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RESEARCH

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An analysis approach for building collapse accident using system thinking approach and SEA model

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Abstract

The frequent occurrence of building collapse accidents not only causes significant casualties, but also jeopardizes local economies. This paper adopts a combinatory assessment approach to showcase the lessons learned from a recent building collapse in Changsha, China. The proposed approach blends the system thinking approach and strategic environmental assessment (SEA) model. It delineates the causes of collapse and provide key leverage points for safety management. The results show that the primary causes for the collapse are the poor construction quality, illegal alterations, and lack of regulations enforcement. The management of rural housing construction in Hunan Province achieved a total score of 4 out of 30. It was also determined that the key prevention measures for abating these deleterious phenomena involve ensuring quality assurance/quality control, efficiently assessing safety risk, and timely performing structural health monitoring. This study is bound to enhance the understanding of collapse accidents and foster the achievement of sustainable cities and communities.

Keywords Building collapse, Illegal construction, System thinking approach, Risk assessment, Structural health monitoring

1 Introduction

Building collapse is one of the most alarming types of construction accidents globally. Over the past decades, building collapse accidents have occurred frequently worldwide, resulting in numerous casualties and significant property losses. These hazards have occurred mainly in India, China, Egypt, Nigeria, and Brazil. For example, Ohenhen and Shirzaei [27] reported a series of 152 building collapses in 2005 in Lagos, Nigeria, which caused more than 200 casualties. Chen et al. [6] also discussed the collapse of a 30-year-old hotel building in Suzhou, China in 2021, which resulted in 17 deaths and 5 injuries. Zhou and Ma [48] analyzed the hotel collapse incident in Quanzhou, Fujian, China, which killed a total of 29 people. Despite the continuous development of construction technologies and improvement of construction regulations, many urban buildings still fail to fulfill their primary function —— ensuring the safety of residents [18, 45]. Yet, the frequent occurrence of such events represents a thorn in the side of local economy and a real hurdle to the achievement of United Nations sustainable development goals (e.g., SDG11: sustainable cities and communities). Efficient design/construction and management frameworks are required to enable a more accurate detection and prediction of such events. In turn, these actions are contingent on the good understanding of building collapse causes.

The necessity for such actions is further underlined by the China's context. In 1988, the Chinese government announced a "dual structure" policy, which distinguished

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urban and rural households, limited the economic migration of large numbers of workers from rural to urban areas, and limited the intensification of the rural–urban binary opposition. The "dual structure" policy also gave rural residents some benefits, such as the right to build a house or building on their homestead [23]. However, buildings in rural areas referred herein as self-built house, lack sufficient supervision (*i.e.*, design specification, approval, quality inspection) and management, resulting in poor-quality buildings. Although significant government efforts have contributed reducing this phenomenon in recent years, some safety risk remain. Research on the current scenario and safety of self-built houses must be intensified and effective solutions must be determined. This can be achieved via consistently providing lessons learned from previous cases, as well as through the thorough investigation of collapse causes.

Many methods have been adopted for building collapse investigation including, simulation-based approaches [24, 36], site investigation [4, 28] and holistic methods [39]. Particularly, holistic methods such as system thinking approach and strategic environmental assessment (SEA) have been widely adopted in the industry owing to some attractive attributes. Table 1 lists the recent development for the application of system thinking approach and SEA model. The system thinking approach enables the decomposition of a system into parts to better capture the interactions among them. Zhang et al. [46] used it as an intuitive way to ascertain the key sources of building collapse and assess risks. Moreover, SEA effectively integrates the principle of sustainability into the structure of urban planning [31]. Tan et al. [34] utilized it to identify new opportunities for sustainability development of bridges, while other studies focused on ensuring transparency and efficiency of decision-making processes. However, although these holistic assessment methods were found quite satisfactory in previous applications, there are some drawbacks that can hinder their effectiveness. For instance, unlike the SEA, the system thinking method is very limited when it comes to evaluate the management problems induced by policies, economy, culture, and environment. Then again, the SEA approach often relies on limited information, which makes it subject to greater levels of uncertainties. In other words, robust assessment approaches are in great demand for enhancing the understanding of building collapse accident. For example, it is believed that the effective combination of system thinking approach and SEA can help achieving more accurate and comprehensive results.

