hash algorithm, the information constantly updated and stored under the action of the above three modules will be transcoded in this form. It is mainly expressed in bloack head as: timestamp, Nbits, parent hash, Melgen tree root hash and block version. The parent hash is a hash value in the last valid block which can uniquely and accurately identify a block.

(b) **Block formation (mid stage of process)**

The block body is composed of transaction quantity and transaction details, corresponding to the contract execution stage, as shown in Fig. 2. The material delivery generates logistics data. The IOT module is responsible for reading the material information and the user's personal update information and storing the information in the contract execution sub module, and then storing in the block form. The smart contract module can query the updated data of the IOT module from the blockchain technology platform, and store the updated and authenticated contract execution data into the corresponding block in the form of block body. The supply chain module can receive the user's feedback generated in each stage of the supply process, real-time authenticate the contract execution, and then flow into the smart contract module. After the above three modules are executed, data such as materials, transportation drawings, and acceptance results will be updated accurately and timely, and the updated information will flow into the block body.

(c) **Block packaging into chain (later stage of process)**

A large amount of information will be generated and stored in the process of contract execution. Whether these stored data are accepted will be based on whether the block body matches the block header information as the standard. Whether these stored data are accepted can be inspected and verified when the materials are delivered. If the block body data does not match the block header, feedback will be processed. The supply chain module can access the feedback information and contract information at the same time for intelligent comparative authentication at any time. When the authentication fails, the block becomes invalid. The original transaction amount will

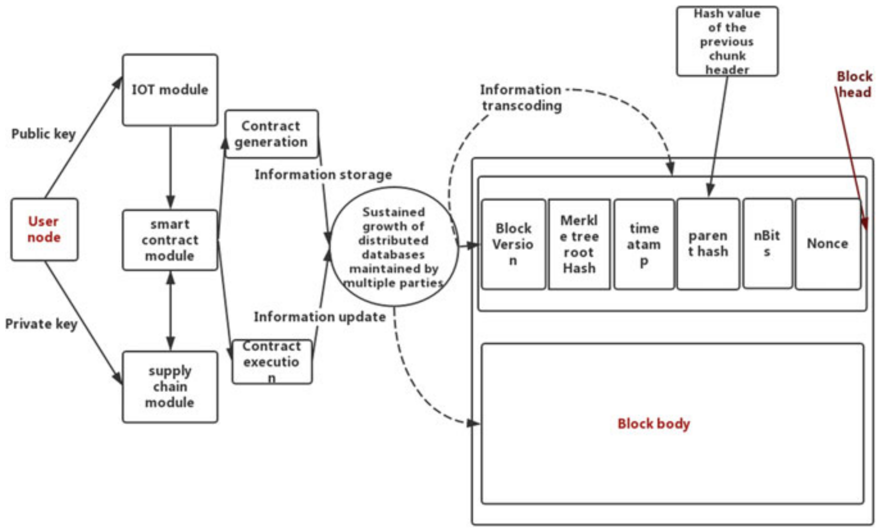

Fig. 2 Basic structure of block head

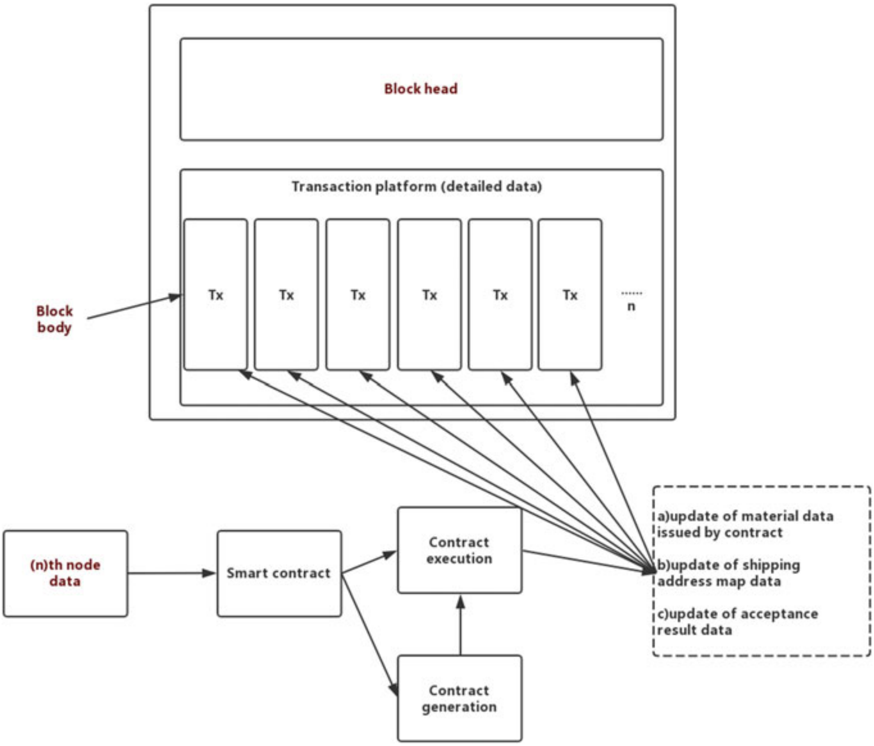

Fig. 3 Basic structure of block body

be calculated and returned by the blockchain platform based on the situation of responsibility backtracking. The original transaction item can be recreated according to actual needs after the block expires. If the material transaction information and subsequent supply situation pass the system authentication, the transaction item can be completed. Finally, the block header and block body are packaged and a new block is formed and stored. Then block will be connected after the last valid block. The blocks will form a chain in the order of transaction formation time. As shown in Fig. 3.

3.3 Building Materials Supply Process for Forming Blocks

The supply process has been updated and reengineered. The whole process can be operated and managed on the blockchain platform, and a block can be formed after the end of one process transaction. According to the time sequence of data storage, the process is constructed in the early stage (as shown in Fig. 4, the purple part), the middle stage (as shown in Fig. 4, the green part), and the later stage (as shown in

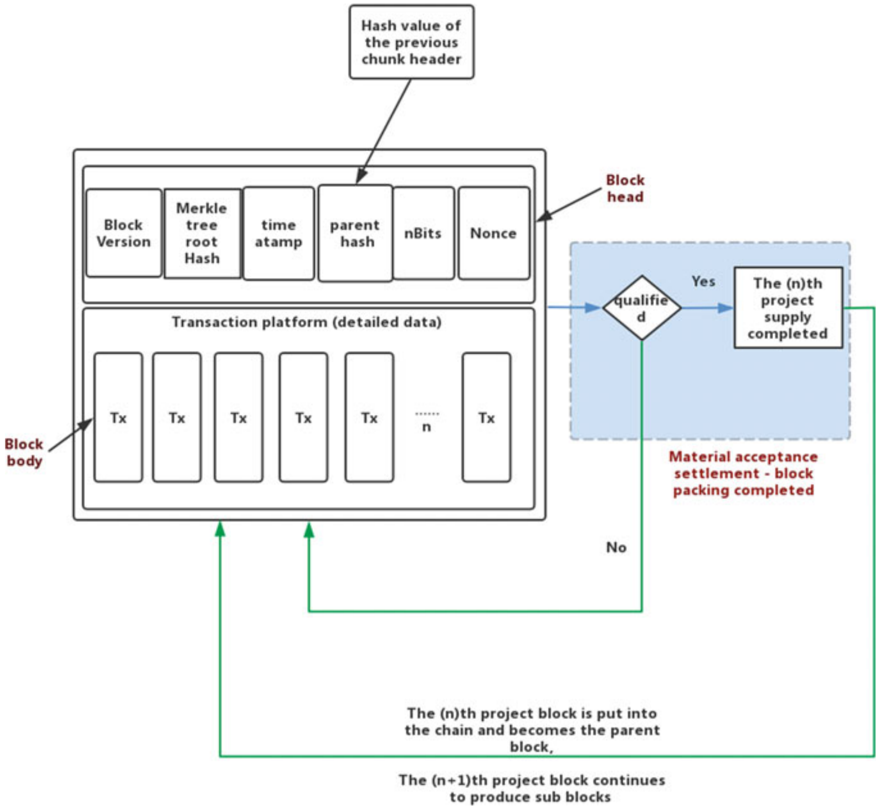

Fig. 4 Material acceptance and settlement - block packing completed

Fig. 4, the blue part). Here, the macro description of the one-time transaction process formed by a single block is shown in Fig. 5.

When a specific project generates demand for building materials, the material purchaser needs to log in and purchase materials from the blockchain platform. The construction unit or the contractor will purchase the materials according to the contract. After the purchaser registers and logs in, the user information will be consolidated and stored in the customer base. Accordingly, logistics service providers, building materials suppliers and building materials manufacturers also have corresponding user data groups. When they interact with other users, these users become countless information points (Fig. 4).

At the beginning of the process, each user node will be matched with each other after logging in the blockchain platform, and initial information interaction will be generated. Due to large product quantity, large transaction amount, high risk in transport during building materials transaction, a single manufacturer may not be enough to meet the demand of the reality, then multiple manufacturers are require. Even a single manufacturer can meet the material needs of consumers, it may not

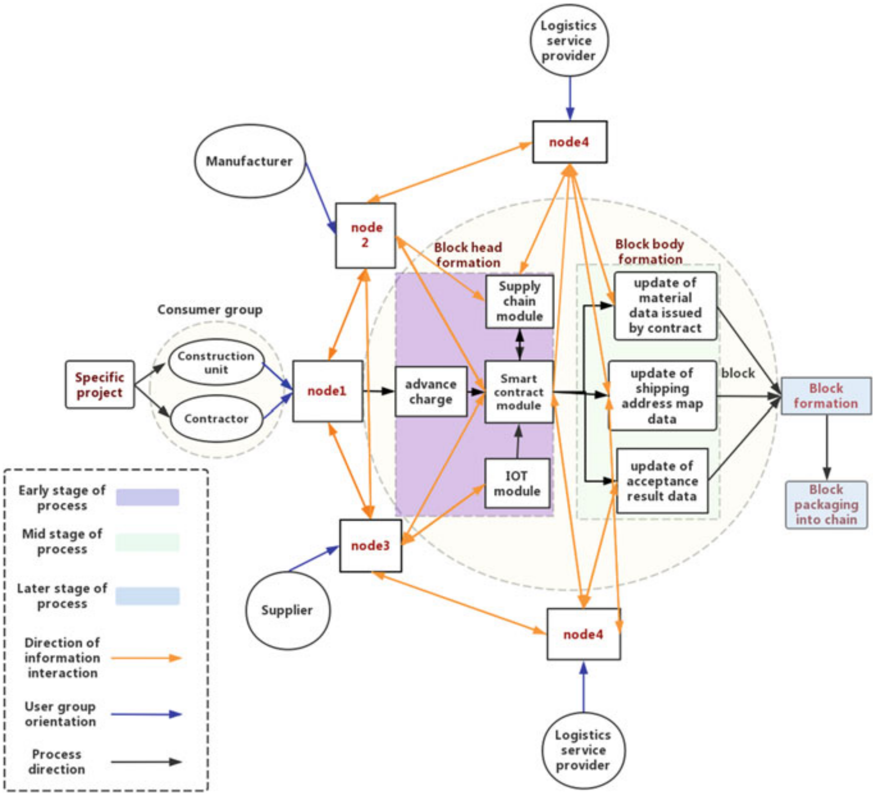

Fig. 5 Block flow chart of building materials supply

have the ability of service and management. Since suppliers can well sort out supply resources, reasonably balance risks, and provide efficient sales services, they can make deals with manufacturers and consumers at the same time and form a reasonable supply–demand relationship. Therefore, there is a triangle relationship among the consumer customers (node 1), building materials manufacturers (node 2) and building material suppliers (node 3) (Fig. 4). When "Node 1" makes the advance payment in the form of digital currency, other relevant nodes will also complete their respective agreements. The interactive information and protocol information will form an smart contract under the joint action of the three modules which will be stored in the block head.

In the middle of the process, the smart contract enters the execution stage. The building materials will be provide by manufacturers or suppliers on time and transport by logistics service providers. The delivery data and logistics data of materials are uploaded to the blockchain system platform by relevant nodes. The information is read by the Internet of Things module and stored in the "contract execution" submodule. At the same time, the information flows into the supply chain network module for inspection and supervision by relevant users of transactions. The supply chain module receives user's feedback generated in each stage of the supply process, and compares the contract information in the smart contract module to verify the execution of the contract, and then flows into the smart contract module. At this time, the "contract generation" sub-module in the smart contract module will also receive the updated data in the Internet of Things module, and complete comparison and authentication with the transaction contract. The authenticated data will be stored in the corresponding block in the form of block body. There are three types of data updates generated in the block body, namely "update of material data issued by contract", "update of shipping address map data" and "update of acceptance result data".

If the block body data is inconsistent with the block head, each user node has the right to initiate feedback of smart contract. After the smart contract module receives the feedback information, it will compare the contract execution information with the contract generation information. If the result is that the content does not match, and the user related to the transaction chooses to terminate the transaction, the transaction fails and the block cannot be formed. The digital currency given for the transaction will be returned via the blockchain platform.

3.4 Overall Process Structure

After the process transformation, it is necessary to manage the process data in the blockchain technology platform, solve the storage problem of "block" and "chain", and form a system.

(a) **Storage problem of "block"and "chain"**

The block is divided into block body and block header. The updated process data will be stored in the newly generated block every time, and the data on the self owned server of each participating user as the node is ensured to be consistent. Multiple processes or single processes with multiple feedbacks will produce new blocks. Each block is linked to the next block and the previous block to form a blockchain [14]. Finally, a number of main chain branches are formed, and the large and small branches are interleaved in chronological order to form a system.

(b) **Derivation of credit system**

The credit history of blockchain data will produce value transmission, thus the delivered credit system. The system can be used to measure the reputation value of each user according to a certain method with all kinds of comprehensive information, and rank them in descending order. Other comprehensive survey information also includes the buyer's quotation information (in descending order) and the seller's price information (in ascending order) collected by the platform in the Internet of things module. In the early stage of the process, during the process of information exchange between consumer groups on the platform, the credit system and the Internet of things module can affect the ranking of user display at the same time.

4 Application Simulation Display

4.1 Conditional Assumptions

At the end of the bidding for project C, the contract relationship between the construction unit A and the contractor unit B is established. The project C has A demand for building material D. The total price of the target material is N and the advance payment is X. If the contract stipulates that the material is supplied by Party A, then the construction unit A shall purchase the material. If the contract stipulates that the material is supplied by Party B, then contractor B shall purchase the materials. Node 1 represents the information delivery point of consumer groups. This node, the information point of building materials sales center (node 4), information point of building materials supplier (node 3) and information point of logistics service provider (node 2) are connected to the network to realize point-to-point information transmission on the blockchain technology platform. E represents the Internet of Things module of the blockchain platform, F represents the smart contract module of the blockchain platform, and G represents the supply chain module of the blockchain platform.

4.2 Implementation and Application

(a) **Early stage of process**

The user who purchases for Project A creates ID A (node 1) and screens appropriate supplier/seller of material D on the blockchain platform. At this time, the display order of both parties is affected by the information of credit system and Internet of Things module. If both parties reach an agreement, the total amount of the agreement is N, and the advance payment X can be paid to the relevant supplier/seller on the platform. In this project order, the electronic signature of project user C 8529C36 is parallel broadcasting on the whole block-chain platform, and the account book of all users in the platform updates this message simultaneously. At this point, the supply chain module backtrack to confirm that C has the ability to pay N, and the digital currency is transferred to the relevant supplier/seller. After authentication, the information flows into the smart contract module, and the sub modules generated by the contract will form the block head.

(b) **Mid stage of process**

During the execution of the contract, the supplier/seller related to the contract will ship the goods within the contract time range, and the information about the model and quantity of material D will be sent out from the information node 3/4; the logistics service provider will then update the information about the transportation status, time and location of the materials(As shown in Fig. 6,Update1 ~ 3), which will be sent by node 2/5; when material D arrives at the agreed project site, user C will check the quality and quantity of material, and the feedback information will flow from module G to module F for comparative authentication. The updated data must flow from module E and G and flow into the contract execution module after authentication from module F, and then be stored in the block body. When the authentication fails, the feedback process at the later stage of the process will be triggered to make a block of the blockchain and the subsequent chain invalid. Finally, the transaction needs to be rebuilt after an effective transaction.

(c) **Later stage of process**

When materials D are transported to the project site, if C is satisfied with the inspection results, the platform will send the amount (N–X) paid by C to the supplier/seller. If not, C can apply to enter the feedback process. If it is necessary to resent or replace 5% of the material D, the platform will send the amount (95% N–X) paid by C to the corresponding supplier/seller, and generate the block 2 to link the previous blocks. The balance amount and the feedback quantity of the material will form a new contract, which will be established in the block head of block 2, and the resent or replaced process data will be stored in the block body. The circulation process will continue until the end of the relationship between supply and demand of building materials. If a 1% refund amount of material D is finally generated, when $n - 1$ blocks are linked into the chain, 1% N of the final balance U that C should have paid to the supplier / seller should be returned to C, and then the balance payment will be made to generate the corresponding nth block.

4.3 Application Results

The application results obtained the building materials supply process system model under the background of blockchain, as shown in Fig. 6. The multiple feedback of single transaction supply or the connection of multiple transaction supply can form multiple blocks, which are connected into a chain according to the time sequence. These chains will always be stored in the blockchain application platform and can be consulted and supervised fair and openly by users of each node.

5 Conclusion

In theory, with the change of data storage and management mode, building materials supply process can be carried out on an pure machine operation system platform without human interference; with the change of information interaction form, the

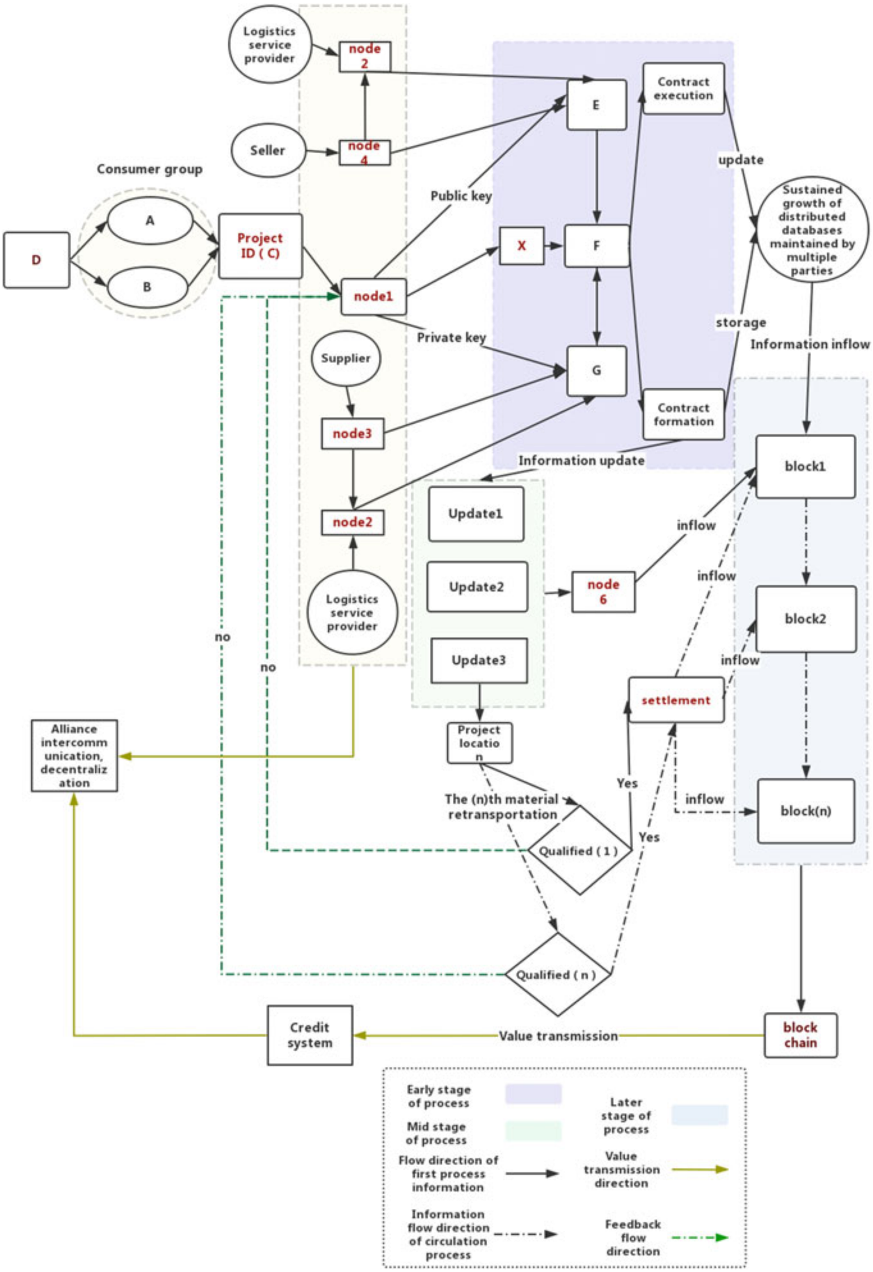

Fig. 6 Building materials supply process system model under the background of blockchain

correlation between nodes will be more accurate and close, and the accountability and backtracking of each link of the process will be more accurate and transparent. If the two changes are carried out in the building materials supply process under the background of blockchain technology, a safe and reliable database will be formed. While the whole people participate, it ensures that the operation of the process and the storage of information are completely fair, just and open.

In practice, the transaction data in the process of building materials supply can not be controlled or changed manually, the transaction relationship among manufacturers, sellers and consumers will be open and transparent, and the initiative of each participant will be increased. They will pay more attention to work integrity and product quality, and reduce the unlimited collection of improper fees or waste of resources. A virtuous market competition and integrity cycle will be formed in the industry.

According to the current development status of the blockchain, there is not single point of failure or loophole except for the clock required for the time stamp [8]. It can provide military-level security for the Internet of Things, supply chain, and smart contract equipment. Whether in theory or in practice, if we can solve the problems of saving cost and resources, update unified blockchain facilities and equipment, and strengthen the technological breakthrough and innovation of hardware and software, we can better realize the reengineering of building materials supply process under the background of blockchain technology.

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Safety Management Model of Construction Project Based on the Cooperation Between Owner and Contractor

Yuxuan Lu, Dan Zhang, and Dawei Chen

Abstract In addition to the contractor's own inadequate safety management ability, a very important reason for the frequent occurrence of injuries and fatalities in project construction lies in the owner's lack of participation and support for the construction process. This paper analyzes the attributes of both owners and contractors and their game relationships and behavioral choices in project safety management, and based on the problems of owners and contractors in production safety management, it proposes a model in which owners and contractors are jointly committed to project safety management, which takes the safety management manuals, procedural documents and operating instructions jointly prepared before the start of construction as a model in which owners and contractors jointly implement safety management basis, by clarifying the respective safety responsibilities and obligations of the two parties, and regulating the safety management behavior of the owner and the contractor in the construction process, thereby reducing the differences between the two parties on safety issues in the project construction process, and exerting the respective advantages of the two parties to effectively prevent and control project injuries and fatalities.

Keywords Contractor · Owner · Co-construction safety management model

1 Introduction

Due to its unique nature, the construction industry is one of the most dangerous industries in the world. The occurrence of construction fatalities and injuries not only causes construction workers to lose their precious lives, but also brings serious economic losses and negative social impacts to all parties involved in the project, including the owner (known as the construction enterprise in China) and the contractor (known as the construction unit in China) [1]. Through the investigation

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of construction casualties in China in recent years, it was found that in addition to the construction enterprise's own safety responsibilities are not implemented and the lack of safety management capacity, the construction unit's own irregularities and the lack of effective restraint and control of the construction unit's safety management behavior, is one of the deep-rooted causes of casualties [2]. Even if the construction unit has the good will to participate in safety management, but what way to take control of the construction enterprise, how to support and participate in the safety management of the construction enterprise, in China's current construction industry safety management field is still in the blank state, which is also one of the important reasons that lead to the frequent occurrence of injuries and fatalities in China's construction industry [3].

2 Problems in the Management of Safety for Owners and Contractors

From abroad, more and more project owners realize that the improvement of safety performance requires the participation and support of owners, and more and more countries have stipulated the safety responsibility of owners in the form of laws, such as the Construction (Design and Management) Regulations in the UK, which stipulate that every project owner should be responsible for the safety of the project, and any owner may even face criminal liability for accidents caused by the negligence of project safety; EU countries Governments in the EU have generally established the owner's safety responsibility in law according to the requirements of EU Directive EEC 92/57. Owners are gradually realizing that accident losses are ultimately borne by the owners, so in developed countries, owners are beginning to be directly involved in the safety management of construction projects [8]. At present, there are three main models of safety management by owners in the world for the construction phase: one is the safety management model based on strict legal supervision represented by the United States; the second is the safety management model based on government guidance and voluntary participation of owners represented by the United Kingdom; and the third is the safety management model with both voluntary participation and legal supervision represented by Hong Kong, China [9]. However, all three models stand from the perspective of the owner and do not take into account the interests of the contractor and the mode of cooperation, which leads to many differences between the two sides on safety issues during the construction process and affects the smooth progress of the project.

In China's building construction production practice, the long-standing notion that building construction safety is the business of the construction unit has led to the construction unit's ability and role in positively influencing the construction unit in safety management activities not being brought into play in the building construction production practice [10]. The current laws and regulations do not specify in detail how the construction unit's participate in safety management and other aspects, so the construction unit's safety responsibilities are often not effectively implemented.

3 Analysis of Owner and Contractor Attributes and Gaming Relationships

Owners are indispensable participants in every project and are the ultimate beneficiaries and risk takers for the use of the construction project. Owners are buyers in the construction market who purchase construction products or services to meet their needs by providing the funds needed for the construction project [4]. As one of the most important members of the construction market, owners usually have a variety of requirements for the construction products and services they receive, including the duration, cost, quality, and safety of the project. In China, the owner is also commonly referred to as the "construction unit" or the "owner".

The owner, in the broadest sense of the term, is first and foremost a consumer in the social nature of construction activity. It provides its own funds, procures the corresponding project, and has ownership of it. The owner, on the other hand, has neither administrative nor proprietary rights in the subject matter procured by it, which is the project and not the contractor's operation, and can only exercise rights and assume responsibility for the components of the project (such as quality, duration, payment, etc.) as agreed in the contract. Likewise, the owner is the organizer of construction activity, a productive activity. The producer is composed of specialized organizations whose purpose is to manage the production process. Obviously the owner also has this attribute and is the organizer of the production activity [5]. The construction activity can be compared to a large sports event, the owner is the "organizer" of this activity, through the bidding, invitation to tender and other ways to convene the organization of various participating units to participate in the construction activity of the project, investigation, design, construction and other aspects of the project, although the degree of participation of the owner in different ways of project implementation varies, but as a project The centrality of production is unquestionable.

A contractor is a construction company with certain production capacity, technical equipment, liquid capital, business qualification to contract construction tasks, and the ability to provide different forms of construction products in the construction market in accordance with the requirements of the owner, and to obtain the price of the project. As an economic entity in the market economy, the contractor will inevitably have the characteristics of an economist [6], i.e., striving to maximize profits, and therefore, in the case of a constant price of construction products, the contractor will inevitably maximize its profits by reducing its inputs.

From the above analysis, in the construction market, as a project owner, hoping to get the lowest contract price, low cost, high quality, short duration of the effect; and the contractor as a seller, hoping to get the minimum input to meet the owner's requirements of the building products, so as to maximize its interests [7]. It is because of the two in the economic properties of the game relationship, which determines the two in the safety management will inevitably have differences: that is, the owner hopes to achieve safety optimization without increasing the cost of safety on the premise, the contractor in order to save costs may use the advantage of information asymmetry, not in accordance with the laws, regulations and contract requirements for safe production (see Fig. 1 for the relationship between the owner and the contractor game). Therefore, only the owner and the contractor to reach in line with the interests of both sides of the safety management requirements, to eliminate the differences between the two in the construction project safety management, can fully mobilize the advantages of both the owner and the contractor, to achieve the best results of project safety management, to ensure the successful completion of the project.

By analyzing the game between the two, it can be learned that the larger the project scale, the longer the project duration and the higher the complexity of the project, the greater the disagreement between the owner and the construction unit tends to be, so the safety management mode proposed under such conditions, in which the owner and the construction unit discuss and build together, can greatly improve the

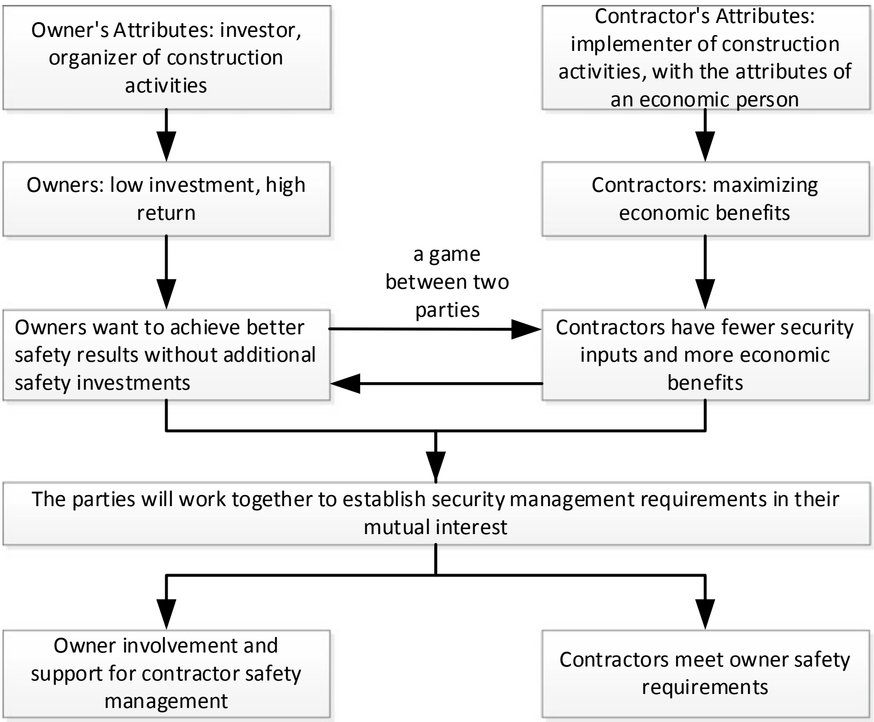

Fig. 1 The game relationship between owner and contractor

safety management effect of both sides and guarantee the smooth realization of the safety objectives of the engineering project.

4 The Framework and Key Elements of the Owner-Contractor Co-Construction Safety Management Model

4.1 Owner-Contractor Co-Construction of Safety Management Model Framework

In order to solve the problem of the lack of effective means for the owner to participate in the safety management of the construction site and the lack of communication between the owner and the contractor, to meet the requirements of the common interests of the owner and the contractor, and to eliminate the differences between them so as to give full play to the advantages of both the owner and the contractor, this paper proposes a safety management model jointly built by the owner and the contractor. The focus of this safety management model is on the joint construction and planning and implementation of the owner and contractor, i.e., the owner and contractor predict the possible dangers in the construction process according to the construction plan and propose corresponding countermeasures, and the countermeasures are reflected in the form of documents, which are coordinated by the owner and managed by the contractor according to the document requirements for construction site safety management. Its specific process framework is shown in Fig. 2.

4.2 Key Elements of the Owner-Contractor Co-Construction Safety Management Model

BIM, as an important means of project safety management, can effectively avoid the above-mentioned problems, and its unique three-dimensional mode can effectively help engineers to effectively analyze and study the distance between the bars in the construction model and conduct a comprehensive technical delivery.

Aiming at the problems of unclear safety management objectives of owners and contractors of construction projects in China's construction industry, non-standardized safety management of construction sites by contractors, and lack of safety production skills of site operators, this paper proposes that the safety management model system documents established by owners and contractors should include management manuals, procedure documents and operation instructions three-level documents. Through the top-to-bottom participation of the owner and the contractor, the three-level system documents are compiled, the common safety management

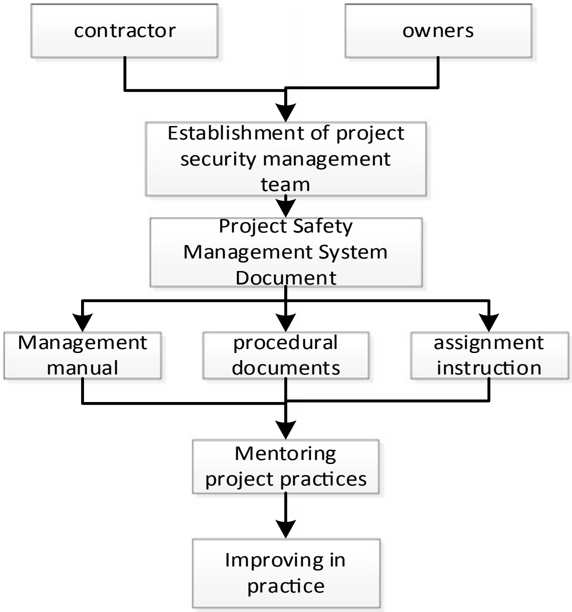

Fig. 2 The framework of safety management model built by owner and contractor

objectives of the owner and the contractor are clarified, the safety management behavior of the construction site is standardized, and the requirements of the management manual, procedure documents and operation instructions are conveyed to all construction site personnel through the entrance education and special education and training and safety briefing by BIM technology, so as to improve the safety productivity of the site personnel. The safety productivity of the personnel.

(1) Safety Management Manual

The safety management manual is a programmatic document of the project safety management system document, which stipulates the operation process of the safety management mode of the project jointly built by the owner and the contractor, and is the basis for the operation of the safety management mode of the project jointly built by the owner and the contractor. The safety management manual includes the guidelines and objectives of project safety management, clarifies the audit and evaluation procedures of the project safety management system document and the resource guarantee for the operation of the owner-contractor co-construction safety mode, and is mainly for the use of middle and senior management personnel at the construction site.

In order to reflect the willingness of the owner and contractor to manage the project safely, the management policy in the management manual should be formulated jointly by the owner and contractor, and in order to ensure the smooth implementation of the model, the management manual should clarify the responsibilities of the owner and contractor in the project safety management as well as the joint commitment of the owner and contractor to the project safety management. The management manual should be jointly signed and issued by the contractor and the owner, in order to give full play to the owner's superior role in the safety management of the construction project, so that when the contractor to implement the management model can get the other parties of the construction project support resources.

Construction site safety management needs to comply with various standards and norms such as national standards, local standards, industry standards, etc. In addition, for group companies, their management behavior is also restricted by the group's rules and regulations, so owners and contractors need to take the above factors into consideration when formulating policies and objectives, and deal with them in a comprehensive manner to formulate policies and objectives that meet common requirements.

(2) Security management procedures document

The safety management procedure document mainly focuses on the guidelines and objectives in the management manual, which is the main basis of construction site safety management and is mainly used by the functional departments at the construction site. It is an important document for regulating the behavior of all parties at the construction site.

The procedural documents mainly include five parts, such as management, environmental protection, hazardous work, key hazards, and occupational health. In order to clarify the scope of application of procedural documents in construction projects and to make project safety management based on evidence, the two parties can negotiate the definitions involved in the procedural documents to make clear provisions. In addition, the owner and contractor in the project safety management of the specific responsibilities should also be reflected in the procedural documents, procedural documents through the owner and contractor in the management of the project needs to assume the responsibility, project management program, management process may encounter unexpected situations and their disposal measures and other content of detailed provisions to regulate the behavior of the owner and contractor, so as to ensure the successful completion of the project (Table 1).

Although occupational health management procedure document is used for construction site safety management, it does not mean that the procedure document is only related to construction site safety management personnel, as it involves various aspects of construction project management and operation, which requires the cooperation of various departments of construction enterprises. In addition, part of the procedure document involves the supervisory unit, so when discussing the feasibility of the procedure document with the safety management personnel of the owner, the owner should coordinate with the supervisory unit on the content of the procedure document involving the supervisory unit, as shown in Fig. 3.

(3) Operating Instructions

The operating instructions are primarily intended to detail the management requirements in the procedures document for the construction site personnel. The operating instructions are mainly for the use of site personnel, its system can still

Table 1 Program file system table

management	environmental protection	hazardous operations	key hazard sources	occupational health
Incentives and penalties Security programmes Accident reports Emergency preparedness and response adverse weather Living quarters management Fire management Operating permits JSA Stop work authorization Education and training traffic safety	storm drain Noise control Solid waste management Dust control light pollution	work at height fire operation crane operation excavate Confined space operations Land wading operations	electrical safety scaffolding Chemicals management Tall formwork support system	Radiographic Safety Personal protective equipment Occupational health management

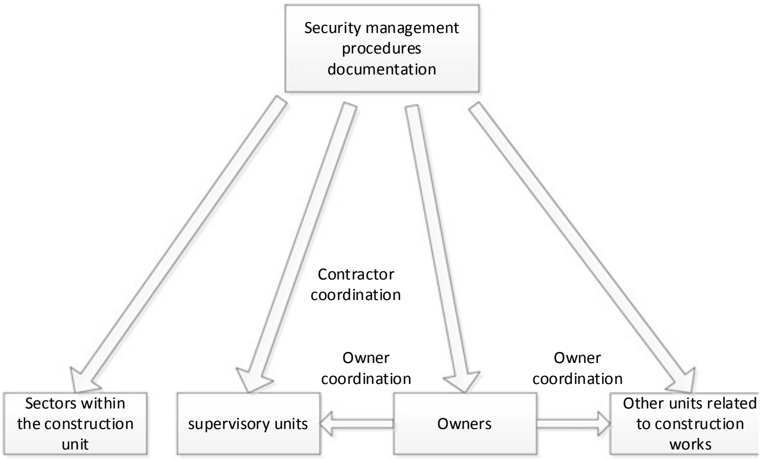

Fig. 3 The relationship of EHS program file parties

be applied to the system of the application file, but its focus should be to inform the construction site personnel how to work and how to deal with unexpected situations.

In order to convey the contents of the operating instructions to the construction site all managers and operators should make the contents of the operating instructions into corresponding training PPT, training PPT is divided into two parts, one is the entrance education PPT, all personnel should receive a unified entrance education

Table 2 Main contents of entrance education training and special education training

Entrance education training	Specialized education and training
Introduction to the project Emergency response procedures Accident report Security management provisions and security management, security communications and exchanges Personal protective equipment and civilized construction Risk management and work permit system environmental protection Safety rewards/penalties and sharing	temporary electricity fire operation work at height Confined space operations Operation of machinery, equipment and tools crane operation excavate

training before entering the site, the purpose of this training is to make all personnel understand the construction site safety management regulations. The second is the special education training, the education training is mainly aimed at the construction site related operating personnel, the main purpose is to make the corresponding operating personnel through this training to understand the work safety points, so as to improve the site operating personnel safety awareness and the purpose of emergency disposal ability. In the process of education and training, the owner is responsible for coordinating all parties who need safety education and training, and participating in and approving the training content of the contractor, and the contractor is responsible for carrying out the training matters. In this paper, based on the implementation of education and training and special education and training in the foreign construction industry, combined with the classification of the types of workers on site in China's construction industry, the main contents of the education and training and special education and training should include, see Table 2 for details.

5 Conclusion

Through the above discussion, it can be seen that the construction project safety management model jointly constructed by the owner and the contractor, the owner's participation in the construction phase safety management put forward specific requirements, is an effective way to solve the owner's non-participation in the construction phase safety management, in addition, the owner and the contractor to jointly construct the construction project safety management model process, but also a co-ordinated owner and contractor views and improve the level of contractor safety management process, so the construction of the model, to improve the owner's participation in the construction phase, to reduce the owner and contractor differences and improve the level of contractor safety management is of great significance.

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Construction Safety Supervision: Target, Strategy and Top-Level Design

Dan Zhang, Yuxuan Lu, and Dawei Chen

Abstract In order to solve the problems of vague objectives and Strategies of China's construction safety supervision, and the unreasonable distribution of main body responsibility, etc., analyzes the particularity of construction safety supervision from the production nature and industrial characteristics, and studies the target location and strategy selection of government construction safety supervision. while according to analyzes the existing problems of construction safety supervision, policy suggestions of systematic reform and innovation is put forward based on the logical path of top-level design from the legal system, system and mechanism aspects.

Keywords Construction safety supervision · Target and orientation · Top-level design

1 Introduction

The construction industry is the most dangerous among many economic and social industries. In the first half of 2018, there were 1732 accidents in the construction industry, resulting in 1752 deaths, ranking first in industrial, mining and commercial accidents for nine consecutive years. Occupational safety accidents occur frequently, causing many construction workers to lose their precious lives. From a global perspective, an important experience is that governments in various countries have effectively reduced the incidence of injury accidents through the supervision and management of the construction industry safety [1]. The Chinese Communist party and government have always attached great importance to the work of building safety production. The number of fatalities in the field of housing and municipal engineering accidents has dropped from 1292 deaths in 2003 to 442 deaths in 2015, with a continuous decline of 13 years. The overall situation of construction safety production tends to improve. However, the current overall situation of construction

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safety production is still severe. In 2016–2018, the number of accidents and deaths has rebounded for three consecutive years [2], and the trend of continuous decline in the total number of accidents for many years has been broken, especially the major casualties such as the "11.24" accident of Fengcheng Power Plant in Jiangxi Province (74 people died) and the "12.29" accident of Tsinghua Fuzhong (10 people died) and other major casualties. The accident investigation conclusion all have the problem of not implementing government safety supervision, which reveals problems from a deep level in government construction safety supervision. Although the government has made some very beneficial changes and attempts in the means and methods of building safety supervision in recent years, it is generally scattered and isolated, some problems highlighted under the new situation, such as the goal orientation of safety supervision and the selection of supervision strategies, and the innovation of construction safety supervision system and mechanism, need to be solved through the "top-level design".

Through reading and sorting out relevant literature, Chinese scholars have studied government building safety supervision from different angles: Yu Hui defined government regulation from the perspective of microeconomics, and pointed out that from the perspective of administrative law enforcement, government departments should control the behavior of a consumer, enterprise or social organization according to laws, administrative regulations and other means or methods. Zhang Shilian, Dong Yong and others proposed that the construction, design, supervision units, government supervision departments, intermediary service organizations and other subjects should build a multi-party cooperative construction safety supervision mechanism, improve the supervision efficiency and level, and achieve the goal of safe production. An Xinrui proposed that government regulation should be classified according to the nature of regulation: On the one hand, sociality Supervision is mainly to protect the health and safety of workers and the environment, reflecting the people-oriented concept; On the other hand, economic regulation, which limits the activity of enterprises by controlling market prices [3]. Wei and Luo established and improved the legal system and organizational system of production safety, built the internal accountability mechanism of enterprises, and strengthened the construction of intermediary service organization puts forward the relevant strategies to improve the construction safety supervision system [4].

2 Overview of Building Safety Supervision

2.1 The Particularity of Construction Safety Supervision

The production methods and industrial characteristics of the construction industry are obviously different from other industries [5], which determines the particularity of government construction safety supervision.

From the perspective of the production method of the construction industry, it is different from the general industrial production method. The open-air operation of construction production, the fluidity of production, the one-sidedness of products, and the discreteness of operation make construction workers need to constantly face the changing construction environment, and they are constantly threatened by new risks, the construction site has become a typical complex system of man–machine-environment intersection. Unforeseen factors and accident risks increase during the construction process, making it more difficult to protect the lives of workers. The economic attributes of enterprises pursuing profit maximization often lack the initiative and enthusiasm in safety investment, safety protection, education and training, etc. This requires government intervention to urge enterprises to strengthen safety management through the formulation of laws and regulations, safety standards and penalties, so as to achieve the purpose of protecting the lives of workers.

From the perspective of the industrial characteristics of the construction industry, first of all, the construction industry is still a labor-intensive industry, with low entry barriers, mainly migrant workers. Due to lack of systematic safety education and training, lack of safety awareness and safety skills, they are often become the object of injury; Secondly, the construction industry is complicated in operation and management, and the construction enterprises and project production are separated, and the various rules and regulations formulated by enterprises are often not effectively implemented in project production. At the same time, the multi-level engineering contracting system leads to numerous stakeholders, and different entities have different attitudes towards safety and risk, which brings certain difficulties to government safety supervision.

2.2 The Target Orientation and Strategic Choice of Government Building Safety Supervision

The target positioning of government safety supervision determines the direction and strategy of construction safety supervision work. The protection of human life is the fundamental goal of government safety supervision in the world. To achieve this goal, we mainly rely on sanctions on the responsible person, compensation for the victims, and accident prevention before the accident [6]. Among them, accident prevention should be the main task of government safety supervision.

Construction workers are not hired by the government but by contractors. Accidents occur on construction projects. Whether workers can be adequately protected depends largely on the contractor's attitude and behavior towards safe production [7]. Therefore, the construction safety supervision strategy should prompt the contractor to take appropriate safety management measures to prevent construction accidents. However, the government safety supervision of the contractor does not mean that only the contractor should be responsible for construction safety, also is not to say that only need for government intervention in the construction phase, but shows that affect contractor's behavior is the government in formulating the basic idea of security related policies and regulations.

3 Problems in Construction Safety Supervision

3.1 Problems in Construction Safety Supervision

Although in practice, construction safety supervision system of our country has played a very good accident prevention effect, but the in-depth analysis of the current construction safety production situation and the cause of the accident can be found that the current safety regulation of architecture in the regulatory target positioning, regulatory strategy choice, or regulatory system and mechanism, also have many problems.

3.1.1 Safety Supervision Objectives and Strategies Are Blurred

China's construction safety supervision work basically revolves around the goal of ensuring the construction safety of personnel, but some local governments and enterprises still blindly pursue the phenomenon of economic development speed. When safety and economic development are in conflict, the protection of human life is ignored [8], it is precisely because of the ambiguity of target positioning that leads to deviations in the selection of safety supervision strategies. In practice, the work content of construction safety supervision agencies is not clear, the construction enterprises are over-supervised and other entities are ignored, and the supervision methods and methods are backward. It also has low management efficiency and is prone to external interference. Accident concealment and underreporting have been repeatedly prohibited.

3.1.2 Unreasonable Allocation of Subject Responsibility

The "Regulations on the Administration of Work Safety in Construction Projects" clarifies that the owner (known as the construction enterprise in China), the contractor (known as the construction unit in China), the supervision unit, the design and survey five parties bear the corresponding safety responsibilities. This highly decentralized responsibility system causes the government departments to supervise multiple objects and cannot effectively concentrate resources. Mutual wrangling between market entities has also made the government agencies overwhelmed by supervision, and the efficiency of supervision has been greatly reduced. At the same time, the regulations on safety responsibility of some market entities are not practicable, for example, the regulations that require construction units to ensure reasonable construction period and cost are difficult to be effectively implemented, which provides space for market entities to shirk and evade responsibility.

3.1.3 Overlapping Responsibilities of Supervisory Departments

At present, my country implements a construction safety supervision system that combines comprehensive supervision and industry supervision, unified supervision and professional supervision, and hierarchical guidance and territorial supervision. The above-mentioned supervision system seems clear, but some problem appeared in the actual operation.

Firstly, the comprehensive supervision responsibilities of the safety supervision department are unclear. The "Safety Production Law" determines that the safety supervision department shall undertake comprehensive supervision responsibilities, and its main purpose should be to play a role of unified management of safety production resources, while coordinating and supporting various departments to perform their own safety supervision responsibilities in accordance with the law. But in the field of construction safety supervision, these two major effects are not obvious. In practice, the safety supervision department did not reasonably consider the needs of construction safety supervision work, and at the same time, its positive role in department coordination is very limited [9]. Secondly, limited by the division of responsibilities between departments, the unified supervision of construction safety by the housing and construction department is limited to policy formulation and qualification management, while the construction process of railway, transportation, electric power and other industries cannot be effectively monitored and cannot be achieved. Unified supervision in the true sense.

3.1.4 The Nature of the Regulatory Agency is not Clear

The "Regulations on the Administration of Work Safety in Construction Projects" stipulates that the housing and urban and rural construction departments can entrust the supervision and inspection of the construction site to the construction safety supervision agency for specific implementation [10]. At present, it not only undertakes the supervision and inspection of the construction site, but also partially undertakes the specific implementation of administrative licensing and administrative law enforcement. However, at present, the per capita supervision area of construction safety supervisors is too large. About 40% of construction safety supervision agencies in the country are not included in the same-level financial budget [11], working funds cannot be guaranteed, and strict accountability systems are generalized. Cause the staff to be unstable. One of the important reasons for the above-mentioned problems is that the nature of the current supervision agency is not clear.

3.1.5 The Supervision Methods Are not Scientific Enough

In the face of the continuous expansion of the scale of construction industry, the traditional, single and backward safety supervision method can no longer fully cover the scope of supervision and the needs of the new situation. The accident investigation work has serious problems such as irregularities, excessive interference, lack of expertise, and poor results. The definition of the cause of the accident is not scientific enough, the division of accident responsibility is not reasonable enough, the punishment for accidents is too light, the cost of violations is low, and violations of laws and regulations occur frequently.

4 "Top-Level Design" of Building Safety Supervision

Facing the new situation of construction industry reform, government construction safety supervision should be based on practical problems, strengthen top-level design thinking, rely on reform and innovation and the two-wheel drive of law-based administration [12], simultaneously cut from the three levels of legal system, system, and mechanism to improve construction safety Regulatory system.

4.1 Starting from the Legal Level, Clearly Monitoring Objectives, Strategies and Responsibilities

4.1.1 Clear Regulatory Objectives

At this stage, the frequent occurrence of accidents and injuries and deaths of construction personnel are the most prominent problems in the field of construction safety in our country. Although economic development and property protection are equally important, it is precisely because of economic factors that frequent production safety accidents occur in practice. Therefore, the only fundamental goal of my country's government construction safety supervision work at this stage is to ensure the construction safety of personnel. The establishment of such a clear goal is conducive to unified understanding and focus, and can lead and guide various construction safety supervision tasks.

4.2 *Starting from the System Level, Clarify the Responsibilities and Nature of the Regulatory Authorities*

4.2.1 Clarify the Scope and Responsibilities of Comprehensive Supervision and Industry Management

The work safety supervision and management department further clarified the coordination of work safety with specialized industry authorities, and should give full play to the role of the housing construction, railway, transportation, water conservancy and other industry authorities in safety supervision, and do a good job in supervising, guiding and coordinating the work of the departments in charge of these industries. In addition, it is necessary to clarify as soon as possible the supervision bodies and responsibilities of the safety production of construction projects without industry authorities such as textiles and metallurgy, as well as the supervision departments and supervision responsibilities of industrial buildings, rural self-built houses, and high-tech parks.

4.2.2 Clarify the Nature of the Supervision Agency

The reasonable and effective allocation of limited law enforcement resources is an important issue facing construction safety supervision. In the face of large-scale construction projects, China's construction safety supervision should gradually shift to law enforcement inspection, focusing on the implementation of the safety responsibility of all parties in the market, supervision of the implementation of various laws and regulations, as well as punishment for violations of laws and regulations. When studying and revising the "Regulations on the Administration of Work Safety in Construction Projects", it is necessary to fully consider the reform requirements of public institutions, clarify the nature of the law enforcement of the supervision agency, stipulate that its core work is to implement inspection and law enforcement on the construction site, and continue to strengthen the capacity building of the supervision agency.

4.2.3 Clarify Regulatory Strategies

According to the systematic principles of modern safety management, good construction safety management should be a kind of management involving all staff and the whole process. For the construction industry, this kind of full participation and safety management of the whole process should be based on the ability to change the safety behavior of the construction enterprise (contractor). Therefore, when formulating safety policies, comprehensive means such as law, economy, science and technology and culture should be adopted to promote the formation of self-restraint mechanism and safety supervision system with accident prevention as the core of construction enterprises.

4.2.4 Defining the Responsibilities of Key Subjects

Construction safety management in foreign developed countries emphasizes the responsibilities of owners and contractors. Based on the above situation, in the main safety responsibility system of construction parties in my country, the responsibilities of the contractor and owner should be highlighted and clarified.

The operator is employed by the contractor. The contractor is the direct beneficiary of construction activities and the direct implementer of construction safety management. The implementation of the responsibility of the contractor plays the most direct and obvious role in the safety of construction. Therefore, we should continue to emphasize the safety responsibilities of the contractor, and encourage contractor to firmly establish the correct concept of "unsafe, no construction".

In the current construction market in my country, owner have strong resource allocation and mobilization capabilities, have the strongest ability to assume safety responsibilities. Therefore, owner should strengthen their safety responsibilities. The first is to stipulate that when the owner enters into a contract with the contractor, it shall require the contractor's safety responsibilities, while supporting and urging the construction unit to implement safety responsibilities; Second is stipulating that the owner shall be responsible for providing sufficient safety production funds and supervising the contractor's reasonable use and safety responsibility for production funds.

Supervision, design, survey and other units are employed by the owner, and their responsibility for ensuring the safety of construction comes from the owner's entrustment and transfer. Therefore, it should be clear that the owner has the obligation to supervise the design unit, supervision unit, survey unit and so on to fulfill the responsibility of construction safety.

4.3 Starting from the Mechanism Level, Reform and Innovate the Safety Supervision Mechanism

4.3.1 Transform Safety Supervision Methods and Improve Safety Supervision Efficiency

Government construction safety supervision should gradually shift to law enforcement inspections, focusing on the supervision of the performance of safety responsibilities of all market entities, supervision of the implementation of various laws and regulations, and punishment of violations of laws and regulations. Strengthen the strength of safety supervision agencies at all levels, strictly enforce safety supervision agencies and personnel assessment, strengthen education and training, and comprehensively improve the level of safety supervision and law enforcement. Reasonably allocate supervision resources, implement differentiated safety supervision, and improve safety supervision efficiency.

4.3.2 Improve the Level of Accident Investigation and Increase Scientific Punishment

One of the important functions of government safety supervision is to investigate the cause of an accident and punish the responsible parties. It is suggested that the current laws, regulations and relevant provisions concerning accident investigation and accident punishment in construction industry should be sorted out, and guidelines applicable to accident investigation and accident punishment in construction industry should be specially compiled to clarify accident investigation procedures of different nature and legal basis of applicable punishment clauses, so as to improve the authority and scientific nature of accident punishment.

4.3.3 Improve the Construction of a Credit System for the Construction Industry

An outstanding feature of the construction industry is mobility. Companies are only registered in one region, while projects may be spread across the country. This feature has created a certain dilemma for construction safety supervision. Therefore, the construction industry must improve the construction of a safe production credibility system as soon as possible, and it is imperative to promote the construction of construction safety supervision informatization projects. Through the information system of all parties and employees, a "blacklist" of enterprises and individuals with dishonest behaviors will be established, and a new supervision mechanism with safety credit as the core will be gradually established.

4.3.4 Play the Role of Industry Associations (or Intermediaries)

The construction industry must cultivate and support social industry associations or intermediary agencies with strong professional skills as soon as possible to provide strong safety production guarantees for the safety of the construction industry. Use market mechanisms to promote the integration of insurance institutions and corporate security, and strengthen risk identification control and hidden danger investigation and governance. Develop safety risk prevention and control standards and credit management methods for insurance institutions, study and formulate enterprise risk assessment index systems, implement floating rates, and use economic means to guide construction companies to continuously strengthen their safety management levels.

5 Conclusion

At present, China's construction safety production is in the "accident prone" stage. Practical experience shows that one of the deep driving factors from the "prone period" stage to the "low incidence period" is the improvement of government management ability. This paper analyzes the particularity and existing problems of China's construction safety supervision, and puts forward measures and suggestions to improve government safety supervision from the three levels of legal system, system and mechanism. Through the top-level design of government safety supervision system and mechanism, various policy tools are used to regulate the attitude and behavior of all parties in the construction market towards safe production, create conditions and environment, and promote all parties to form self-restraint and spontaneous dynamic mechanism. Although this paper puts forward measures and suggestions to improve the government's safety supervision, which provides an important reference for safety management, due to insufficient practical experience, there are still many problems. The content of safety supervision in other regions needs to be studied more fully in the future, so as to continue to optimize the measures and suggestions of government safety supervision.

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Scientometric Analysis and Scientific Trends on Land Trust

Mingfeng Li, Chuan Yang, and Lei Zhang

Abstract Modern land protection and biodiversity conservation depend greatly on the application of land trust. With the accelerated development of land trust organizations, the land trust has become the most effective land conservation method. To draw and analyze the current status of the research on the field of the land trust, we conduct the cluster analysis of co-citation and keywords co-occupation, and comb the evolution of international land trust research from 1990 to 2019. This article collected 1341 related documents included in the "Web of Science" database as the basic data for analysis, combined with bibliometrics method and visualization software to find out the landmark literature with high burst value, and study literature co-citation clusters in the network map. The results show that the main subject of collected literatures is related to ecology and environment. The hotspots of international land trust mainly cover four aspects: conserving private land by conservation easements, impact and response to climate change, collaborative governance, and community land trust (CLT). It is found that the land trust research has formed a clear co-citation cluster differentiation. By analyzing and sorting out the landmark literatures and hotspots in the field of the land trust, the purpose of this study is to provide researchers with more reference for research implementation.

Keywords Land trust · Conservation easement · Ecology conservation · Literature visualization

1 Introduction

Land trusts, initiated by social nonprofit organizations, are working to conserve landscape, habitat, and biodiversity. Such institutions frequently purchase less than full title by accepting the donation or raising trust-type fund. Since the late 1900s, there were organizations in the United States that accepted donations of conservation easements on behalf of the public. The United States has become the most mature

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country in the land trust area through years of development. Nowadays Germany, Japan, Canada, and other countries have also established land trust conservation systems. In 2015, the total area of land protected by land trusts has reached 56 million acres in the United States. The land trust has become the most effective land conservation method in the United States, but also an important part of the environmental protection system [1]. While the land trust is developing rapidly, the issue of land trusts has grown concern between scholars, and a large number of research results have been published. This article aims to better grasp the development trend of land trusts issues and provide a useful reference for further study of this field. We use the literature visualization tool to review the literature of international land trust research from 1990 to 2019.

2 Data and Methods

Thanks to the development of information analysis and technological advancement, a variety number of visualization softwares, such as CiteSpace, VoSviewer, and Gephi can be used to analyze large volumes of literature data. Because of the powerful data processing and visualization functions of CiteSpace, we finally choose to utilize CiteSpace to make a visual interpretation of land trust literature in the recent 30 years. In order to guarantee the accuracy and comprehensiveness of the data source, the literature data is derived from the core collection of the WoS database. The search purviews are "topic (land trust) ". Search criteria are followed: language = (English) and document types = (article or proceeding paper). The time span is 1990–2019. Based on the above retrieval method, after removing repetitive contents by CiteSpace, a total of 1341 articles were retrieved. As illustration in Fig. 1, the number of literatures in the study field was on the rise with the tendency of exponent increase. Based on the method of Natural breaks, we can divide the applied research into three stages. The incipient progress stage was from 1990 to 2004. The number of documents published was at a low level and land trust development was still in the initial stage and did not cause enough attention. The next stage from 2005 to 2015 was the period of rapid progress of research with the fastest increase in literature. A large number of pundits began to focus on land trust development. The final stage started in 2016 when the research tended to be stable. During the last two years, the number of literatures fluctuated slightly but maintained at a high level. As shown in Fig. 2, the research on land trust mainly focused on Environmental Studies (295 articles), Environmental Science(201 articles), Ecology(164 articles), Geography (116 articles) and Regional & Urban Planning (94 articles), which means that the studies of land trust were mostly concentrated in related fields such as environmental science and ecological conservation.

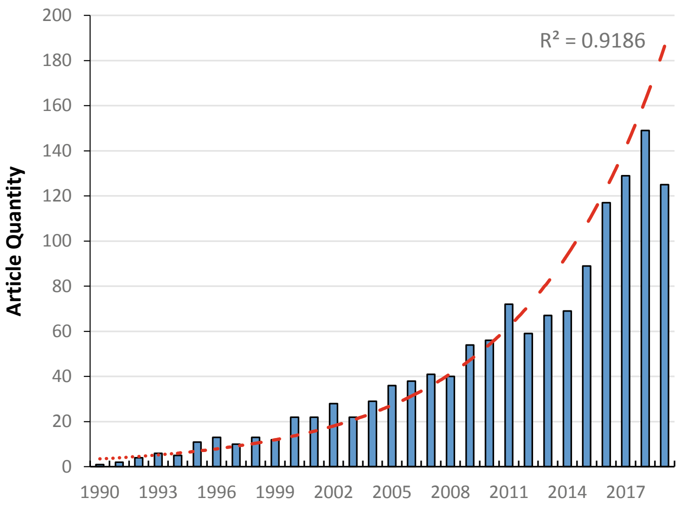

Fig. 1 Annual publication outputs for the search topic land trust

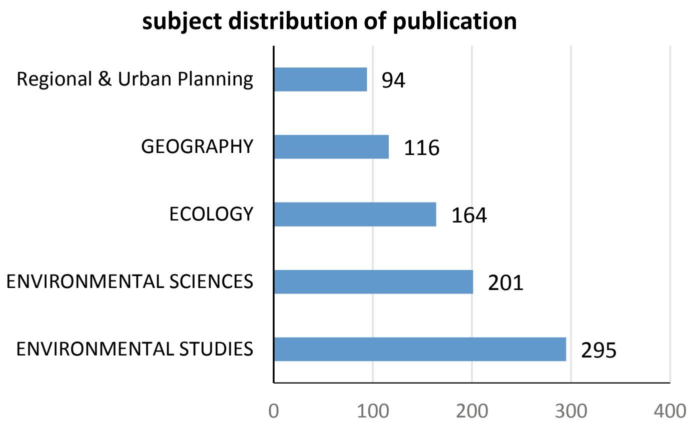

Fig. 2 Classification of major disciplines in literature

3 Result

3.1 Reference Co-citation Analysis

Co-citation refers to the emergence of two or more documents in the third bibliographic reference, and then the two documents form a co-citation relationship, which can be used to explore the development and evolution of a discipline. We select the highest number of times per year cited 50 articles in CiteSpace to build the co-citation network map, and then merge the maps of each year. In order to prevent the atlas from being too confused, the pathfinder algorithm was utilized to cluster the maps. We ran the parameter "cluster" in the CiteSpace, and the reference network of the co-citation relationship of land trust research is plotted in Fig. 3. Figure 3 shows the co-citation analysis of 1341 related research papers in land trust filed from 1990 to 2019. In the clustering map, the nodes represent each cited document. The node size is proportional to the frequency of co-citation, and the link thickness map indicates co-citation link strength. The literature cited in the literature data set reflects the cross-relationship between the literature citations, and the corresponding cited literature constitutes the research frontier. Therefore, based on the co-citation relationship of the highly cited documents that constitute the knowledge base, subject clustering of cited documents can reveal the knowledge base and identify the frontier basic knowledge of a co-citation cluster. Document clustering in connection with the representative title, abstract, keyword in a preliminary analysis, nine major clusters can represent the most representative research direction in the field of land trust. The specific information of clusters is shown in Table 1. The cluster size indicates the number of documents contained in the cluster, and the silhouette value (also called homogeneity) indicates the similarity of the documents of the clusters. The closer the silhouette value to 1, the higher the uniformity of document topics in clustering.

From the analysis of Fig. 3, the following information can be obtained: there are 650 nodes (N = 650) in the cluster map, the total number of connections is 1799 (E = 1799), and the density of the total network is 0.0085 (Density = 0.0085). In this map, the Modularity value is up to 0.901 (Q = 0.901), indicating that there are clear boundaries between the themes of land trust research and significant cluster differentiation.

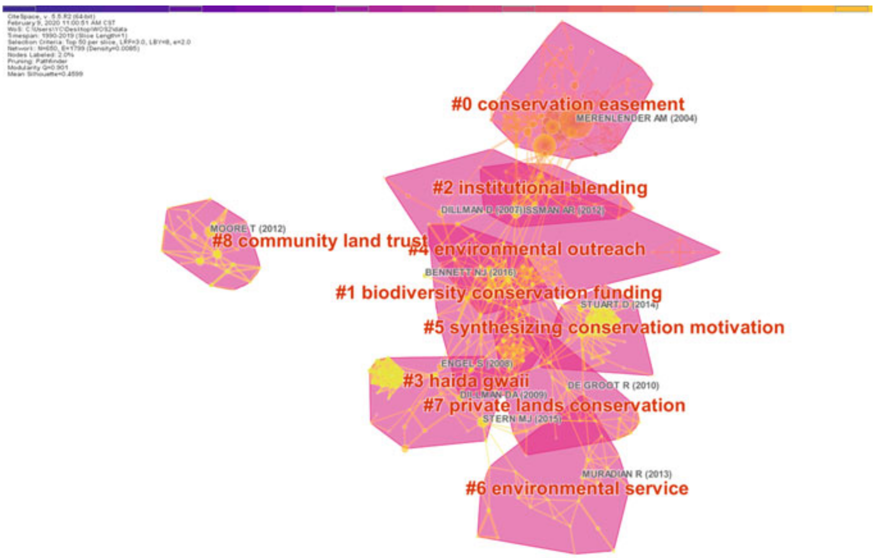

Fig. 3 Cluster of references co-citation network map

Table 1 Specific information of clusters

Cluster number	Name	Size	Silhouette	Year
#0	Conservation easement	73	0.896	2005
#1	Biodiversity conversation funding	56	0.891	2012
#2	Institution blending	31	0.925	2007
#3	Haida Gwaii	31	0.925	2012
#4	Environmental outreach	28	0.864	2007
#5	Synthesizing conservation motivation	27	0.976	2013
#6	Environmental service	26	0.929	2013
#7	Private land conservation	26	0.906	2013
#8	Community land trust	26	1	2014

The Mean Silhouette value is 0.4599, which means land trust research has diverse perspectives, resulting in a large number of small clusters. In addition, the figure shows that there are many connections among the clusters except for clustering 8, which indicates that there are cross-correlations among these research topics, while the silhouette value of clustering 8 "community land trust " is 1, indicating that there is no correlation between the cluster and the others, which represents another research topic. According to the preliminary analysis of the average citation years of each cluster, we can see that the average citation years of clustering 0 "conservation easement ", clustering 2 "institution blending ", clustering 4 "environmental outreach" are earlier. In recent years, the research topics have been divided into 1 clustering "biodiversity conservation funding", clustering 3 "Haida Gwaii ", clustering 5 "synthesizing conservation motivation ", clustering 6 "environmental service ", clustering 7 "private lands conservation ", etc.

3.2 Landmark Literature Analysis

In the co-citation analysis of documents, the literature with high citation burst value deserves attention. Documents with high burst value refer to literatures that have a sudden increase in the number of citations in a short period time. The higher the burst value is, the higher the degree of attention of the literature will be paid to the literature in the corresponding period, and the stronger the frontier representativeness is. As hown in Table 2, the top 5 literatures with the highest burst value are identified by CiteSpace. The five documents were all published around 2005 when the number of documents began to increase rapidly, and all the documents came from the 0 clustering "conservation easement". Thus, it is concluded that "conservation easement" was the point of penetration of international land trust research and the foundation of the subsequent research.

Table 2 Top 5 land trust documents with the strongest citation bursts

Burst	References	Cluster
12.076	Merenlender, A. M., Huntsinger, L., Guthey, G. T., & Fairfax, S. K. (2004). Land trusts and conservation easements: Who is conserving what for whom? Conservation Biology, 18, 65–76. https://doi.org/10.1111/j.1523-1739.2004.00401.x	#0
5.7703	Rissman, A. R., Lozier, L., Comendant, T., Kareiva, P., Kiesecker, J. M., Shaw, M. R., & Merenlender, A. M. (2007). Conservation easements: Biodiversity protection and private use. Conservation Biology 21. 709–18. https://doi.org/10.1111/j.1523-1739.2007.00660.x	#0
5.6436	Fairfax, S. K., Gwin, L., King, M. A., Raymond, L., & Watt, L. (2005). Buying nature: The limits of land acquisition as a conservation strategy, 1780– 2004. The MIT Press, Cambridge, Massachusetts	#0
4.5596	Yuan-Farrell, C., Marvier, M., Press, D., & Kareiva, P. (2005). Conservation easements as a conservation strategy: Is there a sense to the spatial distribution of easements?. Natural Areas Journal. 25. 282–289	#0
4.1269	Kabii, T., and Horwitz, P. (2006). A review of landholder motivations and determinants for participation in conservation covenanting programmes. Environmental Conservation. 33. 11–20. https://doi.org/10.1017/S0376892906002761	#0

These literatures with high burst value can be divided into two categories, one of which is the review literature connecting the preceding and the following. Such as, a systematic review of the land trust research, which point out that the land trust is an attractive approach to land protection and conservation easement can limit the development of land at a lower cost to achieve the purpose of protecting ecological resources. The problem is that land trusts and organizational arrangements are evolving too fast to assess their long-term ecological and social consequences [2]. Other documents include combing the theories of politics, law, economic history, and other disciplines to reexamine the cases of land protection in the United States over the past 200 years [3]; summarizing the influencing factors of landowners' participation in protection actions, and proposing a conceptual model including five major structures: economic dependence on property, private property rights, confidence in perpetual covenant mechanisms, nature conservation equity and nature conservation ethic [4]. The other type of literature in highly burst value is the typical case study. Rissman surveyed staff responsible for conservation easements established by The Nature Conservancy and founded out that most easements aimed to reduce development to protect the core habitat and biodiversity [5]. Meanwhile, conservation easement also allowed the landowner to preserve a wide range of land for private uses, but there were no clear restrictions on the use of private land. Yuan-Farrell used conservation value and threat indicators to evaluate the deployment scope of protective easements in California. The results showed that although the easements cover a wide range, while lacking of specificity. In areas where land prices were higher, easements were not more efficient than purchasing directly [6].

3.3 Co-citation Cluster Knowledge Topic Recognition

As shown in Fig. 3, there are 9 clusters identified by CiteSpace in the topic clustering map of the land trust study field from 1990 to 2019. These clusters reflect the research hotspots and the evolution process of land trust issues in the past 30 years. The extraction and interpretation of the literature information in each cluster are helpful to understand the research issues of each cluster, clarify the relationship between the clusters, and sort out the evolution process of land trust research. Now that the landmark literatures have been analyzed in the previous article, the following will conduct research on the other eight clusters.

Clustering 1. The research theme of this cluster is biodiversity conservation funding. Since the mid-1990s, the number of land trusts has increased considerably. However, the lack of funds remains to impede high-priority lands and waters conservation [7]. More and more scholars are beginning to use special techniques to identify the scope of protection and allocate protection resources. Knight found that many conservation-planning initiatives were based on ecology data (e.g., biodiversity distribution), then they also took into account non-ecological factors (e.g., economic cost of implementation). However, social-human factors (e.g., the ability and willingness of relevant stakeholders to participate) must be taken into consideration to ensure the effectiveness of the conservation-planning [8].

Clustering 2. The research theme of this cluster is institution blending, which reflects the complexity of the processes of transfer and decomposition of property, the emergence of organizations with a mix of public and private characteristics [9]. The diversification of the role of land trusts, the emergence of public–private collectives and non-profit organizations' partnerships reflect the innovation in the protection in rural land. Rissman investigated the influence of social relations and institutional structure on the design and protection of easements by comparing two different regions where land trust organizations hold conservation easements [10].

Clustering 3. The cluster is named Haida Gwaii. Hotte used the Haida Gwaii forest cooperative governance as a case to explore the characteristics of institutions that inspire trust and established a theoretical framework that linked institutions, trust and collective action [11]. Stern summarized the trust related to collaborative natural resource management into four forms and described the impact of different forms of trust on cooperative management of natural resources, which aimed to provide references for researchers and practitioners [12].

Clustering 4. The cluster named environmental outreach also focuses on the impact of public trust on environmental conservation. Improving public trust in environmental organizations is conducive to the implementation of environmental policies. Amber Saylor Mase's research found that the public trusted university organizations and the Natural Resource Conservation Service most, but not environmental protection and land trust organizations [13]. Trust is the foundation of human cooperation, and lack of trust is the main issue in the implementation of the natural resource plan. Lachapelle's study revealed the importance of transparency in decisions, effective leadership, consensus on the framing of risk, and planning scale in affecting trust [14].

Clustering 5. The cluster's name is synthesizing conservation motivation which means the cluster focuses on the factors influencing people's participation in conservation-planning. In this cluster, scholars began to introduce some new methods to explore the influence factors of people participating in various environmental protection plans. Baumgartgetz used meta-analysis to quantitatively compare and analyze the previous literatures and pointed out that the measurement and use of environmental awareness and farmers' attitudes in previous literature were not consistent, and the methods of data collection will affect the results of research [15]. Ranjan compiled and coded relevant documents on farmers' willingness to participate in soil and water conservation plans from 1982 to 2018 to presented a systematic review of all qualitative investigations, and concluded that farmers' economic and management needs and their perceived and actual limitations to conservation behavior would affect their actions [16].

Clustering 6. The cluster is named environmental service which actually means payment for environmental service (PES). Alixgarcia's research pointed out that PES can not only incentivize landowners to protect natural resources but also increased land cover management activities [17]. On the other hand, Muradian argued that over-reliance on PES as a win–win solution might lead to ineffective outcomes [18]. Economic activities that expect to pay compensation to offset high environmental hazards may cause such a situation: due to the increased opportunity cost of protection, only increasing the level of compensation can protect the ecosystem. Therefore, there is a requirement to shift the strategy towards a more targeted policy framework, in which PES constitutes only one of the potential solutions, which may be a more effective way to tackle social and environmental challenges.

Clustering 7. The cluster's name is private land conservation, which indicates that the object of land trust protection is private land. Documents in this cluster mainly explore how to improve the effectiveness of environmental protection on private land. While the role private land in biodiversity conservation became increasingly significant, Kamal summarized the strategies for private land conservation, and then proposed a classification system of private land protection, which provided a framework to identify and described strategies from the perspective of private land tenure and security [19]. Bennetta conducted a survey of practitioners in the United States to gauge their familiarity with seven private land protection methods in different landscape contexts [20]. He advocated targeted efforts to improve the professional capabilities of protection practitioners to meet various challenges on diverse private lands.

Clustering 8. The cluster named community land trust (CLT) whose average citation year is the latest and represents a newer research topic. This cluster's Silhouette value of 1 indicates that the cluster is separate, that is to say, the cluster is not associated with other clusters. As is shown in Fig. 3, the cluster with no connection to other clusters also confirmed this point, so the CLT may have different research issues from other clusters. CLT refers to the land trust organizations that lease the land at a low price while maintaining land ownership, which aims to ensure long-term access to affordable housing among low and middle-income groups. Gray used the case of CLT in the southern United States to examine the role of grassroots community organizing in community organizations in CLT [21]. Moore comparatively reviewed the development history of CLT in different countries, and summed up two major premises for the development of CLT, the agreed resale restriction and resident community governance right [22].

3.4 Thematic Focus Areas

Within an article, the author usually uses the keywords to describe the core content of the research. Generally, if a keyword appears frequently in a certain period, indicating that the keyword reflects a hot topic in the study area during the period. The keywords co-occurrence analysis of the VOSviewer software can be used to extract the frequencies of keywords, also identify and display the co-occurrence relationships in a graphical view. In order to ensure the readability of the map, we merge the synonyms and retain the high-frequency keywords. By introducing the collected 1341 records into VOSviewer, the keywords co-occurrence map was obtained in Fig. 4. Besides, it can be observed that four major clusters can be identified that are shown using four different colors.

The high-frequency keywords in the blue cluster are “land trust”, “conservation easement”, “private land conservation”, “land conservation”and “attitudes". The major focus area of this cluster is focused on conserving private land by conservation

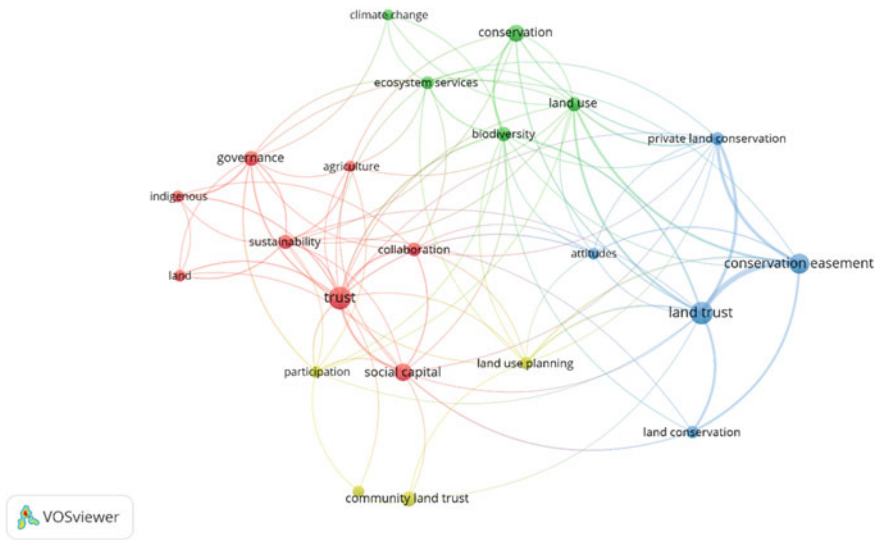

Fig. 4 Keywords co-occurrence map

easements. The transformation of the world's landscapes is growing at an accelerating speed, which has led to the extinction of an increasing number of species and the loss of their habits. Even though the United States has established extensive natural reserves, these reserves are most frequently found in soils with higher altitudes and lower productivity. Assessments of distribution of endangered species indicated that more than 90% of the species are on private land. Therefore, the improvement of the natural conserves system requires consideration of the full geographical and ecological range of cover types and species that occurred on private land [23]. With the continuous growth of development, conventional land conservation strategies, such as governmental acquisition, are restricted by the limited protection funds. As another strategy of land conservation, the use of conservation easement to protect habitat and ecosystems has increased dramatically throughout the past four decades. Land trusts, working to conserve land by acquiring conservation easement, has become the major player in conservation efforts [24]. At this time, scholars have begun to investigate the specific protective effects of land trusts, but it is difficult to obtain relevant data to assess the effects of restrictions. The "attitude"refers to people's understanding of land trust at different levels. It is generally assumed that attitude will drive individuals to participate in land trust conservation. A comprehensive survey of the attitudes of land trust members and the public towards land trust will help attract more volunteers and enhance public support.

The high-frequency keywords in the green cluster are "conservation", "land use", "biodiversity", "ecosystem service" and "climate change". The major focus area of this cluster is focused on the impact and response to climate change. As the climate changes, sea-level rise, climate warming, drought risk, and other hazards are increasing. The Natural reserves can buffer communities from some climate impacts. However, the same climate impacts also threaten protected areas. Natural land in coastal areas provides communities with various ecosystem services, such as temperature regulation, carbon storage, and water conservation. However, as the sea level continues to rise an average 3 mm per year, the ecological service function of reserves is gradually degraded. Federal, land trust organizations, and other NGOs have invested extensive resources to protect coastal natural reserves. Epanchin-Niell's research characterized the distribution and type of coastal protected lands in the eastern United States, estimate their exposure to sea level rise, evaluate the potential impact of this exposure on associated ecosystem services [25]. According to his research, one-quarter of protected land will be affected by 3 foot of sea level rise. Moreover, lacking plans and funding were the greatest challenges in some states.

The high-frequency keywords in the red cluster are "trust", "social capital", "sustainability", "collaboration" and "governance". The major focus area of this cluster is concentrated on collaborative governance. Land protection means the supervision and restriction of land use. With the improvement of the land trust system and the expansion of the scope of the conservation easements, the state has gradually delegated the supervision of natural resources management to local governments, land trust agencies, and other NGOs. As an alternative to conventional protection strategy, land trust can be regarded as a tool for landowners and easement holders to cooperate to protect ecological resources, and the social relationship between them directly affects the implementation effect of the land trust. Also, social capital can promote conservation programs. For example, social networks can help coordinate natural resource management actions and help farmers better adapt to climate change policies, and the establishment of a trust mechanism makes conservation programs more efficient [26].

The high-frequency keywords in the yellow cluster are “community land trust”, “land use planning”, “Kenya”and “participation". The major focus area of this cluster is focused on the community land trust (CLT). Different from the public welfare land trust, which aims to protect ecological resources, the CLT is similar to the affordable housing system in China. Both CLT and affordable housing system are designed to provide housing security for the mid and low-income families. The difference between the two systems is mainly reflected in the exit mechanism. When the buyers of CLT sell their houses, the land trust organizations have the preemptive right and ensure that the house price is within the affordable range of low-income families. In the process of CLT operation, the principal role of land trust institutions is not only to raise funds, acquire land, build and sell houses, but also provide some social services to promote community development, such as providing educational opportunities, and jobs. Additionally, while CLT originated in the United States, many countries have established the CLT system to solve the long-standing housing security problem.

4 Discussion

We used the research method of literature bibliometrics and literature visualization software to make a brief of the land trust-related literature in the WoS core database in the past 30 years and reached the following conclusions. First of all, from the perspective of time development, this field did not attract much attention before 2005. The number of relevant articles growth rapidly accelerated after the publication of five literatures with high burst value. Secondly, based on subject classification statistics, land trust involves cross-disciplinary study. The main subject of collected literatures is related to ecology and environment. As the keywords co-occurrence analysis showed in Fig. 4, The hotspots of international land trust mainly cover four aspects: conserving private land by conservation easements, impact and response to climate change, collaborative governance, and CLT. Finally, based on the co-citation from various reference about land trust, it is found that the land trust research has formed a clear cluster differentiation, the network connections between different clusters are tight, and the research topics overlap. Recently, knowledge groups are mainly distributed in the six clusters of biodiversity conservation funds, Haida Gwaii, comprehensive conservation motivation, environmental services, private land protection, and community land trusts. The research contents include the evaluation of land trust protection effect, the adaptive management of land use in extreme climatic environment, the importance of trust mechanism, and the application of CLT in housing security.

In general, the research on the protection of international land trusts has evolved into a multidisciplinary and rich content system knowledge structure group after years of development. The significance of the research results for land trusts in various countries is: (1) Social welfare organizations should be encouraged to contribute funds Set up natural reserve funds to solve the problem of insufficient government financial investment (2) Complete the natural reserve monitoring mechanism, make full use of big data, 3S technology, and other information methods to obtain real-time information on changes in the protected area ecosystem, and timely respond to changes in the external environment Respond. (3) Cooperate with local residents to participate in community management affairs, create a harmonious community relationship, make full use of local ecological resource advantages on the premise of protection, explore the economic value of ecological leisure, sightseeing, and tourism, and drive regional economic development.

5 Conclusion

In this article, we used CiteSpace and VOSviewer to carry out a visualization study of 1341 literatures related to land trust. The research method of literature bibliometrics overcome the limitations of the subjectivity of artificial screening. Overall, the research object of this study is mainly derived from conservation easement which is the earliest research co-citation cluster topics. The conservation easement is a market-based tool used to protect ecosystem services on private lands through yielding economic incentives to landowners. In the process of achieving the regard, it is worthwhile for researchers to re-think the effectiveness of conservation easement and spatial patterns in conservation funding. On the other hand, the different preferences for conservations by both landowners and land trust professionals is worth to discuss, such as the transactions costs, transaction frequency and easement acceptance. To sum up, how to effectively use conservation easement to better protect the environmental services is a need for land trust organizations to collaborate with the public, for future research.

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Study on the Factors Influencing the Satisfaction of Farm Household Land Trust Circulation—Taking Dengzhou City, Henan Province as an Example

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Abstract From the perspective of farmers, this paper selects Dengzhou as the research area and explores the factors affecting the satisfaction of land trust circulation by constructing a structural equation model. The results show that the impact of family endowment and external environment on farmers' satisfaction with land trust circulation is significant at the 5% level. When family endowment and external environment increase by one unit, the satisfaction of land trust circulation will increase by 0.104 and 0.827 units respectively, indicating that family endowment and external environment have a positive effect on improving farmers' satisfaction with land trust circulation. Therefore, guaranteeing farmers' rights and interests, increasing farmers' income, strengthening local environmental governance, supporting facilities construction, and improving farmers' living conditions are vital to promoting the circulation of land trusts.

Keywords Land trust circulation · Satisfaction · Structural equation model

1 Introduction

Since the reform and opening up, the implementation of the household contract responsibility system has solved the distribution of land use, and it has brought unprecedented dividends to rural economic development. In the context of China's efforts to solve Issues Concerning Agriculture, Countryside, and Farmers, the gradual manifestation of land value makes land transfer an important way for agricultural development and farmers' income. To promote the circulation of rural land, China has introduced a series of policies. In 2014, the "Opinions on Guiding the Orderly Circulation of Rural Land Management Rights and the Development of Appropriate Scale Operation of Agriculture" required to promote the deepening reform of the rural land system and realize the separation of ownership, contracting rights, and management rights of rural land. The No. 1 Central Documents of 2018 and 2019

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respectively emphasized the cultivation of new agricultural business entities and the relevant laws and regulations to free up land management rights. This fully reflects China's support and attention to the deregulation of land management rights, so that rural land can be legally transferred. In recent years, with the gradual expansion of the scale and scope of rural land circulation and the increase of transfer speed, the land circulation model has also developed from a single, traditional spontaneous transfer model to a diversified and innovative development. Land trust circulation is an institutional innovation of land transference.

Land trust circulation means that the landowner (the trustor) entrusts the land to the trustee for operation and management, and the trustee transfers the profits from land development and operation to the beneficiaries as the trust benefit distribution. The biggest advantage of the land trust circulation model is that it is more standardized and guaranteed. Since this land transfer model introduces a trust system, the rights and obligations of the parties to the trust are listed in the trust contract and are bound by law under this model. At the same time, the introduction of the trust mechanism can effectively integrate various production factors. The land trust circulation model is not only conducive to accelerating the modernization of agriculture but also can effectively reduce the transaction costs of the "company + farmer" model. More importantly, the land trust circulation model has transformed farmers' land contractual management rights from rigid non-circulating assets into tradable and portable assets, which is conducive to solving the worries of the transfer of population and promoting the process of urbanization. Besides, farmers can also obtain stable income from the land trust, which helps solve the problem of farmers' pension.

2 Literature Review

In Europe and America, many countries have carried out land trust practice for a long time. The practice has proved that the land trust model is a relatively successful land transfer model. For example, the rural land trust innovation in Vermont [1], Kenya's successful community land trust plan (CLT) [2], and the land trust implemented in Latin American countries [3] have all proved that land trusts can achieve a certain degree of scale operation and can improve land utilization efficiency. Wunderlich Karl Arthur conducted an empirical study on community land trusts in Colorado and found that land trusts can protect valuable natural assets in private property, so land trusts can be used to minimize transaction costs and increase the efficiency of land transactions [4].

A land trust is a way to realize land securitization, which has the dual attributes of land circulation and land finance [5]. China is a socialist country, which is different from Western countries in terms of land ownership. Chinese land is owned by the state or collective. Based on China's special land system, Xingguo Wu [6], Yongfeng Liu, and Jing Xie [7] believe that the land trust circulation model is premised on adhering to collective ownership and not changing the agricultural use of rural land. Dongqin Chang holds that China has not issued clear relevant laws, regulations, and systems for the land trust circulation, which makes the land trust circulation lack basis and sources in the actual operation processes [8]. Ting Li believes that the problem of land fragmentation brought about by the household contract responsibility system makes the circulation of land trusts in trouble, and it is difficult to concentrate trust assets [9]. Currently, entities based on land trust circulation in China have derived two more popular land trust circulation operation modes. One is the government-led trust circulation, which can provide trust parties to credit guarantees, capital injection, risk protection, and other advantages to promote land trust circulation. Weibo Liu found that the government-led land trust circulation can effectively achieve the goal of adjusting the rural industrial structure and promoting the concentration of land, which is of great significance to the promotion of agricultural modernization [10]. Another land trust circulation mode is market-led. The trust company signs trust contracts with local farmers or village collectives, and the government plays a guiding and promoting role in this link [11]. Mingguo Yang holds that whether it is a government-led or market-led land trust circulation mode, the transfer of land management rights can be better completed [12]. Weibo Liu compared the changes in data before and after the land trust circulation, including the area of land circulation, farmers' income, grain output, and the extent of land management. He found that the land trust circulation can increase farmers' income, promote large-scale agricultural operations, and accelerate rural system reforms [10].

In summary, China currently concentrates on three aspects of land trusts: the system construction before the circulation, the operation mode during the circulation, and the evaluation of the benefits after the circulation. It is specifically manifested in providing the basis and guarantees for the implementation of land trust circulation based on the legal level, encouraging the implementation of various circulation modes such as market entities and government entities, comprehensively evaluating the impact and benefits from land trust circulation, and improving existing problems in the transfer process. However, in current research, the study object of system research is the government, the main body of trust operation mode is the government or trust company, and the benefit evaluation is also discussed from a macro perspective. Therefore, most scholars ignore the farmers who are also the main body of land trust circulation. Whether to participate in the land trust circulation, farmers' high satisfaction and general recognition of the land trust circulation are the prerequisites for the smooth implementation of the land trust circulation. Therefore, taking farmers as the main body and farmers' satisfaction as the theme in this article can enrich the Chinese land trust research system.

3 Method

This paper studies the influencing factors of farmers' satisfaction with land trust circulation, which belongs to the farmers' subjective perception and has the basic characteristics of being difficult to directly measure and difficult to avoid subjective measurement errors. The structural equation model is a method of establishing, estimating, and testing the causal relationship model. The model contains both observable obvious variables and latent variables that cannot be directly observed [13].

It can provide observation and processing for latent variables that are difficult to observe directly and incorporate inevitable errors into the model [14]. The structural equation model includes two basic models. The measurement equation describes the relationship between latent variables and indicators, and the structural equation describes the relationship between latent variables. Latent variables refer to variables that cannot be directly or accurately measured. If each variable can be directly measured, the variable itself is an indicator [15].

$$\text{measurement model}: X = \Lambda_x \xi + \delta, Y = \Lambda_Y \eta + \varepsilon,$$

The ε in the formula does not correlate with η, ξ, and δ, and δ does not correlate with ξ, η, and ε. X and Y respectively represent the observed variables of extrinsic latent variables and intrinsic latent variables. Λ_x and Λ_Y represent the factor load of the index variables (X and Y). ξ and η respectively represent extrinsic and intrinsic latent variables. δ and ε are the measurement errors of external variables.

$$\text{structure model}: \eta = \Gamma \xi + \zeta, \eta = B\eta + \Gamma \xi + \zeta,$$

In the formula, Γ is an (m $\times$ n) order matrix, which represents the regression coefficient of the effect of the ξ variable on *the* η variable. B is the (m $\times$ m) order matrix, which represents the directional regression coefficient between η variables. ξ is the error of the internal latent variable. Furthermore, there is no correlation between ξ and ζ.

4 Empirical Analysis

4.1 Research Area Overview

Dengzhou City is located in the southwestern part of Henan Province and belongs to the Yangtze River Basin. As a major agricultural city, Dengzhou currently has an area of 1626.67 square kilometers of cultivated land, and the climate is warm and humid, suitable for planting and growing crops. Dengzhou is a key city for cotton and sesame production in Henan Province, as well as the main national grain production area. It is one of China's 50 commodity grain base counties and is known as the "granary". Under the background of the reform of the separation of powers, Dengzhou City has continuously increased investment in agricultural infrastructure construction, improved agricultural production conditions, organized the implementation of million acres of land consolidation and standardized farmland construction projects, and actively responded to the government's call to actively promote the transfer of farmland contract management rights. Therefore, since 2017, the Henan Provincial Department of Land and Resources has designated Dengzhou City as a pilot to land and resources reform and innovation, focusing on rural land circulation, exploring rural land trust, standardizing facility farmland management, and helping agricultural modernization.

4.2 Basic Situation of the Sample

To in-depth study the influencing factors of farmers' land trust circulation satisfaction, the research team went to Dengzhou City in August 2018 and January 2019 to conduct field investigations. The research team conducted random sample questionnaire surveys and in-depth interviews with villagers from 11 villages in Dengzhou that have already carried out land trust circulation. A total of 400 questionnaires were distributed among this survey, and 383 were returned. The questionnaire response rate was 95.7%. The recovered questionnaires were screened out of invalid questionnaires through the waste volume screening and list deletion method. Finally, 356 valid questionnaires were obtained, with an effective rate of 92.9%. The specific investigation content includes the following points:

The first part is the basic situation of the interviewed households, including gender, age, physical health, education level, working out, and the number of laborers of the farmers participating in the transfer;

The second part is the economic situation of the interviewed households, including annual family agricultural income, annual family non-agricultural income, the gap between the family's annual agricultural income and the family's annual non-agricultural income, and the main source of household income before and after the transfer.

The third part is the living environment situation of the interviewed households, including the respondents' satisfaction with public security conditions, traffic conditions, housing conditions, medical and health conditions, education conditions, and living environment;

The fourth part is the characteristics of the land before the transfer, including the quantity and quality of the contracted land before the transfer;

The fifth part is the land trust circulation situation of the interviewees, including the specific transfer of contracted land and the satisfaction with the trust transfer income, policies, and the trust company's execution ability.

4.3 Establishment and Factor Analysis of Satisfaction Model of Farmers' Land Trust Circulation

4.3.1 Reliability and Validity Analysis of the Questionnaire

Reliability is to test and evaluate the credibility of the questionnaire and to judge the degree of internal consistency and external stability of the questionnaire survey

Table 1 KMO and Bartlett's test

Sampling adequacy of KMO metrics		0.888
Bartlett's sphericity test	Approximate chi-square	2413.906
	Degree of Freedom	153
	Significant	0.000

results. The question design of this satisfaction questionnaire is mostly evaluated by the Likert five-level scale, so the most commonly used method of reliability testing is the Cronbach'α coefficient. The formula for calculating Cronbach's α coefficient is:

$$\alpha = \frac{K}{K-1}\left[1 - \frac{\sum \sigma_{\mathrm{i}}^2}{\sigma^2}\right]$$

The formula K represents the number of questions in the questionnaire, σ_{i}^2 represents the variance of the i item, and σ^2 represents the variance of all survey results;

When $\alpha \geq 0.7$, it indicates that the testing effect is well designed and the reliability is acceptable. This paper runs through the SPSS23.0 software, and the Cronbach'α coefficient of the survey data overall scale is 0.852, indicating that the quality of the questionnaire design is good, and the following research can be continued.

Validity is to test and evaluate the validity of the questionnaire. This article is run by SPSS23.0 software to calculate the KMO and Bartlett globular test of the questionnaire. As shown in Table 1.

The KMO of the survey questionnaire data is 0.888.[1] Bartlett's sphericity indicates that the correlation between the variables is significant, indicating that the variables selected in this article have a high degree of correct measurement, the questionnaire validity is good, and the results are valid.

4.4 Variable Selection and Theoretical Hypothesis

4.4.1 Variable Selection

As the trustee and beneficiary of land trust circulation, farmers' satisfaction with this transfer method will be affected by various factors such as age, education level, land trust circulation income, and external environment. This article refers to the previous research situation, draws on the research experience of scholars such as Cai [16], Huang [17], and Luo [18], combines actual conditions, and follows the principles of availability, operability, and representativeness of indicators to design the structural equation model and select variables. This paper comprehensively selects 5 latent

[1] Kaiser (1974) research conclusions show that KMO value greater than 0.9 is the best, greater than 0.8 is better, and greater than 0.7 is intermediate.

variables and 18 observed variables. Specific indicators and descriptions are shown in Table 2.

4.4.2 Theoretical Hypothesis

The personal characteristics, family endowment, land characteristics, and external environment will affect farmers' satisfaction with land trust circulation. To construct a hypothetical model of factors affecting the satisfaction of farmers' land trust circulation. The hypothesis model takes farmers' land trust circulation satisfaction as an endogenous latent variable and takes farmers' characteristics, family endowment, land characteristics, and external environment as exogenous latent variables. The specific assumptions are shown in Table 3.

4.5 Analysis of Model Regression Results

This paper uses Amos21.0 software to construct and run the theoretical model, and the obtained Chi-square value is 339.371. The evaluation of the degree of model fit can be carried out from two aspects: one is to evaluate the model according to various fitting indexes; the other is to evaluate the rationality and the significance of the parameters.

4.5.1 Evaluation of Fit Index of Theoretical Model

This paper uses GFI, AGFI, RMSEA, and CMIN/df as the absolute fit index evaluation indicators; CFI, NEI, RFI, IFI, and TLI as the relative fit index evaluation indicators; PCFI, PNFI as the simplified fitness evaluation indicators. The fitness indexes and evaluation criteria of the modified model are shown in Table 4.

4.5.2 Significance Test of Model Hypothesis

It can be seen from Table 5 that for the latent variables, both family endowment and external environment have passed the significance test, and the parameter estimates are in line with expectations. The standardized estimation coefficients of the four hypotheses are all less than 1, and there is no violation of the estimation, indicating that the structural equation model can pass the test and the model coefficients are interpretable. The variables with poor significance will be discussed in detail when analyzing the model results later.

Table 2 Index selection and description

Latent variable	Observation variable	Name in model	Variable definitions
Personal characteristics	Age	a1	Actual age (years old)
	Health status	a2	Very poor = 1; relatively poor = 2; general = 3; relatively good = 4; very good = 5
	Education level	a3	Elementary school and below = 1; junior high school = 2; high school or technical secondary school = 3; junior college = 4; undergraduate and above = 5
Family endowment	Percentage of household farmers	b1	%
	Family annual agricultural income after transfer	b2	Below 20,000 = 1; 20,000 to 30,000 = 2; 30,000 to 40,000 = 3; 40,000 to 50,000 = 4; more than 50,000 = 5
	Annual non-agricultural income of the family after the transfer	b3	Below 30,000 = 1; 30,000 to 60,000 = 2; 60,000 to 90,000 = 3; 90 to 120,000 = 4; over 120,000 = 5[a]
Land characteristics	Family contracted land area	c1	Mu
	Quality of household contracted land	c2	Very poor = 1; relatively poor = 2; general = 3; relatively good = 4; very good = 5
External environment	Living environment perception	d1	Very bad = 1; relatively bad = 2; general = 3; relatively good = 4; very good = 5
	Traffic facility perception	d2	
	Perception of public security conditions	d3	
	Perception of educational conditions	d4	
	Perception of medical and health conditions	d5	
	Types of government employment assistance	d6	Kinds
Land trust circulation satisfaction	Satisfaction with the land trust circulation policy	s1	Very dissatisfied = 1; dissatisfied = 2; general = 3; satisfied = 4; very satisfied = 5
	Satisfaction with the trust company	s2	

(continued)

Table 2 (continued)

Latent variable	Observation variable	Name in model	Variable definitions
	Satisfaction with the return of land trust circulation	s3	
	Satisfaction with the timeliness of the distribution of trust circulation income	s4	

[a]The division of household economic income refers to the 2015–2018 Dengzhou Statistical Yearbook

Table 3 Summary of research hypotheses

Serial number	Research hypothesis
H1	Personal characteristics have a significant positive impact on the satisfaction of land trust circulation
H2	Family endowment has a significant positive impact on the satisfaction of land trust circulation
H3	Land characteristics have a significant positive impact on the satisfaction of land trust circulation
H4	The external environment has a significant positive impact on the satisfaction of land trust circulation

4.5.3 Model Output Graph and Parameter Estimation

The evaluation of the fit index and the significance test of the parameters of the model show that the model fits well and the results are credible. The model of the factors affecting the satisfaction with land trust circulation is explanatory. The specific index parameters will be further explained. The measurement model shows the relationship between the latent variables and the observed variables. The specific index parameters are shown in Table 6. The output of standardized coefficients of factors affecting satisfaction with land trust circulation is shown in Fig. 1.

From the results of the structural model, when the significance level is 5%, hypothesis 1 and hypothesis 2 have not passed the test, indicating that the personal characteristics and land characteristics of farmers have no significant impact on farmers' satisfaction with land trust circulation. The explanation for the insignificant influence of the individual characteristics of farmers may be that in the actual survey, the interviewee only includes the head of the household. Measuring the basic situation of the entire family based on the head of the household will be different, and it is difficult to reflect the average age, education level, and health status of family members, which will affect the overall judgment of the family's satisfaction with trust circulation. The explanation for the insignificant influence of the land characteristics may be that the area of household contracted land is related to the number of households.

Table 4 Fitting index measurement indicators

Model adaptation index type	Adaptation index	Adaptation standard	Index value of this article	Result
Absolute fit statistics	CMIN/DF	<3.00	2.591	Good
	RMSEA	0.05–0.08	0.067	Good
Relative fit statistics	CFI	> 0.9	0.910	Good
	NFI	The closer to 1, the better	0.862	Good
	RFI	The closer to 1, the better	0.839	Good
	IFI	The closer to 1, the better	0.911	Good
	TLI	The closer to 1, the better	0.895	Good
Parsimonious fit statistics	PCFI	>0.5	0.779	Good
	PNFI	> 0.5	0.738	Good

Table 5 Structural model: latent variable path coefficient

Hypothesis	path	Standardized coefficient	Significance level
H1	The satisfaction of land trust circulation < –- personal characteristics	−0.027	0.564
H2	The satisfaction of land trust circulation < –- family endowment	0.104	0.048**
H3	The satisfaction of land trust circulation < –- land characteristics	−0.075	0.912
H4	The satisfaction of land trust circulation < –- external environment	0.827	0.029**

*, **, *** respectively indicate the significance level is 0.1, 0.05, 0.001

Comparing the area size without considering the number of households may affect the model results. The indicator of the contracted land area per household should be considered. At the same time, the evaluation of the quality of household contracted land is based on the judgment of the farmers themselves. The strong dependence of farmers on the land affects their objective evaluation of land quality, which leads to inconsistencies with the actual land grading results. Therefore, it may affect the results of the model.

The family endowment has a positive impact on farmers' satisfaction with land trust circulation. When other control variables remain unchanged, for every unit increase in family endowment, farmers' satisfaction with land trust circulation will

Table 6 Measurement model: estimation of latent variables to observed variables

Latent variable	Observation variable	Standardized coefficient	C.R	Significance level
Personal characteristics	Age	0.725	–	***
	Health status	−0.443	−4.227	***
	Education level	−0.500	−4.241	***
Family endowment	Percentage of household farmers	0.166	–	***
	Family annual agricultural income after transfer	0.963	3.060	**
	The annual non-agricultural income of the family after the transfer	0.344	2.782	**
Land characteristics	Family contracted land area	0.785	–	***
	Quality of household contracted land	−0.055	−0.110	Not significant
External environment	Living environment perception	0.779	2.239	**
	Traffic facility perception	0.838	2.243	**
	Perception of public security conditions	0.818	2.242	**
	Perception of educational conditions	0.787	2.240	**
	Perception of medical and health conditions	0.827	2.242	**
	Types of government employment assistance	0.124	–	***
Land trust circulation satisfaction	Satisfaction with the land trust circulation policy	0.860	8.523	***
	Satisfaction with a trust company	0.811	8.827	***
	Satisfaction with the return of land trust circulation	0.819	8.853	***
	Satisfaction with the timeliness of the distribution of trust circulation income	0.482	–	***

*, **, *** respectively indicate the significance level is 0.1, 0.05, 0.001

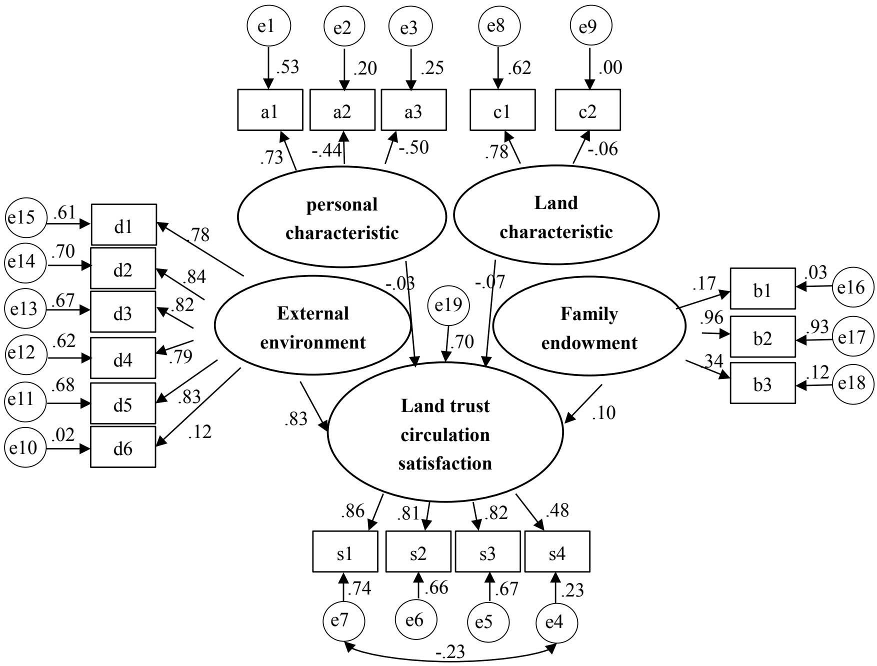

Fig. 1 Output graph of standardized coefficients of influencing factors of satisfaction with land trust circulation

increase by 0.104 units. Hypothesis 3 holds. The external environment has a positive impact on farmers' satisfaction with land trust circulation. With other control variables unchanged, for every unit increase in the external environment, farmers' trust transfer satisfaction will increase by 0.827 units. Hypothesis 4 holds.

From the results of the measurement model, the parameter estimates of the quality of household contracted land are not significant, and the parameter estimates of the remaining 17 observed variables all pass the significance test. Among them, the seven observation variables of personal characteristics and land trust circulation satisfaction are all significant at the 1% level. The factor loadings of the observation variables under the dimensions of the external environment, family endowment, and land trust circulation satisfaction degree are relatively high, indicating that these variables have a better interpretation and can effectively explain potential variables.

4.6 Analysis of the Influencing Factors of Farmers' Land Trust Circulation Satisfaction

4.6.1 The Impact of Family Endowment

Family endowment has a significant positive impact on farmers' satisfaction with land trust circulation. The influence of this latent variable is manifested in three aspects.

The first is the proportion of household farmers. This variable passed the 0.001 significance level test and the coefficient was positive, indicating that the higher the proportion of household farmers, the higher the satisfaction of farmers with land trust circulation. This is inconsistent with previous expectations. The possible explanation is that after the land trust circulation, households with a relatively high number of household farmers can relatively liberate more labor force. Part of these labor force can engage in more non-agricultural activities to obtain higher economic income, and the other part can assist large local business operators in agricultural planting to obtain wage income, so it can effectively improve the satisfaction of land trust circulation.

The second is the annual household agricultural income after the circulation. This variable passes the 0.05 significance level test and the coefficient is positive, indicating that the higher the annual household agricultural income after the transfer, the higher the farmers' satisfaction with the land trust circulation. This is because the mode of small farmer operations has a high degree of uncertainty, which can be reduced through land circulation. The stability and security of land trust circulation are unmatched by other circulation methods. Comparing the land trust before and after the transfer, it can be found that the proportion of households with an annual agricultural income of more than 20,000 yuan before the circulation accounted for 22.2%. However, after the transfer, it accounted for 25.6%, indicating that the land trust circulation has increased the agricultural income for local farmers. Therefore, farmers are satisfied with the advantage of increasing income from land trust circulation.

The third is the annual non-agricultural income of the family after the transfer. This variable passes the 0.05 significance level test and the coefficient is positive, indicating that the higher the annual non-agricultural income of the family after the circulation, the higher the farmers' satisfaction with the land trust circulation. According to the survey results, the annual non-agricultural income of households after the circulation has increased slightly compared with that before the circulation. Before the circulation, the proportion of households with an annual non-agricultural income of more than 30,000 yuan accounted for 30.4%, and after the circulation, it accounted for 33.8%. It shows that farmers participating in the transfer can actively transfer non-agricultural employment, create additional non-agricultural income, improve family economic conditions, and improve the satisfaction with land trust circulation.

4.6.2 The Influence of the External Environment

The factor that has the greatest impact on farmers' satisfaction with land trust circulation is the external environment. This latent variable has a significant positive impact, which is manifested in two aspects.

First, the perception of the living environment, perception of traffic conditions, perception of public security conditions, perception of education conditions, and perception of medical and health conditions have all passed the 0.05 significance level test and the coefficients are positive, indicating that the better these conditions, the higher the farmers' satisfaction with land trust circulation. After Dengzhou city land trust company obtained land management rights, it first carried out land consolidation and construction of ditches, canals, and roads, which greatly improved the local traffic conditions, living environment, and public security conditions. The optimization of these external environments has improved the satisfaction of land trust circulation.

The second is the type of government assistance. This variable passes the 0.001 significance level test and the coefficient is positive, indicating that the more types of assistance provided by the government after the transfer, the higher the satisfaction of land trust circulation. In the process of promoting the transfer of land trust, the government provided various channels of employment assistance and various forms of employment subsidies. At the same time, the government created a good atmosphere of cadre assistance, policy assistance, and mass intervention. The employment assistance provided by the government can effectively improve farmers' non-agricultural employment skills, reduce their dependence on the land, and obtain opportunities in the non-agricultural employment market. This is an important guarantee factor of improving farmers' satisfaction with the land trust circulation.

4.6.3 The Impact of the Land Trust Circulation Process

Satisfaction with land trust circulation policy, satisfaction with a trust company, satisfaction with circulation income, and satisfaction with the timeliness of distribution of circulation income, these four measurable variables pass the test at a significance level at 0.001 and the coefficients are positive. When the other control variables remain unchanged, for each increase of one unit of these four variables, the farmers' satisfaction with land trust circulation respectively increases by 0.86, 0.811, 0.819, and 0.482 units. According to the survey results, 96.1% of farmers approve of the government's promotion of land trust circulation policies. However, farmers' satisfaction with the land trust circulation income is relatively poor. Only 28.1% of the farmers are satisfied with the trust circulation subsidy income. Farmers are less satisfied with the timeliness of income distribution. 46.5% of farmers believe that the release of trust income is slow, which is not conducive to the improvement of farmers' satisfaction.

5 Conclusion and Discussion

This paper studies the influencing factors of land trust circulation satisfaction from four aspects: personal characteristics, family endowment, land characteristics, and external environment. The results show that family endowment and the external environment are important factors affecting the satisfaction of land trust circulation. In the dimension of family endowment, the farmers are most concerned about the change in income after land trust circulation. Dengzhou City has improved the mechanism for increasing farmers' income through land trust circulation. Farmers can obtain income from the fixed income of the transferred land, the wage income from the agricultural operation company's planting, and the corresponding proportion of land dividends. What's more, the factors affecting the satisfaction of the land trust circulation from the external environment are closely followed. Farmers are more concerned about how the land can be improved in terms of housing conditions, living environment, traffic conditions, public security conditions, education conditions, and medical and health conditions after the land trust circulation.

According to the above research conclusions, to improve the deficiencies in the circulation of land trusts, the following policy inspirations can be obtained:

The first is to formulate a reasonable compensation policy for land trust circulation to protect farmers' income. Relevant departments must conduct in-depth investigations into farmer households and listen to their opinions to formulate the basic compensation amount. In actual operation, according to the difference in the quality of farmland, the compensation amount is floated according to the actual economic situation of the farmer family and adjusted appropriately along with the land trust circulation process. The second is to strengthen the governance of the local environment and the construction of supporting facilities while carrying out the land trust circulation. Such as speeding up the construction of medical and health facilities, improving local education forces and strengthening public security. Cultivated land production equipment operated by small farmers that cannot meet the needs of modern agriculture. For large-scale agricultural operators to realize large-scale land management and mechanized operations, they must integrate public resources such as fields, road networks, and water channels. The government needs to improve infrastructure construction, plan the construction of agricultural production facilities, update the irrigation and road facilities for agricultural production, and solve the farming problems of large operators to improve the efficiency of agricultural production and promote the circulation of trust.

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Temporal-Spatial Evolution Characteristics of Urban Land Green Use Efficiency in Urban Agglomerations—A Case Study of the Yangtze River Delta Urban Agglomeration

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Abstract The green use of urban land in urban agglomerations is an important path for the social and economic development of urban agglomerations towards sustainable and integrated development. Take the Yangtze River Delta City Group as an example, using the undesired output super-efficient SBM model to measure the land green use efficiency of 41 cities in the Yangtze River Delta urban agglomeration from 2003 to 2017. On this basis, using kernel density estimation and exploratory spatial data analysis methods to characterize and identify the temporal and spatial pattern evolution characteristics of urban land green use efficiency. The results indicated that: (1) The urban land green utilization efficiency value of the Yangtze River Delta urban agglomeration is on the rise. The average efficiency value has increased from 0.736 in 2003 to 0.773 in 2017, and the number of effective decision-making units has increased from 11 to 13 cities. (2) During the study period, the difference in urban land use efficiency in the Yangtze River Delta urban agglomeration evolved toward a magnified trend and evolved from two-level differentiation to single-polarization. The kernel density curves of each province have their shapes and trajectories in position, kurtosis, peak number, and tail. There is a significant positive global spatial autocorrelation of urban land use efficiency in the Yangtze River Delta urban agglomeration. The local spatial pattern is dominated by HH and LL, supplemented by LH and HL, and geographical existence of spatial neighboring companion effect and spatial proximity spillover effect, forming a spatial pattern of "urban agglomeration and separation". According to this, according to regional differences, implement different policies according to different regions and cities; Taking advantage

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of spatial proximity spillover effects and give play to the cooperative linkage effect of cities in improving the green utilization efficiency of land.

Keywords Yangtze River Delta urban agglomeration · Land green use efficiency · Undesired output · Super efficiency SBM model · Temporal-spatial evolution

1 Introduction

The 2018 National Ecological and Environmental Protection Conference pointed out that green development is an inevitable requirement for building a high-quality modern economic system [1], green has become the theme color of contemporary economic development. On November 1, 2019, the Central Office and the State Council issued the "Guiding Opinions on the Overall Planning and Implementation of Three Control Lines in Land and Space Planning", which clearly stated that urban development boundaries should be delineated in accordance with the requirements of green development [2]. The green use of urban land is the core requirement and key realization path for the optimal allocation and effective utilization of urban land elements in the current social and economic development process, and it is also an important practice activity to implement the ecological protection concept of "green water and green mountains are golden and silver mountains". The Yangtze River Delta urban agglomeration is the region with the greatest intensity of urban land development and utilization and the most mature social and economic development in China. It is the frontier and high ground for my country to participate in international competition. Under the new era requirements, we will strengthen the research on the green land use efficiency of the Yangtze River Delta urban agglomeration It is of great significance to reduce the environmental risks in the development and utilization of urban land, alleviate the contradiction between the social and economic development of urban agglomerations and ecological environmental protection, and lead the green and sustainable development of cities across the country.

The green utilization efficiency of urban land is directly related to the depth and breadth of sustainable urban social and economic development. Under the background of the basic national conditions of more people and less land, the efficiency of urban land use has attracted much attention from the government, and a lot of research has also been carried out in the academic community. The existing literature on the measurement of urban land use efficiency in China started from the traditional measurement of urban land use efficiency. Such research has not yet incorporated undesired output such as environmental pollution into the measurement model. From the perspective of research methods, some scholars use the ratio of economic output to administrative land area to measure urban land use efficiency [3, 4]. However, the single index evaluation method only considers the efficiency relationship between a single input and a single output in urban land use, and cannot fully reflect the efficiency relationship between multiple inputs and multiple outputs in the process of urban land use. Therefore, the evaluation of urban land use efficiency has shifted from a single index to a multi-index evaluation, such as some scholars have constructed a multi-index evaluation system for urban land use efficiency from the aspects of land use structure, land use intensity, social benefits, economic benefits, and ecological environmental benefits [5, 6]. However, the multi-index comprehensive evaluation method has problems such as unclear definition of connotation, strong subjectivity of evaluation index weight, and difficulty in determining the ideal value, which affect the objectivity of evaluation results [7]. With the continuous development of research technology, data envelopment analysis (DEA) can use optimization methods to determine the weights of various input elements, avoid subjective factors, and be more objectively effective for decision-making units with multiple input and multiple output indicators evaluation has gradually become the mainstream method for measuring urban land use efficiency [8]. For example, some scholars used DEA methods that did not include undesired output to measure urban land use efficiency at different scales [9–12]. However, economic output is not the only output in the process of land use. In the efficiency calculation, environmental output such as “three wastes” emissions must also be considered as undesired output of land use to be able to measure land more accurately [13]. The real situation of utilization efficiency. With the deepening of the concept of green development and the advancement of research methods and technologies, the measurement of land green use efficiency in modern cities has gradually become a research hotspot in current land use evaluation. The non-radial and non-angle SBM-Undesirable model improved on the basis of the traditional DEA model can incorporate undesirable output into the measurement model and is favored by researchers, some scholars used this research method to measure and study the green use efficiency of urban land at different scales [14–17]. Although the SBM-Undesirable model can incorporate undesirable output into the measurement model, there is still the problem that the efficiency value of effective decision-making units cannot be decomposed, resulting in the loss of effective decision-making unit information, and the super-efficiency SBM model based on undesirable output can be effective Solve this practical problem [18]. In addition, the green use efficiency of urban land is a process of dynamic evolution in time and space. Due to the different geographic and spatial locations, land resource endowments and socio-economic development stages of cities, the green use efficiency of land resources varies in different cities and at different development stages. The objectively existing temporal and spatial heterogeneity. According to Tobler’s first law of geography, everything in space is related to other things, but the magnitude of this correlation decays with distance, which is also geographic spatial correlation [19]. However, the existing literature’s analysis of urban land use efficiency measurement results is mostly based on the phenomenon description and mechanism explanation from the perspective of management or economics [20], and lacks a two-dimensional perspective of time and space to describe and describe the dynamic evolution of urban land use efficiency. The identification of the characteristics of spatial pattern evolution cannot provide a favorable reference for the formulation of policies in different regions and different cities according to local conditions.

Based on this, on the basis of learning from and absorbing existing research, this article incorporates undesired output into the super-efficiency SBM model, taking the Yangtze River Delta urban agglomeration as an example, using non-parametric kernel density estimation methods to describe 41 sites in the Yangtze River Delta urban agglomeration The time-series dynamic evolution law of urban land green use efficiency from 2003 to 2017 in cities of level and above, an exploratory spatial data analysis method that considers spatial effects is adopted to identify the spatial pattern evolution characteristics of urban land green use efficiency in the Yangtze River Delta urban agglomeration. It is expected to provide reference and reference for promoting the development of cooperation and linkage between cities in the Yangtze River Delta urban agglomeration, improving the green utilization efficiency of urban land resources and the formulation of relevant policies for land and space governance.

2 Research Methods

2.1 Super-Efficient SBM Model Based on Undesired Output

Since the SBM model cannot decompose the effective unit efficiency value like the traditional DEA model, there will be multiple efficiency values at the same time when the decision-making unit is measured for efficiency, which causes the loss of effective information and affects the decision-making unit. In the quantitative analysis of factors, the restricted dependent variable Tobit model is often used for regression, which limits the choice of more other measurement models. Tone proposed a super-efficiency SBM model of undesired output on the basis of the SBM model [21]. This model combines the advantages of the super-efficiency model and the SBM model at the same time. It can incorporate undesired outputs into the model while setting the efficiency value to 1. The effective decision-making unit is then decomposed. The model is constructed as [22]:

$$\min\rho = \frac{\frac{1}{m}\sum_{i=1}^{m}(\bar{x}/x_{ik})}{\frac{1}{r1+r2}\left(\sum_{s=1}^{r1}\overline{y^d}/y_{sk}^d + \sum_{q=1}^{r2}\overline{y^u}/y_{qk}^u\right)} \tag{1}$$

$$\begin{cases} \bar{x} \geq \sum\limits_{j=1,\neq k}^{n} xij\lambda j; \overline{y^d} \leq \sum\limits_{j=1,\neq k}^{n} y_{sj}^d\lambda j;\ \overline{y^d} \geq \sum\limits_{j=1,\neq k}^{n} y_{qj}^d\lambda j; \\ \bar{x} \geq xk;\ \overline{y^d} \leq y_k^d;\ \overline{y^u} \geq y_k^u;\ \lambda j \geq 0; \\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n; \\ s = 1, 2, \ldots, r1;\ q = 1, 2, \ldots, r2; \end{cases} \tag{2}$$

where: Suppose there is n number DMU, Each DMU is made up of m, desired output $r1$ and undesired output $r2$ composition; x, y^d, y^u is the elements in the corresponding input matrix, desired output matrix, and undesired output matrix, ρ is the green use efficiency value of urban land.

2.2 Non-Parametric Kernel Density Estimation

Kernel density estimation is a non-parametric method for estimating the probability density function. Its advantage is that it does not require any parametric model assumptions and can describe the distribution and evolution characteristics of random variables with a continuous density curve [23]:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{xi - x}{h}\right) \tag{3}$$

where:n is the sample number; h is the bandwidth; xi is the sample observation value; $K\left(\frac{xi-x}{h}\right)$ is the kernel function, In this paper, the Gaussian Kernel, which is most commonly used in academic circles, is used to estimate the dynamic evolution of urban land use efficiency in the Yangtze River Delta urban agglomeration.

2.3 Exploratory Spatial Data Analysis

2.3.1 Global Spatial Autocorrelation

Global spatial autocorrelation is an index that measures the spatial correlation of research objects from a global perspective [24]. It embeds the spatial geographic location relationship into data analysis through the setting of a spatial weight matrix. This paper uses the global Moran's I index, which is common in academic circles, to measure the global spatial correlation of urban land use efficiency in the Yangtze River Delta urban agglomeration.

2.3.2 Local Spatial Autocorrelation

Local spatial autocorrelation is an index that measures the spatial correlation of research objects from a local perspective [24]. It reflects the degree of similarity between the observations in the local area and the observations in the surrounding neighboring areas, which can be used to identify the agglomeration and dispersion characteristics of the local spatial pattern. This paper uses the local Moran's index, which is common in academic circles, to measure the local spatial correlation of urban land use efficiency in the Yangtze River Delta urban agglomeration. The local spatial pattern agglomeration can be divided into four types: HH (High–High), LH (Low–High), LL (Low–Low) and HL (High–Low).

3 Indicator Selection and Data Sources

3.1 Index Selection

The connotation of urban land green use efficiency is defined as the comprehensive mapping of the input of land, capital, labor, and other elements in the urban land use system with the economic and ecological environmental output of the urban land use system on the urban space under certain production technical conditions Its essence is to maximize land green economic output at the cost of as little land element input as possible and minimize the loss of ecological environment. Its core is to pursue the coordination and unity of economic development and ecological environment in the urban land use system. The measurement of urban land green use efficiency refers to considering the undesired output on the basis of the traditional land use efficiency measurement, and incorporating the expected output and undesired output into the measurement model. Its essence is to have as few land elements as possible Invest and minimize environmental costs to maximize land green economic output. Based on the connotation and essence of the measurement of urban land green use efficiency, and based on previous literature [25–28], combined with the availability of data, this paper selects the following core indicators of urban land green use efficiency evaluation. (1) Expected economic output: the actual added value of the secondary and tertiary industries (100 million yuan) in the urban district Value Added. (2) Unexpected pollution output: select industrial wastewater discharge (10,000 tons), industrial sulfur dioxide discharge (tons), industrial smoke and dust discharge (tons), and the three major pollution sources of cities as the original indicators of undesired output. Because the DEA model requires that the output index should not be too many, and in order to eliminate the magnitude difference caused by the different units of the three kinds of undesired output, this paper uses the entropy method to calculate the comprehensive index of the undesired output [29]. (3) Land element input: the area of urban construction land (square kilometers) in urban districts. (4) Capital factor input: fixed asset investment in urban areas (100 million yuan), using 2003 as the base period, using the fixed asset investment price index to convert the nominal fixed asset investment value into comparable actual fixed asset investment, and using the perpetual inventory method calculated the capital stock of each city over the years [30]. (5) Labor factor input: the total number of employees in urban units and urban private and individual employees in urban districts (10,000 people).

3.2 Research Objects and Data Sources

The Yangtze River Delta urban agglomeration is located at the intersection of the longitudinal axis of my country's coastal corridors and the horizontal axis of the Yangtze River corridor. According to the membership composition of the Yangtze River Delta City Economic Coordination Association in 2019, the Yangtze River Delta City Group has covered 41 cities in Shanghai, Jiangsu, Zhejiang, Anhui, 3 provinces and 1 municipality. It contains "one core and five circles", with Shanghai as the core. The five metropolitan areas of Nanjing, Hangzhou, Hefei, Suzhou, Wuxi, and Ningbo are the largest and most comprehensive national-level city clusters in China. As of the end of 2018, the Yangtze River Delta urban agglomeration had a land area of 359,200 square kilometers, accounting for 3.73% of the country's land; the permanent population was 225 million, accounting for 16.15% of the country, and the total regional product value was 21.15 trillion, accounting for 23.49% of the country. The Yangtze River Delta urban agglomeration is given the national strategy and historical mission of taking the lead in achieving high-quality development and participating in international cooperation and competition at a higher level. This article takes 41 prefecture-level and above cities in the Yangtze River Delta urban agglomeration as the research object, and takes the urban district as the main body of the study, because the municipal district is a core part of a city, and it is also a hot spot of undesired output in human economic activities. The index data in this article mainly come from "China City Statistical Yearbook (2003–2017)" and "China Construction Statistical Yearbook (2003–2017)". The geographic spatial position coordinate information of the city was extracted with ArcGIS software, and finally the panel data of 41 cities in the Yangtze River Delta urban agglomeration from 2003 to 2017 were obtained.

4 Empirical Results

Table 1 shows the distribution characteristics of urban land green use efficiency in the Yangtze River Delta urban agglomerations in 2003 and 2017. ① From the perspective of the Yangtze River Delta urban agglomeration as a whole, the average efficiency value increased from 0.736 in 2003 to 0.773 in 2017, indicating that urban land green use The efficiency value shows an increasing trend. ②From the perspective of the number of cities in the division, the number of cities in effective decision-making units has increased from 11 to 13 cities, and the number of cities in inefficient decision-making units has been reduced from 30 to 22 cities. ③From the distribution area, Shanghai has always been in the state of effective decision-making units. In 2003, the number of effective decision-making units was distributed in Anhui = Zhejiang > Jiangsu, and in 2017, the number of effective decision-making units was distributed in Anhui > Zhejiang > Jiangsu. Shanghai is the core area of the Yangtze River Delta urban agglomeration, with strong environmental regulations and a high

Table 1 Distribution characteristics of urban land green use efficiency value of Yangtze River Delta urban agglomeration in 2003 and 2017

Interval	2003	2017
Effective DMU	Shanghai, Suzhou, Yangzhou, Hangzhou, Ningbo, Taizhou, Lishui, Huangshan, Bozhou, Chizhou, Xuancheng, (11)	Shanghai, Wuxi, Zhenjiang, Wenzhou, Zhoushan, Taizhou, Lishui, Huangshan, Chuzhou, Lu'an, Bozhou, Chizhou, Xuancheng, (13)
Invalid DMU	Nanjing, Wuxi, Xuzhou, Changzhou, Nantong, Lianyungang, Huai'an, Yancheng, Zhenjiang, Taizhou, Suqian, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Zhoushan, Hefei, Wuhu, Bengbu, Huainan, Maanshan, Huaibei, Tongling, Anqing, Chuzhou, Fuyang, Suzhou, Lu'an, (30)	Nanjing, Xuzhou, Changzhou, Suzhou, Nantong, Lianyungang, Huai'an, Yancheng, Yangzhou, Taizhou, Suqian, Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Hefei, Wuhu, Bengbu, Huainan, Maanshan, Huaibei, Tongling, Anqing, Fuyang, Suzhou, (22)
Mean	0.736	0.773

Note An efficiency value greater than or equal to 1 is an effective decision-making unit city, and an efficiency value less than 1 is an invalid decision-making unit city. The number in brackets is the number of cities

degree of advanced industrial structure, which makes it low in environmental pollution emissions during economic development and high in green land use efficiency. Huangshan, Chizhou, Xuancheng and other places in Anhui are mostly eco-tourism resource-rich areas and restricted development areas. The environmental pollutant discharge accompanying economic output is small, and the green land use efficiency is high.

4.1 Timing Dynamic Evolution Characteristics

Using the non-parametric kernel density estimation formula, and with the help of Eviews10 software to draw the urban land green use efficiency nuclear density curves of the Yangtze River Delta in 2003, 2008, 2013 and 2017 (Fig. 1), respectively from the entire Yangtze River Delta urban agglomeration Scales and sub-provincial scales are used to characterize the temporal dynamic evolution characteristics of urban land use efficiency. The total scale is 41 cities in three provinces and one city, and the sub-provincial scale is Jiangsu (13 cities), Zhejiang (11 cities) and Anhui (16 cities). Shanghai is only included in the global scale as a city, and it has not been separated by the provincial scale.

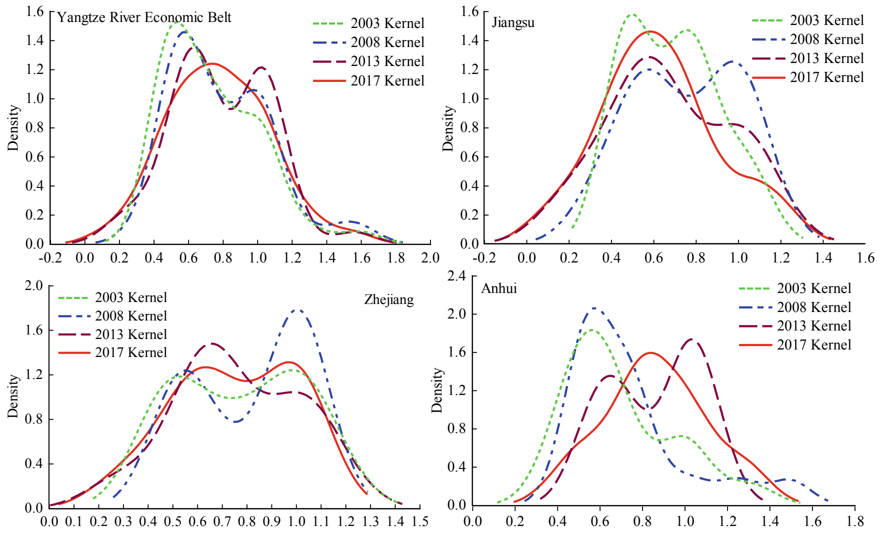

Fig. 1 Temporal dynamic evolution characteristics of urban land green use efficiency in the Yangtze River Delta urban agglomeration

4.1.1 Dynamic Evolution Characteristics of Global Time Series

① From the position of the center of gravity of the nuclear density curve, right migration-left migration. From 2003 to 2013, the overall curve position showed a trend of gradual migration to the right, indicating that during this period, the urban green land use efficiency of the Yangtze River Delta showed an overall upward trend. From 2013 to 2017, the center of gravity of the curve moved slightly to the left, indicating a downward trend in the efficiency of urban land use. ②From the perspective of the peak height of the main peak of the curve, the peak value of the main peak of the curve from 2003 to 2017 shows a downward trend, indicating that the difference in green use efficiency of land in different cities has shown an expanding trend. ③ From the perspective of the number of peaks in the curve, there was a double-peak pattern of main peak and sub-peak in both 2008 and 2013, indicating that there was an obvious two-level differentiation in urban land use efficiency during the study period. In 2017, the curve has a bell shape. The two-level quadrant of urban land green use efficiency disappeared. ④ From the left and right tails of the curve, the tail on the right side of the curve from 2003 to 2017 is slightly larger than the tail on the left, and the tail on the right shows a slight increase in thickness, indicating that more medium-to-high-value urban land green use efficiency has begun to increase. Higher inflows from high-value areas, the proportion of cities in high-value areas has increased. It can be seen that, on a global scale, the urban green land use efficiency of the Yangtze River Delta urban agglomeration has dynamic evolution characteristics of different development levels, efficiency differences, and polarization in different time periods.

4.1.2 Dynamic Evolution Characteristics of Local Time Series

① From the perspective of the center of gravity of the nuclear density curve, Jiangsu and Zhejiang migrated to the right from 2003 to 2008, migrated to the left in 2008–2017, migrated to the right in Anhui from 2003 to 2013, and migrated to the left in 2013–2017, and the magnitude of the migration of the center of gravity of each province is also different. The difference indicates that the provinces in the Yangtze River Delta have their own time differences in the dynamic evolution of the overall level of urban soil green use efficiency. ② From the perspective of the peak height of the main peak of the curve, Jiangsu decreased from 2003 to 2008, increased from 2008 to 2017, Zhejiang and Anhui increased from 2003 to 2008, and decreased from 2008 to 2017, and the fluctuation range of the main peak of each province is also different, indicating that urban land in each province The variation of green utilization efficiency within the region has its own regional characteristics. ③ From the perspective of the number of peaks in the curve, Jiangsu has a bimodal pattern in 2003 and 2008, Zhejiang has been in a bimodal pattern, and Anhui has a bimodal pattern in 2013, indicating that the urban land use efficiency of the Yangtze River Delta has continued to polarize in the province. Time is Zhejiang > Jiangsu > Anhui. ④ From the left and right tailings of the curve, the degree of change on the right side of Jiangsu is greater than that of the left side tailing. The right side tailing showed a thickening trend in 2003–2008, and a thinning trend in 2008–2017. The tail on the left is slightly larger than the tail on the right. The degree of change on the right side of Anhui is greater than the tailing on the left side. From 2003 to 2017, there is an overall trend of thickening. The possible reason is the difference in economic development scale, development structure, and development stage among the provinces in the Yangtze River Delta and between cities within each province. Due to the nature of urban land green use efficiency in different regions and in the same year, the flow of urban land green use efficiency to high-value areas or low-value areas has a certain degree of complexity. It can be seen that the time-series dynamic evolution process of urban land green use efficiency in different regions and different time periods in the Yangtze River Delta is a result of the superposition and symbiosis of regional and time characteristics.

4.2 Characteristics of Spatial Pattern Evolution

4.2.1 Global Spatial Pattern Characteristics

Using the global Moran index formula, with the help of GeoDa software, the global Moran's I index and Z-value (Fig. 2) of the land green use efficiency of 41 cities in the Yangtze River Delta urban agglomeration from 2003 to 2017 are calculated. The results show that the global Moran's I index is positive. In several places between 0.490 and 0.695, Z-value > 1.96, which means that P-value < 0.05 passed the significance test. It can be seen that the spatial distribution of urban land use efficiency

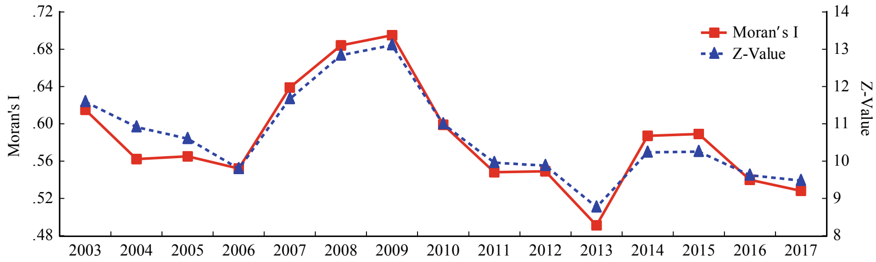

Fig. 2 Global Moran's I index and P-value trend characteristics of urban land green use efficiency in the Yangtze River Delta urban agglomeration

in the Yangtze River Delta urban agglomeration has a significant positive overall Spatial autocorrelation, that is, the green use efficiency of local urban land will not only affect neighboring cities, but will also be affected by neighboring cities. On the whole, the global Moran's I index showed a downward trend from 2003 to 2017, indicating that the global spatial correlation of urban land use efficiency in the Yangtze River Delta urban agglomeration has evolved from a strong correlation to a weak correlation. However, the inter-annual fluctuations are relatively large, and after falling to a certain degree, there will be a rebound rise, but this elasticity gradually weakens. There is a self-adjusting mechanism for inter-annual spatial correlation, but this adjustment mechanism. The function is gradually declining.

4.2.2 Characteristics of Local Spatial Pattern

In order to further identify the local spatial pattern of urban land green use efficiency and the location of spatial agglomeration, the characteristics of the local spatial pattern of urban land green use efficiency in the Yangtze River Delta in 2003 and 2017 are displayed (Table 2). In terms of quantity distribution, HH and LL are the main ones, and LH and HL are the supplementary ones. The urban land green use efficiency has a spatial neighbor effect, that is, when the land green use efficiency in the neighboring areas around the local city is at a high (low) level, the local It is also easier to become a city with a high (low) level of green land use efficiency, or it is more difficult for local cities to transfer to a city with low (high) green land use efficiency. On the whole, the characteristics of local spatial agglomeration and distribution of green land use efficiency in the Yangtze River Delta region are: high-high agglomeration and low-low agglomeration in contiguous distribution, low–high agglomeration and high-low agglomeration showing scattered distribution; high-high agglomeration and low–high agglomeration Neighboring distribution, low-low clustering and high-low clustering adjacently distributed. In 2003, high-high and low–high agglomeration cities were mainly distributed in Shanghai, southern Jiangsu, southern Anhui, Zhejiang and other regions south of the Yangtze River. Low-low agglomeration and high-low agglomeration are mainly distributed

Table 2 Local spatial pattern distribution characteristics of urban land green use efficiency of the Yangtze River Delta urban agglomeration in 2003 and 2017

Types	2003	2017
HH	Shanghai, Wuxi, Suzhou, Yangzhou, Zhenjiang, Taizhou, Hangzhou, Ningbo, Wenzhou, Zhoushan, Taizhou, Huangshan, Chizhou, Xuancheng (14)	Zhenjiang, Ningbo, Wenzhou, Zhoushan, Lishui, Huainan, Huaibei, Tongling, Anqing, Huangshan, Chuzhou, Lu'an, Bozhou, Chizhou, Xuancheng (15)
LH	Nantong, Jiaxing, Huzhou, Jinhua, Quzhou, Wuhu (6)	Nanjing, Changzhou, Suzhou, Hangzhou, Huzhou, Quzhou, Wuhu, Fuyang (8)
LL	Nanjing, Xuzhou, Lianyungang, Huai'an, Yancheng, Suqian, Shaoxing, Hefei, Bengbu, Huainan, Maanshan, Huaibei, Tongling, Anqing, Fuyang, Suzhou, Lu'an (17)	Xuzhou, Nantong, Lianyungang, Huai'an, Yancheng, Taizhou, Suqian, Jiaxing, Shaoxing, Jinhua, Hefei, Suzhou (12)
HL	Changzhou, Lishui, Chuzhou, Bozhou (4)	Shanghai, Wuxi, Yangzhou, Taizhou, Bengbu, Maanshan (6)

Note The type division in the table is obtained with the help of GeoDa software, and the number in brackets is the number of cities

in northern Jiangsu and northern Anhui north of the Yangtze River. In 2017, high-high and low–high agglomeration cities were mainly distributed in southern Jiangsu, Anhui, Zhejiang and other regions, while low-low and high-low agglomerations were mainly distributed in northern Jiangsu and Zhejiang. The status of the local spatial pattern of urban land use efficiency in the Yangtze River Delta is mainly due to the existence of spatial proximity spillover effects, high natural, economic, social and cultural similarities between cities in neighboring regions, and spatial distance Recently, the transportation cost is low, the mutual connection is frequent, the information is quickly and conveniently obtained, and the policies and measures adopted in the land resource management, the intensity of environmental governance, and the economic development have the effect of imitating, learning and competing with each other. A certain law [19], as the distance between cities increases, the spatial spillover effect gradually decays, thus forming a spatial pattern of "cities clustered in groups".

5 Conclusions and Discussion

Based on the panel data of 41 prefecture-level and above cities in the Yangtze River Delta City Group from 2003 to 2017, this paper incorporates undesired output into the super-efficiency SBM model to measure the urban land green use efficiency, and analyzes the Yangtze River Delta from a two-dimensional perspective of time and space. The time series dynamic evolution law and spatial pattern evolution characteristics of urban agglomeration land green use efficiency are described and identified. Draw the following main conclusions and discussion:

5.1 Conclusions

(1) From the overall level of the Yangtze River Delta urban agglomeration, during the study period, the urban land green use efficiency value showed an overall upward trend, the average efficiency value increased from 0.736 to 0.773, and the number of effective decision-making units increased from 11 to 13 cities. From the distribution area, Shanghai has always been in the state of effective decision-making units. The distribution of the number of effective decision-making units was Anhui = Zhejiang > Jiangsu in 2003, and Anhui > Zhejiang > Jiangsu in 2017. Strong environmental regulations, a high degree of advanced industrial structure, rich ecotourism resources, restricted development areas, small emissions of environmental pollutants accompanying economic output, and high green land use efficiency.

(2) In terms of the dynamic evolution characteristics of the global time series, the green land use efficiency of the urban agglomerations in the Yangtze River Delta experienced an evolutionary characteristic of rising-declining during the study period, and the urban efficiency gap showed an expanding trend. Urban efficiency has evolved from a two-level differentiation pattern to a single polarization. In terms of the dynamic evolution characteristics of the local time series, the nuclear density curves of the three provinces have their own shapes and change trajectories in position, kurtosis, peak number and tailing during the study period. The green use efficiency of urban land varies in different regions and between different periods. The time series dynamic evolution process is a result of the superposition and symbiosis of regional characteristics and period characteristics.

(3) In terms of the evolution characteristics of the global spatial pattern, there is a significant positive global spatial autocorrelation in the urban land use efficiency of the Yangtze River Delta urban agglomeration during the study period, but this spatial correlation as a whole shows a strong correlation to a weak correlation Evolution. In terms of the evolution characteristics of the local spatial pattern, in terms of quantity distribution, HH and LL are the main ones, and LH and HL are the supplementary ones. In terms of geographical distribution, HH and LL are contiguously distributed, LH and HL are scattered; HH is adjacent to LH, and LL is adjacent to HL. With the existence of spatial proximity spillover effects, the policies and measures adopted by cities in land resource management, environmental regulation intensity, economic development, and strategic behaviors have mutual imitating, learning and competitive effects, forming the green use of urban land in the Yangtze River Delta urban agglomeration The spatial pattern of "cities divided into groups" in efficiency.

5.2 Discussion

First, land is the carrier of Sansheng (production-life-ecology) space, and it is necessary to adhere to the concept of "green water and green mountains are golden mountains and silver mountains" to guide the social and economic development of urban agglomerations in the Yangtze River Delta and the development and utilization of urban land. Under the framework of the top-level design, we will promote the land and space planning of the Yangtze River Delta City Group, and consolidate the ecological achievements of the "National Major Function Zoning" in the Yangtze River Delta City Group. Second, deepen the structural reforms on the land supply side, make good use of the regional spatial location advantages of the Yangtze River Delta urban agglomeration, and consider the differences in land resource carrying capacity and economic development stages and differences between provinces and cities. Compensation for ecological transfer in key areas of ecological protection. Third, with the help of spatial proximity spillover effects, build consensus, strengthen inter-governmental cooperation and exchanges between cities, build an ecological and environmental community, and jointly promote the integration of urban land use and high-quality economic development.

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Research on the Change of Land Use Agglomeration Based on Kernel Density Estimation and Hot Spot Analysis

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Abstract The spatial agglomeration of land use is one of the most significant characteristics of the urban regional spatial pattern. It is of great significance to analyze the agglomeration changes to the guidance and management of land resources and the intensive and economical use of land in cities. This paper uses the current land use data of Baoshan District in Shanghai during the second and third national land survey to conduct kernel density estimation and hot spot analysis, and to explore the spatial agglomeration changes of various types of land use through comparison methods. The conclusions of the study show that during the period from the second national land survey to the third national land survey, Baoshan District has a large stock of construction land, commercial land agglomerates in a small area, and traffic land increases. According to the characteristics of different land use, relevant policy recommendations are put forward.

Keywords The third national land survey · Kernel density estimation · Hot spot analysis · GIS

1 Introduction

The rapid economic and social development of our country, with the rapid population growth, improper use and transformation of land resources by mankind, can easily cause environmental pollution, ecological damage and other problems, leading to very tense human-land relationship. At present, the process of urbanization in my country is accelerating, and the agglomeration effect of land use has caused changes in the distribution of population and industries, which have a profound impact on the healthy development of the regional economy.

In the context of tight resource and environmental constraints [1], in order to improve the intensive use of land in Shanghai, optimize the allocation of land resources, rationalize regional planning, and promote urban–rural integration, it is

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necessary to analyze changes in the spatial concentration of land survey results It also has important guiding significance for the future optimization of land use structure and industrial structure.

Spatial agglomeration of land use is a phenomenon involving population, industry, land, etc., and has received extensive attention and research from scholars at home and abroad. Western scholars believe that the spatial concentration of economic activities promotes the formation of economic effects through external economies of scale such as shared infrastructure [2]. Domestic scholars believe that the spatial agglomeration trend in the process of urbanization in China is the basic requirement of agricultural modernization [3], and exploring the coordinated relationship between land intensive use and economic development in different regions plays an important role in coordinating the relationship between land and economic development [4], the coexistence of the extension of land use and the extensive use of stock land has made land increasingly a bottleneck for economic growth [5]. Therefore, efficient and intensive land use is a necessary prerequisite for sustainable urban development [6].

Spatial agglomeration of land use refers to the phenomenon that certain types of land are relatively close and distributed in space. It is often manifested as the economic effect produced by the spatial aggregation of various industries and economic activities, and therefore attracts economic activities to a certain area. The centripetal force of proximity is the basic factor leading to the formation and continuous expansion of cities. For example, many cities are now actively constructing high-tech industrial development zones, industrial parks, and free trade zones. By delineating the boundaries of urban development and scientifically planning the spatial agglomeration of different land use types, it has important and far-reaching significance for the healthy and sustainable development of urban economy and ecology.

This paper compares the land use in the second national land survey (referred to as the "SNLS") and the third national land survey (referred to as the "TNLS") in Baoshan District, Shanghai, focusing on the study of the spatial agglomeration of construction land, commercial land and traffic land. Finally, summarize and put forward relevant policy recommendations.

2 Data Sources and Research Methods

2.1 Overview of the Study Area and Data Sources

Located in the north of Shanghai, Baoshan District is the intersection of the Huangpu River and the Yangtze River, and is the landform of the floodplain of the Yangtze River Delta. Divided into two parts: land and islands, it can be called the "waterway gateway" of Shanghai. The whole territory is about 56.15 km long from East to West, 23.08 km wide from North to South, and the area is about 365.33 square kms.

The natural conditions and geographical location in the jurisdiction are very good, providing a strong natural foundation for land development and utilization.

In order to respond to the national land survey of Shanghai's industrial structure and accelerate the coordinated and sustainable development of the region, Baoshan Iron and Steel and Baoshan Urban Industrial Park have continuously adapted to the requirements of the new era since they were built, and actively developed to inject vitality into Shanghai's urban construction. In recent years, Baoshan District's economy has grown steadily and with high quality, the industrial structure has been gradually adjusted, the people's livelihood has continued to improve, and the sense of happiness in life has increased. The economy, society and ecology of the whole region maintain a steady and progressive development trend.

The second national land survey was launched on July 1, 2007, and the result data was aggregated and unified on October 31, 2009. The third national land survey has been carried out since 2017. With December 31, 2019 as the standard time point, the third national land survey will be completed in 2020. On the basis of the results of the secondary survey, and based on the orthophoto map, field survey the land type, area and ownership of the land, and establish an interconnected and shared land survey database integrating image, land type, scope, area and ownership. The third national land survey has wider content, higher precision and deeper evaluation than the second national land survey.

2.2 Research Methods

(1) Kernel density estimation

Density is a field expression of spatial phenomena, and the local aggregation strength is determined according to the spatial relationship between each position and its neighboring element values [7]. The calculation method of kernel density is based on the first law of geography. Geographical things are related in spatial distribution, but the closer things are related, the closer the position to the core element, the greater the density value [8]. Kernel density analysis is used to calculate the unit density of element measurement values (usually points and lines) in the neighborhood. It calculates and analyzes the spatial distribution density of geographic elements based on the kernel density function, and can intuitively reflect the discrete measurement values. The distribution in a continuous area has a wide range of applications in many fields such as geography, social economics, criminology, and epidemiology [7, 8].

(2) Hot spot analysis

Hot spot analysis (Getis-Ord Gi*) statistics measure whether there is a local spatial correlation between each element and the domain [9], and calculate Getis-Ord Gi* statistics for each element in the data set to discover The degree of agglomeration of data features in the local spatial pattern is compared with the sum of all the elements by calculating the local sum of a certain element and its neighboring elements within a given distance [10].

The local statistics of Getis-Ord can be expressed as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{\sqrt{\left[\sum_{j=1}^{n} x_j^2\right]/n - \left(\overline{X}\right)^2}\sqrt{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]/(n-1)}}$$

where x_j is the attribute value of element j, $w_{i,j}$ are the spatial weights between elements i and j, n is the total number of elements, and

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

where G_i represents a statistical function, and X is the mean value of sample features.

ArcGIS visually displays the spatial G_i statistical results, and the G_i function value returned by each element is the z score. For statistically significant positive z-scores, the higher the z-score, it means that high-value clusters (shown in red spots) that present a spatially clustered distribution and higher feature values are more closely clustered; for statistically significant negative z-scores, the lower the z-scores, that is, the denser the low-value clusters (shown in blue spots) that are spatially clustered and have lower feature values.

3 Result Analysis

3.1 Spatial Agglomeration of Construction Land

The construction land increased by 664.07 hectares during the second national land survey to the third national land survey. During the second national land survey, the Youyilu Street and Wusong Street in the east and Dachang Town and Miaohang Town in the south were high-density construction areas. Yanghang Town and Yuepu Town are medium-density construction areas. Luodian Town and Gucun Town in the west and Luojing Town in the north are low-density construction areas. In the third national land survey, the distribution of land density is basically consistent with the second national land survey (Figs. 1 and 2).

During the second national land survey, large red spots were concentrated in Youyilu Street, Yanghang Town, Wusong Street, Songnan Town and other places, indicating that the construction land is highly concentrated in the east of Baoshan District. In the west, northwest, and southwest of the jurisdiction, there are contiguous blue spots, which are small, fragmented but relatively concentrated plots. In the third national land survey, the red pattern extends to Miaohang Town, Dachang Town, and Yanghang Town, adding a lot of large and concentrated construction land. The

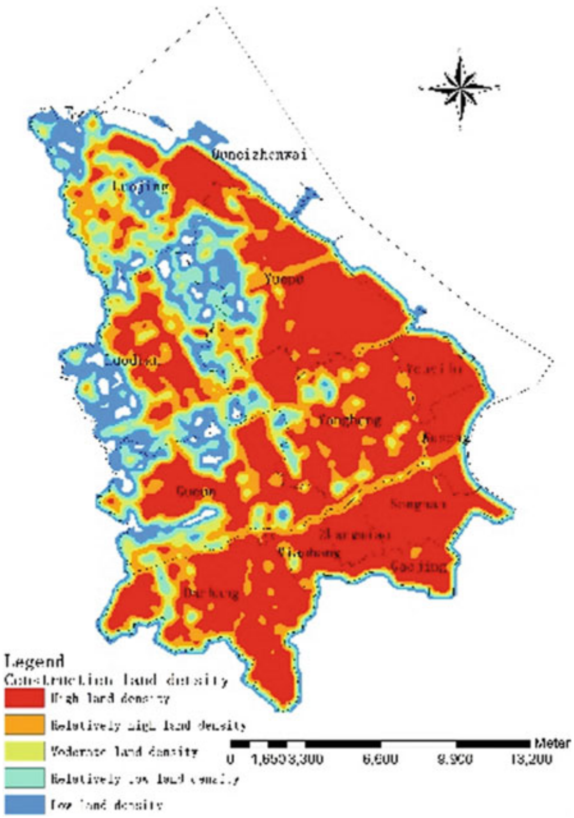


Fig. 1 Construction land kernel density map in SNLS

blue spots are greatly reduced, indicating that the discrete construction land has been reduced (Figs. 3 and 4).

3.2 *Spatial Agglomeration of Commercial Areas*

During the second national land survey and third national land survey, the commercial area increased by 2410.68 hectares. During the second national land survey, there were high-density construction areas in Luojing Town, Gucun Town, and Yanghang Town, and blue low-density construction areas were scattered throughout the district. In Fig. 6, the overall red high-density construction area increases during the third national land survey. The blue low-density construction area in the whole district has greatly increased, and the commercial areas in each town have increased (Fig. 5).

As shown in Fig. 7, when the sporadic red spots are adjusted in two national land surveys, Baoshan District has very limited commercial land. In Fig. 8, the number of red spots increases, roughly distributed in Luojing Town, Yanghang Town, Wusong

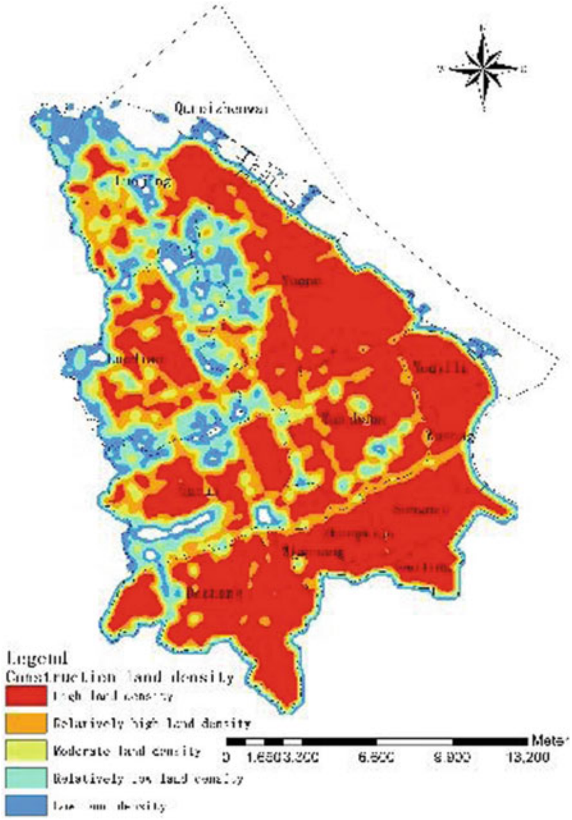


Fig. 2 Construction land kernel density map in TNLS

Street, and Dachang Town. The blue spots (small and scattered agglomeration land) have increased and are distributed in Yuepu Town and Luojing Town. On the whole, the amount of commercial land has increased greatly during the three national land surveys.

3.3 Spatial Agglomeration of Traffic Land

During the second and third national land surveys, the traffic area increased by 353.31 hectares. During the second national land survey, the traffic land was like a dense network connecting the entire Baoshan District, extending coverage and extending in all directions. A small number of high-density traffic construction areas are scattered throughout the district and are the location of traffic distribution points. The traffic area in the jurisdiction is mostly low-density construction. During the third national land survey, based on the survey results of the second national land survey, the construction density of traffic land was increased overall (Figs. 9 and 10).

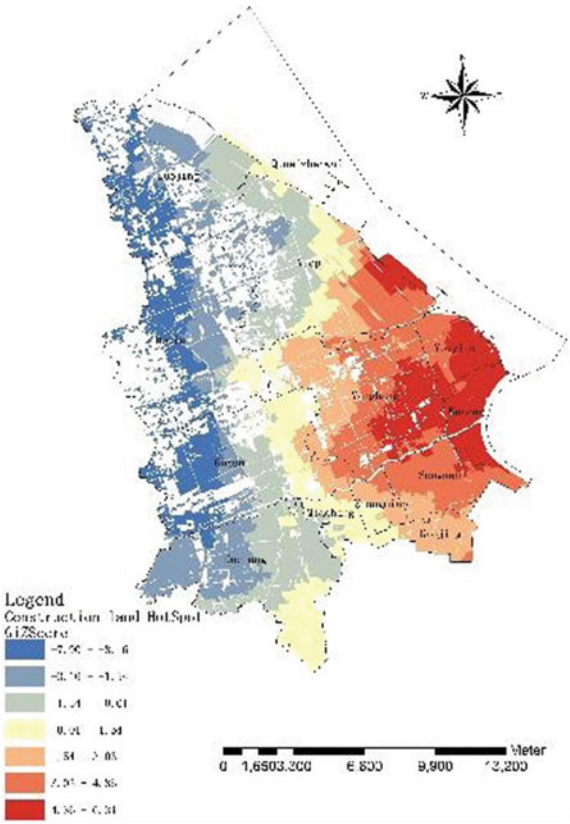


Fig. 3 Construction land hot spot map in SNLS

During the second national land survey, only a few red patterns were distributed in Yuepu Town, Youyilu Street, Songnan Town, and Wusong Street, indicating that there is not much land for traffic agglomeration in the whole area (Fig. 11). There are almost no yellow spots, which is related to the connectivity of the traffic land. Blue spots are evenly distributed throughout the area. In Fig. 12, during the third national land survey, the red spots in the eastern part of the jurisdiction increase, and the degree of intensive utilization becomes higher. There are fewer blue spots in the western part of the jurisdiction, indicating that low-value clusters have been reduced, and a large number of scattered and concentrated traffic land has been demolished or converted to other uses.

4 Research Conclusions

Through the spatial agglomeration analysis of construction land, commercial land and traffic land, the following conclusions are drawn:

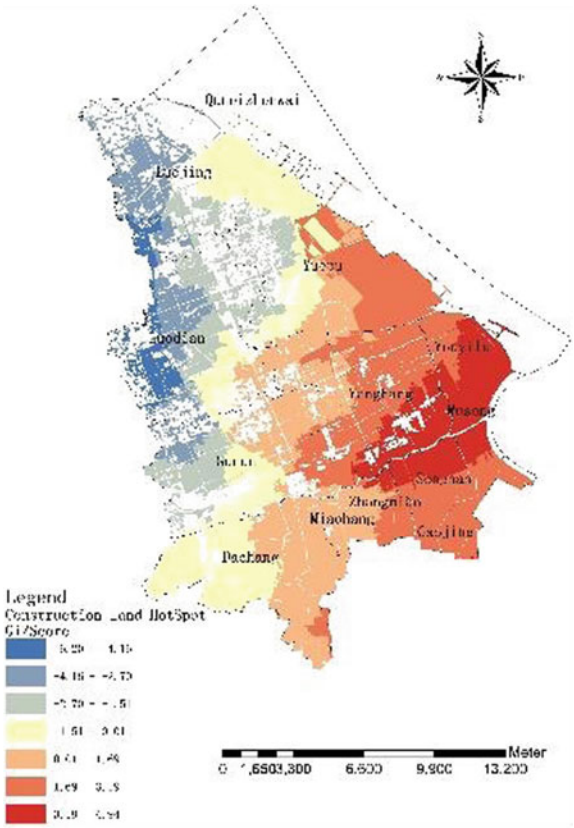


Fig. 4 Construction land hot spot map in TNLS

(1) The total amount of construction land has expanded and the stock is larger. The layout of construction land in the whole district is decentralized, and the development of different towns (streets) has obvious spatial and geographical differences, showing a trend of "strong south and weak north". The government should save and intensively use land, control the scale of construction land, and improve land use efficiency.
(2) Most commercial areas are concentrated in a small area, which is likely to cause traffic congestion and population agglomeration. In general, Baoshan District has "a small number of clusters, but a large number of sparse" commercial areas. The government should increase the development of commercial and service industries in residential areas in order to fully serve more residents.
(3) The distribution of traffic land in the whole district becomes denser. However, the density of roads in the suburbs is slightly lower. The government should improve the traffic road network and rail transit, and realize the joint development of ground and underground.

Fig. 5 Commercial land kernel density map in SNLS

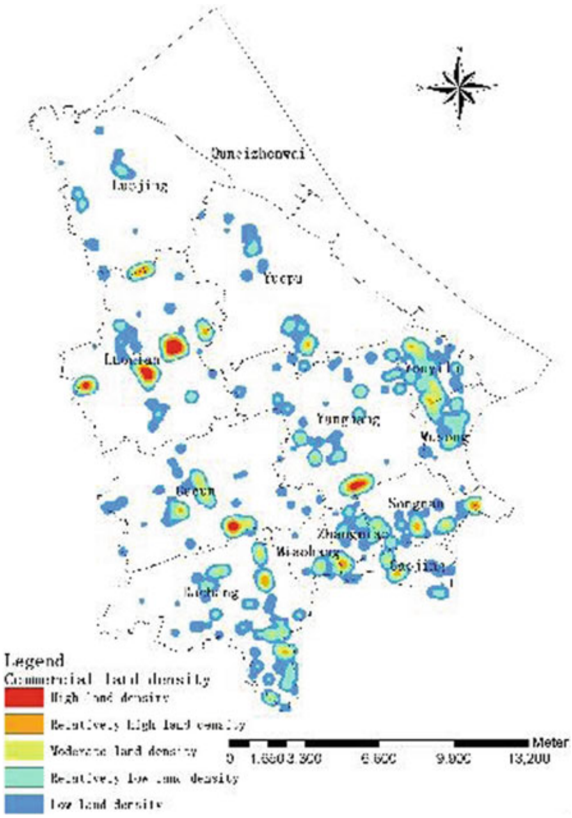


Fig. 6 Commercial land kernel density map in TNLS

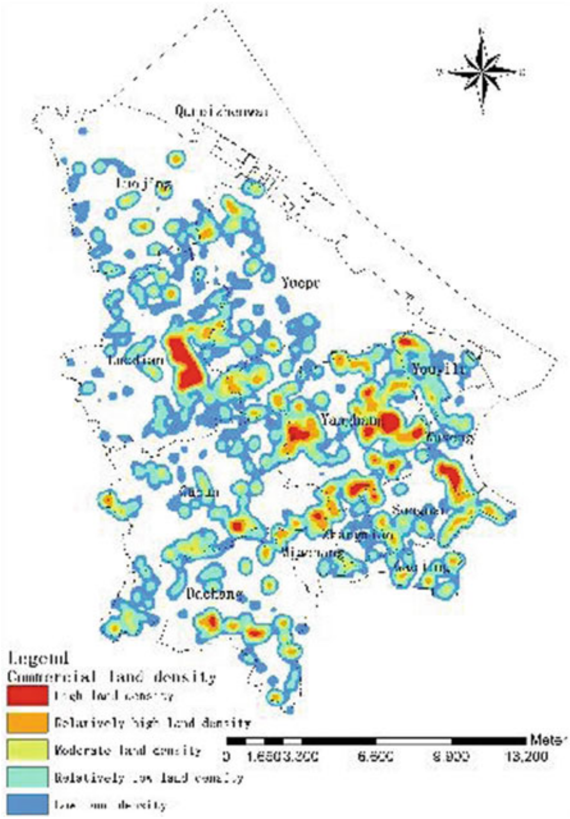


Fig. 7 Commercial land hot spot map in SNLS

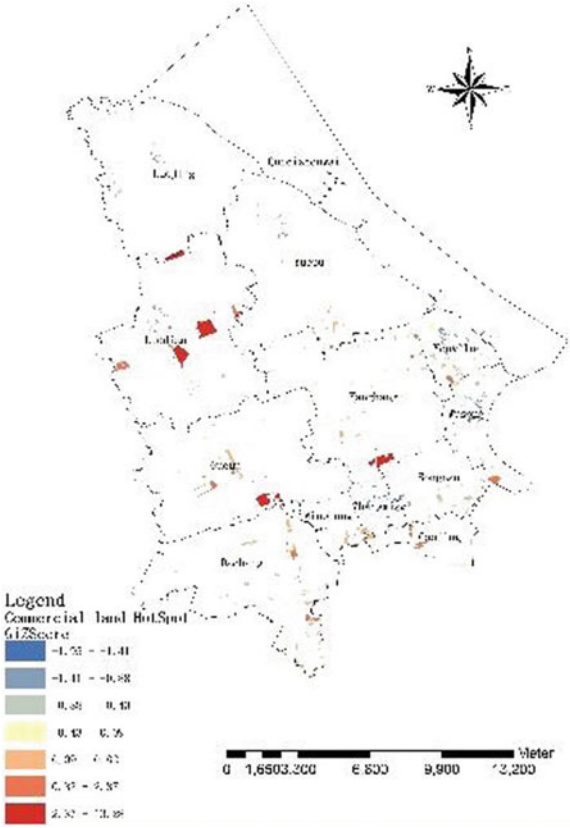
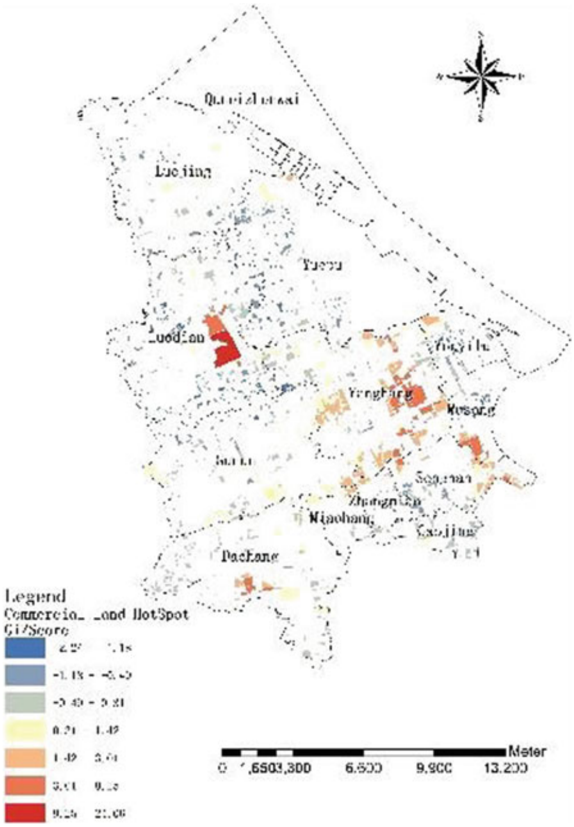


Fig. 8 Commercial land hot spot map in TNLS



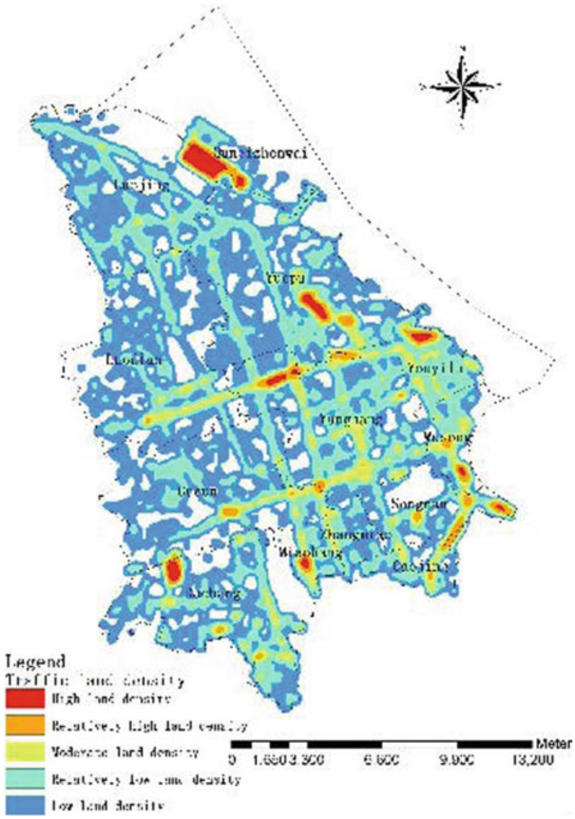


Fig. 9 Traffic land kernel density map in SNLS

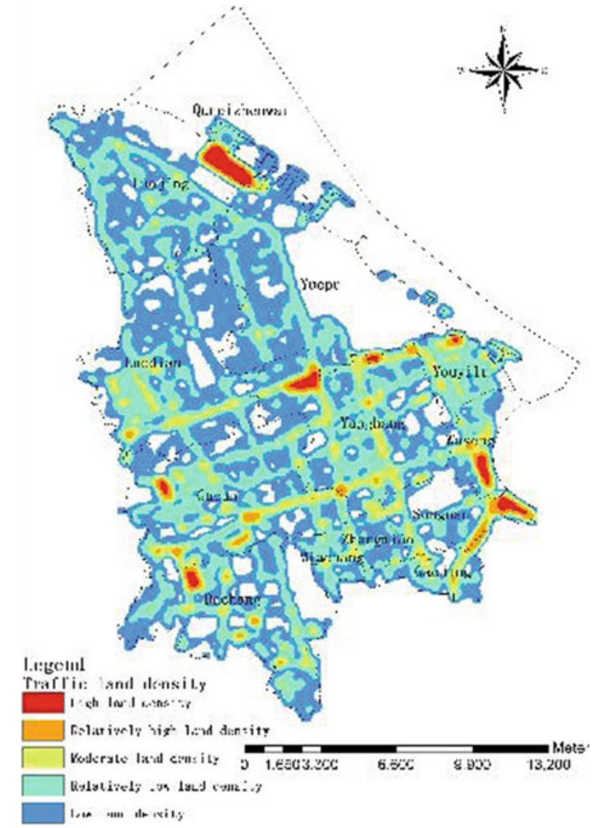
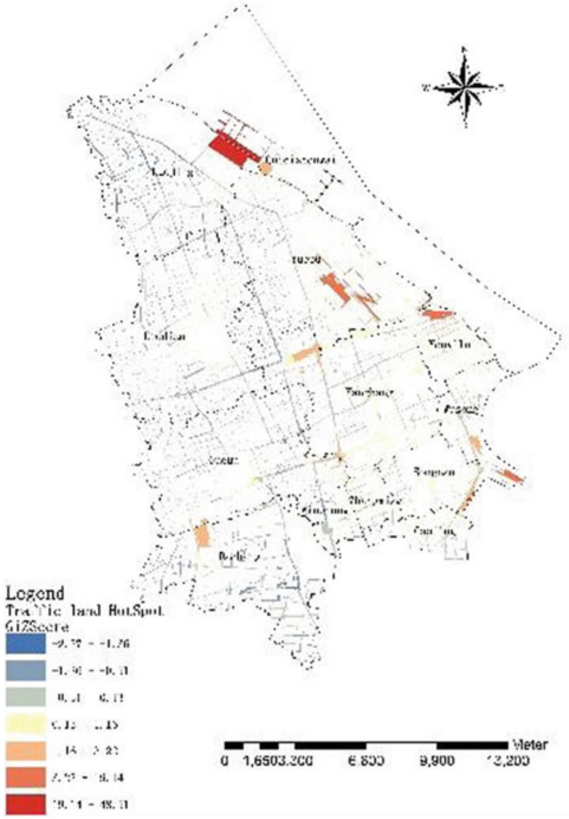


Fig. 10 Traffic land kernel density map in TNLS

Fig. 11 Traffic land hot spot map in SNLS



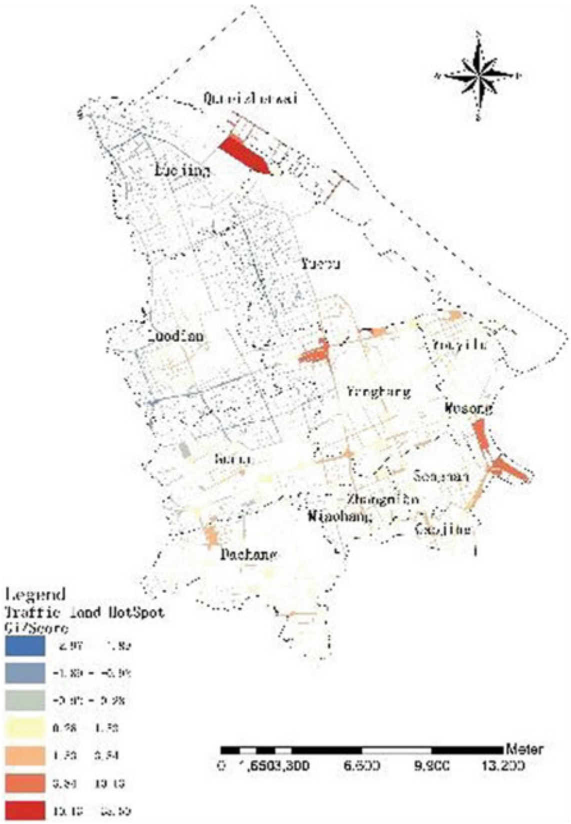


Fig. 12 Traffic land hot spot map in TNLS

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Analysis of the Impact of Commercial Facilities on Residential Housing Prices—A Case Study of Nanjing

Qi Xuan and Guang Yang

Abstract The surrounding commercial supporting factors have consistently been one of the important factors in judging the value of real estate. However, the judgment of commercial supporting factors is not so easy to judge as factors such as rail transit, hospitals, parks. To reflect commercial supporting factors, this article considers Starbucks, which has opened stores in commercial complexes, shopping centers and other high-level commercial service locations, and uses GIS to analyze second-hand housing prices in Nanjing. The results show that the developed commercial supporting areas with Starbucks stores within 1 km of the Nanjing community have a certain effect on the second-hand housing prices of the community, and the second-hand housing prices of the community are also affected by the community's own factors and other location factors.

Keywords Real estate value · Location value · Commercial facilities · Ordinary least squares

1 Research Background and Literature Review

In related research in the real estate field, location value has always been an important factor in judging the value of real estate. Studying the factors that affect the value of real estate has certain reference value for government departments to make plans, real estate developers to invest in land, or common people to buy houses [1].

Location value is mainly affected by factors such as traffic, school district, commerce, and park where the land is located [2]. Many scholars have carried out relevant research on various location factors. Among them, a large number of scholars regarded rail transit stations as the influencing factors to be considered and different cities as research areas, and found that the value-added effect of real estate along the subway line is obvious [3–6]. Wang and Huang [7] studied the impact of the external environment on housing prices and found that the total price of houses with a view

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of the Huangpu River would be 33.6% higher than other houses. Zhong et al. [8] studied the price of houses around Nanhu Lake in Wuhan and found that the landscape does have a positive impact on the value of houses. Chen [9] quantitatively analyzed the impact of major solid waste disposal facilities in Shanghai on the price of surrounding houses. Other scholars also conduct special research on factors such as parks and medical treatment [10, 11]. Commercial facilities, school and other factors are often considered but not the focus of these studies.

In first-tier cities and new first-tier cities, there will be certain commercial facilities around residences, but it is sometimes difficult to define the level of commercial service surrounding residences. In this article, we introduce whether there are Starbucks in the surrounding area as an influencing factor. The location of Starbucks is often located in areas with high levels of business services such as commercial complexes, shopping centers, commercial office buildings, and supporting businesses [12], which can reflect the location factor of the degree of commercial support from the side.

In this article, taking Nanjing, the capital city of Jiangsu Province, as the research object, using ArcGIS spatial analysis and spatial statistical tools, study the impact of high-level commercial service areas surrounding Starbucks on the second-hand housing prices of the residence.

2 Research Area and Data

Nanjing is referred to as “Ning” and is the capital of Jiangsu Province. The city has 11 districts with a total area of 6587 square kilometers and a built-up area of 817 square kilometers. Among them, the study area in this paper is the eight districts of Xuanwu, Gulou, Qinhuai, Jianye, Jiangning, Yuhuatai, Pukou, and Qixia. The three outskirts of Liuhe, Lishui, and Gaochun where purchases are not restricted, are not considered.

Nanjing has a suitable economic environment and well-developed commerce. It has the Xinjiekou known as the “China’s No. 1 Business District”. There are 134 Starbucks stores in Nanjing, and the main distribution is consistent with the research area.

The Nanjing real estate market performed well. This experiment crawled the location of the residential area and related second-hand housing prices, construction years and property levels, from the Lianjia and Anjuke websites, and eliminated the confusing serviced apartments and villa communities. Finally, we selected 1454 apartment communities as the experimental data. There are two principal reasons for choosing second-hand housing information. First, the price of new houses in Nanjing is limited, and the price of second-hand houses can better reflect the real situation of the market. Second, the number of new houses in some mature areas is small or even no new houses are sold, so the data is not universal.

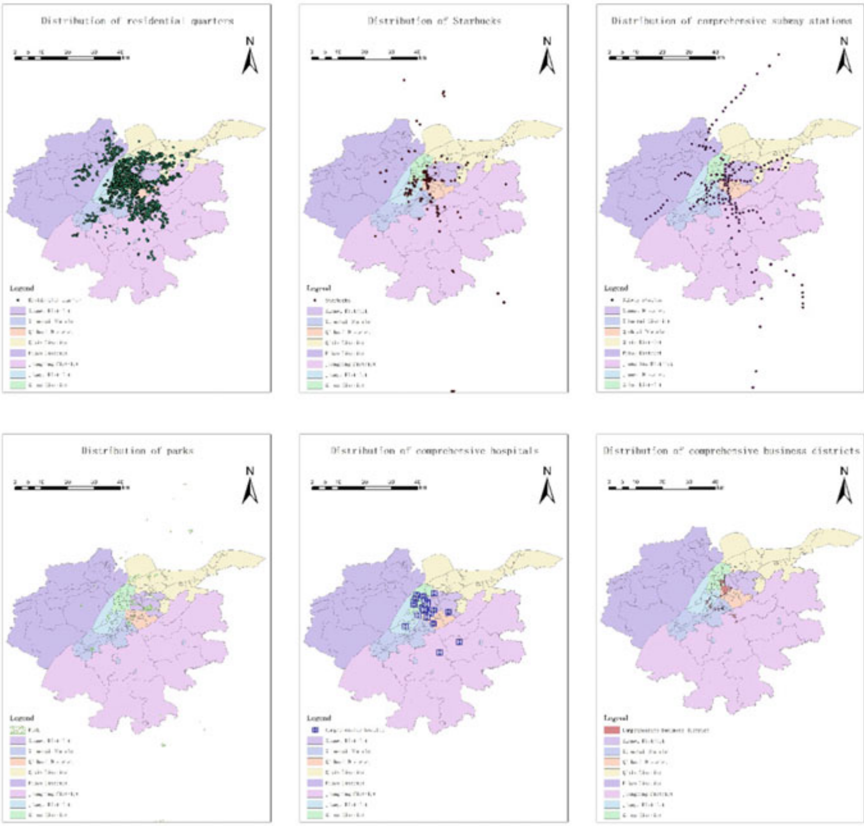

Fig. 1 Research objects and various impact factors

In addition, location data of Nanjing subway stations, office buildings, parks and green space data, and class 3A comprehensive hospital data were obtained as other influencing factors (Fig. 1).

3 Research Methods

3.1 Spatial Autocorrelation

The purpose of spatial autocorrelation analysis is to establish whether a variable is spatially related, and how closely related it is. The spatial autocorrelation coefficient is calculated to quantitatively describe the dependence of things in space, of which Moran's I is the most frequently used. The formula for calculating Moran's I Index is as follows:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} * \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})*(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (1)$$

where: x_i and x_j are the observed values of the average price x of each residential sample point on i and j, respectively, $\bar{x}$ is the average price of n residential sample points, w_{ij} is the spatial weight matrix, and n is the number of residential samples. Moran's I index ranges from −1 to 1. When $I > 0$, the spatial entity presents a positive autocorrelation; when $I < 0$, it presents a negative autocorrelation; when $I = 0$, there is no correlation and a random distribution [13].

3.2 Ordinary Least Squares (OLS)

In statistics, regression analysis refers to a statistical analysis method to determine the quantitative relationship between two or more variables. After determining the spatial autocorrelation, regression analysis can be conducted on the housing price of second-hand houses and possible influencing factors such as whether there are Starbucks stores in the surrounding area. The most frequently used method is ordinary least squares (OLS), which minimizes the sum of squared distances from all observations to the regression line. Through ordinary least squares regression analysis, the linear mathematical model that may exist between the housing price of the second-hand house in the community and the various influencing factors can be obtained:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (2)$$

The estimation model obtained by the ordinary least squares method has the characteristics of linearity, unbiasedness, and minimum variance. In addition, the method is simple, and the operability is strong.

4 Data Preprocessing and Quantification of Impact Factors

4.1 Experimental Data Preprocessing

In Internet maps, map coordinates in China have a reliable encryption mechanism. Therefore, the location information obtained by the web crawler is not the WGS84 geodetic coordinate system that can be directly used in ArcGIS software, but the GCJ02 or BD09 coordinate system. GCJ02, otherwise known as the Mars coordinate system, is the coordinate system of the geographic information system formulated by the National Bureau of Surveying and Mapping of China. It is just an encryption algorithm for latitude and longitude data. That is, adding random deviations. Various domestically published map systems (including electronic forms) must at least use

GCJ-02 to encrypt geographic locations for the first time. The GCJ02 coordinate system is currently used by Gaode Maps. Tencent Maps, Google Maps, etc. BD09 is the Baidu coordinate system, encrypted again on the basis of the GCJ02 coordinate system, and is currently used by Baidu Maps. In order to convert GCJ02 or BD09 coordinates into WGS84 coordinates, it is necessary to use the corresponding API interface to develop the corresponding correction plug-in, or use MapGIS and other software to correct the data. Import the corrected data into ArcGIS and convert the data to the projected coordinate system.

4.2 Quantification of Impact Factors

In order to use the OLS tool in ArcGIS to obtain a linear valuation model, it is necessary to quantify the impact factor. Refer to previous literature and combine the acquired data and pre-experiment results, and finally determine the impact factor indicators and corresponding quantitative standards, as shown in the Table 1.

Add the above quantitative results as a field to the attribute table of the shp of residential area for ArcGIS regression analysis.

5 Experimental Results

5.1 Spatial Autocorrelation Analysis

Using the spatial autocorrelation (Moran I) in ArcGIS, Moran's I can be obtained for the prices of second-hand houses. The results are as follows (Table 2).

The larger Moran's I is, it means that the data present a strong positive spatial correlation. P-value and Z-value can reflect the confidence of the calculation result. The smaller the P-value and the larger the Z-value, the higher the confidence. In this study, Moran's I = 0.846796 and $P < 0.001$, which can indicate that there is more than 99.9% probabilities, and the second-hand housing prices show a strong positive spatial correlation.

Although the experimental results show that the housing prices of second-hand houses in Nanjing community show a strong positive spatial correlation. In fact, housing prices are influenced by other factors such as the construction time of the community and the level of property in addition to the geographical location. Therefore, it is necessary to perform a regression analysis on various influencing factors, and obtain a linear estimation model of the influence of each influencing factor on housing prices.

Table 1 Quantification of impact factors

Variable name	Variable explanation	Quantification method
Price	Average price	Original value of average price
School	Elementary school district level	According to the level of the school district, the score is 5 points for the best schools in the city, 3 points for the key primary schools in the city, 2 points for the key primary schools in the district, and 1 point for others
Service	Property level	Quantitatively score the property level based on the level of property fees. If the property fee is 2 yuan or more, 5 points. The score drops by 1 point for every 0.5 yuan less. 0 points for no property
Year	Building age	Score based on the completion time. 5 points are awarded for a residence within 5 years of completion. The score decreases by 1 point for every 5-year interval increase. All residences over 20 years old are awarded 1 point
Ln_xjk	Distance to downtown (Xinjiekou)	Take the natural logarithm of the distance from Xinjiekou as the score
PK	Whether a park within 1 km	If there is a park within 1 km, we use 1 to represent this fact; otherwise, we use 0
S1500	Whether a subway station within 1.5 km	If there is a subway station within 1.5 km, we use 1 to represent this fact; otherwise, we use 0
WP	Whether an office building within 3 km	If there is an office building within 3 km, we use 1 to represent this fact; otherwise, we use 0
Ln_yt	Distance to new downtown (Nanjing Hexi New Town)	Take the natural logarithm of the distance from Yuantong subway station as the score
SB	Whether a StarBucks within 1 km	If there is a StarBucks within 1 km, we use 1 to represent this fact; otherwise, we use 0
Ln_hos	Distance to the nearest top hospital	The natural logarithmic score of the distance to the nearest top three hospitals

Table 2 Moran's I results

Test methods	Moran's I	P-value	Z-value
Random test	0.846796	<0.001	13.294047

Table 3 OLS results

R-squared	0.690467	F-value	($p < 0.05$)	Jarque–Bera	($p < 0.05$)
Price	Average price	Coefficient	Std	Probability	VIF
School	Elementary school district lex‘vel	26,011.97	1667.3	0.000000*	—
Service	Property level	5733.998	243.2056	0.000000*	1.133438
Year	Building age	3307.558	190.4339	0.000000*	1.572481
Ln_xjk	Distance to downtown (Xinjiekou)	1126.836	205.4293	0.000000*	1.86675
PK	Whether a park within 1 km	3226.073	582.3064	0.000000*	1.967656
S1500	Whether a subway station within 1.5 km	1753.763	493.1628	0.000634*	1.386321
WP	Whether an office building within 3 km	3528.371	453.4002	0.000000*	1.289804
Ln_yt	Distance to new downtown (Nanjing Hexi New Town)	−4432.48	439.2479	0.000000*	3.09062
SB	Whether a StarBucks within 1 km	−2189.6	305.107	0.000001*	2.631387
Ln_hos	Distance to the nearest top hospital	1256.062	462.8296	0.009504*	1.357477
price	Average price	−2392.59	411.1789	0.000000*	1.683806

* The asterisk indicates that Jarque-Bera passed the inspection

5.2 Regression Analysis

After the spatial autocorrelation is calculated, the second-hand housing price is used as the dependent variable, and other influencing factors are used as independent variables. We used OLS in ArcGIS to analyze and obtain the following results in Table 3.

R-squared is the degree of fit, which indicates the degree of agreement between the sample data and the model. As a model that is not known or has been proven to be flawless, R-squared of 0.690467 is a good result, which can be used as a reference basis to a certain extent. F-value and Jarque–Bera reflect the confidence of the model. Both are above 95%, indicating that the obtained model has a high degree of confidence. Probability is less than 0.05, which means that the confidence of the results obtained by each impact factor is greater than 95%. VIF is less than 7.5, which means that there is no multicollinearity in each impact factor. The influencing factors are highly reliable and independent of each other. In summary, it can be concluded that this experiment is a relatively dependable linear model.

By comparing the coefficients of the linear model, we can find the influence of different influencing factors on the second-hand housing price. Second-hand house price of a community with a Starbucks within 1 km is 1256 yuan per square meter higher than that without Starbucks, but the impact is not large compared with other factors. The most influential is the school district where the community is located, especially the top schools such as Lhasa Road Primary School, Lixue Primary School, Langya Road Primary School, Youfu West Street Primary School, Fangcaoyuan Primary School and Beijing East Road Primary School. The improvement can reach more than 20,000 yuan per square meter. Nanjing Hexi New Town has developed into Nanjing's most important urban sub-center, and it has jointly affected housing prices with Xinjiekou, the traditional center of the city. Nevertheless, the impact is still less than Xinjiekou. In addition to location factors, the property level and construction period of the community are also relatively obvious to the second-hand housing price. Especially the property level, different grades affect the price of 3308 yuan per square meter. However, this experiment did not specifically study the greening rate, the ratio of parking spaces, developers, etc. The property level is actually a common reflection of these factors. Other location factors also have their unique influence on the housing prices.

In addition to get a linear model, the distribution of residuals is also worth studying. The spatial autocorrelation analysis is performed on the residual results, and Moran's I is 0.618793. It can be seen that the residuals not randomly distribute. Combining Fig. 2 can find some poor fits and analyze the reasons. The whole Nanjing Hexi New Town area is red, that is, the actual price is slightly higher than the model fitted price. It reflects that the Nanjing Hexi New Town area is still the most popular and high-priced area in the Nanjing real estate market. The old residence between Nanjing Hexi New Town and Nanjing's old city wall, the old residence near Xishan Brigde and Tiexin Brigde, and the residence in Pukou District but not in Jiangbei core area are generally blue, that is, the actual price is lower than the model fitted price. In fact, there is likewise a low-priced area. In general, these issues are consistent with Nanjing's contemporary urban planning plan and existing old reform issues.

6 Conclusion

This article mainly takes Nanjing as an example, combined with the community conditions and other location factors. Using Starbucks to determine the developed area for commercial facilities, focus on the impact of commercial facilities on housing prices. The linear model obtained shows that the existence of Starbucks within 1 km of the neighborhood can increase the housing price by RMB 1256 per square meter. This price increase may seem insignificant, but considering that the well-equipped commercial area may overlap with other factors considered in this study, such as comprehensive business districts, subway stations, etc. The housing prices of the community are influenced by multiple factors. After excluding other factors, it is reasonable to consider only the influence of commercial facilities.

In addition, this article considers other factors. Based on this, a conclusion is drawn together, which has certain reference significance for the research on the location of real estate in Nanjing. The results of the experiment are basically consistent with the current development trend, urban planning and real estate market in Nanjing.

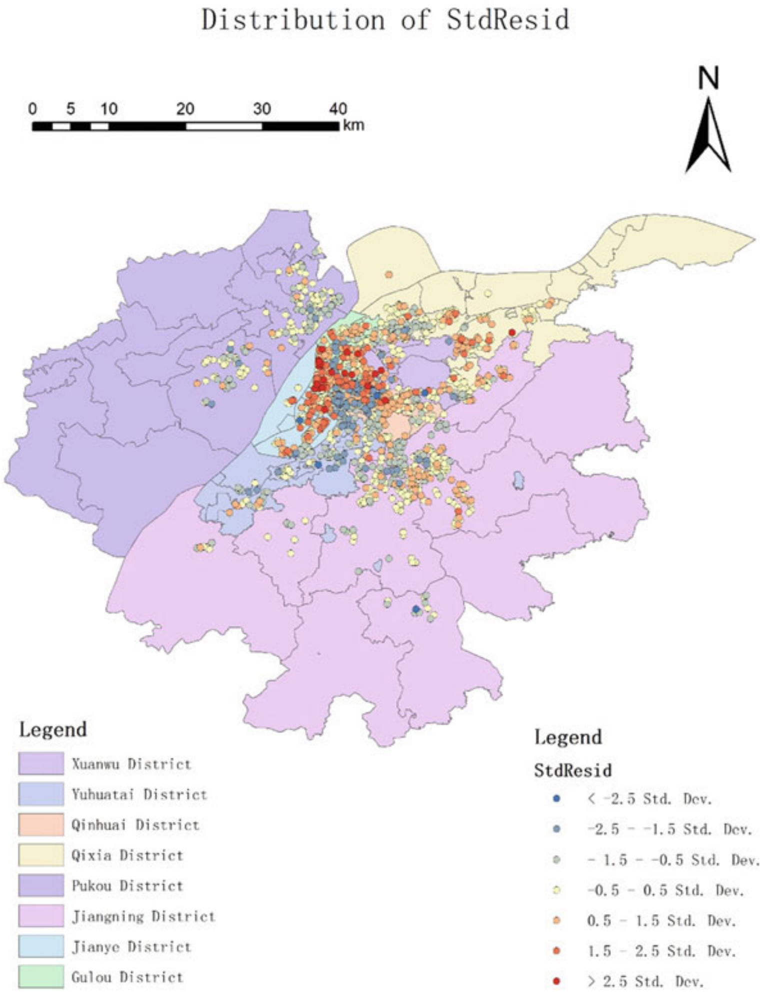

Fig. 2 Residual distribution of OLS results

The research method used throughout this paper is ordinary least squares, and the model obtained is a linear model. However, in this experiment, it can be found that the scattered residuals are not randomly distributed, and show positive spatial autocorrelation, indicating that there are still some problems in using the linear model fitting. In subsequent experiments, nonlinear models or geographic weighted regression can be used for analysis.

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The Industrial Linkages of the Real Estate Industry and Its Impact on the Economy Caused by the COVID-19 Pandemic

Xiaoli Shi, Qianju Cheng, and Menghan Xia

Abstract In Jan 2020, the COVID-19 pandemic appeared and the economies around the world have been affected to different degrees. The real estate industry is influencing the overall trend of the macro-economy due to its important industrial linkages with other sectors. This paper aims to analyze the recently published data of China's input–output table in 2017 to find out the quantitative relationship between the real estate industry and other industrial sectors through classic Leontief and Ghoshian methods and also uses the hypothetical extraction method to further examine the industrial importance of the real estate industry from the perspective of total output. Finally, according to relevant data of the real estate industry in the first quarter of 2020, this paper estimates the associated losses of economic output.

Keywords Input–output model · Real estate industry · Hypothetical extraction method · Industrial linkages · COVID-19 pandemic

1 Introduction

At the beginning of 2020, the COVID-19 pandemic appeared and by March 11, the WHO announced that the new corona-virus had become a global pandemic. The IMF believed that 'the global health pandemic has turned into an economic and financial crisis.' The numbers of confirmed cases of the new corona-virus from January to August 2020 are shown in Fig. 1. We can find that the COVID-19 pandemic in the first quarter of the year in China is the most serious.

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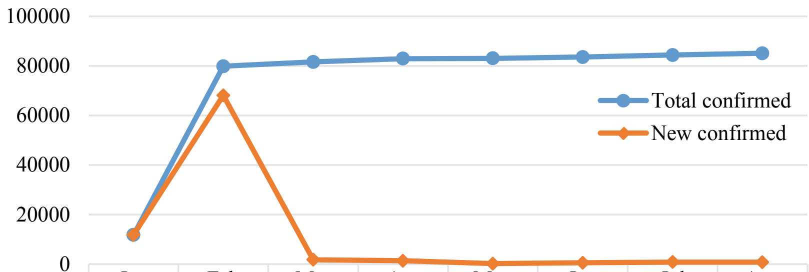

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Total confirmed	11791	79824	81554	82874	83017	83534	84337	85058
New confirmed	11791	68033	1730	1320	143	517	803	721

Fig. 1 New confirmed and total confirmed corona-virus cases of China's in January to August 2020. *Source* http://www.nhc.gov.cn/

The real estate industry has been an important component of the macro-economy in China for a long time, which has a relatively high share of GDP and involves many upstream and downstream industries. In the past ten years, the real estate industry has gotten a rapid development in China. It accounted for 5.43% of GDP in 2009, increasing to 7% in 2019. Even with negative economic growth in the first quarter of 2020, the real estate industry accounted for 7.39% of GDP [1]. Focusing on the real estate industry alone might not show its full economic contribution, since it was closely related to the development of other industries, such as the construction industry, financial industry, leasing and business services, and so forth. From the perspective of social investment, the investment in the real estate industry in a broad sense accounted for one-third of the fixed assets investment. According to the data provided by the People's Bank of China, the new real estate loans accounted for nearly one-half of the total new loans in China each year. At the same time, the industrial group with real estate as the core and related industries continuously provided a large number of jobs. Obviously, employment was closely related to the development of the real estate industry in China.

The sudden pandemic in 2020 has brought a greater impact to the China's real estate industry. Due to the important industrial linkages with other sectors, it will also have spillover impacts on many other industries, which will affect the stable operation of the macro economy. In this context, this paper analyzes the industrial linkages of real estate industry based on input–output model, and further estimates the total impact of real estate industry on the macroeconomic output in China, tracing the potentially negative impact caused by the COVID-19 pandemic.

This paper is organized as follows: the second section is the literature review. The third part of the paper calculates different technical coefficients, backward and forward linkage, while the fourth section applies the Hypothetical Extraction Method (HEM) to describe the important status of the real estate industry. The fifth section estimates the losses of the output under the new corona-virus pandemic. Finally, the paper offers some concluding remarks.

2 Literature Review

Given the strength of the backward and forward linkages characterizing the real estate sector, it would seem appropriate to evaluate the sector's total contribution to the economy by using input–output analysis. Input–output tables and associated models have been developed in China now for over 60 years. The most recent set of information is for 2017 issued by the National Bureau of Statistics of China and these data will be used in the analysis to be conducted in this paper.

Input–output models had been applied to assess aspects of the real estate industry in China in several papers, including Liu [2], Man et al. [3], Liu and Han [4], Sun et al. [5], and Yuan [6]. Liu [2] combined the 2002–2012 input–output tables to measure the impacts of real estate on its upstream and downstream industries, and further explained why the supply and demand of real estate industry had changed. Man et al. [3] established the input–output model of the real estate industry and other industries based on Beijing's 2000–2012 input–output table and quantitatively analyzed the demand-pulling effect and supply-promoting effect of the real estate industry on the other industries in Beijing. Liu and Han [4] used the input–output model based on the input–output tables of China from 2000 to 2010 and the United States in 2010 to compare the effect of real estate industry, and found that the degree of specialization and industry correlation of China's real estate industry was still relatively low. Sun et al. [5] constructed an input–output model to analyze the effect of the expansion of the real estate industry on China's industrial structure and found that the intermediate correlation of real estate industry were low. Yuan [6] used the 2012 input–output tables of Beijing, Shanghai and Guangzhou, and concluded that the real estate industry in those cities all had a wide range of connections, but a low correlation with other industries. They all made some calculations on the linkages between the real estate industry and other industries from a certain aspect. However, these researches on the industrial linkages of the real estate industry were more from the perspective of technical coefficients, and lack of research from the perspective of total output. Moreover, the data used in those papers need to be updated. In addition to using traditional technical coefficient calculations to illustrate the status of the real estate industry, we use the HEM to investigate the importance of the real estate industry, complementing the prior research in this field.

In the development process of each industry, it is inevitable to encounter major public security and crises, and these events may have different effects on the development of the industry. Since the outbreak of the COVID-19 pandemic, some scholars have studied the impact on the industrial sectors. Zeng [7] believed that the industry that had the greatest impact on domestic economic development from the pandemic was the traditional lifestyle service industry, such as catering industry, tourism and entertainment services, housekeeping services, and so on, followed by labor-intensive manufacturing and construction industries, especially those of small and medium size. Liu [8] believed that the negative impact of the pandemic on the producer service industry was greater than life service industry, and the impact on manufacturing industry might be greater than the service industry. Li [9] argued that how big the economic shock would be was related to the policy effectiveness of prevention and control, environmentally sensitive and consumer-intensive industries were most directly affected, such as catering, tourism, transportation, and commercial trade.

From the review of literature, we can learn that under the influence of the COVID-19 pandemic, there will be great uncertainties in the future directions of various industries, and real estate industry will inevitably be affected. Due to the close industrial linkages, it will affect other industrial sectors to the different extent. We try to calculate the industrial linkages of the real estate industry through traditional Leontief and Ghoshian methods, as well as the HEM, and further explore its impacts on the total output caused by the pandemic.

3 The Industrial Linkages of the Real Estate Industry

We use the 149-sector input–output table in 2017 issued by the National Bureau of Statistics of China in this paper, and then aggregate it into 42-sector according to the industry classification standard GB/T 4754–2017. We use the traditional Leontief and Ghoshian methods to calculate the technical coefficients to analyze the input–output structure of the real estate industry and its industrial links with other sectors to find out how important the real estate is in the national economy.

3.1 Technical Coefficients

The main function of the Leontief input–output table is to figure out the technical links between industries of a national economy, and the basic model is:

$$AX + F = X \quad or \quad X = (I - A)^{-1} \times F \tag{1}$$

where A is the direct input coefficient (DIC) matrix, it records the share of regionally supplied inputs per Chinese Yuan of regionally produced output. Let the n gross outputs be arranged in an n-element column vector X, so X is the vector of total output, F is an n-element column vector of final demand, I is the identity matrix. Assume a_{ij} is the element of A, which is the value of input of sector i used in making per unit worth of output of sector j, which can be expressed as:

$$DIC: \quad a_{ij} = \frac{x_{ij}}{X_j} \quad (i, j = 1, 2, \cdots, n) \tag{2}$$

where x_{ij} is the amount of output in sector i used as input in sector j, X_j is the total input of sector j. The Leontief Inverse capture the direct and indirect effect of each sector, and total input coefficient (TIC) matrix is the Leontief inverse matrix minus identity matrix, which presents the sum of direct input and indirect input coefficient matrix, then it can be expressed as follows:

$$TIC: \quad B = (I - A)^{-1} - I \quad or \quad B = \bar{B} - I \quad or \quad B = A + A^2 + A^3 + \cdots + A^{\infty} \tag{3}$$

This perspective is a demand-led version of the operation of the economy. A supply-led version, known as the Ghosh input–output model [10, 11] can be presented as follows:

$$X'G + V = X' \quad or \quad X' = V \times (I - G)^{-1} \tag{4}$$

where G is the direct output coefficient (DOC) matrix, which is in contrast to the direct input coefficients A. X' is the vector of total input, V is the vector of value added, I is the identity matrix. Assume g_{ij} is the element of G, which is the proportion of the product of sector i consumed by sector j in the total output of sector i, which can be expressed as:

$$DOC: \quad g_{ij} = \frac{x_{ij}}{X_i} \quad (i, j = 1, 2, \cdots, n) \tag{5}$$

where x_{ij} is the output in sector i sent to the production of sector j, X_i is the total output of sector i. Total output coefficient (TOC) matrix in the Ghoshian model has a similar structure to the Leontief perspective shown in the following equation:

$$TOC: \quad B' = (I - G)^{-1} - I \quad or \quad B' = \bar{B}' - I \quad or \quad B' = G + G^2 + \cdots + G^{\infty} \tag{6}$$

Through calculation, we get DIC, TIC, DOC and TOC, due to the limited layout, we select the coefficient results related to real estate industry, and only list the top 5 sectors, as shown in Table 1.

As shown in Table 1, there are many industrial sectors that have important technical links with the real estate industry, including finance, leasing and business services, construction industry, etc. All the related industries are very important in the whole national economy. We can see that the top 5 industrial sectors with the strongest links with the direct input coefficient are financial industry, leasing and business services industry, construction industry, information transmission, software, and information technology services industry, as well as real estate industry itself, and the total output of these sectors accounts for 23.46% of total output of overall economy, indicating that the real estate industry directly or indirectly affects the overall economic development with its important industrial linkages. It should be noted that adding up the industrial impacts highly related to the real estate industry will result in a certain overestimation.

Table 1 Technical coefficients and its rank of top 5 sectors

Rank	DIC	Sector	TIC	Sector	DOC	Sector	TOC	Sector
1	0.1116	Finance	0.1435	Finance	0.0979	Finance	0.1343	Finance
2	0.0527	Leasing and business services	0.0839	Leasing and business services	0.0911	Wholesale and retail	0.1234	Wholesale and retail
3	0.0343	Real estate	0.0553	Real estate	0.0454	Leasing and business services	0.0807	Construction
4	0.0089	Construction	0.0232	Transport, storage and post services	0.0372	Information transmission, software and information technology services	0.0783	Leasing and business services
5	0.0058	Information transmission, software and information technology services	0.0228	Paper making, printing and cultural, education and sport article	0.0343	Real estate	0.0592	Information transmission, software and information technology services
% of total output		23.46%		17.11%		18.46%		25.13%

3.2 Forward Linkage and Backward Linkage

Direct backward linkage (DBL) is the column sums of the A matrix, which represents the total value of inputs from other sectors per unit worth of the output of sector j. Total backward linkage (TBL) is the production demand generated by various sectors of the national economy when a certain sector increases a unit of final product, and Normalized TBL is TBL divided by the average, they can be expressed as follows:

$$DBL_j = \sum_{i=1}^{n} a_{ij}; \quad TBL_j = \sum_{i=1}^{n} \bar{b}_{ij}; \quad Normalized\ TBL_j = \frac{\sum_{i=1}^{n} \bar{b}_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \bar{b}_{ij}} \tag{7}$$

Direct forward linkage (DFL) is equal to the row sum of G matrix, which represents the proportion of the output of sector i that served as inputs to all other sectors. Total forward linkage (TFL) reflects the production demand generated by a certain sector when each sector of the national economy increases a unit of final output, and Normalized TFL is TFL divided by the average, they can be expressed as:

$$DFL_i = \sum_{j=1}^{n} g_{ij}; \quad TFL_i = \sum_{j=1}^{n} \bar{b'}_{ij}; \quad Normalized\ TFL_i = \frac{\sum_{j=1}^{n} \bar{b'}_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} \bar{b'}_{ij}} \tag{8}$$

where $i, j = 1, 2, 3, \cdots, n$, $\bar{b}_{ij}$ and $\bar{b'}_{ij}$ are the element of Leontief inverse matrix and Ghoshian inverse matrix respectively. The larger the TBL, the greater pulling power of the real estate industry on the other industries of the national economy. The greater the TFL, the stronger the real estate industry's demand for the development of the national economy. The results are listed in Table 2.

As Table 2 shows, when we only look at a single real estate sector, the DFL and TFL are ranked at 34, relatively low among 42 sectors and the DBL and TBL are at the last place. However, if the industries with important linkages in the real estate industry are collectively regarded as an industry group, we will find that many industries in the group are ranked higher, indicating that the industrial group is important in the national economy.

4 Hypothetical Extraction Method

The technical coefficient calculated above can capture the relationship between industries from the perspective of demand and supply, but in the process of solving the coefficients, the input of the industrial sector itself may be ignored. Hence, many approaches have been developed for identification of relatively important sectors in an economy. Hypothetical extraction method is an important extension among all of

Table 2 Forward linkage and backward linkage

Sector	DFL	Rank of DFL	TFL	Normalized TFL	Rank of TFL	DBL	Rank of DBL	TBL	Normalized TBL	Rank of TBL
Finance	0.7814	18	3.1745	1.0233	16	0.4273	35	1.9940	0.7322	38
Leasing and business services	0.9086	12	3.5325	1.1387	12	0.6725	21	2.7898	1.0244	19
Real estate	0.4119	34	2.0923	0.6744	34	0.2545	42	1.5749	0.5783	42
Construction	0.0459	39	1.0655	0.3434	40	0.7583	14	3.1680	1.1632	14
Wholesale and retail	0.6608	24	2.7472	0.8855	23	0.3351	39	1.8030	0.6620	40
Information transmission, software and information technology services	0.4962	32	2.1478	0.6923	33	0.4776	33	2.2311	0.8192	34
Transport, storage and post services	0.7693	20	3.1128	1.0034	17	0.5470	28	2.3974	0.8803	30
Paper making, printing and cultural, education and sport article	0.7906	17	3.3157	1.0688	14	0.7678	11	3.2192	1.1820	12

those approaches, which is first proposed by Paelinck et al. [12], or Strassert [13]. However, Siegfried [14] is the first discussion in English, and then the method has been developed by Clements [15], Dietzenbacher and Van Der Linder [16], Miller and Lahr [17], Cai and Leung [18], Song et al. [19], Miller and Blair [20], as well as Dietzenbacher and Lahr [21] etc.

The essential idea of hypothetical extraction method is to measure the losses of outputs if a certain sector were removed from the economy. The specific way is to set the *k*th row and column as zero in the original matrix, which seems like "extracting" the sector from the economy. Then, when facing the specified final demand, we can calculate the difference in total output before and after extraction to measure the importance of the *k*th sector in the national economy. Also, the larger the difference in total output, the more important the *k*th sector.

We use recently published China's input–output table in 2017 and extract 42 sectors in turn to calculate their forward linkage, backward linkage, total linkage, without sector total linkage and their relative values respectively. We list the results of the top 5 sectors and the real estate industry in the Table 3.

As shown in Table 3, the relative forward linkage and relative total linkage of the real estate industry are both greater than 1, indicating that both of forward linkage and total linkage are higher than the average level. They are relatively important in 42 industrial sectors and have a greater role in promoting supply in other sectors. Significantly, backward linkage is ranked relatively low, indicating that real estate does have a slightly weaker effect in driving demand for other industry sectors, while compared with the rank of total linkage, the rank of the without sector total linkage declines significantly, the reason for it is that the real estate industry itself has a large output.

We apply the Ghosh model to calculate the forward linkage. Specifically, the forward linkage of the real estate industry is 16.3002, indicating that if all the intermediate purchase of the real estate industry by each sector are zero, then the lost output will account for 16.3002% of the original total output. Relatively, we use the Leontief model to calculate the last three linkages. While, the backward linkage is 1.7034, indicating that if all the intermediate input of other industrial sectors to the real estate industry is zero, and the lost output will account for 1.7034% of the original total output. The total linkage of real estate is 4.9901, indicating that if the real estate is extracted, that is, if the intermediate input and intermediate purchase are all zero, then the lost output will account for 4.9901% of the original total output. And the total linkage without sector is 1.5242, which shows that if the real estate industry's own output is excluded, the lost output will make up 1.5242% of the original output. On the whole, the linkage effect of real estate industry calculated by hypothetical extraction method is obviously higher than the total forward linkage and total backward linkage calculated by the coefficient matrix directly.

Table 3 Industrial linkage based on hypothetical extraction method

Rank	Forward links	Rel forward links	Sector	Rank	Backward links	Rel Backward links	Sector
1	20.6098	1.3368	Chemical products	1	18.2712	6.6802	Construction
2	20.3579	1.3205	Wholesale and retail	2	7.0389	2.5735	Chemical products
3	19.7995	1.2843	Finance	3	6.6149	2.4185	Foods and Tobacco
4	19.7656	1.2821	Agriculture, forestry, animal husbandry and fishery and services	4	5.0898	1.8609	Metal processing manufacture
5	19.3872	1.2575	Transport, storage and post services	5	4.9190	1.7984	Transport equipment
10	16.3002	1.0573	Real estate	26	1.7034	0.6228	Real estate
Rank	Total links	Rel total links	Sector	Rank	Without sector total links	Rel without sector total links	Sector
1	28.0647	5.9164	Construction	1	17.9313	7.5896	Construction
2	11.3331	2.3892	Chemical products	2	5.2387	2.2174	Foods and Tobacco
3	10.8288	2.2828	Foods and Tobacco	3	4.7336	2.0036	Chemical products
4	8.5797	1.8087	Transport, storage and post services	4	4.0374	1.7089	Transport, storage and post services
5	8.5313	1.7985	Wholesale and retail	5	3.8400	1.6253	Metal processing manufacture
14	4.9901	1.0520	Real estate	26	1.5242	0.6451	Real estate

5 Estimates of the Economic Impact of the Pandemic

Due to the impact of the epidemic, China's GDP fell by 6.8% in the first quarter of 2020 to 20.6504 trillion Chinese Yuan (CNY). The GDP of the real estate industry in the first quarter fell by 6.1% to 1.5268 trillion Chinese Yuan, which accounted for about 7.4% of China's GDP. We perform corresponding conversions according to the structure of the input–output table and figure out that the total demand of the real estate industry has decreased by 99.185 billion Chinese Yuan. Meanwhile, the relationship between the impact of total output and the shock of final demand of a single industry can be presented as follows:

$$\Delta x = (I - A)^{-1} \times \Delta f \tag{9}$$

where Δx is the output losses of sectors, $(I-A)^{-1}$ is the Leontief inverse matrix, Δf represents the vector of the final demand shocks of 42 sectors. Through calculation, the output losses of various industrial sectors are shown in Table 4.

As shown in Table 4, each sector has been affected to varying degrees due to the shock in the final demand of the real estate industry (sector 33). As indicated by asterisks in the Table 4, in addition to the real estate industry itself, the other top 3 industries with the greatest impact are finance (sector 32), leasing and business services (sector 34), transportation, warehousing and postal services (sector 29). When the final demand of real estate industry changes, the total output of real estate industry (sector 33) suffered a loss at about 104.671 billion Chinese Yuan, while other 3 sectors suffered the losses of total output at about 14.235 billion Chinese Yuan, 8.324 billion Chinese Yuan, and 2.302 billion Chinese Yuan respectively, which are shown in italics in the table. While the total losses of all of the 42 sectors is 156.203 billion Chinese Yuan.

6 Conclusion

This paper provides a detailed analysis of the input–output structure among real estate industry and other 41 industrial sectors. The study is based on China's input–output table for 42 sectors.

The results show that there are many industrial sectors that have important technical links with the real estate industry, including finance, leasing and business services, construction industry, etc. All the related industries are very important in the national economy. From the perspective of four different linkages mentioned previously, the real estate industry is ranked relatively low, this result may be related to the selected computing technology. Even so, if the industries with important linkages in the real estate industry are collectively regarded as an industry group, we will find that many industries in the group are ranked higher, indicating that its industry group does have an important position in the overall economy.

In order to study the status of real estate more accurately, we must consider the input of the real estate industry itself. We adopt hypothetical extraction method to re-examine the impact of the real estate industry on the macro-economy. The same as expected, the relative forward linkage and relative total linkage of the real estate industry calculated by the hypothetical extraction method are both greater than 1, indicating that the forward linkage and total linkage are higher than the average level. They are relatively important in 42 industrial sectors. It's obvious that the backward linkage is ranked relatively low, indicating that real estate performs much weak in driving demand for other industry sectors, while compared with the rank of total linkage, the rank of the without sector total linkage declines significantly, the reason for it is that the real estate industry itself has a large output.

Table 4 The output losses (expressed in billion Chinese Yuan) caused by shock in the final demand of the real estate industry

# of Sector	Δx	# of Sector	Δx	# of Sector	Δx	# of Sector	Δx	# of Sector	Δx	# of Sector	Δx
1	14.53	8	5.88	15	6.73	22	3.84	29*	<u>23.02</u>	36	3.36
2	4.62	9	2.59	16	3.42	23	0.35	30	16.10	37	1.47
3	6.20	10	22.61	17	2.07	24	14.80	31	15.61	38	5.33
4	2.40	11	9.29	18	8.47	25	2.99	32*	*142.35*	39	0.96
5	1.46	12	20.26	19	5.80	26	0.82	33*	*1046.71*	40	0.14
6	18.66	13	3.88	20	11.98	27	10.45	34*	*83.24*	41	3.69
7	5.12	14	11.38	21	1.17	28	16.63	35	0.00	42	1.63

As for the hypothetical extraction method, although this method can measure the impact of industry on overall output, the method itself still has a limitation. When we eliminate a single sector, it may affect the balanced accounting structure and internal relationships of the input–output table. However, the limitation of this method is difficult to be improved under the current technical framework. Perhaps with the development of input–output technology, local improvements may be used to modify the method in the future.

Due to the impact of the pandemic, the final demand of the real estate industry in China decreased in the first quarter. The output losses of various industrial sectors are estimated according to the input–output table. Thus, from a policy point of view, the policy action oriented to smooth the economic fluctuations should be taken into account, and the measures need to be taken to stimulate the development of real estate industry, such as speeding up the formulation of reasonable property tax policy, refining real estate product types for different groups, optimizing related financial policies, and so on.

The possible problem in this paper is the overestimation of the impact since the demand of the real estate industry has typical characteristics of derived demand. If more comprehensive data for all industries are available, maybe we would get more accurate results. Moreover, if the same method is performed in an inter-regional input–output (IRRIO) environment, the real estate industry would play a different role throughout China.

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Analysis on the Spatial Distribution Characteristics of Commercial Outlets in the Main Urban Area of Chongqing Based on POI Data

Xueqin Zhang

Abstract Commercial outlets are closely related to regional economic development and residents' daily life. Scientific and reasonable commercial outlets layout plays an important role in promoting regional economic development and improving residents' living quality. A correct understanding of the spatial distribution characteristics of commercial outlets is conducive to understanding the current situation and trend of commercial development in this region, and to provide reference for the compilation of commercial planning in the future. Based on POI data, this paper analyzes the spatial distribution characteristics of commercial outlets in the main urban area of Chongqing by using the nearest neighbor index method, the kernel density analysis method and hot spot analysis method. The results show that: ① The commercial pattern of Chongqing's main urban area presents a general trend of agglomeration. ② The commercial outlets in the main urban area of Chongqing show a "one-axis multi-core" distribution model and a distribution state of "more in the middle and less in the north–south". ③ The distribution of commercial outlets in Chongqing shows a trend of "high center-low periphery". By comparing the model results with the actual situation, it is found that the distribution of existing commercial outlets does not match the distribution of actual demand. Moreover, it is found that the distribution of commercial outlets is closely related to the distribution of traffic routes. Therefore, it is suggested that the distribution of commercial outlets can be guided by planning or adjusting the traffic routes, so as to improve the coordination between the distribution of commercial outlets and the distribution of actual needs.

Keywords Chongqing city · POI data · Commercial outlets · Spatial distribution characteristics

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1 Introduction

Commerce is one of the most dynamic and important functions of a city, and commercial space is an important part of urban space [1]. The location and spatial structure of urban commercial space has always been a hot topic in urban geography. The reasonable distribution of commercial outlets plays an important role in improving residents' quality of life and promoting urban economic development. As early as 1920s, foreign scholars began to discuss the location of urban commercial outlets. After 1978, with the process of China's urbanization, commerce gradually became an important part of urban economic activities, and relevant studies on the layout of urban commerce began to appear. In recent years, with the continuous development of big data, geospatial data represented by mobile phone signaling data and POI data have been constantly improved and enriched, making the research on urban commercial network layout gradually scientific and quantitative. POI data represent the entities in life with points with latitude and longitude, and contain highly accurate positioning and detailed attribute information, which can objectively and truly reflect urban economic activities. For example, Zhang Zhibin and Wang Kaijia [2] based on POI data, ArcGIS and Crime Stat software, revealed the layout characteristics of commercial outlets in Lanzhou city from different dimensions by using Ripley's K function, nearest neighbor index and the kernel density analysis method. Zhao [3] collected POI data and combined with quantitative analysis method, analyzed the overall and format layout characteristics of the retail industry in Jinan city, and analyzed the influencing factors of its spatial layout. Based on POI big data, Gao and Zhang [4] explored the spatial distribution characteristics of retail outlets in Xining city, by means of location entropy, Ripley's K function, the kernel density analysis method and local Getis-ORD G* index.

As the economic center of the upper reaches of Yangtze River, Chongqing is one of the important central cities. At present, there are few research results on the spatial distribution characteristics of commercial outlets in Chongqing. Therefore, based on POI data from Baidu Map and ArcGIS 10.6 software, this paper analyzes the spatial layout characteristics of commercial outlets in the main urban area of Chongqing by combing a series of spatial data analysis methods, such as the nearest neighbor index method, the kernel density analysis method and hot spot analysis method. This paper analyzes the clustering situation of commercial layout in the main urban area of Chongqing by the nearest neighborhood index method. The characteristics of commercial pattern distribution in Chongqing city are analyzed by means of the kernel density analysis method. Using the Getis-ORD Gi* index method of hot spot analysis, the cold and hot spots of commercial outlets layout in the main urban area of Chongqing are identified, so as to provide reference for the rational layout of commercial outlets and realize the optimization of commercial outlets layout.

2 Data Sources and Research Methods

2.1 Study Area and Data Sources

Chongqing, China is located between 28°10’ N and 32°13’ N, 105°11’ E and 110°11’ E. It is the only municipality directly under the Central Government and the national central city in central and western China. It is also the financial, economic, scientific innovation, shipping and trade logistics center in the upper reaches of the Yangtze River. As the birthplace of “Bayu” culture and the source of “Hongyan Spirit”, Chongqing is a famous national historical and cultural city. With a total area of 82,400 square kilometers, it now has jurisdiction over 26 districts, 8 counties and 4 autonomous counties, with a permanent resident population of 31,243,200. This paper selects the main urban area of Chongqing as the research area, including 9 districts of Yuzhong, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nan’an, Yubei, Beibei and Ba’nan, as shown in Fig. 1.

Based on Baidu Map, the POI data of commercial outlets in Chongqing’s main urban area in 2017 were obtained, totaling 91,044 pieces. The POI data obtained

Fig. 1 The main urban area of Chongqing

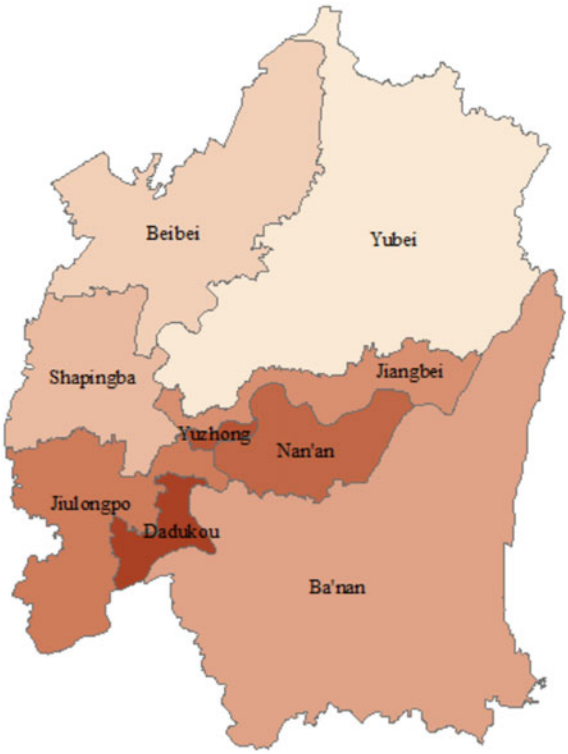


Table 1 Statistics of various commercial outlets in the main urban area of Chongqing

Category	POI subcategory	Quantity	Proportion (%)
Shopping service	Shopping malls, life squares, commercial pedestrian streets, trade marts	658	0.72
Catering service	Chinese restaurant, western restaurant, specialty restaurant, fast food restaurant, cold drink restaurant, dessert shop	62,395	68.53
Living service	Hairdressing and beauty, service hall, post office, photography, logistics and express, laundry	20,853	22.91
Accommodation service	Hotel, guesthouse, homestay, apartment, youth hostel	7138	7.84

contained 6 fields, namely name, category, address, longitude, latitude and administrative division. Due to the wide variety of original POI, including some information missing data or non-commercial data, this paper manually screened and sorted the data, and finally divided the POI data into four categories, namely shopping service, catering service, living service and accommodation service, as shown in Table 1.

2.2 Research Methods

2.2.1 Nearest Neighbor Index

The nearest neighbor index is a geographic index used to show the degree of proximity of point elements. By measuring the average distance value of each point element and its nearest point element, the nearest point element is compared with the expected average distance. The comparison results can reflect the clustering characteristics and spatial distribution of point elements in space. The formula is expressed as follows:

$$\mathrm{NNI} = \frac{\bar{d}_i}{\bar{d}_e} \quad (1)$$

where NNI is the nearest neighbor index, $\bar{d}_i$ represents the mean observation distance, $\bar{d}_e$ is the expected mean distance. When $NNI = 1$, it means that the sample points are randomly distributed in the study area, indicating that the point distribution is random. When $NNI > 1$, it indicates that the distribution of sample points tends to be discrete. The larger the value is, the higher the degree of dispersion is. When $NNI < 1$, it indicates that the distribution of sample points tends to cluster and is relatively close in space [5].

2.2.2 Kernel Density Analysis

Kernel density analysis is mainly used to calculate the density of elements in the surrounding neighborhood [6]. Based on point data, the center of the grid to be calculated is searched with a certain radius to generate a continuous surface representing the density value, and different kernel density values are used to reflect the spatial distribution characteristics of point elements. Its calculation formula is as follows:

$$f(s) = \sum_{i=1}^{n} \frac{1}{h^2} k\left(\frac{s - c_i}{h}\right) \tag{2}$$

where *f(s)* represents the estimate of kernel density at space position *s*, *n* is the number of elements whose distance from position *s* is less than or equal to *h*, *h* is the search radius, the function *k* represents the weight function of space distance [7].

2.2.3 Hot Spot Analysis

The local Getis-ORD Gi* index method, proposed by Getis and Ord, is used to measure whether there is a local spatial correlation between each observed value and adjacent environmental elements [8]. It can detect high-value clustering areas and low-value clustering areas, namely hot and cold spots. In this paper, the local Getis-ORD Gi* index method is used to analyze the hot spots of commercial outlets, and its calculation formula is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{J=1}^{n} w_{i,j}}{\sqrt[s]{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{J=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{3}$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{N} \tag{4}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\bar{X}\right)^2} \tag{5}$$

where *Gi** stands for local Getis-ORD Gi* index, *n* is the total number of elements, $w_{i,j}$ is the spatial weight between the elements *i* and *j*, x_j is the attribute value of element *j* [9].

3 Results and Discussion

3.1 *Analysis on Spatial Clustering Characteristics of Commercial Outlets*

In this paper, ArcGIS 10.6 software was used to calculate the nearest neighbor index of 91,044 commercial outlets POI data collected in the main urban area of Chongqing by means of the average nearest neighbor analysis model in the spatial statistics tool. In order to further analyze the spatial clustering characteristics of different commercial types, the POI data of commercial outlets in the main urban area of Chongqing were divided into four categories, and the nearest neighbor index analysis was conducted for each category of commercial outlets. The calculation results are shown in Table 2.

As shown in Table 2, all kinds of commercial outlets are different in spatial distribution. In terms of the number of POI, the proportion of shopping service category is the lowest, only accounting for 0.72%. POI data of accommodation service accounted for 7.84% of the total, while living service POI data accounted for 22.91% of the total data. The highest proportion is catering service, accounting for 68.53% of the total. From the clustering degree of spatial distribution, the NNI values of shopping, catering, living services and accommodation services are all less than 1, showing the characteristics of clustering distribution. Among them, the NNI of catering industry is the smallest, indicating that the catering industry presents a stronger agglomeration pattern. Living service and accommodation service are close behind, and their distribution patterns are similar. The NNI value of shopping service is the largest, around 0.3, showing the distribution characteristics of general aggregation. The calculation results also show that the overall layout of the commercial outlets in the main urban

Table 2 Statistics of the nearest neighbor index for each category

Category	POI quantity	Proportion(%)	NNI value	P value	Mean nearest neighbor distance (m)	Distribution characteristics
Commercial service	91,044	100	0.1598	0.00	16.7335	Centralization mode
Shopping service	658	0.72	0.2856	0.00	302.9945	Centralization mode
Catering service	62,395	68.53	0.1555	0.00	19.5933	Centralization mode
Living service	20,853	22.91	0.1845	0.00	39.6247	Centralization mode
Accommodation service	7138	7.84	0.2028	0.00	74.4770	Centralization mode

area of Chongqing is in the state of agglomeration distribution, and the distribution characteristics of the catering service are the closest to the whole. In addition, from the analysis of the mean nearest neighbor distance, the value of catering service is the smallest, indicating that the distribution of catering service is relatively more intensive. The mean nearest neighbor distance of the shopping service is the largest, indicating that the distribution of the shopping service is relatively dispersed.

3.2 Analysis on Spatial Distribution Characteristics of Commercial Outlets

3.2.1 Kernel Density Analysis of Commercial Outlets

With the help of ArcGIS 10.6 software and the kernel density analysis tool in Spatial Analyst tool, this paper analyzes the kernel density of 91,044 commercial points of interest collected in the main urban area of Chongqing. The analysis results are shown in Fig. 2. The darker the color is, the higher the density value is.

As can be seen from Fig. 2, commercial outlets in the main urban area of Chongqing are mainly concentrated in Yuzhong, Yubei, Nan'an, Shapingba and Jiangbei district, presenting a layout mode of "one-axis multi-core". "One-axis"

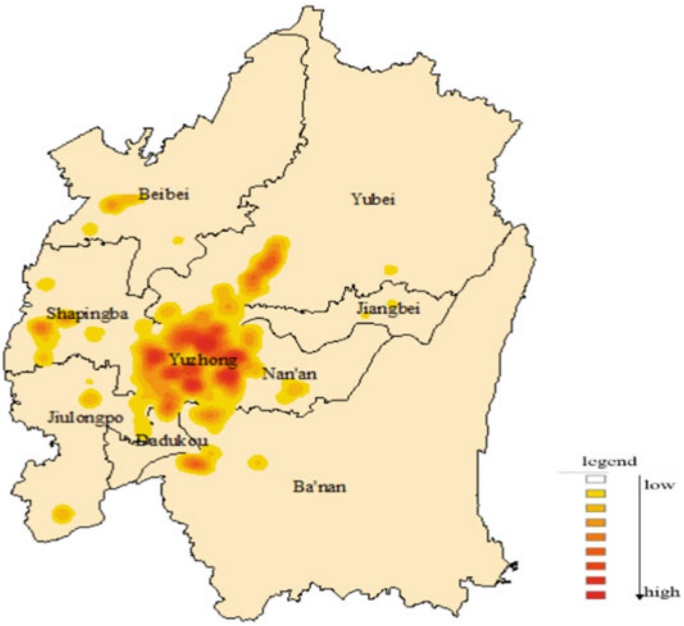


Fig. 2 Distribution density map of commercial outlets in Chongqing's main urban area

refers to the axis from southwest to northeast, from the Jiulongpo and Dadukou district in the southwest, through the Yuzhong district, pointing to the northeast Yubei District. Axis commercial interest points are concentrated in Yangjiaping business circle, Nanping business circle, Jiangbei Guanyin Bridge, Jiefangbei business circle and Shapingba Sanxia Square business circle. As can be seen from Fig. 2, the commercial distribution in the main urban area of Chongqing also has obvious multi-core characteristics, with some large commercial points as the center distribution. Yuzhong District as a whole presents a dense state of commercial outlets. Internally, it is distributed around several core areas, while there are also some core areas in the rest of the main urban area. Chongqing has convenient rail transportation, and the distribution axis of commercial outlets is also the main area through which Subway Line 2 and Line 3 run. The convenient transportation conditions attract many businesses to gather. And it can be seen that the core is mainly some prosperous business circles, which indicates that the results of kernel density analysis are consistent with the actual situation, and the calculation results have certain credibility. Yangjiaping business district is located in Jiulongpo district, with a beautiful environment. There is Sichuan Fine Arts Institute near the business district, which has a strong artistic and cultural atmosphere and more rich commercial activities, attracting numerous consumer groups. Nanping business district is one of the three core business districts in the main urban area of Chongqing. Located in the core area of Nan'an district, Nanping business district is an important business gathering place of Chongqing, integrating fashion shopping, entertainment and leisure, convention and exhibition tourism and other functions. Guanyin Bridge in Jiangbei district is the traditional prosperous business area and the economic and cultural center of Jiangbei District. Shapingba Sanxia Square business circle and Jiefangbei business circle are both old business circles with huge flow of people. The surrounding middle schools and colleges are the main source of driving the development of the business circle.

From the perspective of distribution direction, the commercial outlets in the main urban area of Chongqing show the distribution trend of "more in the middle and less in the north–south", which is in good agreement with the development characteristics of the city. Jiangbei district is the core district and high-end fashion consumption district of Chongqing, Yuzhong district is the commercial center and transportation hub of the city, and Jiulongpo district is mainly characterized by high-tech creative industries. The commercial development of Yuzhong district is mature, and it also drives the development of the surrounding areas to form commercial advantages and characteristics. The commercial density of the area far away from Yuzhong district is relatively low and the distribution is sparse. However, there is some irrationality of the present distribution situation. According to Chongqing's statistical yearbook, the population of Yubei, Jiulongpo and Ba'nan district in Chongqing ranks top three among the nine main urban districts. But the nuclear density analysis results show that there are fewer commercial outlets in these areas, which does not match the existing potential demands.

3.2.2 Kernel Density Analysis of Various Commercial Outlets

In order to further understand the Spatial distribution of interest points of different business types, this paper USES ArcGIS 10.6 software and Spatial Analyst tools to analyze the core density of POI data of four categories of Chongqing main urban area. The analysis results are shown in Fig. 3. The higher the core density is, the darker the color is.

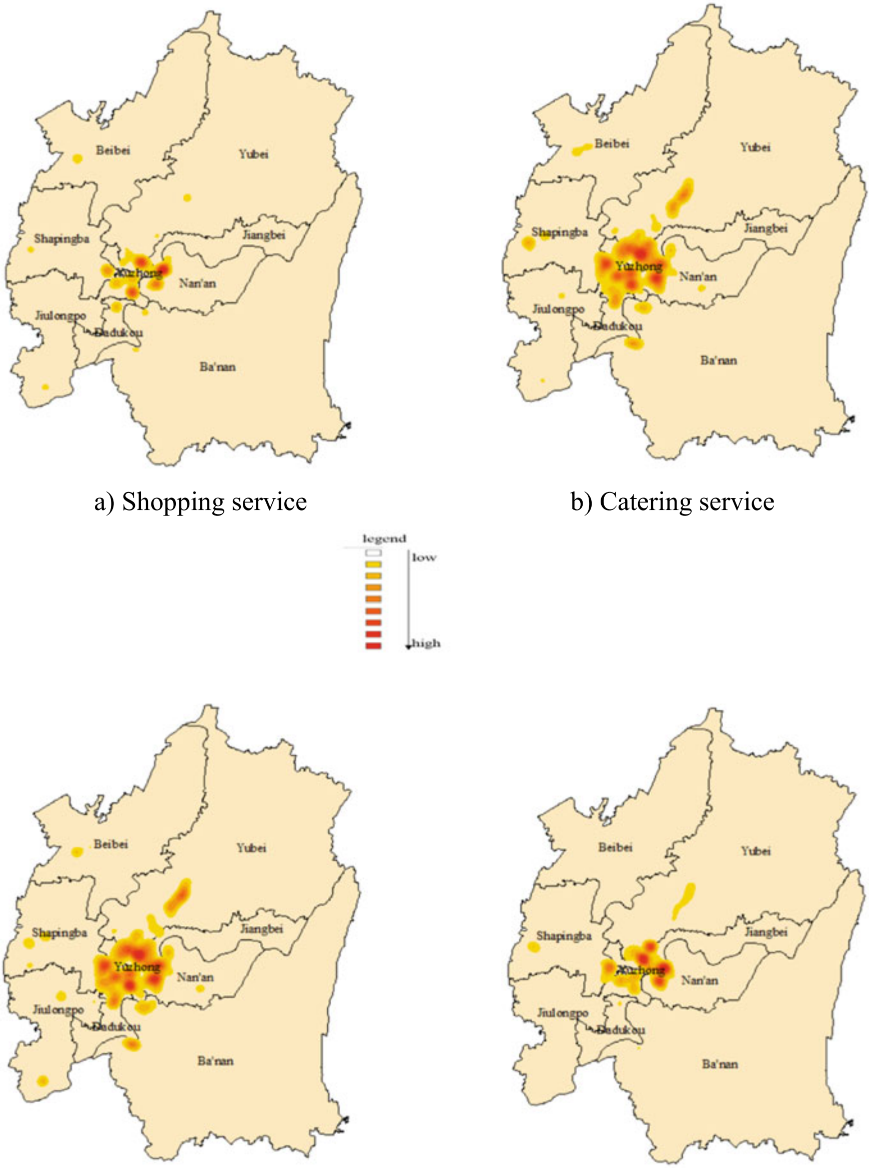
From the distribution density map of different types of business interest points, the shopping core density is highest in Jiefangbei, Guanyin Bridge and Yangjiaping. The distribution patterns of catering and living service categories are similar, mainly concentrated in Ciqikou Ancient town, Guanyin Bridge, Nanping and Yangjiaping. However, the areas with high concentration of accommodation services are located near Jiefangbei and Guanyin Bridge. It can be seen that the distribution density of all kinds of commercial outlets in Guanyin Bridge is relatively high, while that of shopping, catering and living service in Yangjiaping is relatively high. It can be seen from the above results that the commercial outlets in the main urban area of Chongqing are too concentrated in a few areas, and many regions are quite deficient. The future commercial planning and construction are supposed to appropriately transfer the commercial focus to make up for the areas with fewer commercial outlets at present, so as to meet the needs of residents in these regions and promote regional economic development.

3.3 Analysis of Hot Spot Distribution Characteristics of Commercial Outlets

3.3.1 Commercial Network Hot Spot Analysis

In this paper, with the help of ArcGIS 10.6 software, through the hot spot analysis tools, local Getis- word Gi * index calculation, identify the cold hot spots in downtown Chongqing commercial outlets, further understand the distribution of commercial network in Chongqing urban area, cold hot distribution as shown in Fig. 4, blue said cold spots, red orange department said relatively hot spots.

As can be seen from Fig. 4, there are obvious cold and hot spots clustering areas in the main urban area of Chongqing, showing the overall distribution trend of high in the middle and low in the periphery. Hot spots are concentrated in Guanyin Bridge, Jiefangbei and Yangjiaping, which are consistent with the overall distribution of urban commercial areas. These hot spots not only have a high distribution density of their own commercial outlets, but also are surrounded by high-value regions. From the perspective of statistics, they belong to high-density clustering areas. In addition to the central highly clustered area, a higher value also appeared near Yubei district Chongqing garden expo park. The cold zone is mainly distributed in the periphery of the main city, most of which are located in Ba’nan, Dadukou, Jiulongpo, Beibei



a) Shopping service
b) Catering service
c) Living service
d) Accommodation service

Fig. 3 Distribution density map of various commercial outlets in the main urban area of Chongqing

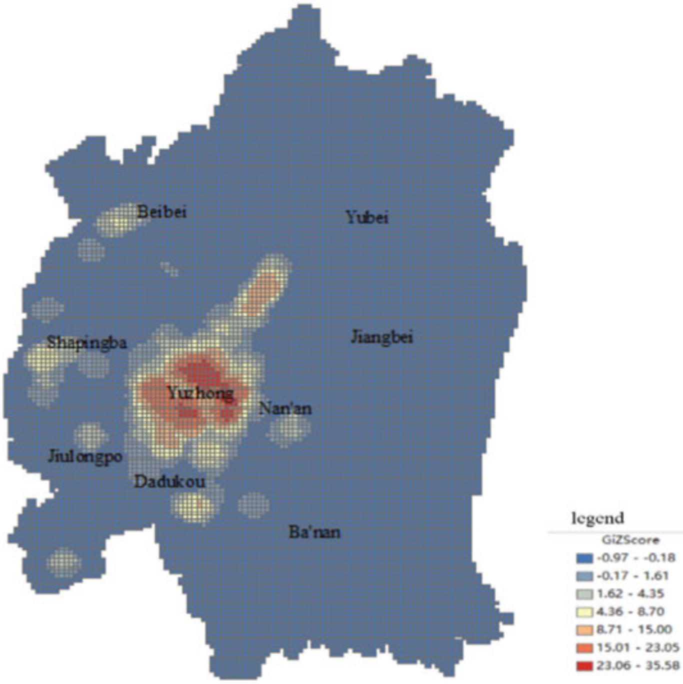


Fig. 4 Distribution of cold hot spots of commercial outlets in the main urban area of Chongqing

district and the northern part of Yubei district. Since the distribution of commercial outlets is greatly affected by traffic, it can be considered to guide the distribution of commercial outlets by planning bus or rail transit routes in the future, so as to improve the commercial vitality in cold areas.

3.3.2 Hot Spot Analysis of Various Commercial Outlets

In order to further analyze the distribution of different types of commercial outlets, four types of commercial outlets were analyzed in this paper, and the analysis results were shown in Fig. 5. The cold spots were blue, while the relative hot spots were red and orange.

It can be seen from Fig. 5 that the hot and cold distribution of catering, living service and accommodation service are relatively similar. The hot spots of the three types of commercial outlets are mainly concentrated in the vicinity of Guanyin Bridge and Jiefangbei business circle, while the cold spots are distributed in the surrounding areas of the main urban area. Besides Guanyin Bridge and Jiefangbei business circle, there are also many small hot spots in the surrounding areas, such as Wanda Square in Feng Shixing road in Beibei district, university town in Shapingba district, and so on. The commercial planning of Chongqing's main urban area in the future can

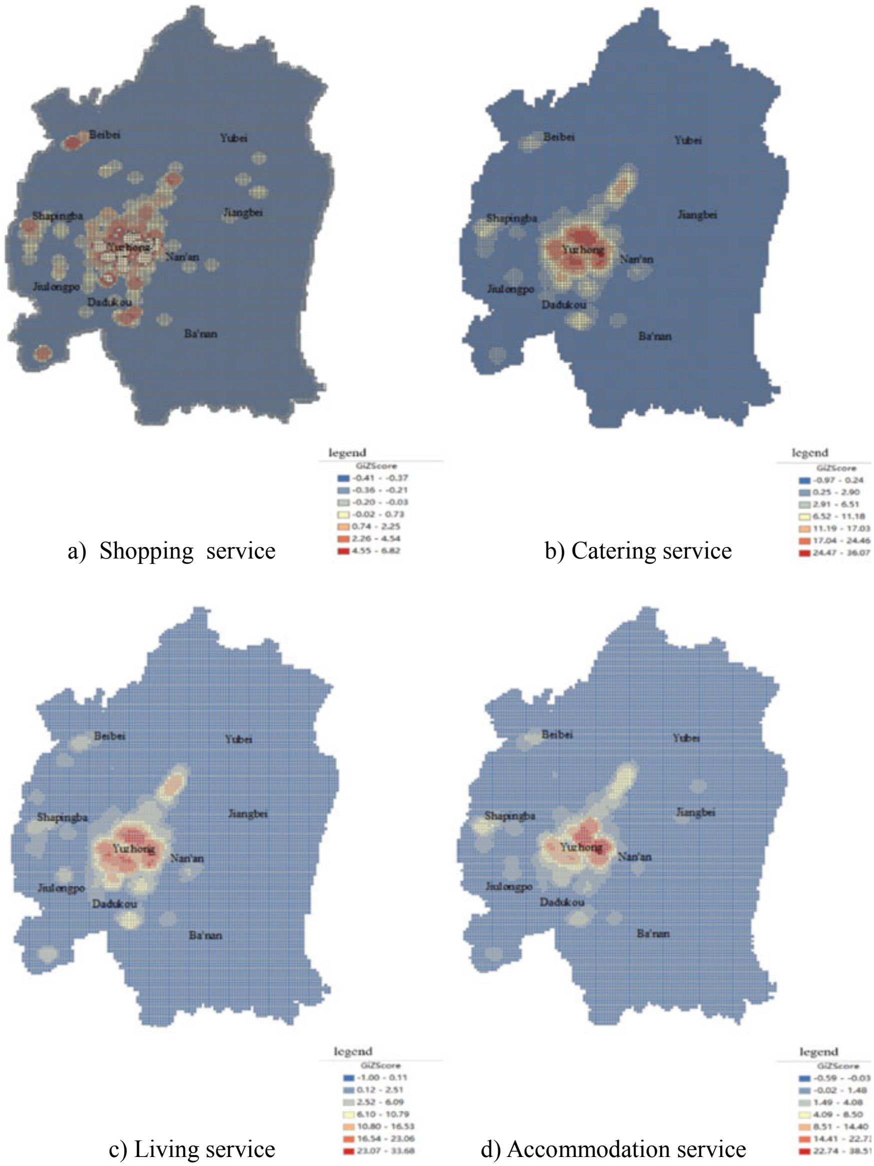


Fig. 5 Distribution of cold hot spots of various commercial outlets in Chongqing's main urban area

expand hot spots through various measures, such as planning rail transit routes, so as to drive the overall booming commercial development of Chongqing's main urban area.

4 Conclusion

Affected by various factors, the spatial distribution of all kinds of commercial outlets is not uniform and the same. Based on the POI data of 91,044 commercial outlets in the main urban area of Chongqing, this paper makes a detailed analysis of the spatial distribution characteristics of commercial outlets in the main urban area of Chongqing by using the nearest neighbor index method, kernel density analysis method and hot spot analysis method and using ArcGIS software. The final analysis results of this paper are consistent with the actual situation of Chongqing, and the main conclusions are as follows:

① The commercial pattern of Chongqing's main urban area presents a general agglomeration situation. The distribution of catering business interest points is the most concentrated, while the distribution of shopping business outlets is relatively scattered.

② The commercial outlets in the main urban area of Chongqing show the layout mode of "one-axis multi-core" and the distribution state of "more in the middle and less in the north–south", which are greatly affected by the degree of traffic convenience. Yangjiaping, Nanping, Guanyin Bridge, Jiefangbei and Sanxia Square business circle are the most important core areas.

③ By hot spot analysis, the cold hot spots of Chongqing's commercial outlets are identified, and the results show that the distribution of Chongqing's commercial outlets presents a trend of "high center-low periphery". The distribution of hot spots of commercial outlets has a high consistency with the current distribution of urban business districts. The guiding role of traffic should be actively used to expand hot spots of commercial outlets and promote the sustainable development of commercial economy in the main urban area of Chongqing.

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Summary of Research on Contract Risk Management of EPC General Contracting Project—Based on VOSviewer Knowledge Graph Analysis

Ying Wu

Abstract With the improvement of China's urbanization level and the development of the socialist market economy, the construction engineering industry is also facing new opportunities and challenges. As the most widely used EPC model in the field of engineering contracting, contract risk management is particularly important, not only related to the economic benefits of enterprises, but also has a significant impact on the improvement of the management level of general contractors in China. This article uses 264 articles of important industry journals in the 2016–2020 CNKI database and the Web of science core database as the data source to deeply analyze the research focus and trend of EPC general contracting project contract risk management. The conclusion shows that the research on the contract risk management of EPC general contracting projects has become mature, and the research interest has shown a downward trend in recent years. The research hotspots mainly focus on "EPC project pre-risk management", "EPC project implementation process risk management" and "Three aspects of risk management in the later stage of EPC projects; the research hotspots of contract risk management of EPC general contracting projects in the future will mainly focus on emerging fields such as "informatization management" and "international engineering projects". This has certain theoretical guiding significance for guiding EPC project contract risk management, improving construction project profit and improving the management level of China's engineering enterprises.

Keywords EPC project · Contract management · Risk management · General engineering contracting · Research review

1 Introduction

With the rapid development of China's economy, China's engineering construction has also ushered in a period of prosperity. The number and scale of construction

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projects have continued to increase, and construction engineering contracts have also changed with the times. For example, Contract clauses have increased, contract content has become increasingly complex, and contract rules are becoming more and more in line with international standards. For general contracting projects, especially EPC projects, they will face complex and diverse risks when signing contracts. For example, due to poor management of the EPC project contract risk, the China Railway Construction Group's cost overrun in the Mecca light rail project was US$ 676 million, accounting for 34.4% of the total contract price. Therefore, for both parties to the contract, risk identification and evaluation must be carried out to prevent possible risks. Therefore, research on contract risk control is imperative.

At present, the research on EPC projects, contract management and risk management has received extensive attention from scholars. On the one hand, scholars have identified the types of risks faced by EPC projects. For example, Wu et al. [1] took the overseas EPC project of contracted engineering as the research object, and concluded that there are different tax risks in the bidding, execution and closing stages of overseas EPC projects. Sadeghi et al. [2] introduced a novel risk category called "recurring risk", which includes risks inherent in EPC projects and risks caused by external issues. It is divided into eight categories. For each risk group, an appropriate risk management strategies, and use surveys to evaluate the effectiveness of each strategy. Some scholars are committed to the evaluation of contract risk management. For example, Jahantigh et al. [3] identified significant financial risks of engineering procurement and construction (EPC) projects, and assessed the financial risks according to the fuzzy TOPSIS model and determined their priorities. Kelleher [4] used extensive experiments in his research to count the factors of project contract changes, and pointed out that there are obvious risks in project operation, and the impact of project risks needs to be measured and evaluated. Some scholars mentioned the importance of EPC project risk management. The EPC contract risk model developed by Lin [5] proposes measures to avoid risks in the form of contracts to reduce losses in the process, thereby increasing the profits of overseas projects. Picha et al. [6] analyzed the importance of EPC contracts using qualitative methods, finding and increasing the understanding of the main terms that caused the dispute added a detailed description, and determined the key factors for the successful completion of the project under the EPC contract framework. Some scholars also discussed the improvement path of contract risk management. Wang et al. [7] pointed out that the reasons and measures for legal risks in construction contract management should be explored from the perspective of legal analysis of construction project contract management. Zeng et al. [8] pointed out that the risks and causes of visas, environmental protection, technical standards, contracts, international talents, and overseas personal safety faced by the project construction process should be analyzed from the perspective of the general contractor. Mabo [9] pointed out that the risks and prevention of the main terms of the contract should be elaborated in a targeted manner from the six aspects of cooperation period, output standards, service requirements, etc., and passed the social capital party's market test, project procurement and procurement results and confirmation negotiation and other links improve the content of the contract clauses. Aandahl et al. [10] pointed out that the project owner can reduce the risk of the project by deploying the level of detail set in the contract by laws and regulations. Wang et al. [11] proposed that in international EPC projects, the relationship with the contractor to reduce the risk in the project delivery process. Yang et al. [12] pointed out that the successful application of partnerships by contractors can play an exemplary role for other contractors, and can create a win–win atmosphere for the government, thereby reducing project risks.

Although the research on EPC projects, contract management and risk management is relatively extensive, the research focus and trends of contract risk management for EPC projects have not been systematically summarized and sorted out, and there are still research gaps. Therefore, this research focuses on future contract risk management of EPC general contracting project has certain theoretical guiding significance.

2 Research Method

This paper uses the method of bibliometrics to search the research literature on EPC project contract risk management, and analyzes related application scope s and research trend through these literature. Bibliometrics is an interdisciplinary subject that integrates statistics, philology and mathematics. After decades of development, it has formed many application categories such as document gathering and dispersing, document accumulation, document citation, etc., and is used in cost management [13], ppp mode, general project contracting [14], risk management [15], project management [16] and other engineering construction aspects. Through bibliometrics and analysis, the structure, characteristics and development laws of science and technology can be described, scientific and technological achievements and talents can be evaluated, and scientific forecasts can be carried out. Information visualization software Vosviewer is a knowledge graph software used to show the co-occurrence relationship between different knowledge units in the literature, and then to characterize the relevance of various subjects. At present, VOSviewer has been widely used in the field of bibliometrics. By analyzing the co-occurrence relationship of journals, disciplines, keywords, authors, etc. in the literature, the corresponding relationship network is constructed to generate related visual maps. This paper uses the information visualization tool VOSviewer to conduct a quantitative analysis on the research trend of EPC project contract risk management, obtains the literature time evolution, high-frequency keyword word frequency relationship and superimposed visual analysis, and reveals the research hotspots and trends in this field.

3 Research Data

This article uses the literature included in the CNKI and WOS database with the most influential journals from 2016 to 2020 as the data source. The data acquisition time is May 18, 2020. The title of the search subject of the Chinese literature is set to "EPC project and contract risk management" or "Engineering general contracting and contract risk management". The English subject heads are set to "EPC project and contract risk management", "Engineering Procurement construction and contract risk management" or "Engineering general contracting and contract risk management". After inspecting the documents one by one and manually removing invalid literature such as news literature, conference literature, interviews and duplicate documents, 136 Chinese documents and 128 English documents were screened to obtain a total of 264 documents.

3.1 Retrieval Data

Statistics of relevant literature from 2016–2020 are carried out to obtain the research trend of EPC general contracting project contract risk management in recent years. Statistics have found that both China's and English literature have shown a downward trend, indicating that the research interest in EPC project contract risk management is declining. On the one hand, it reflects that the research on EPC project contract risk management has entered a relatively mature stage. On the other hand, it also implies that there are gaps in future research on EPC project contract risk management, and new research fields need to be explored (Fig. 1).

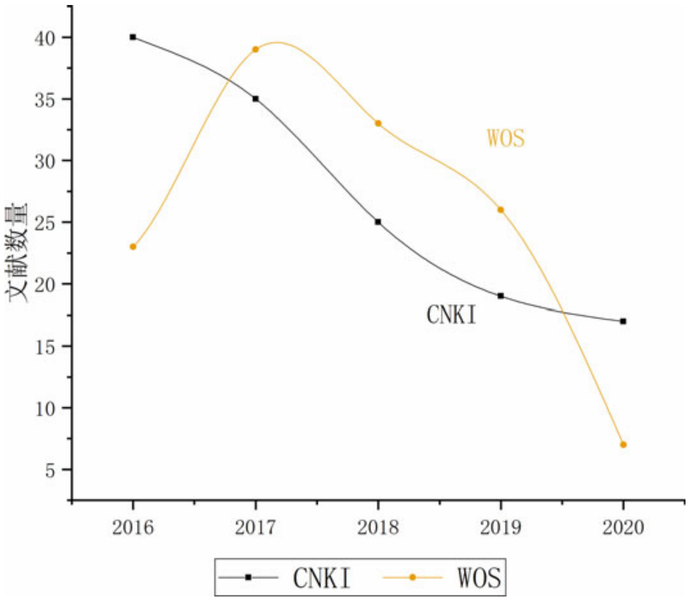

Fig. 1 Relevant literature retrieval analysis

3.2 High-Frequency Keywords

This paper uses the 264 documents in the Sect. 3.1 retrieval analysis as the data source, and uses the information visualization software VOSviewer to perform high-frequency keyword co-occurrence relationships and overlay visualization analysis, and build a keyword heat map (shown in Figs. 2 and 3) and collinearity. The network (shown in Figs. 4 and 5) to characterize the research hotspot and trend of contract risk management for EPC general contracting projects. Among them, in the heat map, each point has a color, which indicates the density of the item at that point, and the color ranges from blue to green to yellow. The more items near a point, the higher the weight of adjacent items, and the closer the color of the point is to yellow. On the contrary, the color of the point is closer to blue. In the co-occurrence relationship network, the size of each dot is related to the frequency of occurrence of the keyword. The thickness of the solid line connecting the dots indicates the strength of the co-occurrence relationship. Through the visual analysis of the co-occurrence of high-frequency keywords and the network, we can obtain the internal relationships of research objects, topics, and disciplines, reveal the evolution process and cutting-edge trends of the field, and more deeply identify the research hotspots of EPC general contracting project cost control.

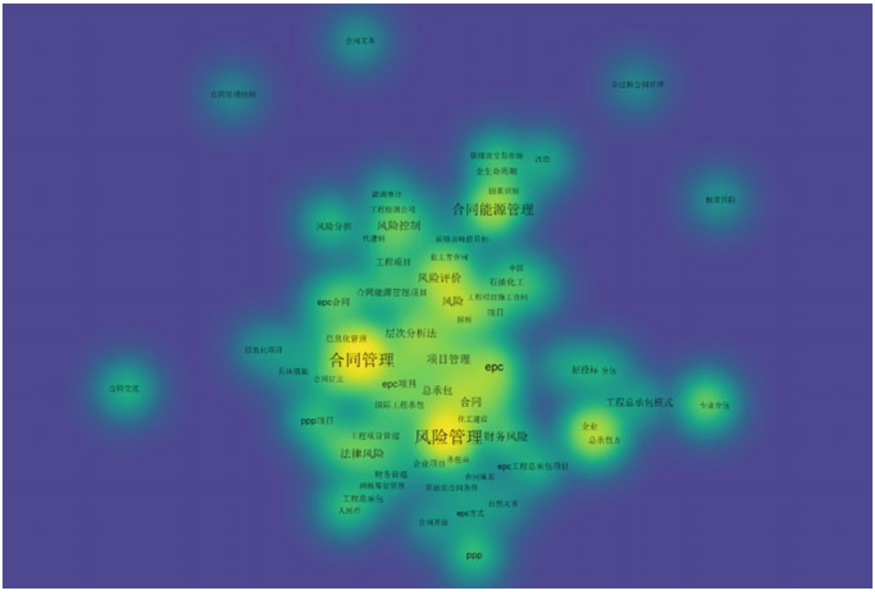

Fig. 2 Heat map of high-frequency keywords related to CNKI

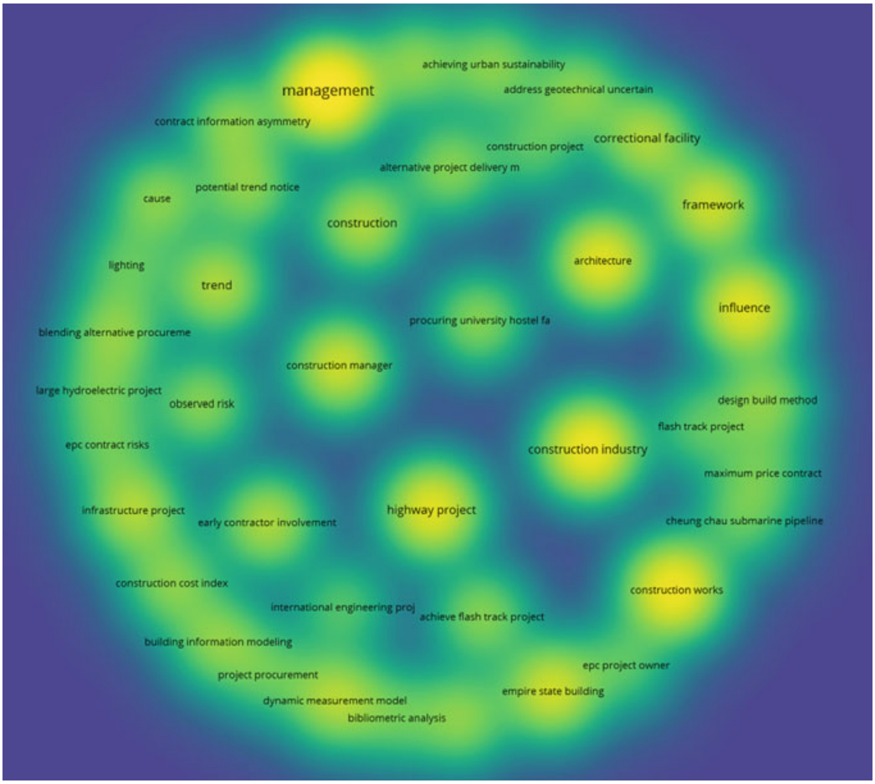

Fig. 3 Heat map of high-frequency keywords related to WOS core database

4 Thematic Analysis

4.1 The Research Hotspot of EPC General Contracting Project Contract Risk Management

As can be seen from Figs. 2 and 3, the research hotspot of EPC general contracting project contract risk management are mainly concentrated in the "EPC project early stage risk management", "EPC project execution process risk management" and "EPC project late stage risk management" three aspects, as shown in Table 1 and Fig. 6.

4.1.1 Early Contract Risk Management of EPC Projects

Early risk management of EPC project contracts needs to pay attention to the formulation of contract clauses and the risk of the contract subject's behavior.

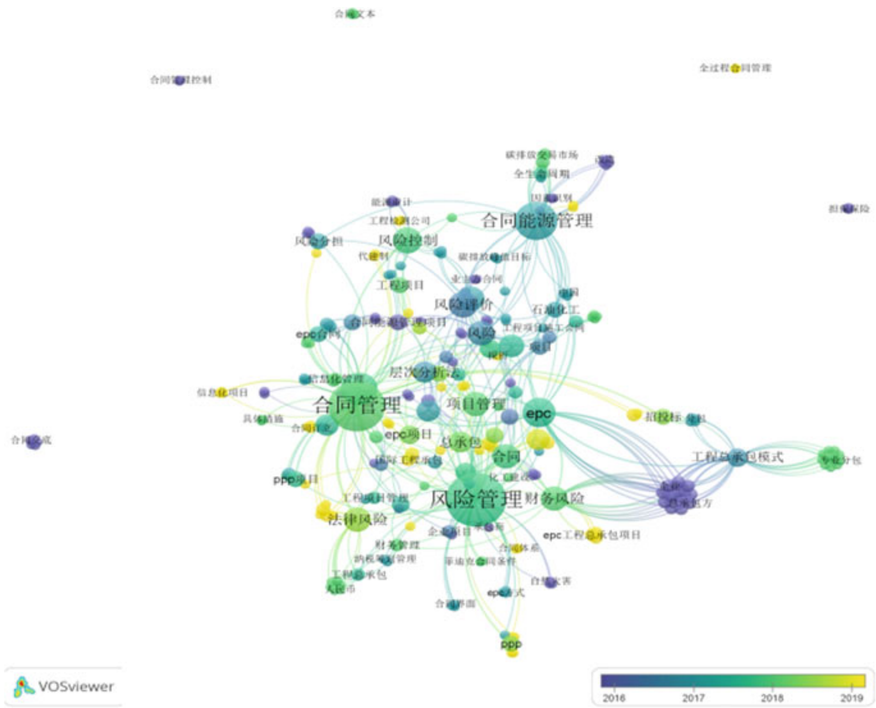

Fig. 4 The superimposed visual analysis of CNKI database of high-frequency keywords

Among them, the main keywords involved in the formulation of contract clauses are “contract text”, “contract system”, “contract agreement” and “contract details”. Previous research has proved the importance of contract clauses risk management. Chen [17] pointed out that contractors must pay attention to the risks of Contract clauses. On the one hand, the key contract clauses of the contract have an extremely important impact on international projects; on the other hand, because international projects generally have a long time from bidding to contract negotiation time, various changes are likely to occur during this period. Liu [18] argued that there are errors, contradictory points, omissions of main clauses, unfinished matters, ambiguities and other issues in the terms of the construction contract, which will lead to major errors in the preparation of bid documents or in the construction of the project, and cause economic losses. Liu [19] pointed out that the contract clause risks of construction enterprises mainly include the tax risk caused by the Yin-Yang contract and the tax risk caused by the defects of the contract itself. The tax risk caused by the Yin-Yang contract will not only affect tax collection work, administrative supervision work and court trial work, but also bring serious tax legal risks to both parties to the construction contract. Some studies point out the key elements of contract clause risk management. Guo [20] argued that relevant personnel must pay attention to the contract review, comprehensively analyze the tax-related clauses in the contract, find out the legal

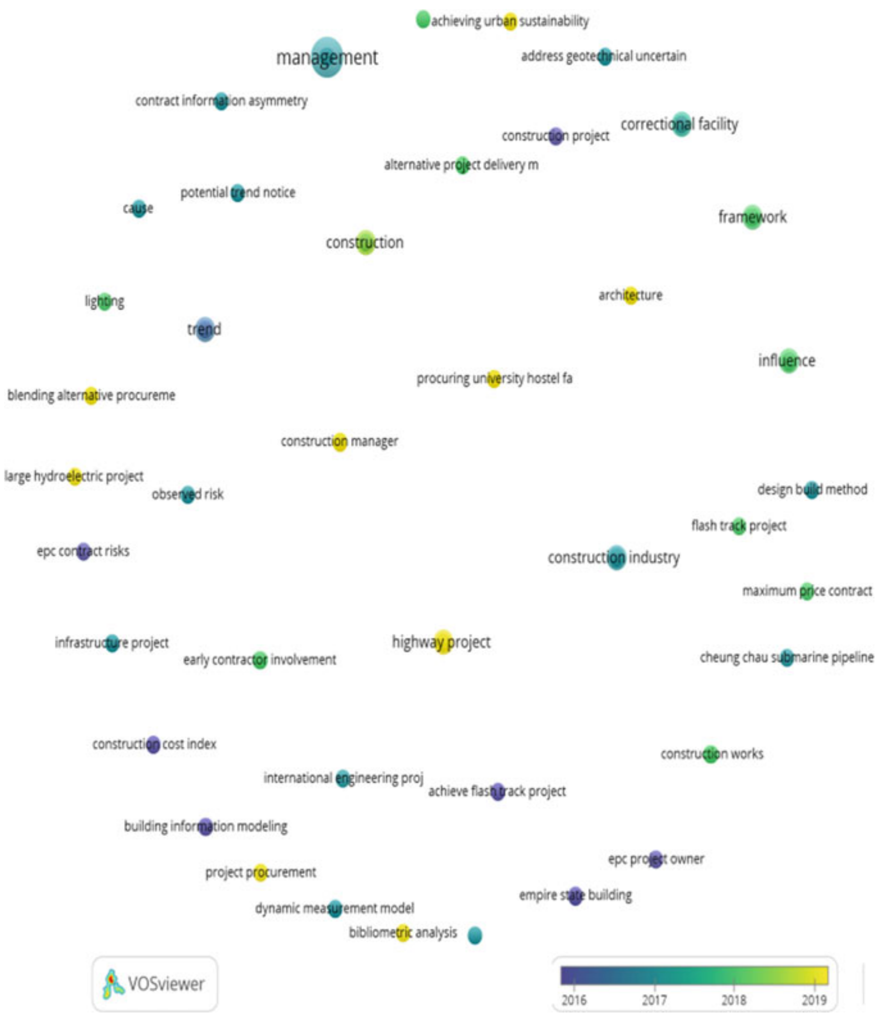

Fig. 5 Visual analysis of high-frequency keywords WOS database overlay

risks, and take measures to prevent the fiscal and tax risks in the contract. Zheng [21] pointed out that the conclusion of contract clauses must follow the principles of equality, voluntariness, honesty and credibility, fairness and justice. Both parties to the contract must carefully consider each clause to prevent the appearance of unequal clauses, unclear meanings, ambiguities, omissions, inappropriate items, and contract types, etc.

The main keywords involved in the risk of the contract subject's behavior are "owner's contract", "subcontractor", "supply contract", "reconnaissance and design enterprise" and "project construction contract". Firstly, when signing the contract, the general contractor has moral hazard, capability risk and coordination risk to

Table 1 Distribution of main high-frequency keywords for contract risk management of EPC general contracting projects

Serial No.	Main high-frequency keywords	Clustering	Serial No.	Main high-frequency keywords	Clustering
1	EPC contract model	A. Contract clauses	36	Project financing	C. Contract risk
2	Ice contract conditions	A. Contract clauses	37	Project risk	C. Contract risk
3	Fidic contract conditions	A. Contract clauses	38	Financing risk	C. Contract risk
4	Model text	A. Contract clauses	39	Financial risk	C. Contract risk
5	Contract system	A. Contract clauses	40	Fund management risk	C. Contract risk
6	Force majeure	A. Contract clauses	41	Operational risk	C. Contract risk
7	Incomplete contract	A. Contract clauses	42	System risk	C. Contract risk
8	Contract text	A. Contract clauses	43	Corrupt practice	C. Contract risk
9	Contract status compensation	A. Contract clauses	44	Performance risk	C. Contract risk
10	Contract interface	A. Contract clauses	45	Risk procurement	C. Contract risk
11	Sign a contract	A. Contract clauses	46	Contract risk response	D. Contract management
12	Contract	A. Contract clauses	47	Contract risk management	D. Contract management
13	Contract confession	A. Contract clauses	48	Contract risk evaluation	D. Contract management
14	Contract formation	A. Contract clauses	49	Contract risk identification	D. Contract management
15	Performance of the contract	A. Contract clauses	50	Contract risk prevention	D. Contract management
16	Contract dispute	A. Contract clauses	51	Safety production management	D. Contract management
17	Contract claim	A. Contract clauses	52	Claims management	D. Contract management
18	Dispute Resolution	A. Contract clauses	53	Tax planning and management	D. Contract management

(continued)

Table 1 (continued)

Serial No.	Main high-frequency keywords	Clustering	Serial No.	Main high-frequency keywords	Clustering
19	Contract management system	A. Contract clauses	54	Standardized management	D. Contract management
20	Contract management control	A. Contract clauses	55	Engineering quality management	D. Contract management
21	Contract management method	A. Contract clauses	56	Supervision and assessment	D. Contract management
22	Contract information asymmetry	A. Contract clauses	57	Regulatory policy	D. Contract management
23	Legal disconnect	A. Contract clauses	58	File management	D. Contract management
24	Subcontractor	B. Subject of contract	59	Financial management	D. Contract management
25	Owner's contract	B. Subject of contract	60	Risk reduction	E. Risk management
26	Supply contract	B. Subject of contract	61	Risk sharing	E. Risk management
27	Survey and design enterprise	B. Subject of contract	62	Risk analysis	E. Risk management
28	Contracts	B. Subject of contract	63	Risk allocation	E. Risk management
29	Engineering construction contract	B. Subject of contract	64	Risk response	E. Risk management
30	Guarantee risk	C. Contract risk	65	Risk control	E. Risk management
31	Refuse to start	C. Contract risk	66	Risk Identification	E. Risk management
32	Engineering claims	C. Contract risk	67	Risk control	E. Risk management
33	Engineering design changes	C. Contract risk	68	Risk transfer	E. Risk management
34	Currency risk	C. Contract risk	69	Risk prevention	E. Risk management
35	Legal risks	C. Contract risk	70	Risk warning	E. Risk management

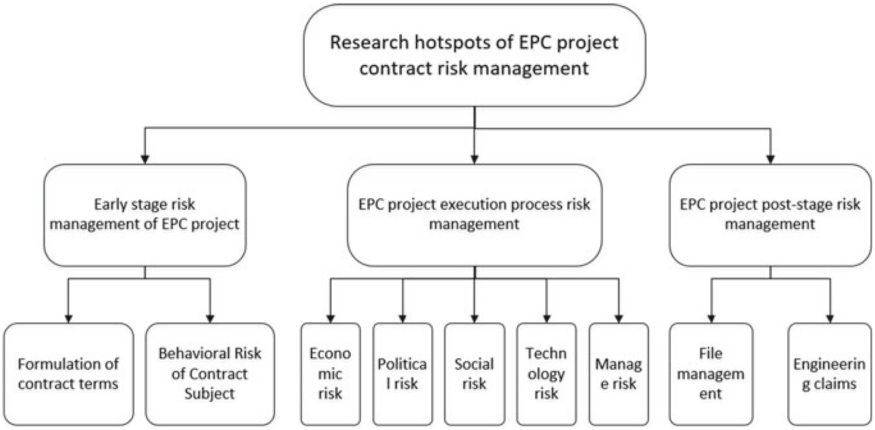

Fig. 6 Research hotspot of contract risk management of EPC general contracting projects

the owner. The owner hopes to choose a general contractor with good reputation, high quality and low quotation, but can only obtain information from bidding materials. In order to defeat many competitors, contractors may choose to conceal or whitewash their own construction qualifications, reputation, technical standards, and construction quality, which may cause the owners to misjudge the actual situation of the general contractor and cause moral hazard. For example, the general contractor concealed wrong records, made false qualifications, fraudulently used the qualifications of others, etc. At the same time, when the contractor prepared the bidding plan, due to the negligence of the preparation, the format and content did not meet the requirements of the owner, and thus missed the opportunity to conclude the contract and caused losses [22]. Secondly, when the general contractor signs a subcontract with a subcontractor, the general contractor sometimes conceals and squeezes the subcontractor in order to obtain more profits. The risk assumed is forcibly transferred to the subcontractor, resulting in moral hazards such as establishing violations of regulations and deceiving the subcontractor [22]. At the same time, the subcontractor is not legally qualified as the subject, the illegal content and form of the subcontractor, the undesirable phenomenon of the subcontractor splitting the contract and then subcontracting, the subcontractor's behavior of relying on the qualifications of other companies, the risk of escrow in the actual construction process will bring great business risks and legal risks to the enterprise, affecting the enterprise reputation, qualification, etc. [23]. Furthermore, procurement has an important impact on the cost, quality and duration of the entire EPC project [24]. Chen [17] pointed out that the procurement risk of the project mainly refers to whether the equipment performance parameters are reasonable, whether there are differences in supply, and whether the construction period of the project is carefully calculated [25]. On the one hand, due to the inadequate supervision of relevant departments and the incomplete national laws and regulations, inferior materials flood the market, damage the quality of the project, and even require rework. On the other hand, when the general contractor is unable to supply in time, the project will be suspended for materials, which will affect the construction period. For those projects with long construction period and high cost, the large fluctuations in the price of construction materials will seriously affect the normal implementation of construction contracts and bring potential quality and safety hazards to the construction of the project [23]. Survey and design are also critical to the success of the project. For the survey and design unit, when the owner selects the design unit, the owner cannot objectively and realistically judge the credibility and technical level of the design unit, and there may be fraudulent behavior of the design unit's qualification. Once the contract is concluded, the owner will face risks such as design delays and changes. For the design cost risk point, the owner will choose a design unit with a lower cost. The fee is low, and the natural design depth will be reduced. During the construction period, there will be more problems and more risks. In short, for the design. When the calculation unit is selected, the design cost paid by the owner must consider the reasonable profit of the design unit, not as low as possible [23]. The construction stage is the final stage of transforming the design plan into the project entity. The construction stage has the characteristics of long time period, high technical content, difficult and complicated construction, etc. The work in the construction stage has a great influence on the realization of the entire project goal [26]. The construction company does not consider market price risks, its own financial strength, and lowers the bid price. The construction enterprise does not consider the market price risk and its own financial strength, and lowers the bidding price. After winning the bid, it is forced by the power of Party A, the limitation of the bidding documents, and compromise in contract negotiation on contract duration, geological, hydrological and meteorological conditions, changes, and price difference adjustment. As a result, the final contract lacks fairness and has some defects. This makes the construction enterprises bear the pressure of project duration, quality, safety, environmental protection, price fluctuations and huge business risks [23].

4.1.2 Contract Risk Management During EPC Project Execution

In the execution of the EPC project contract, the risks in the economic, political, social, technical and management fields must be fully considered.

Regarding economic risks, Yan [23] argued that companies are facing unpredictable contract tax risks, and subcontractors' improper financial management results in their inability to fully deduct output tax and increase tax costs. Lai et al. [27] pointed out that price fluctuations are one of the main factors that cause contract price adjustments, which have a greater impact on the settlement price of the entire project, and require full attention from both parties to the contract. However, in the actual project implementation process, price fluctuations caused. There are many disputes over contract price adjustment.

Political risk is the possibility that political events in a country or changes in the political relationship between a country and other countries will adversely affect the company. In order to avoid the influence of political risks as much as possible, international project signing contracts need to investigate the political stability of the host country in advance, investigate whether there are anti-government armed forces, terrorist forces, and national struggles; whether China's diplomatic relations with the host country are strained; whether the host country is sanctioned by the international community; Whether the government lacks credit, whether project approval is used to delays, whether government officials have serious corruption, etc. [28].

Regarding technical risks, due to the large number of construction projects of construction enterprises and a wide range of technologies, the promotion and application of new techniques and new technologies will inevitably be the phenomenon of neglecting the other in management, which increases business risks. The technical construction method is the basis for controlling the project cost. The technical construction method is unscientific and not rigorous, which will lead to the phenomenon of low production efficiency, wasted work, rework or repeated construction, which will inevitably increase the cost. On the contrary, the excellent construction can be summarized through the accumulation of technology. Construction methods and advanced technology can improve efficiency and save materials, thereby reducing cost input [23].

Regarding risk management, safety and quality are the lifeblood of construction enterprises. Only by focusing on quality and ensuring safety can the construction progress be effectively guaranteed. If safety and quality risk problems occur, it will not only cause serious economic losses to the enterprise, but also the wounded and their families bring misfortune. For construction companies, these problems, ranging from fines to downgrade or revocation of qualifications, have a great impact on the development of construction companies, and the loss of reputation is immeasurable [23].

4.1.3 EPC Project Later Contract Risk Management

The main keywords involved in the later risk management of EPC project contracts are "file management", "project claims", "dispute settlement" and so on. The EPC project involves a large contract amount and a long duration. In the performance of the contract, correspondence, meeting minutes, and visa changes are very frequent. The project leader usually only pays attention to the construction period and project quality, emphasizes the actual amount of work, ignores the deep learning Contract clauses, lacks evidence awareness, does not pay attention to data management, and some companies do not set up special personnel to be responsible for data management and maintenance, or due to personnel changes Part of the data information is lost, which will bring risks to later change claims or audit liquidation [23]. When performing the contract, it is necessary to agree on the terms of breach of contract by both parties in accordance with the principle of fairness, to prevent the owner's unilateral breach of contract from causing unclear claims and procedures, and to strengthen the management of claims and counter-claims, collect and save all evidence of the other party's breach of contract in a timely manner, and ensure that the claim materials are correct Legitimacy, rationality and accuracy; adopt effective claim strategies, and strive for good settlement results through mediation, arbitration, and litigation [28].

4.2 The Research Trends of EPC General Contracting Project Contract Risk Management

Through the superimposed visual analysis of high-frequency keywords, as can be seen from Figs. 4 and 5, it can be found that over time, the contract risk management of EPC general contracting projects mainly focuses on emerging fields such as "informatization management" and "international engineering". On the one hand, in order to meet the development needs of construction enterprises under the new normal of the economy, and to further explore profit growth points, the use of advanced technologies such as BIM to improve the contract risk management level of EPC general contracting projects is an important topic for current construction enterprises [29]; With the development of China's "Going Global" and "One Belt One Road", contract risk management is still the top priority of project operation. contract risk management is one of the most important components in international engineering projects. It is closely connected with the company's relationship and interest chain and is increasingly being valued by foreign contractors. The risks and risks of international engineering contract projects management level is related to the survival of an enterprise.

5 Conclusion

Through bibliometric and visual analysis, this article draws the following conclusions:

(1) Through search and analysis, the research trend of contract risk management of EPC general contracting projects in recent years is obtained. Statistics have found that both China's and English literature have shown a downward trend, indicating that the research interest in EPC project contract risk management is declining. On the one hand, it reflects that the research on EPC project contract risk management has entered a relatively mature stage. On the other hand, it also implies that there are gaps in future research on EPC project contract risk management, and new research fields need to be explored.

(2) Through the analysis of the collinear relationship of high-frequency keywords, the research hotspots of EPC general contracting project contract risk management are mainly concentrated on "EPC project risk management", "EPC project execution process risk management" and "EPC project late risk management" three aspects of management.

(3) Through the superimposed visual analysis of high-frequency keywords, we can obtain that over time, the contract risk management of EPC general contracting projects is mainly concentrated in emerging fields such as "information management" and "international engineering". On the one hand, in order to meet the development needs of construction companies under the new normal of the economy, and to further explore profit growth points, the use of advanced technologies such as BIM to improve the risk management of general contracting projects is an important topic for current construction companies; on the other hand, for emerging fields such as international engineering the contractual risk management of the company will also affect the survival of the enterprise.

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Identification of Spatial Economic Development Model in Chengyu Urban Agglomeration County by Applying Exploratory Spatial Data Analysis

Zhenchuan Yang

Abstract Using the average Night-Time Light Data in the Chengyu Urban Agglomeration County from 2012 to 2019, the spatial weight matrix is defined based on the rook and arc distance contiguity, and the global and local spatial autocorrelation methods in the Exploratory Spatial Data Analysis are used to assess the spatial economic development model of the Chengyu Urban Agglomeration County. The results show that based on rook contiguity, the spatial autocorrelation intensity of the economic development of the Chengyu Urban Agglomeration County can be divided into four ups and downs: in the two phases of 2012–2014 and 2015–2017, the intensity of spatial autocorrelation was on the rise, and the polarization of economic layout was eased; in the two phases of 2014–2015 and 2017–2019, the intensity of spatial autocorrelation was on the decline, the polarization of the economic layout has intensified. Based on the arc distance contiguity, it is preliminarily inferred that the economic impact area of the counties of the Chengyu Urban Agglomeration is about 150 km. Under the two contiguity rules, the economy of the Chengyu Urban Agglomeration County shows a "dual-core" agglomeration development model centered on the downtown area of Chengdu and the main urban area of Chongqing. However, the economic development of other regions needs to be further explored and driven.

Keywords Exploratory spatial data analysis (ESDA) · Night-time light data (NTL) · Chengyu urban agglomeration · Spatial economic development model

1 Introduction

With the acceleration of the global urban process and the continuous expansion of urban extensions, many urban agglomerations have emerged, such as the BosWash agglomeration in the northeastern US, the Pacific Coast agglomeration in Japan,

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the Yangtze Delta agglomeration centered on Shanghai [1]. Generally, the connection between cities in urban agglomeration are highly close, which support global economic development [2]. However, some urban agglomerations also present a Matthew Effect, which leads to the unbalanced and unmatched spatial economic development, such as severe traffic congestion and over concentrated public service resources [3]. Take Chengyu Urban Agglomeration as an example, the two cities of Chongqing and Chengdu gather most of the resources in urban agglomeration. As a result, it is reported that the Gross Domestic Product (GDP) of main urban area of Chongqing and Chengdu accounts for over 55% of that in Chengyu Urban Agglomeration in 2017 [4]. To solve the problem of uncoordinated development among cities in urban agglomerations, it is important to analyze the spatial economic development model of urban agglomerations, which affects the regional form and internal spatial structure. It is also echoed by Jin and Lu that analyzing the spatial structure and causes of spatial economic development model between regions are very useful for accelerating the development of underdeveloped regions and maintaining the competitiveness of developed regions [5].

Previous studies on the spatial economic development model of urban agglomerations can be divided into two categories through different analysis methods: traditional regional spatial and economic difference measurement method and exploratory spatial data analysis (ESDA) method. Traditional regional spatial and economic difference measurement method including Theil Index method [6, 7], standard deviation method [4], coefficient of variation method [8], weighted coefficient of variation method [6, 9], Gini coefficient method [6, 10]. These methods can well reflect the economic differences between different regions from the perspective of statistical characteristic, but cannot superimpose the spatial attributes of the economic data. To overcome this shortcoming, the exploratory spatial data analysis method is employed to analyze the relationship between space and economy [11–14]. ESDA can extract the spatial connection and evolution from complex social and economic phenomenon by describing the spatial dependence and spatial heterogeneity of the data [15]. For example, Julie and Cem applied exploratory spatial data analysis method to conduct empirical research on 138 European regions over the 1980–1995 period, and provided clear evidence of global and local spatial autocorrelation as well as spatial heterogeneity in the distribution of regional per capita GDP [11]. Therefore, the exploratory spatial data analysis (ESDA) method is adopted by this study to analyze spatial economic development model. Furthermore, to enhance effectiveness by applying ESDA method, this study selects night-time light (NTL) as the presentative indicator to describe spatial economic development model. As Zhao et al. [16] and Charlotta et al. [17] pointed out that NTL indicator can better represent economic level compared with traditional indicators like GDP.

On the other hand, in the context of China, as an important support point of country's strategic depth, Chengyu Urban Agglomeration has always been highly concerned by the country and academia on how to achieve coordinated and integrated development within the region [18]. However, the previous studies on the spatial economic development model applying exploratory spatial data analysis (ESDA) method are mostly concentrated in the eastern and central parts of China [19–23],

Fig. 1 Chengyu urban agglomeration county administration division

while less attention is given to Chengyu Urban Agglomeration located in Southwest China. For example, Zhao et al. analyzed spatial economic differences of 184 counties in the Beijing-Tianjin-Hebei region by utilizing ESDA method, and Li et al. explored the spatial economic differences of in Lanzhou-Xining region [20]. Therefore, to better understand the spatial economic relations of Chengyu Urban Agglomeration, this study employed exploratory spatial data analysis (ESDA) method using the average night-time light (NTL) data from 2012 to 2019 to analyze the spatial economic development model of Chengyu Urban Agglomeration.

The rest of this paper is structured as follows: Sect. 2 introduce research area, data source and analysis method. Section 3 demonstrates the application of the exploratory spatial data analysis method through an empirical study on Chengyu Urban Agglomeration and presents demonstration results. Discussions and conclusions are followed by the conclusion in Sect. 4.

2 Research Area, Data Source and Analysis Method

2.1 Research Area and Data Source

The administrative divisions of the Chengyu Urban Agglomeration are shown in Fig. 1, including 142 districts/counties, such as Wuhou, Jinjiang, Yuzhong, and Shapingba. The basic research units in this study are 142 district/county-level administrative units which collectively referred to as counties. It can make a more detailed description of the spatial economic relations within urban agglomeration from the perspective of county, compared with other studies focus on the urban or provincial level [11, 12, 24].

The data in this article is mainly divided into two parts. One is the night-time light (NTL) data, which comes from the 2012–2019 continuous global high-definition night-time light (NTL) data set released by the Chen Fu team of the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences [25]. The average values of NTL data for counties are used as the research basis. The second is the geospatial data of 142 counties in the Chengyu Urban Agglomeration, which comes from the national geographic information resource catalog service system 1:1 million national basic geographic data set.

2.2 Analysis Method

This study uses the most commonly used spatial autocorrelation analysis in exploratory spatial data analysis to characterize the spatial economic development model among county-level units in the Chengyu Urban Agglomeration, including Global Spatial Autocorrelation and Local Spatial Autocorrelation.