This article discusses the lessons learned from a recent self-built house collapse in Changsha, China, via a combinatory causality assessment approach. The objectives are to: (i) provide effective recommendations for avoiding similar accidents, as well as (ii) proposing a new holistic investigation framework. The combinatory approach combines system thinking approach and SEA to analyze the causes of collapse and provide key leverage points for safety management. The remainder of this article is as follows: previous studies are first analyzed to provide a strong theoretical background to our approach. Then, the proposed hybrid framework is scrutinized and applied to the aforementioned case study. Subsequently, results are thoroughly discussed, and the main conclusions drawn. The outcomes of this study provide some key insights into the 'roots' of building collapse.

2 Brief review of literature

A review of previous studies is carried to further understand the state-of-the-art research of building collapse accidents worldwide. A bibliometric analysis is first

Table 1 Recent development for the application of system thinking approach and SEA model in engineering

References	Methods	Applications	Main innovations
Shepherd and Ortolano [31]	Strategic environmental assessment	Sustainable development	Summarized six principles for promoting sustainable urban development through SEA
Xu et al. [44]	Strategic environmental assessment	Analysis of Land Subsidence Factors in Shanghai	Proposed suggestions for the future development of Shanghai
Zhang et al. [46]	System thinking approach	Analysis of the causes of construction accidents	Practical solutions for construction safety management and accident prevention
Tan et al. [34]	Strategic environmental assessment	Project Management of Bridges	Specific management measures for improving the sustainability of infrastructure
Hamma-adama et al. [13]	System thinking approach	Analyzing the causes of building collapse in Nigeria	Proposed a global strategy for preventing building collapse
Shammi et al. [30]	Strategic environmental assessment	Assessing the legislative practices and environmental governance of Bangladesh	Proposed the challenges faced in fully leveraging strategic environmental assessment

performed, followed by a brief interpretation of its outcome. This not only allows situating the research within existing knowledge, but also enables developing the research theoretical framework.

2.1 Bibliometric analysis approach

The bibliometric analysis focused on the construction safety. The analysis was methodically carried out using the Web of Science as the database. The keywords including, self-built, house collapse, illegal construction of houses, building risk assessment, and structural health monitoring of buildings were selected to search for relevant literature. The publication time frame of the literature was constrained to the last five years to analyze the most recent research. The resultant of this filtering operation produced 4946 documents that were imported into the literature visualization tool VOSviewer [37]. This tool was used for co-occurrence analysis and literature coupling analysis. The threshold for the minimum number of keyword occurrences was set to 100. Figure 1 shows the keyword co-occurrence network based on the number of keyword occurrences.

2.2 Bibliometric analysis results

Table 2 shows that extensive research has been conducted on house collapse over the past 5 years. Yet, the rapid growth in the number of publications (see Fig. 2) indicates that housing collapses have become a hot topic of research in recent years. Based on the previously established co-occurrence network, the global ecosystem can be divided into three research clusters namely,

Table 2 Top 10 journals in terms of publication numbers from 2018 to 2022

Disciplines	Publications
Civil Engineering	1073
Environmental Sciences	854
Construction Building Technology	590
Geosciences Multidisciplinary	381
Public Environmental Occupational Health	278
Green Sustainable Science Technology	274
Engineering Multidisciplinary	269
Instruments Instrumentation	269
Engineering Industrial	268
Water Resources	263