2.2.1 Global Spatial Autocorrelation

Global Spatial Autocorrelation reflects the similarity of the attribute values of spatially adjacent regional units. It can be used to analyze the overall spatial correlation and spatial difference of the research area, but it cannot verify the spatial heterogeneity of the local area. Global Spatial Autocorrelation is usually measured by Global Moran's I index [23], which can be calculated as follows:

$$I = \frac{\sum_{i=1}^{n} \sum_{j \neq i}^{n} W_{ij} \left(X_i - \bar{X}\right)\left(X_j - \bar{X}\right)}{S^2 \sum_{i=1}^{n} \sum_{j \neq i}^{n} W_{ij}} \quad (1)$$

where, n is the total number of spatial units in the study area; X_i and X_j is the attribute values of spatial units i and j; $\bar{X}$ is the average of the attributes; $S^2 = \frac{1}{n}\sum_i^n \left(X_i - \bar{X}\right)^2$; W_{ij} is the binary (0,1) space weight matrix.

2.2.2 Local Spatial Autocorrelation

The Local Spatial Autocorrelation can reflect the similarity of the same attribute value between each spatial unit and the surrounding spatial unit, which is used to verify the spatial heterogeneity of the local area and can make up for the defects of the global spatial autocorrelation. Generally, LISA analysis based on Local Moran's I_i is used to measure Local Spatial Autocorrelation [26], which can be calculated as follows:

$$I_i = \frac{\left(X_i - \bar{X}\right)^2}{m_0} \sum_j W_{ij}\left(X_j - \bar{X}\right)$$

where, $m_0 = \sum_i \left(X_i - \bar{X}\right)^2 / n$; W_{ij} is the binary (0, 1) space weight matrix; the sum of j is limited to all neighbors of space unit i, and the number of neighbor space units is determined by the space weight matrix. By Local Spatial Autocorrelation analysis, four spatial economic development models can be obtained: (1) High-High: clusters of high-value spatial units; (2) High-Low: a high-valued spatial unit is isolated in a low-valued spatial unit; (3) Low–High: a low-valued spatial unit is enclosed in a relatively high-valued spatial unit; (4) Low-Low: clusters of low-value spatial units.

3 Empirical Analysis

In exploratory spatial data analysis (ESDA) method, the construction of spatial weight matrix through spatial adjacency rules is the foundation. There are two common spatial relationship rules [27]: (1) Rook contiguity: If the i-th and j-th spatial units have a common boundary, they are considered neighbors, and the element in the spatial weight matrix is 1; otherwise, they are not neighbors and the element is 0. (2) Arc Distance contiguity: If the distance between the i-th and j-th spatial units is within a given critical distance d, they are considered neighbors and the elements in the spatial weight matrix are 1; otherwise, they are not neighbors and the elements are 0. Based on these two kinds of spatial relation rules, this paper carries out the analysis.

3.1 Analysis Based on Rook Contiguity

Arc GIS was used to calculate the Global Moran's I value of the average night-time light (NTL) data of counties in Chengyu Urban Agglomeration from 2012 to 2019, and its significance level was tested, as shown in Table 1.

In Table 1, Moran's I is the global spatial autocorrelation index, Z score is the Z-test score, and p value is the significance test level value. During the whole research period, the estimated values of Global Moran's I were all positive and passed the significance level test, indicating that there was a strong global spatial autocorrelation between the average night-time light (NTL) data in counties of Chengyu Urban Agglomeration. This suggests that the spatial economic development model of 142 counties is spatial cluster.

Furthermore, according to the variation of Global Moran's I, the spatial autocorrelation intensity of county economic development in Chengyu Urban Agglomeration can be divided into four ups and downs from 2012 to 2019: in the two stages from 2012 to 2014 and from 2015 to 2017, the spatial autocorrelation showed a rising trend, and the polarization of economic spatial distribution was alleviated; in the two stages of 2014–2015 and 2017–2019, the spatial autocorrelation showed a downward trend, and the polarization of economic spatial distribution was strengthened. The reason for the increase in the intensity of spatial autocorrelation may be related to the demand for the depth of China's expansion strategy. China regards Chengyu Urban Agglomeration as an important economic growth pole, and implements a series of plans to enhance the intensity of its spatial autocorrelation, such as "Chengyu Economic Zone Regional Planning" and "Chengyu Urban Agglomeration Development Plan". The reason for the decrease in the intensity of spatial autocorrelation may be related to the transformation of China's domestic economic structure and the deterioration of international economic environment. Affected by the economic supply-side structural reforms proposed by China in 2015 and the Sino-US trade friction in 2018, the intensity of spatial autocorrelation in Chengyu Urban Agglomeration has declined.

Arc GIS was also used to conduct LISA analysis, and the level chart of LISA significance was obtained, as shown in Fig. 2.

In general, since 2012, the overall spatial economic development model in Chengyu Urban Agglomeration has remained relatively stable. In terms of the spatial structure of hot spots, most counties in the downtown area of Chengdu and the main

Table 1 The Global Moran's I value of the average night-time light (NTL) data in the counties of Chengyu urban agglomeration from 2012 to 2019 based on rook contiguity

Year	Moran's I	Z score	p value	Year	Moran's I	Z score	p value
2012	0.742119	14.410255	0	2016	0.748205	14.500487	0
2013	0.744942	14.450015	0	2017	0.749992	14.529392	0
2014	0.747064	14.491435	0	2018	0.747875	14.483065	0
2015	0.745263	14.449332	0	2019	0.745026	14.423959	0

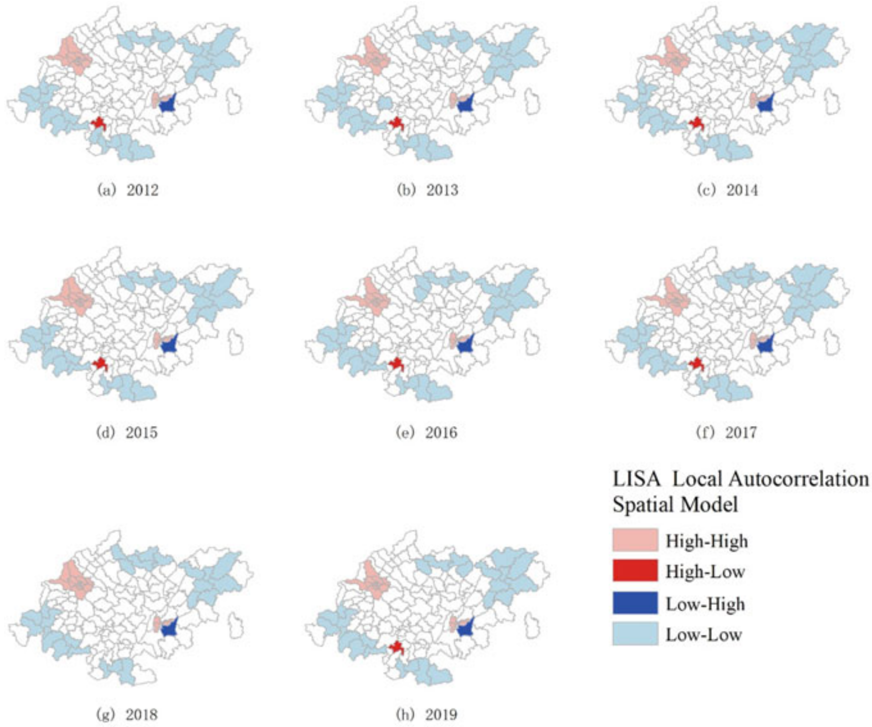

Fig. 2 The level chart of LISA significance based on rook contiguity

urban area of Chongqing belong to the High-High cluster area. However, many counties in the northeast of Chongqing area, the north, the southwest and the south of Chengdu area are all in Low–Low depression area, and the economic development level of these counties has not substantially improved during 2012 and 2019.

From the perspective of variation in the economic development of the four spatial economic development models: (1) in High-High model, Shapingba, Yuzhong, Jiangbei, Nanan, Jiulongpo, Jinniu, Chenghua, Jinjiang, Wuhou, and Qinyang and other 18 counties are always the hot spots. Especially, Dujiangyan county was in High–High model in 2012, 2015, and 2018, while other years in the study period was out of High–High model. (2) in High–Low model, only one county of Chengyu Urban Agglomeration, namely Cuiping county presents High–Low model, which has been maintained in study years other than 2018. This indicating that the siphon effect of Cuiping county is much greater than the radiation effect on the economic development in surrounding counties. (3) In Low–High model, only one county of Chengyu Urban Agglomeration, namely Banan county presents Low–High model throughout the study period. This phenomenon is mainly due to the administrative area of Banan county is large, and internal development imbalance, is only close to Yuzhong, Nanan and Dadukou counties with a high level of regional economic development. (4) In

Low-Low model, Gongxian, Xingwen and Xuyong counties in the south of Chengdu area, Yucheng, Hongya, Hanyuan, Jinkouhe and other 8 counties in the southwest of Chengdu area, Yanting, Nanbu, Yilong, Dachuan and Kaijiang counties in the north of Chengdu area, and Liangping, Kaizhou, Wanzhou, Zhongxian and Dianjiang counties in the northeast of Chongqing area accounting for 21 counties are always in Low–Low model. The counties where the spatial economic development model has changed include Gao, Gulin, Yingjing, Zitong, Shulhong, Langzhong, Yingshan and Xuanhan, a total of 8 counties. In different years, these counties have withdrawn from or entered Low–Low model, and the economic development level of these regions is generally low, lacking of radiation and driving effect.

From the above discussion, it can be found that the spatial economic development model of Chengyu Urban Agglomeration is as follows: On the whole, the economy has certain spatial autocorrelation, but the distribution of economic development in local space has obvious spatial heterogeneity. The heterogeneity is highlighted by the high economic spatial counties agglomeration in downtown Chengdu and the main urban area of Chongqing, while the low economic spatial counties agglomeration in the periphery of Chengyu Urban Agglomeration. Therefore, Chengyu Urban Agglomeration shows an obvious polarization characteristic of "dual-core".

3.2 Analysis Based on Arc Distance Contiguity

The spatial organization of rook contiguity is traditional and strict, and does not take into account the geographical mobility of economic factors. Based on arc distance contiguity, the fluidity of economic development factors is considered, and the observed space units are considered to have a certain radiation distance, and the spatial relationship is determined by taking the radiation distance as the threshold.

The average distance between the center points of adjacent counties in Chengyu Urban Agglomeration is about 30 km by using the tool of calculating the distance between neighboring points in Arc GIS. Considering the influence of different distances on spatial variables, the critical distances of 60 km, 90 km, 150 km, 210 km and 240 km respectively were used to set the spatial weight matrix based on arc distance contiguity. The Arc GIS was used to calculate the Global Moran's I value of the average Night-Time Light (NTL) Data in the counties of Chengyu Urban Agglomeration from 2012 to 2019 under five critical distances, and the significance level test was carried out. The results are shown in Table 2.

It can be seen from Table 2 that, when the critical distance is within 150 km, Global Moran's I value is still positive, and it passes the significance test, indicating that the economic distribution of counties in Chengyu Urban Agglomeration presents a certain spatial autocorrelation. However, when the critical distance is 210 km, Global Moran's I value, although all of them are positive, fails to pass the significance test, indicating that the economic distribution of counties in Chengyu Urban Agglomeration presents the characteristics of random distribution. And when the critical distance is 210 km, the value of Global Moran's I is all negative, indicating that the

Table 2 Global Moran's I estimate of county NTL in Chengyu urban agglomeration from 2012 to 2019 based on arc distance contiguity

Year	60 km		90 km		150 km		210 km		270 km	
	Moran's I	p value	Moran's I	p value	Moran's I	p value	Moran's I	p value	Moran's I	p value
2012	0.5876	0	0.3384	0	0.1253	0	0.0059	0.2075	−0.0240	0.0410
2013	0.5897	0	0.3382	0	0.1250	0	0.0053	0.2300	−0.0246	0.0347
2014	0.5897	0	0.3384	0	0.1251	0	0.0049	0.2445	−0.0249	0.0317
2015	0.5895	0	0.3372	0	0.1247	0	0.0046	0.2585	−0.0250	0.0307
2016	0.5905	0	0.3375	0	0.1245	0	0.0042	0.2733	−0.0251	0.0298
2017	0.5924	0	0.3393	0	0.1250	0	0.0041	0.2777	−0.0253	0.0285
2018	0.5923	0	0.3379	0	0.1239	0	0.0035	0.3070	−0.0255	0.0268
2019	0.5924	0	0.3376	0	0.1239	0	0.0033	0.3131	−0.0258	0.0246

economic distribution of counties in Chengyu Urban Agglomeration presents the characteristics of discrete distribution. According to the first law of geography, all things are related to other things, but things near are more related than things far away [28]. Therefore, it is preliminarily inferred that the influence range between counties of Chengyu Urban Agglomeration is about 150 km.

Under the limit of 60, 90 and 150 km, the LISA analysis was performed on the average Night-Time Light Data (NTL) of counties in Chengyu Urban Agglomeration in 2012–2019 using ArcGIS, and the LISA significance level chart is shown in Fig. 3.

It can be seen from Fig. 3 that the LISA analysis results based on arc distance contiguity are similar to rook contiguity, the Chengyu Urban Agglomeration shows obvious "dual-core" polarization characteristics. However, based on arc distance contiguity, with the increase of critical distance, the number of counties in the "dual-core" belong to high-high areas in the Chengyu Urban Agglomeration increased, and the radiation effect of the "dual-core" was further reflected. There are also a large number of accompanying low–high areas in the periphery of high-high areas. These low–high areas have not been paid attention to by the government for a long time. Their planning and construction are insufficient, the necessary infrastructure and strong industrial clusters are lacking, which lead to poor economic level. These shortcomings have become the main problem hindering the expansion of "dual core" and the integrated development of Chengyu Urban Agglomeration. At the same time, with the increase of critical distance, the low-low areas that were originally only located in the periphery of Chengyu Urban Agglomeration began to spread to the hinterland, and several high-low areas have also appeared. For example, Shizhong, Wutongqiao, and Cuiping counties in the south and southwest, Chuanshan and Shunqing counties in the north of Chengdu area. The economic development of high-low areas has a siphon effect, resources such as funds and talents from the surroundings of high-low areas have been continuously extracted, making high-low areas show high economic values, while the surrounding areas are in depression. From an overall point of view, with the increase of the critical distance, the "Matthew effect"

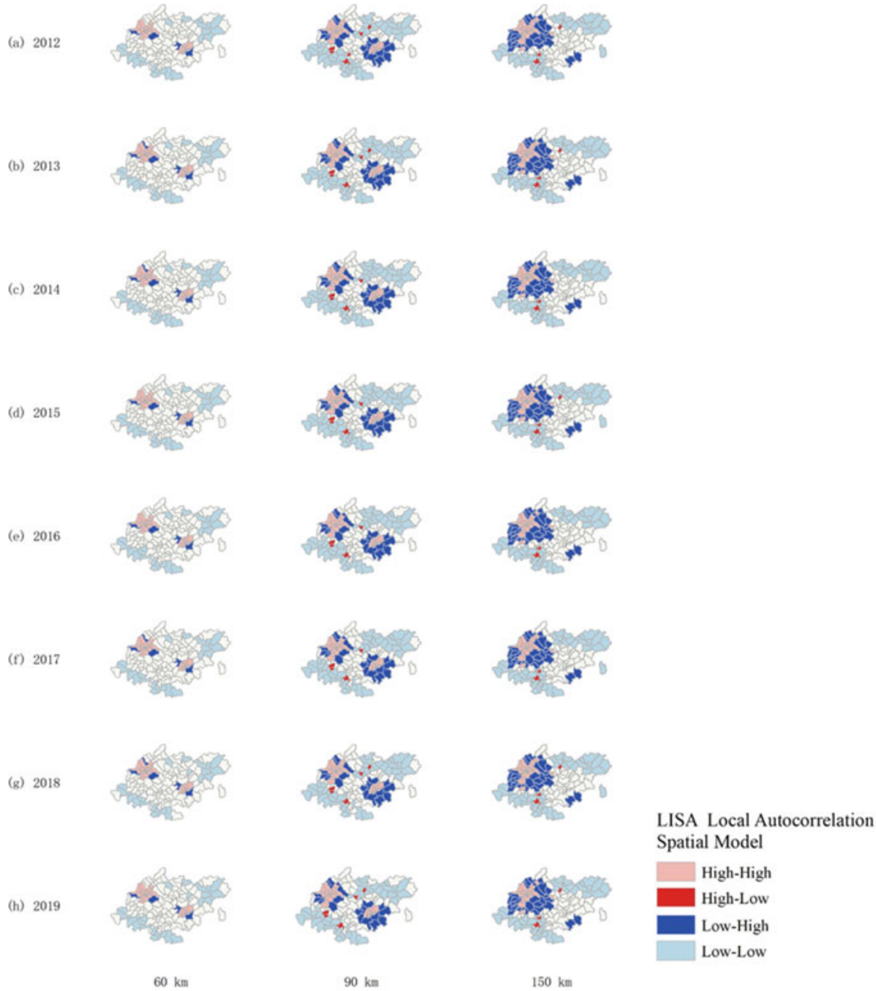

Fig. 3 The level chart of LISA significance based on arc distance contiguity

of economic development in counties of Chengyu Urban Agglomeration becomes more and more obvious.

4 Conclusion and Discussion

This paper uses exploratory spatial data analysis (ESDA) method to explore the county-level spatial economic development model of Chengyu Urban Agglomeration based on Night-Time Light (NTL) data. This study has enriched the research on urban agglomeration by using ESDA method, and for the first time has carried out a detailed discussion on the spatial economic development model of counties in Chengyu Urban Agglomeration. Moreover, Night-Time Light (NTL) data is used as representative indicator to describe economic level, which is considered more effective on the analysis of spatial economic development model.

Based on the empirical study of 142 counties in Chengyu Urban Agglomeration, this study obtained some interesting conclusions, as follows:

(1) Based on the analysis of rook contiguity, from the perspective of global spatial autocorrelation, the spatial autocorrelation intensity of the spatial economic development of counties in Chengyu Urban Agglomeration can be divided into four ups and downs: 2012–2014 is a rising period; 2014–2015 is a falling period; 2015–2017 is a rising period; 2017–2019 is a falling period. From the perspective of local spatial autocorrelation, through LISA analysis, it was found that: Chengyu Urban Agglomeration performs a "dual-core" clustering development characteristic on the downtown area of Chengdu and the main urban area of Chongqing during the study period, where are better developed area. The periphery of "dual-core" area belongs to economic less developed area. And the economic development of each county inside hinterland is independent. Due to the lack of effective spatial organization of economic development, the hinterland areas present a relatively random spatial distribution state, which cannot provide strong support for the integrated development of Chengyu Urban Agglomeration.

(2) Based on the analysis of arc distance contiguity, the economic impact distance of the counties in Chengyu Urban Agglomeration is about 150 km. The spatial economic development model of Chengyu Urban Agglomeration is similar to the analysis result based on rook contiguity. However, with the increase of critical distance, the capacity of radiating to drive economic development in other counties are less and less enough except for the strong radiation capacity of "double core". Thus, more and more low-low areas are generated and spread to the hinterland of the urban agglomeration. In addition, the development of counties around the high-high areas is limited by its own conditions and appears the feature of hollowing out.

In order to solve the problem of unbalanced spatial economic development model in Chengyu Urban Agglomeration. This paper provides three policy advises as follows: (1) The collaborative development mechanism of Chengyu Urban Agglomeration should be designed and implemented from a higher level, which transcends the restriction of Chongqing and Sichuan. (2) Chengyu Urban Agglomeration can strengthen the construction of infrastructure such as high-speed railway and rail transit, which shorten the space and time distance, and contribute to realize the one-hour metropolitan area. (3) Chengyu Urban Agglomeration can carry out regional division of labor and cooperation, and build industrial clusters out of "dual-core" area, which may help with the rise of central and marginal areas of Chengyu Urban Agglomeration.

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Exploring the Job Satisfaction of Chinese Construction Professionals

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Abstract Existing studies showed that the job satisfaction of construction professionals was generally low, and influenced by many factors. But there were few studies focusing on the investigation of construction professionals in China. In this study, the relevant theories were reviewed on the influencing factors of job satisfaction and the moderating effect of demographic factors on job satisfaction, with the aim to evaluate the current situation of job satisfaction of Chinese construction professionals, and to explore the differences of job satisfaction levels among construction professionals with various demographic features. Questionnaire survey was used to collect the perspectives about the job satisfaction from 449 Chinese construction professionals. Statistical analysis results showed that the construction professionals in China generally had a moderate high level of job satisfaction (3.360). The respondents were most satisfied with *interpersonal relationship* (3.953) and *leadership and management* (3.745), while they were least satisfied with *job-related satisfaction* (2.989) and *salary and benefit* (2.837). There were significant differences in some dimensions of job satisfaction among construction professionals with different backgrounds. This study enriches the job satisfaction research in the field of construction management, and provides valuable theoretical reference for managers in the construction industry to improve employee's well-being and job performance.

Keywords Construction professionals · Job satisfaction · Demographic factor · China

1 Introduction

With the rapid development of Chinese national economy and the significant amount of investment into infrastructure, the Chinese construction industry has gradually become an important pillar industry of the national economy. By the end of 2019,

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the number of construction professionals in China had increased to 54.274 million, which is 7.01% of the total employees in China. However, with this high speed of development, many problems emerged that cannot be ignored, such as the low level of job satisfaction and high mobility of construction professionals. In China, professionals in architecture engineering and construction industry mainly work for client, construction enterprise, designers, engineering consulting company and others. Currently, research on job satisfaction mainly focuses on general employees [11] and medical professional [8, 10] and teacher [1, 6, 12]. Very few researches have studied the effect of demographic variables on job satisfaction factors. Therefore, this study aims to investigate the critical factors of job satisfaction, and the differences of job satisfaction among construction professionals with different demographic features (gender, education, position, type of employer, marital status, age, years of working in the construction industry). The research findings are helpful for employees themselves and enterprises to understand the current situation of job satisfaction of the construction professionals in China.

2 Literature Review

Job satisfaction research has been very popular in organizational behaviour [11, 28]. Job Satisfaction defines workers can balance their satisfaction and dissatisfaction in different aspects of work to establish an overall satisfaction [18, 19].The relationship between job satisfaction and job burnout, job intention, work pressure has been explored in existing research [13]. Li et al. [13] analyzed the relationship between job satisfaction and turnover intention of early career employees based on multi-dimensional job satisfaction, and found that there were differences in the influence of six dimensions of job satisfaction on turnover intention, including five dimensions: salary and welfare (−0.216), work itself (−0.205), personal development (−0.181), interpersonal relationship (−0.111) and job competency (−0.110). Dimensions have a significant negative impact on turnover intention, while leadership behavior has no significant impact on turnover intention.

Extensive critical literature review indicates that many factors affect job satisfaction, and there is a complex relationship among them. According to the research of Misener et al. [17] and Shan et al. [24], this research divided the main factors affecting job satisfaction into six aspects: *job-related factors*, *salary and benefit*, *interpersonal relationship*, *career development and training*, *leadership and management*, and *working environment*.

(1) *Job-Related Factors*
The time, stress and content of the work an employee is engaged have a direct impact on his/her job satisfaction [14, 22]. Ren et al. [22] proposed that the length of working time has a direct impact on the job satisfaction of employees. An appropriate working time positively affects the employees' psychological

state, and the work overload would interrupt the normal biological cycle functions and affect their family and social life, which can influence their level of job satisfaction.

(2) *Salary and Benefit*
Salary and benefit are the most important sources of income for most employees [14]. It is the most direct and explicit material affirmation for employees' work [25]. Salary is the main working income for most of the employees. The differences between the salary level of employees and their feeling of reasonable rewarding affect their work enthusiasm [15]. Yang [27] and Tao et al. [25] proposed that whether the benefit system was fair and reasonable directly affected the job satisfaction of employees.

(3) *Interpersonal Relationship*
Interpersonal relationship is the social relationship established by employees in the process of working, mainly including the relationship between superiors and subordinates, and between co-workers. A harmonious co-worker relationship can not only keep employees happy, but also create a productive working atmosphere, exert a positive influence on work initiative and enterprise atmosphere, which will improve employees' job satisfaction [27, 29]. The construction work is usually completed through teamwork, hence a harmonious co-worker relationship will be helpful for employees to maintain a high level of job satisfaction.

(4) *Career Development and Training*
Employees pay much attention to their development opportunities in the enterprise. Therefore whether the career development policy is fair has a great impact on their job satisfaction. When employees believe that the opportunity for promotion is fair, they will be satisfied with their work [5]. Fan et al. [7] found that participation in training had a positive impact on improving the job satisfaction of the new generation of migrant workers.

(5) *Leadership and Management*
The main responsibility of a leader is to coordinate, motivate and manage the members of the organization to achieve the organization goals more efficiently. Competent leaders had a direct impact on employees' awareness of their working environment, as well as on their job satisfaction [4, 16]. In addition, the company's management system also affects the level of employee's job satisfaction. Peng's [20] research showed that poor management system of enterprises restricted the work autonomy of employees and demotivated their work enthusiasm, leading to a low level of employees' job satisfaction.

(6) *Working Environment*
Working environment is the external influencing factor of job satisfaction [4, 21]. The working environments are generally harsh, because of the nature of construction activities, such as high temperature and poor weather conditions. For some construction professionals, they have to work far away from home for long period of time. All these factors may have negative influences on their job satisfaction. In addition, the quality of the working environment directly affects the physiological health and work efficiency of employees [5].

3 Research Methods

The questionnaire survey method was employed to capture the perceptions of Chinese construction professionals on their job satisfaction. Based on critical literature review on job satisfaction, a draft of questionnaire was designed and presented to experienced construction professionals for pilot survey, which resulted in an additional satisfaction evaluation factor: *work-family conflict*. The finalized questionnaire consists of two sections. The first section is to collect demographic features (such as gender and education background) of the respondents in multi-choice format. The second section asked the construction professionals to assess the satisfaction factors according to their own experience in 5 point Likert scale.

Due to the impact of the Coronavirus epidemic in 2020, the questionnaire survey was conducted mainly through online approach and supplemented by face-to-face approach. A total of 480 questionnaires were collected, which produces 449 valid samples for further analysis, including 440 online samples and 9 face-to-face samples. The questionnaire was mainly distributed in Jiangsu Province, located in Southeast China.

The basic information of the respondents is shown in Table 1.

4 Data Analysis

4.1 Descriptive Analysis Results

In this study, SPSS22.0 software was used to test the reliability of the job satisfaction scale. Cronbach's Alpha coefficient of the scale was 0.937, which was significantly over the threshold of 0.7, indicating that the survey results' reliability for further analysis [9].

The descriptive statistical analysis results on the job satisfaction perceived by Chinese construction professionals are shown in Table 2.

According to the statistical data in Table 2, the overall job satisfaction of the respondents is at a moderate high level (3.360). This is similar to the results of Wan et al. [26] on the investigation of job satisfaction of employees in construction enterprises. Among the seven dimensions of job satisfaction, respondents are most satisfied with *interpersonal relationship* (3.953), followed by *leadership and management* (3.745), and *work-family conflict* (3.294). *Salary and benefit* factor is at the lowest level of satisfaction (2.837), and this also corresponds to the conclusion that existing construction professionals are generally dissatisfied with their salary and benefits [2, 23].

The construction industry is labor-intensive with low profit margins. In order to reduce costs, most enterprises adopt low-cost human resource management mode, which makes the respondents dissatisfied with the level of the salary and benefits in general. On the other hand, the working environments in the construction industry

Table 1 Basic information of the respondents

Profile	Classification	Percentage (%)	Profile	Classification	Percentage (%)
Gender	Male	83.96	Marital status	Unmarried	34.30
	Female	16.03		Married	65.70
Education	College Degree and below	31.00	Age	<= 20 year old	0.7
	Bachelor Degree	61.25		21–30 year old	43.43
	Master Degree and above	3.56		31–40 year old	32.74
	Others	4.23		41–50 year old	16.26
	–	–		>= 50 year old	6.90
Position	Grass-roots employees	63.03	Years of working in the construction industry	<= 5 year	34.50
	Department/professional leader	32.52		6–10 years	24.10
	Top managers	2.67		11–15 years	14.70
	other	1.78		16–20 years	12.00
	–	–		>= 20 years	14.70
Type of employer	Client	4.45	Monthly income	<= 3000 RMB	3.34
	Construction enterprise	62.36		3001–6000 RMB	39.87
	Design company	2.90		6001–9000 RMB	26.95
	Supervision company (*Jianli* in Chinese)	24.94		9001–12,000 RMB	14.48
	Engineering consulting firm	4.68		>= 12,000 RMB	15.37
	Others	0.7			

are very poor. Construction professionals undertake high workload with a fast pace. Hence, it is understandable that they have higher expectations for salary and benefit, and comparatively lower level of satisfaction with this aspect.

As to the interpersonal relationship in the construction industry, further interview to construction professionals showed that they generally have good communication and coordination skills [3]. Hence, they are more likely to establish a good working relationship with co-workers, superiors and subordinates. This might also explains why they had a high level of satisfaction in interpersonal relationship.

Table 2 Statistical results of job satisfaction

Dimensions	Mean value	Standard deviation	Rank
Interpersonal relationship satisfaction	3.953	0.780	1
Leadership and management satisfaction	3.745	0.966	2
Work-family conflict satisfaction	3.294	0.958	3
Career development and training satisfaction	3.261	1.043	4
Working environment satisfaction	3.131	0.878	5
Job-related factors satisfaction	2.989	0.824	6
Salary and benefit satisfaction	2.837	1.000	7
Overall job satisfaction	3.360	1.116	/

4.2 *Difference Analysis of Job Satisfaction*

In order to investigate whether the respondents with different demographic features (gender, age, educational background and marital status, etc.) have different perceptions on the job satisfaction level, two sample t-test or analysis of variance (ANOVA) was conducted to different groups of respondents, and the important results are shown in Tables 3, 4, 5 and 6.

4.2.1 ANOVA Results for Subgroup Analysis of Respondents Categorized by Age

ANOVA was used to test the differences of perceptions on various dimensions of job satisfaction among construction professionals with different ages. The analysis results are shown in Table 3.

According to Table 3, construction professionals with different ages have significantly different perceptions on the *interpersonal relationship* satisfaction, *work-family conflict* satisfaction and overall job satisfaction. This result is also similar to that of Wan et al. [26]. In addition, in terms of overall job satisfaction, the aged construction professionals has a higher level of satisfaction than younger generations. When construction professionals are more experienced, it will be more suitable for them to find better work and get higher level of salary. In addition, a more important position will be assigned to them in the organization. As a result, construction professionals appear to get higher level of job satisfaction with the accumulation of age.

Table 3 ANOVA results for subgroup analysis of respondents categorized by age

Dimensions	Mean value					F	Significant
	<= 20 year old	21–30 year old	31–40 year old	41–50 year old	>= 50 year old		
Job-related factors satisfaction	3.400	2.989	2.920	3.071	3.078	0.715	0.582
Salary and benefit satisfaction	2.583	2.769	2.810	2.980	3.089	1.162	0.327
Interpersonal relationship satisfaction	4.333	3.802	4.018	4.128	4.140	3.557	0.007[a]
Career development and training satisfaction	2.583	3.219	3.270	3.343	3.347	0.560	0.692
Leadership and management satisfaction	4.111	3.677	3.753	3.781	4.022	1.012	0.401
Working environment satisfaction	3.222	3.169	3.068	3.069	3.323	0.750	0.558
Work-family conflict satisfaction	2.667	3.214	3.152	3.566	3.893	6.253	0.000[a]
Overall job satisfaction	3.000	3.230	3.350	3.510	3.940	3.176	0.014[a]

Note [a]$p < 0.05$

Table 4 ANOVA results for subgroup analysis of respondents categorized by educational background

Dimensions	Mean value				F	Significant
	College Degree and below	Bachelor Degree	Master Degree and above	Others		
Job-related factors satisfaction	3.065	2.913	3.300	3.263	2.666	0.047
Salary and benefit satisfaction	2.973	2.753	2.750	3.145	3.163	0.92
Interpersonal relationship satisfaction	4.029	3.889	3.792	4.456	3.834	0.010[a]
Career development and training satisfaction	3.351	3.178	3.266	3.790	2.576	0.053
Leadership and management satisfaction	3.871	3.640	3.875	4.246	3.727	0.011[a]
Working environment satisfaction	3.149	3.079	3.500	3.439	2.079	0.102
Work-family conflict satisfaction	3.425	3.198	3.333	3.702	2.985	0.031[a]
Overall job satisfaction	3.480	3.250	3.380	4.00	3.517	0.015[a]

Note [a]$p < 0.05$

Table 5 ANOVA results for subgroup analysis of respondents categorized by working experience

Dimensions	Mean value					F	Significant
	<= 5 year	6–10 year	11–15 year	16–20 year	>= 20 year		
Job-related factors satisfaction	3.079	2.917	2.885	2.937	3.039	1.046	0.383
Salary and benefit satisfaction	2.761	2.884	2.761	2.875	2.985	0.755	0.555
Interpersonal relationship satisfaction	3.796	3.957	4.010	4.124	4.116	2.955	0.020[a]
Career development and training satisfaction	3.213	3.303	3.129	3.435	3.292	0.782	0.537
Leadership and management satisfaction	3.693	3.858	3.616	3.673	3.874	1.147	0.334
Working environment satisfaction	3.228	3.170	2.919	3.062	3.106	1.593	0.175
Work-family conflict satisfaction	3.290	3.062	3.126	3.414	3.753	6.379	0.000[a]
Overall job satisfaction	3.230	3.410	3.200	3.640	3.360	2.272	0.061

Note [a]$p < 0.05$

Table 6 ANOVA results for subgroup analysis of respondents categorized by employer types

Dimensions	Mean value						F	Significant
	Client	Constructor enterprise	Design company	Supervision company	Engineering consult firm	Others		
Job-related factors satisfaction	2.940	2.926	3.046	3.079	3.314	3.200	1.312	0.258
Salary and benefit satisfaction	2.763	2.879	2.577	2.654	3.441	3.250	2.726	0.019[a]
Interpersonal relationship satisfaction	3.900	3.950	3.590	3.982	4.175	3.444	1.160	0.328
Career development and training satisfaction	3.125	3.250	3.077	3.263	3.619	3.333	0.651	0.661
Leadership and management satisfaction	3.567	3.700	3.539	3.824	4.238	3.667	1.637	0.149
Working environment satisfaction	3.433	3.099	3.385	2.994	3.857	3.000	4.360	0.001[a]
Work-family conflict satisfaction	3.183	3.194	3.385	3.452	3.810	3.444	2.575	0.026[a]
Overall job satisfaction	3.150	3.370	3.230	3.320	3.710	3.330	0.631	0.667

Note [a]$p < 0.05$

4.2.2 ANOVA Results for Subgroup Analysis of Respondents Categorized by Educational Background

ANOVA is used to test the differences of perceptions on various dimensions of job satisfaction among construction professionals with different educational background. The analysis results are shown in Table 4.

According to Table 4, it can be seen that construction professionals with different educational backgrounds have significantly different perceptions on *interpersonal relationship* satisfaction, *leadership and management* satisfaction, *work-family conflict* satisfaction and overall job satisfaction. In addition, the higher level of degree for a particular construction professional, the lower level of satisfaction he/she may have with *salary and benefit* and *interpersonal relationship.* This finding is similar to the research results of Yang et al. [27] on cost estimators. It is understandable that construction professionals with higher level of degree tend to have higher level of expectation on salary and benefit, and leadership and management. They may spend more time working for their job, which leads to more work-family conflict.

4.2.3 ANOVA Results for Subgroup Analysis of Respondents Categorized by Working Experience

ANOVA is used to test the difference of perceptions on various dimensions of job satisfaction among construction professionals with different years of working experience. The analysis results are shown in Table 5.

As shown in the Table 5, construction professionals with different years of working experience have significantly different perceptions on *interpersonal relationship* satisfaction and *work-family conflict* satisfaction. By comparing the mean value, it was found that construction professionals with 16–20 years of working experience had the highest level of job satisfaction. Similarly, Lv (2014) also found that technical employees in the construction industry with different years of working experience had significant differences in the dimension of external satisfaction, among which employees with 15–20 years of working experience had the highest external satisfaction.

4.2.4 ANOVA Results for Subgroup Analysis of Respondents Categorized by Employer Types

ANOVA is used to test the differences of perceptions on various dimensions of job satisfaction among construction professionals working for different types of employers. The results are shown in Table 6.

As shown in Table 6, construction professionals working for different types of employers have significantly different perceptions on *salary and benefit* satisfaction, *working environment* satisfaction and *work-family conflict* satisfaction. Further interview with construction professionals found that different types of employers have significantly different level of salary and benefit. In most cases, the construction professionals working for the real estate developers have higher level of payment, but they also generally had a higher level of workload.

5 Conclusions

In order to evaluate the job satisfaction level of Chinese construction professionals, and explore the different perceptions of different types of construction professionals, a questionnaire survey was administered to 449 construction professionals working for a variety of stakeholders. The research results showed that the Chinese construction professionals had a moderate higher level of job satisfaction (3.360). In each dimension, respondents were most satisfied with the *interpersonal relationship* (3.953), *leadership and management* (3.740) and *work-family conflict* (3.294). In contrast, they were less satisfied with *job-related factors* (2.989) and *salary and benefit* (2.837). It was also found that the older the construction professionals were and the longer their working experience they had, the higher level of satisfaction they had with their salary and benefits. Their education level had a "U" shaped relationship with their job satisfaction. The years of working experience also had a positive relationship with job satisfaction level. Construction professionals working for engineering consulting firm had the highest level of job satisfaction. These findings are valuable to understand the current situation of job satisfaction of construction professionals in China and the influence of demographic factors on job satisfaction. Construction enterprises can develop more effective human resource management system, to improve the well-being of their employees and management performance.

There are two main limitations in this study. Because of the influence of COVID-19, the survey was mainly conducted in Jiangsu province, and the results can not represent the situation of China broadly. In addition, some other types of construction professionals were not included in the survey, such as subcontractors and material suppliers. Therefore, a broader survey can be carried out in the future to more comprehensively explore the current situation of job satisfaction of construction professionals in China.

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Research on Cost and Benefit of BIM Application for Construction Enterprises in China

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Abstract Building Information Modelling (BIM) was considered as an effective management tool in improving construction project performance. However, the research into the investment and return on BIM application in the context of the Chinese construction industry is still very limited. Through literature review, the cost factors and benefit indicators of BIM application in construction enterprises were identified, and an evaluation framework of BIM application cost and benefit for the construction enterprises was developed. The questionnaire survey was conducted with 37 BIM professionals to determine the critical cost factors and benefit indicators of BIM application in construction enterprises through the relative importance index (RII) approach. The results indicate that *personnel salary* (0.707), *hardware cost associated with BIM software operation* (0.680) and *consulting service fee* (0.647) are critical cost factors for BIM application, whereas *reduction of change* (0.847), *improvement of design quality* (0.847), and *reduction of project rework* (0.820) are critical benefit indicators for BIM application. The research results provide a theoretical basis for construction enterprises to formulate BIM development strategies.

Keywords Construction enterprise · BIM application · Cost · Benefit · Evaluation indicator system

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1 Introduction

In recent years, the scale of construction projects has increased significantly, the construction technology has become more and more sophisticated, and the requirements of construction projects have enhanced greatly. Therefore, an effective application of BIM by construction enterprises can continuously optimize the efficiency, maximize profits and minimize the construction costs. Since BIM provides the latest, accurate and comprehensive engineering database, construction enterprises can achieve a higher-level of collaboration with other project participants on BIM platform, which can prevent the problems of traditional fragment project delivery method. For example, in Jingdong Group Logistics Park construction project, during the process of joint design review using BIM, 165 problems were found in the drawings in advance and consequently design changes were proposed timely, which also effectively prevented rework and saved the construction cost of RMB 680,000 [35].

To promote the wide application of BIM in Chinese construction industry, the Ministry of Housing and Urban–Rural Development, and other departments continuously issued relevant policies and standards. However, the application of BIM in China is still very low with comparison to other developed countries. One of the primary barriers is that the cost and benefit of BIM application is uncertain and research in this area has been very limited. Additionally, existing research also indicated that majority of benefits of applying BIM in construction project can be achieved in the construction process. However, the investment and return on BIM application from the perspective of construction enterprises is not fully explored, which might restrict the wide application of BIM among these entities. Considering BIM application can save cost, reduce project delivery time and improve quality, promoting the application of BIM by Chinese construction enterprise can further improve their competitive edge in the international construction market. Therefore, this paper aims to identify the critical cost factors and benefit indicators of BIM application from the perspective of construction enterprises.

2 BIM Application Cost and Benefit Evaluation Factors Identification

To identify the BIM application cost and benefit factors for construction enterprises, it is necessary to identify the cost and benefit indicators of BIM application through comprehensive literature review. It was found that some research focus on analyzing the cost and benefit components of BIM application and established an evaluation system. For example, Sun [28] determined the BIM benefit evaluation system based on the combination of literature review and BIM technology application content. Using Delphi method and statistical analysis, five dimensions (finance, product, organization, management and strategy) with 17 factors of BIM application benefit evaluation system was developed which included return on investment, reduction rate of project time, and qualified rate of product. However, no research was conducted on the evaluation of BIM application cost or benefit from the perspective of Chinese construction enterprises.

In the literature review process, 14 publications related to the cost of application BIM were identified. Ahn et al. [1] pointed out that the cost of applying BIM includes BIM software cost and BIM manager salary, which is 0.75–1.5% of the project cost. Xie et al. [33] used literature review method to identify the cost components of BIM application from the perspective of the whole project life cycle, including software cost, hardware cost, labor cost and other costs, and used the DEMATEL method to identify the key cost influencing factors of BIM application, such as market development condition, knowledge sharing, relationship between software, capability maturity model for software, and policy suitability. A total of 8 cost factors of BIM application were accumulated. The cost of BIM application in construction enterprises can be divided into two categories: direct cost (e.g., Giel and Issa [7], Malkin [23], Tan and Guo [29], Wang et al. [30]) and indirect cost [15, 16, 23, 36]. Direct costs are tangible costs that can be measured in currency. The direct costs of BIM application in construction enterprises mainly include the cost of purchasing BIM hardware and software (e.g., Giel and Issa [7], Malkin [23], Tan and Guo [29], Wang et al. [30], Zhao and Yuan [38]), the cost of consulting (e.g., Malkin [23], Wang et al. [30], Yuan [36], Zhao and Yuan [38]) and training (e.g., Giel and Issa [7], Li [15, 16], Malkin [23], Wang et al. [30], Zhao and Yuan [38]), and the personnel salary (e.g., Gie and Issa [7], Malkin [23]; Wang et al. [30], Xie et al. [33], Zhao and Yuan [38]). And the indirect costs mainly refer to the costs brought by the introduction of BIM technology by construction enterprises, such as opportunity cost (e.g., Li [15, 16], Ma et al. [22], Malkin [23], Yuan [36]), coordination cost (e.g., Chen [5]) and marketing cost (e.g., Chen [5]).

In addition, the benefit generated through BIM application for construction enterprises can also be divided into direct benefit and indirect benefit. Direct benefit includes economic benefit (e.g., Bai et al. [2], Barlish and Sullivan [3], Giel and Issa [7], Jin et al. [12], Nepal et al. [24], Song et al. [27], Wang et al. [30]) and product benefit (e.g., Bai et al. [2], Giel and Issa [7], Jin et al. [12], Li [14, 17], Song et al. [27], Tan and Guo [29], Xu [34]), and indirect benefit includes management benefit (e.g., Bryde et al. [4], Li et al. [20], Luo et al. [21], Han et al. [8], Rao [25], Sun [28]), organizational benefit (e.g., Barlish and Sullivan [3], Han et al. [8], Luo et al. [21], Nepal et al. [24], Shen et al. [26], Wu [31]) and strategic benefit (e.g., Bryde et al. [4], Jin et al. [12], Li et al. [19], Han et al. [8], Rao [25], Wu [31], Xu [34]). Huang et al. [11] investigated 204 projects in Singapore and found that the rework rate in projects with BIM application was lower than those projects where BIM is not applied. Furthermore, 64% of the construction projects without applying BIM had rework, while only 46% of the construction projects applying BIM had rework. Huang [9] established the model of engineering cost management based on large amount of BIM application data, aiming to analyze the competition in bidding stage, optimize the bidding scheme, improve the competitive edge of enterprises, simulate construction in construction stage, reduce change and control construction cost, and realize the benefit of BIM applications. Based on the above literature review

Table 1 Overall sample analysis of the importance of BIM application cost factors

Cost factors		Mean	Std	RII	Ranking
Direct cost	Hardware cost associated with BIM software operation $\mathbf{C_1}$	3.460	0.931	0.686	2
	Hardware cost related to assisting BIM application $\mathbf{C_2}$	3.027	0.957	0.584	8
	Software cost $\mathbf{C_3}$	3.324	0.747	0.632	4
	Personnel salary $\mathbf{C_4}$	3.514	0.961	0.708	1
	Training cost $\mathbf{C_5}$	2.973	0.866	0.600	6
	Consulting service fee $\mathbf{C_6}$	3.081	0.954	0.638	3
Indirect cost	Opportunity cost $\mathbf{C_7}$	3.081	0.924	0.622	5
	Coordination cost $\mathbf{C_8}$	3.054	0.848	0.589	7
	Marketing cost $\mathbf{C_9}$	2.865	0.855	0.551	9

results, this paper constructed the benefit index framework of BIM application in construction enterprises (see Tables 1 and 2).

3 Data Collection and Analysis

3.1 Data Collection

Based on critical literature review, a draft of questionnaire was designed and presented to experienced BIM construction professionals for pilot survey. The finalized questionnaire includes three sections. The first section solicits the respondent demographic information, including gender, age, and education background. The second and third sections asked the respondents to assess the importance of each factor (using five-point Likert scale, in which “1” means “totally disagree” and “5” means “totally agree”) relating to BIM application cost and benefit, which is derived from literature review results.

Due to the impact of the outbreak of Coronavirus epidemic in 2020, the questionnaire was primarily distributed and collected through online approach. Fifty-seven questionnaires were administrated to BIM professionals in construction enterprises and 43 were returned, which produced 37 valid questionnaires (with a valid rate of 86.05%). Among the respondents, 86.49% were male, close 90% had undergraduate or above education experience, close 65% of them had more than one years’ working experience in the construction industry and over 50% of them had been working on more than three projects using BIM.

Table 2 Overall sample analysis of the importance of BIM application benefit indicators

Benefit indicators		Mean	Std	RII	Ranking
Economic benefit	Reducing construction costs $\mathbf{B_1}$	3.892	0.809	0.784	7
Product benefit	Improving quality of design $\mathbf{B_2}$	4.081	0.759	0.838	2
	Reducing the number of changes $\mathbf{B_3}$	4.243	0.683	0.859	1
	Reducing rework on projects $\mathbf{B_4}$	4.135	0.713	0.838	2
	Saving project delivery time $\mathbf{B_5}$	3.649	0.824	0.741	11
	Improving the quality of projects $\mathbf{B_6}$	3.703	0.777	0.735	12
	Improving the safety level of projects $\mathbf{B_7}$	3.541	0.900	0.697	13
Management benefit	Reducing project risk $\mathbf{B_8}$	3.757	0.723	0.762	10
	Enhancing the integration between different disciplines in the company $\mathbf{B_9}$	3.946	0.743	0.795	5
	Enhancing the cooperation between different stakeholders $\mathbf{B_{10}}$	3.784	0.886	0.762	10
	Improving communication efficiency $\mathbf{B_{11}}$	3.946	0.780	0.800	4
	Improving the efficiency of work $\mathbf{B_{12}}$	3.892	0.567	0.784	7
	Improving the accuracy of quantity takeoff $\mathbf{B_{13}}$	3.838	0.800	0.773	8
	Reducing the number of claims $\mathbf{B_{14}}$	3.378	0.893	0.697	13
	Reducing the number of disputes $\mathbf{B_{15}}$	3.784	0.750	0.762	10
	Reducing operation and maintenance cost $\mathbf{B_{16}}$	3.676	0.852	0.746	15
	Improving operation and maintenance efficiency $\mathbf{B_{17}}$	3.811	0.660	0.768	9
Organizational benefit	Improving the efficiency of manpower use $\mathbf{B_{18}}$	3.378	0.953	0.670	14
	Improving the ability and quality of employees $\mathbf{B_{19}}$	3.730	0.962	0.768	9
Strategic benefit	Improving the company's competitive advantage $\mathbf{B_{20}}$	4.162	0.800	0.832	3
	Improving customer satisfaction $\mathbf{B_{21}}$	3.892	0.774	0.789	6

3.2 Reliability Test

The *Cronbach's alpha* is generally employed to assess the consistency of different indexes in the same dimension. According to the above standards, this paper used SPSS22.0 software to analyze the reliability of the cost factors and benefit indicators of the application BIM of the construction enterprises in the questionnaire data, respectively. The *Cronbach's alpha* values of cost factors and benefit indicators are 0.703 and 0.913, respectively, which indicates that the stability and reliability of questionnaire data over the threshold for further analysis [32].

3.3 Analysis on the Relative Importance of BIM Application Cost Factors and Benefit Indicators

According to Jin et al. [12], relative importance index (*RII*) was adopted in this paper to measure the magnitude of the cost factors and benefit indicators of BIM application. Ranging from 0 to 1, the *RII* value is calculated with Eq. (1).

$$\mathrm{RII} = \frac{\sum w}{A \times N} \tag{1}$$

where, *W* represents the Likert score (numerical values from 1 to 5) selected by each respondent in the questionnaire. *A* represents the highest score for each item (*A* is 5 in this survey), and *N* represents the number of valid questionnaires. The higher the *RII* value of a factor or indicator, the higher its importance for particular factor or indicator.

3.3.1 Analysis on the Relative Importance of BIM Application Cost Factors

RII was used to collate the importance of each direct cost factor and indirect cost factor based on the perspective from respondents. The results were shown in Table 1.

In order to understand whether the respondents with different demographic features (gender, age and educational background) have different perceptions on the importance of cost factors, two sample t-test or analysis of variance (ANOVA) was conducted to different groups of respondents. And the results found that all *p* values are higher than 0.05, indicating that survey participants have similar views on the importance of BIM application cost factors, regardless of their gender, age and educational background.

From Table 2, it can be seen that the critical cost factors of BIM application for construction enterprises are personnel salary, hardware cost associated with BIM software operation, and consulting service fee.

(1) Personnel Salary
For a single BIM application construction project, the salary of personnel shall be based on the time to hire BIM engineers in the whole project cycle. According to *51job.com*, BIM engineer's salary range is 6000–15,000 Yuan per month. If the construction enterprise subcontracts the BIM application package of the construction project to a BIM consulting firm, the contract amount should be considered as the salary of personnel. Currently, in order to fully apply BIM in their construction projects, some Chinese construction enterprises have recruited a large number of BIM professionals, and established an independent BIM application department, including managers, software developers and so on [14]. In this case, the personnel salary will be much higher with comparison to single application.

(2) Hardware Cost Associated with BIM Software Operation
Hardware cost associated with BIM software operation includes the cost of purchasing hardware/equipment such as computers, storage servers or workstations used by BIM engineers. BIM technology has a high requirement for computer hardware standard, and sometimes the existing computers at the construction enterprises cannot meet the requirements of efficient use of BIM software. Procurement of necessary computers and virtual equipment is a large initial investment for construction enterprises in this type of hardware cost [6].

(3) Consulting Service Fee
As mentioned above, sometimes the BIM application work is outsourced by construction enterprises to a BIM consulting company through bidding, if they do not have in-house BIM talents. For some construction enterprises, they prefer to develop their own BIM team and consider BIM as their long-term development goal. In this case, they may also need the professional service from BIM consulting company for training. In the long run, construction enterprise should follow this later strategy for BIM application, since outsourcing BIM services to other consultants will increase their costs significantly when their business is booming [14].

According to the survey report of Dodge Data & Analytics (2015), construction enterprises invest most of the BIM cost through promotion incentive mechanism (20% of the budget for BIM application) to encourage employees to use BIM, and this part of cost can be considered as personnel salary. This investigation result is also similar to current research which highlights the importance of personnel cost in applying BIM in Chinese construction enterprises.

3.3.2 Analysis on the Relative Importance of BIM Application Benefit Indicators

Similar to the cost analysis, the results *RII* about BIM application benefit are shown in Table 2.

Similarly, two sample t-test or ANOVA was conducted to different groups of respondents. And the results indicated that survey participants have a similar view on the importance of BIM application benefit indicators, regardless of their gender, age and educational background.

From Table 2, it can be found that the critical benefit indicators of BIM application in construction enterprises are *reduction of change* (0.847), *improvement of design quality* (0.847), and *reduction of project rework* (0.820).

(1) Reduction of change
Before construction, BIM can be used to carry out the clash detection among various disciplines and to optimize the drawings. Since majority of changes are design oriented, and as a result the changes can be reduced because design error or omission is prevented through applying BIM in the design process [31]. In addition, BIM can be used to simulate the construction of project, and in this process, the construction methods can be verified and communication between different stakeholders can be improved. These will also lead to less changes to the site construction.

(2) Improvement of design quality
As mentioned above, the integration of design from different disciplines can be achieved through using BIM technology in the design process. This enables the design team to detect design errors and omissions which cannot be effectively implemented in the traditional design process [7]. In addition, the design team member can get timely information about the change of design from other designers or other participants (e.g., subcontractors) and make revision accordingly. BIM can also facilitate designers carrying out design performance analysis to optimize the design, such as saving energy during the life cycle of project construction and operation. All these can improve the design quality with the assistance of BIM application.

(3) Reduction of project rework
Huang et al. [10] claimed that the rework of the construction project is due to the owner's changes to the contract content, design and procurement errors, suppliers' errors, changes and omissions in materials, machinery, manufacturing and transportation, construction enterprises' conflicts or inappropriate cooperation with the subcontractors and other factors. Construction enterprises can use BIM to verify the drawings from the client and detect quality problems before construction, which will significantly reduce rework in construction projects.

Kaner et al. [13] found that through applying BIM in the projects the design quality of construction projects was significantly improved for error-free drawings, and the labor productivity was steadily improved. These research results are similar to the findings of current paper. However, Bryde et al. [4] concluded that the most influential benefit of BIM application was cost control (60%), followed by communication and project time (27%). This is contradictory to current research which indicated that the most critical benefits through BIM application were strategic benefit, product benefit and economic benefit.

4 Conclusion

Building Information Modelling (BIM) was considered as an effective management tool in improving construction project performance. However, the research into the investment and return on BIM application from the perspective of Chinese construction enterprises is scant. Understanding the actual cost and benefit of BIM application is a precondition of adopting BIM in their business. This paper aims to identify critical factors influencing the cost and benefit of BIM application in the Chinese construction industry. Questionnaire survey to BIM professionals was conducted to gather their insights and statistical analysis was followed to obtain research results. It was found that *personnel salary* (0.707), *hardware cost associated with BIM software operation* (0.680) and *consulting service fee* (0.647) are critical cost factors for BIM application, whereas *reduction of change* (0.847), *improvement of design quality* (0.847), and *reduction of project rework* (0.820) are critical benefit indicators for BIM application. In addition, construction professionals with different demographic features share similar perceptions about the importance of cost and benefit factors. Cost and benefit frameworks were also developed according to the data analysis results.

The BIM application cost and benefit evaluation system constructed in this paper can enable construction enterprises to comprehensively calculate the investments and returns of BIM application in actual construction projects, which will be helpful for them to formulate effective policies for their business operation. In addition, the researchers in this field can embark on future study about the cost and benefit of BIM application from the perspectives of other stakeholders. Due to the outbreak of Coronavirus epidemic and less availability of BIM professionals with comparison to other research topic in construction management field (e.g., risk management), only 37 valid responses were gathered for data analysis. Similarly, Zhang's [37] research in PPP also used 46 valid survey response for statistical analysis. Considering this, the research findings of this paper are valuable for researchers and practitioners understanding more comprehensively about the cost and benefit of BIM application in Chinese construction enterprises.

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Review of Learning Causal Bayesian Network for Diagnostical Analysis in Construction Resources Management

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Abstract With the increasing scale and complexity of infrastructure and building projects, construction resources must be managed and utilized to nearly full efficiency to meet the project needs and performance criteria. In recent decades, various computerized resource management systems have been deployed by contractors to keep daily records of resources including labor, material, and equipment, for the purposes of book-keeping and decision support. This paper discusses the learning of causal Bayesian network from data for knowledge acquisition, presentation, and decision support for diagnostic analysis of resources. The most important concept of Bayesian network learning, i.e., Markov blanket and d-separation, is studied for discovering the causal relationships among the decision variables and outcomes from data and then creating the Bayesian network for diagnostic analysis. One application is used to illustrate the Bayesian network learning for failure analysis of construction equipment.

Keywords Causal relationships · Bayesian network · Artificial intelligence · Construction resources · Diagnostic analysis

1 Introduction

In recent decades, large amounts of investment have been directed to infrastructure and building projects worldwide. With increasing scale and complexity of projects, the contractors are confronted with the challenges of managing resources effectively and efficiently to gain competitive edge in the market. Most of the large and medium sized contractors have deployed computerized resource management

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system for tracking and managing resources, such as Enterprise Resource Planning (ERP) systems, project management systems, human resource management systems, material and equipment management systems, etc. These systems provide day to day records of resources, but also provide management and performance related data which can be turned into a set of performance metrics in the form of dashboard for decision support by contractors. With large amounts of data collected, there is increasing need for analyzing the data for fact-based decision support, i.e. shifting from experience based decision-making approaches to intelligent data-driven paradigm.

Among all the machine learning algorithms, Bayesian network is one of the most favorable choice for diagnostic analysis because its simplicity and explicit form of knowledge representation in a visual format. Based on the concept of Bayesian probability, Bayesian network is a probabilistic graphical network model depicting the casual or dependency relationships among the decision variables describing the controls, decisions, observation, etc. in a system. The ability of presenting the interdependences among various decision variables in a visual and compact format is one of the most plausible features of Bayesian network for decision support, which allows the decision makers to depict, update, and validate the models for decision support in an engineering system.

Although Bayesian network can be constructed based on expert knowledge, namely Bayesian Belief Network, Bayesian network can also be machine learned from data through supervised or unsupervised learning. As a matter of fact, Bayesian network learned from data reflects the hidden cause-effects relationships in an engineering system, which cannot be elicited by experts due to the dynamic and complex nature of the system. On the other hand, it is also possible for the known relations or prior knowledge of rules be pre-defined visually in the system before learning of causal relationships from data.

Diagnostic analysis is a common task in engineering system, with the goal of identifying the decision factors or events that can lead to a problem outcome such as cases of underperformance, anomalies, or a pre-defined state. In construction resource management, diagnostic analysis is widely used for various management activities for improving productivity, labor safety performance, optimization of equipment deployment and operations, to name a few. Bayesian network has demonstrated capability in modeling and resolving diagnostic problems.

This paper first reviews the Bayesian network and applications, discusses the inference of causality among the observations using Markov blanket assumption and d-separation, then uses two application examples in labor safety management, and construction equipment management respectively to explore the methodology and issues involved in Bayesian network learning.

2 Bayesian Network for Decision Support

The Bayesian networks can handle well those decision support tasks involving multiple factors in a complex system under uncertainties, and Bayesian Network modelling has been applied to construction management for decision analysis. In McCabe et al. [1] and McCabe and AbouRizk [2], the Bayesian networks are combined with simulation models for automatic resource optimization on earth-moving operations. In their research, Bayesian Belief Networks are used to suggest remedial actions on equipment resources that will improve the project performance. McCabe [3] also discussed the opportunities of Belief networks for various engineering applications. Chung et al. [4] applied Bayesian techniques on a tunneling project for updating the TBM penetrating rate based on accumulated evidence on project performance. Bayraktar and Hastak [5] applied a Bayesian network in a decision support system for evaluating different construction strategies based on the Bayesian Network predictions on a set of project performance indicators. Even though these research publications demonstrated the effectiveness of the Bayesian network in prediction under uncertain and complex conditions, most of the Bayesian networks were created with expert knowledge on decision variables and cause-effect relationships identified primarily by domain experts.

3 Causality Induction from Data

Bayesian network is a directed acyclic graphical network with decision notes and directed connecting arcs. The directed arcs in the Bayesian network indicate causal relations, with arrows pointing to the child nodes or effect nodes. Except for root nodes with a prior distribution over a range of values (discrete), every node is conditional on its parents, aka, a case of multiple causes leading to a common effect. Every node has decedents except for the sink node, which denotes a result without further effects within the system boundary. Figure 1 shows a Bayesian network for diagnostic analysis of reworking of rebar works in construction activities.

According to Howard [6], definition of a node must pass the clarity test, its states must be clearly defined without ambiguity. In Fig. 1, node *PoorSiteConditions* should be described by a set of weather and workface measures, such as wind speed, temperature, number of workers on the workplace, as agreed upon by decision makers. As uncertainty prevails all the time, only these abnormal conditions will be defined as in the state of *Poor*. Unfortunately, not all the variables (either cause or effect) can be measured, expert judgement is necessary for some variables, like the *Ambiguity of Design*, measuring whether design details are insufficient for inexperienced rebar fixers to interpret correctly.

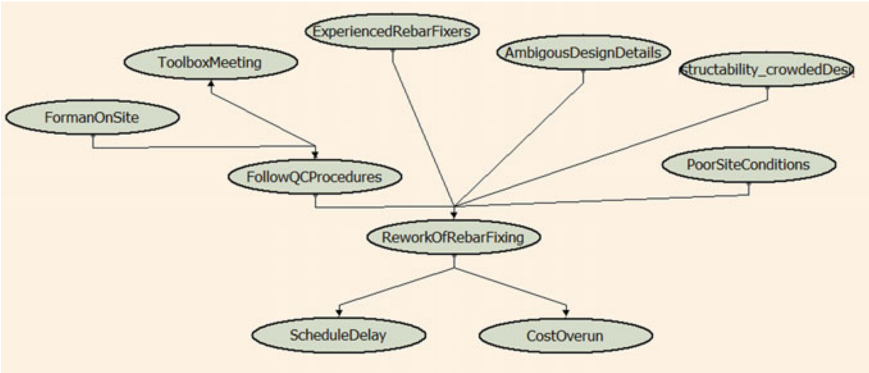


Fig. 1 Bayesian network for rework of rebar fixing

4 Definition of Markov Blanket

Markov Blanket is defined for a decision node for casual structure learning. Pearl [6] defined the Markov Blanket of a node X in a Bayesian Network as the union of the following three types of neighbors: the direct parents of X, the direct successors of X, and all direct parents of X' s direct successors. The state of node X is independent of the nodes outside the Markov blanket family, which is coined Causal Markov Condition by Pearl [7].

This definition shields the Node X from the rest of the network other than its close neighbors in Markov Blanket, i.e. the state of Node X is only dependent on the nodes in its Markov Blanket. For Example, the note *FellowQCProcedures* has its parents notes *FormanOnSite* and *ToolBoxMeeting*, its child note *ReworkofRebarFixing*, these four notes are in a kin family of Markov blanket. The note *ReworkofRebarFixing* has 5 parent notes and 2 child notes.

5 Dependency and d-separation

Given two variables X and Y, or two nodes in the causal graphical model, only a correlation or association relation can be inferred between them, no causality can be inferred without additional variables for establishing sets of conditional probabilities.

If the variables X and Y are independent, knowing the state of one variable will provide no evidential information on the state of the other one:

$$P(X) = P(X|Y) \text{ and } P(Y) = P(Y|X) \tag{1}$$

or

$$P(X, Y) = 0 \tag{2}$$

However, this does not indicate that the two variables X and Y have no dependency relationship, the dependency relationships can exist through a third or fourth variable.

If Z stands for an evidence or condition for X and Y, If X and Y are independency given Z, there must be a probabilistic statement as shown in Eq. (3):

$$P(X|Z) \cdot P(X|Z) = P(X, Y|Z) \tag{3}$$

where

$P(X|Z)$—Probability of X Given Z.

$P(Y|Z)$—Probability of Y Given Z.

$P(X, Y|Z)$—Probability of both X and Y Given Z.

In Fig. 1, *Lack of Experience* of a rebar fixer is not dependent on *Ambiguity of design drawings*, and vice versa. Knowing one will give no information on the other, which indicates the statistical independency between the two variables.

d-separation (d stands for "directional") is used to determine if a variable X is independent of Y given evidence Z. The intention is to create a mapping between the directed acyclic graph (DAG) and the conditional probability information. A triplet case involving three variables X, Y and third variable Z is the basic form of independence for judging if two variables are independent based on a third or other variables, therefore indicating dependency or independency between the two nodes. Assuming X, Y, Z is a discrete joint set of variables, there are three possible causal relationships, which are shown in Fig. 2 and explained below:

1. Diverging node on common causes (X and Y are d-separated, conditional on Z. no direct connection between X and Y.)
   As shown in Fig. 2a, the diverging case indicates that Node Z is a common cause of effects X and Y. X and Y is independent conditional on Z. If the condition of Z is known, X and Y becomes independent, i.e. P(X|Z)=P(X|Y, Z), and P(Y|Z)=P(Y|X, Z), X and Y do not give mutual information given the state of Z.

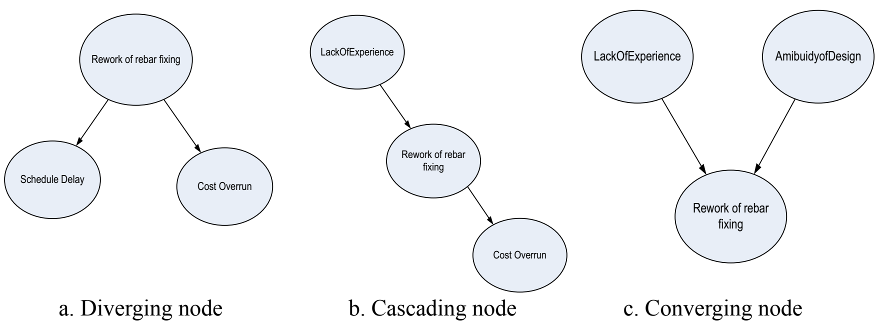


Fig. 2 Three triplet relations of d-separation

For example, in the case shown in Fig. 1, once we know there is a rework on rebar fixing, schedule delay and Cost overrun are separate effect with no mutual information.

The joint probability of the three variables is taken as Eq. (4):

$$P(X, Y, Z) = P(Z) \cdot P(X|Z) \cdot P(Y|Z) \tag{4}$$

2. Cascading case on chained effects (X and Y are d-separated) (I(X,Y|Z)), no connection between X and Y.

   A cascading case is shown in Fig. 2b, where X causes Z and then Z causes Y, X is a direct cause of Z and an indirect cause of Y, X and Y is dependent. However, if the state of node Z is known (yes—rework of rebar fixing), X and Y is not dependent anymore, node *costOverrun* cannot be inferred from the node *LackofExperience*.

   The joint probability of the three variables is taken as Eq. (5):

$$P(X, Y, Z) = P(X) \cdot P(Z|X) \cdot P(Y|Z) \tag{5}$$

3. Converging case on common effects (X and Y are de-separated, conditional on Z) (I(X,Y|Z)), X and Y are independent on each other, given the state of Z.

   The converging case is shown in Fig. 2c, which shows two independent variables X and Y cause a common effect Z. X and Y are independent conditional on Z, the reason is once we know the condition of Z (rework of rebar fixing), and knowing the state of X (lack of experience) being true will diminish the possibility of "Ambiguity of design", and knowing X being false will increase the possibility of Y, this is the "explain-away" effects [8].

   The joint probability of the three variables is taken as Eq. (6):

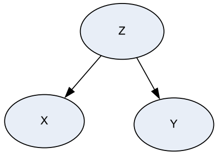
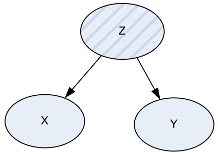
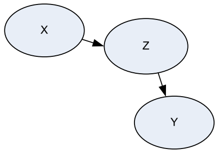
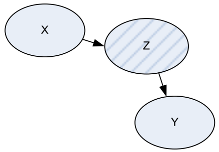
$$P(X, Y, Z) = P(X) \cdot P(Y) \cdot P(Z|X, Y) \tag{6}$$

The triplet cases of independency relations are summarized in Table 1.

D-separation of all the other cases involving multiple sets of variables can be judged based on the triplet cases. For example, in Fig. 3 node *ExperiencedBarFixer* is independent of node *CostOverrun* as there is no active path between the two nodes. In summary, if two variables X, and Y are d-separated, it means all the chain paths between X and Y are blocked, there are no active paths.

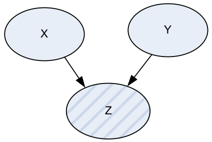
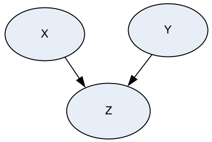
In order to map the conditional independency statements to a DAG, the following faithfulness condition must be satisfied: *The observed probability distribution P of a set of observed random variables V satisfies the Markov condition with the causal DAG G containing the variables, all conditional independencies in the observed distribution P are entailed by the Markov condition in G, we say we are making the causal faithfulness assumption* [8]. Faithfulness condition ensures all the conditional dependency and independency statements are described by graphical Bayesian model, and verse versa.

Table 1 D-separation relationships for triplet relations

	Active	Blocked (inactive)	Remarks
Common cause relation, tail to tail		 (if the state of Z is known)	Given the state of Z, X and Y are independent: $I(X, Y\|Z)$ $P(X, Y, Z) =$ $P(X) \cdot P(Z\|X) \cdot P(Y\|Z)$
Casual chain relation, head to tail, or tail to head		 (if the state of Z is known)	Given the state of Z, X and Y are independent: $I(X, Y\|Z)$ $P(X, Y, Z) =$ $P(X) \cdot P(Z\|X) \cdot P(Y\|Z)$

(continued)

Table 1 (continued)

	Active	Blocked (inactive)	Remarks
Common effect (v-structure) relation, head to head, or collider	 (if the state of Z is known)		Given the state of Z, X and Y are not independent on each other anymore: $\bar{I}(X, Y\|Z)$ $P(X, Y, Z) = P(X) \cdot P(Y) \cdot P(Z\|X, Y)$

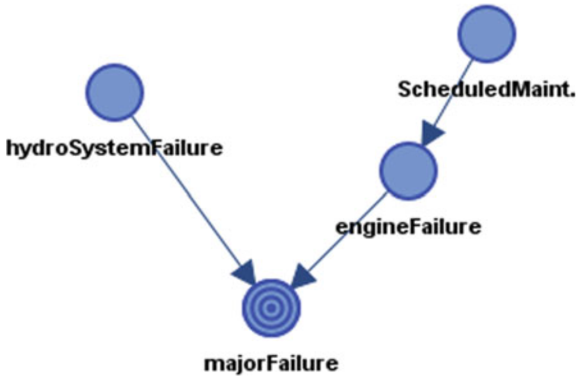


Fig. 3 Major failures of Caterpillar motor scrapers

6 Learning Bayesian Network from Data

There are two categories of approaches for learning Bayesian network structures: the first category is constraint based, i.e. build the causal Bayesian network based on the conditional independence and dependence condition statement in the training data; the second category is search and score based, which uses a scoring approach to measure the fitness of Bayesian network structure to data, and repeatedly modify and improve the network until the optimum structure is obtained. Score and search method has gained popularity due to its simplicity and effectiveness.

Score and search method aims to find a Bayesian network structure that is the best to describe the training data. If the number of variables and the number of state of each variable is small, the computer can conduct an exhaustive search to compare all types of possible structures to find the best one using a scoring method such as Minimum Description Length (MDL). In reality, if the number of variables and number of variable states increases, its possible search space is super exponentially increasing and it becomes an NP-complete problem for which an exact solution becomes impossible. As a result, greedy search algorithms (genetic algorithm, etc.) are used to search for local optimum solutions, with multiple restart with the aim of escape out of local optimum.

7 Minimum Description Length (Score)

Entropy is a measure of "uncertainty", i.e. the amount of information contained in one fact about another. Claude Shannon [9] proposed the measure of entropy using Eq. (7):

$$H(x) = -\sum_{x \in X} p(x) \times \log_2 p(x) \tag{7}$$

If H(x) is 0, there is no information on the likelihood of event from the observation x, a larger value indicates larger amount of information. For example, in Fig. 1, if we know there is a rework of rebar fixing for a slab, then the activity of pouring concrete for slab will likely be delayed, but we do not know if the slab construction in another building will be delayed.

Minim Description length score of a Bayesian network model can be measured using the weighted average of model complexity and fitness of model as shown in Eq. (8) with the given dataset for training:

$$MDL(B, D) = \alpha * DL(B) + DL(D|B) \tag{8}$$

DL(B) represents the Bayesian network graph and probabilities, DL(D|B) represents the likelihood for the data given the Bayesian network. Coefficient α is to adjust the weighting of the two measurement scores to strike a balance between the model complexity and model fitness to data, with the second term being introduced to avoid overfitting problem in learning the model.

The starting network structure can be randomly generated or constructed using existing domain knowledge. By searching over the neighborhood of a current network structure (i.e. trying to add, delete, or reverse an edge), improvement of the structure in terms of MDL is evaluated for each possible change, and the best change is chosen for the next step.

If the network structure cannot be improved through local search or has reached an optimum, restart with another network structure and repeat the optimization process, finally the global optimum structure can be selected from the multiple local optimum structures generated.

8 Application: Failure Diagnostics of Construction Equipment

A contractor operates a large fleet of equipment for road construction works, and the equipment failures must be diagnosed with repair works completed as soon as possible. Minor repairs can be completed in the field with minimum impact on the project, yet major failures may involve lengthy time of diagnostics, waiting for replacement of components, or replacement of a substitute equipment. The contractor needs to analyze the equipment failure data and identify those factors which have caused the major failures with time to repair exceeding 3 h. 108 records on major failures were extracted from the equipment maintenance database in a 4-year period for the all the Caterpillar Motor Scrapers in the contractor's equipment fleet.

The Bayesian network in Fig. 3 is trained with the failure records using BayesiaLab [10]. It shows that among all the subsystems of the equipment, both engine failures and hydraulic system failures tend to cause major failures of the equipment. Scheduled maintenance (implemented strictly or not) has direct causal effects on the engine failures, and subsequently resulting in major failures of the equipment.

9 Conclusions

Managing construction resources involve the tasks of evaluating the resource performance and taking corrective actions in the case of underperformance or failures. Large amounts of data collected through computerized system allow for in-depth analysis of these data for continuous monitoring and improvement. Continuously developing AI tools and increasing computing power can help to generate causal knowledge for diagnostic analysis, which is an important decision support task in resource management.

Causal Bayesian network is a graphical network with directed acyclic graphic links, knowledge and rules can be acquired explicitly from observed data through machine learning algorithms. This paper discusses basic concepts and methods related to Bayesian network learning from data, including causal relationship learning, Markov blanket, d-separation, search and score algorithm for Bayesian structure learning etc. The two application examples show that Bayesian network can be built automatically with intuitive results through the learning and training process. Although the data sample size may not be large enough to allow for building of a complex network structure, partial network structure shows clearly the cause-effect relationships between different decision and outcome nodes, these uncovered relationships may not be easily quantified by the domain experts in some cases. In addition, The AI software allows the incorporation of known domain knowledge into the Bayesian network through a visual interface in the form of predefined decision variables, relationships, constraints, etc. before the Bayesian network learning. Some limitations in this research include limited size of data for network learning, and its non-experimental and explorative nature.

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Examining Waste Generation from Construction Activities of High-Rise Building Projects in India

Janardhana Swamy Vegulla and Djoen San Santoso

Abstract Economic growth and urbanization in developing countries lead to significant construction activities that generate a huge amount of waste, which is a key problem in various cities. In this regard, managing waste should become an important and integrated task in project execution. This study aims in examining waste generated from construction activities of high-rise residential building projects in Hyderabad, India with focus on two main materials of construction projects: reinforcement bar and concrete. The research follows qualitative approach by using two high-rise residential building as the case studies. Site observations on the activities related to the two materials were carried out. The results of the site observations were used as inputs to interview three project personnel of each case study for clarifications on the observations and to have in-depth exploration and understanding of the observations. The result of each project was presented, and cross-case analysis was conducted to compare similarities and differences on the factors related to the waste generation.

Keywords Construction activities · Waste minimization · Construction material · Sustainable construction

1 Introduction

The importance of infrastructure to support economic growth is undeniable. Many countries allocate large amount of funds to support their infrastructure development. The rapid growth of infrastructure means increasing numbers of construction activities, which consequently generates a large amount of waste. Waste can be produced at any stage of construction process from design to the operation and maintenance stage [1]. Many studies on this topic focused on waste composition [2], classification [3], and effects to project performance [4]. It is observed that less has been explored in analyzing waste generation during construction process related to main materials

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in construction projects, i.e., concrete, rebar, wood, brick, etc. Therefore, this study tries to fill this gap by analyzing waste generation from construction activities related to two main materials: rebar and concrete. High-rise building projects are selected as the case study as it is reasonable to expect that more waste issues are faced by this type project and more skilled trades involve in the activities compared to other project types. The study was conducted in the high-rise residential building projects in Hyderabad, the fourth most populated city in India.

2 Waste Generation in Construction Projects

The unregulated extraction of natural resources to support infrastructure expansion activities has led to resource constraints and environmental degradation by the construction industry [5, 6]. Studies show that construction industry produces large amount of waste and at a construction site level, it is estimated that up to 15% of materials purchased end up as wastes [7] with more than of half of these wastes were deposited in the landfill [8]. Construction waste can be one of the dominant factors on the environment if proper disposal exercise is not adhered [9]. Efforts in reducing waste, reusing reusable materials, and recycling materials (3Rs) need to be introduced or intensified to reduce the amount of waste. An extensive amount of waste can be produced from a construction project if the project does not consider constructability in the design process [10]. This waste is not good for the project itself in term of wasting money and for environment.

In supporting constructability, the concept of green building needs to get better attention both from professionals and policy makers as people attitude towards waste has great influence on waste generation at construction activities [11]. Sustainability concept needs to be integrated in the life cycle of construction project by introducing appropriate waste management and a proper analysis can be done to control the construction waste generation. In achieving this sustainability and efficient execution and operation, life cycle Assessment (LCA) and life cycle cost (LCC) need to be used as methods to assess and reduce the impact buildings exert on the environment [12, 13].

A study on waste generation in high-rise building construction in Thailand conducted by Thongkamsuk et al. [14] found that lack of effective waste management, no proper maintenance of storage and logistics, influence of supervisors, contractors, and workers on construction lead to increase in waste. Parisi et al. [15] concluded from multiple regression analysis that waste generation in high-rise buildings construction in Brazil was influenced by number of floors, waste reuse and recovery, floor plan compactness, construction system and floor plan compactness, construction system and floor plan area. Factors affecting waste generation in construction projects were examined by Nagapan et al. [16] with finding showing that materials handling and management, site and procurement management, and design were the important factors. With the sustainability concept in mind and time efficiency, many projects now shift to prefabricated approach where rebar and concrete are the main components [12] and, consequently, wastage in these materials will indulge in heavy loss.

3 Research Methodology

The factors affecting waste generation in construction projects were studied and compiled from previous studies to be used in the data collection process. This study applied case study approach in analyzing waste generation through observation and interviewing. Two ongoing high-rise residential building projects were identified for the study with requirement that the projects should have progressed more than 60% so activities that generated waste can be properly observed. The two case studies are owned by well-established real estate companies that have other projects in Hyderabad city as well as in other cities.

The research focused on activities related to two main materials: concrete and reinforcement bars. Site observations for six days were initially conducted to each project for the activities related to rebar and concrete and how wastes were generated from the activities were observed and noted with inputs of factors affecting waste generation from previous studies were taken into consideration. Basically, the site observation tried to observe from the arrival of rebar and concrete to the site, the activities related to these two materials, the generation of waste, the collection and storage of these wastes, and finally until these wastes were removed from the project.

Once the initial site observation had been completed, interviews were arranged with three personnel of each project: project manager, site engineer, and site supervisor to learn the waste generation and possible mitigations by framing interview questions from past studies as well as on-site observation. These respondents were selected to represent the site managerial and implementation levels so information on the site management and actual implementation can be collected. Another site observation was conducted to confirm the results of the interviews or to observe other factors from the interviews that may have been missed in the initial observation. This data collection process took place from September to December 2019. These site observation and interviews were analyzed using content analysis to do case-wise for each project and cross-case examinations by comparing the results of Case A and Case B.

4 Results and Discussion

The results of case-wise analysis are presented first by initially describing the project followed by analysis on rebar and concrete waste generation followed by cross-case analysis which are presented in tables.

4.1 Case Study A

The first case was a gated community of luxurious apartments with 25 floors under construction. The building has an area of 98,986 m^2. The project was started in March 2018 where 12,694 metric tons of rebar material used, and 16% of waste has been deployed until August 2019. Rebar waste generally arises from slab and column works, cutting and bending works on-site and due to unforeseen conditions. First, material comes to the construction site and placed aside on ground with the help of crane. Then distributed to blocks wherever required. At the workshop, the rebar is cut, and bending is done as per the requirements. The wastage occurs while cutting the rebar due to man made errors for example negligence of workers, lack of supervision at workshop, design change, doing wrong work etc. Entire waste is dumped into one common place in the construction site where it will be segregated. If rebar can be reused, it will be sent for straightening through a rebar straightening machine. If cannot be used, then rebar waste will be sold as scrap.

The entire structural work of the project is dependent on concrete material and about 114,900 m^3 was consumed until August 2019 and 7% has been declared as waste. Due to mistakes by unskilled laborers while pouring concrete, waste occurs when shifting concrete through buckets, pouring mistake at columns, beams, leakage at joints, technical errors, and vehicle movement. Concrete comes from the RMC plant on-site to the construction area. Then pouring takes place at columns beams etc. Concrete waste goes to dumping yard where crusher present and robo sand is produced, this is used again in RMC instead of river sand.

4.2 Case Study B

The second case was a high-rise residential project with 34 floors under construction when the researcher conducted site visits. The building has an area of 84,984 m^2. The project was started in October 2016 where 12,938 metric tons of rebar material used and 14% of waste has been deployed until August 2019. Rebar waste arises from wrong works at slab and column, cutting errors, design changes due to man made mistakes—negligence, lack of supervision at workshop, design change, doing wrong work, client requirements etc. All the waste is dumped into one common place in the construction site at sub cellar level and sold as scrap for half rate and that is used to buy new rebar material.

In this project, 190,142 m^3 of concrete material was consumed until August 2019 and 9% has been declared as waste. Concrete waste arises when shifting concrete through hydraulic pressure pumps for installation of slabs, beams, and leakage at joints. Concrete gets transported to the construction area from RMC plant on site. Concrete waste in any activity mostly man-made mistakes. To reducing waste, the remaining concrete is used in backfilling works and the remaining sent to dumping yard.

4.3 Cross-Case Analysis

The comparisons of similarities and differences between Case A and Case B for waste generation of rebar and concrete are tabulated in Tables 1 and 2, respectively.

The sources of rebar waste for the two projects are in general the same. Both projects applied similar process since the arrival of rebar to the site, storage, waste collection, and removal of rebar waste. Man-made error and design changes are the two main sources of waste. Rebar waste collection in Case A is better as the project properly segregated the rebar waste that can be reused from others from the beginning. This reduces time in doing segregation later when action is taken to reuse or remove the rebar. The reusing of rebar in Case A was imposed by the management to reduce cost and minimize waste. Case B has less attention on reusing the rebar waste. Most if not all rebar waste is sold to scrap vendor for recycling.

As mistakes due to human error is one of the main issues in this rebar waste generation for both cases, proper guidance, instruction, and supervision should be provided to avoid workers making unnecessary mistakes causing waste, especially in the rebar workshop. Monitoring waste from the rebar workshop can be done to reduce waste generation. Educating workers on optimizing the use of rebar by proper arrangements of cutting rebars and reducing mistakes can be considered, as well as providing incentive in reducing this waste.

As shown in Table 2, concrete leakage when pouring is one of the main issues of this material waste. Waste collection and disposal of this waste is in general the same for both case studies with Case A showed more systematic waste management than Case B. Both projects also tried to optimize this waste by using it to backfill the foundation work with Case A showed more efforts in optimizing the use of remaining concrete and minimizing waste by proper supervision and control. Workers' mistakes in pouring concrete were observed in both projects, which can be avoided with proper supervision. An approach in recycling the concrete waste was followed in Case A where the concrete waste is crushed and used for ready mix concrete (RMC) plant. On the other hand, as the case for rebar, Case B assigned less attention in reusing or recycling the concrete waste. In most cases, the waste went to landfill. As preventive measure is always better, accurate estimation on the amount of concrete needs should be done to avoid large amount of waste in the process.

5 Conclusions

The two case studies of high-rise residential building projects indicate that initiatives to reduce waste in the projects exist, but they are not seriously taken and not systematic. The efforts mostly more on what to do with the waste generated than in reducing waste generation in the process. Therefore, increasing awareness and knowledge on environment protection from construction activities are essential as also suggested by He et al. [17]. While managing waste is important, reducing waste is a better

Table 1 Comparison of rebar waste generation between Case A and Case B

Rebar	Case A	Case B	Similarities	Differences	Remarks
Source	Cutting, design changes, wrong works at installation of beams, columns, stirrup making	Waste from wrong works, rebar cutting, design changes	Arrival and storage of rebar material is the same for both the cases Collection of waste and dispose in a common area is the same for both the cases Rebar waste is sold to scrap vendor is the same process for both the cases	Case A has material quality test Case A has organized well with respect to rebar waste collection Proper segregation of waste to reuse is being followed by case A Recycling of waste by selling to scrap vendor is followed in case B	Poor supervision in case B at time of waste generation and very minimal reuse in small works Case A insists its workers to forcefully reuse the rebar waste Proper supervision while cutting rebar, installation of various activities should be thoroughly checked
Flow	Material comes to workshop for cutting and bending works according to requirements Waste arises in cutting due to lack of proper supervision, wrong works, and changing design of structure according to client requirement	Material sent to workshop for cutting and bending works based on drawings Waste arises due to unskilled workers cutting extra lengths which cannot be used			
Discharge	Waste collect at each activity and at every block, weekly shift of waste to steel dump yard is done Segregation of reusable waste, and then sent to vending machine workshop, and the rest scrap sold to vendor	Waste is collected and sent to common dump area Most of the rebar scrap generated is sold to vendor			

Table 2 Comparison concrete waste generation between Case A and Case B

Concrete	Case A	Case B	Similarities	Differences	Remarks
Source	Shifting concrete through buckets, pouring mistake at columns, beams, leakage at joints, technical errors, and vehicle movement	Shifting concrete through hydraulic pressure pumps, leakage at joints	Waste collected at each block, sold to scrap vendor if not used is the same for both the cases Waste used for foundation backfilling works is the same in both the cases Workers mistake at concrete filling works is seen in both the cases There is no protection of concrete coming from RMC plant with exposure to extreme weather conditions	Case A has good vehicle movement Proper quality test before sending concrete to site for works is being implemented in case A Proper de shuttering is done in case A Proper tackling of leftover material and daily transportation of waste to dump yard is followed in case A Excess waste generated on site is segregated to reuse instantly is done in case A Concrete waste is crushed and used in RMC plant to reproduce concrete is followed in case A In case B concrete waste is dumped into landfill if not taken by scrap vendor	Case A has proper supervision at time of waste generation Case A tries to reuse maximum amount of concrete if not cured Case B has poor supervision and maximum waste sold to vendor or sent to landfill Case A has good policy on waste controlling from management side to the site engineer, supervisor, and workers where case B can learn to improve waste control onsite
Flow	Material comes from RMC plant to construction site Shifted to buckets or transported to work area by hydraulic pumps Waste due to improper handling, wrong works, leakage of joints, technical errors due to lack of proper supervision Excess waste generated onsite is transferred to other blocks	Material comes from RMC plant to site Shifted by hydraulic pumps to work area Waste occurs due to technical errors, excess waste occurs at slab work as workers ignoring supervisors' orders, no control when leakage occurs at joints			
Discharge	Handling waste is not reused and goes to dumping yard Crusher present at RMC plant and robo sand is generated which will be reused for concrete production. Waste is also used in backfilling works	Concrete waste is used in backfilling works Waste also used for PCC works wherever it can be used Most of the waste goes to dumping yard, sold to scrap vendor in one or two months			

approach as this will save cost and effort. This approach, to be effective, can be stipulated in the contract document of the project as also supported by Wang et al. [18] that the most effective way to foster project practitioner's environment behavior is to establish the priority of environmental goals in project contracts. Providing engineers and workers on site with knowledge on how to avoid waste generation can be introduced. This will minimize human error in generating waste. An incentive scheme can also be introduced to motivate this waste reduction. Proper equipment maintenance to avoid leakage of concrete during pouring is another solution. Additionally, developing control system in cutting and bending rebar to avoid mistake and in concreting to avoid technical mistake need to be considered.

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Research on the Spatiotemporal Expansion of Chongqing Derived from Integrated DMSP-OLS and NPP-VIIRS Nighttime Light Data

Fangchen Shi

Abstract In the past few decades, China has been implementing a large-scale urbanization process, and this trend will continue to be maintained in the future decades. However, the temporal and spatial expansion of different cities shows different characteristics. This paper takes Chongqing as the research object as a typical representative of the development of cities in western China. Through the integration of NPP-VIIRS and DMSP-OLS data, a long-term and comparable integrated data set for the research object from 1992 to 2017 is formed. This research further selects the data of 1992, 1997, 2002, 2007, 2012, and 2017 as the research time nodes to explore the spatiotemporal expansion of Chongqing. The findings of the study are as follows: (1) The extent of urban expansion in Chongqing is showing an increasing trend as a whole, but the expansion of the main urban area in Chongqing is the main area, showing the obvious characteristics of "single-core expansion"; other areas have not achieved significant development. (2) The urban expansion of Chongqing showed different characteristics in different time periods, which was mainly affected by policy and national conditions changes. (3) The urban expansion elasticity coefficient in Chongqing is irrational in different stages. (4) The overall spatial distribution of Chongqing generally presents a "southwest-northeast" pattern. And its spatial evolution shows obvious characteristics of expansion first and then contraction with the spatial center of gravity moved to the northeast at the early stages and then to the southwest. The research suggests that Chongqing Municipal Government should pay attention to the construction and development of underdeveloped areas outside the main urban area to enhance the interconnection between different areas and strengthen the hierarchical and organic links between various areas, thus further to continuously improve the level of opening up of the city.

Keywords Nighttime light data · Data integration · Spatiotemporal expansion pattern · Chongqing

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1 Introduction

Urbanization is an inevitable trend of economic and social development. In the past few decades, China has been implementing a large-scale urbanization process, and this trend has been accelerating, in which urban spatiotemporal expansion has shown different characteristics [5]. However, there were many problems in the process of urban expansion [2]. It is mainly manifested in the cost of massive consumption of farmland and natural resources, which has seriously damaged the environment and the interests of economy and society, brining impacts on the urban spatial structure and changes in the urban form [16]. For example, the undesirable urban expansion has causes irreversible damage to the ecological and human environment, reducing the level of utilization of public service facilities, causing further division of social classes and even aggravating the decline of urban centers [8]. Some cities expanded and developed directly from densely built areas, which has not followed the law of compact development [1].

In May 2020, Premier Li Keqiang of the State Council of China proposed in the 2020 State Council Government Work Report to deeply strengthen and promote the construction of new urbanization, instructing that the central cities should increase the comprehensive leading role in maintaining a reasonable scale and speed of expansion [21]. The characteristics of urban spatiotemporal expansion are indicative for measuring the level of regional urbanization and population agglomeration [24]. The reasonable scale and speed of urban expansion is conducive to the sustainable development of the city, and the rapid expansion of the city will cause the intensified contradiction between population, resources and environment conversely [23]. Therefore, the research on the expansion process and pattern of the city is of great significance to the understanding of regional development and the relationship between population and land.

Chongqing is the only western municipality directly under the Central Government of China, and it is also an important national central city in the country. It is positioned as an economic center in the upper reaches of the Yangtze River, an important national modern manufacturing base and also a pilot zone for comprehensive urban and rural comprehensive reforms [11]. The Chinese government also proposes to build Chongqing into an open highland and an international metropolis to speed up the formation of urban agglomerations with large radiation effects. Relying on the main urban area of Chongqing, it has proposed to strengthen the connection with the surrounding cities and form a number of urban agglomerations with strong radiating driving ability. Chongqing has been focusing on building a city cluster centered on the main urban area of Chongqing, which would strengthen the connection with the infrastructure and industries, speed up the construction of an efficient and convenient transportation network based on rail transit, achieve dislocation development in the industrial layout, and form a development pattern of complementary advantages and coordination and interaction with Fuling, Wansheng, Changshou, Jiangjin, Hechuan, Yongchuan, Nanchuan, Shuangqiao, Qijiang, Tongnan, Tongliang, Dazu, Rongchang, Bishan and Guang'an in Sichuan [20].

At present, the main contradiction in Chinese society has been transformed into a contradiction between the people's growing need for a better life and unbalanced and inadequate development. The unbalanced and insufficient development between urban and rural areas restricts people's needs for a better life in this area. Therefore, accelerating urban and rural economic development is not only an effective measure to implement the two major development themes, but also an important front to eliminate major social contradictions, and it is a topic that of both time significance and theoretical value. As a typical representative of the cities in western China, the study of time and space expansion in Chongqing is of great value for understanding the development characteristics of cities in western China, especially for the Chongqing urban agglomeration.

Currently, many scholars have carried out a lot of research on the urban spatial pattern [15]. Many of them use economic statistics to study the economic development characteristics and industrial structure of urban agglomerations, for example, Ma and Zeng [13] use patent databases to carry out innovation and cooperative research on urban agglomerations. Cao et al. [3] use Landsat and other remote sensing data to identify the spatial boundaries and expansion characteristics of cities or urban agglomerations. In addition to high-resolution optical remote sensing data, multi-source social perception big data is used to identify urban spatial functions and topic semantics, evaluate urban spatial perception, and evaluate urban vitality when finely portraying the internal characteristics of the city. On the one hand, the most used data sources are social and economic statistical data such as population and GDP. Although statistical data is easy to obtain from the Bureau of Statistics and other channels, there are several disadvantages such as inconsistent scope and caliber, and these kinds of data are easily restricted by administrative units. Luminous remote sensing detects night lights can reflect the information of human activities and it has been proved to have a strong correlation with many socio-economic indicators and has been widely used in the field of social sciences, such as socio-economic parameter estimation, urbanization monitoring and evaluation [10]. Croft [7] first proposed the idea of using night light data to extract urban areas. Henderson et al. [9] realized global luminous remote sensing city mapping by setting a dynamic threshold method. Chen et al. [6] were the first to use luminous remote sensing to study the process of urbanization in China. However, the time for research is relatively limited, and it does not have long-term effectiveness and integrity. It is worth noting that the United States DMSP-OLS and NPP-VIIRS are currently the two most widely used luminous remote sensing data [19]. Therefore, if the research on urban space expansion needs to focus on both long-term sequence and effectiveness, the effective integration of DMSP-OLS and NPP-VIIRS data becomes an important approach [12]. And the night light data provided by the US National Defense Meteorological Satellite is easy to obtain, which can overcome a series of shortcomings of traditional methods and is suitable for large-scale, long-sequence urban spatial expansion and research on economic indicators related to human activities.

It can be seen that there are few comparative studies on urban space expansion using the integrated long-term night light data. In addition, the research objects are mainly urban agglomerations, but there are few studies on cities. Thus, this paper takes Chongqing as the research object through integrating the NPP-VIIRS and DMSP-OLS data. And a long-term and comparable integrated data set for the research object from 1992 to 2017 is formed. This paper selects the data of 1992, 1997, 2002, 2007, 2012, and 2017 as the research time nodes to explore the process and pattern of the spatial expansion and evolution of Chongqing, expecting to understand the development characteristics of Chongqing from a new perspective and provide reference for the sustainable development of the city.

2 Data and Research Methods

2.1 Data

The night light data uses DMSP-OLS stabilized light image set and NPP-VIIRS image, the time span is 1992–2013 and 2012–2017 respectively. The spatial resolution of the DMSP-OLS image is about 1 km, and no on-orbit radiation correction is carried out. The pixel is only scaled with gray value of light intensity, and the range is [0, 63] [10]. The DMSP-OLS stabilized light image set is collected by 6 satellites: F10 (1992–1994), F12 (1994–1999), F14 (1997–2003), F15 (2000–2000), F16 (2008). Among them, different sensors acquire images of the same year. Therefore, the night light data acquired by different satellites in a long sequence has certain differences in compatibility and stability. And series of correction preprocessing methods are required to make it in the long sequence. The spatial resolution of the NPP-VIIRS image is about 500 m, and it has a stronger detection capability and can detect the subtle reflected light on the earth's surface [25]. The above two kinds of data can be downloaded from the official website of the National Oceanic and Atmospheric Administration (NOAA). The DMSP/OLS data download website is: http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html; The NPP/VIIRS data download website is: https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html.

There are big differences between NPP-VIIRS and DMSP-OLS image attribute information: ① The two types of images have attribute differences in temporal resolution, spatial resolution and spectral resolution. ② The two types of images have their own defects: the DMSP-OLS image set is acquired by six generations of satellites, the continuity between the images is not strong, and the maximum DN value of the images is 63, and there is a light saturation effect in the central area of developed cities; The low-value detection capability of the NPP-VIIRS images causes occasional noise in the data set. When integrating the two images, the above issues need to be considered comprehensively to obtain the best fitting effect.

Therefore, due to the numerical difference between the two types of lighting data of DMSP-OLS and NPP-VIIRS, as well as the diversity and spatial imbalance of urban development in different regions, the published simulation data set integrating the two types of lighting data is directly used to develop different urban agglomerations.

2.2 *Methods*

2.2.1 DMSP-OLS and NPP-VIIRS Image Integration Method

According to the attribute differences and characteristics of DMSP-OLS and NPP-VIIRS images, this article adopts the following integration schemes:

(1) Image preprocessing such as unified spatial resolution and projection transformation, masking and resampling;
(2) Image correction based on the invariant target area method (Including saturation correction and continuity correction) and noise reduction processing;
(3) Based on the correlation of the DN values of the two images in overlapping years, this paper establishes the optimal functional relationship of NPP-VIIRS fitting DMSP-OLS images, and constructs the long-time sequence of night lights Image collection.

For the correction of DMSP/OLS lighting data, this article mainly refers to the methods of Elvidge et al. [17] and Cao et al. [4]. Their methods mainly perform saturation correction and continuity correction on this type of lighting data, and the main steps are as follows:

(1) According to the research of Cao et al. [4], this paper uses the invariable target area method to select the invariable target area, namely, taking the municipal district of Hegang City in Heilongjiang Province as the constant target, at the same time extracting a total of 26 periods of stable images from 1992 to 2013 and the night light images corresponding to F16 2006 radiation calibration.
(2) Mutual correction and saturation correction between different sensors. After fitting the correlation between the reference image and the image to be corrected through functions such as quadratic function, cubic function, exponential function, and power function, the power function with the highest goodness of fit is used for fitting correction. Therefore, this paper uses a calibration method based on standard sensors and further takes Jixi City in Heilongjiang Province, where the urban development is relatively stable, as the constant area, and selects the higher cumulative DN value in each sensor image.
This paper using F16 sensor as the standard sensor, and a regression model is established. The formula is as follows:

$$DN_C = a \times DN^b \tag{1}$$

In the formula, a and b are fitting coefficients, DN is the image pixel value before correction, DN_C is the image pixel value after power function correction. The images in the long-time series of DMSP/OLS night light image data sets after mutual correction are comparable. At the same time, the images in each period weaken the saturation of the image pixel DN value.
(3) Continuity correction of images between different years. For images taken by two sensors in the same year, the images of the same year acquired by different

sensors in the mutually corrected image data set are corrected according to the following formula:

$$DN_{(n,i)} = \begin{cases} 0, & DN^1_{(n,i)} = 0 \& DN^2_{(n,i)} = 0 \\ \left(DN^1_{(n,i)} + DN^2_{(n,i)}\right)/2, & \text{otherwise} \end{cases} \quad (2)$$

In the formula, $DN_{(n,i)}$ represents the DN value of the i pixel in the image of the nth year after correction; $DN^1_{(n,i)}$ and $DN^2_{(n,i)}$ respectively represent the DN value of the i pixel in the night light image obtained by two different sensors after mutual correction in the nth year. The above steps still cannot solve the problem of abnormal fluctuation (or instability) of the pixel DN value between images in different years in the image data set. The problem can be corrected by the following formula:

$$DN_{(n,i)} = \begin{cases} 0, & DN_{(n+1,i)} = 0 \\ DN_{(n-1,i)}, & DN_{(n+1,i)} > 0 \& DN_{(n-1,i)} > DN_{(n,i)} \\ DN_{(n,i)}, & \text{otherwise} \end{cases} \quad (3)$$

For the correction of NPP/VIIRS light data, this paper mainly refers to the research of Ma et al. [14], Wang et al. [22] and Shi et al. [18]. The correction of this type of night light data mainly includes background noise processing of light images, outlier processing and continuity correction. Generally, the urban area light value is usually greater than 30, and the area with a DN value less than 30 is an area with less human activity, which will not have a major impact on the extraction result of the urban area. Therefore, the part of the NPP-VIIRS simulated image whose DN value is greater than 30 is selected as the area to be evaluated, which is as follows:

(1) Noise treatment: The NPP/VIIRS lighting data used in this paper is derived from the monthly average night lighting data released by NOAA (the annual data were released in 2015 and 2016). In order to make the data processing of each year have a unified standard, this article uses monthly data as the original data. Since the original monthly data does not filter out the aurora, fire, boat and other temporary lights, it is necessary to reduce the influence of these unstable night lighting lights and background noise. According to the method of Shi et al. [18], the area with a pixel value of 0 in the 2013 DMSP-OLS night light data is extracted as a mask to filter the noise pixels in the monthly average in the NPP-VIIRS night light data. At the same time, this paper sets the pixel value of the negative pixel in the NPP/VIIRS night light data to 0. After completing this step, the monthly data of each year will be combined into annual data by means of average values.
(2) Outlier handling: This step refers to the study of Ma et al. [14], which is to extract effective light data by setting a suitable threshold interval

to remove the light data that is too low and too high. Commonly used threshold setting methods include the percentage method, the total light area increasing method and the economic intensity method. This paper uses the economic intensity method. Because the light radiation value and the degree of economic development show a significant positive correlation, the lighter the lighter the more developed the economy, that is, the greater the radiation value. The maximum brightness value near the Oriental Pearl TV Tower in Shanghai was selected as the maximum threshold of light brightness, such as 166 in 2014; for the minimum threshold, the part of the NPP-VIIRS simulated image with a DN value greater than 30 was selected as the waiting Evaluation area.

(3) Continuity correction: For the annual data obtained after noise processing and abnormal value processing, the continuity correction of the NPP/VIIRS data set is carried out in accordance with the aforementioned method for continuity correction of DMSP/OLS data.

It should be noted that, since the image data taken by two different satellites is used, the data of DMSP/OLS and NPP/VIIRS after the above-mentioned steps may have data gaps. In order to reduce this effect, the light image data of the last year during the study period can be used as a mask extraction to uniformly extract the light data of the past years.

2.2.2 Analysis Methods on the Spatiotemporal Characteristics of Urban Expansion

(1) **Chronological analysis method of urban expansion**

The urban spatial expansion intensity (EI) is the proportion of the growth of the urban space in a certain time span to the total area of the regional land, which can directly reflect the urban spatial expansion speed of each spatial unit. The calculation formula is:

$$EI = \frac{UL(t + \Delta t) - UL(t)}{TL \times \Delta t} \times 100 \tag{4}$$

where: EI represents the urban spatial expansion intensity; UL $(t + \Delta t)$ and UL (t) represent the urban built-up area in year $(t + \Delta t)$ and year t, respectively; Δt is the time span of the study, and TL represents the total land area of the urban.

The urban expansion elasticity coefficient (UEEC) is mainly used to explain the relationship between the expansion rate of urban built-up areas and the growth rate of non-agricultural population. It can reflect the reasonable degree of urban built-up area expansion and population distribution. The calculation formula is:

$$UEEC(\mathrm{i}) = \frac{\mathrm{BA(i)}}{\mathrm{POP(i)}} \tag{5}$$

where: UEEC(i) represents the elastic coefficient of urban expansion in the i-stage; BA(i) is the average growth rate of the urban built-up area in the i-stage (%); POP(i) is the average growth rate of the non-agricultural population (%). When UEEC(i) equals 1.12, it indicates that the urban built-up area expansion and population distribution are reasonable; when UEEC(i) is greater than 1.12, it indicates that the urban expansion is too fast or there is a loss of non-agricultural population; when UEEC(i) is less than 1.12, it indicates that insufficient urban expansion or the non-agricultural population is growing too fast.

(2) **Spatial analysis method of urban expansion**
Standard Deviational Ellipse (SDE) is a spatial statistical method that reveals many aspects of the spatial distribution of variables. It uses an ellipse with specific characteristics to characterize the overall spatial layout of the elements and determine the directional factors. The center of the ellipse is the average center of the spatial distribution, which reflects the relative position and change of the center of gravity of the geographic element layout; the long axis and the short axis represented by the standard deviation in the X and Y directions respectively represent the main trend direction and The degree of dispersion in the secondary direction; the azimuth angle reflects the main trend direction of its distribution; the area of the ellipse indicates the degree of concentration or divergence of the spatial distribution of geographic elements. The standard deviation ellipse can show the dynamic characteristics of the spatial distribution of the discrete data set in the center of gravity, spreading range, density, direction and shape over time.

3 Results and Discussion

3.1 *The Extraction Results of the Built-Up Areas in Chongqing*

The integrated DMSP-OLS and NPP-VIIRS Nighttime Light Data is shown in Fig. 1. It can be seen that the overall extent of Chongqing's urban expansion is showing an increasing trend, which is mainly based focus on the expansion of the main urban area in Chongqing, showing the obvious characteristics of "single core expansion".

The main urban areas of Chongqing, namely, Yuzhong District, Jiangbei District, Nan'an District, Jiulongpo District, Shapingba District, Dadukou District, Beibei District, Yubei District and Banan District, have always been key areas for expansion and development. Furthermore, Hechuan, Jiangjin, Yongchuan, Changshou, Fuling, Nanchuan, Tongnan, Tongliang, Dazu, Rongchang, Qijiang, and Bishan also showed

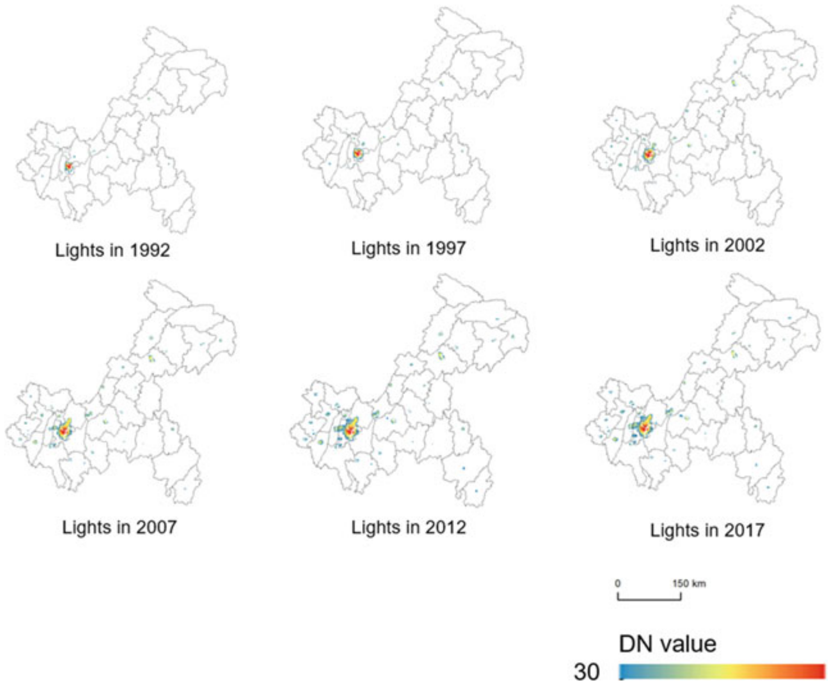

Fig. 1 The night light images of Chongqing after calibration and simulation in 1992, 1997, 2002, 2007, 2012, and 2017

weak expansion trend. But there seems almost no expansion trend in other regions. This indicates that the urban expansion of Chongqing is a very unbalanced, with large differences between regions.

In this paper, further statistics are made based on the above extraction night light value results, Fig. 2 shows the changes of Chongqing's spatial expansion scale from 1992 to 2017. As shown in Fig. 2, from 1992 to 2017, Chongqing's overall scale expanded significantly. The scale increased from 376 to 1929 km^2, with an increase of 513%, which is mainly because in 1992, the Chinese government designated Chongqing as an open city along the river. Relying on location advantages and policy support, Chongqing has gathered a large number of high-quality industrial elements, and the city scale has been continuously expanded. In 1997, Chongqing was established as a municipality directly under the Central Government. Since this year, the brightness of night lights in Chongqing has maintained a significant increase trend, which means that human social economic activities had become more active since then. After 2012, Chongqing's urban expansion began to show a slight tightening trend.

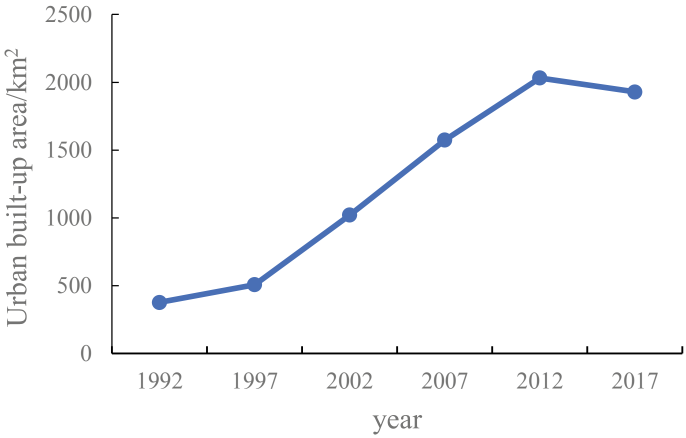

Fig. 2 The changes of Chongqing's spatial expansion scale from 1992 to 2017

3.2 Analysis on the Temporal Evolution of Chongqing's Urban Expansion

3.2.1 Analysis of Chongqing 's Expansion Intensity (EI)

According to Formula (4), the expansion intensity of Chongqing during the study period can be obtained. The changes in the spatial expansion intensity of Chongqing from 1992 to 2017 are shown in Fig. 3. The urban expansion of Chongqing is divided

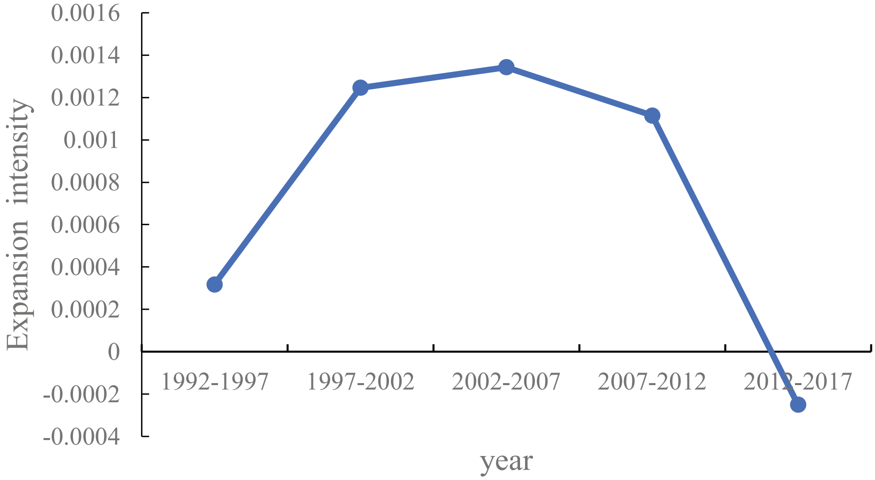

Fig. 3 The expansion intensity of Chongqing during the study period

into 4 stages: 1992–1997 is the high-speed expansion stage; 1997–2002 is the high-level steady growth stage; 2007–2012 is a low-speed decline stage, and 2012–2017 is a rapid decline stage.

From 1992 to 1997, China was in a period of transition from a planned economy to a market economy. The driving force of urbanization under the influence of policies was not fully stimulated. Therefore, the urban spatial expansion intensity of Chongqing was relatively low in that period. From 1997 to 2002, China's industrialization process was extremely rapid, which led to the rapid development of urbanization and rapid expansion of urban construction. Especially after Chongqing was established as a municipality in 1997, various favorable policies in Chongqing attracted a large number of people and the industry in Chongqing also developed rapidly. Therefore, the urban expansion of Chongqing during this period showed a situation of "high-level, steady and rapid growth". After 2002, Chongqing's expansion rate remained at a high level, but maybe due to limited resources and Chongqing's unique mountain geographic features, its expansion rate slowed slightly. After 2010, China has entered a period of "new normal". China has increased its control over urban land development, and urban construction has gradually become more rationalized. Therefore, the spatial expansion intensity of Chongqing has dropped rapidly and maintained a relatively stable expansion intensity.

3.2.2 Analysis of Chongqing 's Urban Expansion Elasticity Coefficient (UEEC)

According to Formula (5), the expansion elasticity coefficient of Chongqing during the study period can be obtained. As is shown in Fig. 4.

It can be seen that the UEEC increased at early stages and then decreased in the late period. It reached the maximum value (4.74) in 1997–2002 and the UEEC value is much higher than 1.12, and the UEEC was the minimum and negative in 2012–2017 (−0.21). This indicates that the growth rate of the built-up area before 2007 was much higher than that of the non-agricultural population, suggesting that the urban expansion was too fast and the non-agricultural population growth was insufficient due to the rapid urbanization. It is worth noting that after 2007, the expansion rate of Chongqing's urban built-up areas was lower than the growth rate of non-agricultural population. The main reason was that Chongqing's built-up area construction had basically formed and matured, so the development of built-up areas was slow, while as previous studies suggest that the industrial model of Chongqing used to be dominated by agriculture, heavy industry and low-end manufacturing. However, it has been implementing various policies to promote high-tech industries, upgrade industrial structure, and develop characteristic industries such as tourism in recent years. So, the non-agricultural population in Chongqing has greatly increased. These two factors may have caused Chongqing's UEEC to decline or even be negative.

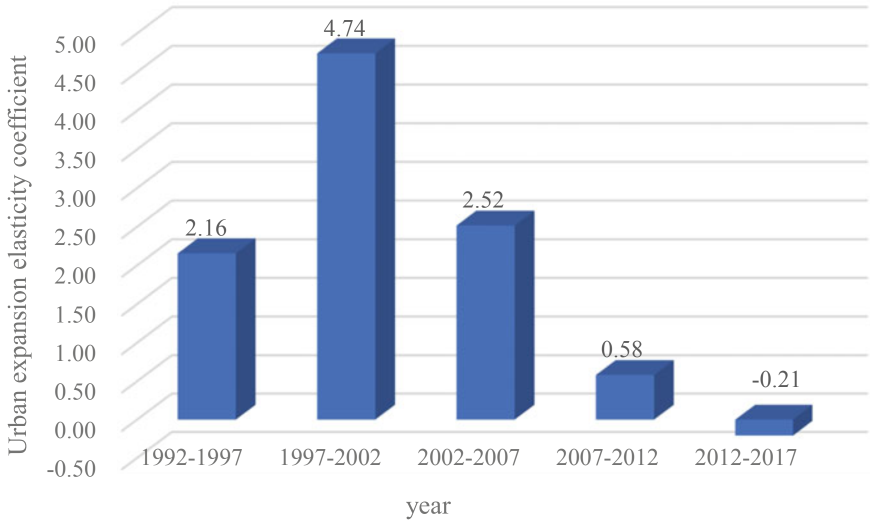

Fig. 4 The expansion elasticity coefficient of Chongqing from 1992 to 2017

To sum up, the UEEC in Chongqing is irrational in different stages. Before 2007, the urban expansion was too fast and the non-agricultural population grew insufficiently; after that, the non-agricultural population grew too fast and the built-up area expanded slowly.

3.3 Analysis on the Spatial Characteristics of Chongqing's Urban Expansion

The standard deviation ellipse processing is performed on the night light data of Chongqing in the GIS software, and the result is shown in Fig. 5, showing that the overall spatial distribution of Chongqing generally presents a "southwest-northeast" pattern, and its spatial evolution shows obvious characteristics of expansion first and then contraction, and the spatial center of gravity moves to the northeast at the early stages and then to the southwest.

And the corresponding standard deviation ellipse data is shown in Table 1.

It can be seen from Fig. 5 and Table 1 that the area of the characteristic ellipse has increased from 8864.20 km^2 in 1992 to 20,617.89 km^2 in 2017, indicating that the scope of the spatial distribution of Chongqing during the study period has increased, and the urban distribution density has shown a downward trend. The major axis of the characteristic ellipse increased from 87.14 km in 1992 to 116.95 km in 2017, and the minor axis increased from 32.38 km in 1992 to 56.12 km in 2017. At the same time, the azimuth of the ellipse has rotated clockwise from 60.17° in 1992 to 63.37° in 2012. The results show that during this period, Chongqing's urban expansion both diverged

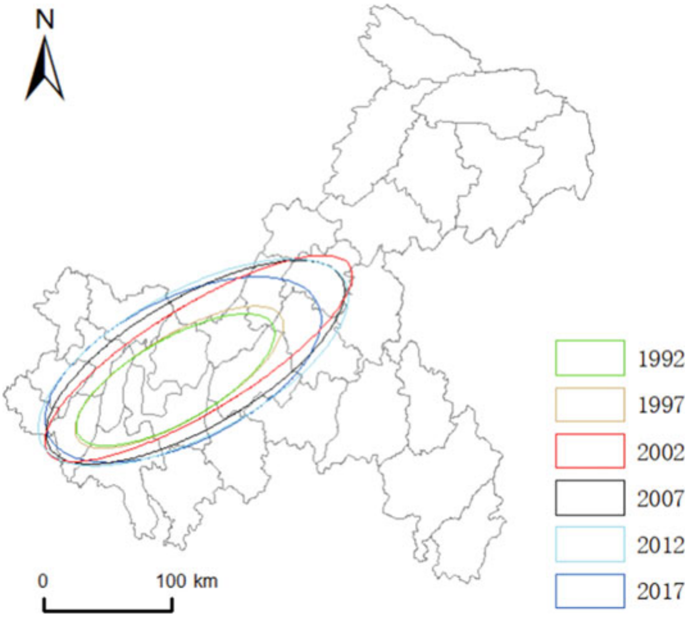

Fig. 5 Standard deviation ellipse of night light data in Chongqing

Table 1 Standard deviation ellipse data of night light data in Chongqing

Year	Shape area	Center X	Center Y	X Std Dist	Y Std Dist	Rotation
1992	8864.20	161,245.9	3,132,880	32.38	87.14	60.17
1997	9604.596	164,065	3,134,890.23	32.99	92.67	58.87
2002	17,831.38	179,014.4	3,149,569	40.99	138.49	58.33
2007	20,876.84	176,446.3	3,146,791	50.50	131.59	59.49
2012	23,755.09	174,989.3	3,146,535	56.41	134.07	61.46
2017	20,617.89	167,182	3,140,822	56.12	116.95	63.37

in the long-axis and short-axis direction, namely the southwest-northeast direction, and the northwest-southeast direction respectively. And the growth of the urban system along the short-axis direction was more obvious. The spatial distribution direction (long axis direction) of the urban system rotates clockwise.

4 Conclusion

By integrating the two images of DMSP-OLS and NPP-VIIRS and searching for the optimal power function fitting model, a long-time sequence of night light image sets in Chongqing from 1992 to 2017 was constructed in this paper. The main conclusions are as follows:

(1) The extent of urban expansion in Chongqing is showing an increasing trend as a whole, but the expansion of the main urban area is the main area, showing the obvious characteristics of "single-core expansion", and other areas have not achieved significant development. It shows that the urban expansion of Chongqing is a very unbalanced development model with large differences between regions.
(2) The urban expansion of Chongqing showed different characteristics in different time periods, which was mainly affected by policy and national conditions changes.
(3) The urban expansion elasticity coefficient in Chongqing is irrational in different stages. Before 2007, the urban expansion was too fast and the non-agricultural population grew insufficiently; after that, the non-agricultural population grew too fast and the built-up area expanded slowly.
(4) The overall spatial distribution of Chongqing generally presents a "southwest-northeast" pattern. Its spatial evolution shows obvious characteristics of expansion first and then contraction, and the spatial center of gravity moves to the northeast at the early stages and then to the southwest.

Therefore, the Chongqing Municipal Government should pay attention to the construction and development of areas outside the main urban area to balance the distribution of industries and population in Chongqing so as to avoid overcrowding in the main urban area. In addition, Chongqing should also enhance the interconnection between internal regions, such as establishing the transportation corridors, speeding up the construction of underdeveloped areas to rapidly increasing the overall development of other regions. Finally, a systematic Chongqing urban agglomeration plan will be established to strengthen the hierarchical and organic links within the city, thereby continuously improving the level of opening up of the city.

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Driving Factors Analysis on Urban Vibrancy: A Case Study of Chongqing Main Area

Xi Chen

Abstract In line with the rapid urbanization, urban vibrancy has received more attention for it is an important indicator to promote urban sustainable development. However, there are few studies on the driving factors of urban activities in Chongqing from the micro-scale. By using kernel density analysis in ArcGIS and geographic detector tools, this paper investigates the urban vibrancy based on night lighting date and its driving factors in Chongqing main area, China. These driving factors can be divided into three categories, namely land use, transportation services, and public services. The empirical results show that: ① the spatial distribution of urban vibrancy in Chongqing main area presents the characteristics of "multi-core"; ② the differences among these driving factors of urban vibrancy is not significant, among which population density plays the most important role; ③ the effect of driving factors exhibits a synergistic enhancement of any two factors, which indicates that the influence of any two driving factors can further improve the difference of urban vibrancy.

Keywords Urban vibrancy · Driving factor analysis · Kernel density analysis · Geographic detector · Night lighting date

1 Introduction

Urban vibrancy is a comprehensive indicator to describe the active degree of urban social activities, which has been introduced to many areas, like urban geography, urban planning, and urban economy. As the understanding of urban vibrancy can provide valuable references to sustainable urban development, The research of urban vibrancy has attracted various scholars [4, 8, 12]. The conception of urban vibrancy can be traced back to the urban diversity proposed by J. Jacobs, who considered that urban vibrancy can be reflected by urban socioeconomic activities. Specifically, it can be reflected by the degree of population aggregation expressed [4]. With further

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studies, the significance of urban vibrancy for urban sustainable development has been widely recognized. It is appreciated that analysis of driving factors of urban vibrancy is conducive to promoting the rational planning of cities, providing scientific policy reference, and stimulating the development potential of cities [5].

Based on point of interest (POI), thermal map, Internet platform, or other dates, previous literatures used spatial analysis techniques to investigate the urban population concentration and social activities from a micro perspective [1, 3, 6]. Ta et al. [8] used POI, public comments, and taxi data to evaluate the urban vibrancy of Shanghai from the perspective of economy, society, and culture. Zhang et al. [12] identified the urban vibrancy of Hangzhou city, China, by using GIS and data of Baidu thermal map. Wang et al. [10] analyzed the urban vibrancy characteristics of State-Level New Area based on night light data. Other studies introduced different methods to analyze driving factors of urban vibrancy based on the POI data. Liu et al. [4] used ArcGIS analysis tools to research the influence of driving factors of urban vibrancy in Beijing, China, namely infrastructure level, public green space, and land-use intensity. Shu et al. [7] employed geographic detector in researching the effects of macro-economy, traffic conditions, and public services on the consumption vibrancy of Chengdu city, China.

The above review shows that previous literatures have made some progress in the research of urban vibrancy. However, the data used in analyzing urban vibrancy can not fully reflect the aggregation degree of urban population. Although the evaluation of urban vibrancy contains different dimensions and types of data, the choice of data is selected subjectively, and is hard to cover all types of urban socioeconomic activities. As urban night lighting data is open data that can be directly obtained, it can not only measure the spatial distribution and economic development of cities but also reflect the concentration of urban social activities. Based on its authenticity and comprehensiveness, urban night lighting is an important indicator to describe urban vibrancy. As few studies describe the urban vibrancy based on night lighting date, it is necessary to analyze urban vibrancy by using urban night lighting data.

In line with the above discussion, this paper aims to investigate the urban vibrancy based on night lighting data and its driving factors. This paper can provide valuable references for policy-makers to publish effective policies, which further improve sustainable urban development. The remainder will analyze the performance of urban vibrancy and explore the driving factors of urban vibrancy. The driving factors are derived into three categorifies including urban public services, transportation services, and land use. The spatial distribution of each driving factor is obtained and analyzed by the ArcGIS platform. The grid cell Map with a scale of 2 km $\times$ 2 km is shown in Fig. 1, and the research object is the nine districts in Chongqing, China. To provide a decision-making basis for urban vibrancy planning and construction, the effect of driving factors on urban vibrancy is explored by using the geographic detector.

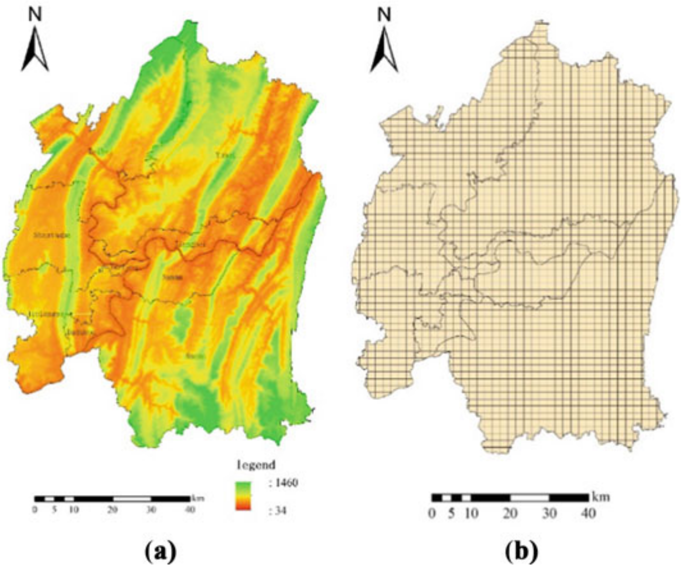


Fig. 1 Location of the study area: **a** elevation map of study area; **b** research area network grid

2 Method

2.1 Study Area

As one of the Chinese autonomous municipalities, Chongqing has a very large urban area. But the resources and population of Chongqing are mainly concentrated in the central area, which includes Yuzhong District, Jiangbei District, Nan'an District, Jiulongpo District, Shapingba District, Dadukou District, Beibei District, Yubei district, and Banan District. The scale of Chongqing main area is shown in Fig. 1 and the different color reflects differences in attitude. Chongqing's main area is a typical area to study urban vibrancy. Therefore, this paper selects the main urban area of Chongqing as the research object.

2.2 Date Collection

The main data sources of this study include four aspects. (a) Map data, which is obtained from the Baidu map. (b) Night lighting data of Chongqing Main District in 2017, which is from the high-precision global high-definition luminous data which is based on the research of radiation transmission model of NPP/VIIRS (NPOESS Preparatory Project/Visible infrared Imaging Radiometer) luminous satellite monthly products, set released by Chen Fu team of the Institute of remote sensing and digital

Table 1 Content and quantity of POI data

Type	Context	Number
Transportation facilities	Subway station, bus station, port wharf, parking lot and other related facilities	18,378
Science and education culture	Schools, training institutions, museums, science and technology museums, cultural centers and other related facilities	12,920
Medical service	Hospitals, clinics, emergency centers, community health service centers and other related facilities	11,980
Comfort station	Public toilets, men's and women's toilets	2904

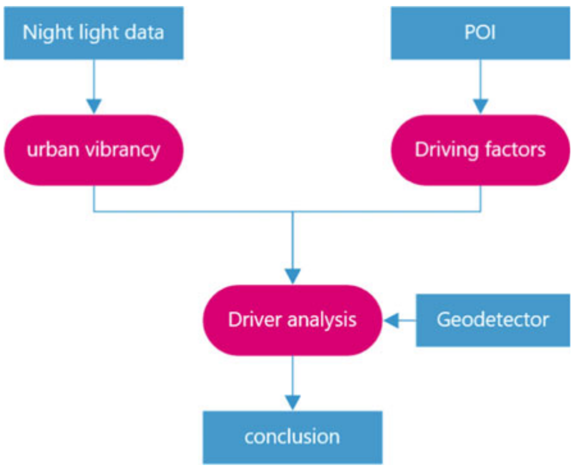
earth, Chinese Academy of Sciences. (c) POI data. This data is from the Baidu map and is captured by crawler software. The specific location has been converted to the WGS1984 (World Geodetic System) coordinate system, the details of POI data are shown in Table 1. (d) Statistic data. The regional population data of nine districts in Chongqing city is from Chongqing statistical yearbook 2018, and the administrative area of each district is from the national administrative division information query platform.

3 Research Framework and Research Methods

3.1 Research Framework

The research framework of this study is shown in Fig. 2. In order to study the driving factors of urban vibrancy in nine districts of Chongqing City, this paper describes the

Fig. 2 Research framework



urban vibrancy with urban nighttime lighting data, explores the potential factors of urban vibrancy through literature reading, and describes the distribution of driving factors with POI data. The ArcGIS software is used to make the network grid, and the Kernel density analysis is used to analyze driving factors. Finally, The processed data is imported into the geographic detector to explain the role and internal correlation of each driving factor.

3.2 Research Framework

3.2.1 Kernel Density Analysis

This method using POI data chooses a grid as the center to search the feature in a certain radius and calculates the density of features in the surrounding neighborhood. This method generates a continuous surface to represent the density value and uses different kernel density values to represent the spatial distribution characteristics of features [2].

$$f_{(s)} = \sum_{i=1}^{n} \frac{1}{h^2} k\left(\frac{s - c_i}{h}\right)$$

where $f_{(s)}$ is the kernel density of feature s; n is the number of features whose distance from s is less than or equal to h; h is the search radius; k is the weight of spatial distance.

3.2.2 Geographic Detector

The geographic detector is a statistical method to detect spatial heterogeneity and explore its influencing factors which are developed by Jinfeng Wang's team [9]. In practical application, type quantity analysis is better than continuous data analysis, which can detect the interaction between the two factors and overcome the traditional regression model which only depends on multiplication relationship to judge the interaction between the two factors [11]. The basic formula is as follows:

$$q_{D,U} = 1 - \frac{1}{n\sigma_U^2} \sum_{i=1}^{m} n_{D,i} \sigma_{U_{D,j}}^2$$

where n is the number of grids divided in the study area; m is the number of classification or stratification of variables; $n_{D,i}$ is the number of research cell grids in the classification i; σ_U^2 is the total variance of consumption activity in the study area; $\sigma_{U_{D,j}}^2$ is the variance of consumption activity in classification i. The value range of $q_{D,U}$ is [0, 1]. The larger the $q_{D,U}$ value is, the stronger the driving force of D to the spatial heterogeneity of urban consumption vibrancy is.

4 Analysis the Urban Vibrancy of Chongqing Main Area

By import obtained global high-definition night light data set in 2017 and the map of Chongqing nine districts into ArcGIS software, the night light map of nine districts in Chongqing in 2017 is extracted on the map, as shown in Fig. 3.

It can be seen that the urban vibrancy of nine districts in Chongqing presents the “multi-core” distribution characteristic. The major core is Yuzhong District, while the small cores are Shapingba central area, Jiangbei District Central Area, and Yubei District southwest area.

The core of urban vibrancy represents the distribution of population agglomeration and urban resources. The core of Yuzhong District is rich in business and tourism resources. Firstly, it has many major tourist attractions, such as Jiefangbei and Guanyinqiao. Secondly, it has many medical resources, like Chongqing Daping

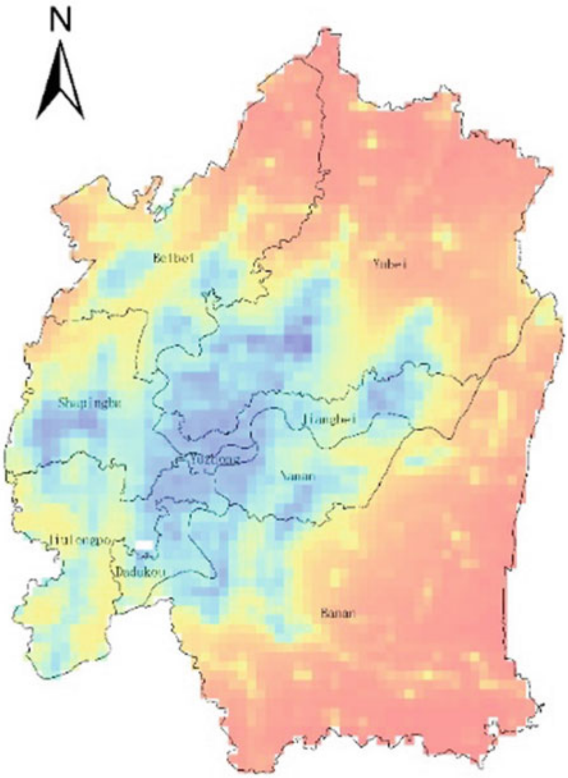


Fig.3 Night light map of nine districts in Chongqing City in 2017

Hospital and the Children's Hospital Affiliated to Chongqing Medical University. Thirdly, it is surrounded by Chongqing University, Chongqing Normal University and Bashu middle school, and Nankai Middle School. As for the small core, the middle of Shapingba District is located in the university town. This area has rich educational resources, like Chongqing University, Sichuan Fine Arts Institute, Chongqing Medical University, Chongqing University of science, and some business circle is produced surrounding those educational resources.

In conclusion, the distribution of urban vibrancy in Chongqing is scattered, which is in line with the urban planning and development of Chongqing. Since 1960, the Chongqing Preliminary Urban Planning has put forward the planning layout of "large dispersion, small concentration, and plum blossom point". In 1983, the Chongqing Urban Master Plan from 1981 to 2000 first proposed the urban distribution structure of "multicenter, group type". Under these backgrounds, The main area of Chongqing has formed a multicenter and multicore distribution of urban vitality [13].

5 Results and Discussion

5.1 Driving Factors Detection

By using POI data and statistical data, this section will explore the impact of each driving factor on the urban vibrancy of Chongqing main area. Based on the literature review and review, this study focuses on three driving factors of urban vibrancy: public services, transportation services, and land use [7]. Specifically, this study uses population density to express land use degree, uses POI data of transportation facilities to express transportation service factors, and uses science, education and culture, medical services, and public toilets to express public service factors.

First of all, all kinds of data should be imported into ArcGIS software to convert these data into projection coordinates. According to the requirements of geographic detector for data discretization, all kinds of data need to be analyzed and divided into five categories by using the Natural Discontinuity Method. The maps that reflect the distribution of driving factors are shown in Fig. 4.

In the above figures, Fig. 4a reflects urban land-use factor. Figure 4b reflects urban traffic service factor. Figure 4c–e reflects urban public service factor, which includes urban cultural density of science and education, medical service, and public toilets. In geographical detector, q refers to the driving effect of each driving factor. The greater the q value, the greater the driving effect. By importing driving factors of urban land use, urban traffic service, and urban public service into the geographical detector, the q value of each driving factor can be obtained as shown in Table 2.

It can be seen from the above table that although population density is macro data, the value of its driving effect is the highest as 0.416, which indicates that population is the key driving factor of urban vibrancy. As for the perspective of transportation services, the driving effect of transportation facilities on urban vibrancy is 0.408,

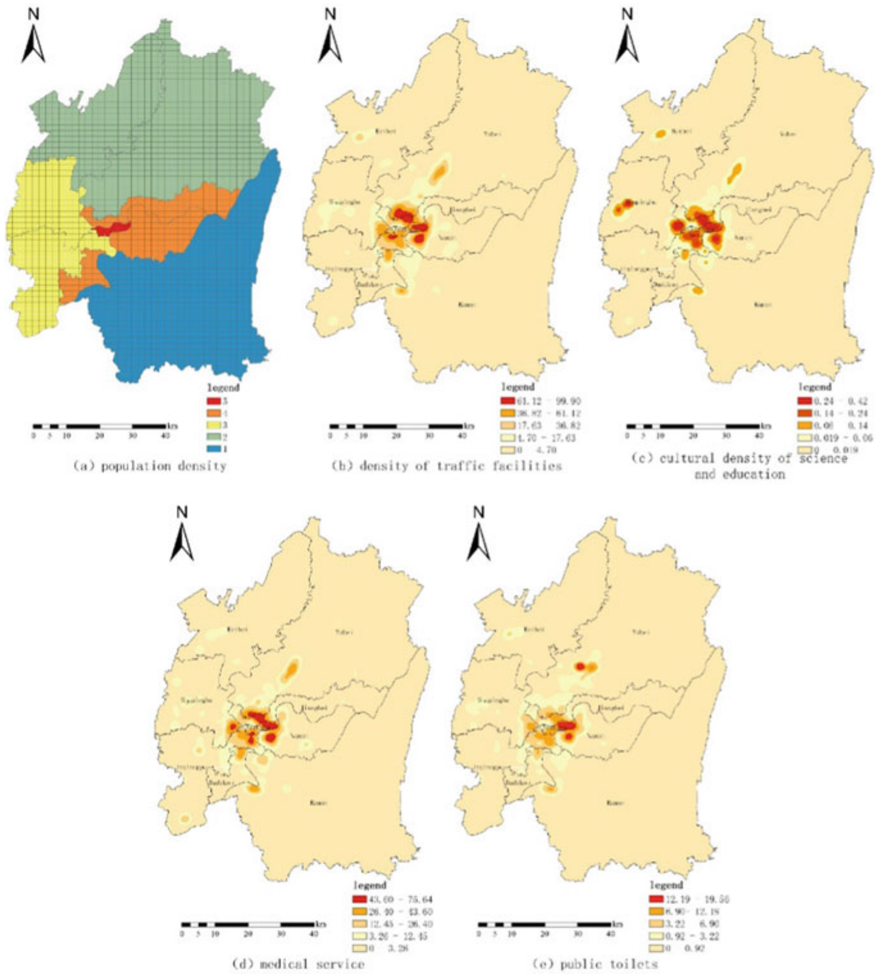


Fig.4 Discrete distribution of driving factors of urban vibrancy

Table 2 Detection results of driving factors

Type	Driving Factors	q
Land-use factor	Population density (X1)	0.416
Urban traffic service	Density of traffic facilities (X2)	0.408
Public service	Cultural density of science and education (X3)	0.321
	Medical service (X4)	0.401
	Public toilets (X5)	0.388

which indicates that transportation facilities are the second key driving factors of urban vibrancy. This is in line with the objective law of more convenient transportation in urban prosperous areas. In public services, the driving effect of medical service density is 0.401, the driving effect of public toilet 0.388, the driving effect of Science and education culture density is 0.321. It indicates that the agglomeration effect of urban medical service facilities is slightly greater than that of public toilets, and is greater than that of science and education culture. In the above analysis of the core of urban vibrancy, we can see that these core areas have rich medical and scientific, and educational resources, but the driving degree of medical treatment is the greatest among the three resources.

Among the five driving factors, population density is the most important factor, while science, education, and culture are the least. Therefore, in order to alleviate the pressure on the core area of Chongqing's main urban area, it is necessary to formulate a certain policy to balance the population density of each district and distribute medical services, science, education, and cultural facilities in the whole district. At the same time, it is necessary to strengthen the establishment of transportation facilities in key planning areas, to promote the development plan of "multicenter, group book" and balance the core development of each district.

5.2 *Interactive Detection of Driving Factors*

After detecting the interaction of each two factors, we can see that the value of each two factors is larger than a single factor, as shown in Table 3. It indicates that the driving degree of each two factors is greater than that of a single factor, namely, the influence of any two driving factors will improve the difference of urban vibrancy. This indicates that the spatial characteristics of urban vibrancy are the result of multiple factors, and there is a complex synthesis between the spatial differentiation characteristics and the influencing factors, especially under the comprehensive effect of urban population density and traffic service facilities.

Table 3 Driver interaction detection junction

	X1	X2	X3	X4	X5
X1	0.416	–	–	–	–
X2	0.635	0.408	–	–	–
X3	0.580	0.423	0.321	–	–
X4	0.613	0.459	0.422	0.401	–
X5	0.617	0.444	0.407	0.442	0.388

6 Conclusion

Taking the main urban area of Chongqing city as the research object, this paper describes the spatial characteristics of urban activities based on the night light data. Then this paper analyzes the driving factors of urban vibrancy, including land use, transportation services, and public services by using ArcGIS kernel density and geographic detector tool. The conclusions are as follows: (1) the urban vibrancy of the nine districts of Chongqing city presents the spatial distribution characteristic of "multi-core" with the Yuzhong District as the main core and small core in each district. This characteristic is in line with the development mode of "multicenter and group type" in Chongqing. (2) the difference among the driving effect of each driving factor is not significant, among which population density plays the most important factor. (3) according to detecting the driving force of each two driving factors, the influence of any two driving factors will reduce the difference of urban vibrancy.

Understanding the spatial characteristics and driving factors of urban vitality from a micro perspective is of great significance to urban development planning and decision-making. To improve the overall planning and layout of Chongqing, urban planning can be guided by transportation facilities to decentralize public service facilities such as medical, science and technology, culture, and so on. In this way, the core pressure of the main urban area can be relieved and the coordinated development of urban social economy can promote.

The driving factors involved in this study can be further expanded. The research on the driving factors of urban vibrancy is from a static perspective, but do not investigate the development change of urban vibrancy from a dynamic perspective. Further analysis and discussion can be made in the future.

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Quantitative Review of Cross-Regional Mega Infrastructure Operation and Maintenance Management Research

Lin Chen, Qiting Guo, Yuanxin Zhang, Xiaolong Xue, and Zeyu Wang

Abstract While developing economies has built many mega infrastructure projects that begin to serve the public, developed economies are facing aged mega infrastructure systems, that need better maintenance and management. Many scholars have studied the mega infrastructure operation and maintenance (O&M) even though the majority mainly focused on construction management. There lacks a thorough review of the research in mega infrastructure O&M management. In order to gain an overview of the cross-regional mega infrastructure operation and maintenance management research and to identify the hotspots and the evolution of the state of the art between1992 and 2020, this study used bibliometric analysis and social network analysis through CiteSpace and VOS Viewer to analyzed and visualize the relevant literature data of Web of Science. This research used 646 bibliographic data from the core collection of Web of Science. The keyword co-occurrence network and co-citation network analyses showed the hot research topics, influential publications, and evolution trend in mega infrastructure O&M management. This research contributes to the body of knowledge and can guide scholars about popular research topics and emerging ones in the area.

Keywords Cross-region · Mega infrastructure project · Asset management · Operations and maintenance management · Bibliometric analysis

1 Introduction

With the continuous growth of global population over the past decades, a lot of young people prefer to stay in metropolitan areas due to better infrastructure and more opportunities [1]. Traffic congestion has become a common phenomenon in most major cities (e.g., Shanghai, Beijing, New York, San Francisco, and Atlanta) [2–4], demanding for mega infrastructures because they can meet the needs for a big population. Mega infrastructure connects cities, resources, and residents of different

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regions, which is the external manifestation of cross-regional mega infrastructure [5]. Some scholars define projects with an investment of more than $1 billion as mega projects [6]. In 2014, mega projects accounted for 21% of global construction expenditures, but this proportion was only 4% in 2005 [7].

While developing countries, such as China, currently have a large number of mega infrastructure projects in operation, their experience, theory and model in operation and maintenance (O&M) management of cross-regional mega infrastructure projects are still in a rudimentary stage in comparison to developed countries, that have matured organizational models of mega infrastructure projects O&M. The National Institute of Building Science defines facility O&M as a wide range of services, capabilities, processes, and tools to ensure that the facility performs the designed functions in the built environment. Maintenance also refers to the combination of technology and related management measures, aiming to maintain or restore a project or system to a state where it can perform its required functions [8]. The scope of O&M management mainly includes five aspects: space management, asset management, maintenance management, public safety management and energy consumption management.

In fact, most developing economies play more emphasis on project construction than O&M because of the lack of a project lifecycle perspective [9]. Previous research has shown that O&M accounts for about 40% of a project lifecycle cost. O&M is also critical to offer end-user with high quality service. As increasingly more mega infrastructure project into operation and the significance to the urban community, many scholars in developing economies started shifting their attention from construction to O&M of mega infrastructure projects. But, there lacks a review on the state of the art in mega infrastructure O&M management research.

Therefore, this paper analyzes the literature retrieved from Web of Science in terms of keywords co-occurrence and co-citation networks. Based on the scientific knowledge graph, this paper analyzes the evolution of cross-regional mega infrastructure O&M management research, the space–time adaptability of cross-regional mega infrastructure projects, the evolution pattern of the O&M management mode of cross-regional mega infrastructure projects.

2 Data Collection

Founded in 1963 by Eugene Garfield, a well-known American bibliometrics expert, now Web of Science (WOS) is a database product of Thomson Reuters Group. As an interdisciplinary, international large-scale comprehensive document retrieval tool, WOS covers lots of renowned peer reviewed journal articles, authoritative international conferences proceedings and monographs in various disciplines. It is considered the most prestigious database used for bibliometrics and text mining. In addition, WOS provides advanced search functions with Boolean links, which improves the accuracy of the search results. Thus, this study chose to retrieve relevant literature data from WOS.

Cross-regional mega infrastructures offer services for human basic needs, social well-being, and economic activities related to national security and development [10–12]. Cross-regional mega infrastructures are man-made built environment, which improves the living environment of human beings [13, 14]. Therefore, this study defines cross-regional mega infrastructure as an engineering facility that crosses geographical boundaries, connects cities, populations, and resources in different regions, and provides public services for cross-regional social production and residents' lives and the general conditions of survival and development. Mega infrastructure itself and external environment are characterized by great complexity. To ensure the comprehensiveness of literature data relating mega infrastructure O&M, this study embodies the "cross-regional mega infrastructure" into infrastructures like roads, highways, railways, expressways, high-speed railways, pipeline corridors, and power grids, etc.

3 Research Methods

Both bibliometric analysis and social network analysis (SNA) were used in this paper to understand the structural distribution characteristics of the subject area from a graphical perspective, and generate new methods and ideas for this research. The bibliometric analysis is based on bibliometrics to study the literature information, including publications, scientific terms, authors, citations, and cited references. Bibliometric analysis is mainly to analyze the co-words of the literature citations, authors and keywords. It is helpful for this research to identify hot topics and evolution pattern and predict the future trend of research topics in this field. SNA is a quantitative analysis method developed by sociologists based on mathematical methods and graph theory [15]. SNA can visually show the attributes of individual nodes and their relationships.

The research procedure of this paper is shown in Fig. 1. First, using Boolean links in the WOS database to combine the key search terms into advanced search formulas; Then, document category and type filter were employed to improve relevance to the research topic. There were 849 literature data after the initial screening. Second, after downloading 849 literature data, manual screening was performed based on the abstracts and keywords of the documents to filter out the irrelevant ones. The final document data was 646. Finally, SNA and bibliometric analysis were used to generate the keyword co-occurrence network, document co-citation network of the research field so that it can visualize the research hotspots and predict the research development trend based on network characteristics, identifying the network structure [16].

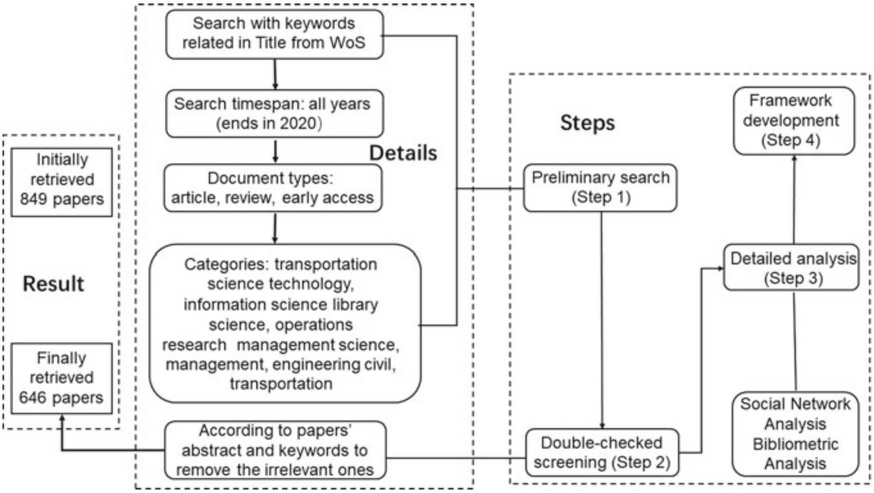

Fig. 1 Research methods and workflow

4 Bibliometric Analysis

4.1 Overview of the Publications

The publication time of papers in a certain field shows the development trend of the field over time. The number of literatures published in mega infrastructure O&M is seen a continuous growth over time, indicating that the field continues to receive attention. The analysis in the time dimension is based on the the publication time of the paper. Specifically, from 1992 to 2020, the annual number of documents published in cross-regional infrastructure O&M management research is shown in Fig. 2. On the whole, the growth of research papers has been relatively slow for a long period of time from 1992 to 2007. The annual number of papers grow to 20, accompanied with a fluctuating upward trend from 1992 to 2020. The number of publications reached

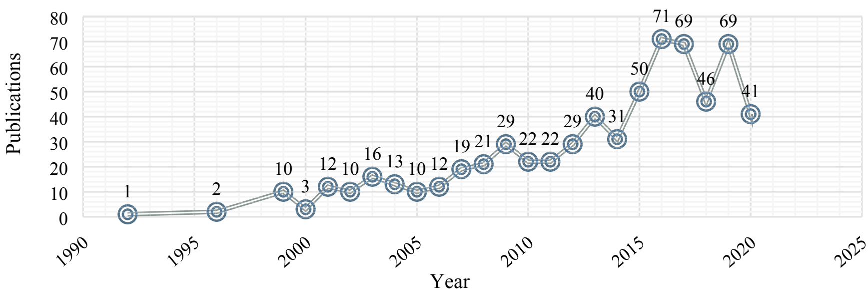

Fig. 2 Publications per year from 1992 to 2020

a small peak in 2016 with 71, and then experienced a sudden decline to 46 in 2018. Since 2019, the number of postings has rebounded. As of the time this research was completed, the data in 2020 is not definitive yet.

4.2 Analysis of Keywords Co-occurrence

According to co-word analysis, when two words (topic words, keywords, etc.) appear in the same document, they are considered to have a co-occurrence relationship. The more words appear in the same documents, the closer the relationship between the two topics. When two papers are frequently cited together, they are often cited separately too. If the frequently cited papers represent key concepts, methods, or experiments in a field, then common patterns can be used to map the relationships between these key ideas in great detail. Changes in the common citation pattern over time can provide clues for professional development [17].

The number of nodes in the keyword co-occurrence map is related to the number of co-occurrences. The number of co-occurrences between two keywords specified dictates the nodes that appear in the graphs. The visualization of the graph is poor if there're too many or too few nodes shown in the network. Therefore, in order to improve the degree of visualization and avoid ignoring the key information in the graph, the minimum number of co-occurrences of keywords was set at 3 when importing the dataset into VOS Viewer. 206 of the 2147 keywords showed in the graph based on the criterion.

VOS Viewer stipulates that the color of each node in the density view depends on the density of the item. That is, the color of the node in the graph depends on the number of items near the node and the importance of neighboring items. The density view is particularly useful for overviewing the general structure of the graph and contrasting the most important areas [18]. The color transition of the node colors from green to yellow to red in Fig. 3 indicates that the number of co-occurrences of nodes is increasing, and the nodes in red are located in the center of the graph, which indicates that the node occupies an important position in the network and is the core node. The red model, maintenance, optimization, management, and infrastructure are the key nodes in the network and play the critical role in the network.

According to Table 1, it can be seen that the three nodes labeled by optimization, maintenance, and model rank top 3 based on frequency. CiteSpace uses purple circle to represent high centrality. The nodes labeled model, optimization, maintenance, management, and system are surrounded by the purple circle (see Fig. 4). Also, they are at the center of the network, indicating that the keywords are the key research content in this field. They are the mainstream research direction in cross-regional mega infrastructures O&M management.

The distance between nodes indicates their relationship. Nodes that are clustered together have a higher frequency of co-occurrence and a closer relationship; while some are far away from each other, having less co-occurrence frequency, or even no

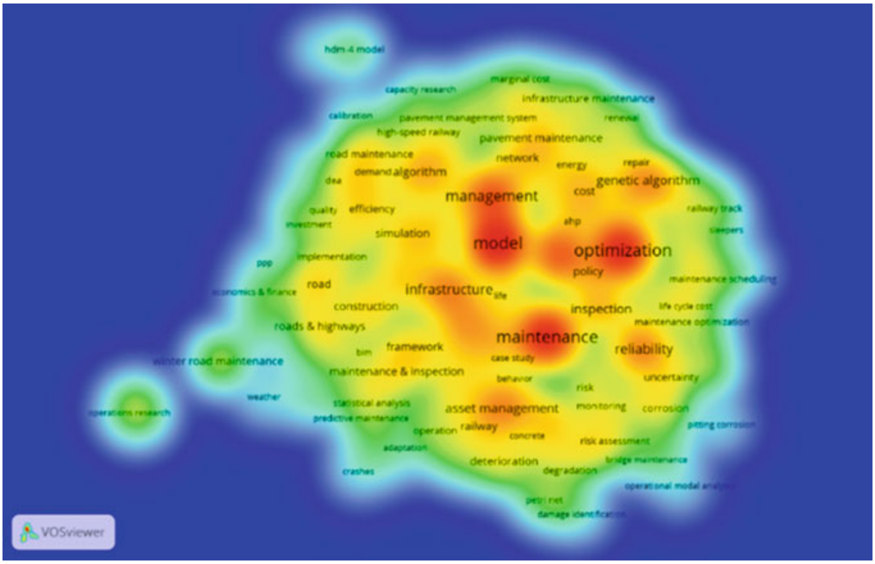

Fig. 3 The density visualization of the keywords co-occurrence

Table 1 The frequency of keywords (>20)

No.	Keyword	Frequency	Degree	No.	Keyword	Frequency	Degree
1	Optimization	181	46	7	System	61	52
2	Model	140	44	8	Infrastructure	48	39
3	Management	107	40	9	Genetic algorithm	34	32
4	Maintenance	92	51	10	Reliability	28	40
5	Pavement maintenance	72	20	11	Performance	22	38
6	Pavement management system	66	12	12	Road	21	18

connection, meaning they are distant or independent. The nodes labeled model, optimization, maintenance, management, and system in the map are close to each other, indicating that the mainstream research directions in this field are interconnected.

In order to discover the hot research topics in this field accurately, this research further uses CiteSpace to calculate the keyword betweenness centrality and mutation coefficient (see Table 2). The centrality of nodes in the network measures the importance of the location of nodes in the network. There are two types of nodes that may have high betweenness centrality: (1) pivot nodes that are highly connected to other nodes; (2) nodes located between different clusters. We are more interested in

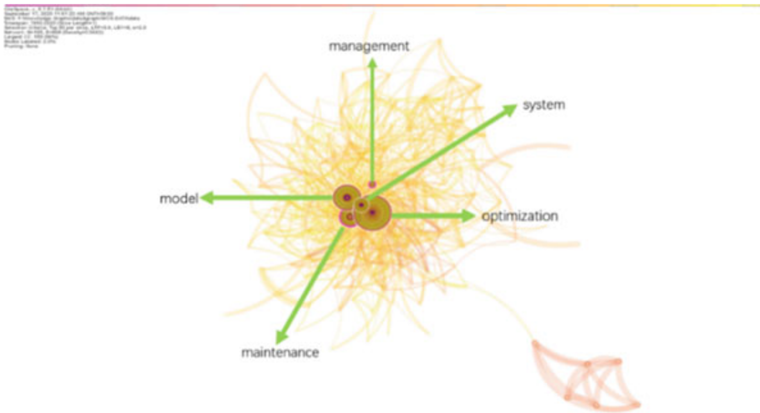

Fig. 4 Keywords co-occurrence graph produced by CiteSpace

Table 2 The centrality of keywords

No.	Keyword	Centrality	No.	Keyword	Centrality
1	Maintenance	0.24	5	Infrastructure	0.15
2	System	0.22	6	Performance	0.11
3	Management	0.17	7	Model	0.11
4	Optimization	0.15	8	Reliability	0.11

the second type of nodes, which are more likely to cause emerging trends than the first type of nodes [19].

The higher the centrality of a keyword, the more important it occupies in the network structure. According to Table 3, the betweenness centrality of maintenance is 0.24, the central betweenness degree of system is 0.22, and the central betweenness degree of management is 0.17, followed by optimization and model. Figure 4 shows that most of these keywords with higher value of centrality are located in the center of the network, reflecting the focus and research hotspots of cross-regional mega infrastructure O&M management research, and having important implications for the future research and development direction.

Burst detection determines whether a given frequency function has statistically significant fluctuations within a short time interval [20]. Through burst detection, the keywords whose frequency of appearance has sudden growth can be found. It's an

Table 3 Keywords that have the highest value of sigma

No.	Keywords	Mutation coefficient	Sigma value	Central mediation	Frequency
1	Optimization	18.88	14.34	0.15	181
2	Management	8.60	3.79	0.17	107

Table 4 Relevant index of keyword co-occurrence network

Number of nodes	Edge	Module value (Q value)	Mean Silhouette	Network density
165	868	0.3619	0.4425	0.0642

important indicator for measuring future research. The Sigma value is introduced as a measure of scientific novelty. Based on two transformative discoveries, it determines the text that may represent new ideas [20], which combines the importance of nodes in the network structure and the time. The literature with high Sigma value usually has a certain degree of innovation, and has an important enlightening effect on the knowledge structure of the research field.

Optimization first appeared in the paper—Exploring the influence of pavement preservation, maintenance, and rehabilitation on Arkansas' highway network: an education case study, published by Kiihnl Lin in 1992. Management first appeared in the paper—A fuzzy logic expert system for selecting optimal and sustainable life cycle maintenance and rehabilitation strategies for road pavements, published by Santos, Joao in 1992. The Sigma values of optimization and management are 14.34 and 3.79, respectively (see Table 3).

According to Table 4, it can be seen that the network is a large and complex co-occurrence graph composed of 165 nodes through 868 edges. Network density is the ratio of possible connections [21], which can be used to describe the density of nodes in the network. The range of network density is between 0 and 1. A large network density value indicates that there are more communications between nodes and the network information circulation is better. In general, the density of large-scale networks is lower than that of small-scale networks.

Modularity is used to describe how much a given graphic can be organized into a community. Modularity captures how well a given partition compares to a random wired network [22]. The size of the Q value is related to the division of communities in the network. The closer the Q value is to 1, the stronger the community structure is divided, that is, each clustering discrimination is obvious. In actual networks, this value is usually between 0.3 and 0.7. It is generally believed that if the Q value is more than 0.3, the cluster structure is more significant.

Table 4 indicates that the network density of Fig. 4 is 0.03619, and the modularity is 0.3619. According to Fig. 4, the overall scale of the network is relatively large, the research coverage is relatively broad, the concentration and the clustering structure are mediocre. The node structure inside the network is denser, and the node structure near the edge of the network is looser. This means that there is high link density in the network with poor node relationship, the difference in node size is obvious.

4.3 The Cluster Analysis of Keywords

In this study, CiteSpace was used to perform cluster analysis on keywords and algorithms were used to extract keywords to label the clusters. As shown in Fig. 5, CiteSpace divides keywords into 9 clusters. Silhouette represents the average profile value (S value) of the cluster and the uncertainty that needs to be considered when interpreting the property of the cluster. The S value is between −1 and 1. When the S value equals 1, it means that the cluster is perfectly separated from other clusters [20]. In CiteSpace, it is generally believed that the cluster is reasonable when S value is greater than 0.5, and the cluster is convincing if S value is more than 0.7. According to results, the S values of clusters 0, 3 and 4 are between 0.5 and 0.7, the rest clusters all reached up to 0.7 and above, indicating that the clustering discrimination of the network is relatively high. Obviously, the credibility of each cluster is relatively high and it has strong persuasiveness.

The average appearance year of each keyword in cluster 8 is the earliest, indicating that the early development of cross-regional infrastructure O&M management research and development mainly focused on the road O&M. The average appearance year of each keyword in cluster 2 and cluster 4 is the latest, indicating that the current stage of the development of cross-regional infrastructure O&M management research is mainly focused on distributed optimization and railway. This study further analyzed the two representative clusters, cluster 0 with the largest number of clusters and cluster 8 with the highest S value.

The result shows that the capacity of cluster 0 reaches to 30 nodes, and the average value of the year when each keyword appears is 2010. Table 5 presents 8 keywords with highest frequency in cluster 0, the keywords with higher frequency are management, pavement maintenance, pavement management system, genetic algorithm, multi-objective optimization, decision making. Those keywords also have the higher value of degree and centrality. To some extent, they stand for the main content of the

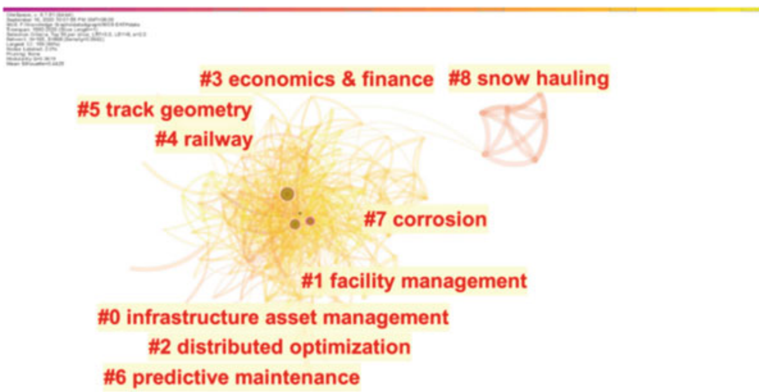

Fig. 5 Cluster analysis

Table 5 The Top 8 keywords with highest relevant indices in cluster

No.	Frequency	Degree	Centrality	Keyword
1	107	40	0.17	Management
2	72	20	0.05	Pavement maintenance
3	66	12	0.04	Pavement management system
4	34	32	0.10	Genetic algorithm
5	17	18	0.03	Multi-objective optimization
6	17	28	0.09	Decision making
7	9	9	0.01	Analytic hierarchy process
8	8	8	0.11	Pavement management

Table 6 The information about cluster 8

Frequency	Degree	Centrality	Keyword
6	6	0.11	Winter road maintenance
4	5	0.01	Snow hauling
4	5	0.01	Operations research
4	5	0.01	Snow removal
4	5	0.01	Snow disposal
2	4	0.00	Arc routing

cluster. According to results, the S value of this cluster is 0.584, which indicates that the cluster is reasonable and has high credibility.

From Table 6, it can be seen that there are 6 keyword nodes in cluster 8, and the average value of the year when each keyword appears is 2006. Among them, the keywords with high frequency are winter road maintenance, snow hauling, operations research, etc. This cluster mainly focuses on the O&M management of winter roads, including snow removal, snow disposal, arc routing, etc. The S value of this cluster is 0.989, which indicates that the cluster has a good structure and high reliability.

4.4 Analysis of Cited References

Literature co-citation analysis means that if two or more papers are cited by one or more later papers at the same time, it is said that these two papers constitute a co-citation relationship. The co-citation strength of a document is measured by the number of co-citations. The more co-cited documents, the higher the co-citation strength and the higher the similarity. Document co-citation analysis enables the basic knowledge structure of the research field to prove the number and authority of the references cited in the published literature [23]. As the main bibliometric method, document co-citation analysis can be used to identify potential relationship patterns

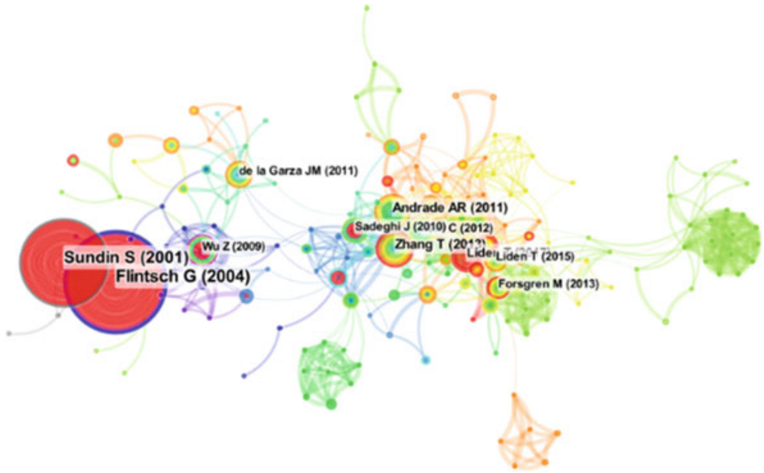

Fig. 6 The network visualization of the high-cited references during 1992 and 2020

between articles based on the citations cited in the articles. This type of analysis is different from a typical research review and can extract information from references for cluster analysis. The advancement of the information technology of indexing and retrieving academic work makes this method more viable [24].

CiteSpace analyzed homogeneity or similarity of the cluster nodes. Nodes that are cluster together exhibit a higher level of homogeneity. In co-occurrence networks, homogeneity is usually determined by the similarity of underlying disciplines or topics. Nodes with high connectivity are more likely to cluster, while nodes with different or poor connections from other nodes are farther away from each other. Most of the main basic documents in this field are located in the center of the network, because they are often cited as references by the same document, so their connectivity and centrality are high [25].

According to Fig. 6, the size of the nodes of the document co-citation network represents the number of citations of the document, the color of the line represents the time of the first co-citation. These two nodes represent the papers written by Gerardo W. Flintsch in 2004 and Sten Sundin in 2001 (see Table 7). They showed a high frequency of co-citation with other documents and a strong connection with other cited documents. They are authoritative documents in cross-regional mega infrastructure O&M management.

CiteSpace usually uses red color to denote the highly explosive documents in the network, Through Fig. 6, some of the nodes have changed greatly in a short period. Among them, the node represents the paper titled *An optimization model for integrated planning of railway traffic and network maintenance*, has the latest (see Table 7) explosive time, which shows that this document is a new development direction in the field, deserving more attention.

Table 7 The details about the high-cited references

Title	Journal	Author	Year
Soft computing applications in infrastructure management	Journal of Infrastructure Systems	Gerardo W. Flintsch Chen Chen	2004
Artificial Intelligence–Based Decision Support Technologies in Pavement Management	Computer-Aided Civil and Infrastructure Engineering	Sten Sundin Corinne Braban-Ledoux	2001
Pavement Preservation Optimization Considering Multiple Objectives and Budget Variability	Journal of Transportation Engineering	Zheng Wu, Gerardo W. Flintsch	2009
An analytical solution for the finite-horizon pavement resurfacing planning problem	Transportation Research Part B: Methodological	Yanfeng Ouyang, Samer Madanat	2006
Scheduling preventive railway maintenance activities	Journal of the Operational Research Society	G Budai, D Huisman, R Dekker	2006
Development of improved railway track degradation models	Structure and Infrastructure Engineering	Javad Sadeghi, Hossein Askarinejad	2010
An optimization model for integrated planning of railway traffic and network maintenance	Transportation Research Part C: Emerging Technologies	Tomas Lidén, Martin Joborn	2017

5 Conclusion

With continuous population growth and urbanization, a large number of mega infrastructure project in developing countries are put into use, meanwhile, many developed economies are facing aged mega infrastructure system, that require attention in their efficient operation and effective maintenance. The proportion of mega infrastructure in global construction expenditures was 4% in 2005. And it increased sharply to 24% in 2014, which is still growing. Nonetheless, there lack an overview of the research regarding mega infrastructure O&M management. Thus, this study aims to provide a quantitative review of the literature published in this area through bibliometric analysis. A total of 646 bibliographic data were used for the analysis. The keyword co-occurrence analysis showed that model, optimization, management, and maintenance were the hot topics in the field of cross-region infrastructure O&M. Those research themes also showed a close relationship. The cluster analysis showed that 9 clusters were formed and labeled by the keywords. The cluster “infrastructure asset management” was the most popular research topic. Combining the keywords co-occurrence analysis and cluster analysis, it was shown that the research evolution trend in this field and the mainstream topics identified from the keywords co-occurrence graph. We conclude there's still an urgent need for a large number of professionals to make a longer-term contribution to the development of the cross-regional major infrastructure O&M management.

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Effectiveness of Prefabricated Construction in Major Public Health Emergency Management: A fsQCA Analysis

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Abstract The construction and management of emergency medical facilities is critical during major public health crisis. In recent years, the outbreak of pandemics, such as SARS, Zika, Ebola, and COVID-19, has continuously driven higher requirements on the government's prevention and control capabilities. In response to the dire challenges of COVID-19, the ability to swiftly construct medical facilities to fight the epidemic, quickly and effectively prevent and control the spread of the virus, has been greatly valued globally. It is shown that compared with traditional on-site construction, prefabricated buildings, characterized by high productivities in factories, high quality, ease of cost estimation and management, short on-site construction time, and less labor intensive, have become a more practicable option and witnessed a surge for emergency medical buildings in fighting epidemics. This research aims to allude to the effectiveness of emergency management of major public health incidents from the perspective of the prefabricated buildings. Based on the framework of the prefabrication system to refine antecedent variables, this research employed the fuzzy set qualitative comparative analysis (fsQCA) to analyze 15 emergency medical projects, either the "Xiaotangshan" model or the "Combination of Peace and Warfare" model in China. Eight internal antecedent variables and three outcome variables were extracted from these cases to explore the antecedents and path configuration affecting the effectiveness of emergency management of major public health events. The finding of this study can serve as a reference for public agencies and industry leaders to improve the effectiveness of emergency management of major public health incidents by taking full advantage of prefabrication construction.

Keywords Public health emergency management · Prefabricated construction · Epidemic control and prevention · fsQCA · Congiguration analysis

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1 Introduction

During the rapid outbreak of an epidemic and patients surge, it is critical for emergency management deployment that can quickly build emergency medical facilities (e.g., AAA hospitals) to control the spread of virus [1]. Faced with multiple requirements, such as construction period, cost, quality, and large-scale crowd gathering restrictions, traditional cast-in-place construction systems are difficult to meet the requirements in epidemic prevention and control [2]. The features of construction industrialization: standardization, factory mass production, automation, and efficient organization and management, are aligned with the requirements in epidemic prevention and control and the development of the construction industry [3, 4]. At this stage, the main systems of construction industrialization include steel structure systems, precast concrete structure systems, and composite wood structures [5, 6]. Among them, the steel structure and precast concrete structure systems are not only suitable for the pure medical and emergency projects [7, 8], are also applicable to the construction of a comprehensive medical and health center that adopts the combination of peace and war model [9, 10].

The pure quantitative analysis or qualitative analysis research methods in the field of emergency management in the past has led to the big data retrospective research in high labor, time cost, and the credibility of small sample research of individual cases are typically challenged among them [2, 11]. This research selects a new cutting-edge research method in public management and sociology: qualitative comparative analysis (QCA). QCA is a research method that combines qualitative and quantitative analysis and is committed to solving complex social issues induced by multiple complex concurrent causes and effects. This method incorporates the advantages of quantitative analysis and qualitative analysis in case studies and influencing factors identification, and can establish credible causal relationships and internal patterns from small and medium-sized case bases.

The QCA is suitable for public health emergency response in the study because this method does not emphasize the net effect of a single variable, but identifies the relationship between variables from a set perspective, and it uses Boolean algebra as the basic operation principle of data to study how multiple internal antecedent variables are combined into a path configuration to explain the generation of outcome variables among them [12]. Therefore, qualitative comparative analysis abandons the net effect of a single variable, but explores the causal relationship between variables based on the overall perspective and configuration [13].

Considering the characteristics of epidemic prevention and control variables, that is, the variable assignments extracted in emergency management cases are difficult to be fully defined by the Boolean dichotomy of 0 or 1 [14]. Therefore, this research explores the factors affecting the effectiveness of emergency management of major public health events through the sub-method of the qualitative comparative analysis method: the fuzzy set qualitative comparative analysis method (fsQCA), which aims to explore the causal relationship through small and medium sample data [15]. Therefore, this research aims to improve the effectiveness of emergency management of major public health events by the prefabricated building system, and the research method was the fuzzy set qualitative comparative analysis method, and it strives to deal with major public institutions such as, the COVID-19, from the perspective of construction industrialization. This study provides decision-support for public health emergency facility construction [16].

2 Research Methods

2.1 Cases Collection

The fsQCA is based on small and medium-sized case libraries, which can be used with a sample size of 15–80. Since many systematic emergency medical projects are still in the planning or construction process during the epidemic, the data are scarce, but it can be used on a sample size of 15–80 [12]. The sample size referenced the previous researchers using QCA in the field of public management and sociology, which generally use 20–40 cases. The identified research cases consist of two typical emergency medical projects in Beijing that adopted the "Xiaotangshan" model and the "Combined Peace and War" model during the SARS period, and 13 national emergency medical projects during COVID-19.

2.2 Cases Database Establishment

The specific steps for constructing the case database are as follows: first, take the cases collected by the research team based on the boundaries of various provinces and cities across the country as the first-level candidate case database; second, follow the selection principles set by this research topic to further narrow the scope to form a typical case library; finally, search, expand and organize the supporting materials of the cases in the typical case library and their homologous derived materials, and further conduct repeated comparisons and confirmations through the triangulation method, and finally form a case library [10]. The construction of a typical case follows the following principles:

i. the project engineering management system reflected in the selected case is universal and representative, that is, the engineering management method system used in the case has great academic research value. Not only in academic research, the private domain has been extensively studied, and the public domain has been widely concerned by the people and the media.
ii. the selected case types strive to achieve diversification, that is, the selected cases occur in the region (large and medium cities across the country), time span (the construction period varies from weekly to annual), and the project

construction model ("Xiaotangshan" and "Combination of Peace and Warfare" modes) and other dimensions reflect the characteristics of diversification [8].

iii. the selected case sources and supporting materials have high credibility, wide audiences, diversified platforms, etc. The data sources are mostly national large-scale news platforms. Since most of the materials obtained in this research are second-hand materials, the supporting materials for the selected cases need to be more comprehensive, including materials obtained through various channels, such as media reports at all levels, academic papers, Zhihu posts, press conferences, etc. [17]. The triangle test method was repeatedly compared and cross-checked to ensure that the case-based data have a high degree of credibility. Finally, 15 neighbor avoidance conflict cases were formed as the case database of this study.

2.3 Variables Extraction

This research mainly starts from the perspective of prefabricated building system, based on the theoretical framework of construction industrialization and major public health incident emergency management, and it is oriented to extract a causal variable system including 8 internal antecedent variables and 3 outcome variables [12]. Interpretation of internal and antecedent dependent variables and assignment rules are:

(1) emergency medical building reference model. The assignment rule is that the building system mainly refers to the assignment of the combination of peace and war mode with a value of 1; mainly refers to the assignment of the "Xiaotangshan" mode to 0″. The selection of the emergency medical building reference model is the core of the entire emergency medical project, because the choice of the model ultimately determines the time node for the delivery of the entire emergency medical project into the epidemic prevention war, which is to play a pure emergency response during a large-scale epidemic. Medical is still in the post-epidemic era as a triad of medical, education, and scientific research to continue to play its value, which is directly related to the local government's overall planning and medical resource allocation and other major decisions [18].

(2) total construction period. The assignment rule is: the total construction period of the entire project from project site selection to acceptance, delivery and use, the value of not more than one month is assigned to 1, and the value of more than one month is assigned to 0. During the fight against the epidemic, time is life, and the speed, at which emergency medical projects are put into use is directly related to the lives of patients and the effectiveness of the work of medical staff. The control of the construction period is the lifeline that runs through the entire project planning and construction, and is also a major inspection of the pre-assembly construction system [10].

(3) architectural design service life. The assignment rule is: 1 for more than 50 years; 0.6 for more than 25 years and less than 50 years; 0 for less than 25 years. In general engineering project management, the design service life of buildings is divided according to the classification levels in the "General Principles of Civil Building Design" according to GB 50352–2005. This indicator is a key factor related to cost budget and construction period control in architectural design. It is closely related to internal antecedent variables (1), (2), (4), and is an internal antecedent variable that needs to be paid attention to.

(4) level of emergency medical items. The assignment rule is: after the emergency medical building is officially put into use, the index can reach the standard of tertiary A hospitals or the highest standard set by the local hospital for specialized infectious diseases, the assignment is 1; the assignment that cannot be achieved is 0″. A few notes on the grade evaluation of emergency medical items: First, the measurement standards are affected by the mode adopted by the building, that is, the measurement standards for emergency medical projects that adopt the "Xiaotangshan" mode or the combination of peace and war mode are two sets of measurement standards system. Specifically, high-quality emergency medical projects using the "Xiaotangshan" model need to meet the highest standards set by local hospitals for specialized infectious diseases, while high-quality emergency medical projects using the combined peacetime and wartime model can meet the requirements of the national medical and health system, the index requirements of Grade A general hospitals. Therefore, for the sake of the rigorousness, the evaluation rules of this variable in this research distinguish and explain the evaluation criteria of emergency medical items derived from the two systems.

(5) special functional requirements for buildings, such as the "three zones and two isolation" functional zoning and negative pressure ward equipment that appeared in the emergency medical project to deal with the new crown epidemic. The assignment standard is "the assignment of special functional areas with construction needs is 1; No special requirements are assigned as 0″ [1]. Research and practice have proved that the use of "three zones and two isolation" functional partitions and negative pressure ward equipment in emergency medical projects is significant for improving the cure rate of patients and reducing the infection rate of medical staff role [8]. Carrying out special structural planning in emergency medical projects and setting aside special cost budgets to set up functional zones and negative pressure wards are valuable lessons learned from the fight against the new crown epidemic.

(6) wet work on site. The assignment rule is: in the construction process of the building site, except for the elevator room, the assignment of the cast-in-place process is basically not required to be 1; otherwise, the assignment is 0. According to the basic requirements of construction industrialization and prefabricated building system, that is, standardization of architectural design, factorization of component production, construction mechanization, and scientific organization and management, the construction site should minimize wet

operations, such as cast-in-place molds; but Considering the overall safety of the building, the construction industry code clearly stipulates that even if a highly mature pre-assembly system is adopted, all elevator rooms of the building should be cast-in-place to strengthen the rigidity and integrity of key parts of the building, so consider partially exclude the elevator in wet conditions.

(7) constructors' enthusiasm. The assignment rule is: the assignment of a single work of more than 8 h per shift is 1; the assignment between 6 and 8 h is 0.8; the assignment below 6 h is 0. Staff enthusiasm is designed to the content of organizational structure and incentive mechanism in management, and it also involves disciplines, such as psychology. It is difficult to accurately assign values. Therefore, this paper chooses a quantitative indicator of single labor time to simplify the study of this variable.

(8) completeness of related supporting facilities. The assignment rule is: the value of 1 for more than 10 cooperative enterprises in communications, power, logistics, medical equipment, etc.; the value of 0.8 for 6–10 companies, and 0 for those below 6″. A well-functioning emergency medical building system requires the coordination of communication technology, IoT management, medical equipment and medicine manufacturing, and energy supply. Therefore, the completeness of related supporting facilities is a key indicator to measure the operation of emergency management projects [19]. Table 1 shows the assignments of the variable values based on each of the 15 cases.

Table 1 Variable assignment results

	EMBRM	TCP	SJNX	EMIL	SFRB	SWOC	CSE	CRSF	JGBL1	JGBL2	JGBL3
CASE1	0	1	0	0	1	1	1	1	1	1	0
CASE2	0	1	0	0	1	1	1	1	1	1	0
CASE3	0	1	0.6	0	0	1	0.8	0	0	0	1
CASE4	0	1	0.6	1	1	0	1	0	1	1	1
CASE5	0	1	0.6	1	1	0	0.8	0.8	1	1	0
CASE6	0	1	0.6	0	1	1	0.8	0.8	1	0	1
CASE7	0	1	0.6	0	0	1	1	0	1	0	1
CASE8	1	0	1	1	1	0	0.8	1	0	1	1
CASE9	1	0	1	1	1	0	0	1	1	1	1
CASE10	0	1	0.6	1	1	0	0.8	1	0	0	0
CASE11	1	0	1	1	1	0	0	1	1	0	1
CASE12	1	0	1	1	1	0	0.8	1	1	0	0
CASE13	1	0	1	1	1	0	0.8	1	1	1	1
CASE14	0	1	1	0	1	0	1	1	1	1	0
CASE15	1	0	1	1	1	0	1	1	1	0	1

3 Data Analysis

There are two univariate necessity analysis indicators used in this paper. The first is the consistency index-Consistency, which is used to judge whether X is a necessary condition for Y. The consistency formula is simplified as follows: consistency $(Xi \leq Yi) = \sum[\min(Xi, Yi)]/\sum Xi$; the criterion is as follows: if the condition X is a sufficient condition of Y, hat is, Y is a necessary condition of X, then the fuzzy set score of X is less than or equal to the fuzzy set of Y Set score value, and the consistency index is greater than 0.8. Another index: coverage index-Coverage- to determine the degree of interpretation of the condition X for the result Y [13, 14]. The coverage rate formula is simplified as follows: Coverage $(Xi \leq Yi) = \sum [\min(Xi, Yi)] / \sum Yi)$. This indicator describes the explanatory strength of the conditional variable X to the outcome variable Y. The value of the coverage index is positively correlated with the explanatory strength of X to Y. After calculation by the fuzzy set qualitative comparative analysis method (fsQCA) software, the necessity analysis result of a single condition variable is obtained (see Table 2).

The framework refines the internal antecedent variables, and combines the emergency management benefit measurement standards to refine the outcome variables. Through fsQCA, 15 emergency medical project cases are systematically compared and analyzed, aiming to find the necessary conditions and path configurations that affect the effectiveness of the emergency management of major public health events

Table 2 Necessity analysis

Antecedent variables	JGBL1		JGBL2		JGBL3	
	Consistency	Coverage	Consistency	Coverage	Consistency	Coverage
EMBRM	0.42	0.83	0.38	0.50	0.56	0.83
~EMBRM	0.58	0.78	0.63	0.56	0.44	0.44
TCP	0.58	0.78	0.63	0.56	0.44	0.44
~TCP	0.42	0.83	0.38	0.50	0.56	0.83
BDSL	0.70	0.79	0.65	0.49	0.82	0.70
~BDSL	0.30	0.82	0.35	0.64	0.18	0.36
EMIL	0.58	0.78	0.63	0.56	0.67	0.67
~EMIL	0.42	0.83	0.38	0.50	0.33	0.50
SFRB	0.92	0.85	1.00	0.62	0.78	0.54
~SFRB	0.08	0.50	0.00	0.00	0.22	1.00
SWOC	0.33	0.80	0.25	0.40	0.33	0.60
~SWOC	0.67	0.80	0.75	0.60	0.67	0.60
CSE	0.77	0.79	0.80	0.55	0.69	0.53
~CSE	0.23	0.82	0.20	0.47	0.31	0.82
CRSF	0.80	0.83	0.85	0.59	0.64	0.50
~CRSF	0.20	0.71	0.15	0.35	0.36	0.94

during the fight against the epidemic [5]. Enlightenment from optimized deployment of emergency management in my country's public health system. From the perspective of a single condition variable, it can be found that the variables of "emergency medical building reference mode", "special functional requirements of buildings", and "integrity of related supporting facilities" have the closest relationship with emergency medical project management benefits; at the same time, combining the above conditions.

The combined path is analyzed, and the following findings are obtained (see Table 3):

(1) among the 8 internal antecedent variables, the variables of "emergency medical building reference mode (EMBRM)", "special functional requirements of buildings (SFRB) ", and "i completeness of related supporting facilities (CRSF)" are in the consistency index in the necessity analysis of the outcome variables, obtaining a higher value indicates that the extraction of internal antecedent variables and the setting of assignment rules are more reasonable. The selection of the above internal antecedent variables can indeed produce a strong explanatory power for the results. "Emergency medical building reference model "," special function requirements of building", and "completeness

Table 3 Configuration analysis

Antecedent variable	JGBL1				JGBL2			JGBL3		
	1	2	3	4	1	2	3	1	2	3
EMBRM	⊕	⊕	⊕	•	⊕	⊕	⊕	⊕	•	⊕
TCP	•	•	•	⊕	•	•	•	•	⊕	•
BDSL	•		•	•	•	•	⊕	●	•	●
EMIL	⊕	⊕	●	•	●	⊕	⊕	⊕	•	⊕
SFRB	●	●	●	●	●	●	●	⊕	•	•
SWOC		•	⊕	⊕	⊕	⊕	•	●	⊕	●
CSE	•	•	•	⊕	•	•	•	•	⊕	•
CRSF	●	●	⊕	●	⊕	•	●	⊕	•	•
Consistency	1.00	1.00	1.00	0.92	1.00	1.00	0.83	1.00	0.92	1.00
Raw coverage	0.13	0.23	0.07	0.20	0.10	0.13	0.25	0.13	0.27	0.07
Unique coverage	0.08	0.18	0.07	0.20	0.10	0.13	0.25	0.13	0.27	0.07
Solution consistency	0.58				0.48			0.47		
Solution coverage	0.97				0.90			0.95		

Note ●Denotes inclusion of the antecedent variable, ⊕ represents exclusion of the antecedent variable; Big dots stand for core condition, little dots means non-core conditions, void means whether inclusion of the variable has no influence of related supporting facilities" are necessary conditions for the outcome variables. Other internal and pre-dependent variables, such as: "total construction period (TCP)", "emergency medical item level (EMIL)" and other three consistent indicators. The coverage rate of the indicators are relatively large, but they do not meet the above-mentioned necessity condition determination rules, so although these variables have a greater impact on the ultimate emergency management benefits, they are not enough to become a necessary condition for the outcome variable.

(2) further analysis of the condition combination path results found: among the 6 path combinations that affect the results of emergency management benefits, the results of emergency management benefits = construction workers' enthusiasm (CWE) + site wet operation conditions (SWOC) * completeness of related supporting facilities + emergency medical project level (EMPL) * completeness of related supporting facilities + special function requirements of buildings * completeness of related supporting facilities + emergency medical item level * building special function requirements + emergency medical item level * the coverage rate of related supporting facilities perfection is up to 0.63 (see Table 3). Emergency management benefit results = emergency medical building reference model * total construction period * building design service life (BDSL) * emergency medical item level * building special function requirements + site wet operation situation * construction staff enthusiasm * completeness of related supporting facilities + emergency medical building reference model * The total construction period * building design service life + emergency medical project level * special function requirements of building + site wet operation conditions * construction staff enthusiasm * the consistency of the perfection of related supporting facilities is up to 0.93 (Table 3).

4 Conclusion

With the increasingly more frequent and impactful outbreak of pandemics (e.g., SARS, Zika, Ebola, Covid-19), it requires speedy, safe and cheap facilities to fight emergent public health crisis. Prefabricated construction meets all the requirements for pandemics fighting due to its short duration, less labor intensive, better quality, etc. Critical medical facilities can be built within a short period without clustering a large group of workers on the construction site, that has a risk of spread virus. However, the effectiveness of prefabricated construction in major public health emergency management has not be substantiated in practice. So, this research aims to evaluated its effectiveness through real-world cases using fsQCA.

Through the above research, this paper found that among the 8 internal antecedent variables that affect the benefits of emergency management, the relationship between the variables of "emergency medical building reference model", "building special function requirements", and "integrity of related supporting facilities" and emergency medical project management benefits is the closest. In an environment where the industrialization of construction is gaining great popularity in the construction industry, the prefabricated building system has become the mainstream construction practice of emergency medical buildings. The successful experience of Beijing, Wuhan and other places should be promoted in the future deployment in response to major public health emergency management.

5 Limitation

This study has certain limitations: (1) The access to data is limited, and even though the information mutual verification and testing of data, but there may still be selective deviations. The next step can be improved by in-depth investigation; (2) Although the corresponding relationship between causal conditions can be explored through qualitative comparative analysis, the relationship between variables, the investigation of dynamic correlation mechanism still needs to return to the case for further interpretation. (3) The benefit of emergency management is a major social issue involving multiple subjects and multiple disciplines. This research mainly starts from the perspective of construction industrialization. Future studies should consider the deficiencies of other perspectives, conduct multi-subject and interdisciplinary research.

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A GIS-Based *K-Mean* Clustering Algorithm for Characteristic Towns in China

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Abstract The unbalanced development among regions and city-towns has attracted considerable attention due to the rapid China's urbanization process. What promote the characteristic town, a key node in China's urban system, to be the new driving force of China's urbanization development and national economic adjustment are population, living environment, rural vitality restoration and economic innovation. However, the unitary development of characteristic towns will exert an adverse impact on the long-term economic development. On the condition that previous academic work focuses less on the spatial clustering, spatial features based on the Chinese city-town system are thus introduced in this paper, and then the basic data is integrated through the Orange platform for statistical analysis. Finally, on the basis of the spatial featural visualization obtained through nearest-neighbor search, the *K-mean* algorithm and GIS tool are applied to perform the visualization and conduct spatial analysis of characteristic town. The results indicate that: (1) premised on the large gap in the towns' quantity, the distance between characteristic towns and prefecture-level cities as well as major cities is quite different in diverse regions; (2) the characteristic towns can be divided into four types in space, where this four spatial clusters are gradually increasing from east to west; (3) different spatial characteristic types require various unfolding policies.

Keywords Characteristic towns · *K-mean* · Clustering · GIS

1 Introduction

In China, the largest developing country, recent trends in rapid urbanization have led to a proliferation of studies paying greater attention to the imbalance between urban and rural areas [1]. On the one hand, the swift growth of urban population

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challenges urban human settlements [2, 3]. On the other hand, with the rural population declining, China's rural areas have gradually lacked vitality and lagged behind in development [4]. Population growth and the urgent need to improve the residents' live in urban and rural have facilitated the development of small towns becoming a significant part in urbanization [5]. At the same time, with the labor costs rising rapidly in China, the economy cannot rely on cheap labor for sustainable development [6]. In July 2016, the central government of China announced to cultivate about 1000 CTs by 2020, and then the rural revitalization strategy was proposed in 2017. Considered as a prominent driving force for urban and rural economic development [7], the characteristic town, a platform for industrial upgrading and economic structure adjustment as well as a new carrier to promote urbanization, has received positive responses across the country [8]. However, simply expanding characteristic towns prompts some local governments and real estate companies to pursue short-term profits, which stimulate the real estate bubble [9]. Simultaneously, ignoring regional differences also makes policy formulation mismatch the development practice needs [10]. Although characteristic towns have attracted extensive attention this year including spatial distribution, little academic work has involved their clustering especially spatial clustering in the Chinese city-town system.

What is commonly known about the clustering algorithms includes *K-mean* Algorithm [11] for rapid iteration of point-based clustering, the *EM* algorithm [12] with maximum likelihood estimation obtained by calculation from incomplete data, and the DBSCAN clustering algorithm based on the density-based notion of cluster, which can more efficiently locate clusters of arbitrary shapes [13]. In addition, mean-shift, a mountain-climbing algorithm based on kernel density estimation to estimate the offset mean of each data point in d-dimensional feature space, is widely used in cluster analysis, image segmentation, information tracking, etc. [14–16]. Ward's Agglomerative Hierarchical Clustering Method is adopted to establish a hierarchical nested cluster tree by calculating the similarity between different data points, which can be divided into bottom-up merging and top-down splitting [17]. Among these algorithms, *K-mean* Clustering Algorithm excels at simple principle, low computational complexity and significant clustering effect, which contributes to processing a large amount of data in a short time. This cluster algorithm can evaluate the similarity by the distance between two points, that is, the closer the distance, the greater the similarity, and the farther the distance, the smaller the similarity. In urban research, it can not only use *K-mean* clustering to predict the weather based on urban climate data, but also combine communication systems such as remote sensing image and GSM communication to organize urban information, including the features of different urban buildings, and use it as an offline navigation system, which is convenient for managers to plan urban layout [18–20]. Meanwhile, *K-mean* clustering, as a classic clustering analysis method, extends spatial clustering techniques that can support knowledge mining in GIS generalization processes [21], as well as evaluate the complex features about specific regional terrain distribution by combining data sources from digital elevation model (DEM), to achieve the computing speed and information demand required by simulation-based city model [22, 23].

Orange taken in this study is a component-based machine learning library, combining symbolic, string, numerical attributes and meta data information. In addition to various visual views, Orange has over 100 toolbox widgets and interactive data analysis modes whose powerful data comparison and exploration capabilities can help us with data mining through visual programming or python scripts to build predictive models for data sets with numerous information [24, 25]. Biologists apply Orange this visual programming tool to efficiently conduct microarray data analysis, which facilitates exploring mysteries in gene expression, structure and function, and they also combine Orange with algorithm analysis method to construct a whole set of disease prediction system that contributes to extracting effective decision information from the huge database, which plays a great role in the diagnosis and treatment of diseases [26, 27]. With the help of the Orange platform, enterprise managers have developed a customer analysis platform, which can conduct personalized treatment of customer relations and detect the most predictive variables quickly and reliably, making it convenient for managers to make timely responses to possible market changes [28, 29]. Therefore, this paper proposes the analytical framework to integrate basic statistical analysis, calculate distance and analyze based on *K-mean* Algorithm, and perform visualization and spatial analysis supported by GIS since the Orange platform has a major impact on powerful function, fast computing speed, positive visualization effect and flexible application of programming technology. Under this analytical framework, spatial characteristics of characteristic towns are introduced from the city-town system in China and spatial clustering is ultimately fulfilled. The rest of this article is structured as follows: Sect. 2 introduces the basic data, analysis framework and main methods applied in the research; Sect. 3 reports the spatial characteristics and classification results; Sect. 4 offers the discussions and conclusion.

2 Materials and Methodology

2.1 Analytical Framework

The emerging industrial towns studied in this paper include 403 characteristic towns, which accounts 11.8 million people provided by the statistics department of the Chinese government. In addition, 35 major cities are included in the study with 305 prefecture-level cities (excluding Hong Kong, Macau and Taiwan), which cover major urban areas and urban populations on the Chinese mainland (see Fig. 2).

To complete spatial clustering under the Chinese cities-towns system, the following analytical framework is designed (Fig. 1). First of all, the spatial characteristics and *K-mean* algorithm are introduced as the core to classify the characteristic towns. Secondly, building on the visualization of analysis objects with GIS, spatial characteristics are acquired through nearest-neighbor search. Finally, the spatial visualization of the characteristic towns' classification results is realized.

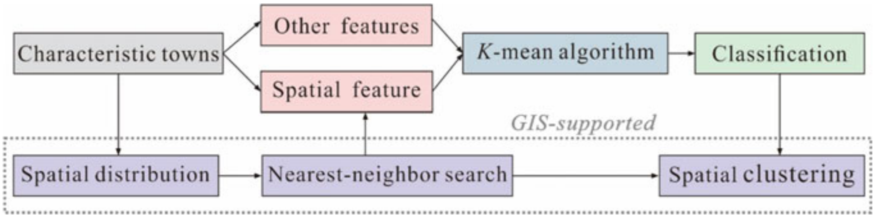

Fig. 1 Analytical framework

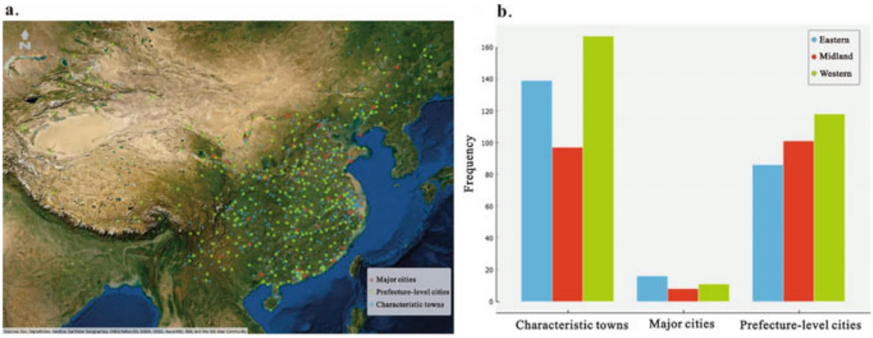

Fig. 2 Spatial distribution of cities-towns (**a**) and their statistics in the different regions (**b**)

2.2 City-Towns and Nearest-Neighbor Search

In this study, Geo Map module (https://orange.biolab.si/widget-catalog/geo/geomap) in the Orange platform is applied to visualize the spatial distribution of city-towns (Fig. 2a). Referred to the urban spatial distribution pattern and different regional statistical graphs about the 35 major cities, eastern cities account for 45.71%, central cities 22.86% and western cities 31.43%, and their proportions in all cities are distinctly 2.15% 1.08% and 1.48% with 4.71% in total; Among 305 prefecture-level cities which 28.20% are in the eastern region, 33.11% central and 38.69% western, occupied 11.57%, 13.59% and 15.88% respectively, while 41.05% generally; Likewise, 34.49% characteristic towns are in the east, 24.07% middle, and 41.44% west, totaling 403accounting for 54.24% on the whole, where 18.71% in the east, 13.06% middle, and 22.48% west (see Fig. 2b).

To get the quantitative spatial characteristics with GIS, we search the adjacent cities in the characteristic town space and calculate the distance between them. Specifically, in light of the spatial distribution data shown in Fig. 2, searching the major cities and prefecture-level cities closest to the featured towns through the nearest-neighbor search tool, we calculate the Euclidean distance respectively.

Nearest neighbor (NN) searching, a fundamental operation that combines machine learning, database, signal processing and other disciplines, can find the data item mostly resembling target data in the database according to the similarity. That seeking the top K data item closest to the target data is K-nearest neighbor retrieval (K-NN). We have a database of points $\mathrm{X} = \{x_1, \ldots, x_n\}$, and on an input query q, we hope to return the nearest (or approximately nearest, or K-nearest) point(s) to q in x using some similarity measure [30, 31], which is usually defined as the Euclidean distance that the linear distance between two points in space. Faced with the massive data every day, many work has been done initially in document retrieval systems, where some scholars used NN to store and query information employed the sorting method to enhance the structure of information system and established substructure search components [32]. Subsequently, the higher capable algorithm expanded and innovated on the basis of the tree search structure was applied for effectively nearest neighbor searching to the topological spaces arise in motion planning [31, 33]. Besides, involved with the mobile space and time environment, a networked computer system is established to be delivered precisely to target users [34, 35].

2.3 K-Mean Algorithm

Widely applied in statistics, image processing, medical diagnosis, information retrieval, biology and machine learning, *K-mean* algorithm that the major way to mine data, first proposed by MacQueen in 1967, plays a key role in realizing this research [36]. After combining with other algorithms, the current *K-mean* algorithm has become more complex and powerful. For example, both PSO-km and Lloyd's *k-mean* clustering algorithm attempt to shorten time via finding the best solution in the initial stage [37, 38]. In the three-dimensional processing and visualization of medical images, using *K-mean* algorithm to segment the scanned images can obtain the detection results more quickly and accurately [39]. Meanwhile, some researchers propose optimization algorithms like multi-objective *K-mean*, which reduces the computational time consumed by cluster data, making the algorithm analysis results reach 100% accuracy, greatly increasing the amount of handling data [40, 41]. For the data points in the *K-mean* cluster, which is defined as the centroid of the cluster. Based on the objective function to update the clustering centers iteratively, the algorithm process starts from k arbitrary clustering centers in the space, then divides the set of given objects into k subsets according to the distance. It can be seen that the *K-mean* clustering result depends entirely on the initial centroid selection.

The calculation process is as follows: choosing any k clusters from all N sets of data as cluster centers, calculating the distance from each set of data to each cluster center, identifying the nearest neighboring distance center, recalculating the cluster centers of each separated class, repeating the above two steps until the new cluster centers are equal to or less than the specified threshold.

The *K-mean* algorithm divides the data into k categories. it is $Kc = \{c_1, c_2, \ldots, c_k\}$. Each c_k has a cluster center; the Euclidean Distance formula is used to calculate the square sum of distances about cluster center $\mu\kappa$ in different groups:

$$\text{Mean}(c_k) = \sum_{x_i \in c_k} |x_i - \mu_k|^2 \tag{1}$$

The goal of clustering is to minimize the square sum mean $(Kc) = \sum_{k=1}^{K} mean(c_k)$ of distance.

K-Means++, as an unsupervised learning algorithm proposed by David Arthur and Sergei Vassilvitskii in 2007, is an initialization method for clustering NN with a great speed in practice. This clustering method can randomly select the initial cluster center, and then select the second center from the remaining points, whose probability is proportional to the square of the distance to the NN [42]. This way of increasing iterating frequency reduces unstable influence in the calculation and overcomes that the initial point selection affects the classification consequence in *K-Mean.* What measures NNS standard is the Manhattan distance, proposed by Hermann Minkowski in the nineteenth century, which calculates the absolute difference between coordinates in accordance with straight lines, to compare the similarity between objects and obtain cluster membership [43, 44]. Manhattan distance excels in calculating speed with better performance than Euclidean distance. In terms of Silhouette scores, an evaluation index for judging the cluster analytic quality, rang in $[-1, 1]$ while the larger the value, the more reasonable the clustering. Ward linkage connects clusters through a similar degree between objects in the same cluster, and then minimizes the internal square sum about each cluster, which minimizes intra-cluster variation and maximizes inter-cluster variation. Silhouette Index (SI), based on measuring the distance between objects and clusters, can assess the clustering technical via the ability to discover partitions or select the best partition [45, 46].

3 Results

3.1 Spatial Features

The proximity about 403 characteristic towns to major cities and prefecture-level cities shows that the total characteristic towns are 139 in the eastern region, accounting for 34%, and there are 97 in the central region, accounting for 24%, while 167 the largest number is in the west, accounting for 42%. In the east, the maximum distance between characteristic towns and major cities is 130.92, the minimum is 1.69, and the median is 36.90. While the distance from the prefecture-level cities is 262.28, the nearest is 6.32, and the median is 87.72. The maximum distance between the characteristic towns in the central region and major cities is 191.58, the minimum 10.43, and the median 41.09. The farthest distance between a western characteristic town and major cities is 231.80, the closest 2.68, with a median value of 52.46, and the longest distance from the prefecture-level cities is 1486.74, the nearest 10.59, and the median value 151.56. Kernel density estimation (KDE), also called the Parzen-Rosenblatt window method as well as a non-parametric method for estimating the

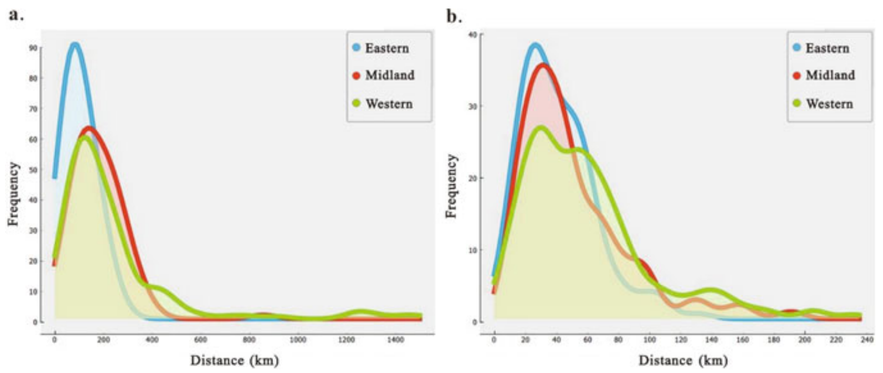

Fig. 3 Results of the distances from characteristic town to nearest major city (**a**) and prefecture-level city (**b**)

probability density function on random variables, starts from the sample data and keeps a close relationship with the histogram [47, 48]. Combining with Fig. 3: (1) Fig. 3a shows the kernel density estimation regarding the distance between characteristic towns and cities. In terms of distribution, the east, middle and west have obvious right tailing characteristics. And there is no distribution in the east in 1300–1400, indicating that the closest distance is little in 400–1400 with a flat shape, whose distance is mostly in 0–400. Focused on the kurtosis point, the highest concentration is in the east, whose peak is extremely higher than the other two regions. In addition, the main peaks are all within 0–200 in three regions, which is the main range from characteristic towns to major cities. (2) Fig. 3b presents that the east, middle and west are still right-tailed forms, mainly ranging in 0–100, while 120–240 is little with a slightly fluctuating peak accompanied the rise distance. The main peaks are all 20–40 in three districts, which mostly covers the nearest neighboring distance between the characteristic towns, and the prefecture-level cities are the largest located in this range, indicating that the eastern is the highest. Moreover, the two typical distance peaks in the three regions are similar, following decreasing trends from east to west as well as the right tailing.

3.2 Clustering Results

To reflect the differences in characteristic towns, we not only used nearest-neighbor distances to incarnate the spatial characteristics but also employed several variables for the other features, containing (1) the total local populational number; (2) the local residential proportion representing the local household registration within the total population; (3) per capita GDP showing the economic development level in the local towns; (4) the proportion of regional non-agricultural output value excluding agricultural.

The calculation and analysis of *K-mean* are obtained via corresponding modules in the Orange platform, where specifically observing the clustering scores that the Silhouette (contrasts average distance to elements in the same cluster with the average distance to elements in other clusters) to select the optimized results. The different classifications and Silhouettes are: 2(0.452), 3(0.327), 4(0.223), 5(0.208), 6(0.226), 7(0.208), 8(0.221). Choosing the highest classification method in the Silhouette score, we calculate the Manhattan distance (the sum of absolute differences for all attributes) between each attribute.

Figure 4a presents the hierarchical clustering outcomes, measuring distances between clusters with Ward linkage [49]. For hierarchical clustering classification results, we filter a 40% height ratio and check the silhouette scores about each attribute. Further, we utilize the Geo Map module to visualize the spatial clustering based on the classification (Fig. 4b). Figure 4 shows that C1 has the largest number, with 292 in total, accounting for 72.46%, followed by C4 with 63, accounting for 15.63%, while C2 with 30 totally, occupied 7.44%. The least is C3, only 18, accounting for 4.47%.

To be clear, the east, middle, and west are 79, 89, and 124 in the C1, occupied 27.05, 30.48, and 42.27% within C1 while accounting for 19.60, 22.08, 30.77% in the overall characteristic towns. Similarly, three areas in the C4 category are 44, 2, and 17, accounting for 69.84%, 3.17%, and 26.98% during the C4 category, while 10.92%, 0.50%, 4.22% of characteristic towns respectively. The C2 category, in the eastern and central regions, is rarely 1 and 5, owning 24 in the west. The proportions are 3.33, 16.67, 80.00% in the C2 while accounting for 0.25, 1.24, 5.96% inside the characteristic towns. Final for C3, the eastern regions are the most distributed with 15, while the central and western are 1 and 2. The proportions in C3 are 83.33, 5.56, 11.11%, and in characteristic towns are 3.72, 0.25, 0.50%.

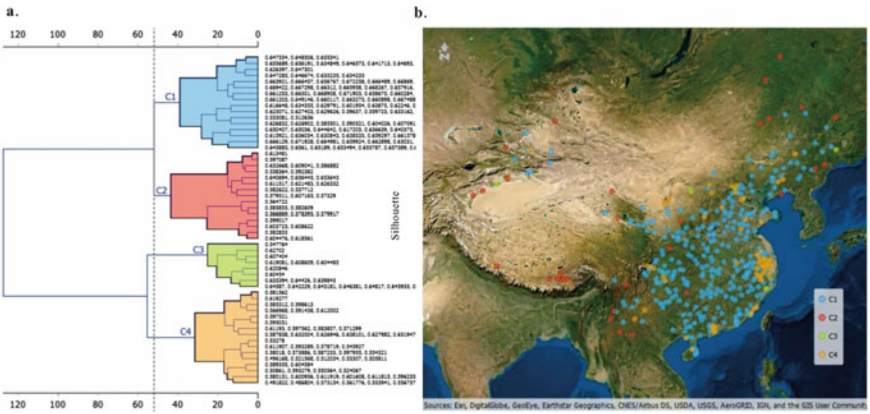

Fig. 4 Hierarchical clustering results (**a**) and spatial clustering results (**b**)

4 Concluding Discussions

Chinese government's policy orientation remarkably influences the construction of characteristic towns, which are evenly distributed across the country. Numerous factors such as economic density, population density, resource endowment, local market, transportation facilities, policy orientation generate that characteristic towns are mostly located in suburban areas. However, some characteristic towns blindly imitate and simply copy successful cases, divorced from the local resources, rural culture, and industrial characteristics. Without "characteristics" and substantive industry, characteristic towns cannot realize sustainable development. Therefore, given that there are critical influences like resource endowment, local markets and transportation facilities, characteristic towns should sufficiently utilize the core radiation of key urban agglomerations. In addition, the construction should not only optimize the external material environment but also be adapted to local conditions following local characteristics and regional differences. Finally, characteristic towns should strive to fulfill "one thousand towns, one thousand policies" and highlight the local features.

The prevalent Orange platform software to empirical research adopted for this study is an approach to interactive data mining for rapid qualitative data analysis in recent years. What Orange's visual programming can realize is remembering user choices and giving combination suggestions with scatter, bar, tree, network, and linear graphs as well as constantly increasing components and convenient scripting interfaces. As the classification analysis of characteristic towns is completed by *K-mean* algorithm and combined with spatial features, a series of subsequent spatial distribution, nearest-neighbor search and spatial clustering are all supported by GIS to accomplish the visualization of analysis objects. Taking the limitation of *K-mean* algorithm into account, *K-Means*++ is selected as the initialization method for clustering calculation, while Manhattan distance as the distance standard for the similarity between feature vectors, and Ward linkage as the measurement for distances among different clusters. What still remains to be solved is that the data sources are limited and inaccurate, and the restrictive characteristic variables obtained from plentiful reference materials are not sufficient enough to comprehensively reflect the discrimination among characteristic towns.

Under the Chinese city-towns system, spatial features are introduced in this paper and *K-mean* algorithm is applied to conduct classification analysis and GIS-based spatial visualization for 403 characteristic towns, and then spatial features obtained by nearest-neighbor search are optimized to realize spatial clustering eventually. The following results are found through the urban spatial analysis due to the Orang platform: (1) the eastern major cities occupied 45.71%, and the western prefecture-level cities are 41.44%. Nevertheless, under the overall urban spatial distribution, there are 305 prefecture-level cities, accounting for 54.24%, which are much higher than major cities; (2) Compared city-town nearest-neighbor distances, the distances between characteristic towns and prefecture-level cities are generally greater than those between characteristic towns and major cities. In the western region with 42%

of characteristic towns, the NN distance is 1486.74 farthest from the prefecture-level city with a median of 151.56; (3) observing the optimized clustering scores, four spatial clustering types can be obtained. In the C1 category, which accounts for 72.46% totally, the western region is mainly distributed with accounting for 30.77% in the total characteristic towns, while the remaining categories are relatively small. Viewed within the group, C1 and C2 are concentrated in the western region, but C3 and C4 in the eastern region. However, there still some limitations remain to be explored in this paper. Further research with a greater focus on the powerful data mining and visual programming about the Orange platform, optimization of the analysis framework, and integration of data, methods and consequence as well as the collaborative development with GIS is thus suggested. Moreover, further research may benefit from examining and expanding the spatial heterogeneity of characteristic town distribution and the difference of development region under the Chinese urban system.

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Research on the Pricing of Endowment Real Estate Based on Principal Component Characteristic Price Model: Guangdong Case

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Abstract Based on the principal component semi-logarithmic hedonic price model, 13 indicators are selected from three dimensions: subject characteristics, neighborhood characteristics and regional characteristics of pension institutions to study the pricing of 322 pension institutions in 21 prefectures and cities in Guangdong Province. The results show that the number of beds, the number of stars, the proportion of tertiary industry to GDP, per capita disposable income, per capita GDP, the change rate of service price index, the average price of commercial housing, the number of regional hospitals and the aging rate of population have a significant impact on the price of pension institutions.

Keywords Hedonic price model · Pension real estate · Service pricing · Population aging

1 Introduction

The price of pension institutions is the main factor restricting the choice of institutions for the elderly to provide for the aged. The pension income affects the decision-making of pension style of the elderly [1]. The price and service quality of nursing homes decreased with the intensification of market competition [2]. The five-star rating of nursing homes had an impact on private payment prices, raising the star rating of nursing homes by one notch, and prices rose 4.8–6.0% [3]. The price of nursing homes in Germany is positively correlated with regional income level, density of nursing homes, characteristics of the elderly, characteristics of labor force and quality of nursing facilities [4].The intervention of local government in the UK plays an important role in the pricing of private and public nursing homes [5].

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The pricing of pension services not only includes the recovery of tangible input costs such as bed fees, personnel expenditure, goods and services expenditure, depreciation of fixed assets, debt interest expenditure, etc., it is also affected by the characteristics of pension institutions, the surrounding environment, urban economic development and other factors. (a) The main characteristic factors of pension institutions, it mainly includes institutional location, adoption area (proportion of other districts and counties), the proportion of the elderly who cannot take care of themselves, the number of nursing beds, the total number of beds, the number of floors, floor area, building area, the source of housing use, service quality, the length of operating time, the allocation of service personnel per 100 beds, operation and service costs, institutional stars, and so on. (b) Neighborhood characteristics of pension institutions: degree of development of business circle, distance of business circle, market competition. (c) Regional characteristics of pension institutions: demand for pension services of regional institutions, market scale, income of the elderly, regional prices and consumption level; fee gap between public institutions and private institutions for the aged, occupancy saturation of public institutions for the aged, government financial subsidies and so on.

2 Research Method

The hedonic pricing model was based on eterogeneous commodity consumption theory and hidden market theory. Old-age services mainly include accommodation, catering, professional care, medical and health care, life care, entertainment and hospice services. As a heterogeneous commodity, pension service coincides with the premise of hedonic price theory product heterogeneity.

Typically, the hedonic pricing model regresses property prices against a host of utility-bearing characteristic of property. In this study, the price characteristic factors of pension institutions are divided into three types: architectura1 features, neighborhood characteristics and regional characteristics. It is calculated based on the following formula:

$$\mathrm{P}_i = P(S_i, N_i, Q_i) \tag{1}$$

where P is the service price of pension institutions; $\mathrm{S_i}$ is the architectural feature vector; $\mathrm{N_i}$ is the neighborhood factor vector; $\mathrm{Q_i}$ is regional characteristics vector.

In order to solve the problem of many independent variables in the hedonic price model and the multicollinearity among all variables, the principal component analysis method was used to reduce the dimension of independent variables in order to improve the accuracy of the estimate.

Suppose a matrix X composed of m characteristic variables of n samples of pension institutions.

$$X = \begin{vmatrix} x_{11} & x_{21} & \cdots & x_{n1} \\ x_{12} & x_{22} & \cdots & x_{n2} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{vmatrix} \tag{2}$$

In order to eliminate the effects of different units and dimensions, the collected data was standardized to form matrix X, which is expressed by $Z_{j.}$

$$Z_j = \frac{x_{ij} - \overline{x_j}}{s_j} \tag{3}$$

The r_{jk}, formula for calculating the correlation coefficient of sample data is as follows:

$$r_{jk} = \frac{1}{n-1}\sum_{i=1}^{n} Z_{ij}Z_{jk} \tag{4}$$

The correlation coefficient matrix R is constructed, and the formula is as follows:

$$R = \left(r_{jk}\right) \times m \times m \tag{5}$$

The eigenvalues of the correlation matrix R are calculated, and the eigenvector $L_{j,}$ converts the standardized L_j into principal component $F_{j.}$

$$\mathrm{L}_j = (l_{j1}, l_{j2}, \ldots, l_{jm})^T, j = 1, 2, \ldots, m \tag{6}$$

$$\mathrm{F}_j = ZL_j = l_{j1}Z_1 + l_{j2}Z_2 + \cdots + l_{jm}Z_m, j = 1, 2, \ldots, m \tag{7}$$

With the service price of pension service institutions as the dependent variable, the first K principal component F whose cumulative contribution rate is more than 85% is selected as the independent variable, and a semi-logarithmic hedonic price model is established.

$$LnP = \alpha_0 + \alpha_1 F_1 + \alpha_2 F_2 + \cdots + \alpha_K F_K + \varepsilon \tag{8}$$

where LnP is the logarithm of the service price of endowment institutions; a_0 is a constant term; a_i is a parameter to be estimated, indicating that the unit absolute change of principal component F leads to the relative change of P; ε is a random disturbance term.

3 Case Study

3.1 Research Area

Guangdong Province is located at the southernmost tip of the Chinese mainland, bordering the South China Sea, bordering Hong Kong and Macao. In 2012, Guangdong Province entered an aging society. At the end of 2019, there were about 15.18 million people aged 60 and above, accounting for 13.18% of the total household registration population. There were 1781 pension institutions in the province, with 489,000 beds for the elderly, with 34 beds for every 1000 elderly people. Affected by the level of economic development, population policy and the improvement of migrant population, public health and quality of life, the degree of aging in Guangdong Province is “upside down” with the economic development level of various cities. Showing a gradual slowing trend from the east and northwest of Guangdong to the Pearl River Delta region. The inter-provincial labor inflow is the main factor affecting the regional differences of population aging in Guangdong Province. the paired migration of the elderly and their children from outside the province has further deepened the contradiction between supply and demand in the pension market.

3.2 Variable

The economic development of various prefectures and cities in Guangdong Province is not balanced, and there is a great difference between the price level and the cost of newspaper services. in economically developed areas, the house price is high, the consumption level is high, the nursing fee is high, and the cost of pension service is relatively high. The independent variables are the characteristic factors implied in the price of private pension institutions, which are mainly divided into three categories: institutional main body characteristics, neighborhood characteristics and regional characteristics, with a total of 13 characteristic variables. The main results are as follows: (1) The architectural characteristic factors: the number of beds (X_1), occupied area (X_2) and star (X_3) taken as the main characteristic variables to characterize the scale, comprehensive matching and service quality of the pension institution respectively. (2) Neighborhood characteristic factors: the number of bus lines within 0.5 km of pension institutions (X_4), the distance to the nearest park (X_5), the number of general hospitals (X_6) and the ranking of ambient air quality (X_7) were used as neighborhood characteristic variables. characterize the traffic access, landscape, medical facilities and ecological environment around the pension institution respectively. (3) Regional characteristic factors: The per capita GDP (X_8), population aging rate (X_9), the proportion of tertiary industry to GDP (X_{10}), per capita disposable income (X_{11}), the rate of change of service price index (X_{12}) and the sales price of commercial housing (X_{13}) were used to characterize the economic strength, pension demand, industrial structure, consumption capacity, price level and living cost of the area where the pension institution is located.

3.3 Data

A total of 322 private pension institutions were selected from 21 prefecture-level cities in Guangdong Province. The data are mainly from: online websites (http://www.laoren.com/; http://www.yanglaotiandi.com/; http://www.yanglaocn.com/), Baidu map data, and Guangdong Province cities National Economic and Social Development Statistical Bulletin. The variable assignment and descriptive statistics are shown in Table 1.

3.4 Result Analysis

The principal component analysis of 13 characteristic variables is carried out by using SPSS20.0 software, and the KMO value is 0.689. The Bartlett spherical test shows that there is a certain correlation between the variables, so it is more appropriate to use principal component analysis to aggregate the indexes. Using eigenvalues greater than 0.7 as standard extraction factors, the first seven factors cumulatively explain 85.91% of the characteristic variable information, which can be analyzed instead of the original 13 variables. The eigenvalues, cumulative contribution rate and principal component score coefficient of each factor are shown in Table 2.

The index of load greater than 0.7 in the rotational component matrix is extracted as the principal component index. The variables that determine the size of F_1 are mainly X_8, X_{10}, X_{11}, X_{12} and X_{13}; the variables that determine the size of F_2 are X_6 and X_9; the variables that determine the size of F_3 are mainly X_4; the variables that determine the size of F_4 are mainly X_1; the variables that determine the size of F_5 are mainly X_5; the variables that determine the size of F_6 are mainly X_2; the variables that determine the size of F_7 are mainly X_3.

The stepwise regression method was used to estimate the parameters of the seven principal components, and the goodness of fit of the model was 0.63. The stepwise regression runs to the end of step 4. At the level of 5% significance, F_3, F_5 and F_6 are excluded from the model, and the coefficients of F_1, F_7, F4 and F_2 are of economic significance. The regression coefficients of principal component variables that pass the 5% significance test and their significance test results are detailed in Table 3.

According to Eq. (8), it is concluded that the hedonic price model is:

$$LnP = 7.767 + 0.291F_1 + 0.087F_7 + 0.079F_4 + 0.073F_2 \tag{9}$$

Table 1 Variable assignment and descriptive statistic

Feature type	variable	Variable description and quantization	Min	Mean	Max	Standard deviation
Architectural features	P	Monthly price (RMB/month)	1000	2837.58	29,000	2382.92
	X_1	Number of beds (unit)	100	239.97	3419	383.96
	X_2	Covers an area of 10,000 m^2	0.12	8.72	60.52	35.80
	X_3	Stars (1–5 stars are 1–5 points, no stars 0points)	0	1.39	5	1.68
Neighborhood characteristics	X_4	Number of bus lines within 0.5 km (strip)	0	4.36	16	3.17
	X_5	Distance from the nearest park (km)	0.1	1.37	10	1.28
	X_6	Number of regional hospitals (seats)	8	9.78	15	3.76
	X_7	Ambient air quality ranking	1	13.07	21	6.561
Regional characteristics	X_8	Per capita GDP (10,000 yuan per person)	2.71	9.82	33.59	6.39
	X_9	Population ageing rate (%)	10.6	15.78	25.41	3.21
	X_{10}	The proportion of tertiary industry in GDP (%)	42	56.8	74	11.73
	X_{11}	Per capita disposable income (10,000 yuan per person)	2.09	4.16	6.5	1.82
	X_{12}	Rate of change of service price index (%)	0	1.81	4.9	1.31
	X_{13}	Selling price of commercial housing (10,000 yuan / M^2)	0.42	2.02	10.39	2.06

Table 2 Principal component score coefficient

Composition	Eigenvalue	Cumulative variance contribution rate	Variable	F_1	F_2	F_3	F_4	F_5	F_6	F_7
1	4.38	33.693	X_1	−0.053	−0.062	0.12	0.998	0.024	−0.078	−0.015
2	1.84	47.851	X_2	−0.011	−0.011	0.008	−0.084	−0.005	0.992	−0.054
3	1.434	58.885	X_3	−0.098	−0.013	−0.025	−0.019	0.035	−0.058	1.033
4	1.137	67.634	X_4	−0.051	−0.002	0.882	0.115	0.109	−0.006	−0.033
5	0.869	74.316	X_5	0.026	0.002	0.136	0.017	0.999	0.005	0.047
6	0.843	80.801	X_6	0.02	0.445	0.365	0.035	0.143	0.054	0.095
7	0.665	85.913	X_7	0.07	0.357	0.104	0.048	0.152	0.071	0.036
8	0.628	90.746	X_8	0.239	−0.065	−0.039	−0.071	−0.061	0.042	−0.014
9	0.496	94.558	X_9	−0.073	0.432	0.228	−0.105	0.019	−0.009	0.047
10	0.433	97.891	X_{10}	0.241	0.1	−0.022	0.083	0.199	−0.095	−0.142
11	0.173	99.219	X_{11}	0.23	0.081	−0.067	−0.018	−0.018	0.041	−0.011
12	0.066	99.725	X_{12}	0.213	0.101	0.118	−0.02	0.069	0.092	0.059
13	0.036	100	X_{13}	0.218	−0.098	0.084	−0.152	−0.014	0.068	−0.041

Table 3 Stepwise regression coefficient table that passed the 5% significance test

Variable	Non-standardized coefficient	Standardization coefficient	T-ration	*P* value	VIF
a_0	7.767	0	297.855	0	
F_1	0.291	0.517	11.183	0	1
F_7	0.087	0.155	3.347	0.001	1
F_4	0.079	0.14	3.023	0.003	1
F_2	0.073	0.13	2.819	0.005	1

4 Conclusion

From the three dimensions of institutional subject characteristics, neighborhood characteristics and regional characteristics, 13 characteristic factors are selected to study the prices of 322 private pension institutions in 21 prefectures and cities in Guangdong Province. it is found that the semi-logarithmic hedonic price model based on principal component analysis can better fit the non-linear relationship between characteristic factors and the price of private pension institutions. Nine of the 13 characteristic factors have a significant impact on the price of private pension institutions, and their relative importance is in the following order: the number of beds, stars, the proportion of tertiary industry in GDP, per capita disposable income, per capita GDP, the rate of change of service price index, the average price of commercial housing, the number of regional hospitals and the aging rate of population. Based on the research conclusion, this paper puts forward the following suggestions: First, improve the payment and compensation mechanism of old-age services, and improve the consumption and payment ability of the elderly. Second, promote the rating of old-age care institutions and establish a pricing mechanism linked to star-rated performance. Thirdly, according to the social average cost of regional pension services, combined with the affordability of the elderly, market supply and demand and other factors, scientifically formulate the guidance price standard and price adjustment mechanism of private pension institutions. Finally, the implementation of support policies for private pension institutions will promote the misplaced development of public and private pension institutions.

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The Embedding and Construction of Community Network Public Space: Study on the Path of Community Governance Under the Background of Urbanization

Cui Zhiyu, Zhou Ling, Jiang Xiaowen, and Li Yanan

Abstract Improving urban community governance is of great significance to the modernization of China's governance system and capacity. Community public space is the basic field of community governance and an important material carrier for the cultivation of community public spirit and publicity. However, in the modern society of continuous transformation in China, the reduction of the internal communication needs of community residents and the transformation of external communication forms have greatly eliminated the inward potential and outward tension of constructing community publicity in the traditional community public space, and the cultivation of community publicity is facing new challenges. With the development of digital information technology and people's active participation in the practice of network communication, the network public space has become a new space form. By extending and expanding people's social interaction through the network, the community network public space has assumed the function of cultivating community publicity. Therefore, to promote the embedding and construction of the community network public space has become the referable direction to explore the path of community governance in the current transitional society.

Keywords Urbanization · Community governance · Network public space · Publicity

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1 Introduction

At present, with the profound change from planned economy to market economy, the rapid advancement of urbanization and the continuous popularization of housing commercialization, our society is undergoing the transformation from traditional society to modern society. As the space community of people's life, the urban community represented by commercial housing residential district is the basic unit of urban social governance, and becomes an important carrier to reshape social relations, promote social integration and social solidarity. In June 2017, The central committee of the communist party of China and the State Council in the opinions on strengthening and improvement of urban and rural community governance explicitly pointed out: "community governance is a matter of major policy implementation and concerns the vital interests of residents and the harmony and stability of urban and rural communities", which illustrates the significance of urban community governance to the modernization of China's social governance system and capacity.

Space is the basic material condition of governance. Community public space promotes the realization of community governance by promoting residents' social contacts, developing community social relations and fostering community public spirit, and becomes the main place of community governance. However, against the background of rapid urbanization, the basic subjects, behavioral logic and basic ways of community governance are all facing the requirements of reform. Community public space, as the main place for the cultivation of community publicity, is of great significance in promoting the transformation of community governance. In the context of community heterogeneity, atomization of residents and popularization of Internet, the ability to cultivate community public spirit and publicity of traditional community public space is dispelled and squeezed. With the rapid development of digital information technology and diversified demands of community residents, how to effectively build community publicity and promote the effective development of community governance? In the framework of promoting the transformation of urban community governance under the background of urbanization and informatization in China, this paper analyzes the new challenges faced by the cultivation of community publicity in the transformation society in China, that is the reduction of the internal communication needs of community residents and the transformation of external communication forms have greatly eliminated the inward potential and outward tension of constructing community publicity in the traditional community public space; At the same time, this paper analyzes the new spatial form brought by the development of digital information technology namely the network public space which reconstructed community publicity, and discusses the important role of community network public space in community governance. On the basis of fully understanding and mining the intrinsic function and value of the community network public space, this paper makes a new exploration on the path of community governance under the background of urbanization from the perspective of embedding and constructing the community network public space.

2 The Mission of Urban Community Public Space in the Transformation of Community Governance Under the Background of Urbanization

Since the reform and opening up more than 40 years ago, the rapid advancement of urbanization has been promoting the continuous transformation of urban community governance up till now, which makes China's community governance face a series of new variables: First, the development of market economy has greatly changed the main body composition of community governance on the macro. During the planned economy, the community existed only as the auxiliary of the social management system dominated by the unit system under the "strong state-weak society". to assist in the management of "three no" personnel without a unit. The government as the unitary subject of community governance has the final decision in the management and construction of the community. The development of the market economy, the growth of market subjects and the allocation and flow of resources outside the unit system are constantly enhancing the independence of the society, thus enhancing the independence of the community as the basic unit of the society. The form of community governance organization with the government as the sole subject no longer meets the requirements of the new economic development, and the subject of community governance is facing a change from "unitary" to "pluralistic". Second, the disintegration of the system of units above the middle view has greatly changed the behavioral logic of community governance. The diversification of resource distribution channels brought by the disintegration of unit system under the market mechanism increases the discourse power of the market and social subjects to a certain extent, and makes the appeal of the society become an important consideration factor for effective social governance. For community governance, the disintegration of unit system directly eliminates the basic channels of the original form of social governance organization, making the basic path of community relying on the government from top to bottom authoritarian management no longer smooth. At the same time, the diversified development of society and the market-oriented allocation of resources make the demands of community residents more diversified. The community has become the gathering place of social problems and contradictions, as well as the migration point for implementing social policies and providing social services. Community governance has to give more consideration to the demands of community residents, and it's behavioral logic is changing from top-down under planned economy system to bottom-up under market economy. Thirdly, the micro changes of urban population structure bring about the diversification of community residents' needs, which greatly changes the basic way of social governance. Driven by the combination of market economy and urbanization, different groups such as unit people, community people and floating population have made urban population structure increasingly complex, and the atomized population in urban communities has increased in large numbers, as a result, the urban population structure dominated by "unit people" in the period of planned economy has undergone tremendous changes. Under the new historical background, the multivariate population structure brings diversified demands of community residents, so it is necessary to establish a new community governance network that can express will, appeal for interests and respond to demands. The traditional unitary and arbitrary basic way of community governance is facing the pressure of changing to the basic way of multiple negotiation.

Community public space is an important spatial form of urban community and an important place for the daily life of community residents [1]. In community governance, it has become an important field for the development of community social relations and the cultivation of community publicity. Community public space gathers people with differences in certain social interactions, promotes the formation of social relations at a broader level in the community, provides material places for community residents to express their interest demands and participate in community governance, and becomes a material carrier to cultivate community awareness and public spirit [2]. Therefore, it plays a media role in connecting multiple community subjects such as grassroots government, social organizations, community elites and community residents [3], and is an important carrier to promote the reconstruction of community governance relation and an important starting point to promote the transformation of community governance.

3 Deconstruction and Reconstruction of the Publicity of Urban Communities in Modern Society

The emergence of the Internet, especially the mobile Internet, has greatly changed the way of social structure and connection. The concealment, timeliness, convenience and leap-forward time and space of network communication provide objective conditions for people to express their demands, timely communication, sharing feelings and other spiritual needs as well as the expression of civil rights. More and more people gather through mobile Internet [4]. Therefore, the Internet provides a new possibility to break the dilemma of communication and interaction in modern society, and forms a new space—cyberspace, which not only has the characteristic of privatization, but also has the characteristic of public, and we call it the network public space. Through the flow of digital information, the network public space realizes the connection of social communication between people, and promotes the production and reproduction of social relations, then realizes the remodeling of public space [5] and publicity in the information society.

3.1 The Deconstruction and Squeeze of Urban Community Publicity in Modern Society

The concept of "publicity" originated from the west, which means that people pursue higher survival value and social significance after overcoming the limitation of pursuing the maximization of their own interests. These values and meanings include democracy, fairness, justice and other values that serve the best interests of citizens. Therefore, publicity is not only the natural demand of human beings, but also the essential difference between public space and other spaces [6]. Community publicity is based on the values within the boundaries of the community and conforms to the public interests of the community residents. It arises from the open and equal social exchanges among the community residents, their concern for the community public affairs and their pursuit of the community public interests. As mentioned above, community public space is an important field to cultivate community publicity. However, in the modern society of continuous transformation in China, the inner potential and outer tension of constructing community publicity in the traditional urban community public space are being dispelled and squeezed constantly, which makes the cultivation of community publicity in urban community face new challenges.

First, with the enhancement of heterogeneity and atomization of urban communities in modern society, the potential of constructing community publicity in the public space of traditional urban communities has been eliminated internally. With the continuous development of urbanization and the rapid popularization of housing commercialization, the heterogeneity of urban communities is constantly enhanced, while the housing form of commercial housing, which is dominated by unit buildings, fully respects the privacy of residential housing space, but further intensifies the isolation and indifference of neighborhood relations [2]. The continuous development of the market economy accelerated the population mobility, and the "unit people" in the original community were replaced by more and more atomized residents, which makes the social relationship between the "acquaintance society" under the traditional unit community is increasingly alienated. And then, the strangeness among residents leads to the decrease of social communication motivation and communication behavior, thus eliminating the potential of constructing community publicity from the inside of traditional urban community public space.

Second, with the continuous development of digital information technology in modern society, the tension of constructing community publicity in traditional urban community public space has been squeezed externally. In modern society, the popularization of the Internet especially the mobile Internet, has brought about great changes in social structure and communication. Network communication has become a new form of interaction among community residents, which to a large extent has replaced the actual communication behaviors of community residents and reduced their actual communication needs. At the same time, the development of digital information technology also provides objective material conditions for the "online" handling of community affairs. More and more residents express their demands, exercise their rights and conduct private affairs through the Internet, which further strengthens the aggregation effect of the Internet. In the case, the function of traditional community public space to promote community social interaction and residents' participation in community affairs has been greatly reduced by the community network public space, and the tension of constructing community publicity in traditional community is dispelled by the rise and popularization of cyberspace.

3.2 The Reconstruction of Community Publicity in Community Network Public Space

Network public space is a new form of social space based on Internet technology, and sociality is its basic attribute [4]. The advent of network society makes the construction of community public space face new challenges, but at the same time, the emergence of "WeChat group" and other new network public space provide new opportunities for the reconstruction of community publicity.

First, the community network public space increases the social intercourse of community residents. Compared with the traditional public space, the network public space has great advantages in space openness, accessibility and convenience, which makes the network public space more conducive to the cultivation of community publicity. First of all, from the perspective of the openness of the public space on the Internet, internet technologies and platforms provide the community residents with access to the online public space at any time. For community residents, as long as they can surf the Internet and meet the basic technical requirements, they can enter the community public space. At the same time, the reality of cyberspace also lays a foundation for the realistic communication of community residents in the public space of community network. Secondly, from the perspective of the accessibility of the public space of the network, the community network public space is an open public platform facing all the people in the community. As long as the residents of the community can theoretically enter the public space, so the community network public space is accessible for all the community residents. Finally, from the perspective of the convenience of online public space, through the development of QQ group, WeChat group, community forum and other online public space, the community greatly reduces the cost of community residents to participate in social communication. Community residents can communicate in the online public space anytime and anywhere, and the expansion of communication will not be affected by the restrictions of time, place and way.

Second, the community network public space has optimized the governance of community public affairs. Grang argues that less control over how people communicate online, while allowing more open communication in a many-to-many manner, which allows the Internet to remedy or correct the crisis of engagement that Habermas describes [7]. The concealment, timeliness, convenience and transparency of network communication enable community residents to have more open communication in the community network public space, and to express more diversified and multi-dimensional views and appeals on the public affairs of space, such as housing, public security, afforest, school district, transportation, public services and community affairs related to their own interests, thus, it stimulates the initiative and enthusiasm of community residents to participate in community affairs, makes residents return from "private sphere" to "public space", and finally optimizes the governance of community public affairs.

Thirdly, the community network public space promotes the realization of community public interests. Community residents through community network public space more and more involved in the community public affairs management, which makes the community can directly effective insight and respond the needs of the community residents in community governance, Through insight, residents' sense of responsibility to the community is cultivated, while in response, residents' sense of belonging to the community is enhanced, it is helpful to construct a good pattern of community governance and to promote the realization of community public interests. Cultivating community residents' sense of responsibility towards the community is conducive to helping them establish a sense of "community ownership", so as to enhance the endogenous power for them to participate in community governance and make them willing to invest more time to initiate and participate in discussions in the online public space. To enhance community residents' sense of belonging is to make them feel the convenience of community life through community network public space, such as community business information, volunteer service, party membership registration, community help and other functional information. And through the illustrated work progress display, residents' complaints and responses, online booking and offline services and other matters, the residents can feel the governance status of community public affairs in the first time, so as to promote the emotional identity and cohesion of community residents. The promotion of sense of responsibility and belonging can cultivate the public spirit of community residents from two aspects of "reason" and "feeling" and promote the realization of community public interests.

Visible, community network public space with its openness, accessibility and convenience, greatly expands the social interactions between community residents, develops social relations within the community, becomes an important place for community residents to express their demands and participate in community public affairs, reconstructs the community publicity with community public interest as the value criterion and promotes the realization of community governance transformation.

4 An Analysis of the Path of Community Governance: The Embedding and Construction of Community Network Public Space

The theory of governance emerged in the 1990s. Based on the analysis and research of current scholars, governance subject, public interest and coordination mode are the key words to understand the connotation of governance from the perspective of the logical structure of governance. Therefore, governance simply refers to the process in which governance entities manage their common affairs in various ways in order to achieve common governance goals. Community governance refers to the process of effective management of community public affairs by various governance subjects in the community in order to realize community public interests [8]. The key to understand the connotation of community governance is still in the logical structure of governance, that is, the subject of community governance, the public interest of community and the way of governance. The network public space reconstructs the community publicity in modern society by increasing the social interaction of community residents, optimizing the governance of community public affairs and realizing the community public interests, and provides new possibilities for the expansion of the urban community governance path under the background of urbanization.

4.1 Promoting the Integration of Online Public Space into the Real Life of Communities

With the continuous advancement of urbanization, community heterogeneity and atomization of residents make the traditional urban community public space face many difficulties in building community publicity. However, the development of digital information technology and the popularization of mobile terminals make it possible to build community publicity based on network public space. As an online space based on digital information technology, the online public space is characterized by concealed, timely, convenient and time-crossing communication, which can greatly promote the communication between community residents, but it is still a virtual space that is different from the real society. Therefore, the establishment of community network public space such as WeChat group, QQ group and community forum should be timely embedded into the real life of community residents. For example, discussion on community public affairs such as community cleaning, division of parking Spaces, setting of access control CARDS, etc. which are closely related to the life of community residents, as well as unimpeded channels for the expression of community residents' demands, make a close connection between the community network public space and the real life of community residents, which effectively connects online communication, interaction, response, mobilization of residents and resource sharing with offline participation in public activities, service application, opinion feedback and other affairs, thus makes the public space of social network a public space with virtual and real, online and offline coupling effectively that does provide a connection channel for the relationship reconstruction between community and residents as well as between residents.

4.2 Build a Community Governance Platform Based on the Network Public Space

Relying on the emergence and development of digital information technology, community network public space, diverse forms and different functions, such as community WeChat group, QQ group, community forum and community WeChat public number. Therefore, it is necessary to give full play to the different functions of different Spaces and build a community governance platform for different forms of cyberspace. At present, the common community network public space is mainly the community WeChat group and QQ group, some communities have their own official website, internal forums, or the community WeChat public number. According to the functions of these different space forms, it can be divided into interactive communication platform and transaction platform. In the use of interactive communication platform, WeChat group and QQ group and other tools have strong interactive communication function, and can meet the scene of multi-person communication at the same time. Moreover, the establishment of community WeChat group and QQ group is relatively easy, through two-dimensional code scanning or have a common acquaintance into the group, you can join the common space. Therefore, WeChat group or QQ group can be used as the main platform for community residents to interact and communicate, share information and express their demands. In the use of the transaction platform, some message boards set up in community forums can satisfy the expression of residents' demands, but they do not have enough initiative in the release of official community information. The appearance of WeChat public account greatly makes up for the deficiency of this function, which can timely disclose important community information, for example, issues related to the immediate interests of residents, such as the promulgation of government social security policies and the handling of community welfare issues, and can largely meet the needs of online community "party affairs, government affairs and services", thus promotes the integration of online and offline community governance, so as to promote community governance in modern society.

4.3 Standardize the Order of Cyberspace and Construct the Justice of Community Space

Public interest is the fundamental direction of governance and publicity is the conversion of the value of public space. The publicity of community public space is realized in the process of connecting community residents, generating community social relations, cultivating community public spirit, shaping community social capital and realizing community public interests, so it is a value system based on justice and striving to achieve public good [9]. The "openness" and "publicity" of the space are the most important property characteristic. "Openness" means being open to all people within a certain range, and "publicity" means that open space is an important space for the cultivation and growth of residents' publicity [10], which is conducive to maintaining social relations in the community [11], and helps to promote community public issues discussion, community public interest expression [12]. Compared with the traditional urban community public space, the community network public space has the advantages of concealment, openness, convenience and so on, that has great advantages in the process of maintaining community social relations, promoting the discussion of community public issues, and expressing community public interests. But at the same time, these advantages of the public space of social network will also eliminate the existing publicity of the community under certain circumstances, such as easy to lead to network violence, topic control, purchase of water army and other behaviors. If not handled well, it will not only affect the relationship between the residents of the community, but also damage the image of the community in the hearts of residents, thus resulting in a loss of trust among residents. As Professor Shen Jianlin pointed out, the differences and disputes between the reconstruction theory and the deconstruction theory in the public domain exactly reflect the duality of the public domain in the cyberspace [13]. Therefore, in the face of this dual nature, it is necessary to strengthen the rule of law in cyberspace and actively publicize the provisions of "Forwarding libel information 500 times into crimes" issued by the Decision of the Supreme People's Court and the Supreme People's Procuratorate on Several Issues concerning The Application of Law in Criminal Cases involving defamation by Using Information Network Facilities, and respond to residents' needs in a timely manner and pay attention to resolving contradictions among residents, so as to prevent community residents from exhibiting communication behaviors that deconstruct the public sphere, such as extremization, violence, irrationality and fragmentation; At the same time, we should strengthen the guidance of community residents, advocate civilized Internet access, and strive to guide community residents to transform from individual "netizens" to the public [4], so that they can adhere to the spirit of public rationality, actively pay attention to public events, supervise public power, safeguard public interests, and become an active construction force in community space disputes.

5 Conclusion

Community is the common place of modern urban residents' life. Strengthening community governance is necessary to meet the people's ever-growing needs for a better life, and it is the front position to realize the modernization of China's governance system and capacity. Community public space as the main place of community governance and material carrier, the significance lies in that it can bring people together, strengthen the link between residents and community social relations, discuss public affairs and foster community public spirit, hence leading to the construction of community publicity, then become an important gripper for community governance, and it is of great significance to strengthen the construction of community governance system and promote urban governance. However, in the modern society undergoing continuous transformation, the heterogeneity of community, atomization of residents and the constant popularization of network communication make the potential and tension of building community publicity in traditional community public space being dispelled and squeezed constantly, and the construction of community publicity is facing new challenges. How to effectively build community publicity and promote the effective development of community governance is well worth studying. This paper focuses on the importance of community publicity for community governance and the construction of community publicity against the background of the continuous development of urbanization and informatization in China, through an in-depth analysis of the difficulties faced by the construction of community publicity in the traditional community public space and the opportunities provided by the community network public space for the construction of community publicity, this paper discusses the way to strengthen the community governance in the transition to modern society—the embedding and construction of community network public space, in order to promote the good realization of community governance through the construction of community publicity.

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A Study on Benefit Distribution of Multi-agent Urban Residential Land Supply Based on Game Theory

Huayun Song and Hao Wang

Abstract Since the economic reform and opening up, the urbanization of China has been continuously advanced. Housing shortage has become one of the key problems for the sustainable development of megacities. The Chinese government has adopted the strategy of "multi-agent land supply" to expand land supply. Facing the government's promotion and market demands, the benefits acquired during the land supply drive many stakeholders to implement pilot policies. Under the above background, this paper intends to construct the relationship network from the perspective of benefit distribution, analyze the benefit distribution among various agents and compare the difference between the urban land reserve mode and multi-agent land supply mode based on the game theory. The result showed that promoting the multi-agent land supply mode was more likely to achieve the Nash equilibrium and benefit distribution was more balanced along with the promotion of the policy.

Keywords Urban residential land · Multi-agent land supply · Urban land reserve mode · Game theory

1 Introduction

With the rapid development of economy, the urbanization of China has been constantly improved. The urban built-up area has expanded rapidly from 22,439.3 km^2 in 2001 to 56,225.38 km^2 in 2017, increasing by 150.57%. However, due to the non-agriculturalization of the population and the transfer of population to the central city, the demand for urban residential land is particularly prominent among various types of land. Housing shortage has become one of the key problems for the sustainable development of megacities [1]. Urban residential land, as the basic element of housing construction, is the root cause of housing supply and it has the dual attributes of market products and government guarantees. Nevertheless, from

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the results of urban residential land supply, the situation is not satisfactory. The land price has been so expensive that the apartments cannot be afforded by the low- and middle-income group [2]. The supply of affordable housing is seriously insufficient, and the supply structure of residential land is unbalanced. In addition, in the supply process, the forced acquisition and the corruption in the land transfer process have also occurred from time to time. Land revenue plays an irreplaceable role in fiscal revenues and expenditure, local governments do experience the dilemma of relying heavily on land finance while not finding alternatives or incentives for reform [3]. Skyrocketing land prices resulting from the intoxicating nature of land finance created real estate bubbles in urban China [4]. All the above problems are closely related to the monopoly of government in the urban residential land supply market.

In the 19th National Economic Congress of the Communist Party of China, accelerating the establishment of a land supply system through multiple sources and multi-agents has become a major requirement in the future plan. Polit policy with use of collective construction land to build rental housing policy in 2017 and the new "land management law" promulgated in 2019 broke the dualistic pattern of urban and rural land market in China, broke the monopoly of government in primary land market, and provided legal guarantee for the use of collective construction land for the rental housing construction [5]. They achieve the multi-agent and multi-channel supply, relieve urban residential land supply and the structural contradictions. The multi-agent and multi-channel supply of urban residential land makes the land supply process diversified and forms a more complex network of urban residential land supply. At the same time, benefit distribution in land supply has always been the core issue in the process of land circulation, and also a hot issue in the research of China's urbanization. Nowadays, the new urban residential land supply mode has changed the inherent benefit distribution pattern, which will have an impact on the benefit distribution of all agents in the process of urban residential land supply. The relationship and benefit distribution among agents in the process of urban residential land supply are worthy of attention and further study.

In the land market, local governments face conflicting interests of dual roles, namely market regulators and participants, and such role conflicts lead to the increasing dependence of local governments on land finance [6]. The rapid urbanization in China is based on the deprivation of rural collectives' benefits. If sustainable balanced development of urban and rural integration would be achieved, we must gradually detach local governments from land finance [7]. Multi-agent supply will weaken the government's monopoly position in land supply and improve the residential land supply marketization [8]. Li et al. [9] pointed out that the higher the degree of land marketization, the more effective land and housing supply will be. As a result, researchers are actively exploring the practice of multi-agent land supply and deeply analyzing the benefit protection and distribution of each agent in land supply.

Multi-agent residential land supply has been gradually implemented in China's megacities. Shenzhen has issued related documents, which referred that in 2035, Shenzhen will raise the construction of various types of 1.7 million apartments, with talent apartment and public rental housing in total of not less than 1 million. Beijing plans to roll out 1000 ha of collective construction land for rental housing from 2017 to 2021, and most of these rental housing projects will be put on the market by 2020. It can be seen that the urban residential land markets of these megacities are facing huge changes. Therefore, how the new supply mode changes the relationship among multi-agents and the benefit distribution in the residential land market is an important issue related to the development of the policy in the future.

Therefore, this paper explores the network of multi-agent residential land supply under the new residential land supply mode, analyzes the benefit requirements of all agents in the process of land supply, and expounds the internal benefit distribution that constitutes the network. On the basis of the relationship between agents and their benefit relationships, analysis of urban residential land use game theory in the process of the multi-agent supply benefit distribution. This article strives to provide opinions and suggestions for land supply system reform, provide experience and theoretical support for multi-agent land supply.

2 The Relationship Network of Multi-agent Land Supply

In the process of transfer from the rural collective land to the urban residential land, there is often a huge increase in land appreciation, among which the benefit distribution of each agent often arises social concern. Land finance dependence has promoted the marketization of land in the current state of economic development in most cities, so local governments will give priority to residential at the same level of land finance dependence [10]. Previously, the supply process of urban residential land has maintained the main conversion process of land original occupiers—local government—real estate enterprises. Multi-agent residential land supply means that the supply agent of residential land changes from government only to more agents, and the land form changes from traditional land for sale to land for sale and land for rent (seen in Fig. 1). The exploration and practice of multi-agent land supply are different, such as the “three old” reconstruction in Guangdong Province, the urban renewal in Shenzhen, the redevelopment of low-efficiency land in urban areas, and the construction of rental housing on rural collective construction land. [11] explored the potential relationship between the reconstruction of urban villages and public housing supply through urban planning and policy intervention, and proposed the framework of upgrading urban villages to provide public rental housing by taking a project in Xiamen as an example [11]. Tian et al. [1] discussed whether the collective land reform alleviates the housing shortage in China’s mega-cities. Lin et al. [12] take Beijing as an example to discuss the linkage of the construction of public rental housing and the reconstruction of Village in City [12]. Even though many researchers have paid attention to the new way of residential land supply in China, few take the new residential land supply system as a whole and explore its characteristics.

As seen in Fig. 1, the contracts among agents are almost gaming in pairs, namely the rural collective (or the urban stock land original occupier) and local government,

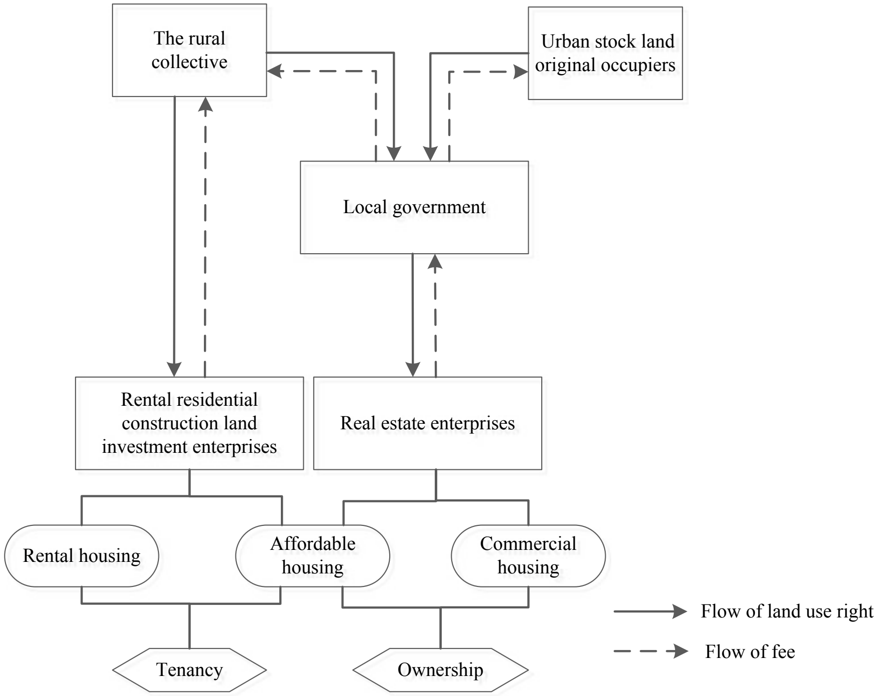

Fig. 1 The relationship network of multi-agent residential land supply

local government and real estate enterprises. The relationship between the government and the rural collective mainly involves the resettlement compensation standard and the definition of housing property rights. Similarly, the government plays games with the original land occupiers on the compensation for the withdrawal of industrial land. Generally, the government mainly determines the compensation through detailed investigation and obeying relevant policies and standards. For example, Beijing has promulgated the measures for compensation and resettlement of requisitioned land in Beijing. The game point between government and developers lies in the formulation of urban planning and preferential policies in terms of land transfer fees. Through urban planning, the government determines the appropriate development intensity and corresponding construction of supporting public facilities to ensure the overall interests of the city. Under the original residential land supply mode, urban land development directly increased the fiscal revenues of local government [7].

The demands of the rural collective can be divided into the following two aspects. First, to obtain land value-added income and reasonable housing compensation. Land is the most core resource of villagers. After providing residential land to the market, villagers hope to enjoy more value-added land income. In addition, due to the demolition of original houses, they also hope to obtain reasonable housing compensation. Second, improve the living environment of villagers. The villagers hope to get rid of their peasant status in the multi-subject land supply, complete the rural infrastructure and public facilities, improve the living environment and improve the quality of life.

According to the existing multi-agent land supply practice, the government can be the initiator of the multi-agent land supply project or the main implementer of the development project according to the characteristics of the specific project. The government should not only regulate the market behavior, but also regulate its own behavior, and gradually withdraw from the direct participation in the supply of residential land to indirect guidance the supply of land.

Urban stock land original occupiers (e.g. state-owned enterprises and public institutions) hold some idle lands in the city. Under the strict land use control, the transfer of stock land will be restricted. In reality, many enterprises and public institutions have formed a large number of idle land due to poor management and industrial transformation. Urban stock land original occupiers can participate in the multi-agent supply of residential land by changing the land use, making up the transfer of funds and other procedures to transfer idle lands as residential lands.

Real estate enterprises are the main body of the market economy, with strong financial strength and excellent development technical ability. The income of real estate enterprises often comes from the leasing or sales of real estate products after the project construction and development. As a producer of housing, real estate enterprises possess excellent real estate development technology and mainly pursue economic profits in the process of multi-agent supply of residential lands. The cost of housing development project is different from the production cost of general commodities. It always has long time cycle and huge investment and its cost control can change greatly. The participation of real estate enterprises in the multi-agent supply of residential land is directly related to the final housing pricing, and also determines the level of their own profits to a large extent.

Besides the real estate enterprises, other types of enterprises as the main body of market, have abundant capital, and also hold various resources and experience of project development. In the process of multi-agent land supply, they can not only independently complete the operation and implementation of the project, but also cooperate with the government or the original land occupiers to carry out the land development. The government can give way to the market and ensure the implementation of the project by relying on the power of the market. However, the government needs to regulate the relationship between various stakeholders, and supervise the behaviors of developers.

Specifically, the new way of land supply from the rural collective to investment enterprises is monitored by the local government and some tax and administration fee should be charged. Government-led land circulation is more sustainable than market-led land transfer in promoting urban development [13], so proper participation and monitor in the new way is necessary. Based on game theory, [14] studied the bargaining process between developers and residents on the distribution of benefits, and considered the role of the government in achieving the goal of fairness or efficiency through various regulatory strategies [14].

3 Game Model for Benefit Distribution of Multi-agent Residential Land Supply

The concrete implementation measures for the multi-agent supply of residential lands are still in the stage of exploration and there are still not normative documents for that. The successful development of multi-agent supply of residential lands based on the interaction relationship between all the stakeholders and the impact on the economic and social development. As a result, each agent in the process of the multi-agent supply of residential land will to fight for their own benefits.

Game theory has been widely used in the study of land value-added benefit distribution. In the traditional incremental residential land supply, the government pursued the maximization of fiscal revenue and social benefits, the rural collective pursued more land compensation and the real estate enterprises pursued the high plot ratio of construction projects and obtained rich development profits after the completion of project development [15]. In the multi-agent residential land supply, local governments are not the only land suppliers and no longer dominate land supply. Instead, they guide collective organizations to conduct independent and open transactions, participate in multi-subject land supply as managers, formulate transaction conditions, transaction rules and regulate the behaviors of both parties, and protect the legitimate rights and interests of both parties. In conclusion, the multi-agent residential land supply can be divided into two types of land supply, namely the urban land reserve mode and the multi-agent land supply mode.

3.1 The Development of the Game Model

The pre-assumptions of the game as follows: (1) the relationship between game players was non-cooperative and they were independent stakeholders; (2) each stakeholder rational economic man; (3) game players had an accurate and complete understanding of the game structure, rules, characteristics of each other, and utility functions of other players.

The players of this game model mainly include local governments, the rural collectives and land use enterprises (e.g. read estate enterprises, rental housing investment enterprises), which are represented by g, r, e. The strategy set of participants is S, where $S_j = \{s_j\}$, which shown in Table 1. In the game model of this study, local governments g have two strategies. The first is to maintain the existing urban land reserve mode by reserving rural collective land, and then selling it publicly. The second is to carry out multi-agent land supply mode innovation, allowing rural collective land to be traded directly with land use enterprises. Therefore, the strategy set of the government was $S_g =$ {urban land reserve mode; multi - agent land supply mode}.

Rural collectives r and land use enterprises e make their own strategic choices under the established land supply mode of local governments. When

Table 1 Parameters in the game model and their description

Agents	Game strategy			
Local government	Urban land reserve model		Multi-agent land supply model	
Rural collectives or original urban land occupiers	Forced to join in the land expropriation	Self-use	Autonomous trading	Self-use
Enterprises	Land purchasing in the primary land market	Not purchasing	Land purchasing in the public land markets	Not purchasing

the government adopted the urban land reserve mode, the rural collective's strategy set was $S_r = \{\text{forced to join in the land expropriation; self - use}\}$ and the land use enterprises' strategy set was $S_e = \{\text{land purchasing in the primary land market; not purchasing}\}$. When the government adopted the multi-agent land supply mode, the rural collective's strategy set was $S_r = \{\text{autonomous trading; self - use}\}$ and the land use enterprises' strategy set was $S_e = \{\text{land purchasing in the public land markets; not purchasing}\}$.

3.2 A Game Model for the Urban Land Reserve Mode

When local governments adopted the urban land reserve mode, the process can be divided into two stages, namely the stage of land expropriation and the stage of land transfer. The parameters we suppose are in Table 2.

Therefore, the strategy combination $\mathrm{I}_1\left(U_{g11}, U_{r11}, U_{e11}\right)$ was adopted and the utility function of the players are as follows:

$$\begin{aligned} U_{g11} &= P_1 + S_2 + T + R_g \times (1 - \alpha) - m - C_{g-r} - C_{g-e} \\ U_{r11} &= m + S_1 - C_{r-g} \\ U_{e11} &= P_2 - P_1 - T - R_e \times (1 - \beta) - C_{e-g} \end{aligned}$$

If the rural collective does not sell its own land, it chooses to operate the collective land through farming and other ways to make profit $\mathrm{I}_2\left(U_{g12}, U_{r12}, U_{e12}\right)$. The total revenue from operate the land by the rural collectives themselves was represented as W and the utility function of the players are as follows:

$$\begin{aligned} U_{g12} &= 0 \\ U_{r12} &= W \\ U_{e12} &= 0 \end{aligned}$$

When the mode of urban land reserve is used for land supply, the government takes funds to carry out the primary land development in the process of land expropriation.

Table 2 Parameters in the game model and their description

Parameters	Description
m	The compensation for land expropriation received by rural collectives
C_{g-r}	Negotiation costs of the government
C_{r-g}	Negotiation costs of rural collectives
S_1	Benefits received by the rural collectives after the land expropriation
R_g	Debt risk from the investment in the land primary development by the government
α	The probability of the debt risk
P_1	Land transfer fee charged by land use enterprises
T	Taxes charged by land use enterprises
C_{e-g}	The cost of purchasing land
C_{g-e}	The cost of organizing bidding
R_e	Land premium risk in the land market
β	The probability of the high premium risk
P_2	The total revenue from land development by land use enterprises
S_2	Benefits to the society

If the compensation negotiation with the rural collective is not successful, the time of land expropriation and demolition was prolonged and the probability of debt risk α was improved. This will not only increase the debt risk of government finance R_g, but also easily lead to land expropriation conflict. Local governments forced the rural collective to join the land expropriation and then they transfer the lands to land use enterprises at a high price, which makes the land transfer fees P_1 collected far higher than the land acquisition compensation m given to the rural collectives [16]. Most of the land value-added gains are occupied by the government, which easily leads to farmers' discontent and conflicts, posing a threat to social stability. Under the current land law, rural collective land can only be sold if it is expropriated by local governments. In the process of land expropriation, the rural collective was a vulnerable group and the land expropriation compensation only accounts for little proportion of the land transfer proceeds. Land use enterprises purchased the right to the use of land is to obtain income through development and utilization. If enterprises purchased lands from the land primary market, they need to pay the higher land transfer fees P_1 and taxes T, and still need to face premium risk R_e and high probability of premium risk β, under the situation of construction land supply constraints.

Due to the monopoly of the government, some informal land transfers have already happened in the real world. From the perspective of maximizing self-benefits, land use enterprises and the rural collectives may choose to trade in the informal land market to acquire lower land costs and higher land transfer compensation [17]. It urges the government to change the existing land supply mode and explore the multi-agent land supply mode.

3.3 A Game Model for Multi-agent Land Supply Mode

In the multi-agent land supply mode, local governments are not the only land supplier. They no longer dominate land supply, but act as the manager to guide the rural collectives to participate in multi-agent land supply. Local governments formulate transaction conditions, rules and regulations in order to protect their legitimate rights and benefits. The relationship between agents was shown in Fig. 2. The parameters we suppose are in Table 3. Therefore, the strategy combination $\text{II}_1(U_{g21}, U_{r21}, U_{e21})$ was the positive one under the multi-agent land supply mode and the utility functions are as follows:

$$U_{g21} = S_2 + P_3 \times \gamma + P_f \times \delta$$
$$U_{r21} = P_3 \times (1 - \gamma) - C'_{r-e} + S_1$$

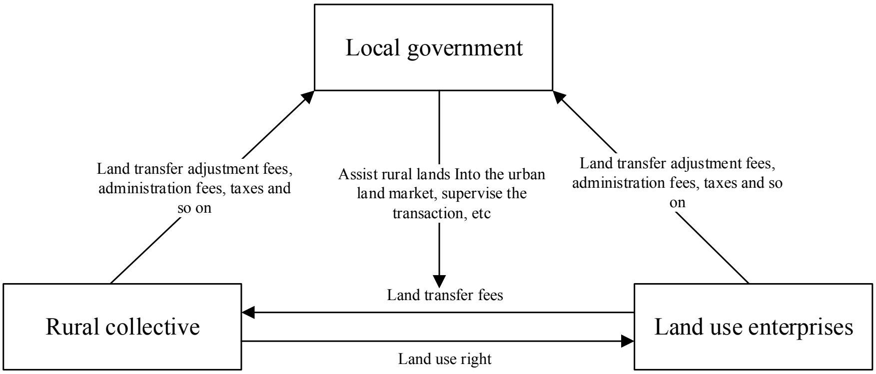

Fig. 2 The relationship of agents under the multi-agent land supply mode

Table 3 Parameters in the game model and their description

Parameters	Description
P_3	Land transfer fees after negotiations between rural collectives and land use enterprises
C'_{r-e}	Negotiation costs of rural collectives
C'_{e-r}	Negotiation costs of the government
P_4	The total revenue from land development by land use enterprises
S_1	Benefits received by the rural collectives after the land expropriation
S_2	Benefits to the society
γ	The proportion of the land transfer fees to charge the land transfer adjustment fees, administration fees and taxes from the rural collectives
δ	The proportion of the revenue of land development to charge the land transfer adjustment fees, administration fees and taxes from the land use enterprises

$$U_{e21} = P_4 \times (1 - \delta) - P_3 - C'_{e-r}$$

If the rural collective does not sell its own land, it chooses to operate the collective land through farming and other ways to make profit $\text{II}_2\left(U_{g22}, U_{r22}, U_{e22}\right)$. The total revenue from operate the land by the rural collectives themselves was represented as W and the utility function of the players are as follows:

$$U_{g22} = 0$$
$$U_{r22} = W$$
$$U_{e22} = 0$$

For the local government, multi-agent land supply mode changed its role from a dominant player to a manager, so as to avoid the cost of negotiating with rural collectives and carrying out primary land development in the process of land acquisition. With the development of information technology, farmers' awareness of property rights was also constantly improving [18]. If they chose to self-use the land, the economic benefits by farming are very small, and it is difficult to improve their income and living conditions.

3.4 Game Equilibrium Analysis

As we know, local governments cannot thoroughly implement the multi-agent land supply policy, and give up the original land reserve mode. The two land supply modes must exist simultaneously, which could both help local governments regulate land supply and maximize the marketization of land supply. The supply proportion from different sources is the core issue, which determines the equilibrium degree of benefit distribution and the stabilization degree of housing prices. This study discussed the proportion of residential land supply from various sources from the perspective of benefit distribution and the stabilization of housing price. Furthermore, it provides plans for the implementation of new policies and strategies at the city level in the future.

Some scholars from the provincial level and city level surveyed the land value-added income allocation proportion for the urban land reserve mode. The proportion of income distribution of the rural collectives, local government and land use enterprises at the provincial level of is 3.70:22.32:73.98, and the city of allocation proportion is 4.21:26.01:69.78 [19]. There is a large gap in the income distribution of land value-added income among local governments, the rural collectives and land use enterprises. Peasants are in a weak position under the urban land reserve mode and they were only forced to expropriate lands and to enjoy little part of the land value-added income. Even though the government and land use enterprises acquire most of the land value-added income, the government takes on large debt risks and the land use enterprises burden large premium risks, which are prone to reducing

Table 4 The proportion of benefit distribution under different scenarios

a%	1%	20%	50%
Local governments	24.3	22.6	23.8
Rural collectives	5.5	10.4	20.6
Enterprises	68.3	47.4	38.5

their benefits. It is difficult to reach Nash equilibrium because of the large gap in benefit distribution among all agents.

This model focuses on exploring the impact of policy implementation on benefit distribution among various agents in the software Anylogic. Along with the implementation of the policy, land lease of residential land supply will increase on the market, it will gradually increase the proportion of urban residential land. In this model, the proportion of land supply from the multi-agent land supply mode is assumed to be a%, and it is set as four supply levels of 1, 20, 50 and 80%. When a % = 1%, it means that the policy has just been implemented, and there is no large-scale response in the society. Rural collectives and rental housing investment enterprises are in observation, and fewer rural collectives participate in the compliance lease of rural collective land. When a% = 20%, it means that the multi-agent land supply mode has achieved good results. The policy has been understood by rural collectives and relevant investment enterprises and they could gradually participate in urban residential land supply. When a% = 50%, the policy is well known to the public. At this time, rural collectives and related investment enterprises participate in the stable growth period of rural collective land lease, and relevant compensation and income have formed a certain scale and standard. The simulation results are shown in Table 4.

Through the establishment of a multi-agent system model to simulate the impact of the implementation of the policy on the distribution of interests of each subject in the supply of urban residential land, this paper finds that with the continuous promotion of the policy, the supply of land for rental housing increases, the rural collective can distribute more benefits, and the local government can distribute less benefits.

In the multi-agent land supply mode, the government no longer directly participates in land expropriation and land transfer, but reshapes the property right relationship, assists the transaction of collective construction land, and supervises the land transaction. From the game analysis above, it can be concluded that local governments, as managers, receive land transfer adjustment funds, administration fees and taxes. Compared with the urban land reserve mode, the distribution of land value-added income in the multi-agent land supply mode is inclined to the rural collectives, which occupies the dominant right of land supply and enjoys more land value-added income. Local governments assist in the land transactions and collect fees in proportion, which not only reduces debt risks and lowers service costs, but also increases government fiscal revenue. For land use enterprises, they get the land at a more reasonable price, avoid the high premium risk in the market, and relieve the debt pressure of enterprises. Under the mode of multi-agent land supply, local governments allow multi-agent land supply and the game model can achieve Nash equilibrium.

4 Conclusion

This paper expounds and analyzes the demands of the stakeholders in the multi-agent land supply and establishes the game model for the urban land reserve mode and multi-agent land supply mode. The strategy combinations of two modes are illustrated, and the game equilibrium is obtained after the game analysis. The benefit distribution of multi-agent residential land supply is more even and Nash equilibrium is reached, which promotes the development of multi-agent residential land supply system.

After studying the distribution of benefit among the participants under different land supply modes and making game analysis, it can be seen that by maintaining the existing urban land reserve mode, farmers' property rights and benefits cannot be guaranteed and they may prefer to choose informal market transactions. While the government occupies a large amount of land value-added income in land acquisition and land transfer, it also bears the risk of debt and the pressure of land acquisition disputes. At the same time, land use enterprises bear a high premium risk, which is not conducive to their profits. The benefit distribution in the previous mode indicates a large gap in the distribution of benefits among agents.

By adopting the multi-agent land supply mode, local governments can avoid debt risks, which not only reduces the occurrence of land acquisition disputes, informal land transactions and other problems, but also reduces the cost of government service management. The value of the rural collective's land assets is manifested and enjoys more value-added income. Land acquisition costs and debt risks of land use enterprises are reduced, which provides better opportunities for enterprises to make profits. The benefit distribution along with the promotion of the policy indicates that the benefit distribution of agents is more balanced. Therefore, it is necessary to implement the multi-agent land supply system because the compromise among the three parties can better achieve the game equilibrium.

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Exploring Critical Success Factors for Fully Prefabricated Assembly Technology Adopted by Urban Tunnels

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Abstract The application of fully prefabricated assembly technology in urban tunnel construction can effectively alleviate a series of negative problems caused by traditional cast-in-place construction techniques, such as traffic congestion and environmental pollution. Despite this, their prefabricated rate is relatively low and is yet to be improved. A potentially important reason is the lack of the comprehensive evaluation mechanism to determine the factors which can promote the development of fully prefabricated assembly technology in the urban tunnel projects. As a prelude to the development of such a mechanism, this paper aims to explore the critical factors for the successful application of full prefabricated assembly technology in urban tunnel construction. A thorough and comprehensive collection of various factors that can affect the success of constructing full prefabricated assembly urban tunnels were identified from a multi-stakeholder perspective. Through face-to-face and online questionnaire survey geared towards urban tunnel projects participants with fully prefabricated assembly technology experience, the opinions of various parties were sought and evaluated in relation to the selected success factors. The data are then analyzed with various statistical techniques in terms of mean score ranking, factor analysis, sensitivity analysis and other methods. The results uncover eight sets of critical factors: technology, building side, external environment, construction unit, scientific research team, factors of other participants, influencing factors of project construction, policies and laws. The first four common factors are more sensitive to full prefabricated assembly urban tunnels. The research findings are expected to promote the development of fully prefabricated assembly urban tunnel projects.

Keywords Factor analysis · Full prefabricated assembly · Urban tunnels · Critical success factors

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1 Introduction

With the continuous increase in the number of vehicles in China, the urban transportation infrastructure industry is also developing rapidly. As one of the transportation infrastructure industries, urban tunnels can effectively alleviate urban traffic pressure and greatly improve land utilization. Urban tunnels have relied on traditional cast-in-place construction for a long time, which not only has low construction efficiency and difficult quality control, but also brings many problems such as traffic occupation, garbage pollution and noise [1, 2].The application of fully prefabricated assembly technology in urban tunnel construction can effectively solve the above problems, especially shorten the construction period and reduce labor intensity [2]. Under the background of sustainable green development, in order to promote the rapid development of fully prefabricated assembly urban tunnels industry, realize the goal of ecological civilization construction and improve the efficiency of urban operation, this study identifies and analyzes the critical success factors of the successful application of fully prefabricated assembly technology adopted by urban tunnels.

Critical Success Factors (CSFs) are generally considered to be a critical factor or activity needed to ensure the success of a company or organization [3], and it can effectively identify the critical factors in the development of fully prefabricated assembly urban tunnels. In addition, the sensitivity analysis can scientifically rank the importance of CSFs, so as to provide reference for the large-scale application of fully prefabricated assembly technology in urban tunnels.

Scholars have applied CSFs in such infrastructure projects as highway [3], subways [4], infrastructure [5], prefabrication housing [6], and integrated pipe corridors [7]. Although Reilly has introduced "CSFs" into the field of tunneling projects [8], domestic and foreign scholars still have little research on urban tunnels, especially fully prefabricated assembly urban tunnels CSFs. At the same time, literature review, factor analysis and other methods are often used in CSFs related research. For example, Hsueh and Chang [9] used literature review, expert interviews, questionnaire surveys, severity index, principal component analysis and other methods to determine the four CSFs of Taiwan's PPP infrastructure projects: a supporting legal framework, a good investment environment, and selection of suitable PPP projects and public support. Ghanbaripour et al. [4] conducted a study on the CSFs in the Iranian subway construction project, 23 CSFs were finally determined by literature review, focus group meetings, questionnaire survey and data analysis, such as goal setting and high-level management support.

Although there are a lot of researches and application of the fully prefabricated assembly technology in the field of construction, there is few tunnel construction using such technology in China [10] because of many restricted factors such as political environment, construction costs, construction capabilities, and the maturity of related technologies. Therefore, exploring CSFs for fully prefabricated assembly technology adopted by urban tunnels is necessary and feasible. This paper firstly extracts the initial list of influencing factors of the fully prefabricated assembly urban tunnels through literature analysis and semi-structure interviews. Secondly, it uses factor analysis is conducted to effectively identify CSFs of the fully prefabricated assembly urban tunnels development. Finally, the common factor with the highest sensitivity degree to fully prefabricated assembly urban tunnels is obtained by using sensitivity analysis.

2 Research Methodology

2.1 Determine the List of Success Factors

2.1.1 Literature Research

(1) References related to "tunnel success factors", "full precast assembly tunnel", "precast assembly success factors", "underground road success factors", rail transit success factors", "transport infrastructure project success factors", "Highway success factors", "underground pipe gallery success factors" were searched through CNKI, SCI and EI database.

(2) Manual screening was carried out on the collected literature to eliminate papers that were not relevant to the research topic, and the research topic was selected to be highly relevant, a total of 20 literatures with high correlation degree were obtained ranged from 2000 to 2020. And literature more published in journals such as *Journal of Management in Engineering*, *Journal of Construction Engineering and Management* and *Sustainability*. Finally, 29 influencing factors were analyzed and extracted.

2.1.2 Semi-structured Interview

The identified factors were scrutinized and verified by a series of face-to-face interviews with six practice industry experts and two academics. A pilot study was conducted to ensure that the questions were intelligible, unambiguous. According to expert opinions and pilot survey results, 27 success factors were confirmed in this paper, after removing 3 irrelevant factors, correcting 1 ambiguity factors, combining 1 similar meaning factors, and supplementing 2 unique factors, as shown in Table 1.

2.2 Data Collection

The questionnaire contains two parts: the interviewees' professional background and the degree of agreement of the 27 success factors. All questionnaires adopt the Likert five-point scale (1 point = "strongly disagree"; 5 points = "strongly agree"). A total of 300 questionnaires were distributed and 280 were recovered, with a recovery rate of 93%. Samples with improper answers, missing items, and

Table 1 27 success factors and mean value for full prefabricated assembly urban tunnels

No.	Success factors	M	Rank	No.	Success factors	M	Rank
CSF1	Political environment	4.50	3	CSF15	Comprehensive financial capability of construction unit	4.26	18
CSF2	Economic environment	4.35	12	CSF16	The commitment and support of the management of the construction unit	4.52	2
CSF3	Social environment	4.46	8	CSF17	Incentive policy	3.77	27
CSF4	The maturity of prefabricated assembly process	4.46	8	CSF18	Mandatory policy	4.09	21
CSF5	Feasibility of technical solutions	4.45	10	CSF19	Legal environment	3.79	26
CSF6	Advancement of technical solutions	4.47	6	CSF20	Coordination and risk management capabilities of participating parties	4.33	14
CSF7	Factor yization of prefabricated components	4.38	11	CSF21	Design unit's ability	4.33	13
CSF8	Research capabilities of the research team	4.60	1	CSF22	Ability of engineering supervision unit	4.11	20
CSF9	Investment in scientific research funds	4.18	19	CSF23	Ability of consulting unit	4.31	17
CSF10	Prefabricated assembly process training	4.06	22	CSF24	Good infrastructure and transportation planning	4.04	24
CSF11	The business ability of the building side	4.49	4	CSF25	Complexity of construction	4.32	16
CSF12	Similar project experience of the building side	4.48	5	CSF26	Favorable working conditions	3.96	25
CSF13	Similar project experience of construction unit	4.33	14	CSF27	Quality and stability of on-site workers	4.06	23
CSF14	The business ability of construction unit	4.47	6				

abnormal values were deleted, finally 246 valid questionnaires were obtained, with an effective rate of 82%. The sample size is enough to do the sensitivity analysis [9]. The respondents were from government agencies, construction units, building side, design units, supervision and consulting units, etc. Among them, 71.1% of the respondents had more than four years of working experience, and 16.3% had a "very understanding" of the fully prefabricated assembly urban tunnels. The results show that the questionnaire has good validity and authenticity.

2.3 Statistical Analysis Methods Adopted

Statistical techniques adopted in this paper include terms of mean score ranking, factor analysis and sensitivity analysis.

2.3.1 Means and Standard Deviations

The calculation of sample mean and standard deviation is one of the common methods used to determine the importance of success factors. It is generally believed that the smaller the mean value is, the higher the recognition degree of success factors is and the smaller the standard deviation is, the smaller the volatility of success factors is. As shown in Table 1, the mean value of 30 success factors is greater than 4, and the remaining 5 are all greater than 3.7, indicating that the 35 success factors selected are the success factors for the fully prefabricated assembly urban tunnels.

2.3.2 Factor Analysis

Exploratory factor analysis is a multivariate statistical method, which simplifies the original variables with intricate relationships into a few core factors by dimension reduction. Its purpose is to explore the internal relationship between the original variables and factors, and realize the classification and reconstruction of the original variables [11]. Therefore, this study conducted exploratory factor analysis based on the recovered original data to obtain the final fully prefabricated assembly urban tunnels CSFs and extract the corresponding principal components.

2.3.3 Sensitivity Analysis

Success factors sensitivity analysis aims to determine which success factors have a greater potential impact on the success of the project. Common sensitivity analysis methods include factor analysis, fuzzy comprehensive evaluation and analytic hierarchy process. In this study, the fuzzy comprehensive evaluation method was used to analyze the sensitivity of success factors, and the sensitivity degree of each common factor was reflected by the index weight.

3 Results and Discussion

3.1 Analysis of the Importance of Success Factors

The success factors were ranked according to the average value, and the results were shown in Table 1. The top three success factors are the scientific research ability of the research team (f11), the commitment and support of the management of the construction unit (f16), the political environment (f01). Through literature comparison, it is found that the category of the most important success factors affecting the development of fully prefabricated urban tunnel projects is different from that of highway [3] or subway [4] projects. This is due to the characteristics and particularities of the fully prefabricated urban tunnel projects.

3.2 Factor Analysis Results

In this paper, the sample the Cronbach's α of this sample is 0.888, less than 0.7, which shows that the internal consistency of the sample is relatively high. Meanwhile, KMO = 0.771 > 0.7, and Bartlett's test value is 0.000, indicating that the structure validity is meritorious and suitable for factors analysis.

The 27 success factors were ranked according to the mean (Table 1 presents the mean ranking), and factor analysis was conducted using principal component analysis and maximum variance rotation method. The factor screening standard is to ensure that the KMO value is greater than 0.7 and the commonality of all variables is greater than 0.5. Meanwhile, variables with factor load greater than 0.5 are selected to ensure that there is no double load. And eight common factors are obtained (Table 2). The characteristic value of each common factor is greater than 1.0, and the cumulative contribution rate reaches 75.537%, indicating that these eight common factors can effectively reflect and explain most of the information of the original data. The factor loading of each is greater than 0.5, and the commonality is greater than 0.5, indicating that most of the success factor information can be reflected by the extracted common factors.

Through factor analysis, eight sets of critical factors for the successful application of fully prefabricated assembly urban tunnel projects are obtained. They are summarized as follows:

(1) Technology. In factor analysis, the common factor accounts for 11.775% of the total variance of the key variable, which includes four success factors: f04, f05, f06 and f07.
The construction of fully prefabricated urban tunnel projects requires strong technical support, such as manipulators and spreaders, specially designed for fully prefabricated assembly, and the other intelligent machineries. At the same

Table 2 Results of factor analysis

Common factors	Success factors	Factor loading	% of variance explained	Common factors	Success factors	Factor loading	% of variance explained
Technology	CSF4	0.763	11.775	Influencing factors of project construction	CSF24	0.914	11.751
	CSF5	0.932			CSF25	0.692	
	CSF6	0.862			CSF26	0.888	
	CSF7	0.844			CSF27	0.828	
Factors of other participants	CSF20	0.911	11.675	Construction unit	CSF13	0.909	9.558
	CSF21	0.755			CSF14	0.557	
	CSF22	0.658			CSF15	0.828	
	CSF23	0.888			CSF16	0.627	
External environment	CSF1	0.835	8.761	policies and laws	CSF17	0.900	7.883
	CSF2	0.806			CSF18	0.609	
	CSF3	0.745			CSF19	0.865	
Scientific research team	CSF8	0.653	7.180	Building side	CSF11	0.919	6.955
	CSF9	0.830			CSF12	0.895	
	CSF10	0.765		-	-	-	-

time, advanced technology in the feasibility study stage will help ensure the quality and duration of the project [6].

(2) Influencing factors of project construction. This common factor construction accounts for 11.751% of the total variance of the factor analysis, which includes four success factors: f24, f25, f26 and f27.

Fully prefabricated assembly technology refers to the technology of assembling prefabricated components from the factory to the construction site. Therefore, good infrastructure and efficient and safe transportation routes are one of the important conditions for the project. At the same time, the simple construction procedure and good operating environment promotes the project [5]. The management status of the construction site, the allocation of personnel and equipment, the technical level and stability of front-line workers, etc. are also important factors.

(3) Factors of other participants. This common factor accounts for 11.675% of the total variance of the factor analysis, which contains four success factors: f20, f21, f22 and f23.

The ability and experience of the participating parties can effectively promote the implementation of the fully prefabricated technology in the tunnel projects. Reasonable risk sharing mechanism can influence the expected demand of participants and the expected profit, so as to promote the project successfully. Meanwhile, the cooperation of all the participating parties are also crucial.

(4) Construction unit. This common factor accounts for 9.558% of the total variance of the factor analysis, which contains four success factors: f13, f14, f15 and f16. The mean rank of these four common factors are respectively: 14th (4.33), 6th (4.47), 20th (4.26) and 2nd (4.52).
As the initiator of the project, commitment and support from the management of the construction unit are critical factors affecting project planning, schedule and communication [3], such as the attitude of active adoption of the fully prefabricated assembly process and support in the implementation process. The ability of the construction unit and the degree of experience in the successful construction of fully prefabricated assembly urban tunnels are also crucial.