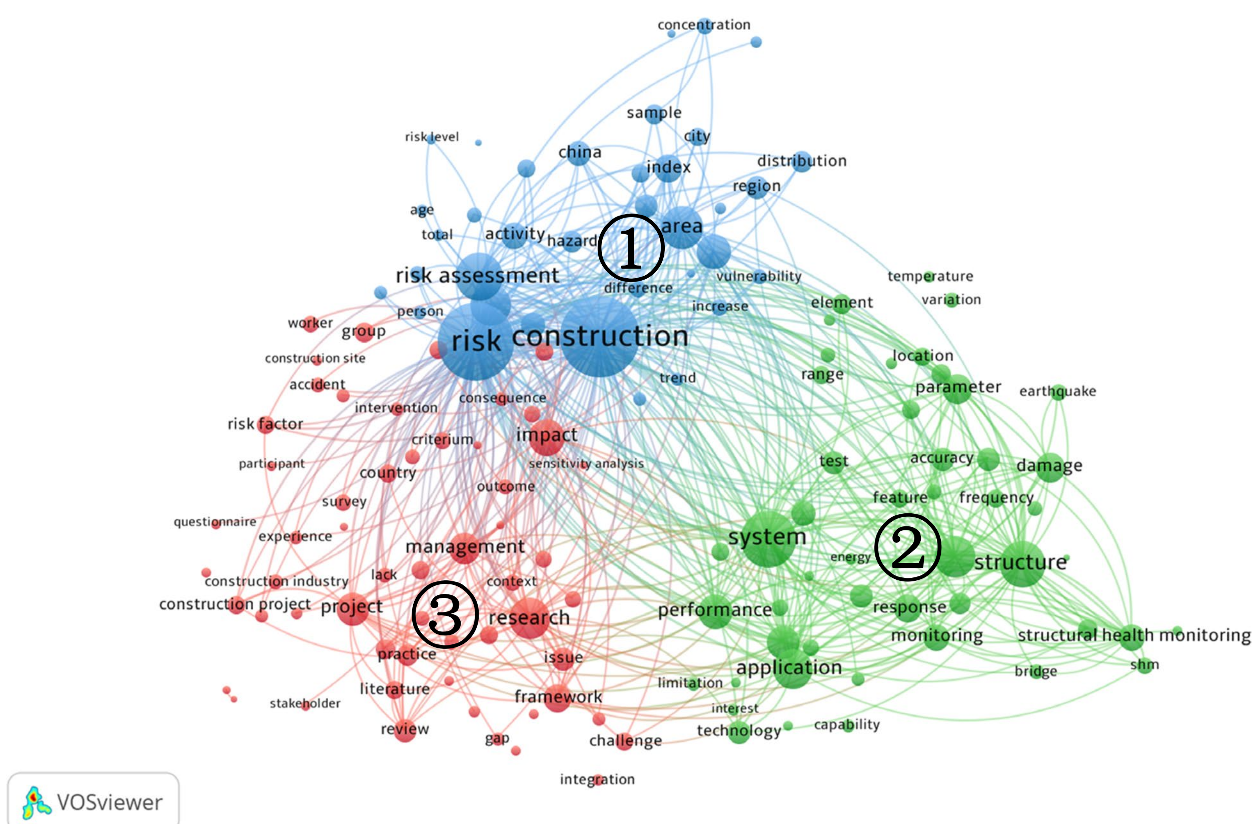

Fig. 1 Co-occurrence network of building safety research

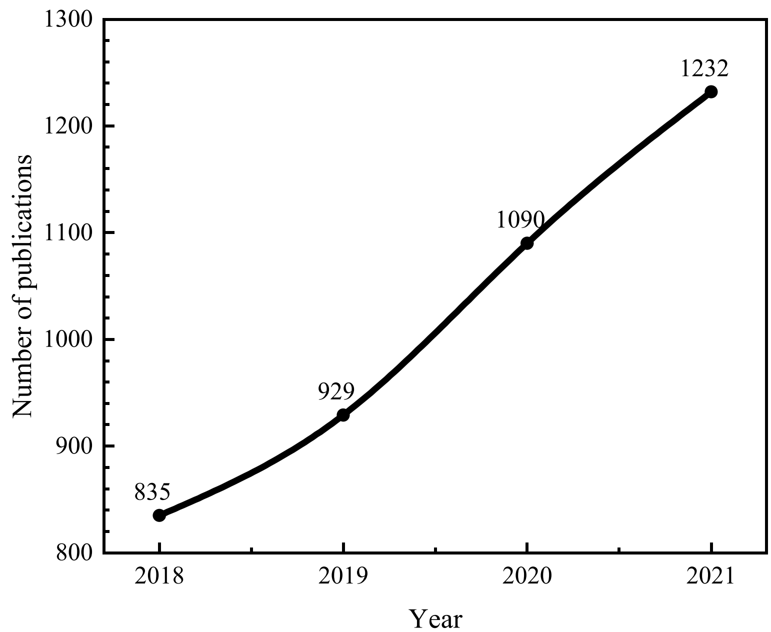

Fig. 2 Number of publications on house collapse from 2018 to 2021

construction risk assessment, structural health monitoring systems, and building project management.