(5) External environment. This common factor accounts for 8.761% of the total variance of the factor analysis, which contains three success factors: f01, f02 and f03. The mean rank of these three common factors are respectively: 3rd (4.50), 13th (4.35) and 8th (4.46).
As an important transportation infrastructure construction project, the fully prefabricated assembly urban tunnel cannot succeed without a favorable political and social environment, as well as public support [6], and the political environment has the greatest impact. However, China's social capital support is still insufficient. The fully prefabricated assembly urban tunnel projects are different from the integrated pipe gallery project. The economic environment of the tunnel projects directly affect the traffic flow, which has a greater impact on the later operating income of the project [4]. At the same time, the early capital requirements of fully prefabricated assembly urban tunnel projects are much higher than that of traditional urban tunnel projects, so the economic environment is the critical factor to be considered in the decision-making stage of the project.

(6) Policies and laws. This common factor accounts for 7.883% of the total variance of the factor analysis, which contains three success factors: f17, f18 and f19.
Since 2013, the government has repeatedly promulgated relevant policies and laws to promote the development of prefabricated assembly projects [3]. Relevant government policies will directly or indirectly affect technological progress [12], such as incentive policies and mandatory policies. In addition, the increase of research funds and the material and spiritual incentives for researchers will affect the enthusiasm of researchers and also promote technological progress [13].

(7) Scientific research team. This common factor accounts for 7.180% of the total variance of the factor analysis, which includes three success factors: f08, f09 and f10. From the mean value, f08 ranks the first (4.60) and is the most important factor. However, other factors ranked low, respectively: 24th (4.17) and 28th (4.06).

The scientific research team should strengthen their scientific research ability in the construction technology of fully prefabricated assembly roads and tunnels [6]. And the investment of scientific research should be increased to ensure the research and technology development. The new technologies, new materials and equipment are very important to the application of fully prefabricated assembly.

(8) Building side. This common factor accounts for 6.955% of the total variance of the factor analysis, which consists of two success factors: f11 and f12. The mean rank of these two common factors are respectively: 4th (4.49) and 5th (4.48).

Due to the unique nature of full prefabricated assembly urban tunnels, the accumulation of experience of building sides in past projects is an important predictor of project success [14]. At the same time, the strong project management ability and business level of the building side will also promote the success of the fully prefabricated assembly urban tunnel projects.

3.3 Sensitivity Analysis Results

Based on the data collection and factor analysis results of this study, the sensitivity analysis of common factors of fully prefabricated assembly urban tunnels was carried out in this paper. The modeling steps based on the sensitivity analysis are as follows:

(1) Determine a set of grade choices. Design scale score selection, D $= \{d1, d2 \ldots dn\}$ In this study, the five-point Likert Scale is used (i.e. $d_1 =$ "strongly disagree"; $d_5 =$ "strongly agree").

(2) Determine the weight of each factor and common factor.

$$W_i = \frac{M_i}{\sum M_{ii}} \tag{1}$$

where, W_i is the weight of factor or common factor; M_i is the mean of factors or common factors, and $\sum M_{ii}$ is the sum of the mean of all factors or common factors.

(3) Determine the membership function for factors. The response frequency of factors is analyzed when d is selected. Taking f15 as an example, the membership function of this factor is:

$$F = \frac{0.000}{SD1} + \frac{0.012}{SD2} + \frac{0.069}{SD3} + \frac{0.333}{SD4} + \frac{0.585}{SD5} \tag{2}$$

(4) Determine the membership function for each common factor.

$$\mathrm{C} = W_i^{\circ} P_i \tag{3}$$

where, C is the final evaluation matrix and ○ is a fuzzy composition operator, and P is the function matrix for each common factor. Taking "building side" as an example, its membership function is calculated as:

$$\begin{aligned} C_8 &= (0.501, 0.499) \times \begin{vmatrix} 0.000 & 0.012 & 0.069 & 0.333 & 0.585 \\ 0.000 & 0.012 & 0.069 & 0.346 & 0.573 \end{vmatrix} \\ &= (0.00, 0.012, 0.069, 0.339, 0.579) \end{aligned}$$

(5) Determine the index of each common factor.

$$\mathrm{I} = \sum_{i=1}^{5} C \times D \tag{4}$$

Taking "building side" as an example, its index is calculated as follows:

$$I_8 = (0.00, 0.012, 0.069, 0.339, 0.579) \times (1, 2, 3, 4, 5) = 4.482$$

(6) All indexes are normalized and ranked.
The ranking of the sensitivity degree on common factors is presented in Table 3. Sensitivity analysis shows that common factors have greater influence on the success of fully prefabricated assembly urban tunnels. Technology ranks the first with the index weight of 0.132, indicating that the common factor has the greatest sensitivity to the fully prefabricated assembly urban tunnels. As a major transportation infrastructure construction project, the maturity of fully prefabricated assembly technology and the feasibility of technical scheme are the decisive factors for the successful application of fully prefabricated assembly technology in urban tunnel construction [15].

Table 3 Sensitivity analysis results of common factors

Common factors	Weight for each common factor	Index	Index weighting	Ranking
Technology	0.154	4.560	0.132	1
Building side	0.078	4.482	0.130	2
External environment	0.115	4.439	0.129	3
Construction unit	0.152	4.394	0.128	4
Scientific research team	0.111	4.300	0.125	5
Participants other factors	0.148	4.270	0.124	6
Project construction influencing factors	0.142	4.103	0.119	7
Policies and laws	0.101	3.888	0.113	8

Followed by building side (0.130), external environment (0.129), construction unit (0.128), scientific research team (0.125), factors of other participants (0.124), influencing factors of project construction (0.119), policies and laws (0.113). The analysis results will help participants to adopt more effective strategies to promote the success of the project. The ability and experience of the construction unit and the building side, as the developer and the contractor of the fully prefabricated assembly urban tunnels, are the main promoters to ensure the successful completion of the project and effectively improve the project benefit [16]. Due to the characteristics and particularity of fully prefabricated assembly urban tunnels, the proficiency of relevant technicians in fully prefabricated assembly technologies, the feasibility and advancement of technical schemes will affect the progress and quality of the project [3]. This requires matching scientific research teams with strong scientific research ability to effectively use the scientific research funds, so as to ensure the innovation and progress of the fully prefabricated assembly technology [6]. Therefore, the sensitivity of "research team" to the development of fully prefabricated assembly urban tunnels is relatively higher than "factors of other participants" and "influencing factors of project construction". The analysis results will help stakeholders to focus on several common factors that rank high in sensitivity.

4 Conclusions

The factor analysis and sensitivity analysis were conducted in this study to explore CSFs for fully prefabricated assembly technology adopted by urban tunnels, the following main conclusions are drawn:

Firstly, twenty-seven CSFs were identified and eight sets of critical factors were extracted as the CSFs of fully prefabricated assembly urban tunnels, and the eight sets of critical factors are: technology, influencing factors of project construction, factors of other participants, construction unit, the external environment, policies and laws, scientific research team and building side. Secondly, three top CSFs were discovered which are the research team's scientific research ability, the construction unit management commitment and support, political environment. Finally, four most sensitive sets of critical factors were revealed which are technology, building side, external environment, construction unit.

Based on the research results of this paper, the following suggestions are given: Firstly, to ensure continuous technological innovation and support, the national standard, industrial standard and local standard of fully prefabricated assembly technology should be improved as soon as possible, and a complete system of prefabricated assembly components should be established to ensure the feasibility and advancement of the technical scheme. Second, each construction participant should strengthen their own comprehensive ability, accumulate project construction and management experience, take effective measures to reduce costs, and the management should give strong support in the application process of fully prefabricated assembly technology. Third, the construction of fully prefabricated assembly urban tunnels should rely on the local stable political and economic environment, and the understanding, support and consent of the public are particularly important. The research outputs of this study are very impactful in promoting the development of fully prefabricated assembly technology in urban tunnel projects.

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Factors Influencing the Adoption of Blockchain Technology in the Construction Industry: A System Dynamics Approach

Timothy O. Olawumi, Stephen Ojo, Daniel W. M. Chan, and Michael C. H. Yam

Abstract The construction industry is always a slow adopter of innovative technologies than other sectors of the economy. Although some technologies, such as Building Information Modelling (BIM), robotics, among others, have been implemented, their adoption has faced some challenges. Blockchain technology is also considered a game-changer for the construction sector with the functionalities and capabilities to improve the construction supply chain, improve transparency, sustainability, and the like. Hence, this study using the system dynamics approach aims to conceptualize the complex causal interrelationship of the key factors influencing blockchain technology adoption in the construction industry. The analytical findings revealed that stakeholders' awareness and satisfaction, support from top management, and the development of standardized and compatible blockchain solutions would enhance its adoption in construction firms and the construction industry. The study also emphasizes the need to integrate blockchain technology with the existing technologies towards facilitating the delivery of smart buildings and cities as well as enhancing the operation of modular integrated construction (MiC) projects both in Hong Kong and overseas

Keywords Adoption · Barriers · Benefits · Blockchain · Construction · System dynamics

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1 Introduction

The construction industry in recent years has been implementing some advanced technologies towards automating construction works and activities. These initiatives are considered critical to the future of construction [1]. Some of these key technologies include Building Information Modelling (BIM), RFID (Radio-frequency identification), augmented reality, Industry 4.0, and, recently, blockchain technology. For instance, BIM has a wide range of applications from building projects to transportation engineering projects, etc. [2, 3], similarly to the other range of technologies. The use of these technologies has given rise to the concept of smart building and cities [4, 5], which has the prospect of improving information sharing, security, data exchange, among others, throughout the project lifecycle and between project partners [6].

However, the fragmented nature of the construction industry [7], the issue of mistrust, coordination, and lack of confidence among contracting parties [8] have made construction stakeholders and firms not to be able to maximize the benefits of some of these technologies. For example, in utilizing BIM in a project, a lot of risks and legal liabilities do arise, which is still a drawback to the concept of automating construction information [9] and the use of these tools. Some of these BIM legal issues include model ownership, who is liable for errors in the model, copyright, and intellectual property protection [10].

Blockchain technology (BCT), a distributed ledger technology based on a peer-to-peer system, is regarded as a verifiable system to address trust, transparency, and risk management in a construction project. Hunhevicz and Hall [8] believed the benefits of using BCT would address most of the current drawbacks of other technologies. More so, traceability is another key functionality of BCT, which is a critical requirement in the supply chain [11]; which has enhanced blockchain adoption in sectors such as agricultural and food sector [12]; pharmaceutical [13]; recycling, e-procurement [14], among others. Incorporating blockchain and existing tools such as BIM and RFID in construction projects can address social and environmental sustainability issues along the construction supply chain.

A study by Elghaish et al. [15] also demonstrated the BCT system's core functionality in enabling automated and distinctive financial transactions in construction projects. Also, its decentralized nature will help improve coordination and collaboration in the industry [16]. However, apart from academic-based reviews and pilot test-runs of BCT in the literature, there is no known application of blockchain in construction projects despite its numerous benefits as a disruptive technology and its functionalities to address some shortcomings of existing systems such as BIM, geosystems, among others. BCT's slow uptake in the construction sector is not surprising because the adoption rate of BIM and other new and innovative tools are usually slow [17, 18].

Given the above, the current study aims to identify the key factors and their causal relationships as it influences and facilitates the adoption of BCT in the construction industry. These influencing factors for BCT adoption will be examined at the organizational and project level and at the industry level to ensure a holistic implementation of blockchain in construction firms and projects. The study's findings will help construction stakeholders, organizations, and policymakers understand the complexity of the interrelated factors that affect blockchain implementation and how to resolve it. The findings will also assist the relevant stakeholders in implementing blockchain and associated technologies in the industry. The paper reiterated the need for the construction industry to explore the various functions of BCT towards quantifying the actual benefits.

2 Literature review

In all countries of the world, the construction industry will continue to be pivotal to economic development because of its large revenue base. It is one of the biggest industries in the world. Adoption of blockchain technology in the construction industry will offer huge potential for sporadic development. BCT has significantly improved the construction industry with wide innovations that have changed the industry's status quo. Many studies have been carried out on the application of blockchain technology to the construction industry, and some of them will be reviewed and examined in this section. Sheng et al. [19] provided a solution to the problem caused by a lack of uniform and transparent information in the management of quality information, which leads to disputes among parties. The study proposed a landmark solution through the development of a novel blockchain-based framework for managing quality information. The framework is called the product organization process. Shojaei et al. [20] presented the implementation of smart contracts in the construction industry by integrating blockchain and BIM.

The authors' developed a Hyperledger fabric, which was applied in simple construction projects and later extended to smart contracts applications. The developed model provided an adequate solution to the problems of numerous litigations experienced in the traditional method of contract agreements and implementation. The blockchain application in this study proved that blockchain is an efficient system of overseeing construction projects through the maintenance of a tamper-proof record of projects from the starting point to the completion. The project's record in this digital way provides enough evidence that BCT can be used in dispute resolution. Kim et al. [21] identified several blockchain technology applications to the construction industry and the potential benefits the adoption can bring to the industry. The benefits include easy resolution of legal disputes, reduced transaction cost and time, and entrenchment of transparency in the industry.

All aspects of smart contracts for construction purposes ranging from contract initialization, payments, implementation, programming, and certification were examined by Ahmadisheykhsarmast and Sonmez [22]. The use of smart contracts decreased the cases of litigation in courts, significantly thereby saving costs and time. Yadav and Singh [23] presented the adoption of blockchain technology to the supply chain. The work proposed an efficient, sustainable supply chain management (SSCM) as a replacement for the traditional supply chain management. The principal components of the BCT as related to the supply chain. The components were analyzed and used to model the sustainable supply chain using the principal component analysis. The proposed SSCM generated a better result than the traditional supply chain management upon implementation. Li et al. [24] analyzed the current state of distributed ledger technology (blockchain) by analyzing the different areas in the construction industries with the major objective of enhancing coherent adoption. The authors' emphasized the need for a coherent and not a diverse adoption of the BCT in the construction industry. Kouhizadeh and Sarkis [25] focused on the adoption of blockchain technology to supply chain management identifying potential uses among green supply chain management with numerous functions and activities. The authors' concluded that blockchain is a disruptive technology with numerous opportunities across all sectors of national development.

Related blockchain application in other fields: Blockchain's wide adoption and success in cryptocurrency has made it very attractive to many other sectors of the economy [26]. Many practitioners and organizations have keyed into it because of the need to ensure efficient supply chain competitiveness and improvement [27]. Blockchain technology is a distributed ledger system [28]. The BCT is a peer to peer system (P2P) because each network node has an equal privilege to network information and resources. Resources are shared without starvation because race conditions cannot occur. Like a typical P2P network, there is no single point of failure, and the coordinator cannot be as in a centralized system. The BCT has been widely adopted in cryptocurrency and, precisely, in bitcoin because of the decentralization, security, and transparency it provides. It also eliminated all the problems encountered in a centralized system. Bitcoin has eliminated the need to go through any third party as in the traditional financial transactions. All nodes in the network have access to all resources in an equal way. The potentials of blockchain and its hype are difficult to parse [29].

The proponents of blockchain have emphasized that this technology's wide application will bring about efficient supply chain management. Warehousing, inventory, choice of material, and distribution in supply chain activities will all be positively influenced by the adoption of blockchain technology [25]. This is the drive behind the hype of this technology. The application of BCT to smart contracts has also attracted attention from the organizations in the construction industry. The contract signing, agreement, and implementation have been a big issue in the construction industry, causing so many litigations between the partners involved. The introduction of BCT has automatically eradicated this problem.

3 Research Methodology

The research data were sourced from the Scopus database, and this was used because it offered extensive coverage of a substantial number of articles and journals [30] compared to ISI Web of Science (WoS) and also contained significantly (if not all) the papers in WoS [31, 32]. The search criteria were 'Blockchain,' *and* 'Construction' *or* 'benefit' *or* 'barrier' *or* 'driver,' and the articles searched were confined to English and construction-related without any regional or geographical restrictions. All blockchain articles related to the construction industry with the chosen criterion were selected without any restrictions. The research design and framework followed a comprehensive approach in which blockchain adoption in construction industries was predicated on three basic factors: drivers, barriers, and benefits.

The influencing factors were viewed principally from two perspectives of organizational level and industry level. These levels gave birth to two causal loops used for the research design and analysis. The first causal loop was developed by crystallizing the key factors that influence BCT adoption in construction firms and processes, representing the organizational/project level. The second causal loop focused on the variables considered salient to BCT adoption at the industry level. The two causal loops developed using the system dynamic approach were used to establish the research framework.

3.1 System dynamics and modelling

The system dynamics modelling was used to determine the factors influencing blockchain technology adoption in the construction industry. System dynamics and modelling are mathematical algorithms employed in the accurate modelling of cause-effect situations in a particular problem. Unexpected situations and uncertainties in real-life situations are not easy to represent in a problem but can be accurately represented through forward and reverse loops used in system modelling and dynamics. System dynamics and modelling has been applied to several types of problems, and it starts with problem formulation, framework design, causal loop modelling, dynamic modelling, and implementation [33].

It has also been widely applied in solving problems in the construction industries. For this particular study, system dynamics and modelling is used in the design of causal loops, which are instrumental to the formulation of causal effects and feedbacks into the factors influencing the adoption of blockchain technology in the construction industries, such as a study by Saka et al. [18]. It consists of different nodes and arrows, which generates the feedback loops into the system. Causal loop diagrams were drawn with Vensim PLE software (version 7.3.5). Sapiri et al. [34] provide an in-depth study on system dynamic modelling and the use of the Vensim software.

The nodes and arrows form the feedback loops into the system. Loops are categorized into a reinforcing loop or a balancing loop, and a reinforcing loop is denoted by even negative signs or only positive signs. In contrast, a balancing loop is characterized by odd negative signs. Reinforcing loops causes instability in the system because changes increase as the feedback loop changes. The balanced loops are more stable because of their oscillation growth.

4 Results and discussion

This section discusses the influencing factors that affect the adoption of blockchain technology in the construction industry and the development of the causal loop diagrams for their interrelationship at the organizational and industry levels.

4.1 Factors affecting BCT adoption

The analysis of the extant literature revealed several factors – barriers, benefits, and drivers to the adoption of BCT in the construction industry. A key factor affecting the adoption of BCT is the immaturity of the technology [11], although it is more than a decade old. However, it has mostly be employed in cryptocurrency transactions such as Bitcoin, Ethereum, etc. Hence, it still needs more improvement and development to actualize the potential benefits, such as facilitating the tracking of products for sustainability issues [25]. Another key barrier to its adoption is scalability [35]. Scalability relates to the limited rate at which a blockchain system can process transactions (TXs), and is affected by the block size limit and the average time to validate each block TXs. Existing blockchain platforms such as Bitcoin, Ethereum still face this issue. However, the proposition of solutions such as the lightning protocol and sharding partitioning schemes but Bitcoin and Ethereum is still in the pipeline.

More so, this scalability problem of blockchain solutions and the computational intensiveness, needed to validate TXs results in TXs delays and subsequent energy costs. The massive energy consumption by blockchain systems [36, 37] is a major hindrance to its adoption in the construction industry in which clients and firms face much emphasis on cost reduction [7, 38]. Although employing BCT in construction projects is beneficial to enhancing sustainability in such projects [39], the increasing energy cost of BCT infrastructure needs to be checked. For example, for each mined Bitcoin Tx block, 4 kg of carbon are emitted compared to an average of 5 kg for humans per year. Other barriers relate to lack of expertise [29], reluctance to invest in new systems, lack of awareness [40], the disparity in information disclosure in the construction supply chain [41, 42], among others.

Despite these barriers, as earlier highlighted, there are numerous benefits to outweigh these challenges to its adoption. A key benefit is using smart contracts in BCT [43] to improve construction efficiency and manage contract risks. Also, the use of BCT will enable stakeholders in construction projects to operate in a trustless environment that promotes transparency and accountability. BCT is a decentralized network that does not require a third-party validation or authority [37] to maximize this benefit. Blockchain application in the construction supply chain can reduce the intermediation between the client, contractors, suppliers, and other numerous participants in the supply chain. The disintermediation of the supply chain is possible in BCT due to its capacity to promote TXs among participating peers [44]. More so, the integration of BCT with other technologies [6, 45] will help expedite the implementation of smart buildings and cities in the built environment and aid the digitalization of the supply chain.

4.2 Causal relationship of the influencing factors of BCT adoption

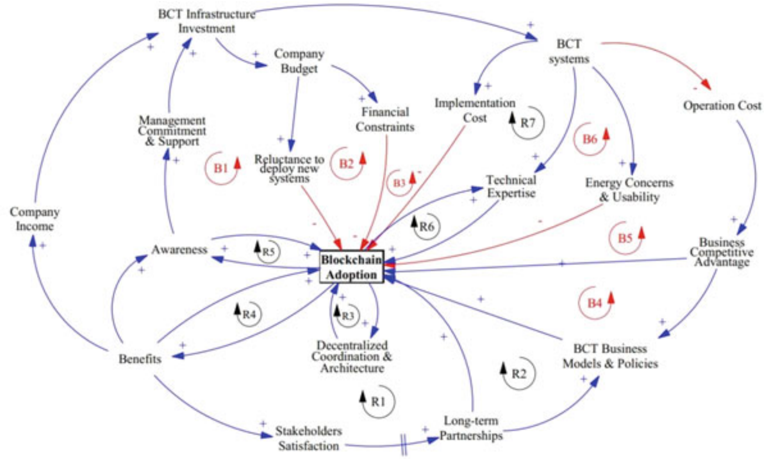
Causal loop diagrams were employed in this section to illustrate and understand the dynamics of the interrelationships of the several variables that affect BCT adoption in the construction industry. In order to effectively model and investigate the complexity of the causal relationships of these factors, two dynamic models were developed. The first one examines the causal interrelationship at the project/organizational level, and the second causal loop focuses on the interrelationship at the industry level.

4.2.1 Causal effects at the project/organizational level

Figure 1 illustrates the causal relationships of the influencing factors at the project and organizational level. Overall, 13 loops were identified, which comprises of seven reinforcing loops and six balancing loops.

The reinforcing loop in the causal loop diagram of Fig. 1 are:

R1: Loop R1 is a reinforcing loop driven by the satisfaction derived by construction stakeholders from the benefits gained from their adoption of BCT in their projects. An increase in this satisfaction will lead to supply chain participants engaging in long-term partnerships with crucial project collaborations brought about by the peer-to-peer system of blockchain, and this will lead to further adoption of BCT in the long-run.
R2: More so, an increase in these benefits will enable stakeholders to engage in long-term project collaboration and, as a result, prompt them to develop appropriate business models and policies to manage the BCT-enabled projects. The resultant effect is increased blockchain adoption.
R3: An increase in BCT adoption in construction projects will positively influence the coordination and management of such projects and vice versa.
R4 & R5: As seen in reinforcing loops 4 and 5, an increase or decrease in derived benefits and level of awareness of BCT will have a resultant effect on its adoption in the construction industry.
R6: Blockchain adoption will influence organizations to enhance their knowledge and experience in using and to manage BCT systems, which will further aid its application in future projects. However, firms that fail to adopt BCT will have no experience in the management of the BCT system.
R7: Construction firms adopting BCT and deriving significant benefits will see an increase in its income, which will encourage the investment in BCT infrastructure



Reinforcing loops

R1: Blockchain adoption +→ Benefits +→ Stakeholders satisfaction +→ Long-term partnerships +→ Blockchain adoption.
R2: Blockchain adoption +→ Benefits +→ Stakeholders satisfaction +→ Long-term partnerships +→ BCT Business models & policies +→ Blockchain adoption.
R3: Blockchain adoption +→ Decentralized coordination and architecture +→ Blockchain adoption.
R4: Blockchain adoption +→ Benefits +→ Blockchain adoption.
R5: Blockchain adoption +→ Awareness +→ Blockchain adoption.
R6: Blockchain adoption +→ Technical expertise +→ Blockchain adoption.
R7: Blockchain adoption +→ Benefits +→ Company income +→ BCT infrastructure investment +→ BCT systems +→ Technical expertise +→ Blockchain adoption.

Balancing loops

B1: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ Company budget +→ Reluctance to deploy new systems −→ Blockchain adoption.
B2: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ Company budget +→ Financial constraints −→ Blockchain adoption.
B3: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ BCT systems +→ Implementation cost −→ Blockchain adoption.
B4: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ BCT systems −→ Operation Cost +→ Business Competitive Advantage +→ BCT Business Models & Policies +→ Blockchain adoption.
B5: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ BCT systems −→ Operation Cost +→ Business Competitive Advantage +→ Blockchain adoption.
B6: Blockchain adoption +→ Awareness +→ Management commitment & support +→ BCT infrastructure investment +→ BCT systems +→ Energy concerns & Usability −→ Blockchain adoption.

Fig. 1 Causal loop showing the interrelatedness of the influencing factors at the organizational level

and systems with a resultant increase in their staff's technical expertise and more deployed BCT-enabled projects.

The balancing loops in the causal loop diagram include:

B1: Causal loop B1 represents a key balancing loop in BCT adoption in a firm. An increase in BCT adoption will have an increasing or decreasing effect on the awareness of top management, which will, in turn, affect their commitment and support for blockchain in their enterprise. A positive commitment can result in investment in the blockchain, which inevitably increases the firm's budget. Such an increase in the budget might make the top management reluctance to deploy new BCT systems in their firm and invariably stiff further blockchain adoption.

B2: Loop B2 is somewhat similar to B1; however, in this case, an increase in the company budget will increase the financial constraints faced by the firm and vice versa. The resultant effect is an increase or decrease in BCT adoption with such firms or projects.

B3: An increase or decrease in investment in BCT system by the construction firm's management will determine the number of available BCT infrastructure to be deployed for construction processes, which in turn affects the high cost of implementing the system. An increase in the implementation cost will negatively affect the future adoption of blockchain.

B4: Availability of BCT systems in an organization will lead to a decrease in its operating cost over time and give such firms a competitive edge over its rivals and enable such firms to develop appropriate BCT business models to consolidate the superiority in the business.

B5: Like loop B4, an increase or decrease in the competitive advantage a construction enterprise has over its rivals due to its adoption and investment in BCT system will have a resultant effect on future BCT adoption.

B6: Causal loop B6 is another balancing loop between an increase in blockchain adoption and energy cost and usability concerns of BCT systems. The increasing energy cost of managing existing BCT systems is a determent to its implementation in the construction industry. Kaur and Gandhi [36] suggested removing block size limit and improving the TXs validation process to reduce time spent on committing a TX block and the resultant carbon footing.

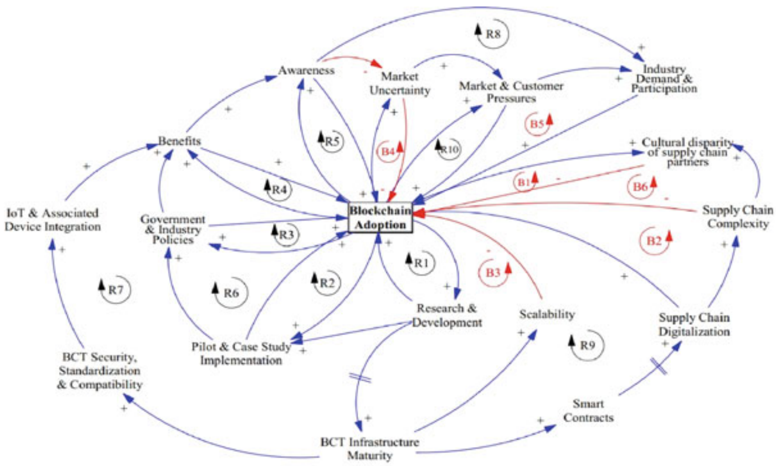
4.2.2 Causal effects at the industry level

Figure 2 illustrates the causal relationships of the influencing factors at the industry level. Overall, 16 loops were identified, which consists of ten reinforcing loops and six balancing loops.

The reinforcing loop in the causal loop diagram of Fig. 2 are:

R1–R5: The reinforcing causal loops R1–R5 are key influencing factors that can single-handedly advance blockchain technology implementation in the construction industry. An increase in the adoption of BCT will increase its benefits (R4) to the industry and the awareness of stakeholders (R5). Also, when the government develop an interest in BCT and develop relevant regulatory policies and standards (R3), which will further improve its adoption. An increase in BCT-related research (R1) and relevant case study project implementation (R2) will enable construction firms and other stakeholders to adopt BCT if its performance is evaluated positively.

R6: BIM adoption influences researchers and software developers to conduct more studies and develop BCT tools suitable for construction processes. The developed



Reinforcing loops

R1: Blockchain adoption +→ Research & Development +→ Blockchain adoption.
R2: Blockchain adoption +→ Pilot & Case Study Implementation +→ Blockchain adoption.
R3: Blockchain adoption +→ Government & Industry Policies +→ Blockchain adoption.
R4: Blockchain adoption +→ Benefits +→ Blockchain adoption.
R5: Blockchain adoption +→ Awareness +→ Blockchain adoption.
R6: Blockchain adoption +→ Research & Development +→ Pilot & Case Study Implementation +→ Government & Industry Policies +→ Benefits +→ Blockchain adoption.
R7: Blockchain adoption +→ Research & Development +→ BCT Infrastructure Maturity +→ BCT Security, Standardization & Compatibility +→ IoT & Associated Device Integration +→ Benefits +→ Blockchain adoption.
R8: Blockchain adoption +→ Benefits + Awareness +→ Industry Demand & Participation +→ Blockchain adoption.
R9: Blockchain adoption +→ Research & Development +→ BCT Infrastructure Maturity +→ Smart Contracts +→ Supply Chain Digitalization +→ Blockchain adoption.
R10: Blockchain adoption +→ Market & Customer Pressures +→ Blockchain adoption.

Balancing loops

B1: Blockchain adoption +→ Cultural disparity of supply chain partners -→ Blockchain adoption.
B2: Blockchain adoption +→ Research & Development +→ BCT Infrastructure Maturity +→ Smart Contracts +→ Supply Chain Digitalization +→ Supply Chain Complexity -→ Blockchain adoption.
B3: Blockchain adoption +→ Research & Development +→ BCT Infrastructure Maturity +→ Scalability -→ Blockchain adoption.
B4: Blockchain adoption +→ Market Uncertainty -→ Blockchain adoption.
B5: Blockchain adoption +→ Awareness -→ Market Uncertainty +→ Market & Customer Pressures +→ Industry Demand & Participation +→ Blockchain adoption.
B6: Blockchain adoption +→ Research & Development +→ BCT Infrastructure Maturity +→ Smart Contracts +→ Supply Chain Digitalization +→ Supply Chain Complexity +→ Cultural disparity of spply chain partners -→ Blockchain adoption.

Fig. 2 Causal loop showing the interrelatedness of the influencing factors at the industry level

systems could be tested on real-life case study projects. A positive progression in its implementation in these projects will lead the government to legislate its use and develop appropriate policies in collaboration with professional bodies and industry stakeholders. The resultant effect is increased benefits accruable to the involved firms and stakeholders, which will, in turn, enhance BCT adoption.

R7: A key barrier to BCT adoption is the immaturity of its technology. Hence, further industry research will ameliorate this challenge towards the rapid development of BCT infrastructure and improve the security and standardization of blockchain systems. Once BCT technologies are more standardized, it will

enhance its interoperability with other BCT solutions and other technologies such as BIM, GIS, RFID, sensors, among others. Using these integrated technologies will positively strengthen the benefits of BCT implementation in the construction industry and make passive clients and other industry practitioners adopt BCT further.
R8: A key driving force to BCT adoption is the active demand and participation of industry practitioners; hence, benefits from its adoption and increased stakeholders' awareness will prompt them to adopt blockchain.

R9: The availability of matured BCT systems and the use of smart contracts will enhance the digitalization of the supply chain and results in more adoption.
R10: A positive pressure from developers, customers, and the construction market would lead to more adoption of blockchain in the construction industry.

The balancing loops in the causal loop diagram (Fig. 2) include:

B1: Partners in the construction supply chain tend to hold information critical to their survival and competitive advantage over rivals. Blockchain brings transparency in TX, which traditional participants in the supply chain oppose; hence, it will make them uninterested in BCT adoption.
B2: The digitalization of the construction supply chain will increase the complexity of the supply chain and managing this complexity will negatively affect BCT adoption.
B3: The scalability problems are beyond developing more efficient and matured BCT systems. Hence, its associated challenges need to be solved; otherwise, blockchain adoption might be slowed in the industry.
B4: Bitcoin, a key BCT-based financial system, has generated mixed public perceptions, mostly negative. Therefore, stakeholders in the construction industry might be hesitant to adopt blockchain.
B5: Improvement in stakeholders' awareness will reduce the market uncertainty about BCT adoption, making industry practitioners and customer demand BCT application in their projects.
B6: An increase in the construction chain's complexity will further affect the disparity among the participating stakeholders, with the resultant negative effect on BCT adoption.

5 Conclusions

The construction industry is a massive sector with a considerable impact on the livelihood of human and the ecosystem. However, the construction process is fraught with several challenges that inhibit the project's success and make for unsustainable products. Hence, many technologies such as BIM, RFID, etc. and lately, blockchain has been developed to address these issues and automate the whole life cycle of built assets. The paper explores the literature to examine the relevant benefits of blockchain adoption and other influencing factors affecting BCT adoption in the construction industry. BCT's potential advantage to address some shortcomings that discourage the industry from implementing other technologies and facilitating sustainability in construction projects makes the need for this study more worthwhile.

A review of the literature help to deduce the key influencing factors affecting the adoption of blockchain technology in the construction industry, while system dynamics via the development of causal loops helped model the causal interrelationships among the key factors. The most significant influencing factors at the organizational and industry levels are awareness, benefits derivable from BCT adoption, stakeholders' demand, and satisfaction. More so, for the organizational level, the key factors are continuous support from top management, investment, and deployment of BCT infrastructure, the need for decentralized coordination of construction activities. However, the implementation and energy cost of BCT systems has a prohibitive effect on its adoption. The increasing budget of the firm can make the management reluctant also to deploy new systems.

Meanwhile, at the industry level, the key factors related to government policies in support of blockchain and BCT-research and development, will pave the way for increasing effectiveness and standardization of BCT infrastructure. Scalability problems of BCT systems are still a hindrance as well as the current public opinion about blockchain. Also, the issue of non-disclosure of information by supply chain partners needs to be resolved to improve BCT implementation in the construction industry. The knowledge and understanding of these key factors will help industrial practitioners and other stakeholders to adopt BCT in the industry.

More so, the illustration of the causal relationship between the identified variables will better help stakeholders implement blockchain in their projects. A BCT-based supply chain network will be very suitable for modular integrated construction (MiC) projects where there are varied chains of supply partners. A limitation of this study is that a single corpus database (Scopus) was used, and future studies could consider more databases articles for review. Further research is necessary to provide empirical modelling and analytical evaluation of these factors. An investigation of the value of blockchain technology for the construction market and business in general and MiC projects, needs to be conducted to facilitate its wider adoption.

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The Impact of Emotional States on Construction Hazard Perception and Recognition Abilities

Dan Chong and Hao Su

Abstract Workers' hazard identification abilities have been recognized as one of the main factors to reduce the construction accidents. If the construction workers can identify various hazards in a timely and accurate manner during the construction process, it can effectively avoid the occurrence of safety accidents. Based upon the recent discovery that emotional state impacts hazard risk perception. The purpose of this study is to explore the relationship between different emotions states and hazard identification abilities. To induce and measure the emotional state of 30 subjects, the International Affective Picture System (IAPS) pictures were used. Subjects were ask to complete safety risk assessment form to test the hazard identification abilities. The results uncovered that subjects were in a state of positive emotions such as forgetfulness and excitement, their accuracy in hazard identification will decrease, and the feedback time will be shorter, making it easier to ignore the dangers around them. The research findings are expected to help construction workers avoid unsafe behaviors due to mental reasons, thus enhancing the construction safety management.

Keywords Construction safety management · Hazard identification · Emotional states · Hazard risk assessment

1 Introduction

It is unexpected that the industrial accident rate has increased with the boom of construction industry in China recently. Concluded by Ministry of Housing and Urban–Rural Development of People's Republic of China (2019), the rate of accidents and the rate of death in accident were raised by 6.1% and 4.1% in 2018 respectively. Zhang claimed that the safety accidents had brought 465.1 billion-yuan-worthy

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loss in 5 years (2011–2015), which was accounted as 0.16% of GDP and 0.72% of government revenue. Due to the high hazard and significant loss of the construction industry, construction safety management has been attaching academics and practitioners.

Many researchers believed that construction hazard perception and recognition abilities can influence hazard rate. Shin claimed that injured workers have a higher ability to identify hazards, and they do not indulge in risk-taking behaviours. [8] A study by Mostafa Namian [7] in 2018 showed that workplace interference can have a negative impact on workers' hazard identification and safety risk perception and safety performance. Carlos research found that workers who have been trained in high-participation methods can identify a greater proportion of hazards [1]. In 2016, Jeelani pointed out that training programs are not designed to maximize hazard identification capabilities, although they can improve workers'safety knowledge. Factors affecting safety risk perception include personal factors such as employee experience, knowledge and emotional state [9], self-protection and safe behaviour [3],and workplace factors such as safe climate and social norms [2]. In order to be able to better judge and measure the risk assessment capabilities of construction personnel, Hallowell quantified personal safety risk perception as the product of the expected damage frequency and severity caused by exposure to danger [4].

However, these researches did not point out the specific factors affecting construction hazard perception and recognition abilities, which is the research gap in this field. Therefore, this research will try to study a specific factor of construction hazard perception and recognition abilities.

This research will study the relationship between emotion and construction hazard perception and recognition abilities because there are many evidences shows that the relationship may exist. In 1962, Schachter proposed that physiological arousal and emotional experience will feed back to people's cognition. The International Affective Picture System (IAPS) [6] is a widely used and accepted method to induce Emotions that does not involve deception, and is easily standardized. Based on the multi-dimensional method, the emotional characteristics of each picture in IAPS are three dimensions, namely valence (pleasure-not faster), arousal (relaxation-tension), and domination (control-domination). Each picture uses a self-assessment model (SAM) [5] to obtain the mean and standard deviation.

Hence, this research will study the relationship between emotion and construction hazard perception and recognition abilities through the following questions. First, this research will try to find out whether there is a relationship between emotion and hazard recognition and safety risk perception. Second, if the answer for the first question is yes, then how emotion affects hazard recognition and safety risk perception, for instance, whether the correlation is positive or negative, and how strong the correlation is. Third, what are the possible advices can be proposed to reduce construction accidents according to the results of the second question.

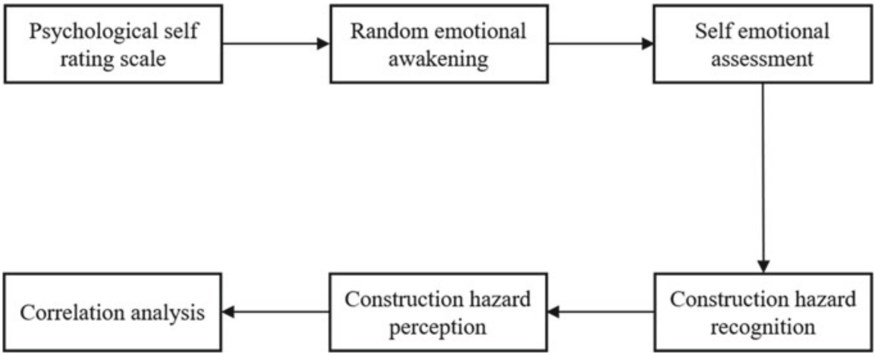

Fig. 1 Protocol of research design

2 Research Method

2.1 Research Design

There are six steps included in this process: (1) subjects complete psychological self rating scale; (2) awaking participants' 3 types of emotion by showing pictures randomly; (3) subjects accomplish self emotional assessment; (4) subjects finish construction hazard recognition test; (5) subjects finish safety risk perception test; (6) researchers make correlation analysis of emotional state and hazard identification abilities. (Fig. 1).

2.2 Experimental Preparation

In this experiment, the program E-Prime2.0 was used to randomly present The International Affective Picture System (IAPS) pictures to awaken emotions. [2, 6]. The resolution of each IAPS picture is 1024 * 768, and the default settings of display brightness, contrast and colour are unified.

Before the experiment began, the subjects will be asked to calm down their expected state and complete the Self-Rating Anxiety Scale (SAS) and Self-Rating Depression Scale (SDS) to ensure that the subject's current mental state is normal. After the psychological self-rating scale, the subjects were asked to read the informed consent and sign it carefully, in order to let the subjects understand the purpose of the experiment. To make it clear that the purpose of this experiment is only to collect data on the identification of construction hazards under different emotions, and does not involve their personal privacy; their registered personal information is only used for experimental purposes and will be kept safe and confidential, except for the experimenters and the subjects.

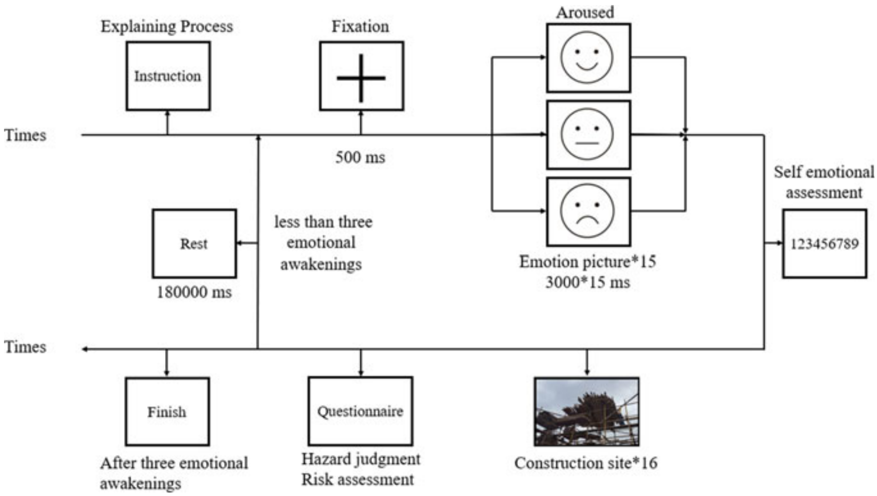

Fig. 2 Experimental process

Pre-simulation will be carried out before the formal experiment to make sure the subjects understand the experimental process and types of construction risks, which helps the subjects assess the degree of danger to them in a better way.

2.3 Experimental Process

At the beginning of the experiment, a guide was presented to explain the process and purpose of this experiment. Emotional arousal pictures appeared with each presented for 6 s. After 15 pictures, the emotional self-state was evaluated from "unhappy = 1" to "Happy = 9". After the evaluation, 15 pictures of the construction site were presented. The subjects needed to judge whether there were hidden safety hazards in the pictures. If there is any, press 1, if not, press 0 to complete the risk assessment form and end the rest for 3 min. The experiment was repeated for a total of three rounds, and the goal awakening emotions were different in each round in a random order. (Fig. 2).

2.4 Emotional Arousal and Hazard Identification

2.4.1 Emotional Arousal

In this study, 30 positive pictures, 30 negative pictures and 30 neutral pictures were selected from IAPS picture library as stimulation materials. The selected positive pictures generally include sports, life scenes, animals, environment, and babies. The neutral pictures are mostly daily necessities (such as kitchen utensils), abstract artworks, mushrooms, buildings, etc., and the negative pictures are mostly traffic accidents, The scene of violent murder, corpses, disabled individuals, etc.

The valence mean of the selected image of negative emotion is 1.78 and the arousal mean is 6.36. The valence mean of the selected image of neutral emotion is 4.92 and the arousal mean is 3.37. The valence mean of the selected image of positive emotion is 7.83 and the arousal mean is 5.139. The variance of the valence score of each image is not greater than 2.4.

2.4.2 Construction Hazard Recognition

In this study, a total of 120 real photos of the construction site were collected from online and offline. Among them, there were 30 pictures without danger, and the remaining 90 pictures were divided into 6 categories according to the hazard: (1) 30 falls from a height (2) electric shock 21 photos of fire accidents (3) 12 photos of collapse accidents (4) objects struck 12 photos (5) 9 photos of mechanical injuries.

Give the collected pictures to the experts. From the collected pictures in different categories, the safety engineering experts were required to evaluate them in five-point scale from two dimensions: (1) Whether the picture directly express such construction lurking danger. (2) Whether the situation in picture is common in the construction site. 1 for Very Bad; 2 for no; 3 for General; 4 for Good and 5 for Very Good.

A total of 11 questionnaires were received for this scoring, including 8 valid questionnaires. Based on the scores of the 8 questionnaires for the pictures, delete the pictures with an average score of the last 30%. There are 27 risk-free pictures finally retained, a total of 65 dangerous pictures: (1) there are 21 high-risk falls, accounting for 32.3%; (2) there are 16 electric shock and fire risks, accounting for 24.6%; There are 11 photos of object strike risk, accounting for 16.9%; (4) there are 11 photos of collapse risk, accounting for 16.9%; (5) there are 6 photos of mechanical injury risk, accounting for 9.2%.

2.4.3 Construction Hazard Perception

In this study, In order to be able to better judge and measure the risk assessment capabilities of construction personnel, a safety risk assessment form will be used. (Table 1) It quantifies the perception of personal safety risks as the product of the expected damage frequency and severity caused by exposure to danger [4]).

Safety Risk = Frequency of incidents × Severity of incidents.

Expected injury frequency caused by danger: the number of accidents that occur within a certain period of time (for example, the number of injuries per working hour). The severity of the danger: the magnitude or severity of the consequences of a security accident.

Table 1 Safety risk assessment

Injury type	Injury frequency			
	Once every week	Once every month	Once every year	Once every ten years
1.Discomfort/pain				
2.First aid				
3.Medical case				
4.Lost work time				
5.Permanent disablement or fatality				

2.5 Data Collection and Analysis

2.5.1 Data Collection

In 2013, Park proved that the effect of emotional stimulation of pictures by students is more significant [7]. Wonil discovered through students the U-curve relationship between physical strain and productivity of construction workers. Therefore, in this experiment, we will select 30 graduate students majoring in construction management and will be selected as subjects in the future.

A total of 30 people participated in this experiment, including 12 boys and 18 girls, The average age is 23 years old. A total of 1,450 data were collected, including 1,274 valid data, and the efficiency of the data 87.9%.

2.5.2 Data Analysis

This research will analyse data mainly in two different ways: descriptive analysis and correlation analysis. Descriptive analysis will show position and spread of the set of data. Correlation analysis will study the specific relationship among these three variables (emotion, hazard recognition and safety risk perception).

3 Findings

3.1 Descriptive Analysis

3.1.1 Feedback Time

It can be seen from Table 2 that when people are in a negative emotional state, the minimum value of emotional feedback time is 1.3 s, the maximum value is 10.5 s, and the average value is 4.5 s; the minimum value of construction feedback time is 1.1 s, and the maximum value is 26.1 s, the average is 8.5 s. When people are in a state of neutral emotion, the minimum value of emotional feedback time is 2.2 s, the maximum value is 9.7 s, and the average value is 4.9 s; the minimum value of construction feedback time is 1.0 s, the maximum value is 23.9 s, and the average value is 7.5 s. When people are in a positive emotional state, the minimum value of emotional feedback time is 2.3 s, the maximum value is 9.4 s, and the average value is 4.7 s. The minimum value of the construction feedback time is 1.0 s, the maximum value is 27.6 s, and the average value is 7.7 s.

Table 2 Feedback time

		Minimum	Maximum	Mean	Median
Construction feedback time	negative	3143	26,138	8555	**8139**
	neutral	3047	23,979	7568	**6880**
	positive	3048	27,666	7735	**7166**
Emotional feedback time	negative	1332	10,450	4507	**3729**
	neutral	2172	9671	4961	**3691**
	positive	**2334**	**9448**	**4772**	**3419**

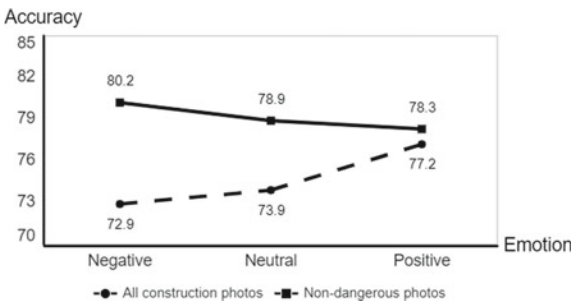

Fig. 3 Hazard recognition accuracy

Table 3 Emotional level and construction feedback time

		Construction feedback time
Emotional level	Pearson correlation	−0.445**
	Sig	0.000
	N	1274

** means correlation is significant at the 0.01 level (2-tailed)

3.1.2 Hazard Recognition

As shown in Fig. 3, when people have negative emotions, the correct rate of risk judgment is 72.9%; when people are in a state of neutral emotion, the correct rate of risk judgment is 73.9%; when people have positive emotions, the correct rate of danger judgment is 77.2%. The accuracy of danger judgments on positive emotions is higher than on negative emotions. If the non-dangerous photos are removed, when people have negative emotions, the correct rate of danger judgment is 80.2%; when people have neutral emotions, the correct rate of danger judgment is 78.9%; when people are in positive emotions, the correct rate of danger judgment is 78.3%.

In the pictures of all construction sites, the accuracy of positive emotions was high. After removing the safe and non-hazardous pictures, it was found that the accuracy of negative emotions is high. This study shows that when subjects feel sad, they will be more alert to surrounding affairs, and judge pictures that are not dangerous as dangerous; on the contrary, when subjects were happy and excited, they often think that there is no surrounding affairs. dangerous.

After this study, more attention will be paid to the subject's judgment and perception level when danger exists, so the pictures that are not dangerous will be deleted.

3.2 Correlation Analysis

3.2.1 Emotional Level and Construction Feedback Time

As shown in Table 3, there is a significant correlation between the two variables, and it is a weak negative correlation as well. It means that when people are in a negative emotional state, they are more likely to be immersed in their own emotional state, thus prolonging the feedback time for potential safety hazards.

3.2.2 Emotional Level and Hazard Recognition Accuracy

As shown in Table 4, these two variables are significantly correlated in a weak negative way. It means that when people are in a positive emotional state, they tend

Table 4 Emotional level and Hazard recognition accuracy

		Hazard recognition accuracy
Emotional level	Pearson correlation	−0.225**
	Sig	0.000
	N	1274

** means correlation is significant at the 0.01 level (2-tailed)

Table 5 Hazard recognition accuracy and safety risk perception

		Safety risk perception
Hazard recognition accuracy	Pearson correlation	0.325**
	Sig	0.000
	N	1274

to think that everything around them is safe because they are too happy and excited, thus reducing their judgment rate of safety hazards.

3.2.3 Hazard Recognition Accuracy Rate and Safety Risk Perception

As shown in Table 5, there is a significant correlation between the two variables, and it is a weak positive correlation. It means that when people's level of safety risk perception is higher, their hazard judgment accuracy rate is also higher, and they can correctly judge the safety hazards that exist around them.

3.2.4 Emotional Level and Safety Risk Perception

It can be seen from Table 6 that the safety risk perception and emotion level are significantly correlated in a negative way when facing the risk of falling from high altitude ($p = 0.05$). The level was significantly correlated the perception of safety risk and emotional level was significantly correlated with a level of 0.05 when faced with an object to strike this risk, and was negatively correlated. Emotional level and safety risk perception have no significant correlation.

People who show negative emotions will be more careful and cautious about the risks of falling from the sky and striking objects. Relatively people with positive emotions can better protect themselves against electric shock and fire.

Table 6 Emotional level and safety risk perception

Category			Safety risk perception
High falling	Emotional level	Pearson correlation	−0.345**
		Sig	0.005
Fire or shock hazard	Emotional level	Pearson correlation	0.145*
		Sig	0.013
Object strike	Emotional level	Pearson correlation	−0.229*
		Sig	0.050
Collapse accident	Emotional level	Pearson correlation	−0.085*
		Sig	0.016
Mechanical injury	Emotional level	Pearson correlation	−0.015
		Sig	0.891

** means correlation is significant at the 0.01 level (2-tailed)

4 Discussion

This study still has some limitations. For example, the main object of this study is students, and the degree of understanding about the construction site is limited. It is recommended that construction workers carry out the same experiment to get more comprehensive results. In addition, this experiment can also be more carefully distinguished and discussed when includes different types of work, thus increasing the reliability and universality of the results.

5 Conclusion

This study shows that the state of emotion affects people's ability to recognize hazards and their perception of risk.

The accuracy of recognizing High falling and Object strike is higher than other hazard types', because High falling and Object strike are more feared than others.

The safety risk perception of hazard is lower than the one of natural emotion, when participants have positive emotion. The reason for this decline is that being overexcited will reduce the feedback time of hazard, which will lead to neglect of surrounding hazard and eventual accidents. The safety risk perception of hazard is higher than the one of natural emotion, when participants have negative emotion. The reason for this increase is that being obsessed by negative emotion will raise the feedback time of hazard, which will lead to contradiction of surroundings and stronger awareness of self-protection.

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Review of the Quantitative Analysis Methods for Social Life Cycle Assessment in Construction

X. Y. Jiang, X. R. Yao, and S. N. Lyu

Abstract The life cycle sustainability assessment (LCSA) of construction activities has become a subject of considerable interest globally. However, researchers are mainly devoted to analyzing economic and environmental impact assessment of buildings, and there is a lack of a review of the studies on social impact assessment. Therefore, this study aims to review the quantitative methods for social life cycle assessment (S-LCA) in construction through the bibliometric method. Most of the studies on social impact analysis have adopted qualitative and quantitative methods and this study mainly focuses on the studies that used quantitative analysis methods for social life cycle assessment owing to the space limitation. This study found that the research interest in the life cycle sustainability assessment is gradually rising, primarily focusing on case studies, method comparisons, and new frameworks. However, because social impact assessment has significant limitations in the quantification of inventory, the choice of indicators, and the method of impact assessment, this study proposes that the development of social impact factors in the construction field requires to make more extraordinary efforts in the development of new methods, new software, new technologies, decision-supporting tools, and databases.

Keyword Social life cycle assessment · Social life cycle cost · Construction · Bibliometrics

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1 Social Impact Factors in Construction

With the progress and development of living standards, people's requirements for sustainability are gradually increasing. Sustainable development includes three dimensions: environment, economy and society. These three dimensions are interdependent and become the pillars of sustainability assessment, also known as the triple bottom line (TBL) of project sustainability as well. According to the United Nations Environment Programme (UNEP), "the buildings sector—a huge engine of the global economy—still accounts for a significant 36 percent of final energy use" [1]. Therefore, the life cycle sustainability assessment of the construction industry is a necessary link to meet sustainable development. At present, the concept of Life Cycle Sustainability Assessment (LCSA) is widely recognized, whose framework integrates three life cycle technologies: Environmental Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) [2–4].

S-LCA is a technology used to assess potential and verified social impacts during the product life cycle. Like economic assessment and environmental assessment, S-LCA supports sustainable development and is a useful tool for achieving sustainable development. However, due to the lack of effective data collection [5], the dynamic changes in social conditions, and the subjectivity of stakeholder evaluations, the research of S-LCA in construction is still in its infancy. S-LCA is still a young instrument that requires further development [6, 7]. Therefore, it is urgent and necessary to research S-LCA.

In 2009, at the ISO 26,000 (Social Responsibility) Conference of the National Organization for Standardization, the "Guidelines for the Social Impact of Product Life Cycles" (referred to as "Guide") published by UNEP and the Society of Environmental Toxicology and Chemistry (SETAC) were released [6], which provides a theoretical basis for S-LCA. Simultaneously, with the emergence of life cycle theory, increasing studies consider the social impact and social cost into the life cycle assessment. At present, the social impact assessment research in construction mainly focuses on the following three aspects: (1) using qualitative factors and quantitative methods to conduct case research and analysis [8–11], including proposing a new framework and verifying its feasibility [12, 13], (2) putting forward optimization methods [14–17], and (3) comparing multiple cases to obtain the best from them [18, 19].

Although the studies on S-LCA in construction have gain popularity, a thorough review of the application of research methods for S-LCA is lacking. To address this research gap, the aim of this article is to review the quantitative methods related to S-LCA in construction. The existing methods for S-LCA are mostly qualitative and quantitative methods, while this study mainly focuses on the review on quantitative methods due to the space limitation. This study will help researchers and stakeholders to develop a body of knowledge regarding S-LCA and stimulate their inspiration for the application of quantitative methods in S-LCA. It can help maintain the relationships between stakeholders and promote sustainable social development.

Meanwhile, the government can consider multiple aspects to make the best decision, the company can strengthen its reputation, and attract outside attention, and the public can increase satisfaction and happiness themselves.

2 Screening of Literature

This study uses four steps to screen the literature, including database selection, database search, preliminary screening, and fine screening.

Firstly, database selection. The author selects Scopus for screening.

Secondly, database search. Enter the search formula "*TITLE-ABS-KEY (((social OR society OR societal) AND ("life cycle assessment" OR "*life cycle cost*" OR "LCC" OR "LCA") AND (construction OR *building* OR *infrastructure* OR "civil engineering")) OR (("social assessment" OR "societal assessment" OR "social *impact*" OR "societal *impact*" OR "social *cost*" OR "societal *cost*") AND ("*life cycle*") AND (construction OR *building* OR *infrastructure* OR "civil engineering"))) AND SRCTYPE (j) AND DOCTYPE (ar OR re) AND LANGUAGE (English)* " in Scopus database. The search only covers journals published in English. A total of 1,132 articles were identified and the literature related to social factors in the construction field was first published in 1974.

Thirdly, preliminary screening. Since the initial search includes almost all articles, including the word "society" in the construction literature, it is necessary to exclude literature irrelevant to social influence factors and evaluation methods. By screening the title and abstract, the literature related to the structure or clean energy is deleted. Finally, 396 articles remain, which are mainly published in the journals regarding green sustainability and construction projects, such as International Journal of Life Cycle Assessment, Journal of Construction Engineering and Management, and Building and Environment.

Finally, fine-screening. The documents selected in the previous step are downloaded, and the method and discussion part are screened so as to delete the documents not mentioning social factors or irrelevant to the research topic of this study. 220 papers remained for in-depth research and discussion. These documents mainly focus on the social influence in construction projects, social evaluation indicators, social evaluation methods, social costs, and optimization.

By analyzing the above literature, the result indicates that social impact analysis is mostly developed based on two research methods: qualitative analysis and quantitative analysis. Qualitative analysis describes the social impact and the social benefits of construction, while quantitative analysis uses mathematical language to describe impact factors, generally including the measurement of social indicators and social impact methods. There is a lack of the review on research methods of the social impact in construction. Thus, this study mainly discusses and analyzes the social impact assessment methods in the construction field from the quantitative aspect.

3 Quantitative Analysis Methods of S-LCA in Construction

Most researchers use the LCA framework to evaluate the sustainable development factors and potential impacts of buildings [20–25]. ISO14040 provides a standardized framework for implementing LCA. LCA consists of four main phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and life cycle interpretation. It takes social factors as a part of the LCA impact assessment. The life cycle inventory analysis stage includes obtaining social indicators based on previous literature studies, expert interviews, and other methods, and then measuring and calculating the indicators through field data from the National Bureau of Statistics and public data. The research framework of S-LCA is similar to LCA, and the difference is that S-LCA only focuses on social impact. The general framework for S-LCA is shown in Fig. 1 [6] and includes three stages.

1. The first stage is to clarify the purpose and objectives of the research, formulate critical reviews according to different goals, and then define the building functions and function units to determine the scope. ISO 14,040 [26] specifies: "The scope should be sufficiently well defined to ensure that the breadth, depth, and detail of the study are compatible and sufficient to address the stated goal." Besides, because one of the goals of using S-LCA is to promote society's conditions improvement, it is necessary to pay attention to the views of stakeholders and decision-makers. Thus, five main stakeholders are proposed in the "Guidelines", including workers, local communities, society, consumers, and value chain participants.
2. In the second stage, the social life cycle inventory analysis should be carried out, including collecting data in the inventory stage, modeling the system, and

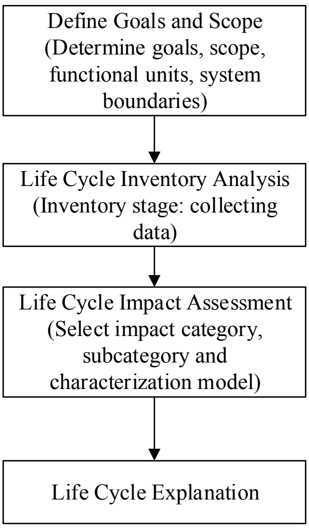


Fig. 1 Quantitative analysis framework of S-LCA

then obtaining sLCI's results. It is necessary to ensure the validity, relevance, and completeness of the data.

3. The third stage is to conduct the social life cycle impact assessment (sLCIA), including selecting impacts and its subcategories, contacting list data and its subcategories and the impact categories, and then calculating the results of characterization. In this stage, it requires to characterize, normalize, and weight the data. Among them, characterization is to transform the social information into interpretable indicators, which can reflect a range of effects. Normalization is to rescale the characterization results to a comparable range based on National Statistical Data, that is, from -1 to 1 or 0 to 1. For example, freedom of association and collective bargaining (FACB) scores between 0 and 10 [13].
4. In the last stage, the interpretation of the social life cycle is carried out, which is to put forward some recommendations for this research evaluation. The current mainstream method for S-LCA research in the construction field is to conduct specific research on buildings in different regions based on the framework of the "Guidelines" [8, 9, 13, 18, 19, 27–37]. In the process of S-LCA analysis, it generally uses methods such as brainstorming, expert scoring, hot spot analysis, and principal component analysis to establish the indicator system [8, 18, 35], and determine the weights of indicators through analytic hierarchy process, interviews and questionnaire surveys [8, 9, 12]. Finally, the scores can be calculated.

Except for the "Guidelines", in Europe, the European Technical Commission compiled EN16309 in the social dimension of the sustainable performance evaluation framework of EN15643-3 in 2014, established a framework suitable for the social performance evaluation of European buildings [10, 38], and provided evaluation methods and requirements for the social performance of buildings. This method is mainly used in the whole life cycle social evaluation of buildings that comprehensively consider health and comfort standards. The steps include: (1) determining the evaluation purpose; (2) clarifying the evaluation object; (3) establishing the relevant scenes of the building use stage; (4) determining the evaluation aspects and indicators, (5) reporting and exchanging evaluation results and data sources; and (6) verifying the consistency and reliability of the results. For the evaluation of the social performance of buildings, the standards refer to quantitative methods. However, if without them, researchers would use a checklist method to evaluate standards. The social performance categories of buildings specified therein include barrier-free, adaptability, health and comfort, impact on the community, maintenance and maintainability, as well as safety and security.

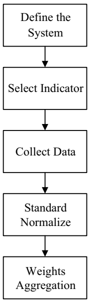
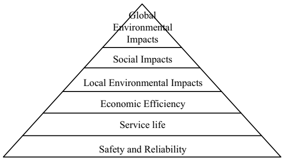
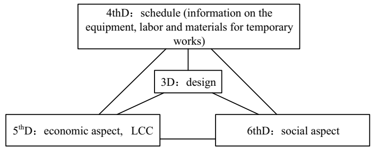
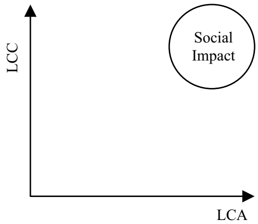
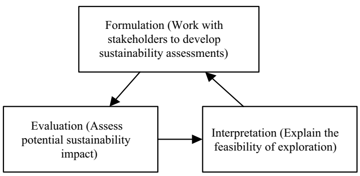
To fully understand the specific impact of construction projects on the environment, economy, and social development, as well as quantify the social impact, researchers combine LCA with TBL and other theories, propose an input–output life cycle assessment (I-O LCA) based on the economic benchmark input–output table [39, 40], the sustainability assessment framework based on economic input–output (EIO-LCA) [41–43] and the hybrid LCA model [16, 44]. The input–output analysis provides a static image of the relationship among different economic sectors within a year and express with currency. Therefore, the social problems of each economic sector can be calculated [40, 45] by: (1) using the technical coefficient matrix, satellite matrix, and social footprint coefficient matrix in I-O LCA to implement this model on MATLABs; (2) using the technical coefficient matrix, Make matrix and Use matrix in EIO-LCA; and (3) using social accounting matrix (SAM) in hybrid LCA. Finally, it can use the economic input–output table to calculate the final demand and indirectly measure the social impact. Such methods are suitable for quantitative models of national and regional analysis, but due to the economic input–output table fails to reflect its operation, it is impossible to conduct a complete life cycle analysis of goods (except vehicles, ships, and aircraft used in public transportation).

To be consistent with sustainable development, the improved eco-efficiency(EE) framework and sustainable development assessment methods [46] are used to integrate environmental, economic, and social indicators into a single measurement standard. The main steps include: (1) proposing the EE measurement, including the ratio of economic indicators/environmental indicators and economic indicators/social indicators; (2) selecting indicators, (3) using linear integration of multiple indicators to perform data envelopment analysis (DEA) on the EE measurement, which is to promote the integration of environmental, economic and social indicators to obtain sustainability scores, and (4) carrying out a sensitivity analysis on the weighting scheme.

Some researchers develop new frameworks for social assessments based on different building characteristics and purposes. Six categories of research methods (RMs) were summarized and the main assessment process and scope of application are shown in Table 1.

- RM1: A conceptual framework based on the life cycle integrated C&D waste management system is developed for the assessment of waste and demolition generated by buildings [47].
- RM2: A life cycle design (LCD) method is proposed to solve the lack of long-term performance and social effects of structural design, which builds a pyramid model, taking social evaluation as the fifth layer and using the historical data of similar projects to predict the possible social impact of the target project through the comparison method[48].
- RM3: An integrated 6D CAD system is developed to automatically assess the sustainability of the building's life cycle, taking economic, social, and environmental impact as the sixth dimension, and using computer-aided systems to evaluate and calculate social impact[12].
- RM4: A sustainability evaluation method HBSAtool-PT that combines questionnaire pairwise comparison and analytic hierarchy process analysis for multi-criteria analysis is proposed for medical buildings[49].
- RM5: In order to compare retrofit alternatives from the sustainable perspective, the Renobuild method is developed, with the horizontal axis representing the environment and the vertical axis representing the life cycle cost, at the same time, the social factors are represented by circles[50]. The larger the circle, the

Table 1 Research methods and evaluation process

Categorizes	Methodology	Evaluation process	Scope of application	Ref
RM1	C&D waste management framework		Life cycle assessment of construction and demolition waste management	[47]
RM2	Life-Cycle Design (LCD) method		Structural design process	[48]
RM3	6D CAD model		Design aid	[12]
RM4	HBSAtool-PT	Index selection → index evaluation	In healthcare building projects	[49]
RM5	Renobuild		Evaluation of renovation alternatives	[50]
RM6	Constructive Sustainability Assessment (CSA) framework		Help decision-makers make decisions	[51]

more beneficial it is to society. Thus, the best choice should be the big circle in the upper right corner of the picture.

- RM6: A constructive sustainability assessment (CSA) framework is proposed by combining life cycle thinking with research and innovation principles, which uses circular and iterative methods to conduct a comprehensive social assessment, enabling sustainable development assessment to be applied to emerging technologies and become part of a broader review method[51].

At present, general data are obtained from the National Statistical Yearbook, Social Hotspot Database (SHDB), development reports, network research, and company field reports. The measurement of quantitative indicators can be obtained from some international conventions and statistics, such as the proportion of child labor from UNCEF and WB, the wage and gender index from OECD, standard working hours from LD, forced labor from ILO, the information on intangible cultural heritage from UNESCO, and the burden of health diseases from WHO.

In addition, in some studies, researchers convert social influencing factors into costs and calculate life cycle costs, which are often used in roads and bridges [52–54]. It generally includes user delay costs, vehicle operating costs, and accident costs.

Finally, a series of decision-making models are developed to optimize case studies using dynamic evaluation, such as the multi-standard decision-making (MCDM) model improving the impact of sustainable development on determining the best pavement design strategy [16], the sustainable evaluation comprehensive value model MIVES [55], a risk decision framework that considers sustainability and flexibility for infrastructure [56], the MARS-H that uses graphical consideration indicators to evaluate different analytical solutions [57], an MODM random compromise programming model developed to find the best allocation [16], and the Pareto curve used to evaluate the optimal solution [17, 31, 58].

4 Discussion and Recommendations

Being a relatively new technique, LCSA is limited in several aspects, in particular in the S-LCA part. These include the quantification of inventory, selection of indicators, and methods of impact assessments. [6, 59] The shortages of S-LCA could even lead to the question that whether LCSA is an appropriate method for quantifying sustainability[3]. Therefore, the study of S-LCA is an urgent problem.

Through the bibliometric method, as well as the review and research of relevant literature on social impact factors in the construction field, it is clearly shown that the status of social factors in sustainable development is gradually rising and attracts more and more attention. At the same time, the use of S-LCA is becoming frequent in construction decision-making. This is because S-LCA can provide an effective decision-making framework for the government, designers, developers, and other decision-makers. Besides, it can consider some social influences in the development of the construction life cycle to realize the development of high quality and quantity of buildings. In addition, S-LCA still has the possibility and necessity to continue to be developed and improved. The consideration of social influence factors will be more perfect, and more frameworks will be developed for different buildings to meet various architectural needs. However, due to cultural differences in different places, stakeholders' views on the same thing will be quite inconsistent. Thus, the social life cycle assessment is very regional, so it is difficult to use a certain assessment to represent a certain type of building.

In order to solve some of the above problems, the current development of social influencing factors in the construction field requires greater efforts in the development of new methods, new software and new technologies, decision support tools, and databases. Due to the subjectivity of stakeholders, it is difficult to use the fixed indicators, weights, and coefficients to evaluate the social influencing factors. The author recommends that it can develop a relatively complete social evaluation database for specific locations to facilitate the collection, supplementation, verification, updating, and summary of subsequent studies. In addition, it is recommended to consider the three sustainable pillars of environment, economy, and society to formulate a comprehensive decision-making framework and set different decision sets for different stakeholders. The above measures are so as to make faster methods and decisions that are beneficial to themselves and society, and to help the government formulate reasonable policies to better promote sustainable development.

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Impact of COVID-19 on the China-Australia Construction Supply Chain

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Abstract The Australian construction industry has historically imported building materials from Europe, US and Japan but more recently seen dramatic increases in imports from Asia. The construction industry is heavily reliant on imports of building materials such as steel, windows, joinery, tiles, float glass and curtain walls from its top trading partner, China. The supply of these building materials was disrupted amid the confusion in response to the initial spread of the COVID virus in China leading to widespread lockdowns and the temporary closure of manufacturing plants. By March 2020, the virus has spread by infected international travelers across the globe bringing numerous cases into Australia. This study aims to examine the impact of COVID on the supply of building materials from China to Australia specifically focusing on the state of Victoria. The objectives of this study are to map out the risks that have crystalised on the China-Australia construction supply chain; examine the impact of upstream disruption in China on downstream activities; and assess how the timing of local pandemic outbreak impacts supply chain performance. Using procurement data from a residential builder, we observed disruption of production, delay, increase of shipping costs and loss from foreign exchange. The delay was up to two weeks due to the shutdown of manufacturing plants in China during the early stages of the pandemic. When the first wave of infections spread into Australia, its impact on the building and construction industry was minimal. The greater impact occurred when limits were placed on site workers during second wave of infections which desynchronised the Australian and Chinese sides of the supply chain. The builder experienced additional two-weeks delay on small scale residential projects and four-weeks delay on a large-scale residential project. These findings may assist the industry to find ways to manage future risk of disruptions to their supply chains.

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1 Introduction

Supply Chain (SC) risks arise from different sources and can be categorised into operational and disruption risks [11, 20, 34, 41]. There have been previous attempts in studying epidemic-related disruptions in the SC including the SARS epidemic. The disruptions caused by the SARS epidemic was limited at first to cancellation of business travels to the affected areas (China, Hong Kong, Taiwan and Singapore), this was followed by limited disruptions in SCs and reports of SARS-related losses by companies like Microchip Technology [21, 31]. Luckily for manufacturers, suppliers and their clients, production and international supply of goods functioned smoothly and the global SC was not affected [37]. While global SCs have also been hit by other diseases and epidemics such as Zika virus, Middle East Respiratory Syndrome (MERS) and Ebola, they have been hit again by a catastrophic, rapid-spreading, disruptive pandemic, known as COVID.

An official Chinese government source [39] reported that cases of unexplained pneumonia was brought to the attention of the Jianghan District Centre of Disease Control and Prevention in Wuhan city on 27 December 2019. Once evidence of human-to-human transmission was confirmed, the city of Wuhan was placed under lockdown on 23 January 2020 with the closure of air, rail and road transport. On the following day, travel restrictions were placed on twelve additional prefectures in Hubei province. To prevent further spread, many cities and provinces across China implemented social distancing restrictions and movement controls from 1 February 2020. By 10 February 2020, twenty-two provinces, municipalities and autonomous regions started to allow residents to return to work. Given that the period of lockdown coincided with the annual Spring Festival, the total number of days attributed to the infection was only about ten days. The pandemic across China was generally stable by mid-March except for Hubei province. The resumption rate for large-scale enterprises in China had reached more than 90% on 20 March 2020 with strong support from the government.

The rapid spread of the virus in China and the subsequent shutdown of manufacturing plants immediately sparked concerns in Australia about the risks of offshoring and procuring up to 60% of its imports from a single country [32]. The first confirmed case of COVID in Australia was a traveler from Wuhan who arrived in Melbourne on 19 January 2020. Australia shut its borders to all non-residents on 20 March 2020 and imposed social distancing restrictions the following day. Non-essential services were closed but construction, manufacturing and many retail shops remained in operation. In early June, all Australian states reported very low infection rates indicating that these restrictions were successful. However, by 20 June, the Victorian government had to re-impose restrictions following a spike in community transmission. Six weeks later, a state of disaster was declared when community transmissions continued to increase, leading to limits being imposed on the number of workers in essentials services and on the construction sector.

In response to the first round of restrictions, the building and construction industry unions and industry associations convened to prepare a set of guidelines to maintain safe operations of construction sites, ensuring the safety of workers and to assist the government in maintaining a strong building and construction industry (Building Cost Information, 2020). The directions for the building and construction industry during the second round of restrictions were more stringent. Construction of critical and essential infrastructure, and services to support these projects were allowed to remain open for on-site works. Large scale construction defined as building projects of more than three storeys (excluding basement) were restricted to a maximum of 25% of normal employees on site compared to normal operations. The shutdown of industries in Australia shows the far-reaching impacts of the pandemic.

COVID pandemic has highlighted the risks of offshoring and imports of building materials for the Australian construction industry. The sector has recently been reaping substantial benefits by offshoring the manufacturing of building materials and components to lower production cost countries in Asia. Estimates of up to 20 percent of building components being imported has been discussed by Bleby [6] indicating that the construction sector is highly dependent on an overseas SC with the associated benefits and risks.

The last pandemic outbreak of similar magnitude was the 1918 Spanish flu during which trade was more localised and international trade was highly restricted by tariffs. Queiroz, et al. [29] present a systematic literature review of thirty five refeered journal papers on the impacts of epidemic and pandemic outbreaks on commercial SCs. The only three papers [15–17] that focused on COVID pandemic were predictive and broad without any focus on the China-Australia construction SC. Consequently, this study is derived from the pandemic-related future research directions pointed out by Ivanov and Das [16]—studying reactions and changes in SCs during COVID with empirical data, estimating the impact on businesses; and quantifying the prolonged impact of a pandemic on all entities on the SC.

Therefore, this study aims to examine the impact of COVID on the supply of building materials from China to Australia specifically focusing on the state of Victoria. Three objectives have been identified for this study. First, is to map out the risks that have crystalised on the China-Australia construction SC; second is to examine the impact of upstream disruption in China on downstream activities; and third, is to assess how the timing of local pandemic outbreak impacts SC performance. Thus, three research questions have been developed.

RQ1: What are the risks that have eventuated during the COVID pandemic on the China-Australia construction SC?
RQ2: What is the impact of an upstream disruption in China on downstream activities in the SC?
RQ3: How does the timing of local pandemic outbreak impact SC performance?

The following contributions are expected from this research. The first contribution is to estimate the delay witnessed by the residential builder because of the disruption that occurred on the China-Australia construction SC due to the COVID pandemic. Second, is to show how local pandemic outbreaks and timing of opening and closing of downstream operations affect SC performance despite the length of the delay upstream. Third, is to reveal where the greatest source of risk on the China-Australia SC may materialise during a pandemic.

The remainder of this paper is organised as follows. In section 2, we discuss literature on impact of pandemics on SC performance and the economy in general. In section 3, we present our case study and the method used to quantify the disruptions. Section 4 lays out the results, followed by discussion and conclusion in section 5 and 6 respectively.

2 Literature Review

2.1 Impact of Pandemics/Epidemics on SCs

Many scholars such as Koyuncu and Enrol [22], Green [12], and Anparasan and Lejeune [2] have studied how to cope with outbreaks of epidemic under humanitarian logistics. Prior to 2020, there was scant literature on the impact of pandemics on commercial SCs [33]. To bridge this gap, Queiroz, et al. [29] conducted a systematic literature review of thirty-five papers that focused on disruptions on commercial SCs and logistics caused by disease outbreaks. The papers covered diseases such as COVID pandemic, Ebola, influenza, cholera, malaria, smallpox and general epidemic/outbreak control. Notably, out of the thirty-five papers, only three of them—Ivanov [15], Ivanov and Dolgui [16], Ivanov and Das [17], addressed the impacts of COVID pandemic on commercial SCs and logistics as at March 2020. These papers will be discussed below.

Ivanov [15] provide the following management insights from simulation of impacts of COVID pandemic on SC performance:

1. Decline in performance is proportional to the duration of the upstream disruption if the pandemic outbreak is restricted to facilities in the upstream echelon of the SC.
2. If the pandemic outbreak is propagated, the timing and scale of disruption propagation will determine performance reaction (i.e., the ripple effect) as well as the sequence of facility shutdown and reopening at different SC echelons rather than the disruption length upstream the SC. The ripple effect refers to negative impacts on the business activities of companies in the SC due to simultaneous propagation of the pandemic from the originating point to other parts of the SC.
3. Positive effect on the total SC disruption duration due to backlog reductions may result from simultaneous disruptions in downstream demand and supply. The highest adverse impact on the SC performance is observed in cases with very

long facility and demand disruption periods downstream the SC irrespective of the disruption length in the upstream part. In cases when the facility recovery at different echelons in the SC is synchronised in time, the least decline in the SC performance can be observed. This positive effect (least decline) is observed because backlog reductions may result from simultaneous disruptions in downstream demand and supply.

Similarly Ivanov and Das [16] arrived at results similar to that of Ivanov [15] with upstream data from China and data from distribution centres in USA, Germany and Brazil. In addition, local outbreak of the pandemic after propagation will have a simultaneous or gradual impact on reserve suppliers and sub-contracting facilities due to regional or national lockdowns [16]. Likewise, Ivanov and Dolgui [17]; and Ivanov and Sokolov [18], and listed 3 relevant reactions to disturbances on linear SCs which are:

1. Stability: capability to go back to a pre-disturbance state and guarantee continuity.
2. Robustness: capacity to survive a disruption or chains of disruptions to sustain planned performance.
3. Resilience: capacity to withstand a disruption or chains of disruptions and recover performance.

Furthermore, other research papers on pandemic impacts on SCs were released after March 2020. They focused on impacts of the COVID pandemic on SCs (Table 1). Other evaluation frameworks, simulation studies and prediction of effects of COVID pandemic on various SCs were developed by Grida et al. [13], Karmaker et al. [19], Singh et al. [36], and Nikolopoulos et al. [27]. Lastly, Chopra and Sodhi [10] classified risks into disruptions (e.g. natural disaster), delays (e.g. inflexibility of supply source, exessive handling at border crossings and change in transportation modes), systems, forecast, intellectual property, procurment (e.g. exchange rate risk and single source procurment), receivables, inventory and capacity.

2.2 Impact of COVID Related SC Disruptions on the Economy

The reports of financial losses, cessation of business activities and massive lay-offs by countries and companies due to the COVID pandemic was unsurprising but came at an unprecedented scale. In China, the National Bureau of Statistics reported that from January to February 2020, industrial output fell by 13.5% year-on-year [24]. Specifically, in a survey of building materials manufacturers across 25 provinces in China, 44% of the companies reported a break in the upstream supply of raw materials; 9% reported an unaffordable increase in the price of inputs; and 63% reported that logistics and transportation were blocked [9]. Qantas, Australia's flagship airline, reported a 91% fall in profits from January to June 2020 [28]; while

Table 1 Relevant literatures on the impact of the COVID pandemic on SCs

References	Sector/country	Purpose	Findings
[23]	Food Retail/Germany	Discuss changing volume and capacity dynamics in road haulage	Increasing volume of freight for dry-products in retail logistics depends on the total number of new infections per day and not on the duration of COVID pandemic
[3]	Transport/Columbia	Examine the short-term impacts on the transport system due to the various policies initiated by the government to slow the propagation of COVID	General reduction in demand for transport, congestion levels and transport externalities. Freight emerged as the most resilient transport component
[14]	Manufacturing and logistics/Finland	Examine the impact of COVID pandemic on manufacturing and logistics	Moderate increase in transportation costs, slight increase in inventory levels, sustenance of good customer service, concern about a second-wave and dealing with long-term uncertainties
[35]	Agriculture SC/India	Examine the impact of COVID related risks to create resilient agriculture SC organisations	Supply, demand, financial, logistics and infrastructure, management and operational, policy and regulation, and biological and environmental risks have a substantial impact in agriculture SC reliant on the organisation's scope and scale
[30]	Food SC	Critical literature review to investigate the impact of COVID-19 on food SC	Unprecedented rise in food insecurity, SC and logistics costs; radical change in consumer behaviour and rise in food safety concerns; and enhanced awareness of food waste and importance of home-grown foods
[26, 42]	Manufacturing and logistics/China	Analyze initial impact and after-shock of COVID-19 pandemic on manufacturing and logistics	Interruption in production, unsatisfied demand and fluctuations in supply and demand, increasing bankruptcy risk to SMEs, and Chinese government subsidies to restart the economy

the Australian economy slipped into recession for two straight quarters to June 2020, the first time in 30 years [1]. From March to June 2020 in Australia, the construction industry lost about 46,000 jobs, manufacturing industry lost about 40,000 jobs while transport, postal and warehousing laid off around 41,000 members of staff [25].

3 Research Method

We examined the procurement of building materials from China for current projects carried out by a local residential builder in Melbourne, Australia. The second author in this research project was employed by the residential builder who agreed to share their procurement program with the research team. To maintain confidentiality of these commercial arrangements, the results will not identify the suppliers, nor the cost of items procured for four case study residential building projects. The building materials procured from overseas included windows, tiles, light steel frames, timber floors, kitchen cabinets and bathroom vanities. Similar quotes were obtained from local manufacturers and suppliers to obtain price and delivery comparisons. As these projects were in progress during the pandemic, many of these procurement decisions were being executed as prices, exchange rates, shipping and delivery information were fluctuating rapidly. The opportunity to obtain the prices and schedules as the pandemic surfaced in China and spread across the world and to Australia, affecting the manufacture, transport and logistics across these two countries is unique and not repeatable. The timeline of the research was divided into five periods as shown in Table 2.

Table 2 Research timeline

Stage of research	Name	Period
1	Pre-COVID	the period up to 22 January 2020
2	COVID in China	from 23 January to 20 March 2020
3	Post-COVID in China	from 20 March in China
4	COVID in Australia	from March to 12 May 2020 in Australia
5	COVID in Australia 2	from 2 August 2020, onwards in Australia

4 Results

A large quantity of building products was procured or planned to be procured from China for the four case study projects. The builder has ascertained that procuring building products from China constitute significant cost savings over the purchase of these products domestically in Victoria or other suppliers in Australia. The builder recognised that purchasing from overseas would involve considerable amounts of effort to plan and coordinate the logistics of international shipping, customs clearance, compliance with Australian standards, quality assurance, and the corresponding lead time for manufacture and shipping.

Having procured previously from China, the builder was fully aware of the potential shutdown of Chinese manufacturers during the Spring Festival in late January 2020 and have accounted for these delays in their construction plan. A delay of approximately 2 weeks have been allocated in all their schedules. As shown in Table 3, the builder has reported that pre-order times from China was between 2 and 2.5 months for standard or off-the-shelf products while bespoke products may take between 3 and 4 months. Delivery times were estimated at 21 days. In comparison,

Table 3 Impact of COVID on building material deliveries

Key performance indicators (KPIs)	Pre-COVID	COVID in China	Post-COVID in China	COVID in Australia	COVID-AU-2
Order lead-times for China (months)	2.0–2.5	2.5–3.5	2.5	2.5	2.5–3.0
Delivery times from China (days)	21 (1)	23–35 (2)	23–35 (2)	23–35 (2)	23–35 (2,3)
Local order lead-times (weeks)	1–2 (4)	1–2 (4)	1–2 (4)	2–3 (4)	4–6 (4)
Local delivery times (days)	2–3	2–3	2–3	3–5	3–7
Exchange rates (AUD:CNY)	4.84–4.88	4.88–4.08	4.08	4.08–5.05	4.93–5.06
Customs clearance (days)	1–2	2–3 (5)	2–3 (5)	2–3 (5)	2–3 (5)
Shipping costs (US$ per TEU)	740–929	753–949		753–1,082	1,094–1,315

Notes (1) 14 days port-to-port; (2) includes 14-day vessel quarantine; (3) containers not returned within 7-days will incur extra charges; (4) items that need to be manufactured may take up to 4–6 weeks; (5) delays for x-ray scans local pre-order times were much shorter at between 1 and 2 weeks while deliveries could be arranged within 2–3 days if the supplier or manufacturer was in Victoria.

As the COVID infections increased and spread across China, news of manufacturers being forced to shut down as their workers were required to remain at home came to the attention of many builders in Australia. Depending on the progress of these orders, manufacturers would report delays in delivery either because of stoppages in production or delays in shipping. Pre-order times were extended by half to one month to cater for the disruption to their production while the shipping times were increased by at least 14 days due to the quarantine imposed on vessels sailing directly from China by the Australian Border Force. Shipping costs declined marginally due to a drop in demand.

By the end of February 2020, many provinces in China have managed to control the spread of the COVID and have recommenced production [5]. Pre-order times gradually reverted to the pre-COVID duration of 2.5 months while shipping remained extended to 35 days due to the 14-day quarantine of Chinese vessels. The greatest concern at this period was the rapid decline of the Australian dollar to Chinese yuan exchange rate from 4.88 to 4.08 which resulted in a sharp 20% loss of revenue for the Chinese supplier as the contracts were denominated in Australian dollars. Amidst the chaos of the pandemic, the Chinese suppliers committed to deliver on their contracts but there were indications that further exchange rate movements may lead to price increases. Despite the improved conditions in China, concerns on exchange rate risk and future deliveries lingered on.

From 23 March 2020, a lockdown was declared in Australia [8]. The building and construction industry was considered to be essential and remained in operation. The fact that the construction sector employed about 10% of the Australian workforce may have played an important role in the government's decision. The prevalence of COVID in Australia brought very little change to the pre-order or delivery times for products from China while local delivery times were marginally increased due to many businesses having to implement their COVIDSafe plans. For the next 2 months, supply logistics and construction operations functioned reasonably well with very few cases of COVID infections in the construction and logistics sectors.

The imposition of stage-4 restrictions in August 2020 brought on a new set of local challenges especially when most construction projects were reduced to only 25% of their on-site workforce. Local delivery times remain short because these suppliers have few other jobs to supply to. However, the local pre-order lead time takes around two additional weeks because of the limited number of workers permitted in manufacturing. The limits on workforce significantly delayed the receipt of material deliveries to site. Limits on port and customs workforce also delayed customs clearance for imported products.

5 Discussion

In view of the results obtained, this section will discuss the SC disruptions and risks that materialised; the impact of an upstream disruption on downstream business activities and on key characteristics of the SC; and how the timing of local epidemic outbreak impact SC performance.

5.1 Supply Chain Disruptions and Risks

As depicted in Table 3, the risks that materialised from the onset of COVID pandemic in China to August 2, 2020 are disruption of production, delays, increase of shipping costs and loss from foreign exchange. These eventuated risks from our results have been reported by Min and Jianwen [26], Yongfeng et al. [42]; Arellana et al. [3]; Hilmola et al. [14] and Chopra and Sodhi [10]. When COVID was restricted to China, the disruptions witnessed were exacerbated in Australia by high dependence on China as a single source of supply for building products which were not manufactured in Australia or were too pricey to be procured locally. Hence, an unexpected massive shift to local SCs may have created more demand than local suppliers could meet. When COVID spread to Australia, disruptions were caused by local lockdowns and reduction in construction workforce to contain the spread of the pandemic. While disruption risk is concerned with the capacity of the upstream manufacturer to produce, delays occur after products have left the originating upstream factory. Reduction in transport demand and capacity, mandatory quarantines, and other extra custom checks contributed to longer delays on the China-Australia construction SC.

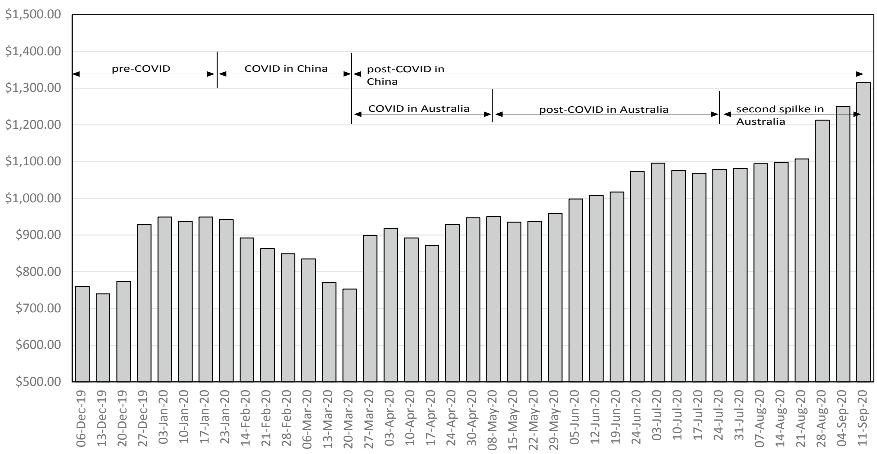

Fig. 1 Shipping cost from China to Australia. *Source* http://info.chineseshipping.com.cn

Figure 1 shows the shipping cost for a standard twenty-foot equivalent unit (TEU) container from the port of Shanghai to major ports in Australia. Shipping cost was maintained at a steady level of approximately US$940 per TEU leading up to the Chinese Spring festival that commenced on 23 January 2020. A combination of the shutdowns during the festival and the impact of the pandemic led to significant declines in the demand for freight transport and the consequential fall in shipping costs from a high of US$949 to a low of US$753 by 20 March 2020. Once the Chinese government declared that the restrictions were over and manufacturing capacity was restored, these freight rates jumped by nearly 20% to US$899 the following week and had continued to gradually increase to a high of US$1,529 on 25 September 2020. Shipping cost is predicted to increase in the near term.

By July 2020, utilisation rates for ships in the port of Shanghai exceeded 95% indicating that manufacturers in China have not only fully recovered from the effects of the pandemic but are exporting to foreign markets to supplement the loss of local production in many other countries affected by the pandemic. In comparison, the freight costs 12 months earlier in August and September 2019 were between US$590 and US$920 per TEU.

Both importers and exporters were exposed to movements in the currency exchange rate and impacted when these rates fluctuated rapidly in response to economic uncertainties. The AUD:CNY exchange rate was extracted from Yahoo finance and plotted in Fig. 2 for the period of interest. The Australian builder reported that all their contracts were denominated in AUD therefore limiting their exposure to exchange risks. The Chinese suppliers were evidently exposed to currency fluctuations of more than 20% during this period. These rapid changes in AUD:CNY exchange rate also posed a challenge to the collection of goods and services tax (GST) on imported goods. According to the Australian Border Force (ABF), the customs value of imported goods must be expressed in Australian currency or converted into

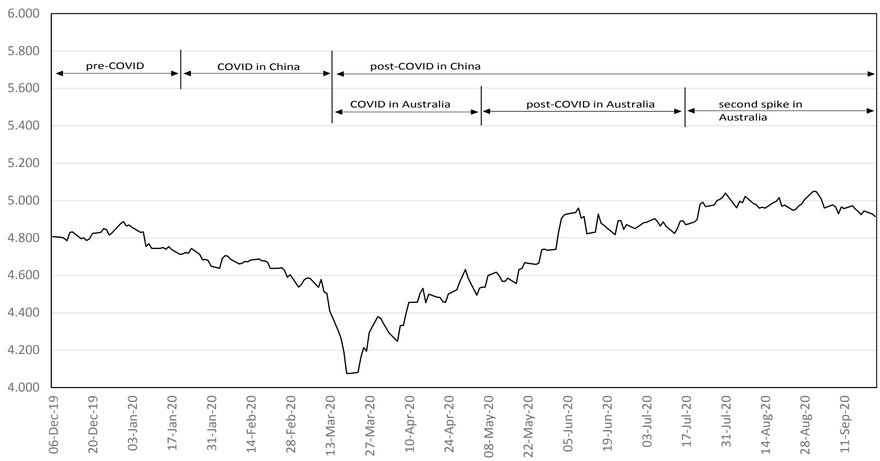

Fig. 2 AUD-CNY exchange rates. *Source* Yahoo Finance

Australian currency at the rate of exchange prevailing on the day of export [4]. This would have created additional problems had the supply contracts been denominated in CNY.

To summarise, disruption of production, delays, increase of shipping costs and adverse movement of foreign exchange were the risks that crystalised on the China-Australia construction SC of the four case study projects. These risks were managed properly for the four case study projects in the short-term due to the shorter duration of the projects. Hilmola et al. [14] confirm that managers in Finland skillfully managed the short-term pandemic risks but were more concerned about a second wave and dealing with long-term uncertainties. Uncertainties like changes in transportation mode can cause further delays and unfavorable adjustment in the SC [10]; while a second wave will cut demand and lead to loss of revenue [15].

5.2 *Impact of an Upstream Disruption in China on Downstream Activities in the SC*

The discussion will start from stage 2 (COVID in China) because during stage 1 everything was normal. In stage 2 (COVID in China), the initial impact of the upstream disruption was limited to China without propagation along the SC. It was estimated that the total delays due to the shutdown of manufacturing and transportation in China was limited to approximately 10–14 days partly because of the Chinese Spring festival. However, generally the SC witnessed longer disruptions otherwise known as ripple effects as shown by KPIs; lead time increased by 0.5 month–1 month (25% to 40%), delivery time increased by 2–14 days (10–67%) and custom clearance days increased by 1 day (50%). Our findings correlate with that of Ivanov [15] as the total delay (ripple effects) experienced by the builder was around 14 days witnessed at the upstream facilities in China.

Stage 3 (Post-COVID in China) and stage 4 (COVID in Australia) occurred simultaneously. The efforts by the Chinese government, eager to promote economic recovery, put in place recovery plans in six key areas including employment, finance, foreign trade, foreign investment, domestic investment and market confidence were very effective. Subsidies provided for the logistics sector include a three-month exemption of port fees for cargoes, reduction in port security fees, and reductions in railway, airport and insurance fees [38]. Other general palliatives rolled out include tax relief/reduction and CNY20 billion support fund to small and medium scale businesses in the most impacted city of Wuhan [26]. This support from the government helped the recovery of lead-times from a peak of 3.5 months to 2.5 months, although less than the normal pre-COVID 2.0 months.

Delays emanating from Australia were centred on increased screening of vessels and health checks on the crews that have departed from mainland China. It was reported that the freight sector in Australia was facing a crisis [40] as many goods shipped from China and elsewhere could not be sold at the stores, were stacked up to capacity at warehouses and container parks. Ivanov [15] predicted the lowest decline in SC performance due to longer delays in epidemic propagation and shorter disruption durations downstream the SC. This is because of the time lag between dispatch from factory and arrival at distribution centers. Our findings confirm that stage 3 and stage 4 had the lowest decline in performance. Notably, the factories in China were recovering at this stage due to the containment of COVID,and Australian importers were receiving the backlog of orders with lead-times of 2–3 months.

Aside from impact on business activities on SC, these disruptions and risks adversely impacted the key survival characteristics of the SC. The stability of the SC was adversely affected as lead-times; delivery times and custom clearance days fell well below pre-COVID levels. The continuity of the SC has not been threatened because government assistance in both China and Australia has played a key role in ensuring businesses remain a going-concern and continue SC transactions. The SC is not robust because planned performance was not sustained majorly as the lockdown in Victoria was prolonged and massively reduced construction activity which aligns to the modelling of Ivanov [15]. The operational components of robustness are reserves, time floats, safety stocks and extra facilities and capacity reservations [18] which were all missing in the SC amid the disturbance. The resilience varies across different echelons of the SC. The manufacturing and logistics in China have recovered their performance to a reasonable extent while Victoria is still emerging from a second wave and gradually lifting restrictions. Overall, the SC is yet to prove its resilience partly due to difference in approaches by the Chinese and Australian governments in handling the pandemic,and partly because of separation of powers within Australia where the Victorian state government has the power to impose and lift restrictions within its jurisdiction. The disruptions adversely affected the stability, robustness and resilience of the SC, the three main survival characteristics of linear SCs identified by Ivanov and Dolgui [17].

5.3 How the Timing of Local Epidemic Outbreak Impacts SC Performance

The China-Australia construction SC was synchronised in time when COVID was limited to China as the builder utilised the materials that were already dispatched from China with little or no disturbances. However, from March 20 to May 12, 2020 during the first wave of COVID in Australia, there was little or no synchronisation because Chinese manufacturers had not produced at all for 2 months. There was little done on orders received from middle of January because of the Chinese Spring festival holiday and subsequent lockdowns. The impact was serious because the builder experienced delays of up to two weeks in receipt of imported materials.

The impact during the second lockdown in Victoria (stage 5) where many warehouses were closed or had reduced staff numbers under the very tight restrictions was the most severe on the builder. Truck loading rates were reduced by 30% to 40% due to the reductions in workforce. Emptied containers could not be returned because there were fewer workers to unload the goods from these containers: attracting extra charges. Data from the Shanghai (Export) Containerised Freight Index (SCFI) reported that in contrast to global "on-time rate index", both port and product on time performance for Australia and the port of Melbourne declined significantly during the month of July followed by another fall in August 2020.

Also, the workforce on medium and large construction sites were slashed by 75% while small-scale construction was restricted to a maximum of 5 people on site. Three out of the four case-study projects were small-scale projects and were marginally impacted by workforce reduction with additional delay of two weeks. The remaining large-scale project was delayed by an extra four weeks. This shows that the second lockdown in Victoria had an asymmetrical impact on small, medium and large-scale projects which corroborates the findings of [14].

The China-Australia construction SC, especially in Victoria recorded the worst performance from May to August 2020 due to desynchronisation caused by the second lockdown in Victoria. The timing of the second lockdown did not match with the reopening of factories in China, rather Chinese manufacturers opened, produced and shipped while Victorian ports, transport lines, warehouses and builders were totally shutdown or working at less than 30% capacity. Also, the economic uncertainties which culminated in consecutive quarter to quarter recession in Australia reduced demand for building projects further creating more disruptions in shipping volume in the SC. These findings agree with the forecast of [15] that the highest adverse impact on the SC performance is observed in the cases with very long facility and demand disruption periods downstream the SC irrespective of the disruption length in the upstream part.

6 Conclusions

This study carried out during the pandemic from March to September 2020 categorised the offshoring risks that have eventuated on the China-Australia construction SC during the COVID pandemic and quantified their impact on SC performance. SC risks due to the pandemic include the shutdown of manufacturing plants; the restrictions on transportation during the spread of the virus in China; and transportation delays, quarantine by customs and shutdowns when the virus spread to Australia. However, due to efforts by the Chinese government to contain the spread of the virus and subsequent incentives to rapidly restore production capacity, the impact of these delays for the delivery of products to Australia was limited to a maximum of two weeks.

Risks of exchange rate fluctuation and shipping cost were not considered significant by the Australian builder as the supply contracts were denominated in AUD. The increment in shipping costs, on the other hand, were paid by the Australian builders. The maximum impact of these risks was about 20% of revenue for currency fluctuations and US$550 per TEU for shipping costs.

The upstream disruption in China was short and restricted which had a limited impact on the SC. The greatest impact arose from the prolonged lockdown in Melbourne which led to desynchronisation in SC activities in China and Australia. The large-scale project considered experienced additional delay of four weeks while the other three small-scale projects were delayed by three weeks. This shows that desynchronisation in SC had a more serious impact on the large-scale project. Thus, during a pandemic outbreak, the greatest source of risks on the SC may not be the originating point of the disease, it could be anywhere on the SC depending on the stability, robustness and resilience of each part. The building and construction industry must utilise their experience from this pandemic to manage future SC risks. A similar future study with a larger sample size of small, medium and large-scale projects will produce a more generalisable outcome.

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Provincial Resource and Environmental Carrying Capacity Evaluation for Territorial Spatial Planning: A Case Study of Zhejiang, China

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Abstract In the context of the construction of ecological civilization, the evaluation of resource and environmental carrying capacity has been elevated to the starting point of the preparation of Territorial Spatial Planning, therefore it needs to provide support and guidance for the follow-up work. However, the traditional cognition and evaluation framework of carrying capacity failed to provide effective support for the preparation of Territorial Spatial Planning. Meanwhile, provincial level is at the core of the scale connection of Territorial Spatial Planning. From this, this article chooses the resource and environment carrying capacity at provincial level as object, combing and summarizing the main content of Territorial Spatial Planning, deriving its two major requirements for provincial resource and environment carrying capacity evaluation. Based on this, explore and build a brand-new cognition of carrying capacity for Territorial Spatial Planning at the provincial level. Finally, the above framework is applied to the case study of Zhejiang Province to provide ideas and reference for the development of relevant evaluation practices.

Keywords Territorial spatial planning · Provincial resource and environment carrying capacity evaluation · Guidance by classification · Sustainable development

1 Introduction

China has a wide range of needs for Territorial Spatial Planning based on the evaluation of resource and environment carrying capacity. Due to anomie behaviors such as extensive use of resources and ignorance of environmental protection in the development process, problems such as resource exhaustion and deterioration of environmental conditions have been emerged, which means the contradictions between economic development, resources, ecology and the environment have become increasingly serious. In May 2019, “Several Opinions on Establishing a Territorial Spatial Planning System and Supervising Implementation” (hereinafter

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referred to as the "Opinions") issued, which clearly stated that Territorial Spatial Planning should be prepared on the basis of the evaluation of resource and environmental carrying capacity. It can be seen that the Chinese government has raised the evaluation of the resources and environment carrying capacity to the height of the starting point for the preparation of Territorial Spatial Planning. Therefore, the evaluation of resources and environment carrying capacity needs to provide basis and support for subsequent work.

As the basic and leading nature of resource and environmental carrying capacity evaluation in Territorial Spatial Planning has become a basic consensus, a set of scientific and practical resource and environmental carrying capacity evaluation system needs to be formed urgently. The academia has accumulated a wealth of case studies in different regions using a variety of evaluation methods for different evaluation objectives [1], and formed four evaluation paradigms including the paradigm based on restrictive factors [2, 3], relative carrying capacity evaluation Paradigm [4–6], research paradigm based on ecological footprint [7, 8] and research paradigm based on multi-factor integration [9, 10]. Different paradigms have their respective scopes of application [11, 12]. Among them, the research paradigm based on multi-factor integration which is convenient for evaluation and quantified results has a wide application range and has gradually become the mainstream [9], Chinese scholars have carried out a lot of research on evaluation index system construction, evaluation model selection and empirical testing [13], 3S technology, system dynamics method [14, 15], multi-objective decision-making method [16, 17] and Neural network algorithms derived from new computer technology [18, 19] are widely used, the research scale involving various levels of countries, regions, provinces, cities and counties [10, 12].

However, despite the development of a richer research system related to the evaluation of resource and environment carrying capacity, many studies only focus on the technical realization of evaluation, and are in a state of contending each other. For example, when constructing an evaluation index system, some scholars have considered it deconstructed into economic growth, population growth and environmental protection [9], some scholars deconstructed it into development and construction, resisting environmental disasters, maintaining the ecological balance of resources and improving social well-being [10], etc., each has innovations but is difficult to be unified in the **Territorial Spatial Planning** in practice. As the starting point of **Territorial Spatial Planning**, there are few discussions on the working logic of resource and environmental carrying capacity evaluation, which makes the carrying capacity evaluation with gorgeous results but no practical significance common [20]. Therefore, what are the characteristics of resource and environmental carrying capacity evaluation in **Territorial Spatial Planning**, and what is its working logic? This needs to be clear first.

In view of that the evaluation of resource and environmental carrying capacity involves various scales, each scale has its own focus. Among them, the provincial scale is an intermediate link in the transmission system of national land and space planning. It is necessary to clarify the main functions of the country and guide the overall area accordingly. The development strategy must also clarify the decomposition of the main function guidance indicators suitable for the smaller-scale units within it. It has the core linking role of the link between the previous and the next. The correlation of various scales is concentrated in this scale, which is representative and urgent for research. Therefore, this article chooses the provincial carrying capacity of resources and environment as research object, discussing the problems raised above in provincial scale and trying to make the provincial carrying capacity evaluation be able to support the **Territorial Spatial Planning** effectively.

2 Research Methods and Research Process

The Research Process of this article and the Research Methods involved are as below:

(1) First of all, study the nature and main content of **Territorial Spatial Planning** by the Method of Induction based on policy documents and references and then conclude the requirements of **Territorial Spatial Planning** for the provincial evaluation of resource and environment carrying capacity by the Method of Deduction.
(2) Secondly, rebuild the Cognitive framework and the Evaluation framework of provincial carrying capacity of resource and environment which meets the requirements of Territorial Spatial Planning, forming the logic connection between them. Methods used include Deduction and Combination Weighting Method composed of AHP Method and Entropy Method and the Difference Coefficient Method, with GIS to visualize the results of the evaluation.
(3) Finally, conduct the case study: apply the frameworks built above to Zhejiang Province in order to demonstrate how the evaluation be taken into work under the requirements of Territorial Spatial Planning so as to provide a reference for how to improve the supporting capacity of the provincial evaluation of resource and environmental carrying capacity for the preparation of Territorial Spatial Planning.

3 Reconstruction of Study Framework

3.1 The Main Content of Territorial Spatial Planning and Its Requirements for Provincial Resource and Environmental Carrying Capacity Evaluation

The “Opinions” pointed out that it is necessary to start from the provision of space guarantees for the implementation of the National Development Plan, based on the Territorial Spatial Planning system, and the control of territorial and spatial uses as means to modernize the territorial and spatial governance system and governance capabilities. It can be seen that the general task of Territorial Spatial Planning is to make a dynamic optimization plan in space and time for the development and protection of land and space in a certain area under the guidance of the national development plan [21] to guide the land and space use control. Its direct result is a "one map" of land space development and protection integrating ecological, agricultural, urban spaces (three zones), ecological protection red lines, permanent basic farmland, and urban development boundaries (three lines), which aims at coordinate the above three goals [22].

At the same time, the expansion of the corresponding strategic goals proposed by the macro-national development plan to the micro-level layout of land and space needs to be achieved by transmission of multi-level scales, and there are differences in the compositeness of regional spatial functions of different scales: as the size reducing, the main function is more prominent; The smaller the scale, the more detailed and specific the functional layout. Therefore, to achieve an effective transmission from macro to micro, it is necessary to accurately implement land and space planning according to the characteristics of each scale, establish a planning system by classification and classification and clearly define the focus of the preparation of Territorial Spatial Planning. Among them, the "opinions" points out that" Provincial Territorial Spatial Planning is the implementation of the National Territorial Space Planning, guiding the compilation of Municipal and County Territorial Spatial Planning, with emphasis on coordination", which means Provincial Territorial Spatial Planning is a kind of cohesion planning.

Therefore, the provincial carrying capacity evaluation of Territorial Spatial Planning needs to meet the following two requirements: (1) Form a connection with goals to coordinate the food production, development and protection of ecology, and to have a clear orientation of functional scale in the three dimensions; (2) Form a docking with the nature of the transmission system of Territorial Spatial Planning with clear correlations among the upper and the lower scale, that is not only show provincial comparative advantages and disadvantages in National scale, but also reflect comparative advantages and disadvantages of the lower scale in provincial scale.

3.2 Cognitive Framework of Provincial Carrying Capacity for Territorial Spatial Planning

After more than a hundred years of development, the concept of resource and environmental carrying capacity has shifted from decentralization to comprehensive integration. At present, most scholars in China define it from the four perspectives of carrying body, carrying object, carrying limit, and carrying scope as "In a certain period of time, under the corresponding climatic conditions, technological level, etc., the limit of the development of the human social and economic system that

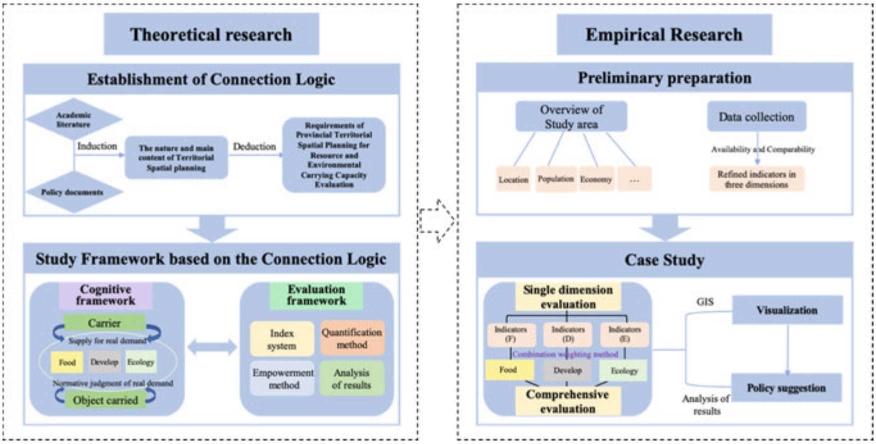


Fig. 1 Map of research process

the natural resources and environmental system in a certain area can withstand [23–25]". However, according to this definition, a variety of evaluation systems can be established, making it difficult to integrate into the requirements of Territorial Spatial Planning. The reason is that the demand for natural resources and environmental elements of the human social and economic system is a kind of induced demand [26]: The demand for arable land resources comes from its function of food output and then can provide human survival needs. Therefore, the demand for arable land resources actually comes from the demand for food. The analysis of real demand answers the question of how natural resources and environmental elements can carry the human social and economic system, which is of practical significance. According to the requirements of Territorial Spatial Planning for carrying capacity evaluation, this paper classifies the real needs of human society for natural resources and environmental systems into food production, construction and development and ecology protection, constructing a cognitive framework for carrying capacity of "carrying body-supply and demand matching-carrying object" (Fig. 1) to form a logical connection with the follow-up work of Territorial Spatial Planning.

3.3 Evaluation Framework of Provincial Carrying Capacity for Territorial Spatial Planning

3.3.1 Evaluation Framework

According to the cognitive framework of provincial carrying capacity for Territorial Spatial Planning, the evaluation framework is constructed from the three dimensions of food production, construction and development and ecological protection:

$$FDE = f(F, D, E) = \begin{cases} f(F_1, F_2, \ldots F_n) \\ f(D_1, D_2, \ldots D_n) \\ f(E_1, E_2, \ldots E_n) \end{cases} \tag{1}$$

In the formula: *FDE* refers to the comprehensive carrying capacity of resources and the environment, which is obtained by the carrying capacity of each dimension; *F* (Food production) refers to the carrying capacity of the grain production dimension; *D* (Development) refers the carrying capacity of the construction and development dimension; *E* (Ecology protection) refers to the carrying capacity of the ecological protection dimension. Carrying capacity of each dimension is obtained by the various detailed indicators related to it.

3.3.2 Index Assignment Method

The provincial scale is the connecting scale in the Territorial Spatial Planning transmission system. It needs to reflect the correlation with the upper and lower scales, therefore it is appropriate to use the relative carrying capacity [6] calculation method as the index assignment method. The relative carrying capacity calculation method firstly selects an area larger than the study area as the reference area(usually the whole country); Secondly divides the population of the area by the stock of certain natural resources and environmental elements to obtain the carrying factor; Then the carrying factor is multiplied by the stock of corresponding natural resources and environmental elements in the study area to obtain the relative carrying population of the study area. The mathematical formula is as follows:

$$P_1 = S_1 \times I \tag{2}$$

$$I = P_0 \big/ S_0 \tag{3}$$

In the formula: P_1 represents the population of a certain type of natural resource and environmental element in the study area, S_1 represents the volume of the element in the study area, I represents the carrying factor.

Although whether the reference area is ideal is still to be discussed, the relative carrying capacity measurement method can clearly highlight the comparative advantages of the lower scales in the higher scales, which is helpful to realize the cohesive function of provincial carrying capacity evaluation, undertaking the macro goals and guiding the micro implementation.

3.3.3 Index Compounding and Weight Determination Method

The provincial carrying capacity evaluation framework for Territorial Spatial Planning involves two levels of composite. First of all, Compound the refined indicators within a single dimension; secondly, the carrying capacity of each dimension is compounded to form a comprehensive carrying capacity. The weighting method is the most common index compounding method, which is widely used in various evaluation studies [27]. The weighting method is used for the first level of compounding and the mathematical formula is as follows (take the food production dimension as an example):

$$F = \sum_{k=1}^{n} \omega_k F_k \tag{4}$$

In the formula: F_{k} refers to each refinement index, and ω_{k} refers to the weight of each refinement index.

To decide ω_{k}, the combination weighting method is adopted in order to weaken the defects of the subjective and objective weighting methods. Among them, the subjective weight part is calculated by the analytic hierarchy process, the objective weight part is calculated by the entropy method, and finally the difference coefficient method is used for combination weighting. The formula is as follows:

$$\omega_k = \alpha\omega_s + \beta\omega_o \tag{5}$$

$$\alpha + \beta = 1 \tag{6}$$

$$\alpha = G\big/m - 1 \tag{7}$$

$$\mathrm{G} = \left[2(1P_1 + 2P_2 + \ldots mP_m)\big/m\right] - (m+1)\big/m \tag{8}$$

In the formula: α and β represent the influence factors of the weights ω_s and ω_o obtained by the subjective and objective weighting methods. G represents the difference coefficient of each component of the subjective weighting method, where m is the number of indicators, and P_1, $P_2 \ldots P$m are the indicators reordered from small to large in the subjective weighting method.

The geometric mean formula is used to achieve the second level of compounding. The serious shortage of single-dimensional carrying capacity has a significant impact on the calculation results of comprehensive carrying capacity, which means it which requires higher relative matching relationships between different resources and can better reflect the concept of sustainable development. The formula is as follows:

$$\mathrm{FDE} = (F * D * E)^{1/3} \tag{9}$$

In the formula: *FDE* points to the provincial comprehensive carrying capacity of Territorial Spatial Planning, F is the carrying capacity of food production dimension, D is the carrying capacity of development dimension, and E is the carrying capacity of ecological protection dimension.

Table 1 Strategies in four situations

Carrying capacity	Carrying state	Corresponding dimension development strategy
High	Surplus	Key layout, complementary output
High	Overload	Control population and optimize layout
Low	Surplus	Appropriate layout, gradual development
Low	Overload	Control population, introduce compensation

3.3.4 Analysis of Evaluation Results

After quantification, three sub-dimensions carrying capacity and comprehensive carrying capacity (4 kinds of carrying capacity are indicated by C) are obtained. Comparing these with the actual population P of the study area, it may present three carrying states: overload, critical and surplus. Among them, overload means $P > C$; critical means $P \approx C$; surplus means $P < C$. At the same time, the overload degree and surplus degree [4] are introduced in order to compare regions with the same carrying state. Among them, the overload degree $\varepsilon = (P–C)/C$ refers to the relative degree of the actual population exceeding the carrying capacity; the surplus degree $\zeta = (C\text{-}P)/C$ refers to the relative degree of the actual population below the carrying capacity. High carrying capacity is not the same as good carrying state. Low carrying capacity may also correspond to a more reasonable carrying state. Overloading means that the number of people that can be carried by a certain natural resource element at the national average level is not enough to carry the population of the study area, and surplus means that a certain natural resource element in the study area can carry a higher population. In fact, only the corresponding areas with high carrying capacity and surplus of a certain dimension have the advantage to undertake the function of this dimension and therefore should be given more consideration. According to the possible results of the evaluation of each dimension, the corresponding development strategy is formulated as shown in Table 1.

4 Case Studies

Zhejiang Province is selected as the research area to carry out empirical application research, aiming at verifying the provincial-level cognition and evaluation framework of resource and environmental carrying capacity for Territorial Spatial Planning constructed in this article can obtain the effective evaluation result which meets the requirements of Territorial Spatial Planning.

4.1 Overview of the Research Area

Zhejiang Province is located on the southeast coast of China, between 118°01'E-123°10'E, 27°02'N-31°11'N, and has 11 Prefecture-level cities including Hangzhou, Ningbo, Jiaxing, Shaoxing, Huzhou, Lishui, etc.; Zhejiang has various types of terrains, among which mountains and hills account for 70.4%, plains account for 23.2%, and waters account for 6.4%; The whole province belongs to the subtropical monsoon climate zone, with four distinct seasons, rain and heat at the same time. Its average annual reduction reaches 980–2000 mm.There are rich biological resources within Zhejiang including one of the highest forest coverage in China, a wide variety of wild animals and plants. At the end of 2019, Zhejiang Province had a permanent population of 58.5 million, with an urbanization rate of 70.0%. The gross regional product is 6,235.2 billion yuan, the added value of the primary, secondary, tertiary industry is 209.7 billion yuan, 2656.7 billion yuan and 3368.8 billion yuan, and the industrial added value structure is 3.4: 42.6: 54.0.

4.2 Construction of Index System

Combining the actual situation in Zhejiang Province, the availability of previous research results and the horizontal and vertical comparability, the refined indicators of food production, development and ecological protection are selected whose weights are calculated through the combination weighting method composed of AHP Method and Entropy Method. The judgment matrix of three dimensions in AHP are displayed in Fig. 2 and the subjective weights of F_1, F_2 and F_3 based on the judgment matrix are 0.65, 0.13 and 0.22 with CR = 0.4% < 10%, the subjective weights of D_1, D_2 and D_3 based on the judgment matrix are 0.125, 0.223 and 0.652 with CR = 0.4% < 10%, the subjective weights of E_1, E_2 and E_3 based on the judgment matrix are 0.143, 0.571 and 0.286 with CR = 0.0% < 10%, all of which pass the conformance test (Fig. 3).

According to the entropy method, the objective weights of F_1, F_2 and F_3 are 0.55, 0.274 and 0.176, the subjective weights of D_1, D_2 and D_3 are 0.271, 0.396 and 0.333 and the objective weights of E_1, E_2 and E_3 are 0.236, 0.306 and 0.458.

Combine the subjective weights and the objectives weights into the final weights by difference coefficient method, which are shown in Table 2.

4.3 Data Sources

The statistical data involved in this article comes from the 2003–2017《China Statistical Yearbook》,《Zhejiang Province Statistical Yearbook》,《China Environment Statistical Yearbook》,《Zhejiang Natural Resources》and《Environment Statistical

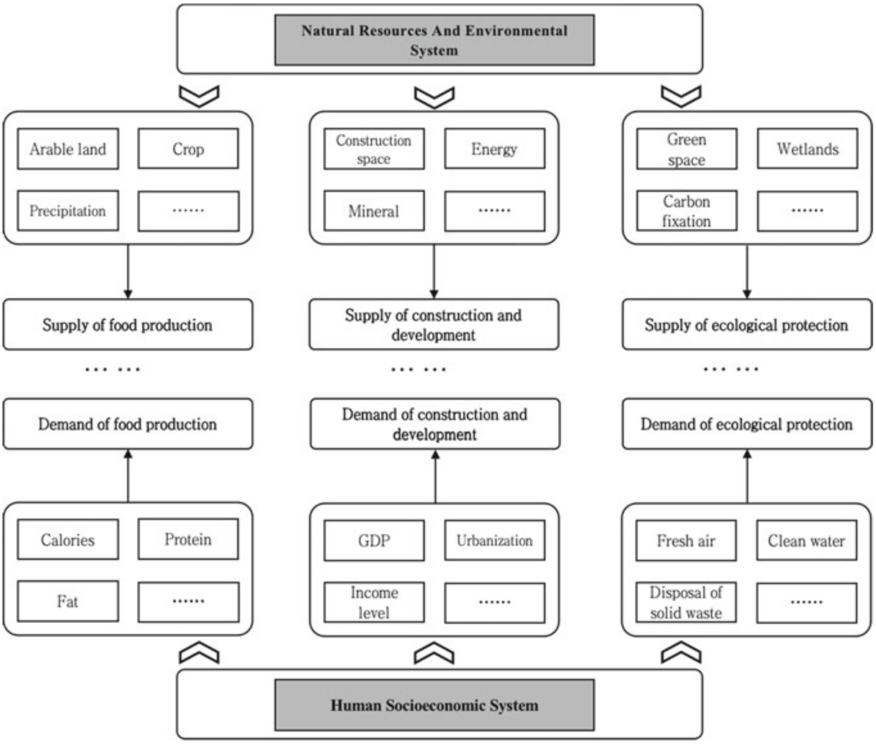
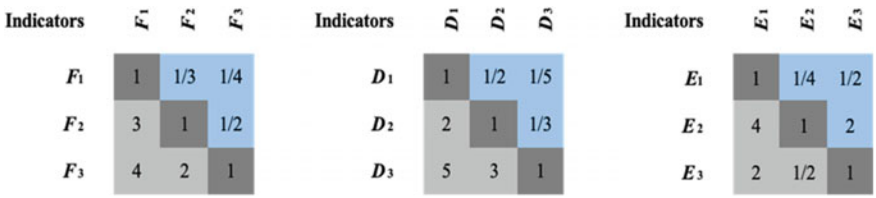


Fig. 2 Cognitive framework of "carrying body-supply and demand matching-carrying object"



Indicators	F_1	F_2	F_3
F_1	1	1/3	1/4
F_2	3	1	1/2
F_3	4	2	1

Indicators	D_1	D_2	D_3
D_1	1	1/2	1/5
D_2	2	1	1/3
D_3	5	3	1

Indicators	E_1	E_2	E_3
E_1	1	1/4	1/2
E_2	4	1	2
E_3	2	1/2	1

Fig. 3 The judgment matrix of three dimensions in AHP

Yearbook》, and the administrative division map of Zhejiang Province is from China Resource and Environmental Science Data Center of Academy of Sciences.

Table 2 Evaluation system

Evaluation dimension	Refinement index	Unit	Weights in each dimension
Food production	cultivated area (F_1)	Hectares	0.567
	Total power of agricultural machinery(F_2)	Ten thousand kilowatts	0.249
	Agricultural water(F_3)	One hundred million cubic meters	0.184
Development	Built-up area(D_1)	Square kilometers	0.245
	Total Investment in Fixed Assets(D_2)	Billion yuan	0.366
	GDP(D_3)	Billion yuan	0.389
Ecology protection	Urban green area(E_1)	Hectares	0.222
	Forest area(E_2)	Ten thousand hectares	0.344
	Wetland area(E_3)	Ten thousand hectares	0.433

4.4 2003–2017 Evaluation Results and Analysis of Zhejiang Province's Carrying Capacity

First, using the nationwide as a reference area, calculating and describing the evolution process of Zhejiang's carrying capacity from 2003 to 2017 according to the index system,it can be concluded that (Fig. 2): (1) The food production dimension is always low and continues to decline, meanwhile it is in an overloaded state and the overload degree has increased significantly; (2) The carrying capacity of the development dimension stays high all the time, showing a significant surplus; (3) The ecological protection dimension is always in an overload state, but the degree of overload is gradually decreasing; (4) The comprehensive carrying capacity is always in overload state, while the degree of overload is relatively stable (Fig. 4).

4.5 Calculation of the Carrying Capacity of Each City in Zhejiang Province in 2017

With Zhejiang Province as the reference area, further calculate the carrying capacity of each city of Zhejiang Province in 2017. In order to show its spatial differentiation, ArcGIS is used to make visualization results (Fig. 5). In the visualization results, different color systems are used to represent different carrying capacities and carrying states. The darker the color, the greater the corresponding carrying capacity, the degree of overload and surplus. The overload state is always expressed in black and white.

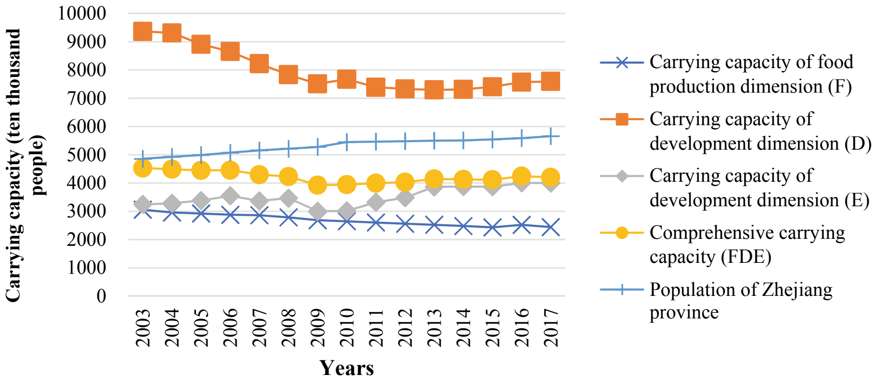


Fig. 4 Changes in three dimensions and comprehensive carrying capacity of Zhejiang province from 2003 to 2017

Based on the above calculation results, it can be concluded that:

1. In the result of food production dimension, Zhoushan has the lowest carrying capacity which is only about 1.33 million people; Quzhou, Jinhua, Huzhou, and Lishui have a carrying capacity of about 4 million people, which is in the middle reaches; Jiaxing, Taizhou and Wenzhou's carrying capacity is relatively high, with more than 5 million person-times; Hangzhou and Ningbo have the highest carrying capacity, reaching more than 6 million. In terms of carrying states, Hangzhou, Ningbo and Wenzhou are overloaded with severe degree; Taizhou and Jinhua are in a critical state; the remaining cities are in surplus, Huzhou, Quzhou City and Lishui City have relatively high degree of surplus.
2. In development dimensions, the carrying capacity is mainly concentrated in northern Zhejiang, the coastal areas of eastern Zhejiang and Wenzhou in southern Zhejiang; Lishui, Quzhou Zhoushan have low carrying capacity; cities in the central region are in the middle reaches. In terms of carrying states, Hangzhou and Ningbo are in a state of obvious surplus, Zhoushan is in a state of relative high degree of surplus, and Shaoxing is critically surplus. The rest of the cities are overloaded: Huzhou and Jiaxing are critically overloaded. Central Zhejiang and Southern Zhejiang all show relatively obvious overloads, with Lishui being the most.
3. In dimension of ecological protection, the carrying capacity is mainly concentrated in Hangzhou, Ningbo, Wenzhou, Taizhou and Lishui, with Hangzhou, Ningbo, and Wenzhou being the highest; the central Zhejiang and Zhoushan areas have low carrying capacity. In terms of carrying capacity, Hangzhou, Quzhou, Lishui, Taizhou, and Zhoushan are in a state of surplus, and Lishui has the highest degree of surplus. Other areas are overloaded. Jiaxing and Jinhua are overloaded nearly twice.
4. The comprehensive carrying capacity of each city calculated according to the equilibrium model formula is basically in line with the order of the city size.

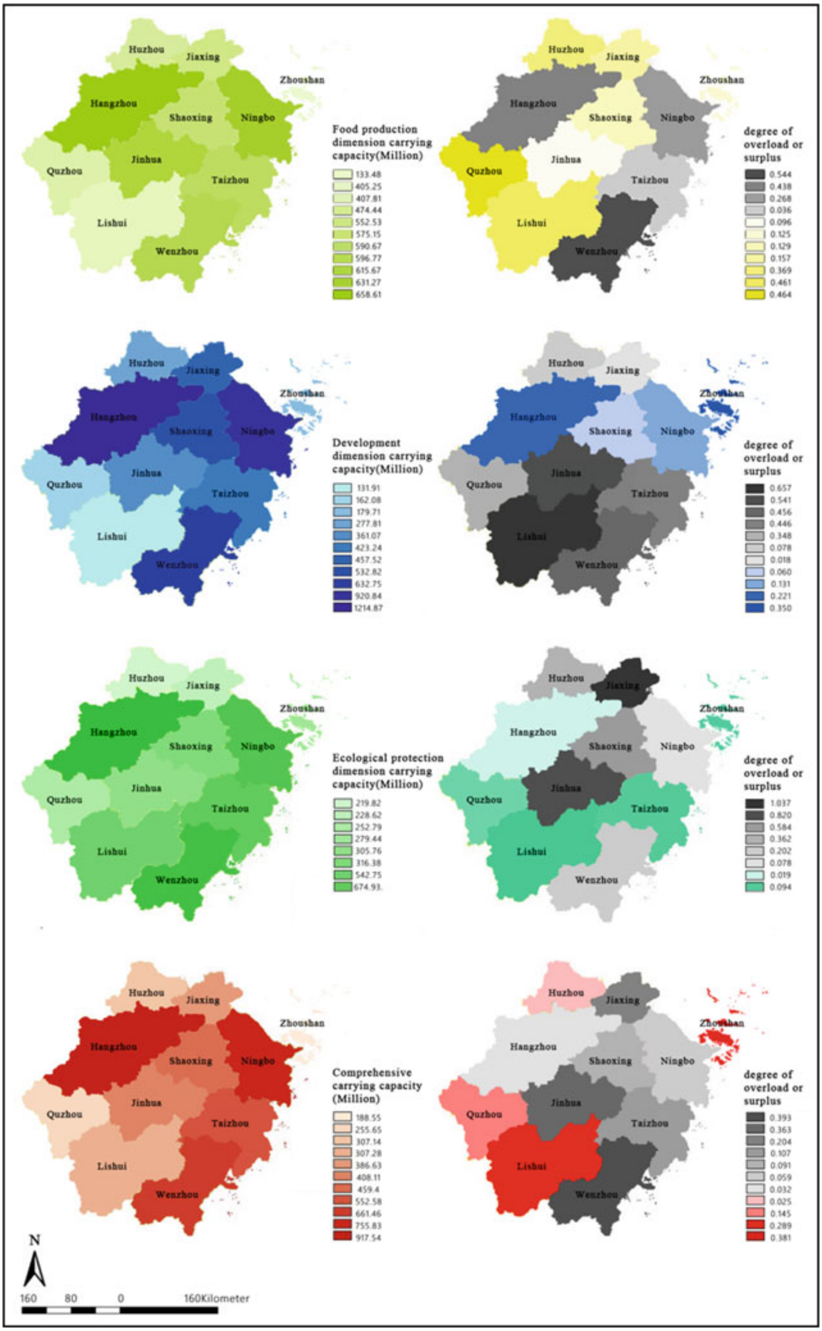


Fig. 5 Distribution map of carrying capacity(left) and states(right) of sub and comprehensive dimensions in Zhejiang province

Hangzhou, Ningbo and Wenzhou have the highest comprehensive carrying capacity, Huzhou, Jiaxing, Shaoxing, Jinhua and Taizhou are at the upper-middle level, while Lishui, Quzhou and Zhoushan are at average and lower levels. However, the comprehensive carrying state of Hangzhou, Ningbo and Jiaxing is a critical overload, while Wenzhou, Jinhua and Shaoxing are in overload states of different degree. Lishui and Zhoushan have a high degree of surplus, while Quzhou City and Huzhou City have a little surplus state.

4.6 Territorial Spatial Planning and Sustainable Development Suggestions Based on Evaluation Results

1. In general, Zhejiang Province has a very high development carrying capacity relative to the whole country, and has always been in a state of surplus with high degree, which means it is one of the most economically developed provinces in the country. Compared with the whole country, the carrying capacity of food production and ecological protection in Zhejiang Province is relatively low, with a high degree of overload and a tendency to expand. The above results indicate that in the Territorial Spatial Planning, construction and development should be the main function to lead the functional positioning and layout of Zhejiang Province. However, it should be noted that the contradiction between Zhejiang Province's "large economic " and "small natural resources " makes the comprehensive carrying capacity appear to be overloaded. This means that in the future, it is necessary to pay more attention to the coordination between different dimensions: for the more moveable food production elements, through the conversion of intra-regional resources such as reasonable construction land reclamation, method of foreign resource trade for the introduction of corresponding disadvantaged elements, effective complementation of different dimensions can be realized. For the ecological protection elements that is difficult to improve through intra-regional and foreign trade, it is necessary to protect the important ecological barrier functions in the region, such as wetland resources and forest resources, to ensure that they are not reduced. What's more, it is necessary to accelerate the transformation to optimized development and high-quality development, accurately eliminate old business formats that are not resource-saving and environmentally unfriendly, and actively explore and cultivate new innovation-driven business formats. In recent years, Zhejiang Province has rapidly developed a digital economy which is a good start (Fig. 6).

2. Furthermore, under the main function of construction and development, the Territorial Spatial Planning and sustainable development of each region will be guided according to the distribution of carrying capacity and carrying status in the province.

The contribution rate of Hangzhou and Ningbo to each dimension and comprehensive carrying capacity is the highest in the whole province as well as the highest

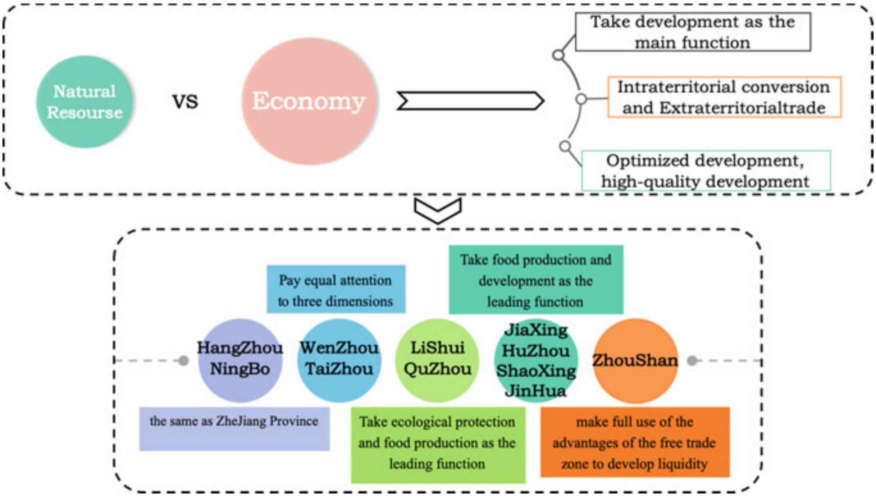


Fig. 6 Territorial Spatial Planning and sustainable development suggestions based on evaluation results

degree of surplus in development dimension. Their ecological protection dimension is close to the critical state, and the food production dimension is overloaded. In the follow-up related work, it should be more responsible for the positioning of the corresponding functions of construction and development, such as listing as a key area of the provincial-level urban construction convenience zone. At the same time, in order to increase the overall carrying capacity and achieve sustainable development, such cities need to undergo intra-regional conversion and extraterritorial trade to supplement the disadvantaged elements. It is necessary to ensure that the amount of ecological resources that cannot be replaced by extraterritorial mobility is not reduced, the quality of which is not deteriorated and the surplus construction and development resources should be appropriately transferred and transformed on the basis of optimized development.

The contribution rates of all dimensions and comprehensive carrying capacity of Wenzhou and Taizhou are all at a high level in the province, and they are all in a relatively unsatisfactory carrying state. The reason is that their population density is too large, putting greater pressure on the rich natural resources and environmental elements in the province. In Territorial Spatial Planning, the three-dimensional function orientation of indicators should be emphasized at the provincial level in such cities which need further analysis in the next-level plan to determine the specific functional positioning of the specific space, and such cities should adopt the strategy of population control, optimized development and improved development quality.

Lishui and Quzhou are located in the mountainous area of southwestern Zhejiang. The carrying capacity of ecological protection and food production is obviously surplus. It can be seen that these two dimensions have outstanding comparative advantages, but the carrying capacity of development is significantly overloaded.

Food production and ecology protection carrying positioning should be taken into more consideration in the Territorial Spatial Planning. At the same time, ecological economy and landscape agriculture are the new economic growth points that have been discovered these years. Such cities should seize their own advantages and strive to explore new systems and mechanisms such as the realization of the value of ecological products to realize the sustainable development which coordinates food production, ecological protection and construction development.

Jiaxing, Huzhou, Shaoxing and Jinhua have high food production carrying capacity and show obvious surplus. They have medium construction and development carrying capacity, but the ecological protection carrying capacity is continuously and seriously overloaded. Among them, Jinhua even also faces severe overload in development dimension. More food production dimension functional can be tilted in the Territorial Spatial Planning, and the development dimension functional positioning can be emphasized. In the future, first of all, it is necessary to adhere to the ecological red line and implement appropriate ecological restoration measures such as returning farmland to forests and returning farmland to grassland, which means that the surplus food production dimension can be used to achieve compensation. At the same time, these cities should pay attention to optimized development during the construction and development process and transform to a high-quality, low-polluting development mode.

Zhoushan City is the only island city in Zhejiang Province, which has a special natural geographical environment. Although the contribution rate of various resource carrying capacity is the lowest in the province, due to the relatively small population pressure it is in a state of surplus. The three dimensions should be equally important in the Territorial Spatial Planning and under the premise of ensuring food production and ecological quality, Zhoushan need to focus on development, and take advantage of the free trade zone to further exert the complementary effect of a larger range of extraterritorial flows.

5 Conclusion

This paper takes the provincial resource and environmental carrying capacity for Territorial Spatial Planning as the research object. Based on summarizing the main content of Territorial Spatial Planning and its requirements for carrying capacity evaluation, it discusses the construction of a new cognition and evaluation framework. Zhejiang province is selected as an example to carry out corresponding empirical application research, the main conclusions are as follows:

1. The essence of Territorial Spatial Planning is a transmission system to implement a macroscopic national development plan into micro-level territorial and spatial use control. It is necessary to pay attention to the relevance of various scales, especially the provincial scale which is a link between the upper and lower scale. The direct result of Territorial Spatial Planning is a "one map" of

space development and protection that integrates three areas and three lines, which aims at making overall coordination of "Food Production", "Development" and "Protection of Ecology". Therefore, the carrying capacity evaluation needs to have a clear orientation to the functional scale of the three dimensions, and at the same time form a docking with the nature of the transmission system of land and space planning, having a clear scale transfer logic.

2. Starting from the real needs of the human socio-economic system for the natural resource and environmental system, the provincial carrying capacity should be defined as "In a certain period of time, under the corresponding climatic conditions, technological level, etc., the ability of the natural resources and environmental system within a province to meet the needs of human social and economic systems for "Food Production, "Development" and "Protection of Ecology".
3. In Evaluation Framework, "Food Production", "Development" and "Protection of Ecology" should be the three factor layers of the index system; The Relative Carrying Capacity Calculation Method and Combination Weighting Method are suitable to quantify and integrate the indicators; The comparative advantage of a certain region to undertake a certain dimension function should be comprehensively analyzed according to the bearing capacity and the bearing state.
4. In case study of Zhejiang Province, it can be obtained the results of carrying capacity evaluation can coordinate the three-dimensional goals, clearly reflect how the provincial scale connects up and down and guide the relevant policy positioning in a targeted manner. Therefore, the cognition and evaluation framework proposed in this paper can probably provide ideas and reference for how to effectively improve the supporting capacity of carrying capacity evaluation for Territorial Spatial Planning.

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Intervening Construction Workers' Unsafe Behaviour with a Chatbot

Linfeng Zhou, Sheng Xu, and Zhixia Qiu

Abstract As an effective method to reduce the unsafe behavior of construction workers, safety training has always been the hotspot of safety management research. In recent years, while there is an ever-growing research interest on developing effective training techniques and methods, few studies have improved safety training with the targeted interactions with construction workers. Therefore, based on natural language processing technology, this paper introduced the chatbot into construction safety training and designed a framework for personalized construction worker safety training on mobile phones. In particular, the single-round question and answer technique with the chatbot was introduced with an illustrative example. Through word segmentation, part-of-speech tagging, similarity calculation, and threshold comparison, questions and sentences from regulations could be compared to determine which sentence should be chosen as the most matching answer, and to improve workers' ability to work safely. In this way, this research provided an innovative, adaptive, convenient and knowledge-rich personalized safety training approach, in the hope of reducing cognitive difficulty and increasing learning interests of construction workers.

Keywords Construction safety · Safety training · Chatbot · Natural language process

1 Introduction

Despite the progress in the AEC industry and its contribution to the economy [1], statistics worldwide show that the high occupational accident rate in the construction

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industry is still a major concern in many countries [2, 3]. According to the US Department of Labor [4], the number of deaths in the construction industry in the United States in 2016 was 991, ranking first among all industries; in the United Kingdom, the number of deaths in the construction industry in 2014 accounted for 31% of the national occupational deaths [5]. Furthermore, of all types of factors leading to construction accidents, construction workers' unsafe behaviour has been established as the most important factor [6–8]. Individual factors are usually regarded as immediate causes of an accident, but they could be alleviated by effective intervening approaches improving workers' safety knowledge awareness and performance [9]. Therefore, construction workers' behavioural safety has become one of the hottest topics in construction research.

Safety training plays a pivotal role to effectively reduce unsafe behaviors of construction worker [10]. Bena confirmed that safety training had a positive impact on reducing occupational injury rate through a research project on 2795 workers. After proper safety training and professional training, the occupational injury rate has dropped by 16% and 25% respectively [12]. However, traditional safety training is mainly based on course teaching supplemented by text materials, which are difficult to be understood and memorised in a relatively short period of time for workers with low literacy. In addition, traditional safety training uses unified training content and training methods, without adoption to workers' personal characteristics such as age and experience. Therefore, the training could not be sufficiently effective, and it brings an urgent need for new training approaches that adapt to lower level of education and stimulate learning interests to improve the current safety training performance.

Adaptive training is believed to be an efficient way to improve training performance and effectivity. With chatbots applications in other fields that encourages efficient and adaptive human-AI interactions, it is expected that with chatbots for the construction safety training, workers will be encouraged to check safety regulations with mobile devices and act safely. Therefore, this research introduced chatbot technique for construction workers' safety training, and is arranged as follows. Section 2 reviewed the development in construction safety training and the up-to-date chatbot technology. Then, the system framework and modules were designed in Sect. 3. Section 4 introduced the single-round dialogue technology, and an example was used to demonstrate the word segmentation, vector conversion, similarity calculation and function realization in the safety training chatbot. Finally, Sect. 5 provided the discussion and conclusion for this research.

2 Existing Research

2.1 Construction Safety Training

Frequent job rotation, comprehensive environment and schedule pressure make effective safety management difficult, resulting in high accident rate [13]. The safety training is the fundamental means and effective way to improve the safety management level, only through scientific and effective training can improve the workers' safety awareness and skill, and to ensure safe production and the implementation of all the work [14]. Mazlan believed safety training is a technique for developing human resources through the enhancement of the skills of workers and their ability to cope with workplace hazards [15]. Althrough there is a long history of using classroom-based trainings to upskill the construction workforce, it is still perceived as an old school manner which does not essentially motivate trainees or take trainees' characteristics into account. Considering the inadequacies of traditional safety-training methods (e.g., passive lectures, videos, demonstrations), advanced visualization techniques such as virtual reality to enable users to actively improve their hazard-identification skills in a safe and controlled environment have been employed [11, 16]. Shamsudin presents a methodology on proposed of Virtual Reality applications in order to enhance occupational safety hazard recognition in construction specifically for piling work at construction sites [17]. To reduce the costs of educational training, enterprises have also started to aggressively introduce e-learning education training [18]. Ahn supported that the site workers trained via virtual environmental simulation using BIM program showed a higher level of understanding than the group of workers who were trained via the conventional lecture approach [19].

Fast development of internet services arises the need of some artificial intelligence solutions that are able to interact between a man and a machine [20]. Neto proposed a Conversational Agent, also known as Chatbot, that adopts the Conversational Analysis, currently used to identify the appropriation of social networks, to recognize Distance Education context [21]. Chan developed a framework for a dialogue system to enhance the capability in understanding user's questions which combining question answering features, a knowledge base as the knowledge provider, and a search module that can handle the relatively difficult querying tasks [22]. In the construction safety field, researchers have demonstrated effective safety-related communication and training and induction schemes can overcome safety challenges effectively [23].

2.2 Chatbots and Their Applications

The first introduction of intelligent chatbots would have originated in the 1950s, when Alan Turing published an article on "Computing Machinery and Intelligence" that first proposed the Turing test, which was considered the ultimate goal of chatbots, allowing machines to talk and think like humans [24]. Born in 1966, ELIZA [25] is considered the first chatbot and was the world's first question-and-answer system, developed by Joseph Weizenbaum of the Massachusetts Institute of Technology. In 1988, Robert Wilensky and others at the University of California, Berkeley, developed a chatbot called UNIX Consultant to help users use the UNIX operating system with natural language [26]. Inspired by ELIZA, Dr. Richard proposed the famous robotic ALICE, which used heuristic template matching to achieve the best human–machine dialogue capabilities at the time, and open-sourced the implementation of AIICE (a new artificial intelligence markup language, AIML). Currently, in the field of chatbot research, the United States, Japan, and other countries are leading the way and have developed chatbot systems with some practicality. For example, Apple's Siri also features AskJeeves [27], AnswerBus [28], MULDER [29], LAMP [30], and so on. Some well-known chatbots include Microsoft's chatbot "Xiao Bing" and Baidu's chatbot "Xiaodu", which are both template-based chatbots relying on a large database to ensure smooth human–machine conversations [31].

Question-pair extraction is an area of research that is closely related to chatbot knowledge extraction. Shrestha studied the detection of question-and-answer pairs in email conversations, and the results showed that the structural features of email topics can improve the recognition of question-and-answer pairs, and while the method is good at recognizing questions in the form of questions, it cannot recognize questions in the form of statements [32]. Jeon studied the role of non-text features in answer retrieval in community question and answer [33]. Ding proposed to use conditional random fields to detect the context information and answers of questions, and use Skip-chain CRF and 2DCRFs models to further improve the performance of answer recognition [34]. Gottipati proposed an answer retrieval method that automatically recognizes the semantic tags of replies and returns relevant answers [35].

For construction projects, existing chatbots are aimed to assist the management of work sites. Some chatbots are adapted to assist scheduling future works and remind managers to fulfill scheduled daily tasks; for example, ConBot, a construction site data assistant produced by Botmore Technology in the UK [36], and SafeTrack, developed by Talania Ltd in New Zealand [37], allows workers and managers to submit daily reports and information of accomplished works via dialogue. In addition, there are other chatbots that focus on site safety issues, such as Workplace Safety Bot, a chatbot developed by the Robust Tech House of Singapore, which allows users to report hazards easily and broadcasts safety reminders to users [38].

Compared to traditional approaches, chatbots could automatically respond to workers in need with proper information with a series of qualified questions, collect useful information through direct messages to provide effective and relevant support, and can also track user behavior by monitoring user data. Therefore, chatbots are employed in this research to provide proper safety knowledge and information to construction workers in need, as a variation of safety training.

3 System Framework and Functions

3.1 System Framework

This research proposed a framework of adaptive safety training system for construction workers, as shown in Fig. 1. The framework can be divided into four layers, namely data, information, process, and application layers.

(1) The Data Layer. The collection and refinement of data is a continuous process, and the incremental information generated during the process helps to update the contents of each database.

(2) The Information Layer. Four aspects of data were stored, namely construction workers' information, construction projects' information, training evaluation, and behavioral safety knowledge. Effective information was extracted from the database.

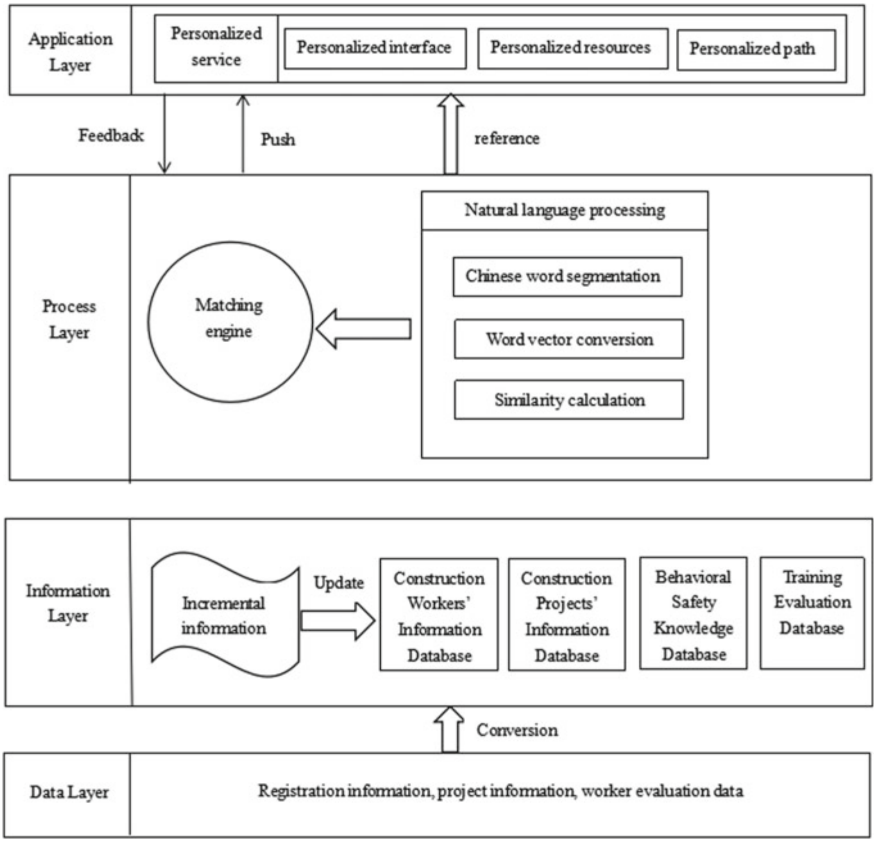

Fig. 1 System architecture diagram

(3) The Process Layer. The process layer extracted the safety knowledge in the knowledge base to answer questions asked by workers. This is the layer of matching engine. It used natural language processing to segment regulations and convert word vectors, calculate similarities of possible answers to the questions and feedback to the application layer.

(4) The Application Layer. The application layer is a direct user-facing module that is used to provide adaptive services to users, including providing a chatbot conversation interface, intelligently pushing adaptive training content, providing a communication platform, customizing learning paths, and providing personalized interventions.

3.2 System Functions

The chatbot subsystem is equipped with five major functions: dialogue question and answer, location-based dialogue question and answer, location alert, incident alert, and training tracking.

The dialogue question and answer function is the core feature of the chatbot module, which enables a single round of question and answer dialogue. This feature requires the user to be as descriptive and accurate as possible when asking a question. For example, "Do I need to put up a horizontal safety net when tying up exterior reinforcing steel?" The correct dialogue process is shown in Fig. 2, while the dialogue process in which an accurate answer could not be obtained is shown in Fig. 3. It can

Fig. 2 Dialogue diagram a

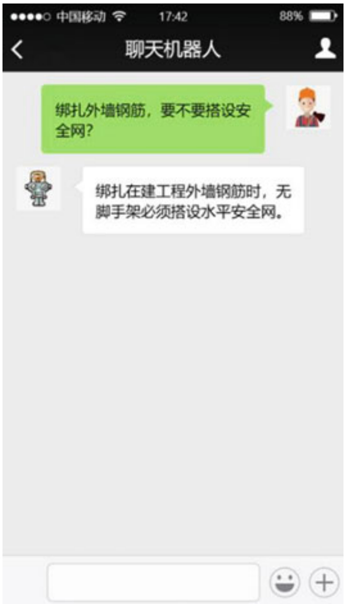

Fig. 3 Dialogue diagram b

also ask users what help they need based on the location information they send, as shown in Fig. 4.

4 Single-Round Answering Technique

The question and answer module of the chatbot is the most essential in the chatbot system. This study focuses on the implementation of the key technique of single-round question and answer and proves the workflow of the chatbot by simulating the problem.

The single round answering is mainly composed of a text preprocessing module and a similarity calculation module. In the similarity calculation module, a word vector dictionary needs to be prepared in advance. These two modules mainly include core functions of word segmentation, word vector conversion, similarity calculation, and threshold comparison, as shown in Fig. 5.

Fig. 4 Dialogue diagram c

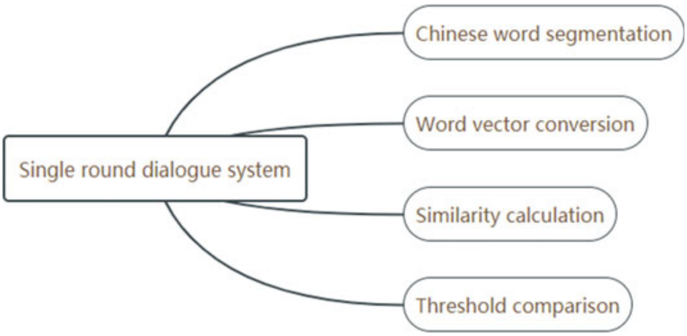

Fig. 5 Single-round dialogue system structure

4.1 Chinese Word Segmentation

In the chatbot subsystem, Chinese word segmentation is required for every input of the system. At present, the common open source word segmentation tools mainly include Jieba word segmentation tool, Han LP word segmentation tool, THUOCL word segmentation tool, Pkuseg word segmentation tool and Fool NLTK word segmentation tool. This project intends to use Jieba word segmentation tool. Jieba word segmentation mainly supports three types of word segmentation modes, precise mode, full mode and search engine mode. This project uses the precision mode to accurately distinguish sentences and label parts of speech. Nouns, verbs, adjectives and adverbs are the four most important parts of speech in a sentence, which can best reflect the information contained in the sentence. Marking the part of speech is helpful to extract key words in a sentence.

4.2 Word Vector Conversion

The word vector is a vector that converts word characters in natural language into a computer-understandable matrix. To improve the efficiency of word vector conversion, a complete dictionary can be pre-trained. Common word vector training models include Word2vec published by Google and Fast Text published by Facebook.

The Chinese corpus is pre-processed with text, and after pre-processing operations such as de-symbolization and word division, the corpus data of the word division version is obtained. If the word belongs to the deactivated word dictionary, it is deleted; if it does not belong to the deactivated word dictionary, it is added to the model and waits for training. When all the words are added to the training model, the word vector dictionary can be obtained at the end of training.

4.3 Similarity Calculation

Statement similarity refers to the degree to which two sentences are semantically similar in the Chinese corpus. The degree of similarity is a value between [0, 1]. The closer the similarity is to 1, the more semantically similar the two sentences are, while the closer the similarity is to 0, the less semantically similar the two sentences are.

This project proposes to use the Cosine similarity calculation algorithm. Cosine similarity is actually a measure of the degree of similarity between two vectors using the cosine of the angle between the two vectors in vector space. The more similar the two vectors are, the smaller the angle between the two vectors will be, and the larger the corresponding cosine value will be. Conversely, the less similar the two vectors are, the greater the angle between them, and the smaller the corresponding cosine value. Formula (1) shows the formula for cosine calculation. The cosine similarity theory can be used to calculate the degree of similarity in meaning between two words.

$$\mathrm{Cos}(\theta) = \frac{\overrightarrow{a} \cdot \overrightarrow{b}}{||a|| \cdot ||b||} \tag{1}$$

This project uses a direct summing of the word vectors of all valid words that make up the sentence to obtain the corresponding sentence vectors. Formula (2) shows the formula for the calculation of the sentence vector. Where S is the sentence, w is the words that make up the sentence, and V is the word vector. The sentence vector can be obtained after calculation.

$$\vec{S} = \sum_{w \in S} V_w \tag{2}$$

Sentence similarity calculation is actually to calculate the similarity between sentence vectors. To facilitate the calculation we first calculate the sentence vector of each sentence from the stored contents of the knowledge base in the manner described above, and save it. After storing the sentence vector of each sentence in the knowledge base, the sentence similarity between the sentence in the knowledge base and the user input question can be calculated according to formula (3).

$$\mathrm{sim}(S_1, S_2) = \frac{\overrightarrow{S_1} \cdot \overrightarrow{S_2}}{\left|\left|\overrightarrow{S_1}\right|\right| \cdot \left|\left|\overrightarrow{S_2}\right|\right|} \tag{3}$$

4.4 Threshold Comparison

After obtaining the similarity between each question in the knowledge base and the question input by the user, of which answer can be returned as the final answer of the chatbot, a threshold comparison needs to be determine here. User input is added to the system. After pre-processing of the input data, the similarity is calculated, then the one with the largest similarity is found, and the threshold is compared to determine whether to return the answer to the question. If the similarity is greater than the threshold, the answer to the question is returned as the output. If the similarity is less than the threshold, it returns empty, indicating that no matching answer is found.

4.5 *Example of Chatbot Dialogue Module*

This section shows how the single-round question and answer technique was applied in the chatbot with a simulated question. Possible answers were articles in the safety regulation, and the four stages in processing the question and answers were demonstrated.

4.5.1 Text Preprocessing

The chatbot dialogue module uses the "Beijing Construction Safety Operation Regulations" to build the knowledge base. Sentences were firstly split in the specification according to different scenarios, then Chinese word segmentation were performed on all the split sentences, and the part-of-speech tagging method was used for part-of-speech tagging with Jieba System, as shown in Fig. 6. Table 1 shows the Jieba part-of-speech description table.

After the word segmentation is completed, the specification terms will be stored in the database as the basis of word vector training.

4.5.2 Similarity Calculation

Next, the question "Should we set up a horizontal safety net when tying external wall reinforcement?" was asked in the chatbot, and the four sentences with the keywords "safety net" in Fig. 6 were selected from the safety regulation as possible answers. Similarity of these four sentences and the question were calculated to determine which one was the most related answer. The second and fourth sentence were used to demonstrate the similarity calculation process in the single-round dialogue:

Step 1: word segmentation

The first step is to perform Chinese word segmentation on the question as well as possible answers from the regulations, and use the part-of-speech tagging method to tag the connecting word system. For example, "绑扎| v" means that the part of speech of "绑扎" is a verb.

- *Question*
  绑扎|v 外墙|n 钢筋|n 时|n , |x 要|v 不要|df 搭设|v 水平|n 安全网|nz ?
- *Possible Answer 1*
  绑扎|v 在建|v 施工|vn 工程|n 的|uj 外墙|n 钢筋|n 时|n , |x 应|v 站|v 在|p 脚手架|n 或|c 操作|v 平台|n 上|f 作业|n 。|x
- *Possible Answer 2*
  绑扎|v 在建|v 施工|vn 工程|n 的|uj 外墙|n 钢筋|n 时|n , |x 无|v 脚手架|n 必须|d 搭设|v 水平|n 安全网|nz。|x

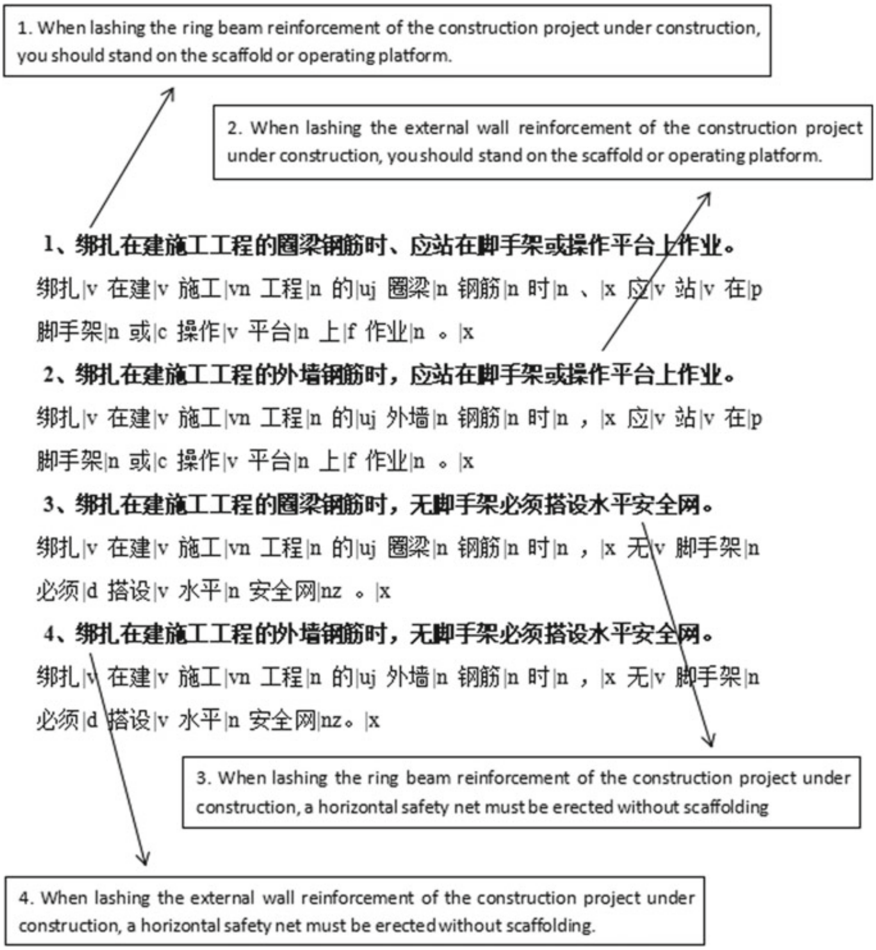

Fig. 6 Chinese word segmentation and labeling

Table 1 Standard split table

c	Conjunction	d	Adverb	f	Position of the word	n	Noun
h	Front component	nz	Other proper names	p	Preposition	v	Verb
vn	Gerund	x	Non-morpheme words				

Step 2: List all the words

The second step is to show all the vocabulary of the question and each possible answers respectively.

- *Question and Possible Answer 1*
  绑扎 外墙 钢筋 时 要 不要 搭设 水平 安全网 在建 施工 工程 的 应站 在 脚手架 或 操作 平台上 作业.

- *Question and Possible Answer 2*
  绑扎 外墙 钢筋 时 要 不要 搭设 水平 安全网 在建 施工 工程 无 脚手架 必须.

Step 3: Calculate the word vector

The third step is to calculate the word vector of each sentence.

- *Word Vectors of Question and Possible Answer 1*
  Question: 绑扎1 外墙1.1 钢筋1.1时1.1 要1 不要1 搭设1 水平1.1 安全网1.1 在建0 施工0 工程0 的0 应站0 在0 脚手架0 或0 操作0 平台上0 作业0.
  The second sentence: 绑扎1 外墙1.1 钢筋1.1 时1.1 要0 不要0 搭设0 水平0 安全网0 在建1 施工1 工程1.1 的1 应站1 在1 脚手架1.1 或1 操作1 平台上1.1 作业1.1
- *Word Vectors of Question and Possible Answer 2*
  Question: 绑扎1 外墙1.1 钢筋1.1 时1.1 要1 不要1 搭设 1水平1.1 安全网1.1 在建0 施工0 工程 0的0 无0 脚手架0 必须0.
  The fourth sentence: 绑扎1 外墙1.1 钢筋1 0.1时1.1 要0 不要0 搭设1 水平1.1 安全网1.1 在建1 施工1 工程1.1 的1 无1 脚手架1.1 必须 1.

Step 4: Calculate the similarity

The last step is to calculate the similarity between the two sentences and the question sentence.

- *Similarity between the Question and Possible Answer 1*
  Question word frequency sentence vector: (1, 1.1, 1.1, 1.1, 1, 1, 1, 1.1, 1.1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0).
  The word frequency sentence vector of the second sentence: (1, 1.1, 1.1, 1.1, 0, 0, 0, 0, 0, 1, 1, 1.1, 1, 1, 1, 1.1, 1, 1, 1.1, 1.1).
  Similarity between the question and Possible Answer 1:

$$\cos(\theta 1) = \frac{\begin{array}{c}1\times 1+1.1\times 1.1+1.1\times 1.1+1.1\times 1.1+1\times 0\\ +1\times 0+1\times 0+1.1\times 0+1.1\times 0+0\times 1\end{array}}{\sqrt{1\times 4+1.1\times 5}+\sqrt{1\times 8+1.1\times 7}} + \frac{\begin{array}{c}0\times 1+0\times 1.1+0\times 1+0\times 1+0\times 1+0\\ \times 1.1+0\times 1+0\times 1+0\times 1.1+0\times 1.1\end{array}}{\sqrt{1\times 4+1.1\times 5}+\sqrt{1\times 8+1.1\times 7}} = 0.52$$

- *Similarity between the question and Possible Answer 2*:

Question word frequency sentence vector: (1, 1.1, 1.1, 1.1, 1, 1, 1, 1.1, 1.1, 0, 0, 0, 0, 0, 0, 0).

The word frequency sentence vector of the fourth sentence: (1, 1.1, 1.1, 1.1, 0, 0, 1, 1.1, 1.1, 1, 1, 1.1, 1, 1, 1.1, 1).

Similarity between the question and the Possible Answer 1:

$$\cos(\theta 2) = \frac{\begin{array}{c}1 \times 1 + 1.1 \times 1.1 + 1.1 \times 1.1 + 1.1 \times 1.1 \\ +1 \times 0 + 1 \times 0 + 1 \times 1 + 1.1 \times 1.1 + 1.1 \times 1.1\end{array}}{\sqrt{1 \times 4 + 1.1 \times 5} + \sqrt{1 \times 7 + 1.1 \times 7}} + \frac{0 \times 1 + 0 \times 1 + 0 \times 1.1 + 0 \times 1 + 0 \times 1 + 0 \times 1.1 + 0 \times 1}{\sqrt{1 \times 4 + 1.1 \times 5} + \sqrt{1 \times 7 + 1.1 \times 7}} = 0.87$$

By calculating the similarity, it showed that the similarity between the question and the second sentence is 0.52, which was less than the similarity between the question and the fourth sentence. Therefore, the fourth sentence "When lashing the external wall reinforcement of the construction project under construction, a horizontal safety net must be erected without scaffolding." was more appropriate as an answer output. Therefore, the chatbot showed that the answer to the question "Should we set up a horizontal safety net when tying external wall reinforcement?" was "When lashing the external wall reinforcement of the construction project under construction, a horizontal safety net must be erected without scaffolding."

5 Conclusion

This paper designs the overall structure of the construction worker safety training system, including data layer, information layer, control layer and application layer. On the basis of the architecture design, the chatbot subsystem are further designed, including a total of 5 major functions, namely the chatbot subsystem, the training and assessment subsystem, the user management subsystem and the information exchange subsystem. Secondly, based on natural language processing technology, a single-round question answering subsystem was designed and implemented, including word segmentation and word vector model in text preprocessing, as well as the similarity calculation algorithm between word vectors. Articles in one of the safety guidelines in China was used for text preprocessing, then questions were asked in the chatbot and answers were selected from several sentences in the safety guideline after similarity calculation and threshold comparison. The construction worker safety training system designed in this project could play an active role in improving the construction safety training and safety performance.

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A Review of BIM Data Exchange Method in BIM Collaboration

Jinfeng Lou, Weisheng Lu, and Fan Xue

Abstract Nowadays, building information modeling (BIM) plays a crucial role in project collaboration. BIM information should be freely exchanged among different stakeholders for the purpose of collaboration. With the development of Information and Communication Technology (ICT), there are many novel data exchange methods for BIM information exchange. However, little literature has attempted to review the current status of BIM data exchange methods. This study aims to provide a comprehensive summary of the status quo of BIM data exchange methods, including file-based method, cloud-based method, and three local data exchange methods. The advantages and disadvantages of each method are identified. This paper reveals that more efforts should be paid for enhancing the capability to deal with large Industry Foundation Class (IFC) files; a more stable, consistent identifier that can uniquely and easily identify an object should be developed; more opportunity in integrating BIM with some emerging technologies, like blockchain, should be seized to solve the problems in BIM data exchange. This study presents an in-depth analysis of the current BIM data exchange method and helps the industry and academia to identify the existing gaps and future directions.

Keywords Building information modeling (BIM) · Data exchange · Collaboration

1 Introduction

Since building information modeling (BIM) first appeared in journal articles [1], BIM has aroused widespread interest in academia and industry in many countries. BIM serves as a digital representation of physical and functional characteristics of a facility, which can be shared among various stakeholders [2]. The richness of data in BIM provides a brand-new way that people design, construct, and operate a building. From this point of view, BIM has led to great transformation in Architecture, Engineering, Construction, and Operation (AECO). BIM is not only a tool for representing

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facilities but also a project and process management technique, covering almost all the information related to the project [3].

Recent years have witnessed a surge of leveraging BIM technology in a variety of applications. It is reported that BIM increased labor productivity from 75 to 240% within a small contractor [4]. With the help of BIM, Lee et al. proposed an ontological method to automate the inference process and gain a more precise cost estimation, reducing the amount of manual work [5]. Liu et al. also developed a framework for integrating change management with BIM and created an automated model updating workflow [6]. Besides, BIM has been regarded as a powerful and disruptive tool for education and training to boost education design and students' learning outcomes [7]. Grilo and Jardim-Goncalves proved that BIM has effectively promoted electronic procurement in the AECO sector [8]. In these cases, BIM can benefit project management a lot.

Another significant advantage of BIM lies in project collaboration. BIM has the ability to improve the collaboration between stakeholders, including owners, architects, engineers, contractors, and suppliers, by conveying accurate information efficiently [9]. The concept of "collaboration" refers to a process during which participants collectively evaluate their differences and seek cooperative solutions that are beyond the vision and capacity of any single individual participant [10]. From a project management perspective, collaboration means an agreement that some experts share and exchange their expertise, information, and experience to fulfill a specific task and reach the project aim [11, 12]. The lack of collaboration in construction projects has been heavily criticized in the literature [12]. The advent of BIM technology provides a digital information platform for the collaboration of construction projects. Information exchange, corresponding to data exchange in BIM, is a crucial basis for participant collaboration. BIM, as a pool of digital data, can convey the proper information to proper participants with the assistance of modern Information and Communication Technology (ICT).

However, BIM-enabled data exchange is also faced with several problems from both social and technical aspects. For the social issues, Gielingh identified the lack of motivation, legal concerns, and industrial unreadiness when integrating BIM into collaboration [13]. In 2004, Kam and Fischer summarized some of the technical problems, such as geometric misrepresentation, loss of object information, application-specific input/output, time-consuming one-way conversion processes, and so on [14]. With the rapid development of BIM and ICT technology, many aforementioned problems have already been solved, and many new ones have emerged. Nevertheless, there is very little literature regarding the current BIM data exchange methods.

This study aims to provide a comprehensive elaboration of the status quo of the prevailing BIM data exchange approach from a technical perspective. Section 2 reviews the file-based data exchange method. The cloud-based approach is reviewed in Sect. 3. Moreover, three local data exchange method is summarized in Sect. 4. Conclusions and future directions are given in Sect. 5.

2 File-Based Data Exchange

File-based BIM data exchange is to directly transfer a specific file to the receiver manually. In the early stages of BIM development, different software vendors had their own file formats, which cannot be recognized by other software. It caused much trouble in project collaboration when the stakeholders used different software. Therefore, as expected, Industry Foundation Class (IFC) format, as a neutral data format, has been widely accepted by existing BIM collaboration standards and various software vendors [15]. Many recently developed applications and studies are based on IFC format[16, 17].

Exchanging IFC-based files is the most simple and straightforward way of communicating BIM information. In IFC schema, one can easily extract a subset of data from the overall model via Model View Definition (MVD), a predefined subset of the IFC schema in light of the receiver's need [18].

However, file-based exchange transfers information in a one-way manner, leading to the results that designers should transfer files repeatedly in each design iteration to ensure all the design changes are considered [19]. The request for BIM information and file transfer is manually made often through emails or other correspondence. And current file-based exchange technologies are incapable of managing data inconsistencies and redundancy, with network resources occupied by excessive files [20]. Moreover, the file-based exchange is unlikely to provide object-level data management without auxiliary tools. For example, different participants may have different access privileges. For a file-based system, the accessibility of data can only be regulated on a file-level instead of an object-level [21]. At the time the authors write this paper, there are ten official MVDs listed on the buildingSMART website [22]. Nevertheless, with the development of IFC and diversified user requirements, the number of MVDs will rise significantly. It is a huge challenge to require all software vendors to implement all these MVDs. buildingSMART is attempting to solve this problem by modularization of the IFC schema [23].

3 Cloud-Based Data Exchange

Cloud computing has long been regarded as transforming information technology. The most widely accepted definition of cloud computing stated that "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [24]. The benefits of cloud computing come in many aspects, such as low cost, scalability, independence of hardware, and venue [25]. Three common cloud service architectures are identified: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). By deployment model, cloud service can also be categorized into four types: Private cloud, Community cloud, Public cloud, and Hybrid cloud. The advent of cloud BIM is considered to realize the function of real-time data exchange [26]. There are already a number of vendors developing their own cloud services, such as Graphisoft's BIM Explorer (BIMx) and BIMcloud, Autodesk's A360, and BIM360, ONUMA System, and Trimble QuadriDCM and Trimble Connect [19].

By combining cloud computing and BIM technology, cloud BIM promises to solve some of the problems, such as lack of computing power and high cost [20]. Cloud BIM also allows real-time access to data, on-demand access to computing resources and applications, which potentially provides a high level of collaboration in a consolidated model [19]. A lot of studies that focus on realizing one or more of these benefits have been conducted. Ding and Xu proposed a framework of BIM cloud storage system, which enables the management of security and licensing, file, work process, and collaboration [27]. Chen et al. developed cloud-based tools to store dynamic BIM data, analyze the data, and visualize the results online [28]. Ma and Sacks developed a cloud BIM platform that allows users to query information, extend IFC schema for a specific use, and exchange data in accordance with predefined MVDs [29]. Zhang et al. proposed a novel multi-server method to balance data interoperability and privacy [30].

However, the collaboration between various cloud BIM software provided by different vendors is difficult [31, 32]. The open standards for cloud BIM collaboration, like the IFC schema, are expected to be developed to tackle this issue [19]. More importantly, organizational and legal problems are regarded as the major obstacles to implementing cloud BIM [26]. For example, shared common platforms, like cloud BIM, create significant vulnerability and uncertainties towards privacy and information security due to their nature of openness and decentralization [33]. Redmond et al. maintained that the current contract does not cover information about the ownership clarity of the BIM model [34]. The lack of a clear statement about responsibility and liability can hinder the adoption of cloud BIM. Moreover, the promotion of cloud BIM is in urgent need of a large number of technicians and professionals to adapt to this new technology [26, 34].

4 Local Data Exchange Method

The above two methods are general methods for BIM data exchange. Recently researchers have developed some other approaches to deal with local data exchange for partial models, including the serialization method, transaction-based method, and blockchain-based method.

4.1 Serialization Method

Some researchers attempted to serialize the contents of IFC files in order to store, transfer, identify, trace objects. Data serialization refers to encoding IFC objects into a format or data structure that can be stored or sent to other applications [35]. The data structure is critical for exchanging data and other applications at an object level.

One of the serialization methods is the "flattening" method. Data exchange relies on an identifier (e.g., the reference number of each line in IFC files and Globally Unique Identifier (GUID)) to trace objects. The line reference number serves as a local reference of an object, but only valid within one file [36]. With the help of these reference numbers, IFC files are organized into an object-based inheritance hierarchy [37]. GUID is a unique and reproductive 128-bit number for identifying objects [38, 39]. Different software has different internal data structures and editing operations, which results in the inconsistency and inadequacy of both the reference number and GUID to be an identifier during the IFC roundtripping process [40, 41]. Some techniques have been developed to avoid using the reference number or GUID as an identifier. The "flattening" method, proposed by Lee et al. [42], is to replace the reference numbers with the actual values by a recursive strategy and decode nested relationships between various instances to form a full and unique description string for an IFC instance itself [43]. In this case, each line of IFC files does not include any reference, and the hierarchical structure is "flattened". Each object can be identified by this unique string directly, not affected by the unstable reference number or GUID. However, such a flattening process may be sensitive to redundant instances [41] and produce an overly long string, which costs a lot of computing resources and time [40].

Some other studies seek to convert an IFC file into a graph. Arthaud and Lombardo developed a method to transform IFC files into oriented graphs [44]. Oraskari and Törmä derived an RDF graph from IFC files and used a Short Paths Crossings Algorithm (SPCA) to assign an identifier to those instances that do not have a GUID [36]. However, these graph-based methods depend more or less on the GUID and can be very time-consuming when IFC files are too large. Additionally, these methods cannot cope with duplicate instances [41].

4.2 Transaction-Based Method

Froese pointed out that collecting common data in a centralized server allows various flexible data management services and enables a series of transaction-based IFC exchange with proper data exchange protocols between distributed parties [45]. An IFC-based transaction is a minimum unit of information exchanged, which is presented in a standardized form. Examples of a transaction can be a request for certain information, notification of changes, online purchasing, and so on.

A lot of research efforts have been paid to build such a centralized server or database for transactional data exchange. Jørgensen et al. developed an IFC model server, supporting functions such as working on partial models, granting different access rights to different users, and versioning on an object level [46]. Beetz et al. developed an open-source IFC server, BIMserver.org, allowing to store, maintain, and query BIM information for different end users [47]. Based on such a platform requiring low cost and technical expertise, many applications have been further introduced, such as open query language (BIMQL) [48] and model view checker [49]. Singh et al. summarized the technical requirements and features for a collaborative BIM server platform by interviews, case studies, and analysis of existing platforms [50]. Lee et al. adopted an object-relational database method to build an object-relational IFC server (OR-IFC), significantly reducing the query-transaction time [51]. In addition to the data exchange within BIM, Du et al. realized the real-time information interaction between BIM and VR via transactional data exchanges [39].

These transaction-based data exchange applications generally benefit from GUID, which could be used to index an object for each transaction. Nevertheless, its disadvantages also lie here. GUID has been criticized for its inconsistency and instability [40]. The transaction-based method can be ineffective when there is no reliable index. Moreover, formal and widely-accepted standards that define the transaction in detail are needed [45]. In a sense, the IFC schema provides a list of vocabularies for communication. But the industry also needs to reach an agreement and establish formal and uniform standards to define the content, format, and constraints in a transaction.

4.3 Blockchain-Based Method

Since Nakamoto proposed the prototype of Bitcoin in 2008, blockchain, as its core technology, has been a buzzword around the world [52]. Nowadays, blockchain has evolved from version 1.0 to 4.0 [53]. Blockchain technology has permeated into all walks of life, including the AECO industry. It can be used to facilitate the BIM collaboration process.

Xue and Lu developed a semantic differential transaction (SDT) approach to capture model changes as SDT records and chronologically collect them into a BIM change contract (BCC) [43]. All the stakeholders can submit their BIM changes to the blockchain, and all history changes of the project are stored in one blockchain, unchangeable. This method addresses the challenge of information redundancy in integrating BIM and blockchain, and turns out to be light and lean, suitable for performing heavy computation [43].

However, the conflict-resolving mechanisms need to be improved by some other sophisticated models [43]. And only two pilot case studies were conducted to prove the feasibility of the SDT approach. More tests considering extensibility and compatibility problems should be carried out within real blockchain shells in the context of practical construction projects [43].

5 Conclusions

BIM data exchange plays a crucial role in BIM project collaboration. With the development of Information and Communication Technology, some previous problems are already solved while some new issues emerge. In this study, the current BIM data exchange methods are comprehensively reviewed. For the file-based data exchange method, it is regarded as the most straightforward way. Still, its disadvantages lie in its one-way file-transfer manner and incapability to manipulate at an object level. For the cloud-based data exchange method, it is praised for efficiency, low cost, real-time access to data, and on-demand access. However, the cloud BIM also faces the problem of lack of open cloud BIM standards, and too much organizational and legal issues, such as privacy, information security, lack of sufficient technicians, and ownership and responsibility clarity. There are some local data exchange approaches developed for partial model exchange. The "flattening" method dissolves all nested relationships between objects and identifies an object by a unique string. Others tried to convert IFC files into a graphic structure. However, these methods are not applicable to large IFC files and depend on the unstable GUID more or less. For the transaction-based method, most of them are based on the GUID, which might be inconsistent. With the help of blockchain, a novel semantic differential transaction (SDT) approach collects the model changes into a blockchain, better solving the problem of redundancy. However, this is a brand-new method, requiring more consideration, such as conflict-resolving mechanisms, extensibility, and compatibility.

Future research directions should focus on: (1) improving the workflow of the construction project to reduce redundancy in file-based transfers; (2) establishing a formal standard for cloud BIM interoperability; (3) developing an efficient serialization algorithm to deal with large IFC files with less computing time and resources; (4) finding a unique, stable, consistent, and easy-to-use identifier to track IFC objects throughout the building lifecycle; (5) exploring more about the potential of blockchain and other emerging technologies in facilitating BIM data exchange.

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Classification of Photo-Realistic 3D Window Views in a High-Density City: The Case of Hong Kong

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Abstract Window view is an intimate medium between occupants and nature, especially in high-density cities like Hong Kong; and thus belongs to the quality of a house or apartment. In literature, researchers found that window views of nature are vital to the occupants' physical and psychological health and productivity improvement. Understanding the view situation at the urban level can facilitate urban environment optimization, urban planning and development policies, and smart city management. Currently, views of nature have been quantitatively studied in satellite images and cars' cameras at a macro or micro level, respectively. However, as an essential supplement to the greenery view information hub at a mesoscale, few studies on efficient visualization and classification of window views at the urban level seem available. This paper presents an automatic approach that captures and classifies photo-realistic views at the windows in a 3D photogrammetric city model. First, by triangulating the window geometries from geo-matched 3D photogrammetric and 2D digital maps, the rich window semantics are registered to the 3D models. Then, the similar window views are visualized in batch with an appropriate focal length and field of view. Finally, the view at each window is analyzed and classified through transfer learning automatically. We applied the proposed approach to the 3D model of Hong Kong Island and found satisfactory results for identifying nature scenes or urban scenes. Once massively adopted, the presented approach can offer novel geographic indicators for billions of urban inhabitants and the Architecture, Engineering, Construction, and Operation (AECO) industry.

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Keywords Window view · View visualization · View classification · View quality · 3D models · Urban

1 Introduction

Windows physically bridge the interior indoor space and exterior environment. A window view is a significant medium for people's access to nature, especially for high-density urban areas such as Hong Kong. A number of studies identified that a good window view of nature plays an essential part in human mental health such as stress relief [1, 2], physical health such as sleep improvement [3], disease remission [4] and working status such as productivity improvement [5]. However, crowded 3D cityscapes and high-rise buildings in high-density development scatter nature views and disparate inhabitants from getting close to nature equally. Window view quality became especially significant during the Coronavirus disease 2019 (COVID-19) pandemic because home isolation and social distancing measures kept billions of people from staying outside.

Besides, nature views from windows could also supplement the urban greenery information hub as the last piece of the puzzle at the mesoscale. In literature, views of nature as an important urban greenery indicator have been widely studied in urban landscape planning and management. For representing an overhead view at a macro scale, remote sensing has been commonly used [6, 7] because of its advantages such as repeatability, synoptic view, and area coverage [8]. For capturing street view at a micro-scale, viewer tools based on handheld or cars' cameras were introduced to visualize the profile view of urban greenery at the street level [8, 9]. However, for a 3D real world, massive window views visualized and classified to achieve greenery vertically at a mesoscale are still indispensable because of the uneasy access, immature technology and insufficient data. Thus, how to capture and classify the 3D window views in high-density cities at the urban level has become a significant and valuable research question, which can facilitate urban sustainability and optimization, including urban health [5, 10], urban environment optimization [11], planning and development policy adjustment [12, 13] and smart cities management [14, 15].

Several studies have been conducted to visualize views of windows in different ways, which mainly include manual drawing, computer simulation modeling, and camera capture. Hellinga and Hordijk [16] proposed an approach using a 180-degree equidistant projection to achieve the view of the window, which could be realized by manual drawing. Turan and Reinhart developed frameworks employing vector raytracing in 3D models to evaluate views quality [17]. For the window design, Li and Samuelson [11] do some manual work such as window location information inputs to visualize the window views based on 3D models of Google Earth, in which the images captured owned more realism due to the fine resources. Abd-Alhamid et al. [18] utilized a fish-eye camera to evaluate window views at different viewing locations in a manually built virtual environment. Some studies relied on questionnaires and surveys [19, 20] to take real photographs from the already-built windows. Although these methods have achieved relatively good results to evaluate the window view quality for different aims, they are all oriented to the single house or few estates with low automation and do not focus on the window view visualization at a larger scale. As a result, they are not applicable and efficient to help capture window views at the urban level due to increasing time-consuming manual works, limited data support, and expensive visualization costs.

For the classification of window views, most studies have been conducted in three methods, including subjective judgement, view feature proportion calculation and their hybrid. Studies on window view quality and impacts mainly use survey, interview or questionnaire methods to assess the views [20–22]. The views from the real windows or in the form of images are classified according to human subjective judgements such as a four-point scale [20], not satisfactory, satisfactory, good, and excellent. Some studies with architectural background calculate view features proportion to help guide the window and layout design using subjective or objective classification criteria [11, 23]. Studies in the field of computer vision have developed mature approaches for image segmentation [24–26]. The proportion of each kind of content feature and other advanced features such as spatial and color structure would be calculated to evaluate the image quality [24]. However, for the evaluation of the view quality at a large scale, classification methods including human judgement are subjective, which cannot reach a common standard. Approaches for quantitative image quality evaluation on computer vision and architectural design are not targeted to the specific window view content classification details directly and thus are not accurate and efficient for urban-level applications. To sum up, few studies available were applicable to window view realistic visualization and classification at the urban level automatically and efficiently.

Oriented to the urban applications, this paper presents a novel approach to capture and classify the views from existing windows of estates automatically, based on the integration of a 3D photogrammetric city model and 2D digital map. By matching the 2D footprint data with buildings' 3D models, window view semantics are registered into 3D models in batch. Then views of windows with position and orientation information can be efficiently captured through 3D GIS visualization methods. In the end, the window views are analyzed and classified by transfer learning automatically. The remainder of this paper is organized into the following sections: methods, a pilot case study, discussion and conclusion.

2 Methods

This paper presents a novel approach to collecting and processing 3D window views. As shown in Fig. 1, the input to the approach is the actual footprint data of the buildings and their photo-realistic models. In the workflow, for view capture and classification of a single building, automatic data processing mainly includes three steps:

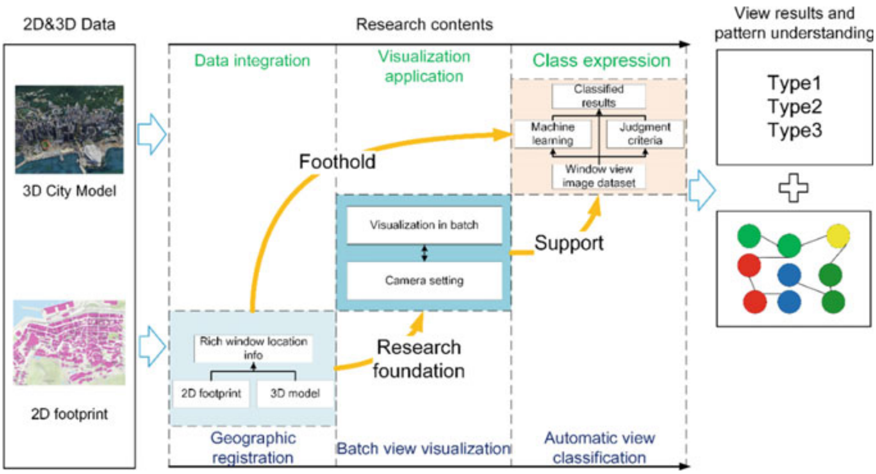


Fig. 1 The research design of the proposed view visualization and classification approach

1) semantic information registration of windows based on geo-matching of 2D and 3D data at the urban level,
2) window view visualization in batch with appropriate camera settings, and
3) automatic window view classification by transfer learning and judgement criteria.

The outputs of the approach include categorized views of windows in three major types.

2.1 *Window Geographic Registration*

For a target building, the first step is window geographic registration. 3D photo-realistic models depict the actual appearance of buildings and their vivid built environment settings, in which the window location and height information can be easily extracted. 2D footprint provides accurate layout geometry information as well as rich static text attributes, in which the window orientation information can be achieved. The integration of them as an information hub of buildings can provide solid data support for view capture. As both 3D photo-realistic models and 2D footprint data have accurate geographic references, buildings can be easily matched. Then semantic information of windows is extracted and registered to 3D models based on the data hub. In this approach, windows within one façade are considered to have the same orientation as their façade. In this way, by turning to the elevation view of each façade, windows can be determined correctly to reduce the visual deviation.

2.2 Window View Batch Visualization

The second step is to visualize window views in batch. In this paper, the center of the window is considered the location of the digital virtual camera. Based on the windows' location and orientation information, the camera can be placed on the targeted window automatically. The focal length of the camera is set appropriately to control the involved view features details. The field of view of the camera is adjusted to control the view size. In this way, a similar visualized result can be achieved to stimulate the real window view. By repeating this process automatically, views of windows in each façade of the target building are captured in batch.

2.3 Automatic Window View Classification

The final step of the proposed approach is the automatic window view classification. In this paper, a deep transfer learning model is used to classify the window views automatically. Views of windows are simply categorized into three types according to the proportion of nature scenes, which regards vegetation view, sky view, sea view or their hybrid as nature view, house view, street view, road view or their hybrid as urban view, and the hybrid of nature view and urban view as hybrid view. The *a-priori* rules are applied to classify the window views. To achieve a complete nature view, we assume that window views with more than 95% nature elements are regarded as nature views. Window views with less than 5% nature elements are urban views while if the proportion of window views' nature elements ranges from 5 to 95%, they are hybrid views. Besides, to extract more urban views from hybrid views, if the percentage of green elements of natural features such as vegetation is less than 5% and the figure for the sky and sea elements is less than 50%, the hybrid view is also considered as the urban view in this article.

3 A Pilot Study

3.1 Window Geographic Registration

Lap-Chee College on Lung Wah Street is a high-rise student hostel of the University of Hong Kong, as shown in Fig. 2. We selected the Lap-Chee College to validate the proposed approach. The scene of the building and its neighborhood environment from the photogrammetric 3D city model is shown in Fig. 2a. The 2D footprint data of it in the GeoJSON format were transferred from shapefile data (iB1000) purchased by the University of Hong Kong. The photogrammetric 3D city model was collected from the Government of Hong Kong [27]. The matched results were shown in Fig. 2b visualized by Cesium (version 1.73, https://cesium.com/).

Fig. 2 Geographic registration of the case building. **a** target building and its environment, **b** geographic registration

Although the boundary line of the building is given by the 2D geometry data, some construction points which are not vertices still exist. Thus, an approach by calculating the angle difference of the line between adjacent points was proposed to determine the vertices and orientation of the building's each façade. The detailed steps are as follows.

1) A 2D building footprint A in the GeoJSON format contains a list of n points $A = \{p_1, p_2, \ldots, p_n\}$.
2) Let $p_{n+1} = p_1$, the direction a_i can be computed for the i-th edge (p_i, p_{i+1}), $1 \leq i \leq n$.
3) If a_{i+1}–a_i $(1 \leq i \leq n)$ is larger than a threshold β, the point p_{i+1} is considered as a vertex of the geometry and recorded.
4) After all the vertices are recorded, the orientation of each facade edge can be calculated. In Cesium, orientation represents the rotation from the local north direction where a positive angle is increasing eastward.

For the case building, the windows can be recognized from the building's front and back views, as shown in Fig. 3a and b. Then by flying to each façade in the elevation view, the center of the window was selected, as shown in Fig. 3c. In the meanwhile, the location and orientation information of windows was registered to 3D models and then collected in the database.

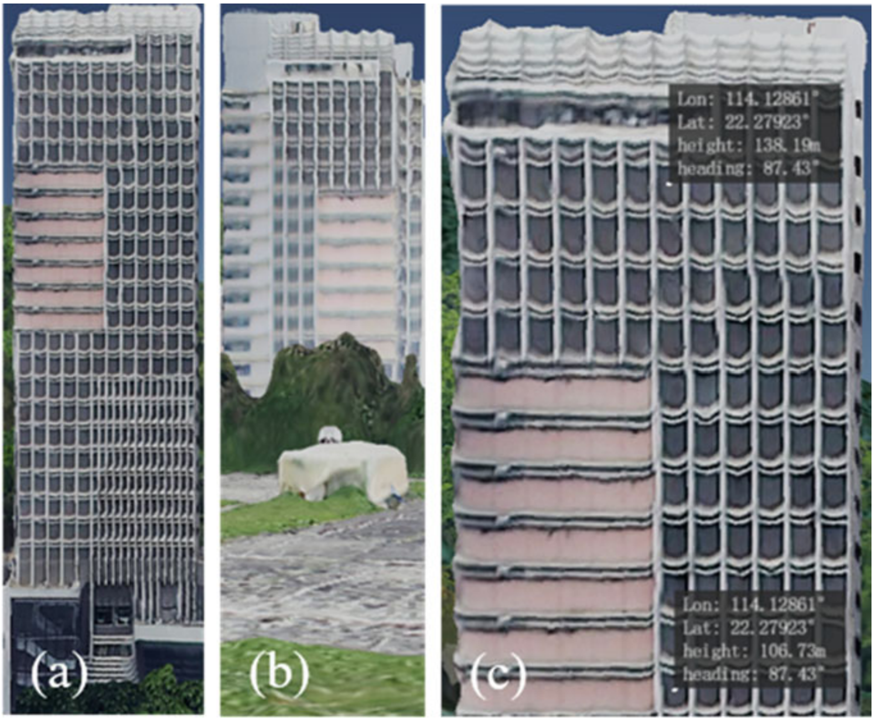


Fig. 3 Location information extraction of windows. **a** front, **b** back, **c** location information collection of windows

3.2 Window View Batch Visualization

The data visualization and procession were based on an open-source platform Cesium. Cesium is a fast, simple, end-to-end platform for tiling, visualizing, and analyzing 3D geospatial data, which was first released in 2011 and has been used as a tool for 3D visualizations that are accurate, performant, and time-dynamic on the web. Camera settings, including camera destination, camera heading, camera tilt, and camera focal length, can be customized using this tool, which makes it possible for users to set the camera at a proposed position and obtain the view shots efficiently by computer programs.

To visualize the window views in batch, a virtual camera mounts on the target window at the 3D coordinate (longitude, latitude, height) with known orientation. And then, by adjusting the camera's focal length and field of view, a similar view of the window is achieved. In Cesium, we used the "zoom" function to control the virtual camera's focal length, and the canvas size was adjusted to match the window's real size. Four test windows were selected to make a comparison, as shown in Fig. 4. Photographs (1a, 2a, 3a, and 4a) for the windows were taken using iPhone X, while the virtual camera captured views of windows (1b, 2b, 3b, and 4b). Based on the

Fig. 4 Comparison of real photos and window view results. **a** ground truth photographs, **b** our view results

comparison results, Cesium's view visualization approach is considered realistic and accurate enough to satisfy the intended purpose. The average time spent on one view image visualization and procession was 3 s.

3.3 Automatic Window View Classification

In this paper, the DeepLabv3, a deep learning model trained on the cityscapes dataset, was used to analyze the visualized results at a pixel level[28]. By deep transfer learning, each pixel of a view image could be segmented into one of twenty classes including vegetation, building, sky, terrain, etc. By calculating their percentages in the photo, classifying the classes into nature or urban groups, and implementing a quantitative comparison according to the *a-priori* rules, the type of view could be determined, as shown in Fig. 5. For instance, the proportion of natural elements of window view #1 is 0.98, which is more than 95%, and thus it is regarded as a nature view.

The deep transfer learning was conducted on the workstation with two Intel XEON E5-2690 v4 CPUs (2.6 GHz, 28 cores), 64 GB memory, an Nvidia Quadro P5000

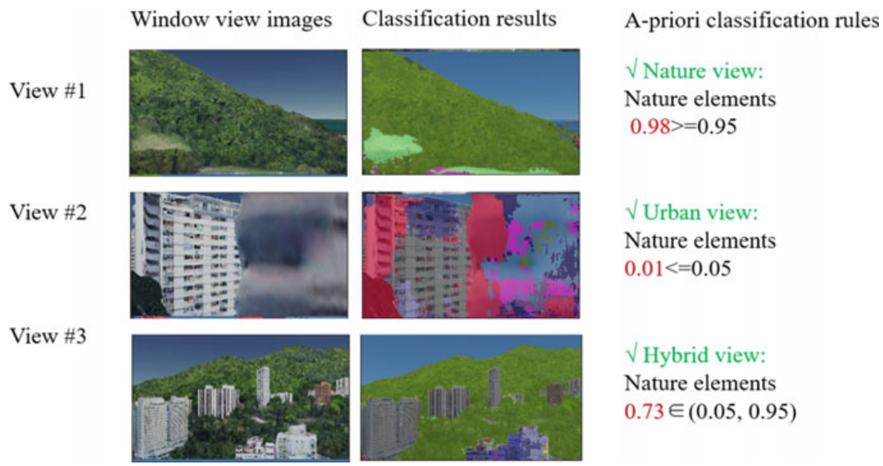
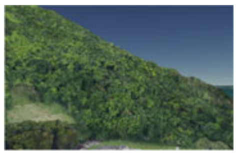


Fig. 5 Window view classification process

GPU and Windows 10 Enterprise 64-bit operating system. The average procession time of one view image was 1.96 s. Based on this way, view images were captured and classified in batch. Examples of three typical kinds of views on floors with different heights are shown in Table 1. For the nature views, higher flats can see more pixels of the sky while the lower flats can only see the greenery. The differences were also noticeable for urban and hybrid views, despite the composition of more types of

Table 1 Examples of three kinds of views on floors with different heights

View type	Lower-rise flat	Middle-rise flat	Higher-rise flat
Nature			
Hybrid			
Urban			

pixels. A clear trend is that higher-level flats offer views with higher-level natural sights, landscape distance, and perceived spaces. In a high-density city like Hong Kong, this access to nature could be preferred. Example applications such as view scoring and analysis can be used for real estate valuation and built environment optimization in the AECO industry.

4 Discussion

View quality on the extent of getting access to nature was difficult to investigate, obtain, and analyze qualitatively or quantitatively in the past, especially in high-density areas. However, with the rising 3D reconstruction technologies, such as oblique photogrammetry, laser scanning, building information modeling, and digital twin cities [29], the proposed approach can provide a novel way to compute the view semantics at the urban level. Compared with existing view visualization approaches that require modeling the outdoor context in 3D or manipulation of extensive data [11, 16–19], the proposed view visualization approach reduces the intensity of human–computer interaction and is more applicable for the urban investigation and analysis. By implementing a comparison test with the real windows views, this approach's views of windows captured and visualized, including full context information, are accurate and realistic enough, providing a refined dataset of realistic-looking results for the urban analysis. Compared to existing window view classification methods [11, 20–23], this approach utilizes a deep transfer learning model and *a-priori* rules to categorize window views quantitatively and efficiently, which are more applicable for automatic large-scale view evaluation. To our best knowledge, it is the first method to automate the process from visualization to classification of window views for urban-level view understanding. Related works mainly focus on the view assessment of a single window or building. Applying them to the large-scale window view visualization and classification would face intensive human–computer interactions, expensive production costs and low-level automation.

This pilot study preliminarily confirms the technological feasibility of the proposed approach. Nevertheless, limitations still exist, and future goals for the proposed workflow are described below. They include the workflow automation improvement, construction of view content quality index framework, and correlation analysis between view index and other urban features. The current workflow requires higher automation. For instance, the window centers were determined by batch selection. Future work could develop a more integrated workflow to further improve the automation of the whole process. A nature view or urban view was classified in this paper, which was rough to make use of views information. Future work was planned to focus on constructing the view content quality index framework and corresponded view classification and scoring by machine learning. Based on view index data, more spatial and correlation analyses could indicate urban phenomenon and patterns.

5 Conclusion

Views of windows that measure the extent to which occupants can access nature are vital to various urban topics on health, sustainability, and optimization. However, the detailed and realistic views data are not well prepared to enable such studies. This paper proposes a novel workflow to help visualize and classify building windows at the urban level. By integrating 2D and 3D data of buildings, geometry information of windows could be registered efficiently. Then, by placing a virtual camera in the center of the windows, similar realistic views are visualized in batch. In the end, window views are classified as nature or artifacts automatically.

Compared with existing view computing approaches, it is the first method to automate the whole process of window view visualization and classification for urban-level view understanding, which lowers human–computer interactions, generates accurate and detailed results. A pilot study confirmed that the effective window view capture and visualization approach could provide a tool for view visualization and analysis at the urban level, which can offer a new data hub for smart city management. Future work focuses on higher workflow automation, construction of view index framework, and correlation analysis between view index and other urban features.

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Modular Construction: Design Considerations and Opportunities

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Abstract The realization of Modular Construction (MC) is impeded by several barriers, e.g., initial investment, logistics constraints, and negative perception. Design, a profoundly creative process to alleviate difficulties in the built environment, is prospected to enhance this construction method. Under this circumstance, many guidelines, recommendations, and avoidances have been proposed to design. However, every coin has two sides. This research, therefore, argues that MC also provides new design opportunities, which have not been yet extensively investigated. It does so by comprehensive literature review and detailed archival study of successful case studies. The result unveils that although MC, by nature, may impose several design limitations, e.g., design simplification, standardization, and limited dimension, it can also serve demands and construct an outstanding architectural design by, for example, a composition of three-dimensional unit, mass customization, and product prototype. This research creates a balanced view of MC in a design process, and highlights the new approach for further design and research development in this discipline.

Keywords Modular construction · Architectural design · Design for excellence · Design for manufacturing and assembly

1 Introduction

Modular Construction (MC) is an innovative construction method, basically comprising the room-sized free-standing integrated units manufacturing in a factory-like environment, logistics, and installation to form an architecture [1, 2]. These units are preassembled with finishes, fixtures, and fittings to minimize work in-situ [3]. If comparing this prefinished volumetric unit to the other prefabricated products, MC is classified a high level of prefabrication [4]. This construction method has

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been applied to many building types, especially in cellular-type building, including hotels, student dormitory, governmental building, and social housing [5].

MC is becoming more widely used, since it has offered numerous advantages to the industry. They include quality improvement [6], construction time reduction [5, 7], productivity enhancement [8], workforce safety [9], and waste minimization [5, 10]. In spite of these various benefits, MC also experiences criticism. The method implementation in the real-world cases is undermined by, for example, the significant investment on the production line establishment [11], and transportation regulations and constraints [12]. In addition, this modernized construction process and machinery need an experienced workforce and technician for operation [13]. These shifts in the procedures also require more attempts from stakeholders and alterations in construction practices [14]. Moreover, there is a somewhat stereotypical perception in the architecture, engineering, and construction (AEC) industry, or even the general public that architectural design is limited by the drawbacks of MC [15, 16].

Many efforts have already been made to support this innovative construction realization. Design, as an initiation process shaping the following activities [17], is currently prospected to be a new faith to alleviate MC difficulties. In such circumstance, organizations and researchers worldwide provide MC design requirements, recommendations, lessons, instructions, and practice examples for practitioners [18–20]. Nonetheless, everything has two sides. While design considerations and avoidances for MC have been extensively studied, the new design possibilities occurred from MC have not been widely debated in the previous research.

This paper, therefore, aims to explore both benefits and limitations of MC to an architectural design process. It is also expected to highlight new design opportunities, derived from MC, for the further design and research development. This is achieved by reviewing literature and revisiting successful case studies. The remainder of this paper consists of four sections. Section 2 provides the background information of MC and architectural design. It is followed by the research methods adopted. Section 4 displays the design considerations and prospects, distinguished in this study. Finally, it reaches the discussion and conclusion parts.

2 Literature Review

2.1 Modular Construction

Modular Construction (MC), sometimes called volumetric prefabricated construction, refers to a construction process of prefinished 3D unit assembly to be a part of or create the whole building [1, 2]. In general, MC consists of three main stages. It begins with manufacturing in a factory-like environment. This system borrows the concept of the production line, the industrial workstation, and repetitive duties, to reduce the amount of work in-situ [21]. Then, a wide range of such modules, from basic structure to fully furnished units, are transported to construction sites for assembly. Finally, all modules are installed, and structural, mechanical, electrical, and plumbing (MEP) systems are connected to form buildings [2]. The method current application includes student accommodations, hotels, hospitals, and governmental buildings [5].

Gibb [4] provides a taxonomy of such units: Level 0 A system uses zero forms of prefabricated units; Level 1 Component and sub-assembly (e.g., lintels); Level 2 Non-volumetric assembly such as 2D precast concrete wall panels or tie beams without usage space enclosed; Level 3 Volumetric assembly such as kitchen, bathroom, utility rooms with usable space enclosed; and Level 4 Modular building like a living unit with full usable space enclosed and some utilities installed. If sticking to the above definition, MC can be considered in Levels 3 or 4 in Gibbs' taxonomy, representing a higher level of sophistication in terms of production, transportation, and assembly.

The characteristics of MC offers numerous advantages to the industry. For example, product quality improvement is given by the factory-like environment in the production line [6]. It makes a variety of actions in construction more repetitive, controllable, and reliable, and contributes to an accurate monitoring system and immediate inspection. Secondly, the settings of MC provide labourers with a safe working environment and reduce their risky behaviours. The number of accidents can be decreased by 80% if adopting MC [5, 9]. Its production line system also boosts the construction productivity by a process revitalization and efficient project schedule [8]. Furthermore, construction waste management gains several benefits from the natures of volumetric prefabrication. It is able to minimize waste from timber formwork, plastering, and smoothening process. By using MC, solid landfill waste can be decreased by 70% [5, 10]. Finally, as on-site and production line tasks can be done simultaneously, it is estimated that the use of 3D unit prefabrication can decrease construction time by 50% and saved 7% of the total project finance [5, 7]. For developers, the shortening of time means a considerable reduction in interest charges and early return of investment capital [22].

On the other hand, MC is also challenged by several drawbacks. Firstly, MC incurs an increase of total construction cost, including the significant initial investment required for the production line establishment and operational cost afterwards. Against the stereotypical view, MC is more expensive than traditional cast-in-situ construction [11]. Moreover, the use of machinery requires experienced technicians, labourers, and experts to handle the modernized processes [13]. In addition, logistics becomes a fundamental concern in MC. One must investigate transportation regulations, routes, and traffic before design, since the delivery limitations directly affect the size, weight, and dimensions of modules [12]. A paradigm shift in architectural design and construction professional practices is also required to implement MC. Due to its restrictions, early coordination among stakeholders, and additional project planning and design efforts are necessary to ensure the construction possibility, prevent the risks, and facilitate the flow of the operations [14]. Finally, MC is suffering from a poor image resulted from technical problems, poor workmanship, short material lifespan, and building performance limitations during the first age of

MC [15]. Some stakeholders rejected the use of MC amid the anxieties of building aesthetics and the fear of monotony in an architectural form [16].

During the past few decades, researchers have introduced several means to mitigate these barriers, such as process supervision, computational technologies integration, construction knowledge sharing, and materials and joints durability improvement [16]. Recently, the trend has shifted the focus to design, as described in the following section.

2.2 Architectural Design

Design, in architecture, is generally a highly dynamic process, involving a number of explorations, examinations, discussions, and determinations, to resolve difficulties in the built environment [23, 24]. It handles with wide ranges of qualitative and quantitative requirements, e.g., regulations, building codes, functionality, buildability, feasibility, programs, sites, context, and human resources [25]. The Roman architect Vitruvius articulated that the process outcome, an architecture, should be of "durability", "utility", and "beauty", if expressed in modern English [26]. Unlike painting or sculpture, this creative process's outcome has a huge impact, since it shapes the following activities, namely manufacturing, logistics, construction, occupation, renovation, as well as demolition [17].

Due to the recognition of its significant, design is prospected to mitigate many difficulties and enhance MC. Many recommendations are generated to encourage this strategy. For instance, the Building and Construction Authority of Singapore (BCA) publishes Prefabricated Prefinished Volumetric Construction (PPVC) guidebook to provide fundamentals, requirements, and practical tips on how to design MC [18]. This report introduces many design concerns, e.g., transportation constraints, module configuration, machinery performance, and joints. The American Institute of Architects (AIA) supports design for MC by giving practice examples and lessons discovered from the previous cases [19]. In addition, the book, "Design in Modular Construction", reviews the generic types of modular construction, displays the application examples, and offers background information for design [20]. Furthermore, previous research encourages an integrated design process and early collaboration for effective design decision making [27]. Another study also highlights the demand for MC design guidelines further development [28].

While many efforts have already been done to corroborate design suggestions and avoidances, the new design opportunities, emerged from MC, have not been extensively explored in the previous literature. Until now, there are many notable modular architectures and successful case studies to be investigated. The new design prospects learned from these cases are expected to be beneficial for designers, and finally, increase the MC adoption.

3 Research Methods

This research adopted a 3-step method to investigate both design constraints and opportunities, emerged from MC, as shown in Fig. 1. It started from a literature review of MC definitions, advantages, and drawbacks, to understand its characteristics and current circumstance. The process and significance of architectural design are also clarified in this step. Then, the second step intended to explore design guidance, suggestions, limitations, as well as new options, arisen from MC. This was achieved by a comprehensive literature review related to architectural design and MC. At this stage, the archives of notable modular architectures, e.g., records from designers, research papers, and drawings, are also revisited. By using these methods, it is able to examine a complex dynamic of architectural design and construction projects from a real-life context, provide an explanation, and identify the causality [29]. Finally, this research analyzed the collected data, and highlighted both design restrictions and possibilities, derived from MC.

In this paper, Nakagin Capsule Tower (NCT) and Habitat 67 were selected to be the case studies. NCT, designed by Kisho Kurokawa, was studied, as it is the first successful high-rise modular architecture for actual use in Japan in the early 1970s (see Fig. 2) [30]. Located at the centre of Tokyo, NCT is a residential building, which consists of two core structures and 140 fully furnished capsules. Described by the architect, NCT aims to create an architecture in anticipation of a new age, achieve full mass production for living modules, and promote industrialization technology in the industry [31]. Praised in the New York Times, the tower is one of the notable magnificent architectures [32]. It has been recorded an architectural heritage by Documentation and Conservation of Buildings, Sites, and Neighbourhoods of the Modern Movement (DoCoMoMo) organization since 2006 [30].

Habitat 67, designed by Moshe Safdie, is a prototype project for fully mass-produced construction system in Montreal, Canada (see Fig. 3) [34]. As the Canadian Pavilion for the World Exposition in 1967, this experiment intends to indicate the

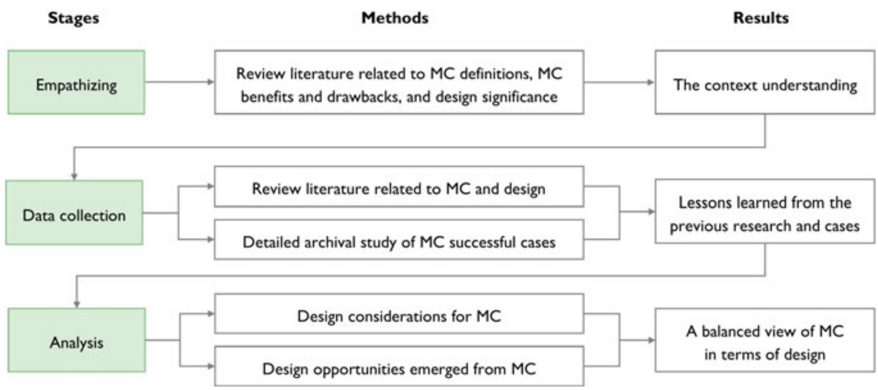

Fig. 1 Research methods

Fig. 2 Nakagin Capsule Tower (NCT) [33]

Fig. 3 Habitat 67 [37]

construction industry shortcomings and pave the way towards the new direction. Composed of 354 precast concrete modules for 158 living units, the building offered high-quality housing with a variety of spaces for dwellers [35]. It was also able to avoid monotony form in the dense urban environment. This case is currently recognized as iconic architecture, influencing the architectural design throughout the past few decades [36].

4 Results

4.1 Design Considerations

After a comprehensive review of previous literature and case studies, several concerns should be pondered during design to encourage MC efficiency, as described below.

Collaboration: Collaboration means a professional practice, which involves stakeholders to work together from the project initiation until the construction completion. It is recommended, since the architectural design for the modular building requires various information from different stakeholders for a precise determination [27]. Both research and practice agree that this approach can improve MC efficiency, prevent redesign and rework, ensure the project constructability, as well as minimize waste generated during construction [27, 38, 39]. The early collaboration also provides designers with a clear idea of MC and maximize flexibility in design options [19]. In NCT, designers collaborated with consultants, manufacturer, and main contractor during design to ensure the manufacturability, transportability, and feasibility of the project [31].

Design standardization: This suggestion refers to the repetitive use of industrial components or modules in design [38]. Based on the characteristics of a manufacturing line, MC requires a larger number of repetition in design for construction feasibility [34]. In NCT, It was adopted to ensure the capsule manufacturability in the container factory and enable mass production in construction [39]. The architect of Habitat 67 also realized this issue and applied the repetition of single standardized three-dimensional precast modules to the design. However, the architecture could still provide 15 different house types by combining one, two, or three modules together [34].

Design simplification: It is generally a design method, which aims to reduce a complex design to basic forms or elements. In the mass production system, the complexity of form means additional tasks, efforts, and costs. In both cases, although several choices of interior design and finishing were offered, all capsule's structure and exterior were kept to be as simple as possible to support the production flow [31, 34, 35].

Logistics constraints: Unlike the traditional in-situ construction, MC requires the transportation of a large module from a manufacturing line to a construction site. Transportation-related concerns should be pondered carefully from the project initiation [19]. They may vary, depending on a project condition, transportation route, as well as production location, which can be on-site, off-site, or even off-shore [40]. The case of NCT provided a practice example related to module logistics. According to the architects, the factory and construction locations, transportation route, legal restrictions, stopover point, on-site storage, and delivery schedule, were studied from the project initiation. The module's design, shape, weight, and dimensions, followed these restrictions to ensure the module transportability [31, 41].

Connection: Apart from logistics, a joint or connection between modules is another critical element in MC. While developing a design proposal, the design team is recommended to consider the joint's manufacturing, structural system, thermal performance, water penetration rate, fire resistance, as well as aesthetics. Collaboration is also suggested to assist in this detailed design [19, 20].

4.2 Design Opportunities

Although the concerns above could be regarded as the agents of design restrictions and shifts in architectural design practice, MC also offered new design potentials. This is realized by detailed archival studies of previous cases, as follows.

A composition of three-dimensional units: Unlike the focus on the composition of planar elements in conventional construction, MC allows designers to form an architecture by locating standardized volumetric modules together to create various architectural forms and combinations [20]. The way to arrange these modules during design resembles the action of installing prefabricated components together in construction. This is ratified by both cases. In NCT, the architect recognized this opportunity, and introduced "a sum of parts" to make a distinctive architectural form by the composition of the manufactured living cells [31, 38]. While, the form of Habitat 67 was clustered from the grouping of elements [34]. This innovative design technique, together with MC, was able to meet demands and avoid monotony architectural form, while the capsule's price was still reasonable [31, 34].

Mass customization: Mass customization refers to "the ability to provide individually designed products and services to every customer through high process flexibility and integration" [42]. It is utilized as both manufacturing and business competitive strategies. In construction, MC, together with this concept, can serve a variety of space required and enable variations in design. In NCT, it provided eight options of interior design [43]. It allowed users to express themselves by selecting or altering several standardized parts like a vehicle, e.g., interior finishing materials, colour, and alternative equipment [31]. This strategy can be adopted to design outstanding architecture and increase client satisfaction.

Product prototyping: One of the advantages of MC is an exemplary product model from original materials and structure. The capsule prototype can also be considered as a reliable method to demonstrate the design ideas and engineering system to buyers. In the case of NCT, the actual capsule was placed on the ground in front of the sales office to make clients have more explicit ideas about the product before purchasing [31].

Product mobility: Architects have proposed many ideas about architecture as a living organism, which needs to be grown, renovated, and renewed during the building life cycle. MC moves this rhetoric closer to reality by producing mobile modules, which can be transported, attached, detached, and relocated. In NCT, the capsules were attached to the main structure by high-tension bolts, allowing the module detachment or replacement without affecting others. This responded to the architect's belief that architecture can metabolize [44].

5 Discussion and Conclusion

5.1 Discussion

This research has several theoretical and industry contributions. It changes the stereotypical view that MC causes design restrictions and monotonous architectural form. Although MC, by its nature, may establish several additional criteria to architectural design, e.g., collaboration, standardization, simplification, logistics constraints, and connection, it also enables several design techniques, e.g., a composition of three-dimensional units, mass customization, product prototyping, and product mobility. For the real-life practice, the results create a balanced view between design limitations and possibilities. Both of them can also be utilized as a guide for design proposal development.

In addition, the research paves the way for further research. It initiates the discourse about the new design possibilities emerged from MC, which have not been extensively debated. The outputs from this study also support the ongoing development of Design for Manufacturing and Construction (DfMA) in construction. Since the recent study raises a critical issue that currently many DfMA suggestions in construction emerges from manufacturing industry background without considering the differences between two industries [45], the key terms and explanations, identified from the construction cases in this study, can be regarded as a part to support DfMA principles development.

On the other hands, several constraints and limitations should be addressed. Firstly, it is structured based on the literature review and detailed archival study. More investigations from real-life practice and feedback from implementation are necessary. Moreover, this is merely a preliminary study of design considerations and opportunities emerged from MC. The application may include, but not limited to, these design directions. Future research is recommended to focus on both sides to expand the knowledge body in this discipline.

5.2 Conclusion

Although Modular Construction (MC) has brought various benefits to the construction sector, it still experiences several barriers. From the project initiation point, design is prospected to mitigate difficulties hindering MC implementation. To support this promising strategy, a plethora of design principles, guidelines, and avoidance are generated; on the contrary, the new design possibilities acquired from MC have not yet been expanded. This research, therefore, reviews previous literature and revisits successful case studies to explore both sides. Eventually, five design considerations and fours opportunities are identified. The outcome corroborates that MC, liked every construction method, may impose several additional concerns to design, but also provides new design prospects.

This research changes the stereotypical view of MC in an architectural design process, illustrates a balanced view, and paves the new way for future research development to concentrate on the new design possibilities, occurred from MC. For practitioners, both identified limitations and opportunities can be utilized to achieve a higher level of stakeholders' satisfaction. The findings also support the current application of DfMA concept in construction. However, the design directions, identified in this study, are merely examples of thousands. More studies and real-life case studies are demanded to develop this sector further.

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The Iron Triangle of BIM Adoption in Construction Project Organizations

Jinying Xu and Weisheng Lu

Abstract Building Information modelling (BIM) is pervasively discussed and applied in the AEC/FM sector, however, its true adoption rate and quality are never ideal. This paper takes the human-organization-technology iron triangle as critical analysis lens of BIM adoption in construction project organizations. It systematically reviews the three vertexes (human, organization, and technology), the three edges (human-organization relationship, human-technology relationship, and technology-organization relationship), and the core (the human-organization-technology relationship) of the iron. On this review, it gives a comprehensive and fresh research and practical perspective for BIM adoption, states the importance of the balance among the human, organization, and technology, and identifies the key issues for future research in BIM adoption.

Keywords Building information modelling · Human-organization-technology relationship · Iron triangle

1 Introduction

Building Information modelling (BIM) is the hottest buzzword in the architecture, engineering, construction, and facility management (AEC/FM) industry. Every player in the AEC/FM industry is trying to harness the advocated benefits of BIM, such as better visualization, increased productivity, enhanced safety management, reduced costs, and a hub for digitalization. However, different organizations, even they are very similar to each other in size, context, and culture, report extremely different results [1]. Many companies are investing most of their money on the software and hardware, only neglecting the human and organization factors during the adoption of the technology. Some examples of human and organizational factors that hurdles the adoption of BIM are: lack of managers' and owners' awareness and support, changes in workflow and inappropriate business model, unclear roles and

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responsibilities for loading data into a model or databases and maintaining the model, lack of effective collaboration between project stakeholders, organizational structure that does not support BIM, need to educate professionals about BIM, workers not familiar enough with BIM capabilities [2, 3]. Without being well-prepared for these problems, the benefits of BIM can never be fully harnessed. This paper points out that, human, organization, and technology form the iron triangle for any technology adoption in organizations, undoubtedly including BIM adoption in construction project organizations [4, 5].

This paper will systematically review the three vertexes (human, organization, and technology); the three edges (the human-organization relationship, the human-technology relationship, and the technology-organization relationship); and the core (the human-organization-technology relationship) of the iron triangle. The iron triangle of BIM adoption in construction project organizations is demonstrated in Fig. 1. It will provide a fresh and comprehensive perspective of assessment for researchers and practitioners when they are planning for the BIM adoption processes, which can help promote the adoption of BIM at a higher speed in all organizations. Figure 1 also presents the structure of the paper.

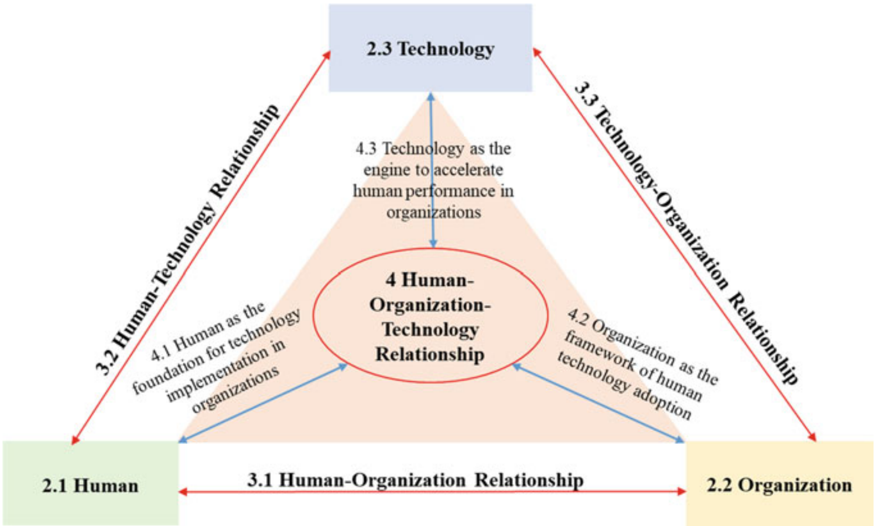

Fig. 1 The iron triangle of BIM adoption in construction project organizations and the structure of the paper

2 The Three Vertexes

2.1 *Human*

Human is a meta-unit of analysis in organization and management studies, allowing to investigate the organizational phenomenon from a micro-level. Any robust organizational theory, practice, regulations need to be rooted in and located at the study of humans. However, it is hard to study human in organizations because a human is complex with their own characteristics, behaviors, thoughts, and his/her interaction with others, the organization, and outer environment. From existing literature which touched human level analysis, there are two types of human features, i.e., human characteristics and the interactions between humans, which receive most attentions in managerial studies.

Humans are people who have their own personality, knowledge, ability, skills, experiences, and other characteristics [6, 7]. These people are the fundamental core elements of every social organization. They are the most important, valuable, and unique assets of organizations [6, 8, 9]. They make organizations go or stop [10]. They are technology developer and technology user. Humans are treated as resources and capitals in economics and human resource management (HRM). In current society where labor is highly divided and specified, organizations are competing for talents. It is believed that putting the right humans into the right jobs at the right time based on humans' qualities and the rapidly changing organizational requirements can enhance organizational effectiveness [6, 8].

At the macro-level, researchers in organizational theory and strategy domains scrutinize how accumulated humans' organizational-level experiences, education trainings, and skills can be strategically beneficial resources to facilitate organizations to accomplish superior performances and win competitive advantages [7]. Many scholars connect human factors with organizational performances [11–13]. As stated by the resource-based perspective, organizational human resource (HR) has great impact on organization performance and thus serve as an exceptional supply of competitive advantages [12]. According to Delery and Doty [13], organizations with better match between HR practices and organizational strategies should have the benefit of greater performance. Specifically, the situational HRM system strength is a key mediating factor through the process of employee's accumulated attributes affecting organizational effectiveness [12]. On the other way, organizational performance can give information and resource feedbacks to support adaptive HRM processes [11]. However, such findings are criticized by lacking additional mediators between HRM and organizational performance and failing to investigate the subjective processes by which HR practices are enacted, perceived, and interpreted [9]. Overall, it is widely accepted that human is a critical factor influencing organizational performance although the internal mechanism largely remains an unrevealing black box.

At the micro-level, in the HR, organizational behavior, and industrial/organizational psychology domains, scholars address human knowledge, skills, abilities, and other characteristics (KSAOs) [7]. KSAOs include the human characteristics such as cognitive ability, reasoning, comprehension, expression, communication, thinking, conscientiousness, personality and other characteristics [14–16]. Other characteristics such as flexibility, willingness to learn new skills, willingness to accept transfers or additional tasks, willingness to respond to whole range of organizational needs, and responsibility are also valued by organizations [17].When selecting HR for organizations, the KSAOs set of a human is the primarily attended attribute. By matching KSAOs and job requirements, organizations are employing through 'a fit between a human's personality, beliefs and values and the organization's espoused culture, norms and values' [18] for their compatibility and competitiveness. Specially, there are two types of KSAOs: general KSAOs and specific KSAOs. The former is obtained previously through general training and education and can be applied to a broad range of jobs across organizations while the latter is usually acquired during working for a specific industry, organization, job, or task, which is hard to be transferred out [19]. Good fitting KSAOs may be the key to fostering improved organization performance [20].

2.2 Organization

Organizations are not only the contexts influencing human activities, but collective actors for accomplishing specific goals through collaborative actions and repositories of resources under public legitimation and social support [21, 22]. They are significant in contemporary society because of their ubiquity, their impact on power and status, their effects on personality and performance, and their contribution to our understanding of human interactions [22]. There are various dimensions in organization studies, among which, organizational structure is the most attended, organizational change is becoming a popular focal point. Organizational structure, the core of any organization, emphasizes how an organization is organized. It stipulates the formal hierarchical positions of humans, their responsibilities and power, and shape the process of organizing. If organizational structure is a static picture of an organization, organizational change investigates its dynamic aspects. In the contemporary society, every organization should adjust to the changing environment and technologies. After reviewing these two significant aspects of organizations, this subsection will narrow down to summarize the special characteristics of construction project organizations.

Organization is framed by organizational structure. The latter is the defining and crucial outline and guideline of an organization. Organizational structure assembles jobs into larger units and outlines hierarchical relations and patterns of formal interactions among humans and units [22]. It has a great impact on the organization effective performance and the relationship among humans. Peter Blau defined organizational structure simply as "the distributions, along various lines, of people among social positions that influence the role relations among these people" [23]. The definition emphasized the significance of human and their relations. Child [24] defined organizational structure as 'the formal allocation of work roles and the administrative mechanisms to control and integrate work activities including those which cross formal organization boundaries'. By allocating work roles, organizational structure formally defines a human's position, hierarchy, role, power, responsibility, and relationship with others in the organization. Trough administrative mechanisms, organizational structure directly shapes organizational routines, processes and actions. Organizational structure can also be regarded as the information structure and decision-making structure [25]. Organizational structure maybe influenced by the organization types [21], size [26], technology [26], and other internal and external environment factors [27, 28]. A key to study the impact of different factors on organizational structure is to investigate the change of reporting, coordination, and authority relationship among humans [28].

Organizational change is one of the most discussed topics in organization studies although it "remained largely backstage as organizational thinking and practice engaged in a discourse dominated by questions of stability" [29, 30]. Instead of emphasizing routinization, standardization, control, and automation, the watchwords for today's organizations are flexibility, customization, and learning [29]. In light of this new setting, stability is replaced by change, which is not a background activity of organization anymore but a dimension of organizational life. Among various definitions of organizational change, two are frequently used: the first one views the organizational change as an variance on selected dimensions observed over time in an organizational entity; while the second takes it as a narrative explanation of event sequences on the way change unfolds [31]. The two definitions represent two ontological perspectives of organizational change. The first views an organization as a social entity maintains its identity while changing from one status to another over time, whereas the second put it as a reification of continuous breaking down and restructuring processes [32]. In this paper, it is accepted that both definitions have their correctness and represent the two aspects of organization and organizational change. Organization is both an entity and a process and organizational change is both a variance and an event-driven changing process.

2.3 Technology

Information technology (IT) is so pervasively and generally used in modern life that although everyone can sense what it is, no one can give an accurate definition to it. IT is perceived as the science or activity of adopting computers (and other electronic equipment) or software to create, collect, transport, store, process, transfer, display, or disseminate electronic information to support decision-making, to reduce the costs of coordination, communications, or information processing, to increase efficiency, productivity, or information sharing of individuals or organizations [33].The functions of IT include collecting, transporting, storing, process, transferring, displaying, and delivering data or information or technology. The final effects of IT are supporting operations, management, and decision-making, increasing labor efficiency and productivity, increasing knowledge of people and developing their abilities of operating technical and social processes.

BIM, an IT in the AEC/FM sector, is gaining momentum in the global construction industry, wherein the form of projects has long been taken as the norm across a significant swathe of activity [34, 35]. BIM, as an advanced revolutionary technology and process to produce, communicate, and analyses building models, has quickly transformed the way buildings are conceived, designed, constructed and operated [36]. Unlike other industries carefully deliberating a design before it is transferred for massive production, every construction project has a unique design, which may not be represented in an easy-to-understand way and to a sufficient level of details before proceeding to physical construction [37–39]. BIM, properly developed, allows pondering different design and construction options on a cyber-platform before they are truly executed on a physical site in a much less expensive way [40].

BIM serves as a shared and reliable knowledge resource for informed decisions during the lifecycle of a facility [36]. Governments around the world see it a strategic development and try to mandate its use in their public works [41]. Companies are compelled to adopt it for fear that they will soon lose their competitive edge if others have moved faster [41]. BIM is even acclaimed to bring a paradigm shift to the global AEC/FM sector [3, 42, 43]. With the development of BIM in the last thirty years, it is becoming a full integration and collaboration hub for the lifecycle management of buildings and infrastructures which can involve the inclusion of time/schedule management, budget calculation/quantity take-off, and lifecycle facility management dimensions [36, 43–48]. Other tasks BIM can enable or support include, feasibility studies, environmental analysis, clash detection, shop drawings creation, visualized constructability review, visual and geospatial coordination for construction of atypical shapes, schedule management for installation of components, and creation of as-built model for facility management.

3 The Three Edges

3.1 Human-Organization Relationship

Like the two sides of a coin, humans create and form organizations, while organizations organize and unify humans to get things done together. Organizations are constituted and enacted by groups of humans and interactions among the humans to achieve objectives cannot be achieved by an individual [28, 49]. Meanwhile, humans in contemporary societies are facilitated and constrained by organizations, or more straightly, they are the organizations they live and work [49]. Organizations are the environment, the structure, and the container of human behaviors. They pay for human's work, share profits with them, rewards them with appraisals and/or internal promotion, and provide them with insurance and job security [50]. Organizations invest in their members' expertise, careers, and extended benefits [17], design training to emphasize knowledge, behavior, and attitudes [51], and provide them with affiliation and welfare motivations [52]. Moreover, from a humanistic perspective, organizations can offer humans with intangible experience such as fulfilment of personal and spiritual desires for growth, meaning, purpose, community, networks, and transcendence beyond simply a steady paycheck [53]. It is evident that there is a highly correlation between organizations' offer for humans and humans' performance, specifically, better organizational offer brings higher identification to the organization and consequently makes humans more committed, more motivated, and performing better [52].

Humans and organizations serve as the micro and meso level systems for analysis, respectively. Human-organization relationship is a focal topic for scholars in fields of management and organization studies. It is also the most studied bi-party relationship in the human, organization, technology triangle. Human is the smallest social unit investigated in the triangle frontline. It is human that develops and uses technologies. Organizations are a group of people organized under certain objectives, structure, and processes. Humans belong to organizations and make up organizations which are the most usual power to promote and implement technologies. When a technology is to be adopted, the relationship between humans and organizations will be reshaped. Therefore, it is significant to review previous research constructs and findings of human-organization relationship.

There is a duality of the interaction between organization and human. On the one hand, organizational structure, strategies, policies, and regulations have a direct influence on human attitudes and behaviors. On the other hand, human behaviors are also one of the driving forces to reproduce organizational structure, processes, and environment over time [23]. An organization should create environment, structure, and processes to develop human's skills, knowledge, and motivation so that they adopt attitudes and behaviors which are influential to the achievement of the organization's objectives [12]. To develop long-term human-organization relationships, organizations should consider not only individuals' expectations, perceptions, and values, but also potential changes in these characteristics over time [54]. A human should also adapt to changing organization actions and fit the organizational structure, regulations, and especially expectations on himself to secure a position, earn a salary, and make contributions.

3.2 Human-Technology Relationship

Humans are intrinsically technological beings or technology users. Technologies are developed and used to enhance, supplement, or disburden human beings. They are undoubtedly a principal part of the human environment, especially in modern society. Humans influence technologies, just as much as they influence us, in every aspect of our daily lives. The research strand 'Philosophy of Human-Technology Relations" studies the mechanisms of influence of technology on humans throughout society and investigates how these influences can be acclimatized in the practice. Currently, there are three primary facets concerning this research topic: (1) Technology and identity, i.e., the way technologies (re)shape human's identity, e.g. freedom, autonomy, authenticity, and personality [55]; (2) Technological mediation, i.e., the mechanism of technologies mediating human-world relations through scientific practice, ethics, and religion [56]; (3) Technology and the society, i.e., the social and political role of technologies in the society [57, 58]. Human-technology relationship includes not only human's accepting or refusing technologies but also human's living with, being transformed by, being dependent on, and being enhanced by technologies [59]. Investigating the human-technology relationship is critical to the development of responsible and sustainable future technologies, which should be designed to maximize human needs and values while minimize friction. In some applications areas, especially those aimed at behavioral change, health and well-being, life-long employability, or a sustainable society, the development of technologies requires the engagement of humans, which is a precondition of their successful diffusion and adoption.

Of all technologies, IT is among the most pervasive ones that have significant impacts on humans. Although various research has studied the impacts of IT adoption at the individual level and agreed on the positive impact of IT on human performance at work, the mechanism of how such relationship happen has not been fully explored. It is found that the ubiquitous IT use has a direct influence on the efficiency, effectiveness or higher quality of human decision-making, and this influence is partially mediated by the extent of IT-facilitated autonomy and the quality of IT-facilitated coordination [60]. IT can provide faster and richer information for their tasks and improve coordination work with co-workers, thus alter the power and decision structure of humans. Such capabilities free humans from always waiting for instructions from upper management via a hierarchy and reduce the needs for repeated 'hierarchical referrals' [60]. Consequently, the features and functions of IT are future altered and enhanced to support humans in autonomy, coordination, and decision making. However, Humans are also viewed as sources of unpredictability and error of technology; moreover, changes in technology will require changes in human (e.g. skill requirements) [61]. The relationship between IT and human is typical in human-technology relationship, i.e., they determinately change each other and co-evolve with each other.

Contradictorily, according to the human agency perspective, which is against treating technology as a determinant of social change, technology is implicated in social exchange at the discretion of human agents [62]. Humans are relatively free to enact technologies in different ways: refuse it, use it minimally, invoke it individually or collaboratively, and improvise in ways that produce novel and unanticipated consequences, especially with computer-based information system [62, 63]. In another word, human agency holds the capacity both to sustain structures and to transform them [64]. Users would resist or reinvent in using a technology that constrain human agency [62]. It is humans that dominate their relationship with technology, each of their engagement with a technology is temporally and contextually provisional, and thus there is the possibility of a different structure being enacted [65]. Although this perspective has its standing and meaning in understanding the relationship between human and technology, it is a bit out-of-fashion since in today's society technology do change humans in a way they may not control. In this paper, it is accepted that humans are in a symbiosis relationship with technology.

3.3 Technology-Organization Relationship

Technology, and its relationship with organizations, especially in the aspect of organizational change in structure, process, and achievement, has gradually becoming a focal point of organizational research [65, 66]. Meanwhile, organizational context and changes are also being investigated by technology researchers. The stream which assumes (1) technology as both a physical object and a social entity, and (2) organization and technology are mangled together as a sociomaterial assemblage receives increasingly more acknowledgement [66]. In its perspective, technologies are reshaping organizations and being reshaped by organizations at the same time in both explicit and implicit ways [62]. As technologies and organizations are undertaking remarkable changes with unprecedented forms and functions, researchers are increasingly developing new concepts to explain the original evident approaches of organizing and using technology in organizational practice [65]. This research will focus on information technology and organizational change, and BIM and CPO based on the relevance of this study.

The technology used in projects is assessed by its level of certainty, complexity and interdependence between sub-activities in the construction project [67]. BIM is a comprehensive technology that can meet the three assessment requirements. A BIM model with parametric objects can definitely enhance the certainty in different aspects of construction projects management, especially cost [68]. BIM has been incorporated with diverse complex functions that cover the whole lifecycle of a construction project and thus lead to a wider use in projects by a greater number of technical functional specialists [69]. As construction projects become more technically interdependent, a one-stop platform to manage interdependence via BIM can increase the informality and flexibility of construction project control in project-based organizations [70]. Thus, theoretically, BIM is beneficial to construction project organizations [CPOs].

4 The Core

4.1 Human as the Foundation for Technology Implementation in Organizations

In the organization-technology relationship, human is the agent to physically and socially implement technology in organizations. Although technologies are the products of human action and therefore the medium of human action, they become constraints on human agency once they are installed and left to use [62]. Humans interpret, appropriate, interact with, change, and even resist a technology in various ways while using it, they shape technology and its effect [62, 71]. Such interpretations, appropriations, and interactions may also differ by time and place, requiring a more contextual and dynamic view of technology-organization relationship [72]. Technologies-in-use can be and are being changed by humans together with the alteration of their awareness, knowledge, behavior pattern, motivations, power, time, environments, and experiences with other technologies, same as all social structures are changed-through human action [65]. Furthermore, the value of the technology to the organization is stimulate and achieved through human agency. Even the opaquest technology must be comprehended and activated by human agency to be effectual [71]. But indeed, the characteristics of technology will also influence the attitudes and actions of human users. More friendly and capable technologies will have definite advantage over those are badly designed and supported. Moreover, humans' interactions with technology in organizations is also situated organizational characteristics such as size, structure, policy, culture, and processes, which can be both facilitating and constraining human's attitudes toward technology. Meanwhile, organization structures are not located simply in organizations or technology, but are enacted by human users [65]. Put it in another way, human, technology and organizations are entangled together and mutually impacted in the organizational technology implementation process. The role of any part should neither be minimized nor be maximized. Especially, human should not be excluded in organization-technology studies because humans are the ones who directly interact with the technologies and thus their feelings, experiences, and opinions should be valued, weighted, and counted in study technology implementation in organizations.

4.2 Organization as the Framework for Human Technology Adoption

Many technologies target at individual users while some professional ones aim to help humans in organizations. It is for sure that in the latter scenario organization is the context of technology adoption for users. But it is argued that organization's spread and training power even kicks in those individual-targeted technologies, because the user community itself is a huge organization where technologies diffused and promoted in planned and unplanned activities [62]. One person's technology adoption attitudes and behaviors are influenced by others'. For the technologies aimed at humans in organizations, improvised learning of the technology was motivated by organization leaders and enabled by other users [62]. More broadly, organizational structure has been investigated to pinpoint its relationship with the technology adoption process, although there is no agreed conclusion about which type of organizational structure best fit the technology adoption [73]. The strategy and focus of organizations towards certain technology are prone to affect individuals' motivational orientations, which may not be a dominant relationship to the human, but it is likely to exert significant effects on the sense and behavior of individuals towards the technology in the aggregate manner and over time [52]. This is because regardless of their own attitude and motivation toward the technology, individuals may feel strong isomorphic pressures to avoid behaving deviant concerning technology learning and adoption [74]. These attributes suggest that organization is shaping human's technology adoption everywhere, just like the atmosphere, through various channels. Consequently, organization is an unneglectable factor in studying the technology adoption by humans.

4.3 Technology as the Engine to Accelerate Human Performance in Organizations

In modern society, technology is a necessity for almost every human and every organization. The social and technical parts of an organization are inherently inseparable, technology mediates human performance in every organizations [66]. The role of technology in organization has increasingly attracted attentions from organizational studies scholars although it has not yet been fully considered in human-organization studies. Technology has accelerated the information transmission speed, changed the work conduction way in organizations, and even shifted the organizing structure of human organizations [25, 54]. Technology has also forced the environment to be quickly changing and intensively competitive. All of these changes have made the technology an indispensable and principal factor in the study of human-organization relationships and an engine to accelerate human performance in organizations [75]. However, current theories of technology and work are either too brutish or too brittle to capture the multiple and subtle ramifications technology has on humans in organizations [66]. Researchers should move toward incorporating instead of separating technology in human, work, and organization. The logic behind technology's impact on human, work, and organization is twofold. One is the bottom-up procedure where technology first affect human habits and behaviors, then improvise procedural, cognitive, and normative variations to accommodate their use of the technology in organizations, and finally shift organizational structure [29]. The other is the top-down procedure where organizations enforce or mandate the technology in organizations, change the work coordination and execution way, and humans have to adapt to the new processes in their work. In real-life practice, the bottom-up and top-down procedures usually take place simultaneously, although sometimes one way will dominate. However, emphasizing the critical role of technology in human and organization does not indicate the support of techno-centric perspective which takes a principally functional approach to understand how technology leverages human action while assume technology as exogenous, homogeneous, predictable, and stable to implement as designed across time and place. This study acknowledges and values the function of technology but defies technological determinism claims about the relationship of technology with organizations [72].

5 Conclusion

This paper has been concerned with human, organization, technology, as an iron triangle of BIM adoption in construction project organization, as well as their bi-party relationships. Every individual construct and their bi-party relationships are of significant influence on each other. While precious studies have laid broad and solid foundation to this research, they have not, however, addressed the tripartite relationship between the three constructs with enough depth, especially in the case of BIM, construction project organization, and professionals. Rather than focusing on single aspects or bi-party relationships in the BIM adoption context, which has been done in the previous research reviewed here, the emphasis of this study is on the human-organization-technology relationship. It summarized that human is the foundation for technology implementation in organizations, organization is the framework for human technology adoption, and technology is the engine to accelerate human performance in organizations. They are highly dependent on each other that they should be viewed as a whole when investigating BIM adoption.

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Understanding Construction Waste Recycling in Hong Kong: SWOT Analysis of the Government's Prevailing Initiatives

Wendy M. W. Lee, Weisheng Lu, and Fan Xue

Abstract The Hong Kong government has implemented the Construction Waste Disposal Charging Scheme since 2006 to promote construction waste recycling among contractors. Under the scheme, in addition to the conventional approach of disposing construction waste at landfills, contractors are given the alternative options of dumping pure inert waste and waste with over 50% by weight being inert materials at public fills and off-site sorting facilities respectively. Yet, the effectiveness of the scheme is questionable. By adopting a mixed-method approach encompassing cross-sectoral learning, attendance of Court hearings and semi-structured interviews, this study aims at understanding the status quo of construction waste recycling in Hong Kong using SWOT analysis, a strategic planning technique from the business sector. Through identifying the inherent strengths and weaknesses of the government's construction waste recycling initiatives, as well as the external opportunities and threats impacting the realization of such initiatives, we have formulated policy recommendations on how construction waste recycling can be boosted in the future. The findings in this paper provide a useful reference for the government's long-term solutions to construction waste recycling in Hong Kong.

Keywords Construction waste · Recycling · Cross-sectoral learning · SWOT analysis · Hong Kong

1 Introduction

Being a compact city in South China with only 1106.81 km^2 of total land area [1], Hong Kong has long been plagued with the issue of scarcity of land [2], and thus has limited space for opening new landfill sites [3]. At the turn of the twenty-first century, construction waste has constituted a considerable proportion of the solid waste being disposed of at landfills every year. By 2002, nearly half of the landfilled waste was construction waste (48.2%) [4]. Despite that the amounts of construction

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waste being landfilled per year had declined in the subsequent years, construction waste continued to account for nearly 40% of the waste being landfilled every year until 2005 [5].

In view of the aggravating situation, the Hong Kong government had endeavored to minimize the amount of construction waste generated through implementing the Construction Waste Disposal Charging Scheme (CWDCS) in 2006. The CWDCS had mandated all construction waste not being reused or recycled to be dumped at the government waste disposal facilities. Such facilities include public fill reception facilities (public fills), off-site sorting facilities (OSFs), landfills or outlying islands transfer facilities, depending on their components. The main contractors or other waste producers need to pay a service charge for disposing each ton of waste. The fee scale is:

- HK$125 for each ton of mixed inert and non-inert construction waste dumped at landfills;
- HK$100 per ton of mixed inert and non-inert construction waste accepted by OSFs; and
- HK$27 for each ton of inert construction waste accepted by public fill reception facilities.

The above service charges were later increased to HK$200, HK$175 and HK$71 respectively in 2017 [6]. Premised on the polluter pays principle (PPP) [7], the CWDCS aimed at reducing the amount of construction waste generated through promoting the reuse and recycling of waste among contractors [8].

During the first year of implementation, the CWDCS appeared to be effective in reducing both the amount of landfilled construction waste (from 2.39 million tons in 2005 to 1.51 million tons in 2006) and the proportion of landfilled waste being construction materials (from 37.0% in 2005 to 27.5% in 2006). Such figures were further reduced to 1.22 million tons and 24.8% respectively by 2011. Unfortunately, the decline in the amount of construction waste generated was accompanied by the aggravation of the issue of illegal dumping during the same period. According to the Director of Audit's reports Report No. 67 [9], the government only received 1517 complaints from the public on illegal disposal of construction waste in public areas in 2005. However, such figure was escalated to 6287 in 2011 [10], and was further increased to 8225 in 2016 [11]. Worse still, the amount of construction waste being landfilled had rebounded to a high level of 1.62 million tons in 2016, constituting nearly 30% of the total amount of landfilled solid waste in that year [12].

The recent intensification of the issue of illegal dumping in conjunction with a rebound in the amount of landfilled construction waste yield two implications: (1) illegal dumping has been increasingly employed by contractors as a means of evading the waste disposal service charges levied on them under the CWDCS; and (2) a considerable proportion of contractors are still reluctant to invest in recycling construction waste. It follows that the CWDCS has failed to meet its initial policy objective—to encourage contractors to recycle construction waste. It is against this backdrop that the following two research objectives have been formulated: (1) to understand the status quo of construction waste recycling in Hong Kong; and (2) to formulate policy recommendations on how construction waste recycling can be promoted in Hong Kong.

This study adopts a mixed-method approach comprising cross-sectoral learning, attendance of Court hearings and semi-structured interviews. This paper is structured as follows. Following this introductory section, Sect. 2 provides an overview of construction waste recycling initiatives in Hong Kong and a review of literature on SWOT analysis, which forms the theoretical foundation of our exploration of the status quo of construction waste recycling in Hong Kong. Section 3 is a description of our research methods. Section 4 reports on the data analyses, results and findings. Section 5 is a discussion of the policy recommendations formulated based on Sect. 4. Finally, conclusions are drawn in Sect. 6.

2 Literature Review

2.1 Construction Waste Recycling Initiatives in Hong Kong

The government has long been playing a leading role in promoting construction waste recycling. Prior to the introduction of the CWDCS in 2006, all construction waste not being reused or recycled ended up being landfilled. Under the CWDCS, apart from the conventional way of transporting construction waste to landfills, two new alternative disposal options were made available:

1. public fills which accept construction waste entirely made up of inert materials; and
2. OSFs that accept waste with more than 50% by weight being inert materials [6].

The service charges of public fills and OSFs are lower than those of landfills or outlying islands transfer facilities. Thus, contractors who are willing to conduct on-site sorting to separate non-inert materials from construction waste can certainly reduce their disposal charges by using public fills or OSFs.

Construction waste being disposed of at OSFs will undergo the processes of mechanical sorting and handpicking. Once the non-inert waste has been segregated from the inert waste, the two types of waste will be transported to the landfills and public fills respectively [13]. Contractors of both public and private projects are entitled to order inert waste from the public fills [14]. In addition, pursuant to a cooperation agreement with the Mainland authorities, the Hong Kong government has been transporting fill materials to Taishan County in Jiangmen for reclamation purpose since 2007 [9].

Furthermore, the government had provided an array of economic incentives to support the development of the recycling industry in Hong Kong. For example, the Recycling Fund has been launched since 2015 which offers funding support to local business enterprises to expand and upgrade their waste recycling operations, as well as non-profit distributing organizations (NPOs) (e.g., professional bodies, research institutes) to launch non-profit making projects to assist the local recycling industry in enhancing their productivity and operational standards [15]. To boost the development of construction waste recycling in the private sector, the government has been operating the EcoPark since 2007, which provides long-term land for recycling companies at affordable rent [16].

Upon a review of existing literature, there is a lack of recent studies investigating waste recycling policies in Hong Kong, particularly regarding construction waste. Wan et al. [17] used telephone survey to explore the impact of socio-demographic factors on the level of support to different waste recycling initiatives launched by the government, including but not limited to the CWDCS, Recycling Fund and EcoPark. It was found that the levels of support to such policies vary significantly among people of different genders, age groups and education levels. Later, Mak et al. [18] identified regulatory compliance, economic incentives, accreditation scheme, and logistics and management incentives as having the greatest impact on construction waste recycling behavior, which serves as a reference point for policymakers to formulate stakeholder-oriented recycling policies. In a more recent study conducted by Bao et al. [19], four facilitating measures to tackle the pre-existing barriers to on-site construction waste recycling in Hong Kong, one of which being provision of more governmental support, were proposed. All three studies had suggested certain directions for the formulation of future construction waste recycling policies. However, none of them had provided in-depth evaluation on the status quo of the prevailing construction waste recycling initiatives in Hong Kong, which is of crucial importance to devise policy recommendations best suited for the current situation of the city. To bridge this research gap, we employ SWOT analysis to examine the status quo of construction waste recycling in Hong Kong.

2.2 Overview of SWOT Analysis

Emerged in the 1960s, SWOT analysis is a highly popular strategic management and planning technique employed by business organizations in formulating competitive strategies [20, 21]. SWOT analysis is powerful in optimizing resource allocation [22]. The term “SWOT” stands for “strengths”, “weaknesses”, “opportunities” and “threats”. By “strengths”, it refers to the strong aspects which can add value to an organization [23]. By “weaknesses”, it means negative aspects of an organization that puts it at a disadvantageous position [24]. Both strengths and weaknesses are internal factors and attributes of an organization which can impact on its long-term development [25]. “Opportunities” are the environmental conditions that enable an organization to take advantage of its strengths and overcome its weaknesses [26]. “Threats” are environmental conditions jeopardizing the actualization of an organization’s objectives which should be avoided [27]. Both opportunities and threats are external environmental factors and attributes beyond the organization’s control [28].

SWOT analysis is conventionally applied by business organizations in evaluating internal (organizational) strengths and weaknesses as well as external (environmental) opportunities and threats. Nevertheless, we consider the cross-learning of this strategic planning technique from the business sector is suitable for this study because business entities and governments share similar rationale in making important decisions. First, in relation to the target of service, while business organizations always endeavor to satisfy the needs of clients, meeting the demands of the public has long been at the top of various governments' priority. One prominent example is that the Hong Kong government conducts extensive public consultation prior to implementing any new policies, including but not limited to the CWDCS. Second, regarding the guiding principle of operation, both business enterprises and governments seek to achieve cost-effectiveness. In the context of Hong Kong, despite that the government had launched a pilot scheme of installing GPS devices in construction waste collection vehicles to track illegal dumping in 2016, the scheme was aborted due to the high administrative costs involved [11]. Another example is the launching of the Recycling Fund in 2015 required prior approval of the Legislative Council's Finance Committee beforehand [15]. These examples illustrate the indispensable role played by cost-effectiveness in public administration. These two commonalities justify the application of SWOT analysis, a concept commonly applied by the senior management of business enterprises, to explore the current waste recycling initiatives led by the Hong Kong government.

3 Research Methods

This study adopts a mixed-method approach incorporating three methods: cross-sectoral learning; attendance of Court hearings; and semi-structured interviews. Figure 1 gives a summary of the research methods.

3.1 Cross-sectoral Learning

Cross-sectoral learning means discovering the best practices across sectors so as to uncover innovative ideas and to enable creative problem-solving, though it may not be possible to directly transfer the lessons learned from one sector to another [29]. For instance, Vanelslander et al. [30] examined the potential of cross-sectoral learning among different transport sub-sectors. Another more recent example is that Tan et al. [31] had developed a set of Design for Manufacture and Assembly (DfMA) guidelines for the construction industry based on the experience of the manufacturing sector, with a long history of adopting DfMA. In this study, we explore the status quo of Hong Kong's construction waste recycling initiatives led by the government by conducting SWOT analysis, a strategic planning model which originates from the business sector.

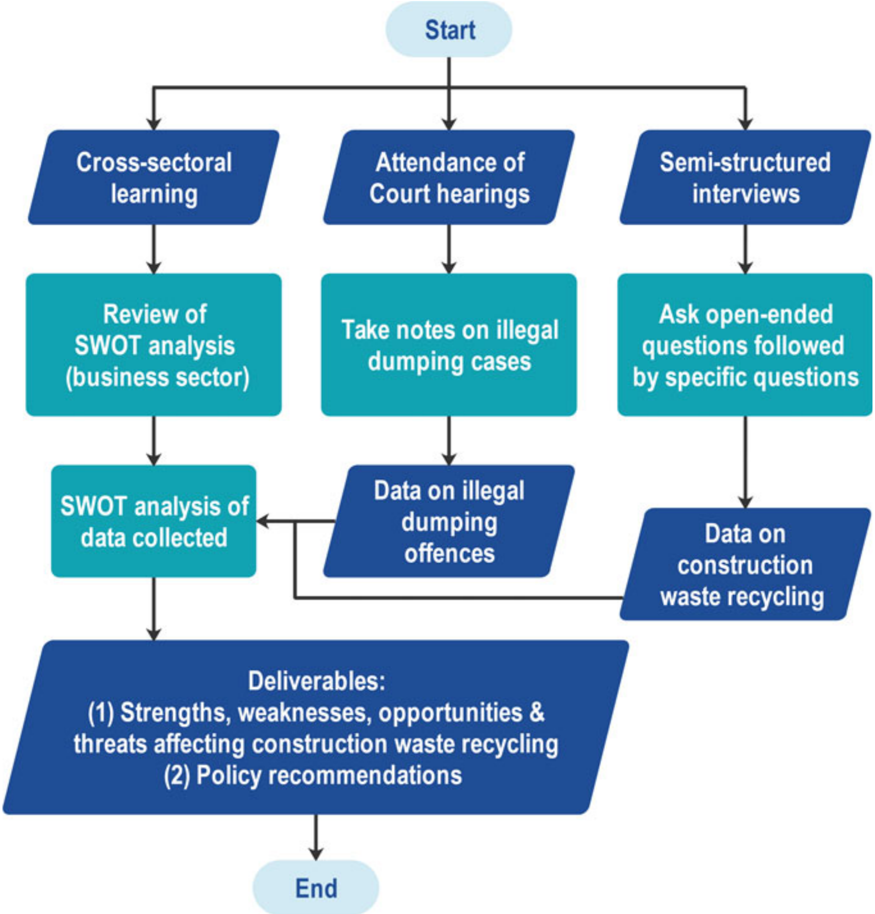

Fig. 1 Summary of research methods

In view of the difference in nature between business enterprise and government, for the purpose of this study, the precise meanings of "strengths", "weaknesses", "opportunities" and "threats" are refined as follows:

- "Strengths" refer to strong aspects facilitating construction waste recycling in Hong Kong within the government's control;
- "Weaknesses" refer to negative aspects impeding construction waste recycling in Hong Kong within the government' control;
- "Opportunities" refer to external environmental factors facilitating construction waste recycling in Hong Kong beyond the government's control; and
- "Threats" refer to the external environmental factors impeding construction waste recycling in Hong Kong beyond the government's control.

3.2 Attendance of Court Hearings

Obviously, contractors' identification of the low-cost alternative of illegal dumping contributes to the limited effectiveness of the CWDCS in promoting construction waste recycling. Therefore, it is worthwhile to garner a background understanding about the phenomenon of illegal dumping in Hong Kong. It is against this background that we had spent 2.5 months on attending Court hearings of illegal dumping offences being prosecuted in Courts in 2019, and notes were taken for further analysis.

3.3 Semi-structured Interviews

To garner in-depth understanding about the status quo of construction waste recycling in Hong Kong, we have conducted a series of semi-structured interviews. As a commonly used qualitative research method [32], semi-structured interviews refer to asking respondents predetermined but open-ended questions [19, 33], which is usually succeeded by raising follow-up questions based on the respondents' initial answers [34]. We had conducted a total of 11 interviews from November 2019 to June 2020. The respondents' backgrounds are highly diversified, ranging from government officials to the senior management of the construction companies and recycling companies (see Table 1 for a summary of the respondents' profiles). Each interview lasted for one to two hours, all of which were audio-recorded with the prior consent of respondents and transcripts were made for each interview. Thereafter, content analysis was conducted. We then further triangulated the results from the semi-structured interviews with the data collected from Court hearings, as well as the SWOT framework to generate more comprehensive findings.

4 Data Analysis, Results and Findings

4.1 Strengths Facilitating Construction Waste Recycling

4.1.1 Provision of Economic Incentives

The government has provided various economic incentives to facilitate the development of the construction waste recycling industry in Hong Kong. Interviewee 5, who takes part in administering applications for the Recycling Fund, explained:

> *In fact, the government has not formally set any precise quota limiting the number of successful applicants. From my experience, so long as the criteria of application has been met, it is very likely that the application for Recycling Fund will be approved.*

Table 1 Profiles of respondents

No.	Role	Experience in construction waste management (years)
1	Senior Inspector of Works, Civil Engineering and Development Department (CEDD)	>20
2	Senior Maintenance Surveyor, Housing Department (HD)	>30
3	Former Building Services Inspector, Housing Department (HD)	>30
4	Chief Property Services Officer, Architectural Services Department (ASD)	>35
5	Senior Engineer, Environmental Protection Department (HKEPD)	>20
6	Senior Engineer, CEDD	>20
7	Director and Registered Architect of an architectural firm	>35
8	Director of a construction waste recycling plant	>12
9	General Manager of a construction waste recycling plant	>20
10	Director and Registered Structural Engineer of a construction company	>15
11	Senior Building Surveyor of a construction company	>20

Interviewee 5 added:

> *Except housing projects launched by the Housing Department, all public projects are entitled to order fill materials from the public fills for free. As for private projects and the Housing Department's housing projects, only a very low administrative fee will be levied for collecting fill materials from the public fills.*

Interviewee 11 reflected:

> *In recent years, it is common practice for the government to use contractual clauses to require contractors undertaking public projects to carry out waste recycling. The government pays additional costs to contractors for incorporating such additional requirement.*

4.1.2 Pioneer in Conducting Recycling Initiatives

In addition to provision of economic incentives, the government itself has been practising various waste recycling initiatives in public projects. One prominent example is that the design team of each public project (i.e., a team of architects from a government department) must formulate a "Construction and Demolition Material Management Plan" (C&DMMP) with particulars on how the construction waste being generated at each project phase will be stored, reused, recycled and/or disposed of at the design stage. As explained by Interviewee 4:

> *The C&DMMP is subject to the approval of a committee, the members of which comprise all senior officials of the relevant department. Once the committee has decided that the plan is infeasible, then the plan will be sent back to the design team for further revision.*

Also, on-site recycling has long been conducted in public projects. Interviewee 4 emphasized:

> *In public projects, it is common to use hydraulic breakers to crush inert waste such as rocks and waste concrete into smaller pieces for future use in road construction.*

Interviewee 6 added:

> *The government has long been practicing on-site sorting and on-site crushing in tunneling projects.*

In the event where the waste generated cannot be reused in the same project, public projects have long been relying on a "matching" mechanism to resolve the problem. As explained by Interviewees 4, 5 and 6:

> *If not all inert waste from the excavation stage of a project can be applied at the site formation stage, contractors would liaise with other public construction sites to see if there is any demand for inert waste. The waste will then be shared with site(s) with such need.*

To promote the development of the construction waste recycling industry, the government pioneered in using green building materials. As reflected by Interviewee 5:

> *In recent years, the government's technical circulars have been promoting the use of green building materials (e.g. green paving blocks) in government buildings.*

4.2 Weaknesses Impeding Construction Waste Recycling

4.2.1 Prevalence of Bureaucracy

Bureaucracy is the major obstacle to construction waste recycling, especially on-site recycling. As stressed by Interviewee 9:

> *The use of on-site recycling equipment would cause nuisance to the residents nearby, and it is necessary to apply to the HKEPD for the relevant licence(s) beforehand. Although it is easy to purchase an on-site recycling equipment, the process of obtaining the relevant licence(s) can drag on for six to twelve months. This accounts for the reluctance of private projects to conduct on-site recycling.*

The stringent requirement on the size of inert materials accepted by public fills is another example illustrating how bureaucracy impedes construction waste recycling in Hong Kong. As explained by Interviewee 6:

The public fills only accept inert materials with diameters not more than 250 mm. Thus, contractors may need to break inert waste materials into smaller pieces before disposing them at public fills. Many contractors, especially those undertaking private projects where waste recycling is not compulsory, are reluctant to spend extra time and resources on meeting such stringent requirement. They would rather dump the inert materials in landfills.

Interviewee 2 added:

The public fills' requirement of only accepting inert materials with diameters not exceeding 250 mm also poses a challenge to public housing projects – Many recent public housing projects are small projects of constructing a few residential blocks at the border areas of existing public rental housing estates. It is difficult to place crushers in such compact sites for the purpose of breaking inert materials into smaller pieces.

4.3 Opportunities Facilitating Construction Waste Recycling

4.3.1 Emergence of New Local Projects

Since 2007, Taishan has been a stable demander of Hong Kong's inert waste accumulated in public fills. However, throughout the years, many worried about the difficulties associated with opening up new outlet(s) for inert waste upon completion of Taishan's reclamation project. Fortunately, in recent years, some new local projects in need of fill materials have been started, which can temporary relief the pressure on the public fills. As explained by Interviewee 5:

It is expected that the Three-Runway System project (commenced in 2016) will be completed by 2024. Being a demander of the inert materials in public fills, this project can continue to relieve the pressure on the public fills in the next couple of years.

Similarly, the Tung Chung New Town will continue to be expanded in the coming decade. Since housing development, which is a predominant component of the project, requires fill materials for land levelling, it is unlikely that the public fills will reach their full capacity in the next few years.

4.3.2 Recycling Companies' Intimate Waste Collection Services

Despite the government's stringent requirements on the content and size of waste accepted by public fills and OSFs, private recycling companies have set much lower thresholds and provide more intimate service, thereby providing alternatives for contractors. Interviewee 9 said:

As a social enterprise, we do not charge contractors any fees for disposing their waste at our recycling plants.

Interviewee 8 added:

> *We only accept inert waste, and contractors must sort their waste into different categories (e.g. red bricks must be separated from waste concrete) before handing over to us. In comparison to the government's public fills which stringently require inert particles to be not more than 250 mm in diameter, we accept inert particulars with diameter not exceeding 500 mm, and our service charges are lower than the public fills.*
>
> *We understand that many contractors are reluctant to use the government waste disposal facilities due to their long distances from the construction sites. In view of this, we also send trucks to collect waste from contractors.*

4.4 Threats Impeding Construction Waste Recycling

4.4.1 Mentality of Profit Maximization and Time is of the Essence in Private Sector

Profit maximization, a deep-rooted mentality among contractors and developers, is a long-standing threat impeding construction waste recycling in Hong Kong. As emphasized by Interviewee 3:

> *In demolition projects, contractors are only willing to recycle metal waste (e.g. copper wires), waste PVC and paper boxes due to their high economic values. However, inert materials (e.g. waste concrete, rocks and soil), which constitute a significant proportion of overall construction waste in most projects, cannot be resold at high prices. Thus, many contractors prefer incurring higher disposal costs of dumping inert waste at landfills rather than allocating resources in conducting on-site sorting and recycling.*

The views of Interviewees 4, 5 and 7 echoed with that of Interviewee 3.

Interviewee 11 added:

> *Contractors of public projects can perform waste recycling because the government will cover the additional expenses incurred in construction waste management. However, in the case of private projects, developers tend to award construction contracts to contractors submitting the lowest bids. It is impossible for such low contract sums to cover the costs of on-site recycling, which is not a contractual requirement. Together with the significant increase in labor costs in recent years, both developers and contractors only opt for means of completing the projects at the lowest possible costs.*
>
> *It should be noted that time is of the essence in Hong Kong's construction industry. If a contractor fails to complete a project within the deadline, then it needs to pay liquidated damages.*
>
> *Thus, no contractor undertaking private projects cares about how to manage waste in a proper manner.*

Also, based on the data collected from the Court hearings, about one-third of the illegal dumping offenders were contractors. This illustrates that contractors have a relatively high tendency to evade the service charges of disposing construction waste at government waste disposal facilities.

4.4.2 Underutilization of Government's Economic Incentives and Services

It is worth to be noticed that the government's waste recycling initiatives failed to gain popular support from the industry players. Obviously, the public fills' service of supplying fill material to projects at zero or extremely low costs (depending on the nature of project) has been underutilized. As emphasized by Interviewee 5:

> *Very few contractors choose to collect fill materials from the government's public fills. According to our internal statistics, only 80 projects (both public and private projects inclusive) had collected fill materials from the public fills during the past five years.*

Similarly, the government's OSFs are also underutilized. As explained by Interviewee 1:

> *In contrast to the landfill sites which are overutilized and with long queues at the entrances, the OSFs are underutilized. According to our internal statistics, each OSF has slightly more than 200 users per day.*

Interviewees 11 and 5's views were confirmed by Interviewees 10:

> *I have neither used the OSFs nor public fills before. Although their service charges are considerably lower than that of the landfills, much time and resources are required to conduct on-site sorting to fulfil their inert waste content requirement. Therefore, I only instruct my employees to dispose all construction waste at landfills.*
>
> *Also, I have never heard of the government's service of allowing us to order fill materials from their public fills before.*

Another major threat which should be noticed is that although the government has been trying to encourage industry players to set up construction waste recycling plants by launching the Recycling Fund and opening the EcoPark, such supportive measures are lacking in popularity. As explained by Interviewee 5:

> *Due to the huge initial capital investment involved, there are only two construction waste recycling companies in Hong Kong, one of which is just a division of a developer's subsidiary construction material manufacturer. Indeed, we receive very few applications for the Recycling Fund every year.*

Interviewee 5's observation is confirmed by Interviewee 9, who is the general manager of the recycling division of the developer's subsidiary construction material manufacturer referred by Interviewee 5:

> *Our company produces construction materials, including both materials made from virgin resources and green building materials. Our division currently operates two recycling plants, one of which is situated in EcoPark. A recycling plant does require huge initial capital investment. Our employer initially set up the recycling plants as a matter of "corporate social responsibility". Most clients still prefer using virgin materials. Our division's green building materials are mainly consumed by public projects and new developments of our holding company. Without sound financial background and stable outlets for end-products, it is really difficult to enter the waste recycling industry despite the availability of Recycling Fund.*

4.4.3 Compacted Sites of Private Projects

Furthermore, although the government has been pioneering in conducting on-site recycling and stockpiling inert waste materials for use at later stages, it appears that the private sector is unwilling to follow due to an array of practical constraints. Interviewees 5, 6, 7 and 11 reflected:

> *Most construction sites of private projects are so small that there is insufficient space for housing on-site recycling equipment. Additionally, due to the lack of space to stockpile treated/recycled waste, the public projects' common practice of using excavated waste generated at an earlier stage for landfilling at subsequent stages can hardly be applied to private projects.*

Such views were confirmed by Interviewee 10:

> *Being the director of a construction company predominantly undertaking small private projects in highly compacted sites, I have neither arranged on-site recycling in my sites nor stockpiled waste for future use before.*

The lack of space for stockpiling of inert waste also hindered the sharing of inert waste among different private projects as in the case of public projects. Interviewee 2 explained:

> *The practice of sharing inert waste among different sites only exists in the case of public projects. But such arrangement seldom exists in private projects.*

Interviewees 10 and 11 added:

> *Our project sites do not even have enough space for stockpiling, not to mention finding potential users of stockpiled waste and waiting for their collection.*

5 Discussion

Admittedly, the government has endeavored to promote construction waste recycling in Hong Kong via a wide range of incentives throughout the years. Prominent examples include: (1) Not setting precise quota to limit the number of successful applicants of the Recycling Fund; (2) Allowing contractors to collect fill materials from the public fills at extremely low or zero costs, depending on the nature of project; (3) Establishing the EcoPark which provides rental concessions to recycling companies; and (4) Mandating contractors to carry out waste recycling in public projects by paying higher contract sums. Meanwhile, the government also pioneers in conducting waste recycling in public projects as illustrated by the following examples: (1) formulating C&DMMP at the design stage; (2) carrying out on-site recycling; (3) matching sites in need of inert waste with sites with surplus supply of inert waste; and (4) attracting new entrants into the recycling industry by pioneering in

Fig. 2 Summary of policy recommendations

using green building materials. Nonetheless, some prevalent incentives or initiatives are bureaucratic in nature (e.g. lengthy process of obtaining licence(s) to use on-site recycling equipment, stringent requirement on the size and content of waste disposed at public fills and OSFs), thereby weakening their strengths.

The government's economic incentives and recycling initiatives also failed to gain popular support from the private sector. The major threats to their success include: (1) private sector's long-standing mentality of profit maximization, cost minimization and time is of the essence; (2) underutilization of the government's services and economic initiatives; and (3) compacted sites of private projects. It appears that such threats cannot be directly offset by the new opportunities emerged in recent years, including the demand for inert waste arising from the two large-scale local new development projects, as well as the less stringent requirements on the size of waste accepted by private recycling companies.

Based on the inherent strengths and weaknesses of the prevalent government waste recycling policies and the external opportunities and threats beyond the government's control, we propose the following policy recommendations (see Fig. 2 for a summary of the recommendations). Firstly, it is recommended that publicity of recycling companies' waste recycling services should be reinforced to combat contractors' reliance on illegal dumping as a means to evade legal disposal charges and preference for recycling metal waste (with higher economic value) rather than inert waste. Knowing that private recycling companies provide more flexible and intimate services (e.g. transportation services), contractors who initially prefer landfills to OSFs and public fills might be attracted to use the recycling companies' services instead. In turn, the pressure on the landfills can be relieved. Secondly, the government should allocate more resources to promote both the Recycling Fund and the public fills' fill material ordering service to the industry players to tackle the issues of few applications for the Recycling Fund despite the high success rate, and underutilization of fill materials in public fills. This suggestion is justified by the fact that the director of a small construction company being interviewed is unaware of the service of ordering fill materials from public fills and there are only two construction waste recycling companies in Hong Kong at the moment. Thirdly, it is of crucial importance for the government to streamline the application procedures of the relevant licence(s) to encourage private projects to adopt on-site recycling.

This study not only serves as a useful reference for the Hong Kong government, but may also provide references to other cities with similar SWOT conditions as Hong Kong in searching for long-term solutions to construction waste recycling. Despite that three policy recommendations to promote construction waste recycling have been formulated, given that all of them require the government's active involvement and leadership, there is a possibility that such policy recommendations can never be put into practice if the issue of bureaucracy remain unresolved. Therefore, it is of crucial importance for future studies to explore the contributing factors of bureaucracy, which is a long-standing problem in Hong Kong.

6 Conclusion

During the past two decades, the Hong Kong government has devoted a multitude of resources to promote construction waste recycling. Nevertheless, the effectiveness of its initiatives is far from satisfactory. By cross-learning the strategic planning technique of SWOT analysis from the business sector, conducting a series of semi-structured interviews and attending Court hearings of illegal dumping offences, this study had identified the strengths and weaknesses of the government's prevailing construction waste recycling policies, as well as the external opportunities and threats beyond the government's control. Based on the findings of the study, we have proposed three policy recommendations to combat the threats hindering the long-term realization of the government's construction waste recycling objectives. This study is novel in that it is the first study evaluating the status quo of construction waste recycling in Hong Kong using a strategic planning technique from an entirely different industry. Despite that the policy recommendations put forward in this study targets at the government, it is believed that the collective efforts of different stakeholders, including the government, contractors, and construction practitioners ranging from frontline staff to senior management, are of utmost importance to the long-term development of construction waste recycling in Hong Kong.

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Construction Inspection Information Management with Consortium Blockchain

Liupengfei Wu, Weisheng Lu, and Fan Xue

Abstract Blockchain can be regarded as a distributed database that records transaction data in a shared manner. This new technology is considered destructive and can transfer many data-driven industries, including construction. On the other hand, as one of the necessary measures to ensure quality, progress, and safety, construction inspection records still rely on paper. This leads to many problems, such as time-consuming, input errors, file loss, and even data manipulation. This research aims to develop a blockchain-based construction information management platform to expand blockchain applications in construction inspection management. First, conduct a literature review to explore blockchain technologies, types of blockchains, blockchain platforms, and existing construction inspection processes and issues. Based on the review, a method called design thinking is used to develop a blockchain prototype. As a result, a consortium blockchain prototype is developed to help inspection information management. The proposed solution is further illustrated through a semi-hypothetical case study. The research also discusses issues related to the current blockchain implementation, which provides numerous opportunities for further investigation. Not only limited to general discussions, one contribution of this research is the development of a configurable prototype so that construction stakeholders can follow and develop their blockchain-based solutions.

Keywords Blockchain · Construction industry · Information management · Inspection · Smart contract

1 Introduction

Blockchain was first known as the basic technology of cryptocurrency in 2008 [1]. Subsequently, blockchain was introduced for applications beyond cryptocurrency. Perera et al. [2] pointed out that blockchain is considered to have disruptive capabilities and can change many global industries, including the construction industry.

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Blockchain can be seen as an immutable ledger, recording information in a decentralized manner. It combines three key underlying technologies: distributed database, cryptography, and consensus protocols [1]. Together, these underlying technologies enable information to be submitted, endorsed, and shared with a high degree of security. Blockchain can be divided into three types, namely public, private, and consortium. They are categorized by the right to access ledger on the blockchain [2]. Many existing blockchain platforms, such as R3 Corda and Hyperledger Fabric, can develop decentralized applications. If the existing platform does not meet user requirements, one can also develop a self-built platform.

Construction inspection plays a vital role in every phase of projects. In general, construction inspections are usually carried out as a contractual responsibility performed by the consultants to offer the client an independent view of construction quality, work progress, and site safety. Most of the existing inspection information is recorded on paper [3]. Issues such as incorrect placement of steel bars, schedule delays, and unsafe operation behaviors are identified and integrated through manual processes; therefore, the process is expensive, inefficient, and error-prone. Also, the construction stakeholders are known for their lack of mutual trust. The development of mutual trust between stakeholders (e.g., clients, main contractors, consultants, and subcontractors) in construction depends on tamper-proof construction inspection records [4]. Nevertheless, existing information management technologies cannot meet the stakeholders' requirements. Faced with such problems, blockchain technology can ensure the inspection information's authenticity through its cryptography, distributed database, and consensus mechanism. Although many studies have been conducted in recent years to discover blockchains' potential in the construction industry, to the best of our knowledge, no current research focuses on using blockchain to ensure inspection information authenticity.

The aim of this paper is threefold: (a) to explain blockchain technology so that stakeholders in the construction industry understand its potential; (b) to develop a consortium blockchain prototype (Hyperledger Fabric-based) by following which stakeholders in construction can develop their case-specific blockchain solutions for managing construction inspection information; (c) To discuss issues related to the current blockchain implementation so that future research can provide potential solutions. The rest of the paper is structured into six sections. In the second section, blockchain and inspection works in the construction industry are introduced. In the third section, the methodology is given. In the fourth section, the blockchain prototype is proposed. The prototype is further substantiated in the fifth section. Discussions are conducted to deepen the understanding of blockchain technology in the sixth section, and conclusions are given at last.

2 Literature Review

2.1 Blockchain Technology

Cryptography, distributed databases, and consensus mechanism are the three basic technologies of blockchain [2]. Blockchain protects transaction data and interactions on the chain through a hash algorithm and public key infrastructure (PKI). PKI guarantees that the transaction data is encrypted and decrypted through the unique relationship between the public key and the corresponding private key, while the hash algorithm ensures that the transaction data is tamper-proof [2]. The blockchain retains a growing set of transaction data, bundled together into blocks of data (Fig. 1). Each block includes the block number, the previous block's hash, the current block's hash, the timestamp, the target difficulty, and the nonce [5]. A nonce is a random number that considers the network rules to identify the hash. The hash value is unique for each block, so if people intentionally or unintentionally alter the block's transaction data, the corresponding hash value will be changed instantly. Each block retains the previous block's hash value to ensure that the current block cannot be changed without changing the previous block.

A blockchain database is not a single information storage source but is composed of ledgers scattered in many locations in a shared manner [2]. A distributed database is also a network where participants (also called peer nodes) can have transactions without intermediaries. The blockchain consensus mechanism makes direct transactions between interacting parties possible. The blockchain's consensus mechanism is to accept the transaction data into the distributed ledger by verifying the transaction data's order and correctness [5]. There are many consensus algorithms to choose from, such as Proof of Work (PoW), Proof of Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT), and each consensus has its own advantages and disadvantages.

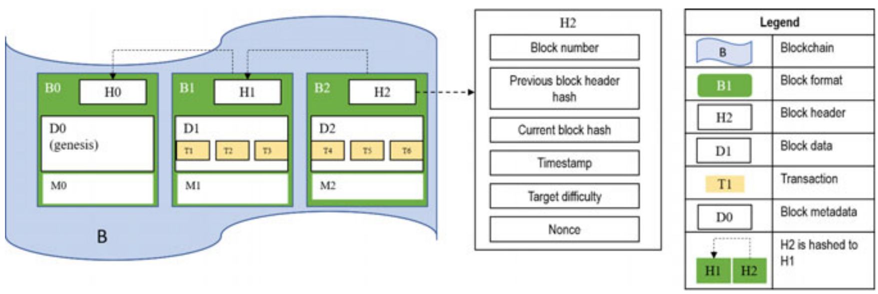

Fig. 1 Blockchain structure

Table 1 Popular blockchain platforms overview

Features	Ethereum [2]	Hyperledger Fabric [2]	Ripple [6]
Industry usage	Cross-industry	Cross-industry	Financial services
Blockchain type	Public	Consortium	Private
Consensus	Proof of work/proof of stake	Pluggable consensus	Ripple protocol consensus
Mining rewards	No	Yes	No

2.2 Blockchain Options

Blockchain can be categorized as public, consortium, and private [2]. The public blockchain allows anyone interested to join, and everyone can read the data on the public blockchain [1]. Public blockchains are commonly used for cryptocurrencies such as Bitcoin. The consortium blockchain only allows a limited number of pre-authorized groups/organizations to read data and submit transactions [1]. The private blockchain is only open to one organization, so the network is centralized [1]. Many existing blockchain frameworks and platforms can be used to implement public, private, and consortium blockchains. Table 1 gives an overview of three popular blockchain platforms. People can also develop customized platforms, but it may be challenging to ensure their code security.

2.3 Construction Inspection

In construction projects, the client entrusts inspectors to manage the project quality, schedule, safety, contract, and other aspects of a business. The inspector is an impartial third party between the client and the contractor who can correctly handle disputes. Besides, inspectors are required to understand engineering and technical knowledge, accounting, and construction regulations. Quality control inspections usually include on-site inspections of materials and construction processes [7]. The purpose of quality control inspections is to ensure high-end quality at delivery. Inspectors can also check quality-related documents, work instructions, and action plans to better control the construction process and prevent opportunism. Besides, regular progress inspections are conducted on construction sites to ensure that the project can be completed within the agreed contract time [8]. Construction inspections are also important to ensure that relevant people work in a safe environment [9]. For example, check whether there are fences to prevent people from falling from heights, ensure that employees wear personal protective equipment, and check whether equipment and work platforms are maintained. On-site inspectors usually keep daily construction logs or on-site diaries, photos, and construction progress meeting minutes, and then submit reports regularly.

There are many problems with construction inspection information management. At present, a large number of inspection works are paper-based [3]; construction inspection records can be tampered with or altered without being found [10]. Also, there may be information gaps between participants because many inspection forms are filled out and sent manually, which leads to informal filling, incomplete attachments, poor real-time sharing, and low efficiency [10]. Moreover, compared with other engineering industries, construction projects are temporary and one-off [11]. Therefore, organizations involved in construction projects find it difficult to maintain long-term partnerships. The development of mutual trust between organizations with different interests is challenging. Without trust, many organizations are reluctant to share detailed inspection information [10]. Participants can cut corners and blame others in collaboration because the existing information management system has very low traceability [10]. Participants may also be dishonest and violate the contract to pursue private interests [10].

Blockchain, with its salient features, has the potential to solve the above-mentioned inspection information management issues. Blockchain can introduce reliability and immutability [12]. Based on the hash algorithm, no one can modify or tamper with approved records [2]. The agreed inspection information is stored in distributed ledgers, and all participants have the same ledger that updates simultaneously. This can enhance information transparency and sharing [2]. In addition, all participants have encrypted signatures based on PKI. Combining the signature with timestamps, the blockchain can ensure the traceability of inspection information [10]. Each inspection document needs to be endorsed by relevant stakeholders based on a consensus mechanism. Therefore, blockchain can establish mutual trust between stakeholders and prevent later disputes [10]. By combining blockchain and smart contracts, inspection information can be automatically checked according to contracts, regulations, and standards to ensure construction quality, progress, and safety. Smart contracts are digital contracts that can perform operations when predetermined conditions are met [1].

3 Methodology

This research used a hybrid approach, which includes literature reviews and design thinking (Fig. 2). Generally speaking, a literature review is a systematic method of collecting and integrating previous research results [13]. As a research method, an organized literature review lays a concrete footing for advancing the existing knowledge system and promoting theory development [14]. Given the difficulty of exhausting all related research work, it is usually necessary to delimit the research scope. Keywords used to search for related papers in this study include “Construction Inspection”, “Blockchain”, “Consortium Blockchain”, and “Hyperledger Fabric”.