2.2.1 Cluster 1: Building risk assessment

This cluster presents the highest co-occurrence and focuses mainly on the study of integrated risk assessment methods in engineering projects to avoid potential hazards. For example, Gunduz and Laitinen [9] introduced a new approach of risk assessment by introducing a probability law for better controlling risk level, which provides more accurate results. Similarly, Li et al. [18, 19] capitalized on entropy-unascertained measure theory to develop a new model for quantitatively evaluating the construction safety risks of renovation projects. Their model provided a new basis for safety management and control of building renovation projects.

2.2.2 Cluster 2: Structural health monitoring systems

The research associated with this cluster revealed that advanced sensor technology and data acquisition techniques enable the systematic detection of buildings defects in real-time [33]. The analysis of the collected data allows characterizing possible structural damage or non-linearities for telegraphing the integrity of a particular structure. Previous studies also show that it supports decisions on historic buildings conservation, design of new structures, as well as management of the life span of completed facilities. AI technology has also often been used in the structural health monitoring system to enable progress monitoring, schedule reliability alerts and forecasting, showing great benefits in terms of operational costs and ease of use [17, 40].

2.2.3 Cluster 3: Building Project Management

This cluster focuses on the study of the management and maintenance of existing buildings and infrastructure. It is closely linked to Cluster I and Cluster II. Through building risk assessment and structural health monitoring, building projects management be carried out more accurately and efficiently [3, 26]. Li et al. [20] explored the critical success factors and their interrelationships in the safety management of construction projects. They ultimately constructed a three-order system of construction success factors (CSFs) comprising six areas. In addition to building safety management, green building project management [38] and building materials management [12] are receiving more attention as the times go by.

Considerable advances have been made regarding research on building safety. While the main focus has been on building risk assessment and monitoring techniques, little attention has been put on the development of robust methods to understand the sequence of building collapse either qualitatively or quantitatively. Such paradigms are required for better understanding building collapse accidents, and so reducing associated losses.

3 Methodology

This study proposes a hybrid causality analysis approach for building collapse accidents. The proposed method combines the strength of two holistic methods including the system thinking and strategic environmental assessment (SEA) methods. Figure 3 shows the flowchart of the self-built house collapse analysis framework used in this paper. The system thinking approach is first used to analyze the causes of building collapse and delineates the direct and indirect triggers. It should be noted that the factors required for the system thinking analysis are delineated through preliminary survey and documented case histories. Then, the reliability of analysis pertaining to the management system of self-build house is enhanced via using SEA's six principles. To better capture the general idea of the proposed framework, a good understanding of its two main components is required.

3.1 System thinking approach

Systems thinking is a method that regards a problem holistically as component of an overall system (set of elements that interact to produce a behavior) and study how this problem interacts with the other constituents of that system [13]. This method promotes an understanding of the underlying drivers and dynamics of complex problems. Systems thinking approaches have been applied to various fields such as engineering, physical science, business management, and policy research [13]. This study will use this paradigm for analyzing the reasons for the collapse of self-built houses via linking the causative factors amongst them, and so, ascertain the key preventive measures. It other words, system thinking approach shall allow visualizing how various collapse causes are interrelated and contribute to the building failure.

Basically, systems thinking capitalizes on causal loop diagrams (CLDs) to ascertain the interactions between system elements and their global behavior. In the CLDs, elements are linked together through causality and polarity, which help define the direction of the influence. It should also be noted the main features of CDLs are feedback loops that can be reinforcing (R) or balancing (B). The former involves a reward that is introduced to promote a specific state/property, while the balancing loop is often characterized by a disruption stemming from state/property change. So, the link of causality and polarity is obtained by determining how one variable affects the other. If two variables A and B move in the same direction, the link from variable A to B will be labeled with a (+) and vice versa. Subsequently, after completing all the links in the loop, the resulting behavior is determined based on the polarity density.

3.2 SEA method

SEA is commonly used to assess management issues related to economic, cultural, human health, and environmental sustainability. In this section, SEA analysis is used to assess the risk probability score for the sustainability of rural self-built houses based on the six principles of SEA [31]. Specifically, it involves: (1) considering the sustainability principles integrally and systematically; (2) assessing projected environmental impact on the urban area due to policy plans and construction; (3) incorporating multiple and correlated impacts comprehensively; (4) paying more attention to the sustainability principles of

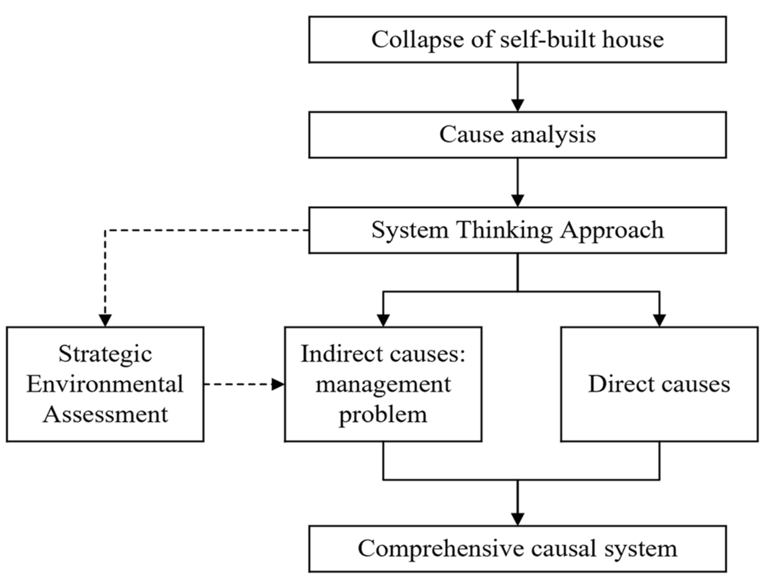

Fig. 3 Flowchart of the proposed self-built house collapse analysis framework

projects rather than PPPs; (5) monitoring and adopting measures to improve environmental management; (6) perfecting legal and public monitoring mechanisms.

3.3 Proposed hybrid system thinking—SEA method

The proposed hybrid strategy is established to ascertain the key causes of building collapse more comprehensively and accurately. The basic idea is to use the strengths of one to tackle the weaknesses of the other. For instance, the system thinking method can help delineate both direct causes as well as management related causes, which in turn can be enhanced by SEA. The incorporation of SEA with system thinking approach lies principally on the analytical interpretation of results. Indeed, after obtaining the results of the system thinking analysis, that of SEA enable enhancing the evaluation of managerial problems induced by policies, economy, culture, and environment, hence, providing a comprehensive overview of the collapse causes. Generally speaking, the implementation the proposed method can be divided into seven main steps:

Step 1: List the factors that cause the collapse of buildings.
Step 2: Determine the relationship between various factors.
Step 3: Use Vensim software [1, 32] to model interplay amongst collapse factors and get the cause-and-effect cycle diagram and cause tree diagram.
Step 4: Conduct a questionnaire survey on experts based on the six principles of SEA.
Step 5: Average the scores of experts to determine the scores of each principle in the SEA.
Step 6: Compare and integrate the final score of the SEA with the main information displayed in the causal cycle and causes tree diagrams.
Step 7: Deduce the main causes of the collapse and propose preventive countermeasures.

4 Case study: analysis of self-house building collapse in Changsha, China

A case of building collapse in Wangcheng District, Changsha City, Hunan Province is taken as case study to evaluate the performance of the proposed approach. Before elaborating on the collapse accidents, we first describe the status of self-build houses in China, which is critical for implementing the proposed approach.

4.1 Current status of self-built houses in Hunan, China

Following the brief discussion provided in the introduction, the current status of self-built houses in China can be discretized into four main components. First, the disordered layout of self-built houses in and their uneven scale has increased the pressure on management [16, 22]. Second, due to the poor construction funding base, and obsolete construction technology, the quality of self-built houses is not satisfactory and remain prone to safety hazards [10]. Third, due to the development of the rural economy, the number of self-built houses in rural areas is continuously increasing. Fourth, due to the limited professional level of construction and management teams, workers awareness on safety precautions is seldom raised, which makes it difficult to guarantee not only their safety, but also building integrity [14].