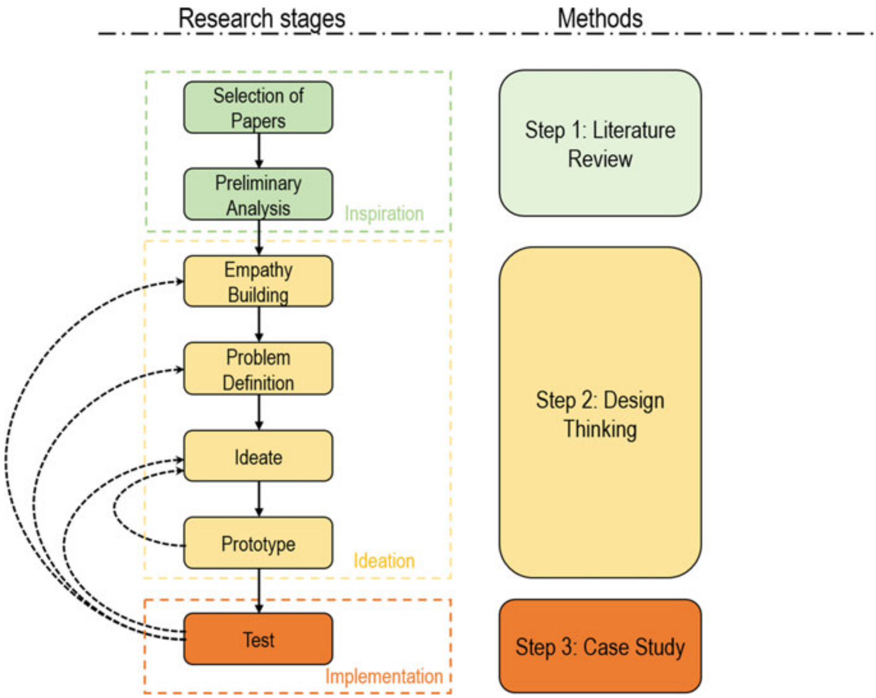

Fig. 2 Research methods

A preliminary analysis was conducted to determine each paper's basic information; that is, the research objectives include blockchain applications and technologies, construction inspection process, information management, and information management systems.

Next, this research adopted design thinking to learn from existing practices and design a prototype suitable for construction inspection information management. It emphasizes "thinking like a designer", who usually focuses on improving a product's functionality according to customer needs [15]. The design thinking process includes five stages, namely, empathize, define, ideate, prototype, and test. In this research, empathy referred to understanding the interrelationships among construction stakeholders (e.g., customers, contractors, and consultants). Next, the key issue was defined. The issue here was to propose a Hyperledger-Fabric prototype so that a consortium blockchain-based system can manage inspection information. Then, group meetings were conducted to discuss and propose various design options. Then, a prototype was proposed. Finally, a semi-hypothetical case study was carried out.

4 Proposed Solution

The upper part of Fig. 3 shows a typical quality, progress, and safety inspection process. The contractor's engineer can submit an inspection request from the construction site. Usually, a client entrusts consultants (e.g., inspectors) to conduct inspections on construction sites. The client's project manager will supervise the entire inspection process in the project-based organization, endorse the consultant's inspection reports, and issue payment instructions if all content meets the contracts and requirements.

To achieve reliability, immutability, information sharing, traceability, and self-execution in business transactions, organizations participating in inspection must have identical and immutable inspection records as the foundation for building trust. Based on the review in Sect. 2.2, the consortium blockchain was selected because it allows multiple authorized parties to join the blockchain network and ensures privacy. Besides, consortium blockchain can provide membership services (e.g., identity authorization and verification) for multiple parties. In the process of cooperation, different information may have different degrees of confidentiality. The ideal platform should provide isolated communication channels to protect privacy. For example, the client can establish an isolated communication channel with the inspector without the contractor's involvement. As a result, the Hyperledger Fabric platform is selected for construction inspection information management.

The designed blockchain system based on Hyperledger Fabric in the lower part of Fig. 3 can enhance inspection information management. This digital inspection platform can benefit all construction stakeholders. The submission of inspection requests can be digitalized and sent to inspectors to perform inspections effectively. Inspectors use their smart devices (e.g., smartphones, iPads) to complete assignments, conduct inspections, approve inspection forms or record any unqualified events, and report to

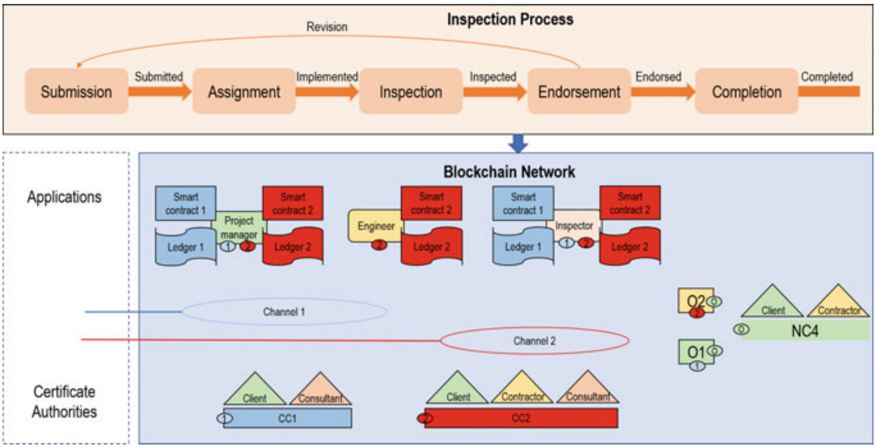

Fig. 3 Proposed Hyperledger Fabric-based solution

the client's project manager through the platform. Photos and conversation records can also prove the inspection process. The advantages of this platform include quickness, digitization, and transparency. Another advantage is that all submitted documents should reach a consensus in the blockchain to prevent future disputes. Most importantly, there is a timestamp on each inspection-related document submitted to the platform. The platform can also enhance trust because the blockchain structure provides security, auditability, and the submitted documents are immutable.

5 Case Study

The inspection progress can be enhanced by using the proposed blockchain. In the designed Hyperledger Fabric blockchain network, the Client, Consultant, and Contractor plan to use this platform to manage inspection information. The Client is the initiator of the network. Client, Consultant, and Contractor can have applications that perform inspection information in two channels. Client and Consultant can privately exchange information about inspections in channel 1, while Client, Consultant, and Contractor can also communicate in channel 2 together. The peer nodes Project manager and Inspector have two ledgers, which record inspection information related to Channel 1 and 2. They also have two smart contracts associated with channels 1 and 2, respectively. In contrast, the contractor's peer node Engineer has only one ledger and one smart contract associated with channel 2. CC1 and CC2 are "Endorsement Policies", so relevant parties can manage their channel access rights through them. Similarly, NC4 allows the Client and Contractor to manage the entire blockchain network. O1 and O2 are two ordering nodes used to manage the channel (e.g., packing inspection documents into blocks). Each organization also has a certification authority that can issue digital identities to their peers.

6 Discussion

There are many existing problems in real life related to blockchain implementation. Security is one of the biggest issues related to blockchain. In the construction industry, practitioners mistakenly believe that blockchain can be a panacea to ensure the information's authenticity. However, there is an off-chain issue that needs to be resolved in the future. For example, there is no 100% secure solution to ensure that information is not tampered with before being submitted to the blockchain. Therefore, it is necessary to convene engineers, blockchain developers, and even lawyers to sit down and discuss the security framework for off-chain issues. Also, because the number of participants in a construction project is limited and clients have strong decision-making power, determining the number of peer nodes in a construction project to reduce the risk of 50% attacks will become a big challenge. A 50% attack means that once someone has 50% of the blockchain network's computing power, they have the opportunity to tamper with the information on the blockchain [2].

Another issue that the construction industry is most concerned about-the economic cost of using blockchain-based systems has not received much attention. Only a small amount of literature calculates the cost of blockchain transactions. However, there is no detailed explanation and case to prove the overall cost of blockchain use. The blockchain cost may include initial platform setup, deployment, cloud storage, ongoing maintenance, and monitoring. Thus, when better empirical data is available, a detailed cost-benefit analysis is required.

7 Conclusions

The purpose of construction inspections is to ensure construction projects' quality, progress, and safety. However, there are many problems with current construction inspection information management. For example, inspection information is easily tampered with and cannot be shared in real-time. The inspection information received by clients is not reliable, and the traceability is low. Besides, it is not possible to automatically check whether the information meets the requirements. In terms of inspection information management, blockchain allows various construction stakeholders to realize immutable, transparent, shared, traceable, and automatic construction inspection information management and builds the foundation for mutual trust.

This paper proposed a blockchain-based prototype for managing construction inspection information in a decentralized manner. The Hyperledger Fabric platform under the consortium blockchain can collect, encrypt, share, and record construction inspection information. With the support of smart contracts, an automated compliance check process can be realized. One research limitation is that the case study was not substantiated by actual projects. Further research should be conducted to test and fine-tune the proposed prototype. Besides, this research discusses issues related to blockchain applications. These issues provide opportunities for future investigations. One of the important contributions of this research is developing a configurable prototype so that construction project stakeholders can follow and develop their blockchain-based solutions.

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How Do Chinese International Construction Companies View Corporate Social Responsibility?

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Abstract Corporate social responsibility has been widely accepted as an essential ethic norm for companies in conducting business. China is now catching up in this CSR cause. An emerging force, Chinese international construction companies (CICCs), provides a meaningful lens through which the CSR perception of construction companies in China can be investigated. The aim of this paper, therefore, is to better understand the way CSR is viewed by international construction companies in China. This is undertaken by content analysis of the 168 CSR/ESG reports of CICCs over the 10 years (2010–2019). To achieve this, a CSR indicator system was formed coving 38 reporting contents/indicators based on both CSR reporting guidelines for Chinese enterprises (i.e., CASS-CSR) and the contents of CSR reports collected. There are three main findings, firstly, there is an enriching trend of the CSR reporting over the 10 years, despite that verification of CSR information is still relatively new to CICCs. Secondly, community involvement is mostly welcomed by CICCs in CSR reports, although these activities reported are mainly conducted in their home countries (i.e., China). Lastly, innovations regarding to technology and environment protection as important competitive strategies have been largely adopted by CICCs in CSR reports. CICCs tend to disclose their remedial strategies while hiding their unfavorable performance. This study contributes to the understanding of CSR development in China. CICCs are encouraged to enhance CSR engagement to gain corporate reputation and competitive advantage.

Keywords Corporate social responsibility · Perception · International construction · China · Content analysis

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1 Introduction

With the globalization of the world economy, companies nowadays increasingly across the traditional national boundaries to undertake construction business overseas [1]. This forms a unique business sector called international construction, in which many construction firms operate not only in their home country but also conduct construction projects in other host countries. In this international construction market, there is a fast expansion of Chinese international construction companies (CICCs). Engineering News-Record (ENR) has ranked the 250 largest international contractors based on new contracting revenues obtained from international construction projects since the late 1970s. On the 2020 Top 250 international contractor list, there are 74 international construction companies from China listed by ENR. The number of Chinese companies remains the top on the ENR lists for years. China's overall international construction business climbed significantly. The total volume of contract accomplishment reached US$120.05 billion in 2019.

China is now positioned in a critical stage that seek new opportunities in international market and encourage people-to-people exchanges among different regions. In this stage, China has developed considerable strengths, e.g., strong financing capability, supply chain sourcing, and hardworking workforce. However, China has also suffered from various weaknesses, for example, unfamiliar with international standards, poor image in quality and occupational safety, and lack of attention to corporate social responsibility (CSR) [2]. CSR research in China emerged only in two decades. Moon and Shen [3] hold that CSR is growing as a management issue in China. To understand CSR issues, Gao [4] examines the CSR reports of listed companies in China. At that time, only a small number of companies published their CSR reports. Wang et al. [5] echoed this finding and further found that large companies, companies with single owner, and companies willing to state their CSR activities disclose more information in CSR reports. Also, firms in environmental sensitivity industries and state-owned enterprises disclose more CSR information related to environmental issues [6].

In the construction sector, CSR presents abundant paradoxes [1]. Construction, on the one hand, is an important industry in scope and scale [7], materializing the built environment, creating many job opportunities, and making a significant contribution to national economies [8]. On the other hand, construction activity is intrinsically "irresponsible", being associated with excessive competition, pollution, quality issues, neglect of occupational health and safety (OHS) and well-being, and so on. Like other business sectors, such as mining [9], food [10], and advertisement [11], CSR issues have also been discussed in the construction sector. For example, Martinuzzi et al. [12] identified CSR activities and impacts of the construction sector. Relevant CSR issues were derived from content analysis, such as community involvement and development [13], environmental protection [14, 15], construction quality and safety [15]. Xia et al. [16] reveal and conceptualize the CSR's state of art in the construction industry. Lu et al. [1] analyzed the CSR trends and prospects for international construction companies. Bevan and Yung [17] demonstrated how CSR has been incorporated and implemented in the UK construction industry.

Although CSR research in construction industry has drawn certain degree of attention, rarely study has been conducted to analyze how CSR is perceived by construction companies of China. Construction activities are now being internationalization, in which situation, CSR has become the key for better cooperation and regional development among economies. Moreover, there are pressures on companies in construction sector to improve CSR engagement, especially for CICCs. CSR scandals such as quality corruption, environmental pollution, and poor local participation are somehow criticized by international media. CICCs seem to consider that CSR is by and large useless. To investigate how CSR is viewed by CICCs is of significance in providing meaningful references for future CSR exercises.

The aim of this study is thus to explore the CSR perception of international construction companies in China, by using content analysis approach on 168 CSR reports of 21 CICCs. It is found that there is an enriching trend of the CSR reporting over the 10 years, despite that verification of CSR information is still relatively new to CICCs. Drilling down to the CSR contents disclosed by CICCs, community involvement is mostly welcomed by CICCs in CSR reports, although these activities reported are mainly conducted in their home countries (i.e., China). Moreover, innovations regarding to technology and environment protection as important competitive strategies have been largely adopted by CICCs in CSR reports. CICCs tend to disclose their remedial strategies while hiding their unfavorable performance. This research contributes to the theoretical perspectives on CSR practices conducted by CICCs. The insights offered by this study will not only provide a fresh lens through which CSR issues in China can be examined, but also allow CICCs effectively manage their future CSR practices.

The reminder of this paper is as follows. Section 2 explains the theoretical foundation of this study. Sample, data, and methods are described in Section 3. In Sect. 4, the analysis findings and limitations are presented and discussed. Section 5 draws conclusions of this study.

2 Theoretical Foundations

Howard R. Bowen, the "father of CSR" [18], argued that social responsibility acts as a role to guide business: beyond profit and loss, businessmen should be responsible for the consequences of their activities [19]. In Bowen's time, social responsibility merely meant business philanthropy or charity. Since then, discussions on CSR have expanded and its definitions have diversified. Carroll's CSR pyramid illustrates that the responsibilities of a business from the bottom to top include "making profits, obeying the law, being ethical, and being a good corporate citizen" [20]. Dahlsrud [21] traces 27 academic definitions of CSR describing, for example, the social and environmental integrative concerns arising from business operations, and ethics-based practices which can contribute to sustainable business success. Despite their differences, a common theme running through these definitions is voluntary interaction with stakeholders' interests concerning economic, environmental, and social aspects.

The notion of CSR has evolved over decades in academia with the popularization of stakeholder theory. Stakeholders are defined by Freeman [22] that anybody is connected with an organization, no matter affect or is affected by it. A company needs to meet with various concerns and expectations due to the divergent interests from company stakeholders [23]. By introducing stakeholder theory, not only shareholders but also stakeholders have the right to affect a company and are under its "protection". As a result, CSR has shifted to the core of a business [24]. Furthermore, legitimacy theory explains the motivations for CSR by asserting that a company can have interactions with socio-political contexts [25, 26]. Researchers emphasize that companies cannot operate without supports from the society formed of various stakeholders. Bound by the social contract exist naturally between an organization and the society in which it operates, the organization is expected to perform actions for social approval so that they can exist in the society and achieve further rewards [27].

CSR reporting has been regarded as an approach to gain legitimacy by meeting the expectations of internal and external stakeholders. CSR reporting means that a company discloses its economic, social, and environmental practices to inform its various stakeholders regarding the company's social impacts [28]. In addition to gaining legitimacy, there are various motivations for companies to report their CSR programs, for example, enhancing corporate image, signaling superior competitiveness, increasing information transparency and supporting employee motivations [29]. There are basically three ways for companies to report their social activities: official websites, annual reports, and CSR reports [30]. CSR reports are also called by companies as non-financial reports, environmental, social and governance (ESG) reports, and sustainability reports.

To guide CSR reporting, international guidelines are promoted by international organizations such as the Global Reporting Initiative (GRI). China is now catching up in this CSR cause. The Chinese government, China's stock exchanges, and government organizations are promoting the idea of CSR to Chinese companies. For CSR practice improvement and standardization, *Shenzhen Stock Exchange Social Responsibility Instructions to Listed Companies guideline* was launched in 2006 by the Shenzhen Stock Exchange (SZSE). The *Notice on Strengthening Listed Companies' Assumption of Social Responsibility (Shanghai CSR Notice)* and the *Guidelines on Listed Companies' Environmental Information Disclosure (Shanghai Environmental Disclosure Guidelines)* were launched in 2008 by the Shanghai Stock Exchange (SHSE). CSR is also regulated in China's Company Law in 2006, requiring companies to assume social responsibility. According to the *2012 White Book of CSR Reports* issued by Chinese Academy of Social Sciences, there are 1006 independent CSR reports released by Chinese companies in 2012, while only 32 issued in 2006. This dramatic growth reflects that CSR reports have become the effective approach revealing CSR activities of Chinese companies.

Cuganesan et al. stressed that it is of importance to identify industry specificity when evaluating CSR performance [10]. This is in line with the view that CSR understanding largely relies on business context of each firm [31]. It is to be expected that CICCs owns idiosyncrasies in CSR reporting due to the heterogenies of their business. CSR reports released by CICCs thus provides a reachable lens through which CSR view perceived by the emerging force in the international construction market can be meaningfully investigated.

3 Research Method

3.1 Sample

To explore the CSR perception of CICCs, the construction companies listed in the SZSE and SHSE were targeted. 56 companies are identified as international construction contractors according to their international businesses and revenues. In December 2008, the SZSE and the SHSE issued the *Notice on Strengthening Social Responsibility of Listed Companies*, which mandated a subset of listed companies to publish CSR reports. These companies include those listed in the *SZSE 100 index,* the *SHSE Corporate Governance Section Index,* and companies operating in the financial sector and those with shares listed overseas. Other companies, however, can decide by their own on whether publish their CSR reports annually. It was found that 21 construction companies have released their CSR/ESG annual reports on SZSE or SHSE website. This is comparable with the 19 selected from 50 companies in Xiong et al. [30]. Among these companies, 3 of them entered the Top 10 on the 2020 ENR list. The sample in this study is 21 CICCs with their profile provided in Table 1. The main businesses of the 18 companies include construction of roads, railways, and buildings. The other 3 companies mainly focus on the business of renovation/decoration.

3.2 Data

The CSR/ESG reports of these 21 CICCs from 2010 to 2019 provides an effective information source for the analysis. According to the GRI sustainability Disclosure Database, most construction companies began to disclose their CSR information from 2006 to 2011. From 2006 to 2009, the number of China's companies issuing CSR reports soared from 32 to 582. Guidelines on Corporate Social Responsibility Reporting for Chinese Enterprises (CASS-CSR) was published in 2009, which provides an important reporting guidance for companies in China. 2010 was thus selected to be the starting year for collecting CSR reports of 21 CICCs. Their reports were retrieved from their websites. However, not all the companies started to report their CSR practices from 2010. For example, *CNCEC* published annual CSR reports

Table 1 Profiles of the selected sample

No.	Company	Main business	No.	Company	Main business
1	AHCE Group	Roads, railways, buildings	12	Goldmantis	Renovation/decoration
2	CAMC	Roads, railways, buildings	13	HRC Group	Roads, railways, buildings
3	CCCC	Roads, railways, buildings	14	Jangho Group	Renovation/decoration
4	CHALIECO	Roads, railways, buildings	15	Jinggong Group	Renovation/decoration
5	CMGC	Roads, railways, buildings	16	NORINCO	Roads, railways, buildings
6	CNCEC	Roads, railways, buildings	17	PCC	Roads, railways, buildings
7	CNEC	Roads, railways, buildings	18	SDGS Group	Roads, railways, buildings
8	CRCC	Roads, railways, buildings	19	SHC Group	Roads, railways, buildings
9	CREC	Roads, railways, buildings	20	SHTEC	Roads, railways, buildings
10	CSCEC	Roads, railways, buildings	21	Sinoma	Roads, railways, buildings
11	Gezhouba	Roads, railways, buildings			

since 2012. Therefore, regardless of those missing reports, a total of 168 CSR/ESG reports were collected for further analysis.

3.3 Method

Content analysis technique was used to analyze text data of CSR reports. Content analysis approach is “a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding” [32]. The method has been used in many studies to assess CSR reporting or disclosure [9, 10].

An indicator system for decoding CSR reports is shown in Table 2. The system includes indicators structured in the CASS-CSR3.0 and adapted to the construction industry. And indicators that frequently mentioned in CSR reports of CICCs are also included, such as M4 Industry responsibility. There are 4 groups with 14 subcategories covering 38 reporting contents/ indicators in total listed in Table 2: (1) G-governance (3 subcategories with 3 indicators), (2) M-market (4 subcategories with 8 indicators), (3) S-society (4 subcategories with 19 indicators), (4) E-environment (3 subcategories with 8 indicators).

Table 2 Indicator system for decoding CSR reports

Codes	Categories	Sub-codes	Subcategories	Contents
G	Governance	G1	Governance	CSR system
		G2	Communication	Communicating with stakeholders
		G3	Capability	CSR training
M	Market	M1	Shareholder	Information disclosure, dividend policy
		M2	Customer	Quality management system, quality certification, customer satisfaction
		M3	Partner	Fair competition
		M4	Industry	Technological innovation, industry development
S	Society	S1	Government	Legal system, prohibiting commercial corruption, tax payment, social contribution value, employment strategies, number of absorbing employees
		S2	Employee	Total number of employees, social insurance, equal employment, employee training system, health management
		S3	Safety	Safety management system, safety education and training, safety investment, number of safety accidents
		S4	Community	Employee localization policy, main charity areas, donation, voluntary activity performance
E	Environment	E1	Sustainable operation	Investment in environmental protection, environmental protection training and education, green office strategies
		E2	Green product	Environmental technology innovation, carbon emissions, integration with business
		E3	Green ecology	Biodiversity protection, public welfare activities for environmental protection

Table 3 An excerpt of the data obtained from content analysis

No	Company	Year	Audit	G-governance			M-market				
				G1	G2	G3	M1		M2		
				G1-1	G2-1	G3-1	M1-1	M1-2	M2-1	M2-2	M2-3
1	CCCC	2010	NA	√	√	-	√	-	√	√	√
		2011	NA	√	√	-	√	-	√	-	√
		2018	NA	√	√	√	√	-	√	√	√
		2019	NA	√	√	√	√	-	√	√	√
2	CSCEC	2011	Yes	√	√	√	√	-	√	-	√
		2018	Yes	√	√	-	√	-	√	-	√
		2019	Yes	√	√	-	√	-	√	-	-
3	NORINCO	2012	NA	√	√	-	√	√	√	-	-
		2019	NA	√	√	-	√	√	√	√	-

The 38 CSR indicators mentioned in CSR reports were manually coded into an MS Excel file. Specifically, if a CSR report mentioned a certain indicator, it will be marked with a "√" into the corresponding cell of the Excel file; otherwise, the cell will be marked with a "-". An excerpt of the coding is shown in Table 3. The table includes the CSR practices reported by CICCs over the past 10 years, forming an information source for further analysis. Based on the content analysis, researchers can have an initial understanding on CSR perception by CICCs.

4 Analyses, Findings, and Discussion

Reporting profiles

From Table 4, the total number of CSR reports issued by CICCs has increased over the 10 years. In 2010, only 7 CICCs disclosed their CSR activities publicly. The number rises to 21 in 2018. The same growth trend is shown in different business domains (i.e. Roads, railways, buildings; Renovation/decoration). However, only 1 CICC has its CSR reports audited by an authorized third-party from 2011 to 2019. Third-party auditors are increasingly incorporated in CSR reports of international construction companies [1]. Auditing can be viewed as an external pressure put on companies [33], ensuring the credibility of the disclosed information in CSR reports. However, auditing seems not be largely accepted by CICCs. Compared with other business sectors such as the mining industry [9], CSR information verification is still relatively new in the international construction sector.

Although there is an enriching trend of the CSR reporting over the 10 years, the disclosure quality of CICCs are still relatively poor. The relevance and completeness of reporting cannot be ensured. Some companies released CSR reports with very limited information disclosed. Although Chinese construction companies are to some

Table 4 Profiles of selected sample

Year	Number of CSR reports	Number of reports (Roads, railways, buildings)	Number of reports (Renovation/decoration)	Number of reports audited
2010	7	6	1	0
2011	13	11	2	1
2012	16	14	2	1
2013	16	14	2	1
2014	18	15	3	1
2015	18	15	3	1
2016	19	16	3	1
2017	19	16	3	1
2018	21	18	3	1
2019	21	18	3	1

extent duty bound to conduct CSR activities, some companies may approach it more as a mere reporting task or lip service rather than a long-term investment.

Finding 1: Community involvement is mostly welcomed by CICCs in CSR reports

CSR activities were identified and categorized into 38 indicators under 4 categories, i.e. governance, market, society, and environment (shown in Table 2). Among these indicators, main charity areas are disclosed in all CSR reports. CICCs are involving themselves in community programs such as school and community construction aid, poverty alleviation, and disaster relief. The majority of CICCs (13 out of 21) also report their total donations to communities. However, these community involvement activities reported are mainly conducted in their home countries (i.e., China). That is, activities for local community in host countries are less desired by CICCs compared to involvement in the home country. CICCs are encouraged to participant more in community programs in the international construction market to gain corporate reputation and competitive advantage.

Finding 2: CICCs tend to hide their deficiency in CSR reports

In the CSR/ESG reports, little negative information is disclosed by CICCs. For example, only 5 (out of 21) companies reported their safety accidents. And 6 (out of 21) companies disclosed information of carbon emissions. This finding is in line with research by Kühn et al. [34], which reflects that CSR reports are often criticized to omit negative information coverage for the purpose of image representation and reputation improvement. Hess [35] describes this phenomenon as dissembling, which refers to "companies disclose favorable information but hide unfavorable information". Dissembling can occur when companies respond to their negative social behavior by stating their positive CSR performance. This is because regulations by Chinese government (i.e. company law, regulations by SZSE and SHSE) usually focus on preventing irresponsibility, thus decrease the public tolerance on the CSR deficiency of companies. The content analysis further found that companies that listed top by ENR list tend to disclose more negative information in their CSR reports. These companies have not only leaded construction business in international market, but also valued CSR activities by viewing it as not just a lip service.

Finding 3: Innovation as a competitive strategy has been largely adopted by CICCs in CSR reports

Innovation can be viewed as a firm's potential to transform its innovative ability to observable performance [36]. The content analysis reveals that the majority of CICCs (18/21) engage in industry development by technological innovation such as new workflow and new materials during construction activities. Moreover, most CICCs (19/21) take measures in environmental technology innovation. For example, investing in environmentally friendly materials, equipment and new technologies/processes, adopting new technologies in waste disposal. This finding echoes with Lu et al. [1] that "the more negative effects a company may cause, the more remedial strategies it will disclose in a CSR report". Construction is viewed as a dirty industry for the hardship of its working environment and the inverse environmental impacts (e.g., carbon emissions, wastes and dusts) it causes. Due to these idiosyncrasies of the industry, CICCs disclose their remedial strategies while hiding their unfavorable performance in CSR reports. Innovation has become a competitive strategy in the international construction market. "Technical capability" and "innovation" are largely included in CSR programs of CICCs, which have indeed been added to price assessment in bidding evaluation system [37].

The study contributes to the theoretical understanding of Chinese CSR. As the largest emerging force in the world, China raised awareness of CSR in the early 2000s to overcome the worldwide image of its serious environmental pollution, sweatshops and unsatisfactory and incident-marred working conditions. The analysis of this paper indicates that China has been on the way to evolving its own ethical norms for corporations. Although Chinese construction companies are to some extent duty bound to conduct CSR activities, some companies may approach it more as a mere reporting task or lip service rather than a long-term investment. This study also contributes to the practical perspective of CSR development in China. To enhance CSR engagement of CICCs, policy makers may guide business to increase transparency to stakeholders, by making an explicit standard such as CSR audit for companies to follow. In the meantime, construction companies in China are recommended to reveal CSR deficiency in their reports to enhance reliability. CICCs are also encouraged to participant more in CSR programs in the international construction market to gain corporate reputation and competitive advantage.

The analysis was based solely on CSR reports published by companies on websites. However, some CSR reports may not able to be found. In addition, this study only includes CSR reporting practices of the 21 listed companies in China, because other unlisted companies might not release their information publicly. This study provides a springboard for further research. It is a good trying to investigate the CSR issues focusing on CICCs. CSR indicator system established in this study can be used to explore CSR heterogeneity by Chinese construction companies, through which various theoretical perspectives on CSR can be confirmed or refuted. The insight will provide a lens through which CSR issues of Chinese companies can be better understood by international market. It will also allow CICCs to manage their future CSR strategies for better competing in the international construction arena.

5 Conclusion

This study explores the CSR perception of Chinese construction companies in the international market. According to CSR reporting guidelines for Chinese enterprises (e.g., CASS-CSR) and the contents of 168 CSR reports of 21 CICCs over a period of 10 years (2010–2019), a CSR indicator system was formed for content analysis. Analysis of the CSR/ESG reports of CICCs showed that there is increasing CSR reporting over the 10 years. CICCs are enriching their CSR contents for communicating with external environment from business. However, CSR audit is still relatively new to CICCs. There are rarely companies have their CSR reports audited by authorized third-party auditors. The study further revealed that community involvement is mostly welcomed by CICCs in CSR reports, although these activities reported are mainly conducted in their home country (i.e., China). Nevertheless, the majority of CICCs hide their deficiency in CSR reports. This largely reflects the phenomenon of dissembling, which implies that companies tend to disclose favorable information but hide unfavorable information for the purpose of image representation and reputation improvement. Lastly, innovations regarding to technology and environment protection as important competitive strategies have been largely adopted by CICCs in CSR reports. CICCs disclose their remedial strategies while hiding their unfavorable performance.

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Prospect of Architectonic Grammar Reconstruction from Dense 3D Point Clouds: Historical Building Information Modeling (HBIM) of Guangdong Cultural Heritages

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Abstract Building information modeling (BIM) of cultural heritages, i.e., historic building information modeling (HBIM), advances the monitoring, maintenance, restoration, and virtual exhibitions of historical buildings. However, due to the elaborate styles and the unavoidable erosion and renovation, the reconstruction of HBIM from the prevalent raw data, such as point clouds and images, is very challenging, especially parametrical and semantic modeling. Recent studies have noticed the potential of architectonic grammar for facilitating parametric and semantic reconstruction. This paper investigates the manual modeling of cultural heritage with the architectonic grammar and proposes a roadmap consisting of four levels of automation, i.e., 'calibration,' 'selection,' 'combination,' and 'generation,' of the architectonic grammar reconstruction. Further quality improvement and cost analysis of these four levels show that 'calibration' and 'selection' are the most suitable options currently for real-world applications. This study inspires the future application of architectonic grammar to facilitate the parametric and semantic HBIM reconstruction and explores the prospect of a new HBIM reconstruction schema.

Keywords HBIM · BIM automation · Cultural heritage · Architectonic grammar · Parametric modeling · Building semantics · Automated model reconstruction

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1 Introduction to Architectonic Grammar Reconstruction

Building information modeling (BIM) is a digital representation of physical and functional characteristics of a facility to enhance data interoperability and serves as the fundamental information infrastructure to facilitate data sharing, construction control, facility management, and decision making [1]. When applied in cultural heritage, i.e., historic buildings, BIM is known as historic BIM (HBIM) [2]. HBIM has received much attention in the past decade due to its promising applications in heritage monitoring, maintenance, restoration, and virtual exhibitions [3].

However, HBIM is not as prevalent as its counterpart of modern buildings, and its automation supported by the software is still limited [3]. The reconstruction of HBIMs could be much more challenging than that of BIMs. Because unlike modern buildings that are prone to be highly regular, concise, or compact, historic buildings are always highly elaborate, both in structures, e.g., the wooden composition of Shanxi Hanging Temple, and decorations, e.g., the facades of Cathédrale Notre-Dame de Paris [4]. Therefore, the complexity of geometry, semantics, and topology of heritages could be very high. Furthermore, erosion and refurbishment are unavoidable in cultural heritages during their long history, which improves the complexity of HBIM reconstruction.

Existing approaches to HBIM take advantage of 3D scanning and photography to capture cultural heritages' surface information [2, 5]. Once captured, mesh models can be created by triangulation from LiDAR points [6] or performing structure-from-motion (SfM) algorithms on images, which is mature and automatic. Next, to create semantic and parametric HBIMs, interactive and automatic solutions have been investigated. For example, Murphy et al. [2] introduced an HBIM system to map the BIM objects from a parametric object library onto point clouds. However, the conversion from point clouds or mesh models to HBIM parametric components still requires much manual effort. Moreover, BIM semantics recognition by segmentation is a typical schema of automatic reconstruction, which could be further categorized into (i) heuristic and (ii) learning approaches [7, 8]. The heuristic semantics recognition methods are, however, limited to simple geometry shapes [9]. Meanwhile, most learning-based semantics recognition methods rely heavily on burdensome manual annotations for training. In addition, both paradigms of segmentation are sensitive to data imperfections, e.g., occlusion and clutter in point clouds or mesh models [10]. Thus, novel semantics recognition and modeling methods are demanded.

Recently, architectonic grammar is exploited for the parametric reconstruction of buildings as a segmentation-free approach [11, 12]. An architectonic grammar regularizes the expressions of elements, forms, and styles from the ground plan to the rooftop [13]. It has some essential properties that facilitate parametric and semantic reconstruction of HBIM [14]. First, architectonic grammar is highly extensible to different architectural styles based on the concept of meta-grammar. Traditional grammars could be found out in the cultural heritages; meanwhile, some architectural modernists, such as *Frank Gehry* and *Zaha Hadid*, have deviated their distinguishable ones. Secondly, architectonic grammar holds a hierarchy from the main structures to the smallest details. More specifically, the grammar covers the definitions of (i) parameters, (ii) geometric primitives, (iii) components, and (iv) component relations. Consequently, researchers and engineers can adjust the parameters and select appropriate geometric primitives and semantic parameters for HBIM. Thirdly, architectonic grammar is compatible with some statistical reasoning frameworks [15], advancing the automatic semantics recognition while preserving the interpretation compared with some "black-box" segmentation-based recognition and reconstruction.

This paper aims at proposing a roadmap for the future automation of the architectonic grammar reconstruction from point clouds. First, we select a set of Guangdong cultural heritage sites and collected dense and colorful 3D point clouds. A manual process then reflects how the architectonic grammars of the target heritage buildings can be organized into the Grasshopper diagrams. A roadmap consisting of four levels of automation is presented in contrast with the manual modeling results. We can recommend the 'calibration' and the 'selection' levels for practitioners.

2 A Case of Guangdong Cultural Heritages

A pilot study was conducted on a case in Xuzai community, Sanxiang Town, Zhongshan City, Guangdong Province, China. We focused on three cultural heritage sites' colorful point clouds scanned by a drone, as shown in Fig. 1. The LiDAR point cloud includes one Tower named Wenge and three watchtowers (486 MB compressed on disk). The point cloud is in the LASzip Compressed LiDAR (.laz) format in the WGS 84/UTM zone 49 N (EPSG: 32649) coordinate system.

Fig. 1 Three study sites as circled around the old street, Sanxiang Town, Guangdong

Wenge Pagoda was built in 1747, 273 years ago, in the Qing Dynasty. The tower has five stories in 30 m in height, covers an area of 39 square meters. It was rebuilt three times in 1819, 1895, and 1984, and became a Historical and Cultural Site Protected at the Zhongshan city level in 1990. A dense cloud of 29,606,820 colorful points were collected from the photogrammetric model of a drone scanning. The mean volume density of it is 7,272,552.5 pts/m^3.

The three watchtowers are scattered nearby in the old streets and alleys. They were built from the end of the Qing Dynasty to the Republic of China for military use. The watchtowers were listed in the category of Historical Buildings in Zhongshan City in 2009 and listed in the Historical and Cultural Protection Areas of Sanxiang Town. The three watchtowers were scanned and collected into two sets of point clouds. The first set with one tower has 13,571,861 colorful points while the second set including two watchtowers of 20,853,279 points.

3 Baseline Parametric Modeling

We utilized the Grasshopper on the Rhino platform (ver. 6) for the manual parametric modeling. Grasshopper is a non-uniform rational basis spline (NURBS)-based visual programming language and 3D modeling software. The value of Grasshopper lies in parametric modeling and human-machine interactive design. Besides, Rhino can create, edit, analyze, and transform the NURBS curves, surfaces, and entities in complexity, angle, or size. The laptop for the experiment ran a Windows 10 (64 bits) on Intel i9-9980HK CPU, 16 GB memory, and NVIDIA Quadro T2000 GPU.

First, the dense point clouds were converted from the data set to ASTEM E57 (.e57) format and Wavefront object (.obj). The three sets of point clouds were centered on the origins. Grasshopper was utilized to rebuild the reference points from the point cloud data. In sequence, it is used to be the center point of the reference plane in the model. Then, the shape's contour line or curve battery by setting the plane figure's relative length details and shows different its location through translation or rotation. Then, the contour line or curve battery of the shape may move up or down, expand or shrink through number battery to form other flat figures of different heights or sizes needed. After that, the shape surfaces can form from external contour lines or curves through covering surfaces. Finally, a series of planes from every module is made up of generated planes in the module and then are composed of the whole model surface.

The architectonic grammar diagram of the pagoda in Grasshopper, as shown in Fig. 3a and b, consists of six modules. The first module consists of the base and the first layer of the pagoda:

1. Firstly, the reference anchor point (0, 0, 0) needs to be found from the 3D could point model.

2. Secondly, the base's hexagonal contour line of 5 m on each side is generated with the reference point as the center point of the graph, then it rotates 15° counterclockwise and moves up 0.4 m.
3. Then, the base's hexagonal contour line moves up to 0.4 m and does the same generation and rotation again. In sequence, the first layers' hexagonal contour line is produced by moving up or down 0.35 m while expanding to 1.1 times or shrinking 0.95 times.
4. Lastly, the above generated hexagonal contour lines are combined into a line composition, and then the set of lines lofting into the first layer plane together with the base one.

The second layer's hexagonal contour line was lifted 4.5 m from the first layer. Similar operations were applied to the third, fourth, and fifth layers. The spire is 3.6 m higher than the fifth layer's anchor point. The fifth layer's middle hexagonal contour moves up 0.6 m and shrinks to 0.8 times, to form the tower roof's reference points. In the end, the spire's point generates a circular reference line, on which the six exterior planes converge as the rooftop of the tower.

The architectonic grammar diagram of the first tower in Grasshopper, as shown in Fig. 3c and d, consists of 2 modules. The first module is the surface composition for the tower body:

1. Firstly, the reference anchor point (0, 0, 0) needs to be found from the 3D could point model.
2. Next, the base's rectangular contour line is generated with the reference point as the center point of the graph, and then it rotates 35° counterclockwise and moves up 8 m to generate the rectangular contour line of the lower top layer.
3. Next, the top layer's rectangular contour lines are produced by moving up 0.1 m, up 0.1 m, or down 0.895 m while expanding to 1.1 times or shrinking 0.95 times.
4. Lastly, the rectangles and lines are lofting into planes.

In the second module, the floor of the roof covers through the principle called the three points to form a plane. Next, the affiliated small house floor generates by the above reference point and sets the lengths of x and y. Finally, a set of horizontal rectangular contour lines of the house are produced by moving up 1.8 m or 0.895 m while shrinking at a rate of 0.9 times. Finally, rectangles cover and lines lofting into planes. Modeling process for the rest towers in Fig. 2c is similar.

The reconstructed models of ancient buildings in Guangdong through computational design software preliminarily perform the buildings' main body shape. Therefore, what is fundamental and essential in reserving while reconstructing the cultural heritage field is that the broken and incomplete physical architectural model shows again in public in virtual architectural models through novel digital tools. Furthermore, one of the usual computational design methods is parametric design, a design process in which the engineering itself is programmed as a function and a process. The design process is automatically realized by modifying the initial conditions and obtaining the engineering results by computer calculation.

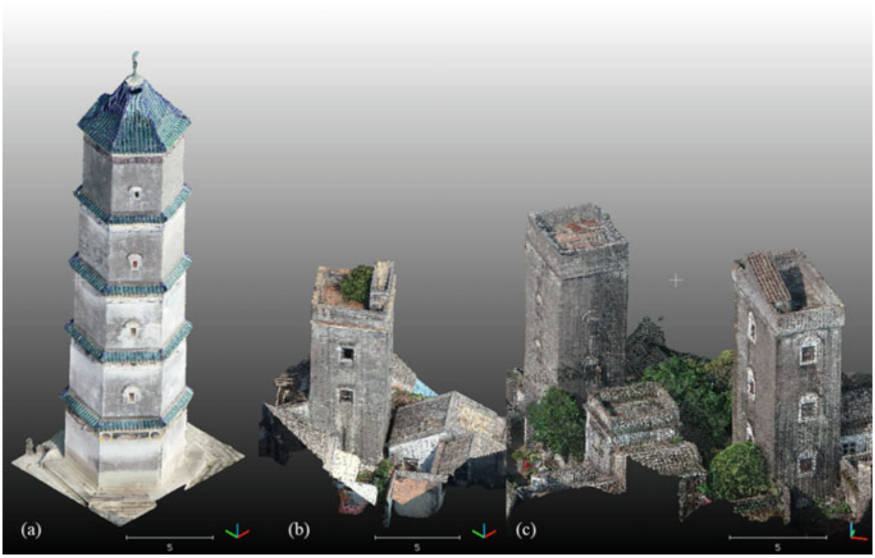

Fig. 2 Dense point clouds of cultural heritage buildings, with a density of >10,000 pts/m^2. **a** Wenge Pagoda (29,606,820 points), **b** a watchtower (13,571,861 points), **c** twin watchtowers (20,853,279 points)

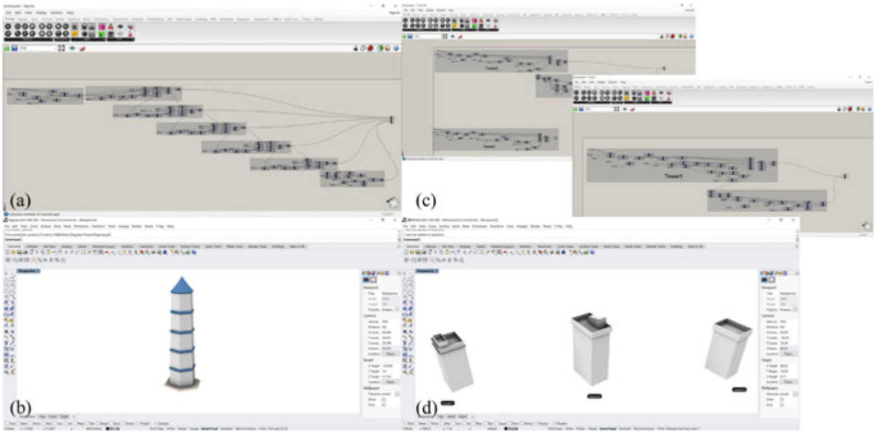

Fig. 3 Grasshopper diagram and parametric models. **a** diagram for Wenge Pagoda, **b** 3D view of (**a**), **c** diagrams for the watchtowers, **d** 3D view of (**c**)

4 A Roadmap to the Automated Architectonic Grammar Reconstruction

The automation of architectonic grammar reconstruction can be projected and classified into four levels, as shown in Fig. 4. We noticed that the diagrams in Grasshopper were comprised of four types of grammar components, i.e., (i) parameters, (ii) geometric primitives, (iii) components, and (iv) relations to new components. Therefore, the most straightforward automation is to let the machine fine-tune the parameters, while the whole diagram structure designed manually remains unchanged. The most challenging automation level is automatic incremental design or revision of new components, while no apparent work demand is there for human modelers. Note that the automation roadmap and the levels are independent of the Grasshopper + Rhino and compatible with other parametric design tools such as Dynamo + Revit.

The first automation level is 'calibration.' At this level, the whole grammar structure still comes from an experienced modeler's manual work. The structure aims to reflect what components and primitives are there in the rough parameters of locations and sizes. The machine will do the parameters calibration, automatically. In this way, the human resource can be partially relieved from the laborious effort on fine-tuning

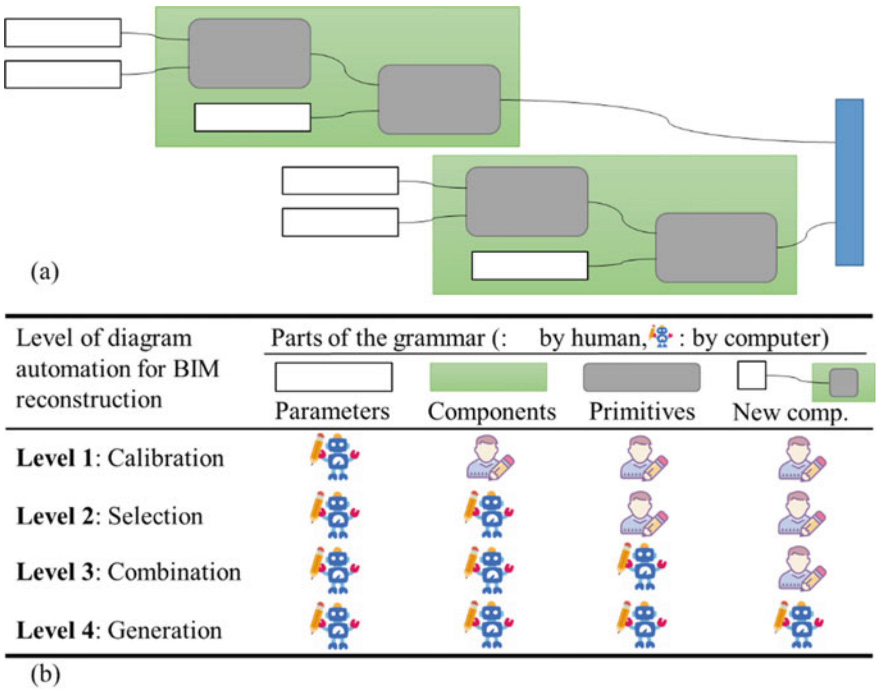

Fig. 4 Four levels of prospect of automation for architectonic grammar reconstruction. **a** a general diagram, **b** table of diagram automation

the small digits in the parameters. Similar parameter optimization approaches are known well in the BIM performance fine-tuning [16] as well as HBIM [17]. The saving will be more considerable if the parameters are interconnected—so that one small change in a parameter leads to impacts to another parameter.

The next level is ‘selection.’ A selection-level grammar reconstruction inherits the parameters automation part of the first level. Additionally, the components are selected automatically from an available library. For the manual work, the modelers first need to prepare a big enough component library—like the BIM component and resources libraries. A sketch diagram of known relations of major unknown components can then guide the machine to search for the best-fit instances in the library. On every trial, the first calibration level will be called to tell the best fitness. Overall, the machine runs in a trial-and-error fashion. For instance, Xue et al. [10] show that automatic ‘semantic registration’ of 8 furniture BIM components to a noisy point cloud. The semantic registration first performed such a ‘selection’ automation, then calibrated the three parameters, i.e., x, y, and heading direction. According to the experiments in Xue et al. [18], over 98% of modeling time was saved.

The ‘combination’ level elevates the selection level by evolving the components. Every as-designed component in the library consists of a system of geometric primitives. A combination-level automation machine evolves these primitives to the best-fit primitives through iterated evolutionary computation. For example, suppose the six sides of Wenge Pagoda in Fig. 2a are slightly different (e.g., deformations within 5 mm), while the selected components by a Level-2 machine are perfectly symmetric. In that case, the Level-3 combination operation will try to select the related geometric primitives inside of the best-fit components for better fitting to the measurement. The combination-level reconstruction improves the accuracy of the Level-2 selection results.

The fully automatic level is classified as ‘generation’ in this framework. The a priori setting of relations among major components is automated at this level. As a result, the relation modeling and arbitrarily new components are created by the machine rather than human export. However, a combinatorial explosion of the computational load growth is expected, due to the complex and nested variables in the four levels. In the near future, the authors are not optimistic about seeing massive applications of this level to modeling cultural heritages.

The selection of an appropriate level can be based on the trade-off between marginal quality and cost. It means if both quality and cost are improved by an automated method, it is strongly recommended. Furthermore, the most recommended level is equipped with maximum bi-objective gains. Because usually, the quality may increase along with the automation level, while the cost is in the opposite direction. For example, Table 1 shows an assumed trade-off table for a company. When we use the “MIN()” function to measure the bottom-line gain, the ‘selection’ is the best level. The highest level may not be the best level. The authors wish to see progressive research and development in the next couple of decades, regarding the drivers and barriers. There is no need to target the highest level at the very beginning blindly.

Table 1 Example trade-off table and recommendation for a company

Level	Name	Quality gain (e.g., accuracy, innovation, semantics, etc.)	Cost gain (e.g., money, time, effort)	Recommendation [e.g., based on MIN(quality, cost)]
1	Calibration	★	★★★	
2	Selection	★★	★★	✔
3	Combination	★★★	(Cost increased)	
4	Generation	★★★	(Cost increased)	

5 Conclusion

The automation of parametric and semantic HBIM reconstruction remains a very challenging topic to date. New schemas are desirable to improve this automation without increasing the cost. Architectonic grammar shows excellent potentials for HBIM reconstruction in recent studies. Therefore, we investigated a pilot case and a roadmap to inspire the future automation of architectonic grammar reconstruction from point clouds. The manual modeling of the selected Guangdong cultural heritages demonstrates how the architectonic grammars of the historic buildings can be organized as Grasshopper diagrams. Next, a roadmap described the four levels of automation is proposed. The quality improvement and cost of these four levels are also analyzed. Consequently, 'calibration' and 'selection' levels are recommended for practitioners based on the prospect of future research.

Following the roadmap, we will further investigate and develop the automatic 'calibration' and 'selection' methods based on architectonic grammar, and search for opportunities to attack the 'combination' and 'generation' levels of architectonic grammar reconstruction. Along with the architectonic grammar reconstruction, the geometric, semantic, and topological definitions in BIM and HBIM will be exploited and formulated. Moreover, advanced evolutionary computation algorithms and design knowledge suitable for solving such non-linear and expensive optimization problems, such as derivative-free optimization (DFO) and Gestalt principles [19, 20], will be employed in our automatic reconstruction.

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A Critical Review of Stakeholder Participation in Urban Renewal

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Abstract Numerous cities around the world are suffering from serious rundown of inner city. It results in lots of core problems in urban development, such as pool living conditions, weak economic growth, increasing social problems, farmland abuse, and low efficiency in urban land use. As an effective way to solve these problems, urban renewal has became a public profile within the urban policies in many countries. Urban renewal involves many stakeholders, which is considered to be one of the important reasons for the complexity of urban renewal. Although various papers related to stakeholder engagement were published in the field of urban renewal, the role and influence of different stakeholders are indistinct and controversial. To fill this gap in literature, this study aims to provide a critical review of recent studies on the stakeholder of urban renewal with a combined methodology of bibliometric analysis and qualitative analysis. Firstly, the bibliometric records are collected from SCI database and SSCI database with the software of CiteSpace 5.6. Based on these papers, an overview of previous studies, including the contents of research trends and research focus among these papers are visualized by using CiteSpace 5.6. After that, stakeholders are identified by the classification and description of stakeholders. Besides, the conflict among stakeholders and how to coordinate the relationship between stakeholders are discussed. Finally, several interesting directions for future research are identified and recommended. This study can be an important reference source for researchers, and also contributes to the urban renewal decision-making in practices.

Keywords Stakeholder participation · Stakeholder analysis · Urban renewal · Sustainable development

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1 Introduction

Many cities around the world are currently suffering from severe deterioration of city centres and undergoing a series of dramatic reconfigurations [1, 2]. It results in lots of core problems in urban development, such as pool living conditions, weak economic growth, increasing social problems, farmland abuse, and low efficiency in urban land use. In order to solve these problems, urban regeneration has increasingly become a public profile within the urban policies both in developed countries and developing countries [3, 4], as most countries have set the urban policy of limiting urban sprawl to achieve the goal of sustainable development. For example, in 2020, Manchester City Council has approved an £80 m regeneration plan for a mixed-use community with 410 new homes at Coleshill Street. China's central government hopes to promote the process of urban renewal. According to *the guiding opinions on comprehensively promoting the transformation of old urban residential areas*, by 2025, all regions in China should strive to complete the task of rebuilding old urban residential areas which were built before 2000. Therefore, urban renewal has become the focus of contemporary public interest and debate.

Urban renewal projects have both the political complexity and systematic complexity [5]. Urban renewal are highly complex and uncertain since various stakeholders are involved in the urban renewal project [6]. Multiple stakeholders' participation and process management in decision-making are the effective ways to solve the complexities [7, 8]. In urban renewal, it is crucial to accurately identify stakeholders [9]. Stakeholders refer to the individuals or groups that can influence or be affected by the urban renewal projects [10]. According to this definition, the stakeholders of urban renewal mainly include government, residents, developers, design units, construction units, financial institutions, suppliers, research institutes, the public and the news media [11]. Those individuals or groups have their own stake or interest in urban renewal projects, and this make urban renewal a controversial issue around the world [12]. Therefore, the interdependence and coordination between different stakeholders during the urban renewal process is the key element towards success [13]. In order to better understand the role of stakeholders, and the relationship between them, this study aims to provide a critical review of recent studies on the stakeholder of urban renewal with a combined methodology of bibliometric analysis and qualitative analysis.

2 Methodology

In this paper, a combined method of bibliometric analysis and qualitative analysis was utilised. First set search rules, the retrieval rule of TS = ("Urban renewal" OR "Urban regeneration" OR "Urban redevelopment" OR "Urban renovation" OR "Urban revitalization" OR "Urban renaissance") AND ("Stakeholder") was utilized in the WOS core collection database. TS represents the field tag of Topic was used

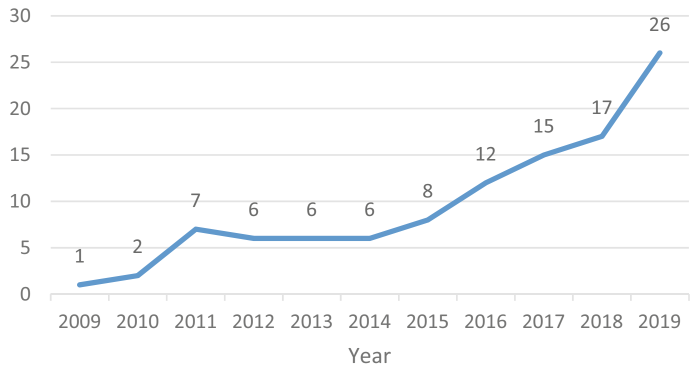

Fig. 1 The number of articles on stakeholder analysis in urban renewal in the WOS core collection during 2009–2019

to search articles, and retrieve related articles. Then, using the CiteSpace5.6 in this paper to do the bibliometric analysis and the focus analysis was used to extract new trends and clusters of topic concentration. According to the results of bibliometric analysis, the articles with high influence in each cluster were identified. After that, a future qualitative analysis was conducted to analyse these articles and the contest among main research clusters.

3 Overview of Studies on Stakeholder Participation in Urban Renewal

3.1 Research Trend Analysis

To reflect cutting-edge research trends, the time span of research on stakeholder participation in urban renewal was 2009–2019 in this paper. 106 journal articles on stakeholder analysis in urban renewal with the language of English were collected in January 2020. Figure 1 shows the distribution of the 106 records. The research on stakeholder analysis in urban renewal became a hot research topic in 2016, and the number of articles had increased each year since then.

3.2 Journal Co-citation Analysis

According to the number of published articles on stakeholder participation in urban renewal, top 5 journals were identified, as shown in Table 1. *Habitat International* with 13 articles occupied the top position, followed by *Cities* that have published

Table 1 The top 5 journals for stakeholder participation in urban renewal in 2009–2019

Journals	Frequency	Count
Urban Studies	69	3
Cities	54	11
Habitat International	45	13
International Journal of Urban and Regional Research	43	2
Land Use Policy	33	5

11 articles. With the journal co-citation analysis, the co-citation frequency of each journal was calculated (see Table 1). The most influential journal was *Urban Studies*, although the number of articles was 3. Taking both kinds of ranking into account, the top 5 journals with relatively high contribution were *Urban Studies, Cities, Habitat International, Land Use Policy, International Journal of Urban and Regional Research.*

3.3 Research Focus Analysis

Key words represent the core contents of articles and research topics of stakeholder participation in urban renewal. With the software of Citespace, getting keywords and excluding key words similar to urban renewal. According to frequency and centrality, 10 keywords were obtained respectively (see Table 2). The key words vividly depict the factors related to the stakeholders in the process of urbanization, mentioning that most of the situations happened in China. Obviously, sustainability is the goal of urban renewal, but to achieve sustainability, we must first deal with the coordination

Table 2 Ranking of key words excluding retrieval words

Frequency	Key words	Centrality	Key words
30	City	0.21	governance
21	Sustainability	0.16	China
17	China	0.14	gentrification
14	Gentrification	0.13	Decision making
13	Governance	0.12	Brownfield redevelopment
11	Policy	0.12	conservation
9	Management	0.11	infrastructure
8	Brownfield	0.11	New York
8	Project	0.11	Construction project
8	Framework	0.10	Housing demolition

between stakeholders. The impact of a project may be small-scale, or it may be on the scale of city, so the stakeholders corresponding to different impacts will be different. From the perspective of centrality, governance is now highlighted and emphasized, and governance means more public participation from a deeper perspective. So what kind of public participation, what role they play in the participation and what kind of power they have need to be defined. However, it is not necessarily accurate to define by human qualitative judgment, so it is necessary to establish a framework. This is very different from our previous decision-making, because we only considered the core stakeholders and ignored the rest, and the remaining stakeholders are also the people whose interests should not be damaged in urban renewal.

4 Discussion

4.1 Stakeholders Analysis

Stakeholder analysis is considered as a process or an approach to support decision-making and strategy formulation by numerous of researchers [14]. It is critical to accurately analyse the stakeholders in urban renewal projects, as the stakeholders cannot be effectively empowered to participate in urban renewal process unless their real interests and needs have been discerned. According to the previous studies, the general contents of stakeholder analysis cover the issues of identifying stakeholders and their interests, analysing stakeholders' impact/priority, and thereby developing strategies [14]. In the field of project management, the identification of stakeholders is divided into broad and narrow perspectives. For urban renewal projects, scholars tend to adopt the definition from the broad perspective, that is, stakeholders are individuals or groups that influence or are affected by the realization of project objectives [15, 16]. Defining stakeholders from the narrow perspective can more accurately identify core stakeholders, but it may leave out some potential stakeholders, such as media and NGOs, which may have an important impact on project decision-making or implementation, then increasing the risk of urban renewal projects [17]. In previous studies, various stakeholders were mentioned in urban renewal projects, such as local governments, competent authorities, owners, investors, users, consulting parties, NGOs, media, which are showed in Table 3. Take the power, accessibility, and attitude of stakeholders into account, all the stakeholders in urban renewal can be divided into three categories: core stakeholders, dormant stakeholders and marginal stakeholders which are showed in Fig. 2.

Core stakeholders exist in the vast majority of cases and are closely related to the process of urban renewal, including the government, developers and residents. Local governments, competent authorities and other government departments belong to the government. They all bring health, safety, and convenience to the community through the process of urban renewal. From a higher level, they promote the increase

Table 3 Classification of stakeholders

Stakeholder	Power	Accessibility	Attitude	Interest	Reference
Local governments	★★★★	Direct	Hard to shake, but can coordinate	Sustainable development of local area, e.g., GDP, employment, environment	[18]
Competent authorities	★★★★	Direct	Hard to shake, but can coordinate	To promote the health, safety, convenience and general welfare on the community through the process of urban renewal	[12, 19]
Other government departments	★★★★	Direct	Hard to shake, but can coordinate	To realize the of duties department	[20]
Developers/investors	★★★	Direct	Firm but may shake	High profit, long-term value, market share, enterprise brand, award	[12, 18, 20]
Owners	★★★	Direct	Firm but may shake	Proper compensation, environmental improvement, enhancement of property value, improvement of housing quality, participation in the decision-making of urban renewal	[18–20]
Users	★★	Direct/indirect	Easy to shake	Sustainable development, e.g., historical and cultural significance, better business environment, better living condition	[21]

(continued)

Table 3 (continued)

Stakeholder	Power	Accessibility	Attitude	Interest	Reference
Non-users	★	Indirect	Easy to shake	Require a medium to invigorate communication among residents	[22]
Consulting parties	★	Indirect	Indifferent	They provide professional suggestions and have a great impact on decision making	[12]
NGOs	★	Indirect	Neutral	Sustainable development of local area, e.g., environmental sustainability, healthy lifestyle, improved educational infrastructure	[20]
Media	★★	Indirect	Neutral	They present emerging opportunities for urban heritage conservation by mobilizing the public to negotiate with the government	[23]
Commerce or trade unions	★	Indirect	Neutral	They create employment opportunities, and realize urban regeneration from the economic level	[24]
Constructors	★	Indirect	Neutral	Profitability, repeat business, awards, prestige	[25]

The number of ★ represents the size of power

of local GDP, increase employment, and protect the environment to achieve sustainable development. Generally, governments play important roles in the process of urban renewal, such as being in charge of policy-making and planning regulations,

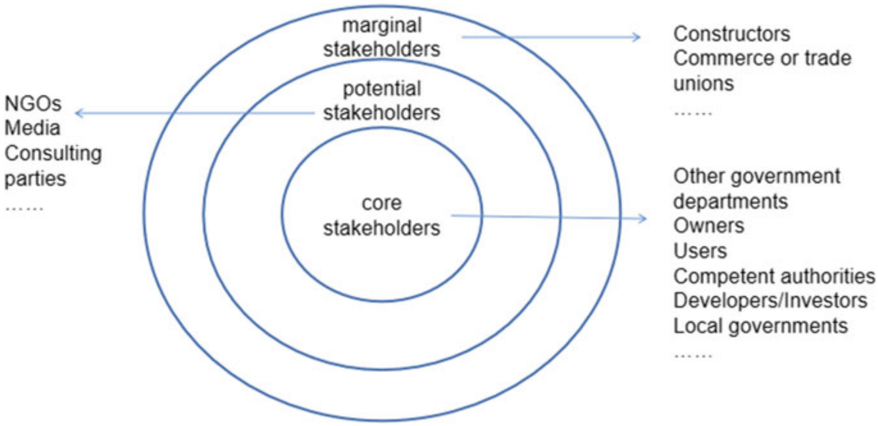

Fig. 2 The classification of stakeholders

coordinating and supervising all activities [26]. In my country's traditional demolition model, the government is dominant, mainly because the government unilaterally formulates and announces the expulsion policy and compensation standards [12]. However, the government would hinder the process of urban renewal in some cases. Nedučin et al. analysed the outcomes of culture-led transformation marked by the laisser-faire attitude of local authorities, and found the government has negative effects on the project due to the poor management and hands-off approach [26]. In order to achieve the goals of sustainable urban renewal, some scholars paid attention on how to improve the ability of governance from the perspective of government. For example, Klusáek et al. distilled several generally applicable good practices for government [27].

In term of developers, the prerequisite for them to participate in urban renewal is that they are profitable. Li, Kleinhans et al. pointed if the housing market go into a recession, developers would be less motivated [28]. In Shanghai, China, there is a kind of urban renewal projects which is called HCR with the mandatory requirement in law to preserve both the original inhabitants and the existing buildings. In this context, developers cannot make a profit, leading to few developers are willing to invest [29]. The characteristics of developers' pursuit of profit are easy to bring trust crisis. In the case of Xiasha village in Shenzhen, the independent development of self-organization had been successful. But when they tried to collaborated with Vanke real estate company, the villagers started to question the allocation of the profits generated by the urban renewal project [30].

Residents related to urban renewal, including owners, users and non-users, usually live in slum areas and dilapidated urban areas [31]. In urban renewal, residents usually pursue appropriate compensation, environmental improvement, property value improvement, housing quality improvement, and the right to participate in urban renewal decision-making, but in fact residents are in a disadvantaged position because their individualized, selfish, and divisive stances in negotiating with the government are difficult to change, and it is easy to trouble local officials. They have to face many personal demands. In this asymmetric and uncooperative game, they have no legal rights and reasonable ways to participate in decision-making, and they lack knowledge about urban renewal and the power to participate in public affairs, and they are sometimes excluded from decision-making in urban renewal. Outside the process [12]. In Yu, Shen et al.'s research, many ordinary residents even acknowledged that their knowledge about urban housing demolition was mainly acquired from public media or the Internet [32]. In addition, tenants as residents are often ignored by the decision makers of urban renewal projects. Xu and Lin found the fate of the project was determined by neighbors who no longer live in the neighborhood but actually have voting rights. Non-registered residents who were only staying in the community had no voice in the process or benefits at all [27].

Compared with the core stakeholders, dormant stakeholders have similar influence, while their difference lies in their initiative. Not every case has interests related to dormant stakeholders. Only when their interests are challenged, they would change from dormant state to active state, so as to have same power as core stakeholders in the project. The ways of participation include providing experience and knowledge, playing a supervisory role. For example, Zhuang, Qian et al. mentioned consulting parties' knowledge and professional suggestions have a great impact on decision making and implementation [12]. And Lee detailed how the news group has helped shift the project priority from being property-led to conservation-led in a project in Guangzhou, China [32]. In addition, marginal stakeholders are also involved in urban renewal. However, they are not of great significance, and there is no influence similar to that of core stakeholders and dormant stakeholders in the process of urban renewal. This is because they are relatively less involved and their interests are rarely violated.

4.2 Stakeholders Conflicts

The process of urban renewal is a complex network, which involves multiple stakeholders and interacts with each other in various ways. Therefore, it is a great challenge to deal with the conflicts among stakeholders. Case study is the most common method to analyze stakeholder conflicts [32–34], so a systematic conflict analysis framework is very necessary. To quantify and measure the conflicts will help us to analyze the conflicts and put forward effective action plans and strategies to reduce the conflicts among stakeholders in urban renewal Yu, Liang et al. used Pawlak's conflict theory to quantify stakeholder conflicts [19]. This method measures conflict from three aspects. Figure 3 shows the whole process of the theory.

In addition, due to the different root causes of conflicts among different stakeholders, the final manifestation will be different. A major portion of current researches related to stakeholder behaviour were focus on the conflicts among stakeholders. Wang and Xiang believed the forms and characteristics of conflicts among the core stakeholders can be summarized as follows: Conflicts between the government

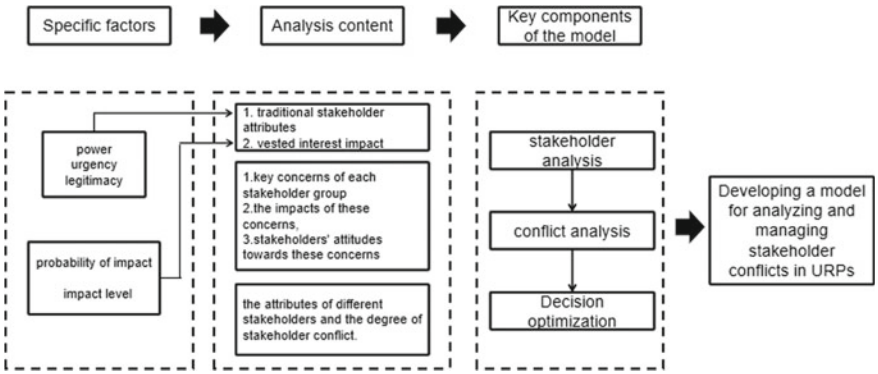

Fig. 3 Pawlak's conflict theory

and owners focus on the distribution of interests; Conflicts between developers and owners focus on the transaction of property rights; Conflicts between the government and developers focus on the implementation rules [35].

Among them, residents, as vulnerable groups, are most vulnerable to the impact of urban renewal. On the one hand, urban renewal can lead to the displacement of the population, because urban renewal and gentrification are irreducible views of the same process [36]. Trop found the impacts of accommodation loss and the lack of affordable housing on existing low-income tenants have already resulted in the displacement of poor households and the alteration of the existing social mix [37]. On the other hand, urban renewal may have an impact on residents' health, so Egan, Kearns et al. introduced a programme named GoWell. It has been designed to measure effects on health and well-being of multi-faceted regeneration interventions on residents [38]. In China's traditional demolition mode, the government plays a leading role, and investors are related to the government. On the one hand, the government unilaterally formulates and publishes expulsion policies and compensation standards. On the other hand, it is difficult for the deportees to change their position in the negotiation with the government because of their individuality, selfishness and division. In this asymmetric and uncooperative game, the expelled have no legal rights and reasonable ways to participate in decision-making. That conflicts in urban renewal mostly occur between residents and other stakeholders.

For example, Tan and Altrock described a case of conflict between residents and government. The residents thought the aim of a project called Enning Road is purely commercial and tourism development in the name of public interest. In order to resist the tremendous demolition and eviction, a letter signed by 220 local residents was sent to the local government [39]. A dilapidated residential redevelopment project in Shenzhen reveals the cause of the conflict between residents and developers, the proposed redevelopment plan and the terms of the relocation agreement were drafted solely by the developer without seriously engaging the households, this put the whole project on hold [35]. Conflicts can also arise within stakeholders. In Lee and Sung's research, the conflict between users and non-users in terms of the possession of public goods [34]. Li, Han et al. developed a power arena analytic framework, and uses it to examine the new power relations among the stakeholders in a dilapidated residential redevelopment project in Shenzhen [40].

4.3 Stakeholder Coordination

When conflicts among stakeholders are not effectively controlled, they can have serious negative social and economic impacts [40], So how to reconcile contradictions has become the focus. Zhou, Zhou et al. pointed good cooperation, communication and information sharing and clarity of roles and responsibilities among participants are effective ways to resolve dispute and coordinate the interest demands of participants [41]. Hin and Xin illustrated an interesting picture of two different outcomes of regime building with the same local government and the same private partner working on two projects in the same local district. When the government and residents cooperate, the project can go more smoothly [8]. In order to coordinate the relationship among stakeholders, on the one hand, Yu and Lee, Yu, Liang et al. proposed conflict-risk assessment models related to stakeholder conflict and solutions [11, 19]. On the other hand, Pipa, de Brito et al. and Amado, Ramalhete et al. described ways to strengthen stakeholder collaboration [42, 43].

As conflicts are mainly concentrated between residents and other stakeholders, public participation is considered to be the most important method in stakeholder cooperation. Public participation has become the research direction of many scholars, but there are still many problems in public participation. Dogruyol, Aziz et al. regarded public participation as the essential ingredient in sustainable urban regeneration planning. And by involving the local community in the planning process, it is possible to ease the conflict by taking the community's perception towards sustainability into account [44]. Yu, Shen et al. thought public participation can mitigate the impulsive actions of key stakeholders [45]. Meanwhile, by collecting feedback from key stakeholders, governments and developers can acquire more useful information. Nevertheless, some consultants argued that an overemphasis on public participation would reduce efficiency [46]. And Zhuang, Qian et al. found most stakeholders, including the public themselves, hold negative perceptions of public participation [47]. In fact, there are still obstacles to public participation. He, Wu et al. believed the barriers is lack of trust and lack of an effective multi-stakeholder negotiation platform [46]. In addition, sometimes, the public participation is a mere formality. Xu and Lin maintained that in Chinese inner-city redevelopment, urban neighborhoods are simply excluded. They found that participatory urban redevelopment is a tool for the municipal government to quicken the housing requisition process for economic development and avoid social unrests for career advancement [27].

Therefore, how to effectively enhance public participation has become one of the research direction of scholars. Yau proposed a land management technique called

Land Readjustment (LR), the LR technique can facilitate the building up of a partnership between various stakeholders in a redevelopment project and allow the homeowners to have a stake and say in the project [48]. Omidipoor, Jelokhani-Niaraki et al. developed a Spatial (GIS-based) Decision Support System (SDSS) which could provides an appropriate tool for the facilitation of participatory renewal procedures in UBAs [49]. Natividade-Jesus, Almeida et al. introduced an integrated methodology to support the planning and management of urban regeneration interventions [50].

5 Conclusion

In terms of the number of articles published, Urban Renewal Stakeholders attracted increasing attention from researchers and practitioners. Network analysis and co-citation analysis were used to identify and visualize the status and trends of Urban Renewal Stakeholders research. Several core journals have published most significant findings in Urban Renewal Stakeholders research, such as Urban Studies, Cities, Habitat International, International Journal of Urban and Regional Research, and Land Use Policy. As for keywords, “city”, “sustainability”, “China”, “gentrification” and “governance” had the most frequency.

On the basis of quantitative analysis, this study makes a qualitative analysis of the literature. According to previous studies, this study identifies and classifies various stakeholders. Core stakeholders’ (government, developers, residents) characteristics and demands in the process of urban renewal are described. In addition, dormant stakeholders and marginal stakeholders are summarized and sorted out. It is precisely that different stakeholders have different demands in the process of urban renewal, so it often leads to conflicts. Due to the residents’ weak position, this study believes that the stakeholders conflict is mainly concentrated between residents and other stakeholders. This study discusses the causes of conflicts and lists specific cases. The conflict between stakeholders had been the barrier of urban renewal. Therefore, it is very important to solve conflicts and cooperate to avoid conflicts. Among them, public participation has been paid more attention because residents are the main body of stakeholder conflicts. This study refers to the views of different literature on public participation, as well as the current obstacles. Finally, it mentions different opinion about how to effectively enhance public participation.

Through the above research, some shortcomings of the current research on urban renewal stakeholders were found, which could become the research direction in the future. First of all, in the identification of stakeholders, There is a lack of a stakeholder analysis framework that can be commonly used in urban renewal decisions. Secondly, the current focus is mostly between the core subjects, and insufficient attention is paid to the marginal stakeholders, for example, residents’ interests are ignored in urban renewal and there are few studies on tenants. Meanwhile, residents as stakeholders, their ability to participate in urban renewal has been questioned because of lack of professionalism. However, there are few studies that question the ability of stakeholders to participate in urban renewal. In addition, how to further improve the participation of consulting parties or NGOs in urban renewal could be explored, such as enhancing the transparency of decision-making by them. Finally, there is no study on the difference between stakeholders in terms of country or region.

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Influencing Factors for Spatial Conflicts in the Resettled Community for Landless Peasants: A Perspective of Space Ternary Dialectics

Hui Gao, Kexi Xu, and Haijun Bao

Abstract The urbanization process in China has been extremely compressed in time and space, resulting in serious conflicts over any given time period. Resettled communities for landless peasants is a kind of transitional community between urban and rural communities. The behaviors with rural life habits are quite common in resettled communities, leading to serious spatial conflicts among residents in the community which is a big challenge to the community governance. The existing studies does not provide a rigorous and structured identification of these factors. Therefore, in order to provide theoretical guidance for the governance of the spatial conflicts of this kind of community, this paper proposed an analytical framework on factors influencing spatial conflicts. Firstly, this paper developed a three-dimensional theoretical framework for the influencing factors of spatial conflicts in resettled community based on Lefebvre's ternary dialectical space view. Secondly, on the basis of three-dimensional theoretical framework, 26 influencing factors for spatial conflicts in resettled community were extracted through the collation of literature and content analysis. Finally an analytical framework on influencing factors of spatial conflicts in the resettled community for both conflict governance and government policy is developed. Also, suggestions are proposed to reduce the spatial conflicts in the resettled community for landless peasants. This paper helps to provide inspiration for the governance of resettled communities and the study on community spatial conflicts.

Keywords Community spatial conflict · Resettled community · Landless peasant · Influencing factor · Community governance

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1 Introduction

With the rapid urbanization in China, large number of landless peasants have been relocated into the resettled communities as a result of land acquisition and demolition of rural house. The number of such community has accounted for more than a quarter of total number of the urban communities [1], and will continue to increase in the future. Resettled community for landless peasants is a kind of transitional community between urban and rural communities. The transformation and development of this kind of community have a direct impact on farmers' transformation into urban inhabitants, and indirectly affect the quality of China's new-type urbanization. However, the transitional characteristics of this type of community have caused serious community conflicts among residents. Compared with other types of urban community, the resettled community has the highest degree of conflict while most of the conflicts are related to the competition for the space resources in the community [2]. In a city that is at the forefront of urbanization, two-thirds of the resettled communities are suffering from various spatial conflicts such as the private occupation of public space, competition for parking space, holding wedding and funeral ceremonies in the open space, growing vegetable by destroying green belt, burning ghost money in the corridor, noise pollution and so on [3]. The reshaping of social relations in resettled communities lags behind the influx of new residents, which will further intensify the community spatial conflict among the residents. The accumulation of such conflict may cause the involution of landless peasants and lead to the outbreak of a mass disturbance. Thus, the governance of community spatial conflict is significant to the sustainable development of resettled communities and landless peasants' citizenization.

The research on social conflicts has been paid much attention and the theory of social conflict has laid a solid theoretical foundation in this field. And then, some sociologists, e.g. Coleman, Cosset and Sanders, put forward the theory of community conflict on this basis. However, constrained by the de-spatialization of sociological theories, the research on the spatial perspective of community conflict has not received much attention until the 1970s with the "space shift" boom in sociological studies. The space production theory classified by various scholars, e.g. Lefebvre, Foucault, Harvey and Soja, has played an irreplaceable role to the rising of studies on spatial conflicts. Among them, the ternary dialectical space view proposed by Lefebvre has an epoch-making significance in this field. Thereafter, the concepts, categories, measures and causes of spatial conflicts are discussed by scholars in the fields of geography, ecology, land management, sociology and economics. In the city or region level, scholars believe that spatial conflicts are arising as a result of different space uses and their associated external impacts in the process of urban expansion [4]. In these spatial conflicts, most of them are relevant to the allocation of scarce resources [5]. In terms of community level, the spatial conflict is generally considered as the conflict among community members accompanied by the scramble for spatial resources in community. In that sense, some scholars have tried to explore factors influencing community spatial conflicts from different perspectives. For example, Wu examined the link between rights recognition and conflict escalation. He found that among the causes of conflicts, lack or abuse of public space accounts for 12.6% [6]. Luisa and Otero argued that the development of affective ties with the neighborhood in which they reside can insulate people from neighborhood conflict [7]. Fu found that community conflicts relate to some factors such as nearby neighborhood planning, ancillary facilities, building quality, and the size of shared areas [8]. Kate raised six clusters of factors affecting conflicts in the refugee and new migrant communities: family; social dislocation and alienation; cross-cultural concerns; support and services; employment, education, and language; and community [9]. Im and Neff explored the process of Hindu Bhutanese elders' cultural losses and found that the cultural alienation between new-type and traditional lifestyles is the critical factor for conflicts between families and communities in resettlement areas [10]. Although the issue of community spatial conflicts has got some attention, some deficiencies are existed in previous studies. Firstly, most of the studies explore the influencing factor of conflicts from a single spatial dimension, such as social space or physical space, instead of developing a systematic analysis framework for influencing factors of spatial conflicts in communities. Secondly, existing research findings on the influencing factor of spatial conflicts are mostly concentrated on the general urban community while the transitional characteristics of settled community for landless peasants are always overlooked. Therefore, based on a theoretical framework of Lefebvre' s ternary dialectical space view, this paper aims to identify the influencing factors of spatial conflicts in resettled communities for landless peasants and then develop a analytical framework on influencing factors of spatial conflicts by utilizing the methods of content analysis and expert's interview. This paper helps to provide inspiration for the governance of resettled communities and the study on community spatial conflicts.

2 Methodology

2.1 Theoretical Framework

By integrating the concept of space with actor's behavior, material carrier and spiritual consciousness, Lefebvre's ternary dialectical space view formed a theoretical framework of space production which integrates spatial practice, representation space and spatial representation. It can also be understood as physical space, social space and mental space respectively. They support and shape each other, which is a dialectical relationship, shown as Fig. 1.

Physical space is the spatial carrier of daily life of residents in the resettled community, and the physical component of the community is the direct factor leading to the spatial conflict in the community [11]. At the same time, the physical component will indirectly affect the conflict by acting on the shaping of social space and

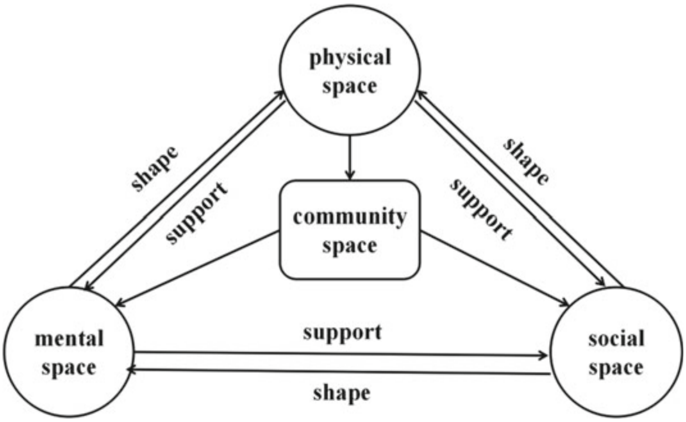

Fig. 1 Theoretical framework on the influencing factors of spatial conflicts in the resettled community

mental space [12]. Mental space refers to the intangible space form directly related to human spiritual activities, which embodies the memory and culture of human beings. It functions as the root cause of spatial conflicts in the resettled community. Social space is formed by social contacts and interactions of residents in the community. The resettled community breaks the traditional acquaintances society in the rural community and present a semi-acquaintances society, which is different from the stranger society in modern urban community. The change of social components such as community social network and community trust is the potential risk of the outbreak of spatial conflicts.

2.2 Methods

On the basis of the theoretical framework, this paper identifies the influencing factors of spatial conflicts from three dimensions that are physical space, mental space and social space through the collation of literature and content analysis. After that, ten experts in related fields were interviewed to identify the relationship among influencing factors. The interviews were conducted in August, 2020 in Hangzhou. And the experts covers three academics in the university, three government officials and four secretaries of resettled communities (See Table 1). The interviews were conducted with the ten experts individually and each interview lasted about two hours. As a result, a list of influencing factors and an analytical framework of spatial conflicts in the resettled community are developed in this paper. The processes of these research activities are illustrated in Fig. 2.

Table 1 Basic information of experts of interview

#	Interviewee code	Title/position	Age	Gender
1	Academic 1	Professor	35–40	Male
2	Academic 2	Professor	40–45	Male
3	Academic 3	Associate Professor	30–35	Female
4	Government official 1	Deputy Director	50–55	Male
5	Government official 2	Section Chief	40–45	Female
6	Government official 3	Clerk	30–35	Male
7	Secretary of resettled communities 1	Secretary of the Party branch	50–55	Female
8	Secretary of resettled communities 2	Director	45–50	Male
9	Secretary of resettled communities 3	Vice Director	35–40	Male
10	Secretary of resettled communities 4	Clerk	25–30	Female

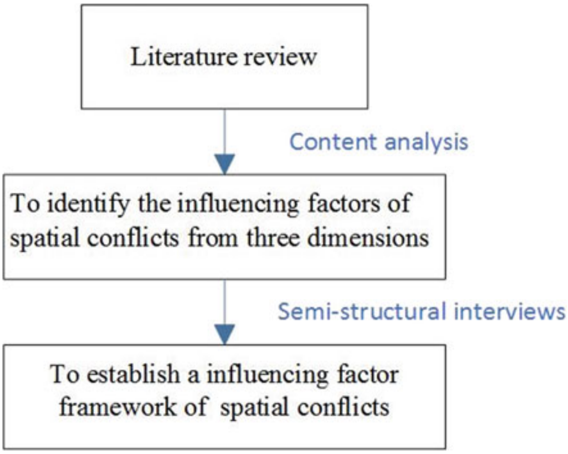

Fig. 2 Flow chart of the research framework

3 Influencing Factors Identification

3.1 Physical Space Dimension

Physical space is the basic dimension of community space which contains physical elements such as building characteristics, natural environment and community facilities. The immediate cause of spatial conflicts in the community is the scramble for physical space resources among residents. According to the function of physical space in the community, all the components of physical space can be divided into three groups: private space characteristics, transition space characteristics and public space characteristics. Based on the classification, nine influencing factors are identified, as shown in Table 2.

Table 2 Influencing factors in the dimension of physical space

Groups	Influencing factors	Reference
Private space	Housing quality	[13, 14]
	Housing density	[13, 15]
	Housing design	[16, 17]
Transition space	Number of access control in the buildings of community	[18]
	The area of public space in the buildings of community	[19]
Public space	Green coverage ratio	[18, 20]
	Road design	[23]
	Public facilities in the community	[21]
	Public facilities around the community	[22]

In terms of the private space, building characteristics, including housing quality, housing density and housing design, are the common factors affecting spatial conflicts in resettled communities. Poor housing quality always trigger inter-group conflicts among residents, governments, developers and other community actors [13, 14]. Meanwhile, the plot ratio in such community is relatively high and the space between buildings is very small, resulting some residents cannot enjoy enough sunlight and then fight for spaces for drying with other residents [13, 15]. What's more, the building form of such community has changed from the irregular and scattered form of traditional countryside to the relatively vertical centralized cell structure. The changing of spatial pattern leads to the alienation of residents, which is another important cause of spatial conflicts [16, 17].

For the transition space, the number of access control in the buildings, as well as the area of public space in the building will directly or indirectly lead to the occurrence of spatial conflicts. The setting of "door" act as the tools of spatial isolation, hindering the social interaction of residents. The greater the number of access control in the building is existed, the worse the neighborhood relationship will be [18]. And the neighborhood relationship is a key factor affecting the intensity of conflict. On the other hand, transition space property rights are normally vague, leading to the public space in buildings is easily to be occupied for storage by residents. The larger the area of public space, the more likely it is to be occupied. This is not merely the occupation of public space, but also bring potential safety hazards, which greatly threaten the safety of residents' life and property [19].

Regard to the public space, characteristics of green landscape, road design and public facilities layout are closely related to the spatial conflict. In the resettled community, landless peasants regard land as the basic means of production and the most reliable living security as before. Thus, they are accustomed to grow vegetables by destroying green belt. And the green coverage rate affects the probability of this kind of behavior [18, 20]. Generally, the planning and construction of resettled communities are merely based on the ideas of the government official and the planning designer while the requirements of residents are usually ignored. Thus, the configuration of public facilities in or around the community is the non-negligible influencing factor for the spatial conflict since it affects residents' satisfaction of the community [22]. Apart from the public facilities, the road design is also related to the spatial conflict due to the behaviour of competition for car parking occurs very often in this kind of community [23].

3.2 Mental Space Dimension

The mental space carries the elements of emotional experience, cognition and consciousness of residents in the community (see Table 3). In the emotion dimension, factors of community identity, sense of relative deprivation, sense of resentment, and land emotion will affect spatial conflicts. Community identity is one of the elements of social cohesion which is able to reduce community conflict [9]. However, the update of the peasant's community identity cannot adapt to the space transformation between the original rural community and the urban community immediately. This fracture of community identity is an important reason that prevents the peasants from integrating into urban life and then generates potential risks for spatial conflicts. Besides, the senses of relative deprivation and resentment generated by the landless peasants as a result of demolition and resettlement are the essential emotional roots of spatial conflicts [23]. In addition, the peasants have a natural affection for the land. When the existing living space structure fails to allow the resident express land emotion rationally, it largely promotes the occurrence of spatial conflicts such as "growing vegetables by destroying green belt" [24].

In the cognition dimension, the factors including sense of identity, cultural cognition and fair perception will lead to spatial conflicts. The identity of the landless peasants is vague, and the dilemma of identity judgment easily leads to the emergence of rule-breaking behaviors and the formation of community spatial conflicts [25]. Cultural cognition refers to the recognition of local culture and behaviors.

Table 3 Influencing factors in the dimension of mental space

Groups	Influencing factors	Literature
Emotion	Community identity	[9]
	Sense of relative deprivation	[23]
	Sense of resentment	[23]
	Land emotion	[24]
Cognition	Sense of identity	[25]
	Cultural cognition	[26]
	Fair perception	[13]
Awareness	Spatial awareness	[8]
	Rights awareness	[24]
	Community memory	[27]

The degree of the cultural agreement is lower, the conflict is more serious [26]. For the fairness perception, it may cause the residents' differentiation and alienation by affecting the communication among different groups of residents [13].

For the dimension of awareness, the factors of space awareness, right awareness and community memory will result in the occurrence of spatial conflicts. When landless peasants use the community space, they take the maximization of private interests as their behavior orientation as a result of lacking public space consciousness. This is a deep spiritual source of conflicts [8]. Meanwhile, the residents' rights consciousness is awakening with the society entering the age of pluralism. Among them, the property right consciousness has the strong correlation with the generation and the intensity of spatial conflicts [24]. Community memory is of great importance in the resettled community as displacement often leads to traumatic memories and immigrants' nostalgia for their past living environment [27]. Although they live in resettled community, their emotional, psychological identity and social memory are still fixed in the village. To some extent, the memory of rural space leads to the conflict between the institutional identity and practical behaviors of resettled residents, leading to the spatial conflict.

3.3 Social Space Dimension

Social space is composed of various social relations in the community. And the neighborhood relationship plays an important role among the social relations. Meanwhile, both the attributes of the resettled community and the cultural environment in the community contribute to the shape of the social environment of such communities. Thus, seven factors for the spatial conflict are identified from three aspects of social space elements, as shown in Table 4.

For the perspective of neighborhood relationship, factors influencing the spatial conflict are consisted of community trust, neighbourhood-watch, and community social network. The resettled community have witnessed the transformation from the traditional society based on blood and geography ties to the industrial society based on occupation and interests ties. The rapid social changes weaken the relationship

Table 4 Influencing factors in the dimension of social space

Categories	Influencing factors	Literature
Neighborhood relationship	Community trust	[28]
	Social network	[29]
	Neighbourhood-watch	[30]
Community attributes	Population heterogeneity	[31]
	Community stigmatization	[7]
Cultural environment	Habitus	[32]
	Cultural lag	[33]

network within the community and lower the depth and frequency of communication between neighbors. It is difficult to rebuild the trust relationship in the resettled community, which threatens the harmony and stability of the community [28, 29]. But the neighborhood-watch will reduce the probability of conflicts and contribute to the resolution of conflicts [30].

In terms of community attributes, population heterogeneity and community stigmatization are the most important factors. In the resettled community, the heterogeneity of the population leads to few contact opportunities among different groups. What's more, the differences of spatial usage habits, lifestyle and values between landless peasants and the migrant population are easy to generate spatial conflicts [31]. Stigmatization is a representative characteristic of resettled communities for landless peasants since this kind of community is the pronunciation of dirty, chaotic and poor in the city [7]. Urban residents always have a common point that the general quality of landless peasants is low. This deepens the antagonism between landless peasants and urban residents which is easy to produce contradictions and conflicts.

From the aspect of cultural environment, both habitus and cultural lag have essential impact on spatial conflicts. The landless peasant's behavior, living habits, customs and even emotion, attitude and values are continued, which result in a series of "cultural fall" phenomenon [32, 33]. At the same time, the traditional habits with a strong local flavor have been internalized in the blood veins of the ancestors of the peasants and will not be easily changed or disappeared. This is an important source of spatial conflicts.

4 Research Findings

The dialectical relationship among influencing factors on spatial conflicts were discussed by the method of expert interview. And the data of expert interviews were coded in Nvivo 10. As showed in Fig. 1, there is a dialectical relationship among physical space, social space and mental space. They support and shape each other. Thus, some influencing factors will directly affect the conflict, while some influencing factors will interact with influencing factors in other spatial dimensions, and then indirectly affecting the conflict. According to the results of coding and the theoretical framework showed in Fig. 1, an analytical framework on the influencing factor of spatial conflicts was developed (see Fig. 3).

Physical space: Some factors including "Road resign", "Housing quality" and "Housing density" will directly result in the occurrence of spatial conflicts. Road design is related to whether space competition will occur in a limited space between residents walking and vehicles driving, as well as the parking of different vehicles. Housing quality problems, such as water leakage, peeling off walls, and poor sound insulation, which are determined by its low construction cost, will frequently trigger conflicts and become important issues that plague the governance of grassroots government. Landless peasants have always had a strong demand for sunlight. The density of building has caused lighting problems for some residents. These factors

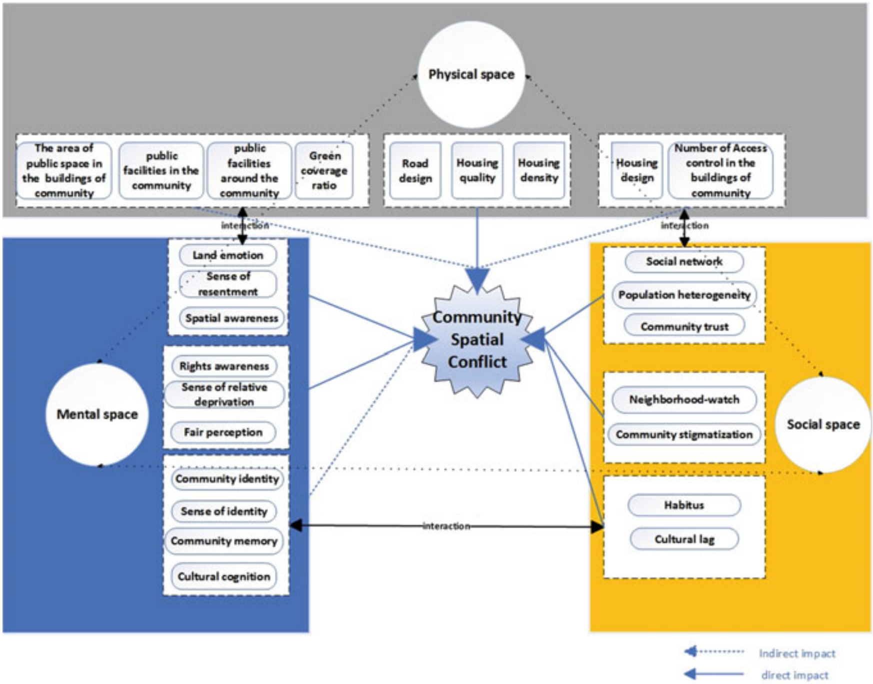

Fig. 3 Analytical framework for factors influencing spatial conflicts of resettled communities for landless peasants

are closely related to the quality and size of the physical space, and easily lead to the competition for space resources among different groups of residents, leading to space conflicts.

But other factors like "The area of public space in the building of community", "Public facilities in the community", "Public facilities around the community" and "Green coverage ratio" will interact with factors in the mental space dimension respectively that are "Space awareness", "Resentment" and "Land emotion". The area of public space in the buildings will arouse the awareness of landless peasants to occupy space. Landless peasants used to have larger living space, so they have the habit of piling up sundries. What's more, they regard the corridor as their private space, which easily causes conflicts between the landless peasants and the property managers. The imperfections of public facilities will arouse resentment among residents and lead to conflicts. Green coverage ratio will affect the behavior of landless peasants to grow vegetables by destroying green belt. Because they think that green coverage is a waste of land resources. The elements of physical space affect residents' awareness and emotion, which leads to the formation of spatial conflicts. Similarly, "Housing design" and "Number of access control in the buildings of community" will interact with factors in the social space that are "Social network", "Population heterogeneity", and "Community trust", resulting in spatial conflicts. Among them, the most fundamental reason is that the transformation from the rural space architectural form to the urban space architectural form leads to the alienation of interpersonal relationships and the loss of traditional social capital.

Mental space: Factors including “Community identity”, “Sense of identity”, “Community memory” and “Cultural cognition” will interact with factors in the social space dimension that are “Habitus”, and “Cultural lag”, resulting in spatial conflicts. Urbanization not only involves the process of a rural population turning into urban population, but also the diffusion of the city culture, way of life and urban civilization to rural areas. Community identity is one of the contributing elements of social cohesion. However, it is difficult for the landless peasants to build the identity of resettled communities in a very short period. Moreover, the sense of identity for landless peasants is actually still in a state of ambiguity between the farmer and citizen. This dilemma of identity judgment can easily trigger some behaviors with rural life habits in the community. The existence of rural spatial memory leads landless peasants to miss their past living environment very often. The cognition of local culture determines the recognition of behaviors with rural life habits. These elements of mental space lead to a cultural lag phenomenon with the influence of habitus. As a consequence, behaviors with rural life habits lead to occurrence of serious spatial conflicts.

But other factors like “Rights awareness”, “Sense of relative deprivation” and “Fair perception”, will direct lead to spatial conflicts. With the rise of residents’ rights awareness, residents are used to express their demands by means of conflict. At the same time, when the sense of relative deprivation and unfair in landless peasants accumulates to a certain extent, conflicts will break out.

Social space: Some factors including “Neighborhood-watch” and “Community stigmatization” will have a direct influence on spatial conflicts. As essential resource of governance of the resettled community for landless peasants, neighborhood-watch avoid incidents that trigger the spatial conflicts. In addition, community stigmatization contribute to conflicts between urban citizens and landless peasants.

5 Conclusions

Based on the ternary dialectical space view of Lefebvre, this paper first puts forward the influencing factors of spatial conflicts from three dimensions that are physical space, mental space and social space through the collation of literature and content analysis. On the basis of expert interviews, an analytical framework for influencing factors of spatial conflicts in the resettled community for both conflict governance and government policy is developed. This paper deepens the understanding of the spatial conflict of the resettled community, and broadens the research dimension of influencing factors on spatial conflicts. It is of great theoretical and practical significance to the governance of spatial conflicts in resettled community for landless peasants.

For the governance of community spatial conflicts, three dimensions that are physical space, mental space and social space, should be taken into account. Physical space is the carrier for residents to express their emotions and realize social interaction. Community conflicts are the embodiment of the contradiction between “the top-down power practice of the government” and “the bottom-up space appeal of the residents”. Therefore, attention should be paid to the residents’ spatial demands. In the process of spatial planning, the integration of “bottom-up” right demands and the “bottom-up” right can be realized by means of public participation, among which the key measure is to construct an administrative absorption system from bottom to top. Meanwhile, the guarantee of physical space needs to be realized by the government. So the planning and the design of resettled communities should keep pace with resettlement. The mental space elements are the roots of the spatial conflict. The sense of relative deprivation, loss and resentment generated by landless farmers in the process of urbanization keeps accumulating in their hearts, and when it expands to a certain extent, conflicts will break out. Along with identity, fairness perception, right consciousness and other factors, the conflicts are bound to have a negative impact. Therefore, it is necessary to pay attention to the spiritual outlook of residents in the resettled community and give them more care. The negative emotions of landless farmers can be gradually eliminated by providing regular activities, community services and other fixed activities. The achievement of social space elements is the fundamental way to solve the spatial conflicts in the community. It can provide more references for the good governance of the community. First of all, we can give full play to the social resources of the resettled community. In other words, to make full use of the advantages of neighborhood-watch in order to build a benign neighborhood relationship. Secondly, The governance of the resettled communities should think more about how to promote integration and communication among different groups of people, including locals and migrants, landless peasants and citizens. Last but not the least, the traditional customs of resettled community are gradually fading away. Landless peasants should be guided not only to keep the memory and awe of their ancestors, but also to adapt their behaviors to urban civilization.

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Economic Analysis of Dynamic Substation Location and Capacity Determination

Shan Jiang, Hongchuan Dong, Yingbo Zhou, Geriletu Bao, and Zhenyu Zhao

Abstract In order to realize the rationality of development sequence and layout of regional substation construction projects and the economic objectives of investment, this paper studies the one-time or stage problems of substation construction, constructs dynamic location and capacity model which explores the cost difference of different substation construction schemes. The model uses ergodic algorithm and harmony search optimization algorithm to adjust the search process and other parameters to improve the ability of global optimization and iteration of the model. Through the optimization constraint relationship, the comprehensive scheme comparison of new substation and expansion is realized, so as to achieve the cost target of the whole process and the minimum number of membership changes. Through a case study, it is proved that the cost management advantages of phased investment and cost of the high voltage line construction can not be ignored. The model provides a new analysis tool for multi-stage cost planning of regional substation location and capacity.

Keywords Substation construction · Dynamic location and capacity model · Harmony search optimization algorithm · Cost target · Membership changes · Case study

1 Introduction

For the sake of improving the optimization efficiency of cost control on the power transmission and distribution projects, scientific substation location and capacity determination is an important prerequisite for power grid planning and construction.

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The multi-stage planning is a series of single-stage planning [1]with logical connection. In order to solve the problem that the amount of data of substation dynamic planning is too huge, based on multi-stage planning, modern heuristic method and intelligent optimization algorithm are applied. For example, Chen Mingfan proposed a method based on agent technology to realize single-stage automatic site selection of substation. Through the application of artificial intelligence, the automatic location of substation can be realized quickly and accurately [2]. Liu Hong proposed a substation location heuristic method based on weighted Voronoi diagram theory, for obtaining better location effect [3]; Chen Hao proposed that the differential particle swarm optimization algorithm can realize the complementary advantages of intelligent algorithm through algorithm composition, improve the efficiency of data optimization's iteration [4].

In view of the existing literature, the existing location and capacity model has not considered the dynamic adaptability between customer demand and power dispatching terminal, and has failed to consider the consistency of long-term and short-term cost targets. On account of the dynamic adaptability of site selection and capacity determination, it is urgent to study the whole process minimization of cost target for multi-stage location and size of substations. Based on the existing results, it is necessary to integrate the game theory into the substation resource planning through the dynamic balance theory of resource demand, which can effectively and dynamically allocate resources distribution and cost performance of usage. Dynamic planning model can reflect the actual needs of project construction more truly and improve the timeliness of project planning. In this paper, the phase states of new substations and expansion projects in the location and capacity model are consistent, and the multi-objective dynamic modeling is carried out by establishing the cost model, finally, the harmony search algorithm is used to improve the efficient optimization ability of the model.

2 Mathematical Model

According to the needs of life cycle cost evaluation of construction projects, a multi-objective dynamic substation location and capacity model is established, and the problems of new construction and expansion of transmission lines between substations and demand sides are also included in the model. The optimization objectives of the model include the minimum cost of project construction and the minimum changes of power supply subordination.

2.1 Mathematical Model of Substation Location and Capacity

Considering the substation construction, purchase of transformers, transmission lines construction, and network loss [5], the stage logical connections of the model are systematically set through program logic constraints, maximum capacity constraints and regional constraints.

The cost targets of the model include substation construction cost, transformer cost, transmission line cost and network loss cost. The total cost function(1) is as follows:

$$MinC = \sum_{n=1}^{N} (Cs_n + Ct_n + Net_n + Clink_n) \tag{1}$$

where Cs_n, Ct_n, Net_n and $Clink_n$ are the cost of substation, transformer, transmission lines and network loss in each stage, N is the total number of project planning stages.

Considering the time value of funds, the discount rate is introduced to allocate the construction investment of the substation in the planning period. The cost of the substation include the cost of the built substation and the new substation. After the built substations and new substations in the region are completed and put into use, the operation and management cost is considered. The cost function of the substation is shown in formula (2). The calculation method of transformer cost is similar to that of substation construction cost.

$$Cs_n = Cs_0\left[r_0(1 + r_0)^m \big/ (1 + r_0)^m - 1\right] \cdot an + Cop \tag{2}$$

where $\mathrm{Cs_n}$ is the annual converted cost of the substation construction cost, $\mathrm{Cs_0}$ is the original construction cost of the substation, $\mathrm{r_0}$ is the discount rate, m is the depreciation life of the substation, and Cop is the annual average operation and management cost of the substation.

The location and capacity model adopts the combination of station and demand side [6] to analyze the dynamic multi-stage cost of substation and its lower level transmission network. The network loss cost function is shown in (3):

$$\begin{cases} \beta = \beta_1\beta_2\beta_3 \big/ U^2 \cdot \cos\varphi^2 \\ Clink_n = \beta \sum_{i=1}^{I} \sum_{j}^{J} (P_{ij} \cdot \cos\varphi)^2 dis_{ij} \end{cases} \tag{3}$$

where $Clink_n$ is the network loss cost, β is the network loss coefficient, β_1 is the average price in the planning period. According to the prediction method, the trend of future electricity price is predicted and the average value is taken. β_2 is the resistance per kilometer of the line, β_3 is the power supply hours in each stage, U is the current voltage level, $\cos\varphi$ is the power factor, P_{ij} is the transmission power value of the i th substation to the j load point, and dis_{ij} is the actual space distance between station and load point considering the geographical coordinate system.

Using the spatial distance between substation and load point in geographical coordinate system to reasonably calculate the amount of network loss. The calculation formula of space distance is shown in formula (4):

$$\begin{cases} rad(x) = 3.1415926x \big/ 180 \\ a = rad(lat1) - rad(lat2) \\ b = rad(lng1) - rad(lng2) \\ dis = 2R \cdot \arcsin(\sqrt{\sin^2(a \big/ 2) + \cos(lat1) \cdot \cos(lat2) \cdot \sin^2(b \big/ 2)}) \end{cases} \tag{4}$$

where *rad* is the radian function of the coordinate system, x is the longitude (*lng*) or latitude (*lat*) value, a and b are the latitude and longitude radian distance values between two points, and *dis* is the space distance value between stations and load point.

2.2 Constraints of Model

The constraint conditions of the model can ensure the consistency of the parameters in each stage of the model, and the dynamic optimization goal in the variable region can be achieved by limiting the range of multi-variable values.

2.2.1 Logical Relation Constraints

$Loc_{newsta}(x_i, y_i)_n = C$ $0 \le T_1 \le T_2 \le T_n \le T_{Max}$ There is coherence between substation and supporting transformer in space and time. For existing substations and new ones, once the spatial location coordinates are determined, the location parameters of each stage are fixed, and the capacity expansion of each stage of substation can be realized by increasing the number of transformers [7]. The constraint expression is shown in (5):

$$\begin{array}{c} Loc_{newsta}(x_i, y_i)_n = C \\ 0 \le T_1 \le T_2 \le T_n \le T_{Max} \end{array} \tag{5}$$

The function of $Loc_{newsta}(x_i,\ y_i)_n$ is that the spatial location of the substation remains unchanged, and also a continuous control function in time. $T_n$is the increasing logical constraint on the number of transformers in the substation.

It is assumed that any stage of the load point in the power grid should be connected to the only adjacent substation, but there is the possibility of periodic adjustment.

$$\sum_k Link_{k,p,n} = 1 \tag{6}$$

where, k is the ergodic value of substation around the load point. No matter which substation is connected with the p load point, the value of connection state is 1, and the value of non connected substation is 0.

2.2.2 Maximum Capacity Constraints

The external load power provided by the substation should be less than the sum of the load power provided by the existing transformer in the substation stage. If the built substation still can not meet the demand of the surrounding load points after reaching the capacity expansion requirements, the new substation shall be selected, and the maximum capacity is limited as follows (7):

$$POWS_{k,n} \leq \alpha \cdot T_{k,n} \cdot POW_t \tag{7}$$

where α is the load rate and $POWS_{k,\,n}$is the external output power of substation k in the n stage.

2.3 Regional Constraints

There are many environmental constraints such as geographical conditions in the site selection of substation projects. Therefore, it is necessary to identify the geographical information of the area in advance to exclude the restricted area.

3 Research Methods

In order to solve the problems of complex model optimization and multi-objective scheme selection, harmony search optimization algorithm is considered to realize the optimization iteration of new station location and other variables, so as to prevent data from falling into local optimal solution. Harmony search uses harmony memory adoption rate and pitch adjustment rate to adjust the variable vector of the whole process in stages [8]. By importing the new harmony vector generated by the judgment step into function to generate the objective function value, and compare it with the worst harmony corresponding function value in the harmony library, eliminate the worst value of comparison, and realize the optimal solution convergence in the circular manner. The specific algorithm flow chart is shown in Fig. 1.

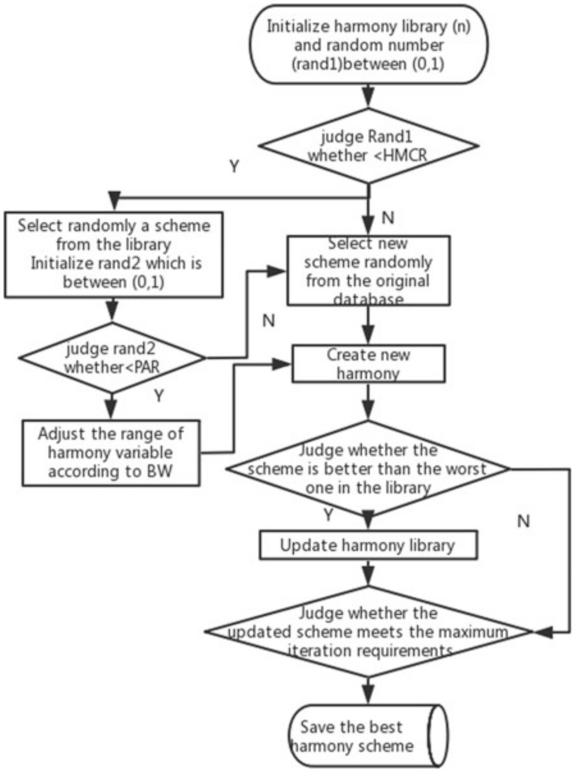

Fig. 1 Structure of harmony search algorithm

4 Solution of Dynamic Location and Capacity Model

From the perspective of multi-stage dynamic programming, this paper studies the state continuity algorithm to realize the planning of the model in each goal year, so as to achieve the consistency of the site selection and capacity model. In this model, the minimum value of station-network construction and operation cost and the minimum value of substation membership relationship changes are set as the solution objectives. The main purpose of the latter is to improve the iteration efficiency of the model algorithm and create a station-load subordination relationship in accordance with the objective law. The model sets the number of new substations, the location of new substations, the number of Substation Transformers, and the station-load connection as the decisive variables. The first three achieve global optimization in each stage through parameter ergodic algorithm, while the latter realizes global station-load connection scheme optimization through harmony search optimization algorithm.

Considering the huge data of the station-load connection scheme, the model temporarily stores each optimization scheme of the station-load connection, calls the optimal scheme group of each stage, selects the coherent optimal scheme from the

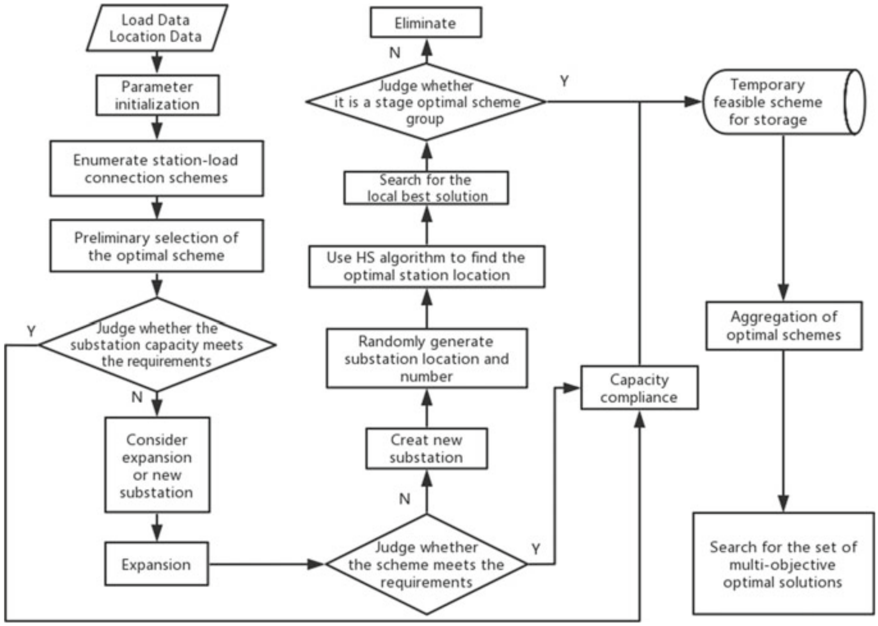

Fig. 2 Structure of dynamic multi-objective location and capacity determination mode

optimal solution group of each stage to locate the substation in the iterative region, and realizes the optimal location and location in the region through the harmony search algorithm. With the increase of stages, the selection area of substation site increases step by step. The operation flow of the model is shown in Fig. 2.

5 Calculation Example

5.1 Instance Data

This paper takes the long-term planning of 500 kV voltage substations in 53 places of a province in central China as an example. On account of the regional load data of previous years, the forecast load data of four goal years from 2020 to 2026 is carried out. The results are shown in Table 1.

By 2018, the study area has covered six 500 kV high-voltage substations, namely JM, SZ, XY, JZ, YC and SY. The original subordinate relationships between 500 kV high-voltage substation and loads are shown in Fig. 3. With the continuous expansion of regional economic scale, part of the regional load points get a leaping development, the need is urgent for regional high-voltage new substation construction or old ones' expansion.

Table 1 Forecast of regional power load

Category	Place	Load in 2018	Load forecast in 2020	Load forecast in 2022	Load forecast in 2024	Load forecast in 2026
1	XC	259.56	314.73	374.19	437.76	501.26
2	FC	253.21	289.04	366.25	421.36	489.76
3	XZ	204.66	253.58	333.58	415.82	482.17
4	CB	254.31	296.35	357.26	399.57	468.31
5	CD	238.73	278.25	323.98	378.56	437.51
…	…	…	…	…	…	…

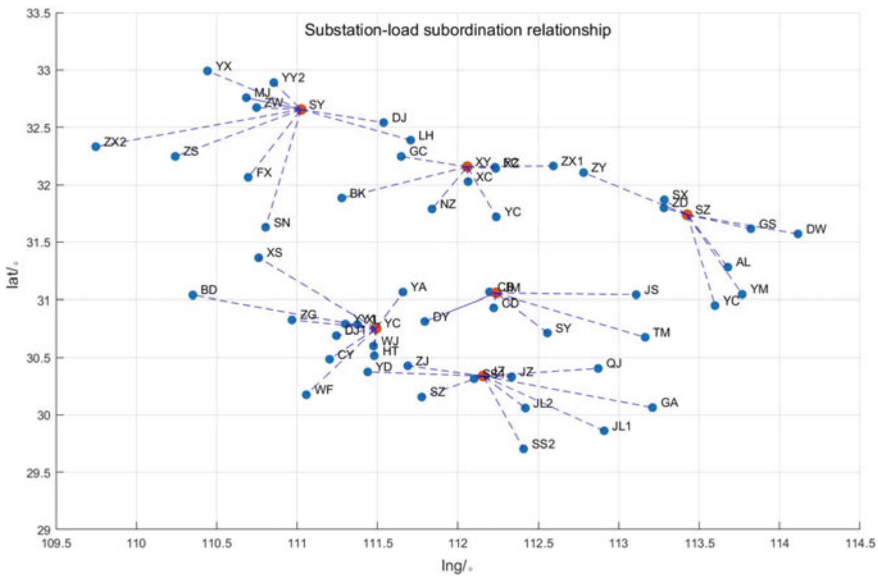

Fig. 3 Original substation-load point affiliation

The parameter data of site selection and capacity determination model are as follows: The capacity type of single transformer in new substation or expansion project is 750, 1 000, 1 200 and 1 500 MVA, the upper limit of transformer quantity is set as 3, the depreciation life of equipment is 20 years, the discount rate is 10%, the original investment cost of new substation is 125.37 yuan/kVA (comprehensive unit price), and the original investment cost of expansion substation is 46.54 yuan/kVA (comprehensive unit price), the cost of each type of transformer is shown in Table 2. The average price of electric energy is 0.48 yuan/kWh, the resistance per kilometer of the line is 0.6 Ω/km, the original cost per kilometer of the line is 1 525 100 yuan/km (comprehensive unit price), the annual power supply hours are 8 760 h, and the power factor cos φ is 0.9.

Table 2 Transformer capacity and cost

Capacity type (MVA)	750	1000	1200	1500
Transformer cost (10 thousand yuan)	3463	4617	5370	6525

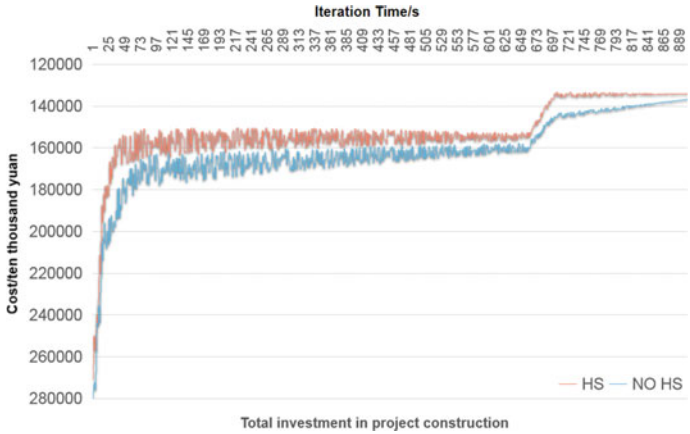

Fig. 4 Comparison between Harmonic search and random algorithm

5.2 Data Analysis

The harmony search algorithm is applied to the optimization of the membership relationship solution. Compared with the random algorithm, the harmony search algorithm significantly improves the optimization speed of the optimal solution of the model, and the data accuracy increases by about 12%, the results are shown in Fig. 4.

In this model, the total cost of each stage is measured by setting the minimum membership relationship and the minimum cost of each stage to determine the optimal cost performance scheme of new construction or reconstruction in the stage. The optimal solution group data determined in this case is shown in Table 3:

In order to select the optimal solution of the planning scheme, the index of line construction cost is listed as one of the reference standards for selecting the optimal solution, which provides the basis for the increase of the transmission line network construction cost caused by the change of the scheme subordination relationship. In the case of the same number of new substations between schemes, the advantages and disadvantages of the substation location scheme can be judged by measuring the line construction cost. The higher the line construction cost, the lower the feasibility of the scheme.

It can be seen from table 3 that the optimal solution of the total construction cost of the project ranges from 1.5 billion to 1.7 billion yuan, of which the construction cost of line infrastructure accounts for 59–63%. In the infrastructure construction cost of

Table 3 Optimal solutions of dynamic location and capacity model

Optimal solution	Total investment cost(ten thousand yuan)	Number of changes in membership	Construction cost of transmission line(ten thousand yuan)	Cost of new power station (ten thousand yuan)	Expansion cost of power station(ten thousand yuan)	Other cost (ten thousand yuan)	Number of new power stations	Number of power stations to be expanded
1	165,423	21	98,939	55,222	9839	1423	4	7
2	159,093	17	95,930	49,127	12,540	1496	3	11
3	162,347	13	101,497	53,937	5539	1374	4	5
4	170,190	16	106,808	47,623	14,380	1379	3	13
5	150,956	11	93,727	44,177	12,299	1542	3	10

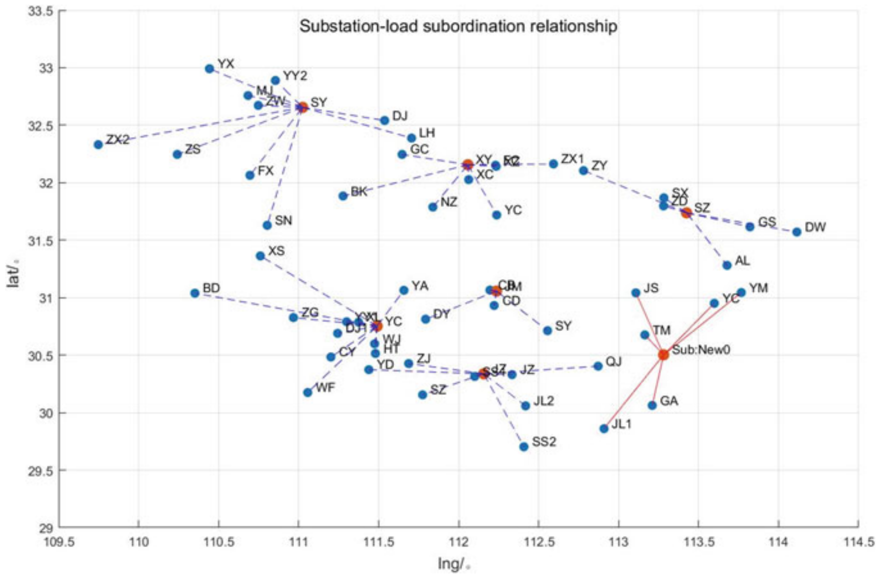

Fig. 5 Affiliation of first stage

substation, the proportion of newly-built substation accounts for 78–90%, while the proportion of expanded substation is relatively small, because the comprehensive unit price of expansion project is low. In the above planning schemes, the optimal scheme is group 5. In this group, in order to meet the requirements of load surge in the first stage of the project, a new substation Sub: New0 with a substation capacity of 750MVA will be built. In the second stage, planning two substations, Sub: New1 and Sub: New2, with the capacity of 750 and 1500 (750 + 750) MVA. In the third, fourth and fifth stages, considering that the load growth of the model is stable and there is no new substation, some substations are expanded on the basis of the original scale. The dynamic planning subordination relationship is shown in Figs. 5 and 6.

In the five planning stages mentioned above, the load demand is mainly met in the form of project expansion in the later stage. From the perspective of optimal solution planning trajectory, the project expansion of substation facilities is an important way to save investment in economic decision-making model. The dynamic planning data of substation location and capacity are shown in Table 4. The expansion scale of the substation depends on the overall development. The algorithm does not simply adopt the step type capacity increasing scheme. In order to consider the comprehensive cost, some substations adopt the step evolution capacity increase mode. For example, the substation Sub: New0 directly adopts 1 × 1500 MVA transformer in the initial stage of the project, instead of using two 1 × 750 MVA models in stages.

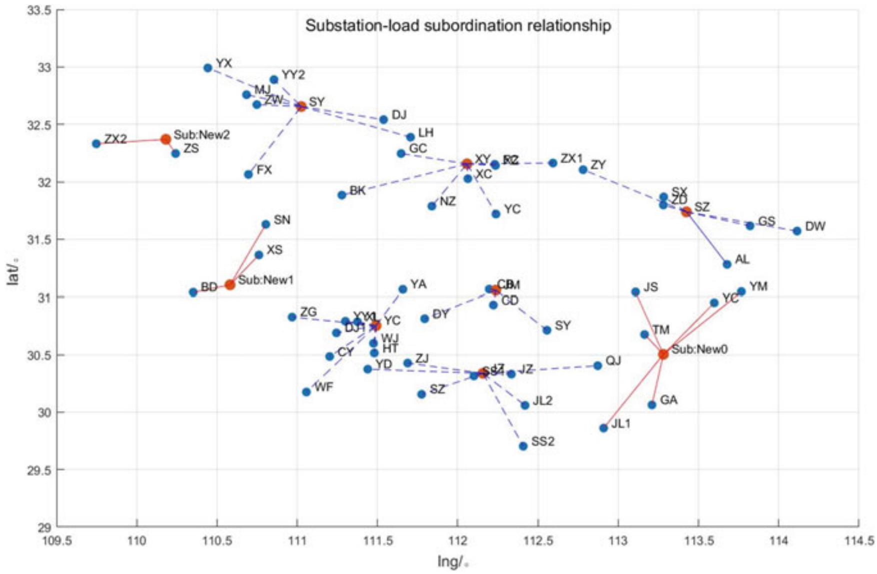

Fig. 6 Affiliation of second stage to fifth

Table 4 Multi stage selection of transformer in substation

Substation	Transformer scale in 2018	Transformer scale in 2020	Transformer scale in 2022	Transformer scale in 2024	Transformer scale in 2026
JM	1 * 1500	1 * 1500	1 * 1500	1 * 1500	1 * 1500; 1 * 750
JZ	2 * 1500	2 * 1500	2 * 1500	2 * 1500	2 * 1500; 1 * 750
SY	1 * 1500	1 * 1500	1 * 1500; 1 * 1000	1 * 1500; 1 * 1000	1 * 1500; 1 * 1000
SZ	1 * 1500	1 * 1500	1 * 1500; 1 * 1000	1 * 1500; 1 * 1000	1 * 1500; 1 * 1000
XY	2 * 1500	2 * 1500	2 * 1500	2 * 1500	2 * 1500; 1 * 750
YC	2 * 1500	2 * 1500	2 * 1500	2 * 1500	2 * 1500; 1 * 750
SubNew0	1 * 1500	1 * 1500	1 * 1500; 1 * 750	1 * 1500; 1 * 750	1 * 1500; 1 * 750
SubNew1	–	1 * 7 * 50	1 * 750	1 * 750	1 * 750
SubNew2	–	1 * 750	1 * 750	1 * 750	2 * 750

6 Conclusion

The multi-objective dynamic location and capacity economic planning model can realize the comprehensive cost analysis of new construction and expansion of substation, and judge the rationality and balance of new construction and expansion in planning cycle and construction cycle from the perspective of construction and operation cost. In this model, the cost and logical membership relationship are set as the optimization objectives, and the harmony search algorithm is used to improve the search iteration efficiency of the optimal solution. With the increase of the time series of the regional load, the algorithm optimizes the power transmission and transformation infrastructure within the region reasonably at the aspect of substation capacity and cost optimization, so as to obtain the optimal solution of the overall construction cost of the project. The model can provide important support for scientific planning and decision-making of regional substation location and capacity.

There will be also some improvements in the model, such as incorporating the reconstruction of infrastructure into the construction of the project, increasing the selectivity of the project. In order to improve the authenticity of route planning, topographic map can be introduced to assist in identifying terrain to enhance the reliability and accuracy of route planning. This kind of method can provide modeling research direction for artificial intelligence substation construction and promote the coordination of human–computer interaction.

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Evaluation of Urban Resilience Based on Entropy Weight Cloud Model—31 Provinces in China

Jiali Deng, Liudan Jiao, Yinghan Zhu, Yu Zhang, and Xiangnan Song

Abstract In recent years, the frequent occurrence of extreme weather, urban overpopulation, resulting in excessive use of resources, serious environmental pollution, traffic congestion and other issues have become increasingly significant, has seriously affected the stability and order of the city, and gradually exposed the vulnerability of the urban system. In order to understand the level of urban resilience in China and strengthen the construction of resilient cities in China, a resilience index system including 16 secondary indicators from four dimensions of economic level, social development, ecological environment and infrastructure was proposed. Entropy Weight Method and Cloud Model were used to evaluate 31 provinces and cities. It was concluded that the urban resilience of Beijing was at a high level, while Hainan and Guizhou were at a low level, Shanghai and Jiangsu are at a higher level, Tianjin and Hebei are at a lower level, and Zhejiang and Shandong are at a medium level. This paper analyzes the calculation results and puts forward corresponding suggestions in order to promote the sustainable development of cities in China.

Keywords Entropy weight method · Cloud model · Urban resilience

1 Introduction

The development of cities is always accompanied by disaster risk. The personal safety threat and financial loss caused by disasters is huge. In recent years, the frequent occurrence of extreme weather and urban overpopulation, resulting in excessive use of resources, serious environmental pollution, traffic congestion and other issues

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have become increasingly prominent, which has seriously affected the stability and order of the city, and gradually exposed the vulnerability of the urban system. For example, the 2008 Wenchuan 8.0 earthquake caused serious damage to more than 100,000 square kilometers, and caused about 69,200 deaths, 374,600 injuries and 17,900 missing people; in 2010, Queensland, Australia, was hit by floods, which affected more than 200,000 residents; in 2012, Beijing rainstorm caused 79 people to die, and 1.602 million people were affected, and about 10,000 houses collapsed, causing the economy loss of 11.64 billion yuan; in 2013, the high-temperature heat wave in Shanghai in summer reached 38 days, making the excess death toll of heat wave increase to 3.9 times of the average value in the past 10 years, reaching 1347 people/year [1]; in 2016, a 7.8-magnitude earthquake occurred in Ecuador, resulting in 262 deaths and 2527 injuries. As a result, the research on how to prevent and reduce disasters, improve urban resilience and build a resilient city is gradually launched.

The word resilience comes from foreign countries and originates from the Latin word "resilio" [2]. This word refers to resilience that is, the meaning of restitution. In 1973, Holling introduced resilience into ecology. With the continuous discussions and researchs on resilience, resilience has also been applied to other fields such as society, economy and engineering. Scholars combine resilience with urbanism to form urban resilience [3]. As early as 2010, some foreign scholars have begun to study the framework of urban resilience evaluation [4]. Cutter et al. [5] constructed the evaluation system of urban resilience mainly considering the six factors of economic, social, infrastructure, institution, ecology and community capacity. Joerin et al. [6] established the climate disaster resilience index (CDRI) model from the economic, material, institutional, social and natural aspects, and conducted an empirical study on the urban resilience of Chennai city in India. Suárez et al. [7] defined urban resilience and urban resilience index from the perspective of social-ecological system, and proposed a method to measure urban resilience. Compared with foreign countries, the research on urban resilience in China started a little later. Basically, the framework study of urban resilience began in 2014. Until now, the evaluation of urban resilience has become a hot topic. At present, there are also some research results on the evaluation of urban resilience in China. For example, Zhang Mingdou and Feng Xiaoqing [8] selected 15 indicators from four aspects of urban ecological environment resilience, urban economic level resilience, urban social environment resilience, and urban infrastructure resilience through analytic hierarchy process (AHP) to conduct urban resilience for cities at prefecture level and above in 30 provinces (except Tibet). The results show that there is a gap of urban resilience in eastern, central and Western China. Li Ya and Zhai Guofang [9] analyzed the disaster resilience strength of 288 cities, of which 82% were at low and low resilience levels. Sun Honghu and Zhen Feng [10] analyzed the haze disaster resilience of the main urban area of Nanjing through the network analysis method (ANP). Zheng Yan and Zhai Jianqing [11] analyzed the disaster resilience of the main urban areas of Nanjing based on the analysis of urban system resilience of 282 cities in China, and put forward policy suggestions for the construction of resilient cities. Although there have been some studies in the field of urban resilience in China, there are still some problems. The most important problem is that there is no accurate and unified definition of urban resilience in China, which leads to differences in the establishment of evaluation index framework due to different personal understanding, which leads to differences in evaluation results.

2 Construction of Urban Resilience Evaluation Index System

The selection of dimension of urban resilience evaluation is very different. After a large number of literatures collection, the evaluation dimensions include 4, 5, 6 and other dimensions. Sun Yang et al. [12] used GIS spatial analysis and superposition function method to evaluate the urban resilience of prefecture level cities in the Yangtze River Delta. They mainly built an evaluation index system of urban resilience of four aspects of ecological environment, municipal facilities, economic and social development. Zhao Jinwei and Xu Hong [13] also evaluated the urban resilience of 17 cities in Shandong Province by the four dimensions of ecological environment, infrastructure, economic development and social development. Xie Xinlu and Zheng Yan [14] established an evaluation index system to evaluate the climate adaptability of Beijing from the dimensions of economy, society, natural resources, technology and risk management. Li Ya and Zhai Guofang [9] selected 32 secondary indicators from six dimensions of economic resilience, social resilience, environmental resilience, community resilience, infrastructure resilience, and organizational resilience. Among them, the number of secondary indicators of community resilience and organizational resilience is relatively small. Therefore, the selection of dimensions of urban resilience evaluation is different. This paper will also construct the secondary index system of the four dimensions of urban economic level, urban social development, urban ecological environment and urban infrastructure.

2.1 Principle of Index Selection

In order to measure the level of urban resilience objectively, comprehensively and scientifically, the following principles are carried out in the process of the determination of urban resilience evaluation indicators. The first one is systematicness. The selection of indicators should be diversified, comprehensive and representative, which can reflect the characteristics of research content and research area. The second is availability. The selection of evaluation indicators of urban resilience should consider that the relevant data can be easily obtained, and the obtained data should be true, reliable and complete, which is the key problem of urban toughness evaluation. The third is concise and scientific. When selecting indicators, it is necessary to consider the relationship between indicators, so that each index can accurately reflect the connotation of the dimensions. The number of indicators should be appropriate, not too much or too detailed, which will increase the difficulty of evaluation, and cannot be too little or too rough, which will affect the accuracy of evaluation.

2.2 Establishment of Index System

In this paper, indicators are collected through literature [8, 13, 15, 16], and screened according to the frequency of each index and the possibility and integrity of data collection to form the evaluation index system of urban resilience in Table 1.

3 Construction of Urban Resilience Evaluation Model

3.1 Entropy Weight Method

Entropy is initially a concept in thermodynamics. It represents the degree of chaos in a system. The greater the entropy, the higher the degree of chaos. In 1948, C.E.Shannon borrowed the concept of entropy in physics to the information theory to describe the uncertainty of information. The Entropy Weight Method is an objective method to determine the weight. Compared with the Expert Investigation Method and Analytic Hierarchy Process, it weakens the subjectivity in determining the weight and makes the weight more accurate and reliable.

Entropy Weight Method is to determine the weight of the index through the variation degree of each index, and then get relatively objective weight through correction. Let the initial data index matrix be $X = (xij)n \times m$, and n is the number of evaluation objects, and m is the number of evaluation indicators, where i = 1, …, n, j = 1, …, m. The specific steps of Entropy Weight Method are as follows:

(1) Standardization of Initial Data.

Standardized treatment of positive indicators: $Y\text{ij} = \frac{xij - \text{Min}(xi)}{\text{Max}(xi) - \text{Min}(xi)}$

$$\text{Standardized treatment of negative indicators: } Y\text{ij} = \frac{\text{Max}(xi) - xij}{\text{Max}(xi) - \text{Min}(xi)} \tag{1}$$

Y_{ij} is the index data value after standardization.

(2) Calculation of the Information Entropy of Each Index

$$Pij = \frac{Yij}{\sum_{i=1}^{n} Yij} \tag{2}$$

$$Sj = -\frac{\sum_{i=1}^{n} Pij \ln Pij}{\ln(n)} \tag{3}$$

Table 1 Evaluation index system of urban resilience

	First level index	Second level index	Number	Index attribute
Urban resilience	Urban economic level	Per capita GDP (10,000 yuan)	1	Positive
		Proportion of tertiary industry	2	Positive
		Proportion of R & D expenditure in GDP	3	Positive
		Fixed assets investment/GDP	4	Positive
	Urban social development	Number of college students per 10,000 students	5	Positive
		Number of beds in medical and health institutions (10,000)	6	Positive
		Registered urban unemployment rate (%)	7	Negative
		Proportion of social security and employment expenditure in fiscal expenditure	8	Positive
	Urban ecological environment	Per capita green space (m^2/person)	9	Positive
		Industrial wastewater discharge (10,000 tons)	10	Negative
		Green coverage rate of built-up area	11	Positive
		Comprehensive utilization rate of industrial solid waste	12	Positive
	Urban infrastructure	Urban per capita water consumption (m^3/person)	13	Positive
		Total urban gas supply (ten thousand cubic meters)	14	Positive
		Per capita urban road area (m^2/person)	15	Positive
		Buses per 10,000 people	16	Positive

P_{ij} is the probability of X_{ij}.
S_j is the information entropy of the index.

(3) Determination of the Index Redundancy

$$Dj = 1 - Sj \tag{4}$$

D_j is the redundancy of each index.

(4) Determination of the Weight of Each Index

$$\omega j = \frac{Dj}{\sum_{j=1}^{m} D_j} \tag{5}$$

ω_j is the weight of each index, $0 \le \omega j \le 1$, $\sum_{j=1}^{m} \omega j = 1$.

3.2 Cloud Model

The concept of cloud model was put forward by Professor Li Deyi in 1995. It has been used in many research fields, such as electric power, computer application, logistics, architecture, climate, etc. Tian Hongna and Sun Qinqi [17] used cloud model to evaluate the innovation ability of green technology of automobile manufacturing enterprises. Chen Weijiong et al. [18] used cloud model to evaluate the emergency management of ship oil spill at sea. Sun Peng et al. [19] used cloud model to study the temporal and spatial distribution of Anhui Province on dry and wet index. Guo Qingjun and Hao Qian used cloud model to study the distribution of dry and wet index in Anhui Province. Wen et al. [20] used the extension cloud model to evaluate the resilience of the subway system. Compared with other evaluation methods, the advantages of the cloud model mainly lie in the qualitative and quantitative conversion of the uncertainty problems. The disaster problems faced by the urban resilience are full of uncertainty. Moreover, the Cloud Model Method is still less used in the evaluation of urban resilience, which needs more research to determine the factors to enhance urban resilience, in order to improve the construction of resilient cities.

The generator of Cloud Model includes forward cloud generator, backward cloud generator, x-conditional cloud generator and y-conditional cloud generator. In this paper, x-conditional cloud generator is used to determine the membership degree. The steps to determine the membership degree of Cloud Model are as following:

(1) Determination of the Comment Set of Each Index
Firstly, the evaluation results are divided into five grades according to the literatures [8, 13], which are represented by grade I, II, III, IV and V. Grade I represents the low level of urban resilience, and grade II represents the lower level of urban resilience, and grade III represents the medium level of urban resilience, and grade IV represents the higher level of urban resilience, and grade V represents the high level of urban resilience.

(2) Determination of the Cloud Eigenvalues of the Corresponding Levels of Each Index
The cloud model includes three numerical eigenvalues: expectation (Ex), entropy (En) and super entropy (He). The maximum value of an index is set as

X_{ij}^{max} as the upper limit, and the minimum value as X_{ij}^{min} as the lower limit. The cloud characteristic value is calculated by the following formula:

$$Ex = \frac{X_{ij}^{\max} + X_{ij}^{\min}}{2} \tag{6}$$

$$En = \frac{\left|X_{ij}^{\max} - X_{ij}^{\min}\right|}{2.355} \tag{7}$$

$He = k$, and K can be empirical value or experimental value. In this paper, the empirical value of K is 0.1.

(3) Determination of the Grade Membership of Each Index Value

$$Enn = randn(1) \times He + En \tag{8}$$

Enn is a normal random distribution with En as expectation and He as standard deviation

$$u0 = \exp\left[\frac{-(x0 - Ex)^2}{2(Enn)^2}\right] \tag{9}$$

x_0 is the collected raw data.

The maximum value and minimum value of each index can best reflect the evaluation results, then the maximum value of positive index is regarded as the ex of level V, and the minimum value of the negative index of positive index is the ex of level I. On the contrary, the minimum value of the negative index is taken as the ex of level V, and the maximum value is the ex of Level I. By the formula (9) and the cloud characteristic value C (ex, en, He), the hierarchical membership function of each index is obtained by MATLAB programming, and the corresponding membership matrix R is obtained by substituting the value of each index into the corresponding membership function.

3.3 Cloud Model and Entropy Weight Evaluation

The weight matrix ω determined by the entropy weight method is multiplied by the membership matrix R determined by the cloud model to obtain the hierarchical membership matrix B of the evaluated city.

$$B = \omega \times R \tag{10}$$

$B = \{b1, b2, b3, b4, b5\}$, where b_i (i = 1,…,5) is the maximum value, which means that the higher the membership degree of the city's resilience corresponding to b_i, and the urban resilience level of the city is in the corresponding level of b_i.

4 Empirical Research

4.1 Sample Selection and Data Sources

This paper will make an empirical analysis on urban resilience of 31 provinces all over China, and get the level of urban resilience of these provinces. This paper will analyze the resilience level of 31 provinces which are Beijing, Tianjin, Shanghai, Chongqing, Inner Mongolia, Shanxi, Heilongjiang, Liaoning, Jilin, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Hebei, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet. All original data sources are national data and the 2018 statistical yearbook.

4.2 Results and Analysis

This paper uses matlab2017b software to calculate the weight of 16 index data of the above 31 provinces by entropy weight method, and the weight results are as follows:

$$\omega = \{ 0.0516, 0.0064,0.1009,0.0428,0.0152,0.1082,0.0119,0.0173,0.0659, \\ 0.1532,0.002,0.0497, 0.1229,0.2139,0.0238,0.0143\}$$

According to the weight results calculated by entropy weight method, the weight of green coverage rate in the built-up area is the lightest, only 0.0020, and the weight values of the five indicators including the weight of R&D funds in GDP, the weight of bed number of medical and health institutions, the weight of total wastewater discharge, the weight of urban per capita water consumption and the weight of total urban gas supply are relatively higher, which respectively are 0.1009, 0.1082, 0.1532, 0.1229 and 0.2139, whose total weight is 0.7, accounting for the majority of the 16 indicators, so we can see the importance of these five indicators.

This paper takes per capita GDP as an example and Table 2 shows the cloud characteristic values of per capita GDP. Its level I interval is [28497.00, 41,059.13], and level II is (41,059.13, 66,183.38], and level III is (66,183.38, 91,307.63], and level IV is (91,307.63, 116,431.88], and level V is (116,431.88128994.00]. The corresponding cloud digital eigenvalues are: Level I (28,497.00, 10,668.47, 0.10), level II (53,621.25, 10,668.47, 0.10), level III (78,745.50, 10,668.47, 0.10), level IV (103,869.75, 10,668.47, 0.10), and level V (128,994.00, 10,668.47, 0.10).Taking Beijing's per capita GDP as an example, The membership degrees

Table 2 Clouds characteristic value of per capita GDP

Evaluation level		Low I	Lower II		Medium III	Higher IV	High V
Grade interval		[28497.00, 41,059.13]	(41,059.13, 66,183.38]		(66,183.38, 91,307.63]	(116,431.88, 128,994.00]	(116,431.88, 128,994.00]
Cloud eigenvalues	EX	28,497.00	53,621.25		78,745.50	103,869.75	128,994.00
	EN	10,668.47	10,668.47		10,668.47	10,668.47	10,668.47

of the five evaluation grades were 5.38438389587016e-20, 1.44965262280874e-11, 0.000015232837602232, 0.062473458944406 and 1.44965262280874e-11, respectively. The membership matrix R of all indexes of a province is obtained by this method, and then the membership degree of the urban resilience level I to V is obtained by using $\omega \times R$.

By analogy, other provinces also analyze the subordinate degree of urban resilience level in this way, and get the membership table of urban resilience level shown in Table 3 (Fig. 1).

According to the Table 3 above, it can be concluded that the urban resilience of Beijing is at a high level, and Hainan, Guizhou, Yunnan, Tibet and Qinghai are at a low level, and Shanghai, Jiangsu, Hunan and Guangdong are at a higher level, and Tianjin, Hebei, Shanxi, Inner Mongolia, Jilin, Liaoning, Heilongjiang, Anhui, Fujian, Jiangxi, Hubei, Guangxi, Chongqing, Shaanxi, Gansu, Ningxia and Xinjiang are at a lower level, and Zhejiang, Shandong, Hebei and Sichuan are in the medium level (Table 4).

From this result, we can see that there is a considerable gap in the level of resilience among various provinces in China. Only Beijing is at a high level of resilience. Among the 31 provinces, 17 provinces are at a low level, and 4 provinces are at a medium level, and 4 provinces are at a higher level. There is a significant relationship between such results and the level of economic development of provinces. Take Beijing as an example, the per capita GDP of Beijing is 128994 yuan/person, and the proportion of tertiary industry is 80.6%, which are all at the high level of all provinces in China. With more developed economy and more concentrated population, the greater the investment in urban infrastructure and the more perfect infrastructure construction, the richer social resources can be provided, such as the greater the investment in medical treatment, education and employment. These provinces are able to resist disasters and recover to the previous state in the event of disasters. Economic development is important, but we can not only focus on economic development. For example, Beijing's economic development is very good, but there are some problems in its environmental situation. The total discharge of wastewater is 133.188 million tons, and the comprehensive utilization rate of industrial solid waste is 74.13%. The discharge of waste water is relatively high, and the comprehensive utilization rate of industrial solid waste is low. Its ecological environment needs further improvement. It is necessary to increase the investment in ecological environment and coordinate the development of economy and environment. We should not destroy the environment for the sake of rapid economic development. At the same time, we should

Table 3 Membership degree of urban resilience level

Provincial capital	I	II	III	IV	V	Evaluation of urban resilience
Beijing	0.1952	0.1590	0.1202	0.2135	0.3650	V
Tianjin	0.2153	0.3473	0.1602	0.1288	0.2021	II
Hebei	0.2066	0.3289	0.2582	0.2796	0.0074	II
Shanxi	0.2472	0.5036	0.1343	0.1009	0.0594	II
Inner Mongolia	0.1637	0.5424	0.1676	0.0797	0.1070	II
Liaoning	0.2016	0.3475	0.3099	0.1808	0.0251	II
Jilin	0.2648	0.4919	0.1419	0.0950	0.0726	II
Heilongjiang	0.2227	0.4196	0.2342	0.1093	0.0569	II
Shanghai	0.1537	0.2212	0.2497	0.2620	0.2001	IV
Jiangsu	0.0248	0.2669	0.2443	0.3393	0.1936	IV
Zhejiang	0.1191	0.3285	0.4103	0.0961	0.1152	III
Anhui	0.1501	0.3755	0.1700	0.3144	0.0718	II
Fujian	0.2076	0.3663	0.2063	0.2535	0.0108	II
Jiangxi	0.2820	0.3266	0.2256	0.2003	0.0268	II
Shandong	0.1304	0.1801	0.4478	0.0849	0.2411	III
Henan	0.2133	0.3258	0.3412	0.1157	0.1032	III
Hubei	0.1039	0.3932	0.2828	0.2700	0.0060	II
Hunan	0.2207	0.3107	0.1639	0.3132	0.0288	IV
Guangdong	0.2624	0.1187	0.1177	0.4030	0.1579	IV
Guangxi	0.3041	0.3827	0.1572	0.2091	0.0230	II
Hainan	0.4642	0.2860	0.0982	0.0582	0.1433	I
Chongqing	0.1416	0.4413	0.1985	0.2736	0.0238	II
Sichuan	0.1806	0.2472	0.4412	0.0789	0.1024	III
Guizhou	0.4339	0.2790	0.1373	0.1216	0.0798	I
Yunnan	0.4422	0.2682	0.1682	0.1793	0.0297	I
Tibet	0.5807	0.1765	0.0896	0.0194	0.1960	I
Shaanxi	0.1616	0.4698	0.2161	0.1831	0.0341	II
Gansu	0.3216	0.4292	0.1333	0.0465	0.1270	II
Qinghai	0.4599	0.2788	0.0821	0.0326	0.1870	I
Ningxia	0.2487	0.3234	0.2016	0.0967	0.1572	II
Xinjiang	0.0706	0.4629	0.1692	0.1266	0.2192	II

protect the environment and improve the urban resilience. Low resilience provinces have a common feature, that is, the per capita GDP and the proportion of tertiary industry are low. This shows that the economy of low resilience areas is underdeveloped and there are problems in the industrial structure, which leads to the low level of the follow-up social development, ecological environment development and

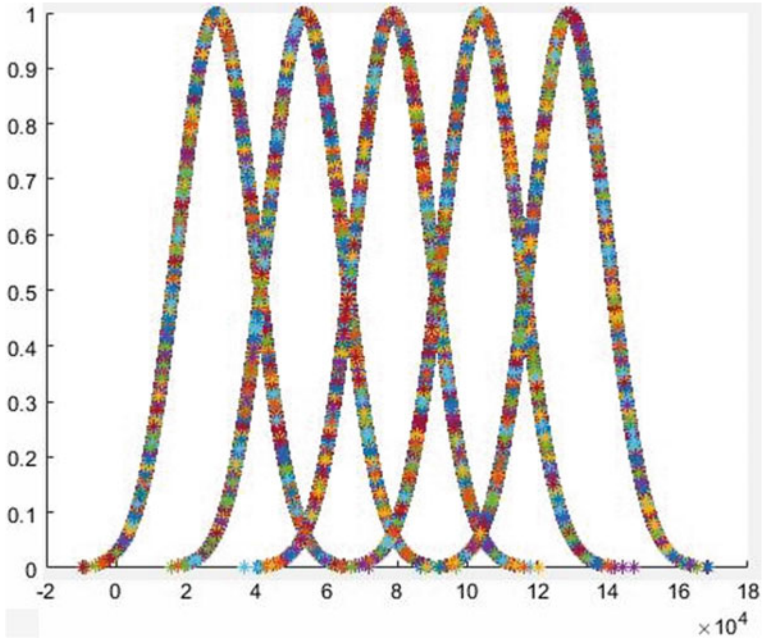

Fig. 1 Membership chart of GDP per capita

Table 4 Urban resilience grade table

Provincial capital	Urban resilience level
Hainan, Guizhou, Yunnan, Tibet, Qinghai	I
Tianjin, Hebei, Shanxi, Inner Mongolia, Jilin, Liaoning, Heilongjiang, Anhui, Fujian, Jiangxi, Hubei, Guangxi, Chongqing, Shaanxi, Gansu, Ningxia, Xinjiang	II
Zhejiang, Shandong, Hebei, Sichuan	III
Shanghai, Jiangsu, Hunan, Guangdong	IV
Beijing	V

infrastructure construction. Therefore, low resilience provinces need to continuously develop economy, at the same time, attention should be paid to adjust the industrial structure, so as to achieve the coordinated development of primary, secondary and tertiary industries.

5 Conclusion

This paper uses Entropy Weight Method and Cloud Model, through the auxiliary calculation of MATLAB programming software, and analyzes the membership degree of 16 indicators of 31 provinces in China in 2017, and finally determines the level of urban resilience of each province. From this, it can be concluded that compared with other provinces, the level of urban resilience of provinces in the eastern region is generally higher than that of other provinces. However, in central and Northeast China, provinces except Hunan and Sichuan are generally in a low level of resilience, and provinces with the low level of resilience are all in the West except Hainan. It also can be concluded that the development of urban resilience in China is extremely unbalanced. Regional differences are large, and most provinces are at a low level. In addition, there is only one high resilience province is Beijing, with relatively few high and medium resilience. It can be seen that there is still a lot of room for development in the construction of resilient provinces in China to eliminate regional differences, which need to be strengthened the resilience of each province through the characteristics of the province.

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Research on the Development of Digital Twins in Construction Industry

Jing Li

Abstract With the development of the Internet of Things, big data, artificial intelligence and other technologies, driven by the emerging building information technology and smart city, digital twin technology has become an emerging research hotspot in the field of intelligent manufacturing and intelligent operation and maintenance of complex systems. This paper first sorts out the development of digital twin technology, the existing preliminary research planning and phased achievements, and then analyzes the application of digital twin technology in the construction industry from three aspects: the full life cycle of architecture, the smart site and the smart city. The research shows that digital twin technology can virtualize the building entity, transmit the data collected by sensors and so on, realize the comprehensive management and control of the building entity, and improve the building construction and operation efficiency. However, digital twin technology is not mature, and the interaction between entity and virtual body can be better realized by combining with other technical means such as AR. Finally, points out that digital twin technology development trend and prospect in the construction industry, the researchers in the field of management and control for complex systems provide certain reference.

Keywords Digital twin · Construction industry · Development tendency

1 Introduction

Digital twin technology is a hot research topic in the field of intelligent manufacturing. Digital twinning is a key technology to realize the mapping of physical system to digital model of information space, it makes full use of sensors arranged in various parts of the system to conduct data analysis and modeling of physical entities, forming a multi-disciplinary, multi-physical quantity, multi-time scale and multi-probability simulation process, and reflecting the full life cycle process of physical systems in

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different real scenes. With the help of various high-performance sensors and high-speed communication, digital twins can present the actual situation of the physical entity almost in real time by integrating the data of the multidimensional physical entity, supplemented by data analysis and simulation, and control the physical entity through virtual and real interaction interface. Digital twins mainly include three parts: (1) physical entities of physical space; (2) Virtual entity of virtual space; (3) Connection data and information between entity and virtual body. There is still no universally accepted definition of the basic concept of digital twinning.

In the development process of digital twin, with the deepening of cognition, digital twin mainly goes through three stages: (1) Digital prototype stage, digital prototype is the initial form of digital twin, is the digital description of the complete machine of mechanical products or subsystems with independent functions; (2) The narrow digital twin stage, proposed by Professor Grieves, is defined as the digital representation of products and their full life cycle; (3) In the generalized digital twin stage, in terms of defining objects, the generalized digital twin extends its scope on a large scale, extending beyond the product to a broader field. Gartner, a world-renowned consulting firm, has ranked digital twins as one of the top 10 technology trends for three consecutive years. It considers digital twins to be the digital representation of real-world entities or systems. Therefore, digital twins become the general name of any information system or digital system.

2 Research Status of Digital Twinning

The concept of digital twins can be traced back to the "mirror space model" proposed by Professor Grieves in 2003 at the University of Michigan's product Lifecycle Management course, which is defined as a three-dimensional model that includes physical products, virtual products and the connection between them. Due to the technical and cognitive limitations of the time, the concept was ignored, and no relevant results were published in the following ten years. Until 2010, NASA first introduced the concept of digital twinning in the space technology roadmap, in order to realize the comprehensive diagnostic maintenance of flight system by using digital twinning. In 2011, the United States Air Force Laboratory clearly proposed the digital twin model for future aircraft, and pointed out that a complete virtual mapping of aircraft should be built based on the high-fidelity simulation model, historical data and real-time sensor data of aircraft, so as to realize the prediction of the health status, remaining life and mission accessibility of aircraft. Since then, the concept of digital twins has attracted extensive attention, and relevant research institutions have begun to study relevant key technologies. The application of digital twins has also expanded from aircraft operation and maintenance to rich scenes such as smart cities, product development and equipment manufacturing.

The first step in digital twin modeling is to create a high-fidelity virtual model that truly recreates the geometry, properties, behavior, rules, and so on of the physical entity. These models should not only be consistent with the physical entity geometrically, but also be able to simulate the physical entity's spatiotemporal state, behavior, function and so on. Because digital twins contain various subsystems, traditional modeling methods may not be able to accurately describe the whole digital twin system, and there is no consistent conclusion for the modeling of the whole digital twin system. At present, digital twin modeling is usually based on simulation technology [1], including discrete event simulation, finite element simulation, etc., and is usually based on general programming language, simulation language or special simulation software to write the corresponding model. However, the simulation only plays a guiding role in the actual system operation process. Therefore, the main idea of digital twin modeling is to supplement and perfect the simulation model with data to realize real-time and high-confidence simulation prediction of physical entities. At present, most simulation modeling methods have some defects, such as poor flexibility, complex configuration and error-prone, etc. In order to realize the digital twin model with high confidence, the high-fidelity modeling and simulation technology should be further developed.

Based on the above methods, some digital twin models have been produced, which can be divided into general model and special model according to their patterns. Among them, special model is the focus of current research. The research content of digital twin model mainly involves conceptual model and model implementation method, in which the conceptual model describes the architecture of digital twin system from a macro perspective and has certain universality. The research of model implementation methods mainly involves modeling language and model development tools. In terms of model realization methods, related technical methods and tools are developing in a diversified way. At present, digital twin modeling languages mainly include AutomationML, UML, SysML and XML, among which AutomationML is the most applied language. Some models are developed based on general modeling tools such as CAD, and more models are developed based on special modeling tools such as FlexSim and Qfsm. In the future, digital twin models need to be strengthened in the connection of industry standard architecture, the establishment of a unified description method and specifications, and other aspects.

3 Digital Twin Integrates Construction Development

3.1 Application of Digital Twinning in the Whole Life Cycle of Architecture

Digital twin is the data center of the entire life cycle of a building [2], which records all models and data of the building from basic design to scrapping and recycling, reflecting the state and behavior of the building at all stages of construction and use. All the stage models and data recorded are callable, and the building is visible in state, controllable in behavior, and traceable in quality anytime and anywhere.

Fig. 1 Application of digital twins in the full life cycle of architecture

In the architectural design stage, a fully 3D labeled product model is constructed, including 3D design model, construction information, whole-process digital sample information, associated attributes, etc. In the process design stage, based on the information such as 3D design model, construction information and associated attributes, the process design based on BIM model is realized, and the process regulations are finally formed, including the BIM model, process database and related process text information and documents. In the construction and production stage, it mainly realizes the collection and reconstruction of building archives, product data packets, planning scheduling, construction information and total factor reconstruction, including the collection and reconstruction of quality data, safety, progress, technical status data, labor database, etc. In the stage of construction operations, the main architecture of the use, operation and maintenance, by nakedness "fusion" form the building upgrades for perception, analysis, can be controlled, the wisdom of life, and the adaptive artificial intelligence through the big data driven, buildings and facilities running strategy of intelligent judgment, achieve self optimization, self management, self maintenance status; Scrap and recycling stages in the building, the main construction scrap and recycling data, including building scrapping and construction materials recycling reason, construction and the actual life time, products, etc., for the next generation of architectural design improvement and innovation, the same type of quality analysis and prediction, based on the analysis of the physical simulation model and product model optimization, etc. To provide data support (Fig. 1).

3.2 *Application of Digital Twins in Intelligent Construction Sites*

(1) **Entity connects the virtual body**
Through the implementation of building networking system, various elements such as "human, machine, material, method and environment" among digital

production of intelligent construction sites or building components can be interconnected. Include: construction project schedule, process, production workshop process of network transmission, the state of the equipment remote automatic data collection, big data intelligent analysis and visual display on the construction site, site and digital production workshop of wisdom "information island" into an information node, the physical elements of the original into the digital space, form a GPS device.

(2) **Virtual body management entity**
Through the building cloud control system and the project management cabin, the construction resources, building components, production equipment and logistics system are checked and inventoried, and the building component library is analyzed and managed statistically. Realized in digital space of physical space inventories for the lean management, the construction project of the processes and procedures for effective visual management, avoid the waste of resources construction, realize resources highly match, can minimize the past construction link too opaque, or insufficient productive resources to bring production delays, also can avoid due to the backlog of production resources production auxiliary to the problem of high cost.

(3) **Virtual bodies cooperate with entities**
Based on BIM + cloud collaborative platform, the project management, construction workers, procurement, technology and other related personnel parallel preparation, collaborative production. Through intelligent collaborative production management, serial work can be turned into parallel work, which can obviously reduce the waiting time of information opacity, improve the efficiency of construction site and shorten the construction period.

(4) **Virtual body optimization entity**
Through intelligent advanced production scheduling algorithm, based on the bottom plan, in accordance with the principle of maximizing economy of the project, the traditional process, standardization and digitalization are established to establish a series of "digital homework books". Realize intelligent production scheduling mode, decompose each process into every minute of each construction worker and mechanical equipment, which can minimize delivery delay and improve the effective utilization rate of construction workers and equipment on the whole.

(5) **Virtual body control entity**
Through all kinds of intelligent equipment of wisdom site workers, data acquisition and intelligent management, digital production equipment and personnel for all kinds of process data in real time dynamic early warning, process monitoring, recording, and other functions, which can realize real-time and dynamic process of construction, strict management control, ensure full control of construction production process. Quality of construction production for a period of time, when a certain regularity, through the processes of the main process parameters and product quality, comprehensive analysis for the technical personnel and project management personnel for process improvement provides a scientific and quantitative reference data, in the later production

Fig. 2 Application of digital twins in intelligent construction sites

process, to avoid bad parameters, to ensure the optimal production parameters, so as to ensure the consistency and stability of products.

(6) **Virtual interactive entities**

hrough the collection, analysis, mining and display of multi-dimensional data such as equipment, production, quality and inventory in the intelligent construction site, it provides various kinds of graphs and reports with scientific and intuitive view for all kinds of personnel, and realizes the synchronous display of physical entities and man–machine interaction in the virtual space (Fig. 2).

3.3 Application of Digital Twins in Smart Cities

Digital twin smart city construction takes cloud, network and terminal to construct technological ecology, establish complete and detailed urban operation state, and focus on building high-precision urban information model [3]. At present, some cities have taken the lead in exploring and practicing the digital twin concept. For example, in 2015, the Singapore government signed agreements with several companies and research institutions such as Dassault Systems of France to launch the "Virtual Singapore" project. The project plan is completely in accordance with the actual physical world in Singapore, twin cities create digital information model, the model built in massive amounts of static and dynamic data, and can according to the objective demand, real-time display, city operation state model is not only the physical world run dynamic display, meet the needs of urban management, also can guide the future of the city construction and operation optimization.

At present, the twin cities for the construction of digital city in various areas of the enthusiasm, wisdom sinks cloud combination, participate in the national standard and the special research plus experience, first put forward "BIM digital twin concept", to build BIMTWIN city digital twin and application platform, platform with BIM, DIM as the core technology, the depth of the fusion of big data [4], cloud computing and digital simulation technology, the mobile Internet, Internet of things [5], such as a variety of a new generation of information technology [6], gradually establish a perfect image of the virtual world, and the real city structures, urban management, industrial management and so on many kinds of application scenarios, improving the capacity of city governance, Build up the digital assets corresponding to the urban physical assets, and build the transparent urban life body. As the support of "bottom core", BIM technology is particularly valuable in the construction of smart cities [7].

In recent years, some countries have also begun to apply digital twinning to the construction of smart cities [8]. For example, Singapore has built City Scope, a simulation system for City operation, to realize simulation optimization, planning and decision, and other functions. In Spain, sensors are widely deployed in cities to perceive the operation conditions of urban environment, transportation, water conservancy and so on, and the data are gathered into the smart city platform, preliminarily forming the prototype of digital twin city. The Xiongan New Area for the first time proposed the construction of a "digital twin city", which clearly states the need for simultaneous planning and construction of real and virtual digital cities [9]. Through digital simulation modeling constructs a model of virtual city, based on all levels in the city layout sensors to collect real-time data of physical city, combined with the virtual simulation data of the city and city of sensor data, driving the development of digital twin cities and optimization, the final implementation of city planning, urban ecological environmental governance, such as traffic control with intelligence services [10]. Ali cloud of brain and digital city twin coincided basically with the approach of the urban construction, it people can't understand very large scale real-time processing by full amount, multi-source data based on machine learning insight found no complicated hidden rule, to surpass the human local suboptimal decisions of global optimal strategy, and in the urban traffic check-up, urban industry in special vehicle monitoring, micro control of urban traffic, urban, the urban strategic planning five application scenario to deploy, prove digital twin cities can promote urban design and construction, auxiliary city management, make the city more wisdom, beauty (Fig. 3).

4 Digital Twin Trends in the Construction Industry

At present, the research and application of digital twinning is still in its initial stage, and there are still many research challenges in industrial applications, such as modeling technology, data analysis, information security and privacy protection, etc. The development of digital twins needs the support of the new generation of information technologies such as the Internet of things and big data. In order to realize the rapid development of digital twins and build an efficient and robust digital twin system, the new generation of information technologies should be integrated.

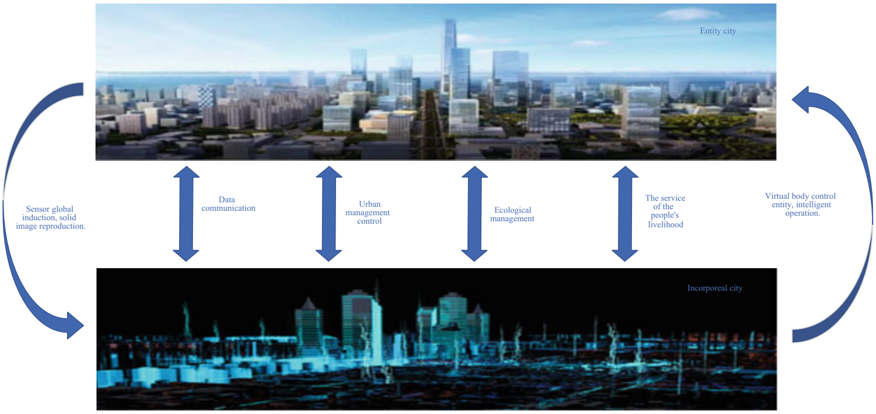

Fig. 3 Application of digital twins in smart cities

Combined with the current status of digital twin development, this paper summarizes the development trend of digital twin in the construction industry [11].

(1) **Building multi-physical modeling**
Digital twins are the real reflection of physical products in virtual space, and the success of digital twins in the field of architecture depends on the fidelity of digital twins, that is, the degree of fitting. Each physical property of the building has its specific model, including computational fluid dynamics model, structural dynamics model, thermodynamic model, stress analysis model, fatigue damage model and material state evolution model (such as stiffness, strength, fatigue strength evolution of materials, etc.).How to relate these models based on different physical properties is the key to build digital twins and then give full play to the role of digital twins in simulation, diagnosis, prediction and control. Based on the simulation results of physical integration model can more accurately reflect and mirror physical product of real state and behavior in the real environment, make the function of the physical products detection in virtual environment and performance and eventually possible to replace the physical prototype, but also can be solved based on the traditional method (each physical properties of the model are analyzed separately, there is no coupling together) health status and residual life prediction products such as timing and geometry dimension of problem. Currently, the AIR Force Research Laboratory is trying to build a digital twin of the body that integrates different physical attributes to accurately predict the life span of the body. Multi-physical modeling will be an important technical means to improve the degree of digital twins fitting and give full play to the role of digital twins.

(2) **Building life cycle data management**
The whole life cycle data storage and management of complex systems is an important support of digital twin system, adopt cloud server running on the system of mass data distributed management, realize the high speed of

data reading and safety redundancy backup, data intelligent parsing algorithm provides sufficient reliable data source, to maintain the operation of the whole digital twin system plays an important role [12]. By storing the whole life cycle data of the system, more sufficient information can be provided for data analysis and presentation, enabling the system to have the functions of historical state playback, structural health degradation analysis and intelligent analysis of any historical moment. Massive historical data but also provides abundant sample information for data mining, by extracting effective features, analysis of data in the data, the relationship between can be based on the data analysis results for many unknown but potentially useful information, deepen the understanding and the characteristics of the system, mechanism and data, to realize digital twin surreal attributes, with the advancement of research, the whole life cycle data will continue to provide reliable data source and support for it. The realization of the full life cycle data storage and management needs with the help of the server distributed and redundant storage, because of the high digital twin system for real-time requirements of the data, how to optimize the data distribution of architecture, storage and retrieval method, obtain the real-time and reliable data read performance, the challenge for the twin system is applied to digital. Especially considering the data security of construction enterprises and information protection in the field of equipment, it is a feasible technical solution to build a data center or data management system with security private cloud as the core.

(3) **Integration of the new generation of information technology**
As the enabling technology of digital twins, digital tie technology is used to realize the bidirectional interaction of models and key data in each stage of the whole life cycle of digital twins, which is the basis of realizing the efficient collaboration of single data source and each stage of the whole life cycle. At present, breakpoints still exist between architectural design, construction, inspection, use and other links, and the continuous flow of digital quantity has not been fully realized. Moreover, the flow of digital quantity at the present stage is one-way, so digital link technology is needed to realize two-way flow. Therefore, the integration of digital ties and digital twins is the future trend of development.

In addition, the integration with augmented reality (AR) technology is also one of the development directions of product digital twins [13]. AR technology is a technology that calculates the position and Angle of the camera image in real time and adds the corresponding image. The goal of this technology is to embed the virtual world in the real world and interact with it on the screen. Will AR technology in architecture design and construction process, on the basis of the actual scene fusion of a fully 3 d immersive virtual scene platform, through the virtual peripherals, developers, construction personnel can see in the virtual scene and perceived in the physical world and the real exactly synchronization, so you can through the virtual operation model to influence the material world, realize the management of architectural design and construction process control and so on [14]. AR by enhancing people see, sound, smell, touch, and hear, will break the person and the boundary of the virtual world, strengthen people and virtual world integration, further blurring the real world and computer generated virtual boundaries of the world, the world of 2 d in allowing people to break through the screen and directly perceived through the virtual world and real world. The fusion of augmented reality and digital twin technology [15] will be one of the important directions in the future development of digital design and manufacturing technology, modeling and simulation technology, and virtual reality technology, and is a higher level of virtual reality fusion.

5 Conclusion and Prospect

In a broad sense, the concept of digital twins expresses a goal form of virtual and real fusion—interactive symbiosis of physical entity and digital virtual body throughout their life cycle. Its enlightening significance for architecture lies in the fact that the traditional visualization and materialization of architecture are meaningful only in the process of transformation, that is, the relationship between the virtual and the real is temporary. Once the building is completed, the relationship will come to an end. The concept of digital twin not only emphasizes the interaction between virtual and material in the process, but also plugs everything happening in the physical world back into the virtual information space in the whole life cycle of the building, and keeps the feedback loop between virtual and material all the time. The concept of digital twinning ensures that Numbers and the physical world remain in harmony throughout the life cycle. The complete realization of digital twin concept must be supported by a large group of virtual and real technologies, such as information acquisition, data mining, information visualization, intelligent construction technology and artificial intelligence. At present, the phased achievements of architecture towards the symbiosis between virtual and reality represented by digital twins may be relatively basic, but undoubtedly make us convinced that digital twins are not a distant future.

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Research Review on Digital Technology of 3D Printing for Construction

Meijiao Rao and Guodong Wu

Abstract 3D printing technology is a new technology that realizes building energy conservation and green development, and is the key to solving the high energy consumption and high pollution in the traditional building process. Based on the basic principles and characteristics of 3D printing technology, this article reviews the status quo of 3D printing technology at home and abroad and its research status in the construction field, and analyzes the existing problems that 3D printing technology cannot be effectively applied in the construction industry. Looking forward to the future application prospects of 3D printing technology in the construction industry, it provides a reference for a systematic and comprehensive understanding of construction 3D printing technology.

Keywords 3D printing technology · Research status · Construction industry · Application prospect

1 Introduction

The Economist magazine once commented: "The impact of great inventions was unpredictable at that time, such as printing in 1450, steam engines in 1750, and transistors in 1950, We still cannot predict how 3D printing will change the world in a long time [1]. "The idea of 3D printing first appeared at the end of the nineteenth century, and it was not until the 1980s that mankind produced the first 3D printer. 3D printing technology is a rapid prototyping technology that can select suitable printing materials to build entities according to user needs. It has been applied in many disciplines. On this basis, this article focuses on the research status of 3D printing technology in the construction field based on the principles and characteristics of 3D

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printing technology, and further analyzes its application prospects in the construction industry.

3D printing is a kind of rapid prototyping technology. It is based on a digital model file, using powdered metal or plastic and other bondable materials to construct objects by stacking them layer by layer (That is, "Layered Modeling Method") [2]. The design process of 3D printing: first model by computer-aided design (CAD) or computer animation modeling software, and then "partition" the built three-dimensional model into layer-by-layer sections, thereby instructing the printer to print layer by layer. The standard file format for collaboration between design software and printer is STL file format [3].

3D printing is a rapid prototyping technology based on digital models, using powdered metal or non-metal materials to construct the spatial shape of objects through layer-by-layer printing. Because of its innovation in manufacturing process, it is considered as "an important production tool of the third industrial revolution." 3D is short for "three dimensions". The idea of 3D printing originated in the United States at the end of the nineteenth century and was developed and promoted in the 1980s. 3D printing technology is generally used in mold manufacturing, industrial design and other fields. It has been applied to many disciplines and various innovative applications are continuously entering the public's field of vision.

2 The Development Process and Status Quo of 3D Printing Technology in the Construction Industry

2.1 The Development History of 3D Printing Technology in the Construction Industry

It can be seen from Table 1 that the 3D printing technology in the field of foreign construction originated in 1997. After 2013, 3D printing buildings emerged world-wide: Europe built multiple 3D printed buildings, 3D printed small houses appeared in the United States, and the Dubai plan. The research and development of some families using the 3D printing technology in the domestic construction field is also keeping pace with the development of the times.

From Table 2, it can be seen that the cooperation of school-enterprise research and development and the support of innovation policies have made my country's 3D printing in the construction field a major breakthrough.

Table 1 The development history of 3D printing in foreign construction industry

1997	The American scholar Joseph Pegna proposed a construction method suitable for free-form components that are accumulated layer by layer and selectively solidified by cement materials. This is the original origin of architectural 3D printing [4]
2007	Italian engineer Enrico Dini introduced a new architectural 3D printing technology-D-Shape, which can print a complete building structure directly on the construction site
2012	Gershenfeld, Professor of the Massachusetts Institute of Technology put forward the concept of digital construction to represent the process of using computer-controlled tools
2017	Engineers from Eindhoven University of Technology successfully printed the world's first 3D printed pre-stressed concrete bicycle bridge using the contour forming process [5]
2018	American Branch Technology company built a large-scale complex building wall based on digital construction technology, which not only has the strength of a traditional wall, but also has a lighter weight

2.2 The Development Status of 3D Printing Technology in the Construction Industry

According to statistics, the top three applications of 3D printing technology in China are industrial machinery, aerospace, and automobiles, which account for 20.0%, 16.6%, and 13.8% of the market share, respectively. The technology is used in various fields. There are also major breakthroughs in research results, such as the research and development of personalized 3D medical rehabilitation technology in the medical field, the use of 3D technology to print micro-channel radiators in the field of computer science, the research and development of 4D printed aircraft in the aerospace field, and the development of catalytic and adsorption materials in the field of chemistry and chemical engineering. Preparation etc. In contrast, the construction field only accounts for 3% of the market share. Although the 3D printing research in the construction field at home and abroad has made continuous breakthroughs, the technology also has significant advantages in architectural modeling and construction speed, but there are also obstacles.

3 3D Printing Building Technology

3.1 Contour Crafting

The "contour craft" invented by Professor Behrokh Khosnevis from the University of Southern California is a large-scale construction process, the goal is to realize the automatic construction of the entire structure and auxiliary components, each building can be customized design, complex curves can also be realized.

Table 2 The development history of 3D printing in the domestic construction industry

Developed by enterprises	2002	Winsun began to develop giant 3D printers, printing "inks" and continuous printing technology
	2014	Winsun built the world's first batch of 3D printed practical buildings
	2017	The 3D printed bus station in Fengjing Town, Shanghai was put into use, laying the foundation for China to move toward the world's leading position of 3D printing
	2019	China's first polymer material viewing bridge made using 3D printing technology was also officially unveiled [6]
Developed by university research institutions	2009	The School of Architecture of Hunan University established the Digital Architecture Laboratory (DAL) to explore the teaching mode of digital architecture courses
	2011	The School of Architecture and Urban Planning of Tongji University verified the performance of a variety of digital equipment
	2013	The Engineering Management Institute of Huazhong University of Science and Technology has conducted research on 3D printing cement mortar masonry technology and carried out a number of technical research work
	2014	The Civil Engineering Safety and Durability Laboratory of Tsinghua University studies the mesoscopic characteristics and mechanical properties of the hybrid glue system 3D printing structure that may be used in engineering structures
National industry-related policies	2016	The Ministry of Housing and Urban–Rural Development of the People's Republic of China issued the "Information Guidelines for the Construction Industry 2016–2020", which stipulates that proactively carry out research on 3D printing equipment and materials in the construction industry, and 3D printing construction technology has received policy support in my country's construction industry [7]

(continued)

Table 2 (continued)

	2018	In the “13th Five-Year” discipline development strategic plan, additive manufacturing technology is clearly laid out as a cross-priority area of the interdisciplinary science department
	December, 2018	China Civil Engineering 2017 Annual Conference issued industry guidance: to closely integrate civil engineering with emerging industries such as 3D printing

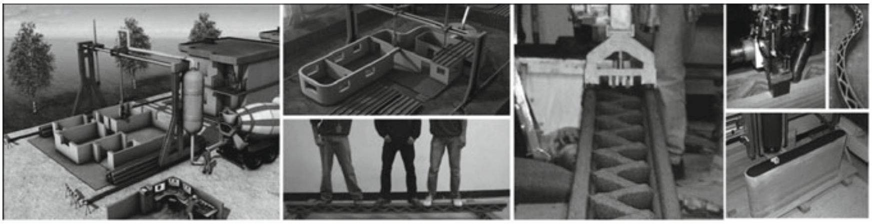

Fig. 1 Outline technology and the printed wall

The characteristic of the “contour process” is that the trowel attached to the nozzle can smooth the printed material to form a smoother surface. If the printing equipment is further upgraded in the future, it is possible to install pipes and electrical facilities, and even to install steel mesh in the printed wall (Fig. 1). The goal of “Profile Technology” is to realize the automated construction of the entire structure and auxiliary components. This technology is also attractive to architects. Because it can build buildings with single and double curvature shapes, it is especially popular with architects who pursue free forms. The contouring process is still in the experimental stage. The R&D team has successfully tested various materials, including plastics, ceramics, composites and concrete. At present, the contour process has printed full-scale structural components, such as walls with complex internal structures or hollow walls. Another potential use of “profile technology” is to explore the extraterrestrial environment.

There are also some shortcomings in the contour process. For example, it is necessary to print a cavity with extremely high performance, requirements in advance, which increases the difficulty of material design; layered pouring of the building wall core will increase the weak area of the joint part of the material, leaving a long-term performance of the material Hidden danger; In addition, its printing accuracy needs to be improved.

Fig. 2 Structure printed with D-shape

3.2 D-Shape

In March 2010, Italian Enrico Dini designed a magical 3D printer-"D-Shape". Unlike the "contour craft" that directly uses concrete as the printing material, the D-Shape printer uses sand mainly. When the printer starts to work, sand and magnesium-based glue will be ejected from thousands of nozzles at the same time. This special glue will stick the sand to a solid like rock and form it into a specific shape. D-Shape printers can also be used to print habitats of aquatic animals and plants, such as strangely shaped coral reefs, which can be used to repair the underwater ecological environment. This technology has been used to build 1.6 m high architectural works called "Radiolaria" (Fig. 2).

The advantages of D-Shape technology are its low construction price, better control of product quality, the ability to customize and repair defective components through scanning technology, and the printed components are smooth and hard. However, the printing process is slow, a large platform is required to support printing, the amount of work to remove unused materials is large, and the printing size is limited by the supporting platform.

3.3 Concrete Printing

In 2008, Lim et al., the Innovation and Architecture Research Center of Loughborough University in the United Kingdom, proposed what became known as "Concrete Printing" in 2008. Building 3D printing technology is also based on the process of concrete spray-extrusion accumulation molding [8].

The printing process is divided into three stages: data preparation stage, concrete preparation stage and component printing stage. In the data preparation stage, the advancement of scanning technology has an important impact on the accuracy of the final printed components. For complex components, the optimization of the printing path can not only save printing time, but also maintain the new mixing performance of the printed materials; in concrete preparation In the stage, it is necessary to effectively control the time. On the one hand, it is necessary to maintain the raw material in the conveying system, and on the other hand, to shorten the path of the material in the conveying system as much as possible; in the component printing stage, the printing extruder needs to adopt a suitable geometric shape. To maximize the contact area between the extruded strips, on the other hand, the movement of the print head must be independent of the deposition direction. The most important thing is to control the consistency of the printing speed and the material flow rate, so that the extruded material has good uniformity, the printing layer has good adhesion and the component accuracy is good. Therefore, it is becoming more and more urgent to establish a suitable geometric model to explore the correlation of pump, printing speed and material flow rate.

The concrete printing guarantees the integrity of the components through the spatial steel mesh. The process is simple and the printing efficiency is high; but the surface of the printing components is rough and the size is limited by the equipment.

4 Problems and Advantages of 3D Printing Technology in the Construction Industry

4.1 The Problems of 3D Printing Technology in the Construction Industry

The rapid development of 3D printing technology has enabled technology to be used in various fields to benefit mankind. At present, 3D printing technology is widely used in medical, aerospace and defense, machinery, agriculture, automotive industry, entertainment, manufacturing, etc., but in the field of construction. The application of 3D printing is still in the initial stage of exploration, mainly because 3D printing architecture still has some problems in terms of technical theory and raw materials, which requires further research and in-depth technical research. The main issues are:

(1) Weakness of material structure performance
The material for 3D printing, namely "ink", is mainly composed of high-grade cement and glass fiber. The glass fiber has a negative impact on the human respiratory system, and the recovery of high-grade cement is also difficult. At the same time, whether the material's bearing capacity, strength, durability, and stiffness can meet the standards of the construction industry still needs the authoritative inspection and certification of experts and management

departments, and there is also a lack of relevant bearing capacity experimental data support, so that the existing ones have come out. Most of the 3D printed buildings are low buildings with 1 to 3 floors, and a few are multi-stored residential buildings. At present, the types of materials are not perfect, and the types of materials suitable for 3D printing are limited. The development of new 3D rapid prototyping materials, especially composite materials, such as nanomaterials and heterogeneous materials, is still the direction of efforts. In addition, the current solidification and hardening speed of printing materials, how to adjust the rapid setting or retardation during molding, to better adapt to the influence of environmental temperature, and to meet the requirements of the structural printing occlusion between successive levels, is a problem that requires in-depth research in 3D printing architecture.

(2) Process defects
According to different principles of architectural molding, mainstream 3D printing technologies can be divided into: rapid prototyping (SLA), fused deposition molding (FDM), selective laser sintering (SLS) [9], layered entity manufacturing (LOM technology). Due to the basic principle of stacking layer by layer, the upper layer material can be superimposed only after the bottom layer material is solidified, resulting in the two layers of material cannot be smooth and excessive, making the structure surface rough. If the exterior and interior decoration are not carried out, it will hinder the façade. The aesthetics of the printed building, and the impact resistance of the printed building is not as good as the traditional house. At the same time, with the existing manufacturing process, its production efficiency has advantages in printing smaller-scale components, but large-scale production has the disadvantage of time-consuming printing, and the cost cannot be improved due to scale.

(3) Immature technology research and development
3D printing technology is used in buildings, and its construction characteristics make 3D printing equipment relatively large, but the large volume of civil buildings has exceeded the printing scale limit of conventional 3D printing equipment. At present, the equipment only meets the construction of small houses and is difficult to be qualified for high-rise buildings. Industrialized mass production; the one-time job of adding steel reinforcement after printing the "plain" material hollow wall is still difficult. The goal is to create a 3D printing system that can effectively continuously print steel wire into a mesh structure and automatically complete the building However, at present, domestic enterprises generally do not arrange sufficient funds for technological research and development, and cooperative research and development between universities, research institutes and enterprises are also lacking, and there is a lack of breakthrough technological progress.

(4) Lack of 3D printing construction industry specifications
3D printing construction technology is a completely new field. There are no relatively complete experimental inspection data and complete theoretical system support in the construction industry at home and abroad, and no systematic norms and related technical standards have been established. Including

materials, processes, precision, software, energy consumption, as well as the quantitative definition of the seismic performance, durability, bearing capacity limit, and service life of the final product, it is urgent to issue corresponding supporting national standards and industry specifications.

(5) Shortage of professional and technical personnel
3D printing technology is a multi-disciplinary professional integrated cutting-edge technology. The application research field of 3D printing architecture in China is still relatively narrow. There is a lack of 3D printing technology related courses in professional teaching in colleges and universities, and there is insufficient teaching staff. Vocational education and various training institutions have not adapted Training and promotion, the construction market lacks a large number of theoretical, academic and application-oriented technical talents, including industrial-grade 3D printers that are complex to operate, and operators also need special training. At the same time, there is a lack of financial support in the conventional technical support links such as equipment purchase, physical experiment inspection, and technical exchange between enterprises.

4.2 The Advantages of 3D Printing Technology in the Construction Industry

The reason why 3D printing technology can be applied to the construction industry is that its technology itself has certain advantages and has the ability to solve problems that cannot be solved by other technologies in the construction industry. The advantages of 3D printing architecture are mainly reflected in:

1. Environmental protection and energy saving. 3D printing is a brand-new construction method that subverts the traditional construction mode. Its biggest highlight is that it can recycle construction waste, solid waste steel slag and other construction waste. At the same time, new buildings basically no longer produce new construction waste. The process reduces construction dust pollution, reduces haze and noise, and realizes harmless production on construction sites.
2. High quality and high efficiency. The entire printing process is controlled by a computer program, and the construction and construction are directly based on the CAD model creation design. The construction error is much smaller than the traditional manual operation method, and the construction period is shortened by 50–70%.
3. Cost savings. The material itself is highly customized and has good plasticity. There is no need for templates or scaffolding. The products are tailored according to the set requirements. Correspondingly, a large number of labor costs are reduced, which can save building materials by 30–60% and reduce labor by 50–80%, while saving transportation, hoisting, material loss, waste disposal, management and other expenses, part of the "ink" can also be drawn from construction waste on the spot, with obvious economic benefits.

4. Construction safety. A large saving of personnel and labor means that the risk of construction operations is reduced, the risk of injury accidents at the construction site will be greatly reduced, and the cost of safety measures for construction will also be saved.
5. Rugged and durable. 3D printing is an integral structure forming, and the proportion of "ink" materials is lighter than traditional building materials, so the seismic performance of the formed building is enhanced; fewer joints, construction joints, etc., also make the building waterproof performance better; special glass fiber The strength and service life of reinforced concrete materials are theoretically stronger than ordinary reinforced concrete, especially the strength of carbon fiber materials is about 20 times that of steel.
6. Advantages of special operations. In the case of printing complex curved surfaces and other special unconventional components, adapting to harsh environmental operations, complex geological construction conditions, etc., 3D printing has more obvious advantages, especially 3D printing will not increase construction costs due to complexity factors, that is, the more irregular, Personalized products, the lower the cost of printing; in addition, in addition to new projects, 3D printing can comply with the "urban repair and ecological restoration" proposed by the Central City Work Conference, and replace the traditional major demolition and construction with urban repair. In line with the general trend of green development [10]; 3D printing has strong adaptability in the restoration and reinforcement of buildings. For example, it can be used in the protection of ancient buildings and ancient cultural relics to accurately restore the damage of ancient buildings and ancient cultural relics. The missing part is an innovative solution to the protection of ancient buildings and cultural relics; 3D printing "black technology" has also been successfully applied to a dangerous bridge renovation project in Nanjing. The construction period is only 10 days, and its strength has reached twice the traditional cement pouring bridge fence after testing.

5 3D Printing Technology Application Prospects in the Construction Industry

A special survey conducted by McKinsey shows that the construction industry is the most productive industry. Data show that in the last 20 years, the global average value-added growth rate per unit time of the construction industry is only equivalent to 1/4 of the growth rate of the manufacturing industry. Surprisingly, the situation in developed countries seems to be more serious. For example, Germany and Japan have almost stagnated in construction productivity growth. Since 1970, the construction productivity in the United States has dropped by 50%. Survey statistics found that 60% of the project construction will be postponed. On the contrary, China's prefabricated buildings are growing at the fastest rate in the world. Although the development started relatively late, in the past five years, domestic prefabricated buildings have driven labor productivity to develop at a high rate of 7% per year.

Compared with traditional buildings, 3D printed buildings have many advantages. Dubai has even formulated a strategic plan to "make 25% of new buildings using 3D printing technology by 2025", hoping to use 3D printing technology to restructure the economy. And the labor market. With the support of digital technology, 3D printing buildings still have a large number of technical difficulties that need to be broken through [11], and a lot of research is still needed in materials, equipment, structural system design, and related technical standards.

5.1 Printing Materials for Construction

The performance of the printing material directly determines the quality of the printed building. The specific indicators of the slurry are mainly suitable setting time, rheological properties, and ultra-high interlayer adhesion. Future research directions and urgent problems to be solved are shown in: ① Based on the requirements of different working conditions, such as temperature and humidity, printing scale, width-to-thickness ratio of printed fabric, and interval time between printing layers, establish the relationship between the composition of the slurry and the rheological properties of the slurry. ② Research and develop admixtures that can control the properties of the slurry, such as enhancers, setting regulators, etc. ③ Establish material strength evaluation methods for different cross-sectional forms (hollow, solid, and ribbed). ④ Develop 3D printed concrete Recycling technology.

5.2 Printing Equipment for Construction

In-situ printing is the goal pursued by the current 3D printing construction technology. Due to the limitations of the existing printing equipment and printing procedures, the in-situ printing technology still faces many problems, and only the splicing technology can be used to prepare components with complex structures. At present, there are various forms of 3D printing, and the equipment corresponding to different forms is different. For example, on-site printing requires a high degree of automation of equipment, and various forms of prefabricated printing require a combination of multiple equipment to achieve personalized artistic modeling. How to select equipment according to the working conditions of the project, the basis and standards for selection are all problems that need to be solved. Therefore, it is necessary to further strengthen the research and development of large-scale printing equipment and the design of supporting conveying devices. Generally speaking, the flexibility, adaptability and convenience of printing equipment are requirements for future development.

5.3 Printing Structure System

Due to its own characteristics and environmental impact, 3D printing is difficult to configure steel reinforcement with current technology. Therefore, in order to improve the crack resistance and toughness of printing materials, it is necessary to design the structure with less ribs or without ribs according to the characteristics of printing; or to develop a coordinated printing technology of slurry and ribs, and a supporting structural design system.

5.4 Printing Related Technical Standards

The development of 3D printing has just started, and there are few studies on the comprehensive strength, stiffness, fire resistance, and service life of 3D printed buildings, especially construction-related and lack of quality technical standards [12]. At present, in addition to the American ASTM which has technical standards for architectural 3D printing, other printing structural design, material performance, testing and quality acceptance standards are blank, and a lot of experimental research and practice accumulation are needed to formulate relevant technical standards. With the maturity of technology and the establishment of standards, 3D printing technology can move towards marketization.

6 Conclusion and Outlook

In principle, there is no big difference between “printing” a house and printing other objects, except that the raw materials used and the scale of printing are different. The walls, floors, panels, structures and appearances of almost all buildings are unique Everywhere is just a different dimension, which means that house construction will develop along the following three different routes:

(1) Full-size printing, that is, the concrete or mortar required for 3D printing is transported to the construction site in the mixing station as it is currently, and the building is printed layer by layer through a giant 3D printer. The limitation is obvious. The larger the machine. The more difficult it is to manufacture, and more importantly, the larger the machine, the worse the printing accuracy and printing speed will be. Therefore, it is necessary to solve basic problems such as materials, control, and accuracy.
(2) Segmented assembly printing. Different types of modules are quickly produced by large 3D printers and shipped to the site for assembly. This mode solves the size limit of the house, but the on-site assembly work involves labor-intensive problems. In consideration of the construction cost, the assembled building may also have various safety hazards and other problems, so the main problem

is the choice of materials and the lightweight of the structure and the maturity of assembly technology.

(3) Collective printing of group robots, that is, a lot of small group robots are manufactured to print each part separately. This mode not only overcomes the size limitation and the size of the robot is also independent of the size of the building, and the robot is intelligent. The requirements can also be greatly reduced. A self-organizing and self-coordinating group intelligence method is also the current research direction of artificial intelligence, but because its current development is not mature enough, it is only a preliminary expectation.

At present, the application of 3D printing in the construction field is still in its infancy. In order to make the application of 3D printing in the construction field more popular in the future, it can be solved from the following aspects. References.

6.1 Improvement of Material Structure Performance

The 3D printing method breaks through the natural form of the material, and the mechanical properties of its printed components and structures have undergone certain changes compared with traditional methods. Although some universities have conducted certain research on the mechanical properties of 3D printed components, such as the in-situ peeling test of concrete cube members of Loughborough University and the compression and flexural test of cubes of Tsinghua University, they involve the overall structure and local (such as beams and columns, etc.) There are relatively few studies on the mechanical properties of nodes, and further research is needed. On this basis, combined with the construction process for mechanical simulation comparison analysis, a 3D printed structural component model library is established, and then the entire structure system is formed, and the process system is used for application.

6.2 Improvement of Mechanical Equipment and Process

Facing the automatic construction of large components on the construction site, the mechanical equipment for building 3D printing must not only have sufficient dimensions, but also be portable, removable, lightweight and high-strength. At the same time, the driving performance of the 3D printing device and the operating performance of the feeding module need to be further optimized. Typical examples include the spatial accuracy, speed, and stability of the robotic arm movement, as well as the discharge speed, stability, and accuracy of the electronic nozzle. Optimization and transformation of the discharge of various materials. In addition, it is of great significance to improve the existing 3D printing device to realize the whole process construction process including printing, planting ribs, installing pipelines, lifting pumping, surface leveling, maintenance and painting, and prefabrication combination.

6.3 Software and Hardware Coordination and Intelligent Control

Comparing the actual printed component or structure with the theoretical design model often results in large deviations. Therefore, the optimization of the interface between modeling design software and numerical control software in the architectural field, seamless information transmission, and the research on the precise control of hardware devices by numerical control software are necessary. Furthermore, the intelligent construction research is carried out on the basis of automatic construction based on automatic control, artificial intelligence is added to the control system, and the design intent of the model is intelligently recognized. At the same time, sensors are installed in the drive module and the conveying module to adjust the dynamics in the printing process. The information is fed back to the control system in real time, and the control system adjusts the printing speed and accuracy to realize intelligent construction.

6.4 Establish and Improve Relevant Technical Specifications

At present, there are several technical genres at home and abroad, but each technical genre has its own business. In order to mature the application of architectural 3D printing and digital construction technology, it is necessary to study and formulate a complete set of technical standards system. On the basis of full research on the materials, machinery, technology, product performance, structural form, scope of application, resource allocation, cost and energy consumption of each type of building 3D printing technology, combined with BIM-based collaborative work mode and green construction technology evaluation Methods: Research and construct a technical standard system of architectural 3D printing digital construction, so as to form a new production relationship and industry ecology in the construction industry under the architectural 3D printing digital construction mode.

7 Conclusion

It has only been a few decades since the invention of 3D printing technology, and the diversification of printing materials has put 3D printing technology on its wings. If 3D printing changes the world, then 3D printing buildings will change the construction industry. Recently, many innovative companies are eager to try 3D printing buildings. The assembly of printed simple houses and printed components has been realized, but it will take some time to print a truly functional building. In addition, the safety and durability of the printed building have yet to be verified.

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Land Use Type Priority Oriented Layers Automated Clipping in GIS System

Chunting Wu, Yuzhe Wu, and Zhenhong Du

Abstract Along with the increasing information and intellectualized management requirements of land and resources, operations for assigning new attribute values to fields while clipping layers are more frequent in actual business. It is a practical problem that how to deal with the sliver polygon with high efficiency, high quality and sustainability. In this paper, based on the current research on the fusion processing method of sliver polygons, combined with the characteristics of land use data and related constraints, from the point of view of the geographical configuration priority and spatial similarity, design a set of clipping processes about land use layers based on geographical configuration prioritization and spatial similarity. While ensuring the high precision and high quality of the layer clipping, the land configuration priority is incorporated into the spot fusion constraint conditions. Finally, an improved automated clipping method that takes into account the preferential allocation of land types is applied to land use layers. The experiment verifies the practical feasibility and effectiveness of the method.

Keywords Land use type · Automatic clip · Silver polygon · Spatial similarity · GIS

1 Introduction

With the rapid development of modern geographical information technology, the requirements of informationization and intelligent management of land and resources are constantly improved. In practical business processing, it is more frequent to clip and assign new attribute values between layers. In the actual process of clipping the land use layer and the range layer, if the clipping is carried out strictly in accordance with the boundary of the range layer, as the two layers are not fully assembled, it is easy to have a large number of long and narrow or excessively small silver polygon, and silver polygon is composed of multiple parts (see Fig. 1d). Different application

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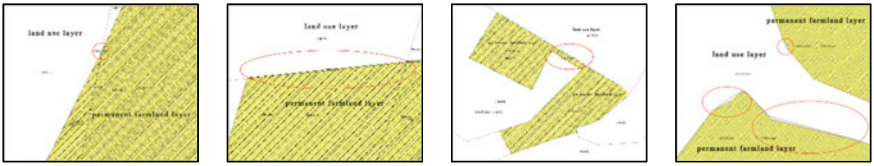


(a) point polygon **(b) narrow polygon** **(c) planar polygon** **(d) multiple-polygon**

Fig. 1 Four categories of silver polygon

scenarios may have the different priority of land use. If using ARCGIS, it's difficult to do the batch operation base on land use type priority oriented in the procession of filter and fusion silver polygon that caused by layers clipped. If we need according to the priority configuration, need artificial judgment and edit each silver polygon, there is a big workload, cumbersome, error-prone, and so on.

Therefore, it is a practical problem to eliminate silver polygon in efficiently, high quality and sustainably way. With the development of computer image research, the research on polygon fusion is developing continuously. As for the shape description of surface elements, use the compactness of surface elements to describe planar elements (Wentz, 1997) [2]. Planar element delicacy is used to calculate shape similarity (Zheng, 2013) [3]. In order to judge the small polygon, the compact degree of planar elements is used (Fang, 2016) [4].

Spatial similarity refers to the similarity of two geographical entities in spatial location, shape, size and other morphological features. Common measures of spatial similarity include orientation similarity, position similarity and so on. Based on the similarity of spatial entity features (position, shape and size), used weighted average method to determine the matching similarity of entities with the same name (Hao, 2008) [5]. A polygon matching method based on neighborhood similarity in view of the situation that spatial similarity is rarely considered in the matching process of planar elements, and improved the matching speed and accuracy through geometric similarity matrix method (Jiao, 2013) [6]. Based on the existing entity matching method with the same name and considering the relationship between force and planar resident land, proposed a planar resident land matching algorithm using force diagram projection (Ji, 2013) [7]. In spatial entity matching, topological relation is also a major index. The topological relation metric is used to carry out rough matching of spatial objects firstly, and then calculates spatial similarity index to carry out quadratic matching (Fang, 2016) [4].

The grow-and-shrink algorithm for polygon fusion processing based on raster data (SchyIberg, 1992) [8], and the buffer was also used for polygon fusion for separated polygons (Bader, 1997) [9]. The polygon fusion algorithm for raster and vector data has been continuously developed. With the proposal and development of Delaunay triangle network, a SDS Data Structure model on the basis of Delaunay triangle network, which can solve the problem of fusion processing of unconnected polygons(Ware and Jones, 1995) [10]. The polygonal space division of Delaunay triangular mesh with boundary constraints was firstly used. Later, in view of land use data synthesis, he proposed the idea of integrating spatial similarity and semantic similarity into the basic rules for the integration with the closest class (Ai, 2000) [11]. Based on this widely accepted idea, a comprehensive method of land use data that takes into account spatial and semantic proximity (Liu et al., 2009) [12]. The two indexes of graph compactance and area change rate of each type before and after fusion, and used ant colony algorithm proposed by M. Origo et al. to obtain better polygon fusion results (Yang, 2016) [13]. In view of the processing of silver polygon focused on in this paper, an automatic fusion processing research on the silver polygon appearing in the automatic updating of land use data based on topological relationship and spatial similarity (Fang, 2016) [1]. The polygon fusion process based on the neighborhood relationship analysis model and skeleton line optimization algorithm, and proposed the boundary repair method using the partitioning model to ensure the consistency and topological integrity of the fused data space(Yu, 2017) [14].

Based on the existing research on small polygon fusion method, we take the characteristics of land use data, related national standard and constraint conditions in think. We design a automatic clipping algorithm based on the land use types priority and spatial oriented. Finally, the experiment verifies the practical feasibility and effectiveness of this method using the land use status data.

2 Related Knowledge

2.1 Definition and Cause Analysis of Silver Polygon

2.1.1 Definition and Characteristics

Silver polygon refers to the polygon whose area is less than a certain threshold or whose shape is too narrow. In this article generally appeared in the land use and range layer on the clipping edge, as shown in Fig. 1. Silver polygon can be roughly divided into four categories: point polygon, narrow polygon, planar polygon and multiple-polygon. It has the characteristics of numerous, small, long and narrow, and have no practical significance.

2.1.2 Cause Analysis

In the process of fieldwork measurement and indoor operation, it has measuring error, manual operation error, the external environment factor error and the system error that caused by measuring apparatus and coordinate correction of GPS. It makes that the entity with the same name in different data sources has the phenomenon of incomplete overlap in spatial position. This results in the appearance of silver polygon when clipping. Since silver polygon is not of practical significance, it needs to be timely processed in the actual business operation, and the silver polygon should be fused to make the clipping result more in line with the actual situation.

2.1.3 Determination Method

The planar element shape index choose the compact degree and the element area as a judgment index, through the establishment of area threshold value S_{Tol}, establish silver polygon measurement index, calculation formula as shown in (1).

$$M = \begin{cases} \frac{S_P}{L_P} & S_P \geq S_{Tol} \\ 0 & S_P \leq S_{Tol} \end{cases} \tag{1}$$

In Formula (1), S_P is the area of undetermined polygon P, L_P is the perimeter, and S_{Tol} is the silver polygon area threshold. When the area of polygon P is less than or equal to threshold S_{Tol}, it is determined that polygon P is a silver polygon. If the area of polygon P is greater than threshold value, then according to the polygon compact-ness size for the corresponding judgment, when the polygon P compact-ness is less than or equal to the compact-ness judgment threshold M_{Tol}, then judge the polygon P for the silver polygon [1].

2.2 Calculation of Polygon Match-Degree Based on Spatial Similarity

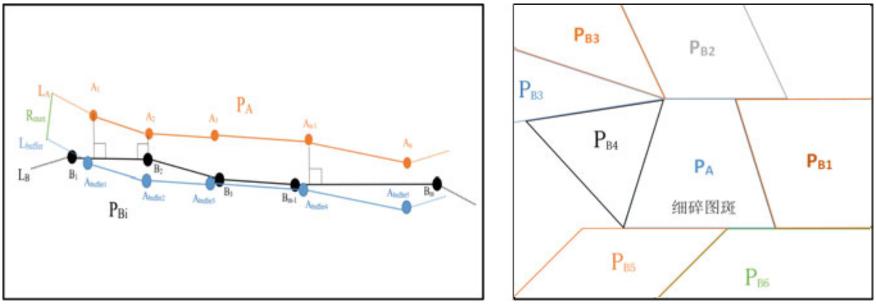
Based on the similarity of position and length, we calculates the candidate set of fused polygon with high spatial match-degree between silver polygon and the surrounding target polygon.

2.2.1 Calculation of Position Similarity

Polygon A(P_A) is assumed to be the silver polygon to be fused, and Polygon Bi(P_{Bi},1 $\leq$ i $\leq$ n) is a polygon in the set of the surrounding target polygon to be matched. The position similarity between P_A and P_B is calculated through the position similarity evaluation function of surface elements, as shown in formula (2).

$$P_{(A,B_i)} = \begin{cases} 1 & P_A \text{与} P_{Bi} \text{ intersect} \\ 0 & P_A \text{与} P_{Bi}\ non-intersect \end{cases} \quad (1 \leq i \leq n) \tag{2}$$

When P_A and P_{Bi} intersect, that is, P(A, Bi) = 1, representing that P_A and P_{Bi} are very similar in spatial positions, then the polygon P_{Bi} will be included Candidate



(a) (b)

Fig. 2 **a** Adjacent boundary(LA, LB, Lbuffer) and **b** silver polygon PA and preliminary fusion candidate polygon set S1

polygon set S1. When P(A, Bi) = 0, a buffer is established for P_A with Rmax as the buffer radius, and intersection detection is carried out. If the intersection is, adjacent boundary of P_A is obtained according to the intersection region. L_A, L_B, L_{buffer} are assumed to be the adjacent boundary of P_A and P_{Bi}, buffer boundary, as shown in Fig. 2a.

As shown in Fig. 2a, L_A and L_{buffer} intersect, so we use formula (3) to calculate the Euclidean distance of the adjacent boundary.

$$\begin{cases} D = \frac{\left|\mathrm{k}x_0 - \mathrm{y}_0 0 + \mathrm{b}\right|}{\sqrt{k^2+b^2}} \\ k = (y2 - y1)/(x2 - x1) \\ b = y_1 - kx_1 \end{cases} \tag{3}$$

The Euclidian distance D from point A_i $(1 \le i \le n)$ to the straight line can be calculated by formula (3–2), where the coordinate values of point A_i are expressed as (x_{Ai}, y_{Ai}), and the coordinate values of the two endpoints of the line segment on $L_{Bi}$$(1 \le i \le m)$ are respectively expressed as (x_{Bi}, y_{Bi}) and (x_{Bi+1}, y_{Bi+1}). Then calculating the distance Di $(1 \le i \le n)$ of all the point A_i $(1 \le i \le n)$ to the adjacent line L_B. When the average value of distance Di $(1 \le i \le n)$ is less than the distance judgment threshold L_{Tol}, the polygon P_{Bi} will be included Candidate polygon set S1.Therefore, through the above complete position similarity determination, get the preliminary fusion Candidate polygon set S1 = { $P_{B1,}$ $P_{B2,\ldots}P_{Bm}$}, as shown in Fig. 2b.

2.2.2 Calculation of Length Similarity

The length similarity of the common edge is an important index for the matching of the longest common edge. According to the calculation formula of Length similarity, as shown in formula (4), getting the Length similarity Length(L_i) $(1 \le i \le m)$ of common edges that between silver polygon and Candidate polygon from Set S1.

$$Length(l_i) = 1 - \frac{\mathrm{len}(l_i)}{\mathrm{Max}(\mathrm{len}(l_1), \mathrm{len}(l_2) \ldots \mathrm{len}(l_n))} \quad (1 \le i \le m) \tag{4}$$

Sorted by the result of Length(L_i) ($1 \le i \le m$), the polygon in top three of high Length similarity will be included Candidate polygon set S2. It is assumed that the common boundary entering the candidate set from long to short is L_1, L_2 and L_3 respectively. In order to ensure that the gap of polygon spatial similarity in final candidate polygon set is within a reasonable range, a filtering model is adopted, as shown in formula (5).

$$Pl_i = \frac{length(L_i) - length(L_{i+1})}{length(L_i)} - \varepsilon \ (1 \le i \le 3) \tag{5}$$

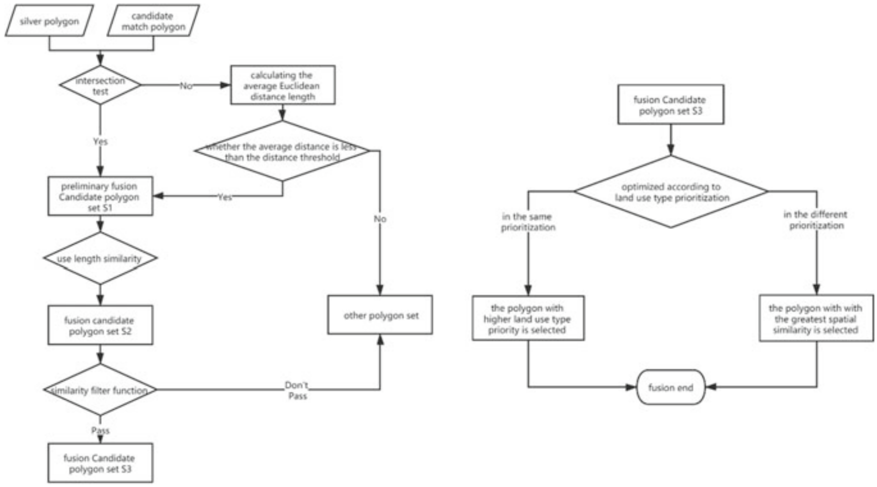
By setting the filtering threshold ε in the formula, the candidate polygon with a large difference in the common edge length were removed from the candidate polygon set. When Pl_i is greater than 0, it means that the length difference between L_i and L_{i+1} is in an acceptable range, so polygon P_{i+1} can be retained.

As shown in Fig. 2b, the preliminary candidate polygon set S1{P_{B1}, P_{B2},...P_{B6}}, sorting based on the common edge length, the polygon P_{B1}, P_{B4}, P_{B5} enter the candidate polygon set S2 {P_{B1},P_{B4},P_{B5}}. Calculating by using the filter model, removing the polygon P_{B5} the large difference of boundary length. Then determining the final fusion candidate set S3 {P_{B1},P_{B4}}, It provides the guarantee of spatial similarity for the following matching calculation based on land use type priority oriented.

2.2.3 Process Framework of Spatial Similarity Polygon Match-Degree Calculation

The characteristic of the land use data is complete coverage. First, based on the grouping by the spatial distribution and characteristics of clipping result attribute values, using intersection test between the silver polygon and candidate match polygon in the same group. If test result is intersect, then the candidate match polygon will be included in the preliminary fusion Candidate polygon set S1. If not, in order to prevent some polygon which there is a high spatial similarity but not the intersection in actual situation, by setting a buffer with Rmax as the buffer radius, then doing the intersection test between buffer and candidate match polygon. If it exists the intersection, calculating the average Euclidean distance length between adjacent boundaries (see Sect. 2.2.1 for detailed schematic diagram and calculation formula). If the average distance is less than the distance threshold L_{tol}, it will also be included in the preliminary fusion Candidate polygon set S1.

For the polygon in the set S1, by calculating the length similarity between each candidate match polygon and the silver polygon (see 2.2.2 for specific calculation method), the first three are selected from the largest to the smallest to be determined as the fusion candidate polygon set S2. In order to ensure that the spatial similarity between the common edges of the fusion candidate set is not too large, the filter



(a) (b)

Fig. 3 **a** Process framework of polygon match-degree calculation based on spatial similarity and **b** process framework of considering the land use type prioritization in fusion selection

function (see Sect. 2.2.2 for specific definition) is used to eliminate the candidate polygon with low spatial similarity and obtain the fusion Candidate polygon set S3.

The specific process framework is shown in Fig. 3a.

2.3 Calculation of Polygon Match-Degree on Land Use Type Configuration Priority

The land use data records the land use attributes of each land parcel. For the polygon entering the fusion Candidate polygon set S3, according to different actual business scenarios and different land use types have different priorities, based on the spatial similarity of the silver polygon and candidate match polygon, the polygon fusion is optimized according to land use type priority oriented.

When the candidate match polygon are at the same priority, the polygon with the greatest spatial similarity is selected for fusion operation. When the candidate match polygon is at different priority, the polygon with higher land use type priority is selected for fusion operation.

The specific process framework is shown in Fig. 3b.

3 Implementation and Test

3.1 Overall Framework

Based on the actual business requirements, the basic process of automatic clipping considering the land use type priority oriented is as follows:

(1) Preprocessing stage: make the conflict check between the range layer and administrative area layer, check whether there is a conflict with the administrative area. If it exists the problems, interrupt follow-up operations, return error area, inform the staff to modify mistake. Until administrative area conflict detection through, it can enter the following clipping step. According to different business application scenarios, the priority of the land use type is determined manually. (2) Clip the land use layer and the range layer in strict accordance with the scope of the range layer. Grouping the result layer according to the data attribute values and spatial distribution. It's aim to improve the efficiency of searching and matching polygon. (3) Determine silver polygon by using the determination method. Then the silver polygon will be added into a set, and other polygon will be divided into candidate match polygon set S. (4) Determine whether each silver polygon is composed of multiple parts. If so, split the image spot into a single polygon and represent it in the form of independent elements. (5) Traverse each group of silver polygon set, calculate the position similarity of each silver polygon and candidate match polygon in set S, and determine the preliminary fusion candidate polygon set S1. (6) Calculate the length similarity of the silver polygon and the polygon in the candidate set S1. And determine the candidate match polygon with the top three length similarity from large to small as the fusion candidate polygon set S2. (7) To sort the three candidate match polygon in S2, a filter function is used to determine the final candidate match polygon in set S3 under the condition that the spatial similarity between silver polygon and candidate match polygon is relatively small. (8) Based on the fusion candidate polygon set S3, the final fusion polygon is determined according to land use type prioritization. (9) After the fusion of silver polygon is completed, the administrative area layer is used to detect the conflicts on the clip result layer. If there is any conflict, the conflict polygon will be processed. (10) Update the area information of the clip result layer through conflict detection, and perform area adjustment operation. (11) Add the topic mark information of the range layer, merge the clip result layer with the land use layer after erasing the topic range layer, as shown in Fig. 4a, and finally return the land use layer after the clip operation.

The complete process is shown in Fig. 4b.

3.2 Example of System Operation

As shown in Fig. 5a, use the part of the permanent farmland layer and the all land use layer in one district. Because the two layer are not completely overlap, the house-site

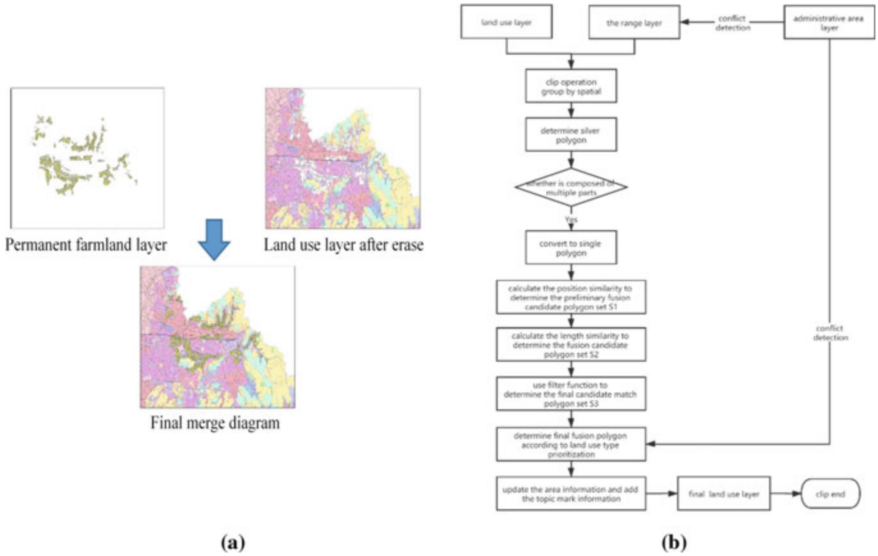


Fig. 4 **a** Schematic diagram of merged clipped range layer and erased land use layer and **b** process of considering the land use type prioritization automatic clipping

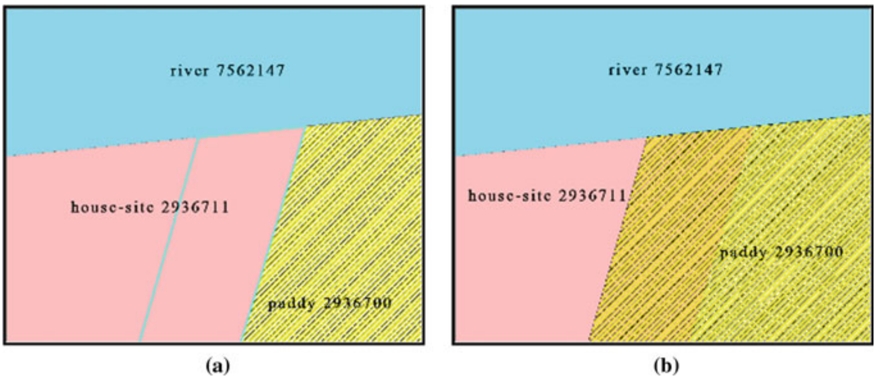


Fig. 5 **a** The range layer and the land use layer are not complete overlap during clipping and **b** results after polygon fusion

polygon(Id 2,936,711) and paddy polygon(Id 2,936,700) intersect, the intermediate blue box is the overlap polygon. In the experiment the silver polygon determining threshold Stol is 5 square metre, the area of the compact degree of threshold Mc is 5%, the filter function threshold is 0.9. By calculating the polygon compactness was 4.17%, the value is less than the compact degree of threshold Mc (5%). Therefore, the polygon is judged to be a silver polygon, and it needs to be processed by polygon fusion.

According to the automatic clipping process, first determine whether the silver polygon is composed of multiple parts, the determination result is a single polygon, and then calculate the spatial similarity with the non-silver polygon in the same group, and determine the candidate polygon set according to the position similarity and length similarity.

According to the analysis, the house-site polygon(Id 2,936,711) and paddy polygon(Id 2,936,700) is high spatial similarity. Based on the land use type priority oriented and the judgement of the range layer restriction, the paddy with relatively high land use type prioritization have been finalized for fusion polygon, the final fusion results are shown in Fig. 5b.

3.3 Experimental Design and Comparison Results

The principle of traditional land use polygon clip and this polygon automatic clipping process is similar. The silver polygon in the clip result needs to make the fusion strategy determine and implement the corresponding batch fusion operations, including silver polygon judgement, polygon fusion on the basic of spatial similarity, mark layer information, merged layer, finally get a land use layer with range layer tag information.

If need to be on the basis of land use type during fusion, it is necessary to determine and make specific fusion operation for each silver polygon. And due to human judgment errors or operation errors make the result may be not correct, it will be need back to the initial state to clipping and subsequent data fusion processing operations. And the Layers automated clipping process consider the land use type priority oriented in this paper, only need to set initial land use type priority, silver polygon area threshold, compact degree, then after submitting the land use layer and the range layer, the clipping operation will be operated automatic, final get the land use layer with range layer tag information after fusion the silver polygon.

3.3.1 Experimental Methods

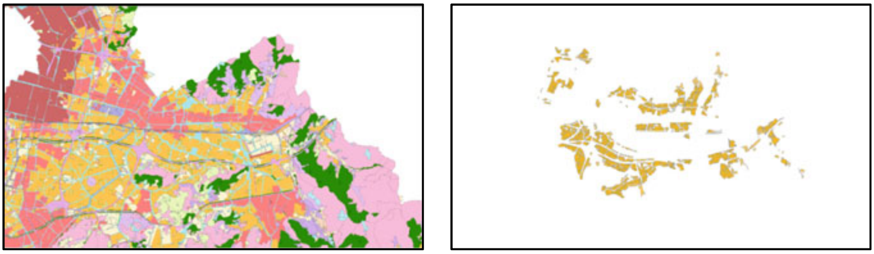
In the experiment, the paper selected range layers with different number of spots, respectively used the traditional manual clipping operation and the subsequent silver polygon fusing method and the automatic clipping method proposed in this paper to clip the current situation of land use layer and range layer, and compared the efficiency and quality of clipping accordingly.

3.3.2 Analysis of Experimental Data

The experiment take the clip of land use layer and a certain area of range layer in one district in Zhejiang province for example. The experimental data for the land use layer as shown in Fig. 6a and the area of the project scope layer (permanent farmland layer) as shown in Fig. 6b, the land use layer feature polygon number distribution as shown in Table 1.

From Table 1, it can be clearly seen that the number of polygon is large and land use types are rich in this land use layer. For the range layers with different number of polygon, the number of silver polygon produced by preliminary clipping is shown in Table 2

As can be seen from Table 2, the number of silver polygon and polygon of range area layers (permanent farmland layer was used in this experiment) are positively



(a) land use layer **(b) range layer**

Fig. 6 Experimental data

Table 1 Number of land use polygon in different type

Land use type	Count	Land use type	Count	Land use type	Count	Land use type	Count
Mining lease	455	Municipal town	3815	Shrubland	28	Other garden	244
Tea garden	1540	Pond	1018	Orchard	1256	Facility agricultural land	265
Urban residential land	3002	Bare land	101	Dryland	3973	Land for hydraulic construction	406
Rural homestead	8760	Inland mud flat	53	River	3539	Paddy field	32,659
Land for scenic facilities	584	Country road	196	Lake	6	Railway land	461
Land for harbour and wharf	9	Other grass	386	Airport	25	Coastal mud flat	20
Highway land	2460	Other forest	2374	Total		70,465	

Table 2 Number of silver polygon after clipping with different number of range layer polygon

Number of permanent farmland polygon count	Number of silver polygon after clipping
100	526
200	1106
300	1618
400	2353
500	3058
600	3645

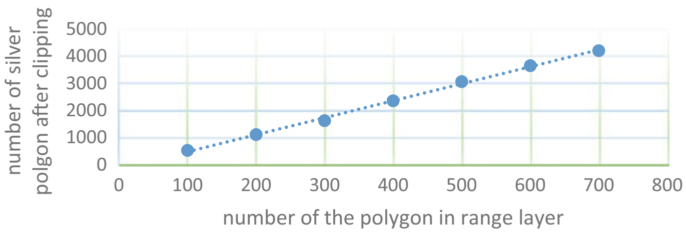


Fig. 7 Number of silver polygon after clipping on range layer with different number of polygon

correlated, and the number of silver polygon is much higher than the number of original polygon, as shown in Fig. 7.

For the a large number of the preliminary clipping results that need to be fusion, if it is necessary to manually determine each polygon and select fusion strategy, the workload will be large. By the end of 2015, the number of county-level divisions in China was 2,850. Therefore, the land use data in China reached an order of magnitude in the hundreds of millions, and the silver polygon will also reach an order of magnitude in the hundreds of millions after clipping operation. If the actual processing scope is expanded to the whole country, in the case of 100 million land use layer data, the number of silver polygon will be very large, so the selection of appropriate constraints to effectively take into account the priority of the automatic clipping will save a lot of human resources and costs.

The thematic range layer (permanent field layer) is made up of 84 dryland polygons and 707 paddy polygons, so the first class of 01, cultivated land, has a higher priority. In this automatic clipping method, in different practical business application scenarios, the priority of land use type fusion can be set according to the actual business requirements, so as to meet the requirements of customized fusion priority in different scenarios.

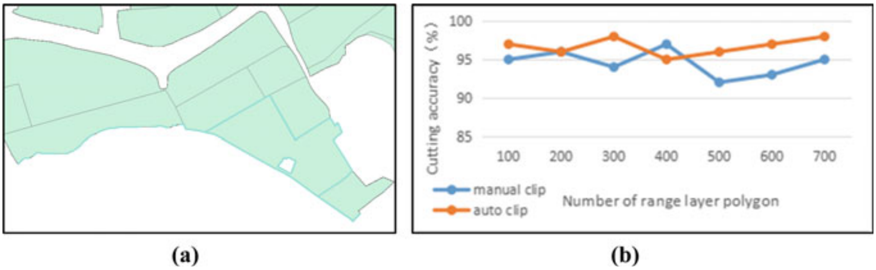


Fig. 8 **a** Abnormal phenomenon of traditional ArcGIS clipping and fusion and **b** quality comparison of automatic and manual clipping results

3.3.3 Comparison of Experimental Results

In the experiments, if you want to take care of each polygon attributes, is in the actual process of artificial processing need to actual judgment of each polygon, so the process again and again, time is longer, and this depends largely on practical operator experience and quality, so in clipping processing time is not comparable.

Traditionally, ARCGIS is used for layer clipping, screen the silver polygon, use fusion tool for batch processing to get the results, as shown in Fig. 8a. The fusion result is composed of multi-part polygons, so it is necessary to handle the fusion abnormal result separately.

From Fig. 8a, we can clearly see that the clipping results shown in the figure are not of practical significance. Therefore, it is necessary to deal with such abnormal silver polygon separately, thus reducing the efficiency of polygon clipping.

Based on many times of trial and error, the automatic clipping method proposed in this paper is compared with the traditional clipping and subsequent polygon processing. The comparison of accuracy between the two is shown in Fig. 8b.

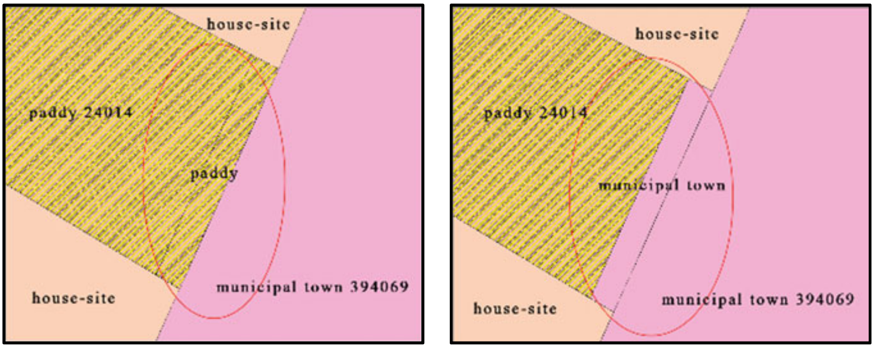
It can be seen from the comparison of the result quality between automatic clipping and manual clipping in Fig. 11 that automatic clipping improves the quality of clipping and following polygon processing. As most of the silver polygon are normal, there is a small difference in the accuracy of manual clipping, following processing and automatic clipping. However, we can see that the gap between the two is widened with the increase of the number of polygon on the range layer. In addition to the difference in accuracy of the two results, the consistency of the treatment results is basically the same, but there are some cases with different treatment results, as shown in Table 3.

The main difference between the two processing methods is the processing of the priority of land use type. Therefore, a special local case is selected to make a comparative analysis of the manual processing and the automatic processing of the priority configuration of land use type, as shown in Fig. 9.

Through the Fig. 9 shows, the different results because of the narrow silver polygon between the paddy polygon(id 24,014) and the municipal town polygon(id 394,069).

Table 3 Consistency between manual and automatic clipping of range layer with different number polygons

Number of permanent farmland polygon count	Number of the same result	Number of the different result
100	511	15
200	1084	22
300	1588	30
400	2321	32
500	3018	40
600	3598	47



(a) Automatic clipping **(b) ArcGIS clipping**

Fig. 9 Comparison of local result of automatic clipping and ArcGIS clipping

For both sides spatial similarity is close, the public edge of the polygon(id 394,069) on the right-hand side is longer, but the land use type is different. Suppose in our application scenario, paddy fields have a higher priority than the municipal town. When the spatial similarity calculation conforms to the filter function setting, the silver polygon will be automatically fused to the paddy field with higher priority of land use on the left.

However, in the process by using ARCGIS fusion tool, the spatial similarity is more taken into account than the priority of land use type. In this case, the candidate polygon with longer public edge is selected, such as that shown in Fig. 9.

4 Conclusion

Clipping the land use layer and Thematic range layer is very common business operations, because the land use layer and range layer does not compete overlap, therefore in the process of clipping will appear a lot of silver polygon, handle a large number of silver polygon is a time-consuming work. And ARCGIS provides operations that do not involve land use type priority oriented, if you need to edit the manual there is a big workload, so sometimes it's difficult to meet the needs of the existing in the scene work. It has become an urgent problem to study the automatic clipping method which takes into account the land use type priority oriented, automatically deal with the problem of a large number of silver polygon in the process of clipping, and to improve the quality of clipping result. Therefore, based on the characteristics of land use layer and thematic range layer as well as clipping requirements, an automatic clipping method based on spatial similarity and taking into account the land use type priority oriented is proposed.

This method is mainly to make up for shortage that clipping layers process doesn't take land use type priority oriented and related constraints such as the lack of administrative boundaries into account. And implementation of spatial similarity and land use type priority to the polygon fusion, it is obtained without silver polygon of the final results.

In this paper, different land use type have different priorities due to their different importance. In traditional clipping and following processing, ARCGIS Desktop conducts batch processing according to the priority of land use type.

In this paper, the automatic clipping method which takes into account the priority of land use type is proposed, which takes into account the priority of different classes configuration on the premise of ensuring the spatial similarity, and reach the automatic clipping that keeps the accuracy of the polygon area and strictly conforms to the boundary requirements of the range layer.

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Family Migration Decisions of Floating Population and Its Influencing Factors—A Case of Wuhan Metropolitan Area, China

Yanan Li, Jiaxin Meng, Chan Xiong, Zhe Zhu, Shiman Wu, and Shanhai Wang

Abstract Familization of migration is a significant feature and development trend of floating population in current China. Achieving the stable and high-quality family migration of the floating population is an integral part of the development of people-oriented and sharing-type urbanization. In this paper, the dynamic monitoring data of floating population in Hubei province from 2013 to 2015 was used to analyze the family migration decisions of floating population, and MLogit model was used to investigate the influencing factors of different migration patterns. The results show that the family size of floating population in Hubei province tends to be smaller and more stable; the factors such as family size, number of children and urban characteristic have significant influence on the migration pattern of floating population. On the basis of this, the paper suggests that the government should strengthen the active guidance to the group that has advantages in family migration, alleviate the pressure of left-behind members' family-care of the semi-family migration families, and promote the stable employment and social integration of the accompanying migrants.

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Keywords Floating population · Familization of migration · Influencing factors · Wuhan metropolitan area

1 Introduction

As an advanced form of population migration, family-based migration has a positive facilitating effect on achieving population' settling down, urban integration and sharing the fruits of urban development. According to the *China Migration Development Report 2018*, the size of China's migrant population has entered an adjustment period, and familization migration has become an important form of migration for China's migrant population. To grasp the "stabilization" and "familization" characteristics of the migrant population, especially to analyze the mobility decisions and migration preferences of the "family-oriented migration" floating population,[1] is of great significance for the government to promote the new type of "people-oriented" urbanization process by making the best use of advantages and focusing on the target.

This paper uses data from the 2013–2015 Migrant Dynamic Survey in Wuhan metropolitan area to study their familization migration status and the influencing factors of their behavioral decisions. On the one hand, it echoes the general trend that "urban areas are increasingly attractive to the migrant population" and "urban agglomerations are the main gathering places for the migrant population in the future"; on the other hand, it provides a new research space and perspective for the study of Wuhan metropolitan area, which is an extension and supplement to the extensive national and city-level research results.

2 Literature Review

Research on family-based migration of floating population began with the determination of familization characteristics. Gu et al. [1], Zhu [2], Yu [3], Zhou [4], Duan et al. [5] summarized the trend of family-based migration of the floating population at the national level, and studies at the regional level also confirmed that the floating population has a clear familization trend (e.g., Zhai Zhenwu et al. 2007; Hou Jiawei, 2009; Song, Jingjing, 2017) [6–8].

In recent years, scholars have focused on the influencing factors of familization migration and the social effects generated by family-based mobility. Scholars such as Wang Wengang et al. [9], Hu and Zhao [10], and Ma [11] have studied the familization migration of different groups at different regional scales, and concluded that individual factors, family factors, and social factors all have an impact on their family-based migration. In terms of social effects of familization migration, scholars have

[1] According to the *China Migrant Population Development Report 2017*, the average household size of the migrant population remains above 2.5, with 81.8% of households with two or more members.

Table 1 Sample points of dynamic monitoring data of Wuhan metropolitan area in 2013–2015

Year	Cities								
	Wuhan	Huangshi	Ezhou	Huanggang	Xiaogan	Xianning	Xiantao	Qianjiang	Tianmen
2013	*	*	*	*	*	*		*	
2014	*	*		*	*	*	*		*
2015	*	*	*	*	*	*	*	*	

examined its effects on women's employment, consumption level, happiness, rural–urban migrants' pension insurance participation, and intergenerational mobility (Ma et al. 2017; Chen and Zhang 2017; Yang 2016; Song and He 2019) [12–16].

While the migration of floating population is an individual or family decision making behavior that is supposed to highlight individual characteristics and several social structural features, such as gender, age, education level, income level, family size, number of children, and urban institutional arrangements, it is clear that family-based migration may also be constrained by regional factors in the inflow city. Although some scholars have included regional differences in the analysis framework (Wang et al. 2017; Zhao and Zhu 2019) [9, 17], the existing results still lack attention to the "city-region" system of the city circle. In view of the main position of the city circle construction in the promotion of new urbanization, this paper will take the Wuhan metropolitan area as the research space to carry out a study on the characteristics and influencing factors of familization migration of floating population.

3 Familization Migration of Floating Population in Wuhan Metropolitan Area

The data used in this paper come from Part A of the questionnaire in Hubei Province in 2013, 2014 and 2015 in the national survey on dynamic monitoring of the migrant population organized by the National Health and Family Planning Commission of the People's Republic of China, which covers basic demographic characteristics, mobility status, employment status, social security and health care of the floating population. The sample points of the questionnaire basically cover the "1 + 8" urban circle of Wuhan, as shown in Table 1. The respondents were male and female floating population aged 15–59 years old who had stayed for one month or more in inflow and were not registered in the district they lived in (county or city)[2]. The total sample size was 5999 households (2013), 5998 households (2014) and 6000 households (2015) respectively.

[2] The age limit of the respondents in 2013 and 2014 was 15 to 59 years old, while the age limit of the respondents in 2015 was 15 years old and above.

3.1 Smaller and More Stable Family Size of Floating Population

The average family scale[3] of the floating population in Hubei Province is 2 to 3 persons, and the proportion of family scale in 2 persons/household and 3 persons/household is more than half (66% in 2013; 65% in 2014; 66% in 2015). In line with the findings of nationwide studies.[4] Similarly, the floating population in Hubei Province has entered a stage mainly characterized by family-based migration, and the proportional structure of various migration states is basically stable.

3.2 Familization Migration Patterns in Relation to the Extent of Mobility, Household Attributes, and Number of Children

In this paper, the analysis of the familization migration pattern is based on the definition of the core family in the existing studies, and "childless couple" and "couple and unmarried children" are taken as the core family. In order to better examine the relationship between migration decisions and various factors, especially family factors, the unmarried are excluded from further analysis in order to better analyze the influencing mechanism of migration decisions of the married.

Drawing on existing studies, this paper classifies the migration status of the floating population into three categories according to the degree of completeness of core family members: the first category, non-family-based migration, in which only one person lives in the inflow without any other core family members; the second category, semi-family-based migration, in which only some core family members live together in the inflow with the absence of some core family members; and the third category, complete family-based migration, in which core family members live in the inflow in a complete form without the absence of any core family members.

Figure 1 depicts the quantitative distribution of the married migrant population' patterns of family-based migration with the migration range, in which the highest proportion of fully family-based migration is achieved by the migrant population whose migration range is within the city and across counties, which gradually decreases as the migration range increases; however, the proportion of semi-family-based migration gradually increases. This indicates that, under the same circumstances, the migrant population who migrate nearby is more likely to achieve complete family-based migration.

The data in Table 2 characterizes the relationship between household characteristic of the floating population and familization migration pattern. Although the number

[3] The family scale here refers to the number of family members living with the migrant population in the inflow area.

[4] Yang and Deng [18].

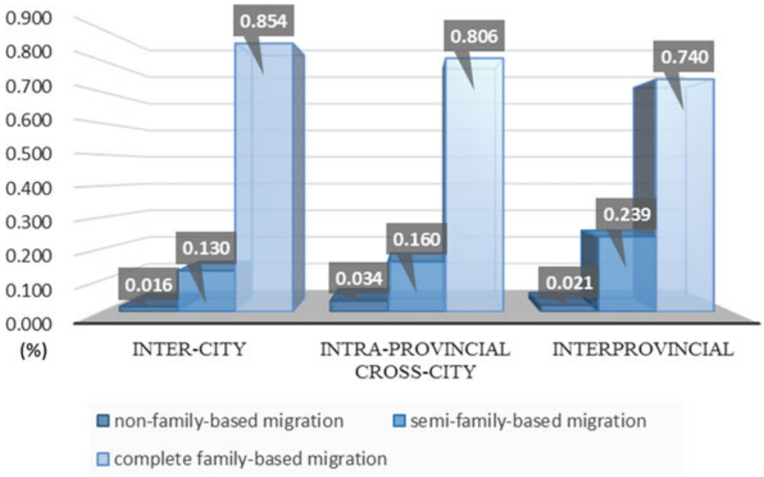

Fig. 1 Distribution of familization migration patterns with different migration range

of households with agricultural household registration accounts for 87% of the total sample size (total sample size is 5341) among the married migrant population in Hubei Province, the distribution of migration patterns is extremely similar. It shows that the household registration characteristic did not become an important factor influencing family-based migration pattern, which means that at this stage, household registration status did not become a facilitating or hindering force in the family-based migration decisions of the migrant population in Hubei Province.

Figure 2 depicts the distribution of family-based migration patterns for mobile families with different numbers of children. In terms of proportions, the more the number of children, the lower the proportion of complete-family migration, but the proportion of semi-family migration increases accordingly. This data indicates that families with fewer children are more likely to achieve complete-family migration than those with more children. The analysis of "time effect" and "economic burden" has been carried out to explain the mechanism of migration pattern choice of married migrant population with different number of children and different age of children.[5]

[5] Zhao and Zhu [19].

Table 2 Distribution of familization migration patterns with different household registration

Household registration (*Hukou*) attributes	Non-family-based migration		Semi-family-based migration		Complete-family-based migration		Sample size
	Frequency	Percentage (%)	Frequency	Percentage(%)	Frequency	Percentage(%)	
Agriculture *Hukou*	96	0.021	796	0.172	3740	0.807	4632
Non-agriculture *Hukou*	30	0.042	103	0.145	576	0.812	709

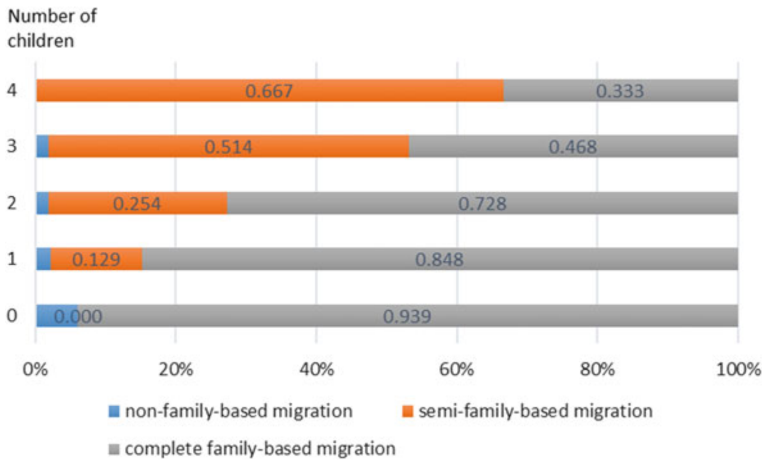

Fig. 2 Distribution of familization migration patterns with different number of children

4 Influencing Factors of Family-Based Migration of Floating Population in Wuhan Metropolitan Area

4.1 Model Setup

This paper adopts the dynamic monitoring data of the migrant population in Hubei Province in 2015 and apply the Mlogit model to estimate the influencing factors of familization migration of the floating population in Wuhan metropolitan area. The analysis of family-based migration of the floating population in the previous chapters uses the married group of total sample in Hubei province. In view of the scope of the "Wuhan metropolitan area" study, the sample of non-Wuhan urban circle cities is firstly excluded[6] to carry out estimation. Then the sample set of other cities will be kept for estimation, and the results will be compared between the two groups of data.

The explanatory variable Y is the pattern of family-based migration, and in accordance with the previous section, the three migration patterns of the floating population are represented by M_0, M_1 and M_2, respectively. M_0 denotes non-family migration, M_1 denotes semi-family migration, and M_2 denotes complete-family migration, where M_2 complete-family migration is the control group.

$$
\begin{aligned}
M_0^* &= f_0(X) + \varepsilon_0 = \alpha_0 + \alpha_1 X_i + \varepsilon_0 \\
M_1^* &= f_1(X) + \varepsilon_1 = \beta_0 + \beta_1 X_i + \varepsilon_1 \\
M_2^* &= f_2(X) + \varepsilon_2 = \varepsilon_2
\end{aligned}
$$

[6] All cities in the Wuhan "1 + 8" urban circle are covered in the 2015 migrant population data except Tianmen city.

where, X_i represents the explanatory variables of the ith sample, including personal characteristics, mobility characteristics, family characteristics, employment characteristics, and city characteristics of the floating population. Table 3 shows the descriptive statistics of explanatory variables for the two groups of samples. Sample 1 is the data of Wuhan metropolitan area "1 + 7" (except Tianmen City) with a sample size of 2467; sample 2 is the data of Wuhan metropolitan area "1 + 7", Enshi Prefecture, Jingmen City, Jingzhou City, Shennongjia, Shiyan City, Suizhou City, Xiangyang City and Yichang City with a sample size of 5341.

4.2 Results Analysis

Considering the sample size distribution[7] of the three migration patterns, the fully family migration pattern (M_2) is chosen as the reference group in this paper. Table 4 presents the estimation results of multinomial logistic regression models for both data groups, and the estimated coefficients in the table are all derived based on the reference group (M_2). The model regression results show that several variables have statistically significant effects on the migration patterns of the floating population.

In terms of individual characteristics, in the metropolitan area extension sample, the age factor of the migrant population of non-family migration significantly contributes to their achievement of complete-migration compared to that of fully family migration, and there is an inflection point for this effect. In the semi-family migration pattern, the gender factor positively influences their transition to full family migration, that is, the semi-family migration pattern corresponding to male household members is more likely to develop into full family migration compared to the semi-family migration pattern corresponding to female household members, which may be related to the more prevalent and easy behavioral pattern of female migration with male.

In terms of migration and employment characteristics, duration and distance of migration, wage level and employment status did not significantly affect the choice of migration pattern, either in the metropolitan area sample or in the metropolitan area extension sample (the full sample of married migrant population in Hubei province). In contrast, family characteristics are significantly associated with migration patterns in both samples: in the metropolitan area sample, family size significantly facilitates the achievement of full family migration in the semi-family migration pattern; in the metropolitan area extension sample, the effect of family size on the non-family migration pattern and the semi-family migration pattern is also significantly positive. It can be seen that in the sample of miniaturized households with an average household size of 2 to 3 members, the cost of complete-family migration is not high compared to large households, and the increase in core members is likely to make

[7] The family migration patterns of urban circle samples were: 78(M_0), 389(M_1), 2000(M_2); the family migration patterns of urban circle expansion samples were: 126(M_0), 899(M_1), 4316(M_2).

Table 3 Descriptive statistics of explanatory variables

Sample 1: metropolitan area sample					Sample 2: metropolitan area extension sample				
variables	Sample size	Mean value	Least value	Crest value	variables	Sample size	Mean value	Least value	Crest value
Gender (female 0; male 1)	2467	0.50	0	1	Gender (female 0; male1)	5341	0.51	0	1
Age	2467	35.77	19	74	Age	5341	36.26	18	80
Education level	2467				Education level	5341			
Junior high school and below	1675	1	1	1	Junior high school and below	3606	1	1	1
High school/junior college	552	2	2	2	High school/junior college	1303	2	2	2
College and above	240	3	3	3	College and above	432	3	3	3
Household registration attributes (agriculture 0; non-agriculture 1)	2467	0.15	0	1	Household registration attributes (agriculture 0; non-agriculture 1)	5341	0.13	0	1
Duration of migration	2467	58	1	341	Duration of migration	5341	61.81	1	443
Scope of migration	2467				Scope of migration	5341			
Inter-city	535	1	1	1	Inter-city	2080	1	1	1
Intra-provincial cross-city	1295	2	2	2	Intra-provincial cross-city	1911	2	2	2
Interprovincial	637	3	3	3	Interprovincial	1350	3	3	3

(continued)

Table 3 (continued)

Sample 1: metropolitan area sample					Sample 2: metropolitan area extension sample				
variables	Sample size	Mean value	Least value	Crest value	variables	Sample size	Mean value	Least value	Crest value
Family scale	2467	3.10	1	7	Family scale	5341	3.10	1	7
Number of children	2467	1.31	0	4	Number of children	5341	1.29	0	4
Monthly salary (RMB)	2467	6937	0	160,000	Monthly salary (RMB)	5341	6320	0	160,000
Employment status (non-employer 0 employer 1)	2467	0.05	0	1	Employment status (non-employer 0 employer 1)	5341	0.07	0	1
Urban characteristics (urban non-central city 0 central city 1)	2467	0.71	0	1	Urban characteristics (urban non-central city 0 central city 1)	5341	0.33	0	1

Table 4 Multinomial logistic regression results of influencing factors

Metropolitan area sample		*Personal characteristics*					*Migrant characteristics*		*Family characteristics*		*Employment characteristics*		*Urban characteristics*
		Gender (male 1; female 0)	Age	Age square	Education level	Household registration attribute	Duration of migration	Range of migration	Family scale	Number of children	Ln (monthly salary)	Employment status	Central city 1/non-central city0
	M_0	− 0.562	− 0.129	0.001	0.103	0.791	0.004	0.034	− 49.802	8.792	− 1.275	2.190	− 0.166
		(2583)	(1198)	(15)	(2685)	(4427)	(22)	(2037)	(6027)	(2104)	(3391)	(5066)	(2994)
	M_1	− 0.657	− 0.174	0.002	− 0.566	0.869	0.004	0.319	− 8.507***	8.365***	− 0.116	1.116	− 0.932**
		(0.434)	(0.133)	(0.002)	(0.410)	(0.627)	(0.004)	(0.299)	(0.520)	(0.596)	(0.483)	(0.761)	(0.453)
Metropolitan area extension Sample		*Personal characteristics*					*Migrant characteristics*		*Family characteristics*		*Employment characteristics*		*Urban characteristics*
		Gender (male 1; female 0)	Age	Age square	Education level	Household registration attribute	Duration of migration	Range of migration	Family scale	Number of children	ln(monthly salary)	Employment status	Central city 1/non-central city0
	M_0	− 0.612	− 0.367**	0.004*	− 0.289	1.033	0.001	0.238	− 15.674***	7.472***	− 0.690	1.404	0.277
		(0.609)	(0.183)	(0.002)	(0.548)	(0.875)	(0.005)	(0.378)	0.781	(0.661)	(0.675)	(1.111)	(0.668)
	M_1	− 0.501*	− 0.079	0.001	− 0.163	0.443	0.000	0.140	− 8.173***	8.388***	0.197	0.094	− 0.737**
		(0.268)	(0.080)	(0.001)	(0.244)	(0.390)	(0.002)	(0.164)	(0.314)	(0.384)	(0.289)	(0.507)	(0.313)

Note *** ($p < 0.01$),** ($p < 0.05$), * ($p < 0.1$) represent that the estimates are significant at the levels of 1%, 5%, and 10%, respectively; the values in parentheses are estimated standard deviations the marginal benefit of complete-migration higher, prompting them to achieve family clustering.

The model results show that the number of children plays a very important inhibitory role in the developmental changes of non-family migration, semi-family migration, and complete-family migration patterns of the floating population. The comparison of the two sample groups shows that this role is more pronounced in the process of changing from semi-family to complete-family migration patterns of the floating population. The fact that the children of the migrant population move with them means that both spouses invest more time and economic costs, so the more children there are, the greater the resistance and lower the probability that the married migrant population will achieve complete migration.

The effect of the central city in the metropolitan area on the migration pattern of the migrant population is significantly positive in the comparison between the semi-family migration pattern and the full-family migration pattern, i.e., the migrant population in other cities in Hubei Province is more likely to change from the semi-family migration pattern to the full-family migration pattern compared with Wuhan City. However, this city characteristic does not influence the married migrant population in non-family migration status (only one person migrates).

5 Conclusions and Enlightenment

The trend of familization migration of the floating population in Wuhan metropolitan area and Hubei province has been remarkable, and the average household size of the floating population is stable at about 3 persons. Through descriptive statistics of the married migrant population sample in Hubei province, it is found that the proportion of floating population who achieve complete family migration decreases in order for those whose mobility ranges from intra-city & cross-county, intra-province & cross-city and cross-province, but the proportion of those who achieve semi-family migration increases in order. The floating population with different household registration did not show significant differences in the distribution of family-oriented migration patterns.

The regression results of the MLogit model for the married migrant sample show that mobility characteristics, employment characteristics, and most demographic characteristics, such as education level and household registration attribute, do not have statistically significant effects on migration patterns. Family migration patterns are mainly influenced by age factors, family size, number of children, and urban characteristics. First, in the metropolitan area extension sample, the gender factor significantly affects the shift from semi-family to complete-family migration; the age factor is significantly positive and inflection point between non-family and complete-family contrasts. Second, the effect of family size on complete-family migration is significantly positive in both samples, which can be justified from the perspective of relatively low migration costs, given the small average family size. In general, the increase in the number of children significantly inhibits further complete-family migration, which is also in line with the findings of the more refined study on the differences in the "impact of children on each spouse". Finally, urban characteristics significantly influence the transition from semi-family to full-family migration in both samples, i.e., the non-Wuhan migrants in Hubei province are more likely to move from semi-family migration with missing core family members to full-family migration than the Wuhan migrants.

Based on the above conclusions, in order to better promote the stable migration of the floating population, promote the development of metropolitan area and the harmonious development of population mobility, the government and relevant departments should actively guide in the following four aspects. Firstly, for groups of the floating population with age advantages, stronger willingness and ability to migrate in a family-oriented manner, and less burden of family migration, the government shall reduce the institutional barriers to their migration, reduce migration resistance, and improve the effectiveness and quality of family-oriented migration. Secondly, for the floating population that cannot achieve semi-family or full-family migration in the short term, we shall better solve the care and education problems of the family members left behind, relying on the outflow cities with relatively good economic conditions. It is essential to alleviate the old and young care and upbringing problems of the family members who have already migrated, reduce mental pressure and enhance the sense of well-being.

In addition, the government shall pay attention to the employment needs of people moving with their families, improve the overall labor productivity of families, and encourage their stable employment and social integration in the place of inflow. Finally, Wuhan, the central city of the urban circle, shall give full play to its scale advantage of public resources, pay more attention to the medical, childcare and education needs of the elderly and children moving with the family, and enhance their willingness to move in steadily.

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Enlightenment of the Kennedy Space Center of the United States to Development of Space Tourism in Hainan, China

Xiaochun Wang, Zhenwei Wang, and Zuo Zhang

Abstract The international influence of Hainan International Tourism Island is not high, which need to create special tourism products to increase their international influence and competitiveness. Aerospace tourism is a new hot spot for sustainable tourism. The construction of Wenchang Space Theme Park in Hainan, China, will greatly enhance the international appeal of Hainan tourism. Kennedy Space Center is the world's most open space center, and its successful operation experience can provide reference for Wenchang's aerospace tourism development. Based on the development experience of the Kennedy Space Center, combined with the existing actual conditions in Hainan, the following suggestions are made for the development of space tourism in Hainan (1) Hainan International Tourism Island should identify the development orientation, build the Center of National Aerospace Science and Technology Education under global and open horizon, through the education and publicity of aerospace in order to promote the development of the space tourism market gradually; (2) It is also should be supposed to enhance the plan positioning, to integrate the tourism resources of the northern part of Hainan Island, and to create a new growth pole Hainan tourism; (3)At the same time, it should deepen the product orientation, make a deep integration of tropical coastal resources and space tourism, create a unique tourism product which the other places difficult to copy. (4) it also should be supposed to strengthen infrastructure construction, to get rid of the obstacles which can hinder the coordinated development of the island, in order to provide the shoring of foundation for resource complementarity and visitors interacting of the island. (5) At last it should build a high level of space center official Website, the official microblogging, WeChat and other networks and new media, carry out overseas marketing actively, and expand the influence of the international market constantly.

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Keywords Space tourism · Kennedy Space Center · Wenchang Satellite Launch Center · Enlightenment

1 Introduction

Hainan is the only tropical island in China. The construction of Hainan International Tourism Island has risen to a national strategy, and the potential for tourism development is huge. However, currently, among the more than 40 million tourists in Hainan, only 0.6 million are international tourists, international influence is very small. How to create characteristic tourism products and increase international influence and attraction are urgent problems to be solved in Hainan tourism.

At 20:43 pm on November 3, 2016, China's largest thrust launch rocket, the Long March 5, was launched at China's near-Equator space launch site, the Wenchang Space Launch Site. The Wenchang City of Hainan Province has suddenly become the focus of the world, and space tourism has also become a new hot spot in Hainan's international tourism island development vision. Aerospace tourism refers to the tourism activities centered on the space launch center and participating in space launches, experiencing simulated aerospace, and carrying out space education and scientific research. Due to the high confidentiality and security of space launches, most space launch centers in the world are not open to the outside world. At present, the most open space center is the Kennedy Space Center in the United States. Traditional tourists' satisfaction with theme parks is mainly reflected in customer experience, entertainment types and quality, food quality, cleanliness and atmosphere, etc. [1, 2]. With the proliferation of theme parks, people are no longer satisfied with simple tourism products and services. Only the unique experience can bring unforgettable experiences to tourists. Providing more kinds of tourists experience can attract tourists and influence tourists' willingness to consume [3]. Exploring and thrilling themes are increasingly popular with tourists [4]. The exploration of space is a common desire of humankind. People are generally full of mystery about aerospace tools and aerospace science and technology. Space theme parks can precisely satisfy this kind of hunting spirit of tourists [5]. There are several space theme parks around the world that are not based on space launch centers but are subject to space science and technology [6, 7], Such as the United States Johnson Space Center, the United Stctes New Mexico Alien Resort, Fukuoka Space World, Jordan Star Trek theme park, etc. With the full development of space exploration, the concept of closed space launch bases is out of date. It can be used as a theme park to face the public, transfer knowledge to more people, and stimulate public imagination and creativity [8]. Some studies have confirmed through experiments that the aerospace theme park field experience and curriculum practice have significantly improved the learning interest and self-confidence of participants' related courses [9]. In addition, unlike ordinary museums or science centers, the popularization of scientific knowledge in space theme parks cannot be limited to general display functions. It must be market-oriented and maintain its cultural functions while providing diverse entertainment services [10]. In general, aerospace tourism still belongs to emerging tourism products in the world. At present, scholars at home and abroad have studied more traditional entertainment theme parks [11, 12], there are few studies on aerospace tourism. However, with the rapid development of global aerospace science and technology, the popularization and popularization of aerospace science and technology are getting higher and higher, and aerospace tourism is quietly evolving into a new tourism boom [13]. In this context, Wenchang Satellite Launch Center will become a precedent for China's space tourism. The unique attraction in Asia and the world will greatly enhance the international competitiveness of Hainan tourism. However, aerospace tourism is a new type of tourism product. How to develop it, how to position, plan, market, and integrate it with existing resources are worthy of timely research.

Kennedy Space Center in Florida, USA is not only one of the most important space launch bases in the United States, but also the world's most open space center. It is one of the most popular feature travel destinations in the United States. According to the statistics in Kennedy Space Center Annual Report, every time the spaceflight launch of the Kennedy Space Center attracts tens of thousands of tourists, it receives 1.5 million tourists every year and annual income is about 100 million US dollars. This paper takes the Kennedy Space Center as an example to analyze the successful experience in its aerospace tourism operation, explore the enlightenment to the construction of Wenchang Space Theme Park, promote the healthy and sustainable development of Hainan Aerospace Tourism, and further improve the international influence and competitiveness of Hainan tourism.

2 Comparison of Development Conditions Between Wenchang Space Center and Kennedy Space Center

2.1 Location, Positioning and Development Status

The Kennedy Space Center (KSC) was founded in July 1962 on the east coast of Orlando, Florida (Fig. 1), it is the most important place for NASA to test, prepare and implement launches for manned and unmanned spacecraft. The Kennedy Space Center is located at 28°35' 28.31″ North, adjacent to the Atlantic Ocean and the Gulf of Mexico. It is a low-latitude space launch base and one of the best locations in the world. The visitor center of the Kennedy Space Center covers an area of about 0.26 km^2. The Kennedy Center performs an average of 11 space launch missions each year. It receives about 1.5 million tourists each year. The annual capital budget is about US$2.1 billion, and the economic benefits it brings are US$3.3 billion, and it can provide about 30,000 jobs for residents. Every dollar invested at Kennedy Space Center can bring about twice the economic growth in the region, half of which is local family income, and each job can provide 1.5 additional opportunities for local completion (Table 1). Therefore, the Kennedy Space Center has always been

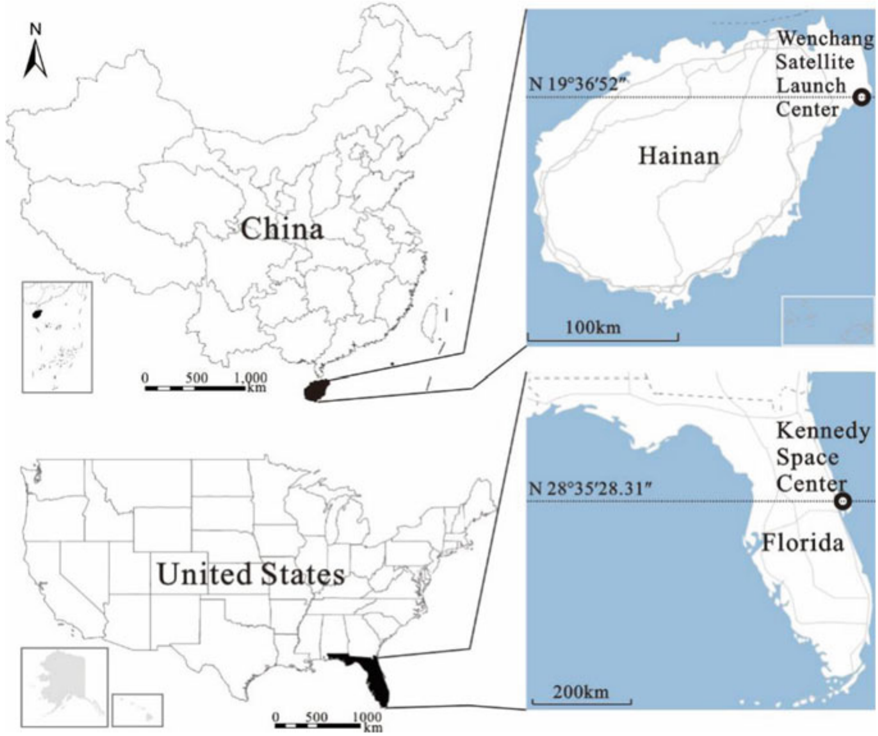

Fig. 1 Location of Wenchang Satellite Launch Center and Kennedy Aviation Center

Table 1 Basic statistics of the Kennedy Space Center (2005–2015)

Years	Visitors/10,000 person-times	Number of launches/time	Annual funding budget/billion US dollars	Economic benefits/billion US dollars	Provide jobs/jobs
2015	160	13	19.75	–	–
2014	140	13	20.31	–	–
2013	150	9	17.88	–	–
2012	150	10	18.49	22	16,500
2011	140	10	23.02	37	26,000
2010	150	11	21.75	41	33,000
2009	150	16	22.59	43	39,000
2008	160	7	23.22	41	40,802
2007	150	13	22.95	40	35,960
2006	140	8	21.47	36	34,000
2005	140	6	23.34	37	35,000
Mean	148	11	21.34	33	28,918

Note The data from the Kenny Space Center Annual Report 2006–2015 the main driving force for economic development in Brevard County and is a major contributor to the economic development of Florida.

Wenchang Satellite Launch Center (WSLC) is located on the east coast of Wenchang City, Hainan Province, China. It is located at 19°36′52″ north latitude and was built in September 2009. It was officially put into use in June 2016. The launch center can launch the Long March 5 series rockets and the Long March 7 launch vehicle. It mainly undertakes launch missions such as geostationary orbit satellites, large-mass polar orbiting satellites, large-tonnage space stations, cargo spacecrafts, and deep space probes. Long-term and heavy-duty moon and deep space exploration missions will mainly depend on the Wenchang Satellite Launch Center in Hainan [14]. The Wenchang Satellite Launch Center is also a low-latitude seashore launch base. Launching at low latitudes and facing the east can use the rotation of the earth to increase the rocket's carrying capacity, help the satellites to enter the orbit, face the sea and avoid densely populated areas, and it has high level of security [15, 16], and the its latitude is lower than that of the Kennedy Space Center. The advantage is even more pronounced than that of the Kennedy Space Center (Fig. 1). It is not only the center of China's space development in the coming years, but also has the opportunity to become a space center in Asia and even the world.

According to the planning and design, a theme park which is "China's only, world-class" and "full of space science, technology, culture and island features" will be built in the area adjacent to the space launch site, covering an area of about 4.06 km^2, which is 15.6 times that of the visitors center of Kennedy Space Center [17]. It will become the first choice for aerospace science and technology enthusiasts and must-see projects for tourists. And it is expected to become a world-class space theme park.

2.2 The Tourism Market

The Kennedy Space Center is in Florida with a land area of 140,000 km^2. In 2015, Florida's GDP was 833.5 billion U.S. dollars. It is the fourth largest economy in the United States and has a total population of 1.90 million. It has surpassed New York and ranks third in the United States. Florida is also known as "Sunshine State," which is a subtropical humid climate. The average annual temperature is 21 degrees, and the seasons are warm and humid. It is very suitable for tourism [18]. Florida is an internationally renowned tourist island and tourism is an important pillar industry in the area. According to data from the Florida Tourism Administration, the site had more than 150 million tourists (of which 66 million were in Orlando) in 2015, and tourism-related consumer spending reached US$89.1 billion, and provided 1.2 million jobs for residents. Relying on the United States, the world's most affordable consumer market [19], in 2015, a total of 89.8 million local tourists were received, accounting for 85% of the total number of tourists, and 15.2 million international tourists, accounting for 15% of the total number of tourists. Among the international tourists, Canadian tourists are the most, nearly 4 million, accounting for 26% of the total number of international tourists, and Chinese tourists are 275,000, accounting for 1.8%.

The total land area of Hainan Province where the China Wenchang Satellite Launch Center is located is 35,000 km^2, about 1/4 of that in Florida. In 2015, the total population of Hainan Province was 9.1 million, about 1/2 of that in Florida, the GDP is 370.28 billion Yuan (CNY), which is equal to 59.45 billion US dollars (calculated according to the average RMB exchange rate of 1 US dollar for the entire year of 2015 equals 6.2284 Yuan), which is only 1/14 of the total economic output of the state of Florida. Hainan is rich in tourism resources, has a fascinating tropical landscape and a unique island style, and its climate conditions are even better than Florida. In 2015, Hainan Province received a total of 44.93 million tourists, which is approximately 1/2 of that of Florida. Looking at the ratio of tourists to the local population, the level of Hainan's tourism development is comparable to that of Florida, which is about 5:1. However, the level of tourism revenue in Hainan Province is much lower than that of Florida. In 2015, the tourism revenue of Hainan Province was 54.3 billion Yuan (US$8.718 billion), which was only 1/10 of that in Florida. In the tourist market, Hainan Province has only 608,400 inbound tourists (including 225,200 Hong Kong, Macao and Taiwan compatriots), which only accounts for 1.35% of the total number of tourists, and its international influence is insufficient (Table 2).

Table 2 Comparative analysis of tourism resources/markets

Item category		Wenchang space launch base	Kennedy Space Center
Location and climate	Latitude	19°36′52″ north latitude	28°35′28.31″ north latitude
	Climate type	Tropical monsoon oceanic climate	Subtropical humid climate
	Annual average temperature	24	22
Province/state tourism development status (2015 data)	Island type	Island	Peninsula
	Tourist market positioning	International Tourism Island	International Tourism Island
	Regional population	9.1 million	19.9 million
	Visitors	44.93 million people	105 million people
	Tourism income	54.3 billion Yuan	US$99.1 billion

Source Statistical Yearbook of Hainan Province, official data released by the Bureau of Population Survey and Statistics of the United States and Tourism Bureau of Florida

2.3 Comprehensive Comparative Analysis

From the above comparison, we can see that there are many similarities between the Kennedy Space Center in the United States and the Wenchang Satellite Launch Base in China. First of all, in terms of geographical location, both of them are located in low-latitude coastal areas, both of which are among the best locations in the world and are one of the few large-scale and high-level space launch bases in the world, and both have an important place in the world; Secondly, in terms of tourism resources, both are in tropical islands with large areas and rich tourism resources. The resources and environmental conditions for the development of tourism are superior; Thirdly, in the source market, both rely on mature tourism destinations. The United States and China are both one of the most consuming-capacity tourist source markets. They have ample tourist markets and are all large aerospace technology countries, the conditions for the development of aerospace tourism are excellent. The Kennedy Space Center in the United States has a history of more than 60 years. Its operating mode is relatively mature, which can provide experience for Wenchang Aerospace's tourism development.

3 The Successful Operation Experience of Kennedy Space Center

3.1 Using Space Center for Science Education

The U.S. is one of the countries that have successfully conducted popular science education in aviation, and it is the clearest among all countries in the strategic positioning of aerospace education. NASA regards education as one of its three major missions and invests US$1–2 billion (approximately 0.5–1% of total space agency funding) for education each year [20, 21]. The Kennedy Space Center's education covers all public, as long as you are interested in aerospace technology, you can find a training program that suits you. The K-12 education program mainly targets preschoolers to high school students. Emphasis is placed on "education and attraction" in order to cultivate students' interest in STEM (science, technology, engineering and mathematics). Higher-Education Programs are aimed at undergraduates and postgraduates, focusing on "retaining talents" and strengthening the aerospace industry team. Informal Education and Electronic Education Projects are education programs for the general public. They focus on popularizing aerospace knowledge to the general public, focusing on "attracting and enlightening" and enabling more people to understand and participate in the aerospace industry. The four global program projects focus on "help and encouragement" and reserve talents for the future.

In 2015, the Kennedy Space Center hosted a total of 814 student activities that attracted 34,281 students from kindergarten to the 12th grade. There were 56 events for 3,909 educators, 383 digital e-learning activities for 15,490 students and teachers using electronic media, and 62 learning activities for 16,500 spectators via the Internet. Each year, the number of people in the central education reaches 80,000.

The Kennedy Space Center places special emphasis on the education of young students in order to introduce as many young people as possible the risks and miracles of exploration and attract more students to join the STEM field so that more Americans can participate in the space industry. Educational activities include the organization of aerospace summer camps, Kennedy educational innovation programs, and astronauts training programs. The learning process is full of fun. With the aid of physical models and high-tech simulations, students can experience the feeling of being in space. At the same time, they will also have the opportunity to personally touch specimens brought back from the Moon and Mars, have lunch with the astronauts, introduce the wonders and colorfulness of space exploration to the public as much as possible, and cultivate more young people interested in this subject.

To stimulate students' enthusiasm for innovation, the Kennedy Center has set up dozens of aerospace science and technology challenge projects such as the Rocket Launching Competition, the Sampling Robot Challenge and the Future Engineer Space Tools Design Challenge each year. Each project will attract nearly a thousand students from dozens of teams in dozens of states across the United States. Some of the challenges are to develop students' hands-on capabilities, such as the Nations Launch Competition, to guide students in learning navigation, control, propulsion, and basic theoretical knowledge required for the successful launch of related electrical systems and aircraft to complete rocket construction and launch. The Annual Robotic Mining Competition, making mining robots and completing landings, excavations, and mining collections on simulated Martian terrain. Some of the products of the challenge project need to be directly used in future aviation exploration, such as finding plants suitable for space growth. In 2014, the champions of the Future Engineers' Space Tools Design Challenge witnessed their design of 3D printers sent to space for recording temperature, pressure, acceleration data and 3D printing activities during the flight.

3.2 *Highlight Features and Combine Teaching with Joy*

Aerospace science and technology are highly sophisticated, and they are often far away and mysterious to the public. However, the space theme tour of the Kennedy Space Center has also been very entertaining, and it has transmitted aerospace knowledge to tourists during entertainment. At the visitor center, visitors can also participate in immersive space experience activities such as the Shuttle Launch Experience, where visitors can relive Apollo's ascent. By simulating capsules, visitors can experience the micro-gravity of the International Space Station. There is also the Astronaut Training Experience (ATX). With the help of a senior NASA astronaut, visitors use a full-scale orbital model to complete a space launch mission control, launch a launch to the International Space Station, and launch a full set of space launches task. At the visitors' center, visitors also have the opportunity to participate in the Astronaut Encounter, each time with different astronauts sharing his flying experience and interacting with the audience. In short, the Kennedy Space Center has truly realized the combination of education and joy, presented boring, high-end technology to everyone in an entertaining way, and delivered the aerospace culture and aerospace spirit to the public in entertainment.

At the Kennedy Space Center Visitors Center, you can see the original Atlantis spacecraft, the returning lunar module, the recreated Saturn V rocket, and the rocks collected from the Moon. But here is not just an aerospace museum. You can visit the launch site on site, including the launch pad, tracked transport vehicle, assembly building, mysterious and complex rocket launch command system. You can also watch the rocket launch from close range and truly experience how spectacular and stimulating the rocket launch is. The two most famous space centers in the United States are the Johnson Space Center and the Kennedy Space Center. The former is the control center and the latter is the launch center. However, in terms of visitor reception, the Johnson Space Center is about 1 million per year, which is far lower than the Kennedy Space Center. The main reason is that at the Kennedy Space Center, visitors can watch the launch in real time, and they can visit the launch site to receive an immersive experience.

3.3 Deeply Integrate Resources to Improve Tourism Attraction

Convenient transportation is the basic condition for supporting tourism development. The Kennedy Space Center is in Florida where land, sea and air traffic are well developed. There are 20 airports with regular routes, 6 international airports, 1600 km of inland waterways, and 5 main cruise ports, 14 deep-water trading ports [22]. It also has 7000 km of domestic railways and 140,000 km of highways, leading to U.S. states through 3 major highways (I-10, I-75, I-95), and 9 secondary highways (I-4, I-110, I) -175, I-195, I-275, I-295, I-375, I-395, I-595) connecting the major towns and cities in the state and form a network of transport networks extending in all directions [23].

The Orlando, where the Kennedy Space Center is located, is one of the most famous leisure tourism cities in the world. In 2015, it received 66 million tourists, which is 1.5 times that of tourists in Hainan Province, known as the "Global Theme Park Capital," with Walt Disney World Resort, Sea World Orlando, Kennedy Space Center, and the Wizarding World of Harry Potter and more than 10 of the world's most exciting and fantastic theme parks, the most famous being Disneyland and the Kennedy Space Center [24].

It is precisely because of the large number of theme parks in Orlando that the attraction of visitors has been greatly enhanced, providing ample tourist resources for the Kennedy Space Center. At the same time, Kennedy Space Center has integrated educational, scientific, and entertaining elements with its unique aerospace theme, forming complementary resources with other theme parks [25]. It has also become one of the theme parks that many Orlando visitors cannot miss.

3.4 Build a Diversified Outreach Channel

The Kennedy Space Center attaches great importance to its outreach work and has established a variety of channels for outreach. The public can visit the visitor center directly for on-site experience, and real-time understanding of Kennedy Space Center's work status through official websites and digital multimedia and magazines. It is also possible to see astronauts and related experts and to understand the progress of space exploration at the Kennedy Center (Fig. 2) through various lectures and exhibitions held by the Kennedy Space Center, which has greatly promoted aerospace tourism.

In respect of traditional media publicity, the Kennedy Space Center mainly promotes through official radio, aviation magazines, product exhibitions, and lectures by experts and scholars. NASA has a dedicated television station (NASA TV). All space missions at the Kennedy Space Center will be live broadcast on NASA TV. The Kennedy Space Center publishes Spaceport magazine regularly every month, with an average of 7,867 readers monthly. The Spaceport Kennedy Space Center also holds dozens of air shows every year, and it reaches hundreds of thousands of people each year through the exhibition. The Kennedy Center astronauts and experts also

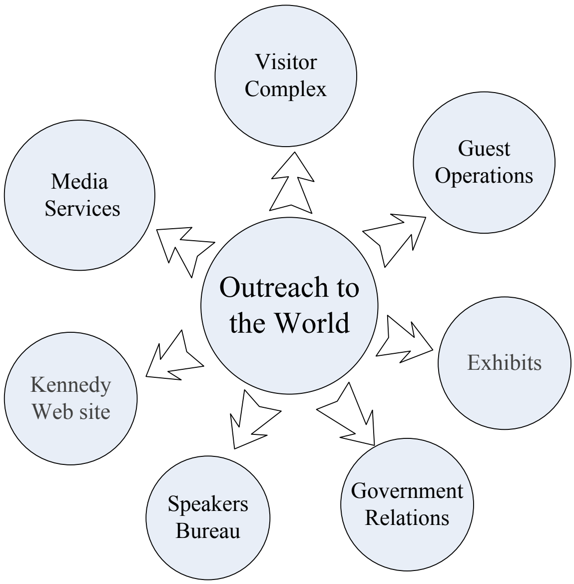

Fig. 2 External framework of the Kennedy Space Center

regularly travel to the country and around the world to hold professional seminars to share their aviation expertise and unique experiences. In 2015, Kennedy's engineers, technicians, and related experts participated in 365 events around the world, a total of 76,461 employees were given speeches.

In order to facilitate the public's understanding of the Kennedy Space Center's dynamics in real time, the Kennedy Launch Center places great emphasis on the construction of the Internet and new media. The public can learn about the Kennedy Space Center's activities in real time through official web pages, Facebook, Twitter, YouTube and other new media. Kennedy Space Center attaches great importance to the construction of official web pages. Its official web pages are rich in content and interactive, with over 10 million-page views each year. The homepage has a countdown to each launch of the rocket and provides live or real-time updates for each space activity and uses video and other methods for display. Weekly update of Inside KSC video. More than 100 related videos are released every year. The average weekly video viewership rate is about 5000. Through the official homepage, you can also find application methods for various education programs, competition participation methods, and notices of activity. The Kennedy Space Center also attaches great importance to the application and dissemination of new social media. The official public numbers have been set up on Facebook, Twitter, and YouTube. The center's Facebook home page and the number of Twitter fans have exceeded 1 million, and it continues to grow every day. And there are nearly 10 million YouTube video views.

4 Enlightenment and Development Suggestions for Wenchang Aerospace Tourism

4.1 Product Positioning and Market Positioning

The Kennedy Space Center is very successful in tourism operations, but the development of tourism is not the core task of the Kennedy Space Center in addition to space launch. Its core mission is to educate and promote space culture. The Kennedy Space Center is the largest and most attractive space science education base in the world. It attracts hundreds of thousands of students through various education programs each year, and stimulates people's interest in aerospace science and technology through aerospace science education, thereby nurturing the aerospace tourism market.

At present, the popularity of aerospace education in China is still relatively low, and space technology innovation is obviously insufficient [26]. Wenchang Space Center must assume this responsibility, and its primary orientation is to serve as the national aerospace science and technology education center. We must not limit our sights to how many visitors visit each year, how much tourism income we earn, and how we must use space theme parks to create joy, dreams, and inspiration for our visitors. Space science theme parks should be used as carriers and aerospace education as the main purpose. Building a space education base that integrates science, enlightenment, and education, and be the second classroom for Chinese youth to understand the development of China's space industry, experience the achievements of space science and technology, and learn the spirit of aerospace and experience space culture.

Florida is a famous international tourist island, but its proportion of domestic tourists also accounts for 85%, mainly for domestic tourists. No matter how much international tourists, there are enough tourists, if people can benefit from tourism development, the tourism development is successful. The fact that Hainan has about 600,000 international visitors each year accounts for only 1.35% of the total number of tourists and has little influence. This fact must be recognized. Based on the domestic market, it does not violate the original intention of building an international tourist island. Many of the world's famous international tourist islands are mainly domestic tourists, Hawaii is 72%, and Canada's Prince Edward Island is 66%, the proportion of domestic tourists in Asia's famous international tourist islands is higher, with Jeju Island accounting for 90%, and Okinawa, Japan accounting for 92%[27]. In addition, according to the annual travel report of the United Nations World Tourism Organization, since 2012, China has been the world's largest outbound tourism market for four consecutive years. Domestic tourists, outbound tourists, domestic tourism consumption, and overseas tourism consumption all rank first in the world, attracting the Chinese tourist market has become an important decision in all parts of the world, Hainan Province must seize the opportunity to serve the domestic tourist market. At the same time, Hainan as an international tourist island, the international market construction cannot be ignored, based on the domestic market at the same time, we must continue to improve the level of basic service facilities, highlight the construction of special culture, expand international influence, and gradually cultivate the international market.

4.2 Resource Integration and Planning

Orlando's intensive theme parks have a tremendous boost to the tourism development of the Kennedy Space Center. Orlando has more than a dozen theme parks and receives more than 66 million visitors each year. These tourists are potential visitors to the Kennedy Space theme park. The diversity of tourism products offers visitors a variety of choices, and the attraction of regional tourists is greatly enhanced.

The development of tourism in Wenchang City lags behind. The high-quality bays such as Mulan Bay, Gaolong Bay, and Fengjiawan are still untapped virgin lands. The rich tourism resources do not play its due role [28]. At the same time, throughout the Qiongbei, there is a lack of attractive tourism projects. Nowadays, the attraction of space tourism in Wenchang City has gradually emerged. On the day of the launch of the Long March 7 rocket and the Long March 5 rocket, Wenchang Longlou Town welcomed tourists of 100,000 and 118,000 respectively. The space travel products have a great attraction for tourists. However, the launch time of the rocket is short, and the participation of tourists is insufficient. After hours of rocket launch, the tourists leave, it is difficult to retain tourists, and the economic impact on the local area is limited. Therefore, Wenchang Space Theme Park should be built as a core tourism attraction in Qiongbei area, and the surrounding resources should be vigorously integrated to overcome the existing “scattered, small, weak, poor” tourist attractions and regional traffic bottlenecks, adhere to the high starting point planning, high grade construction, improve the overall attractiveness of regional tourism, and thus become a new growth pole of Hainan tourism.

According to the experience of the development of aerospace tourism in Florida, it is difficult for a theme park or space museum alone to attract tourists. There should also be other entertainment projects. In the development of Wenchang Aerospace Tourism, it is necessary to highlight the functions of tourism and vacation in Hainan. Hainan is far from the Chinese mainland market. Tourists need to spend a lot of money and time. After the tourists come, there can’t just be a space theme show. They should also let visitors experience the blue sea, blue sky, coconut wind and sunny beach in Hainan. Provide visitors a special experience of watching rocket launches lying on the beach, creating unique tourism products in Hainan that are difficult to duplicate.

4.3 Hardware and Software Facilities Construction and Overseas Marketing

Convenient transportation is a prerequisite for the development of tourism. The Kennedy Space Center is conveniently located in Florida. It has formed a network-like traffic pattern both in and out of the country. Visitors enjoy a high degree of convenience and provides the basis for accessing to the surrounding scenic areas and Resource sharing. Compared to Florida, Hainan Province is not convenient for both internal and external transportation. First, in terms of external transportation, Florida is a peninsula. Through three national backbone highways, it can directly connect to major cities in the United States and Canada. Hainan is an island and far away from mainland China. External traffic can only rely on aviation or ferries. The cost of air transport is relatively high, ferries are relatively time-consuming, and accessibility is relatively poor. Secondly, in terms of internal transportation, all levels of highways in Florida are crisscrossing and form a full mesh coverage. However, the internal transportation in Hainan Province is not yet perfect. In particular, horizontal transportation is relatively backward. The entire island has not yet had a horizontal highway. Tourists in the western region must go to Haikou or Sanya before travelling to the east. Only half of the Hainan Province can be accessed before they arrive. The time and transportation costs are greatly increased, which seriously affects the interaction and sharing of tourists between the scenic spots. Therefore, we must strengthen the province’s road network construction, open the Wanning-Danzhou Transverse Expressway as soon as possible, build a mesh highway network structure covering all cities and counties across the province, and create a 2-h tourism circle throughout the province to realize the entire island.

The Kennedy Space Center has a relatively large number of visitors and is relatively stable. Its strong network and new media publicity have played a crucial role. The Kennedy Space Center attracts millions of viewers each year through official websites, Facebook, Twitter, YouTube and other media. It provides potential tourist sources.

Build a high-level Wenchang Space Center official website. At present, China's Internet industry is very developed and plays an increasingly important role in tourism. According to the "China Internet Development Report for 20 Years" published by the China Academy of Cyberspace, by the end of 2015, the number of Internet users in China has reached 668 million. It has become the world's largest consumer of internet consumption, internet users who have booked airline tickets, hotels, train tickets or travel and holiday products online have reached 260 million, and the proportion of online mobile travel bookings has reached 33.9%. Therefore, we must give full play to the role of the Internet and new media, build a high-level official website of the Wenchang Space Center, and establish an official platform for new social media such as Weibo and Wechat, and implement major push campaigns through blogs, videos, and live broadcasts. We should set up expert and astronaut dialogue columns to form an Internet + tourism model to increase audience participation and attract more tourists to aerospace tourism.

We should carry out global marketing actively. According to a survey conducted by the U.S. Institute of Population and Economic Research, Florida's official tourism marketing organization generates US$3.2 in tax revenue for every dollar invested. Therefore, Hainan must also increase its marketing and promotional efforts. First, in marketing organizations, the government must unite major scenic spots and become strategic partners. Secondly, various scenic spots should develop different tourism resources and products according to the characteristics and preferences of tourists from different countries and carry out targeted marketing and promotion for specific overseas source markets, and constantly expand the influence of the international market.

5 Concluding Remarks

With the vigorous development of China's space industry and the tourism market, aerospace tourism has great potential for development. The construction of Wenchang Space Theme Park will inevitably promote the development of Hainan tourism, and in turn increase the international influence and competitiveness of Hainan tourism.

There are many similarities between Wenchang Satellite Launch Base in China and Kennedy Space Center in the United States. The successful operation experience of the Kennedy Space Center in the United States can provide reference for the construction of Wenchang Space Theme Park. However, compared with the Kennedy

Space Center, Hainan also has problems such as lack of theme parks, imperfect transport infrastructure, low concentration of regional tourism resources, and insufficient international influence. The construction of Wenchang Space Theme Park in China should be based on its own situation, and it should also identify its positioning, broaden its horizons, supplement short boards, and innovate so as to create a "world-class" space theme park.

First, we must identify the development orientation and build a national aerospace science and technology education center. The Wenchang Space Theme Park in China cannot only focus on tourism but must have a holistic and open perspective. It is necessary to use this theme to undertake the responsibility of the national science education in space science. Through education, young people are encouraged to join the space industry. Through space education and publicity, people's understanding of the space industry is enhanced, and the aerospace tourism market is gradually cultivated and expanded.

Secondly, we must improve planning and positioning, and create a new growth pole for Hainan tourism. Adhere to the high starting point planning, high-level construction, the Wenchang space theme park should be built as the Qiongbei core tourist attractions, and we also should integrate the tourism resources in Qiongbei region to form complementary resources, improve the overall attractiveness of regional tourism, and promote Qiongbei tourism development.

Third, we should do a good job of product positioning and create unique and difficult-to-replicate travel products in other places. Coastal tourism resources should be found. There are more than 50,000 islands in the world, of which 180 are islands with an area of more than 2500 km^2. However, there are only few space launch bases, and only a few countries such as the United States, Russia, China, and France have high-level space launches ability, among them, only a handful are open. Hainan Province has both these resources. It is necessary to deeply integrate tropical coastal resources and aerospace tourism to create unique products that are globally unique.

Fourth, we should strengthen infrastructure construction and remove obstacles that hinder the coordinated development of the region, and Continuously strengthen aeronautical construction to provide convenience for international tourists; continue to improve land transportation and build a city-wide effect; do a good job of integrating and sharing information across the island to provide basic support for the tourism resources of the entire island to complement each other and tourists to share.

Fifth, we should actively carry out marketing and continuously expand market influence. It should attract more tourists to participate in aerospace tourism through the construction of a high-level Wenchang Space Center official website, the construction of official Weibo, WeChat and other new social platforms and other means to form the Internet + tourism model, increase audience participation. At the same time, it should increase its overseas marketing efforts and continuously expand its influence in the international market.

Commercial space travel is a very promising market. Based on the Wenchang satellite launch base, Hainan will seize this new highland, support commercial space exploration and conduct space tourism. At present, Space X, XCOR, Blue Origin, Orbital Sciences, Bigelow Aerospace, and Virgin Galactic in the United Kingdom are all conducting intense tests or manufacturing spaceships and conducting space business trips. According to XCOR estimates, the global space tourism market is close to US$50 billion, and China may become one of the largest space travel markets. The 2016 Hurun Global Rich List shows that the number of China's billionaires with more than US$1 billion is 568, which exceeds 535 in the United States. We must seize the opportunity to seize this huge tourism market. We must break administrative barriers, promote relevant legislation as soon as possible, establish specific management rules, and support and standardize the management of commercial space exploration. By opening commercial space exploration, on the one hand, it can ease the financial pressure on the government, stimulate the enthusiasm of nongovernmental science innovation, provide intellectual support for the national aerospace industry, and finally form a prosperous situation in which the aerospace science and technology is fully developed.

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