Nevertheless, some efforts have been made to strengthen the management of rural housing construction, regulate rural housing construction activities, improve the rural living environment, and promote the construction of beautiful countryside, according to the relevant laws and regulations. The Hunan Provincial People's Government has formulated the Hunan Provincial People's Government Decree No. 299 "Measures for the Management of Rural Housing Construction in Hunan Province", considering the current context [25]. This paper compares the management methods formulated by the Hunan Provincial People's Government article by article with the actual on-site practice. Then it quantitatively evaluates the above management methods based on the six principles of SEA.

4.2 Background of the collapse accident

Figure 4 shows the location of Changsha and an aerial view of the neighborhood near the collapsed house. The collapsed building was located near the north gate of Changsha Medical College. It was a six-stories half-brick concrete structure with a construction area of approximately 800 m^2. According to nearby merchants, the building was more than ten years old. Figure 5(a) shows the street view of the collapsed self-built house in 2020. It can be seen that the building had only five floors. Figure 5(b) reveals as of the year 2022, the same building had an additional layer above the original five floors. Then again, Fig. 5(c) illustrates the situation before the collapse, two more layers were built on the roof, which significantly increased the building dead load. It was also reported that after renovation operations, the building hosted a beverage shop on the first floor, a restaurant on the second floor, and a hotel above it.

On April 29, 2022, the aforementioned building collapsed, while the buildings next to it remained intact. Figure 6 shows a photograph of the scene captured from a nearby medical school. The figure shows that after the building collapsed, the rubble was piled up to two stories high, and the buildings on the side that did not collapse were partially damaged. Investigations revealed that on April 13, 2022, the engineering inspection company

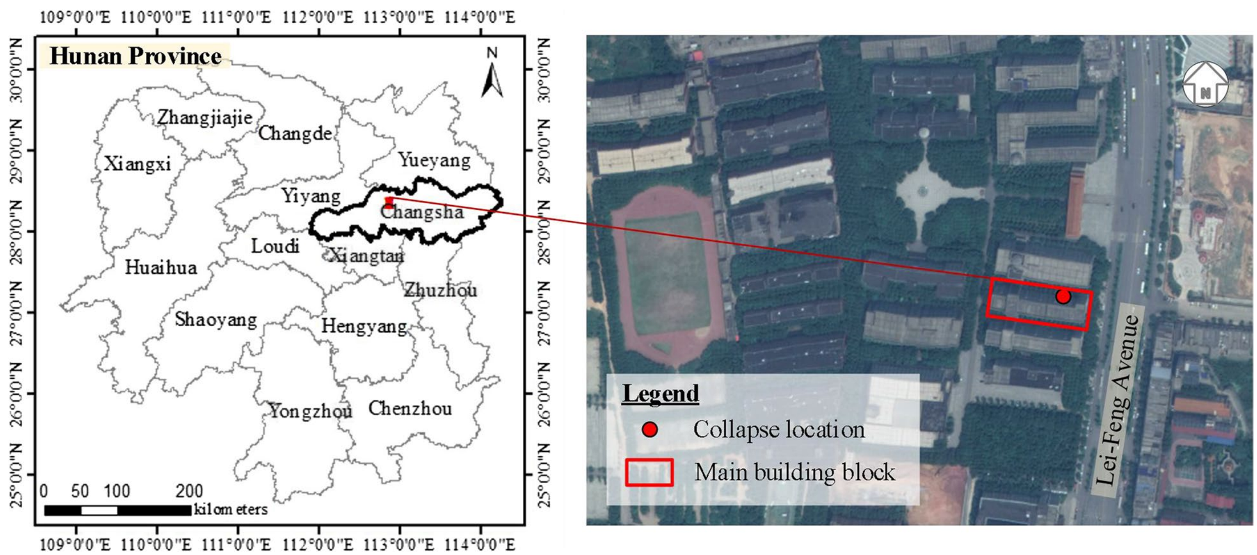

Fig. 4 Location of the building collapse site (picture source: Google map)

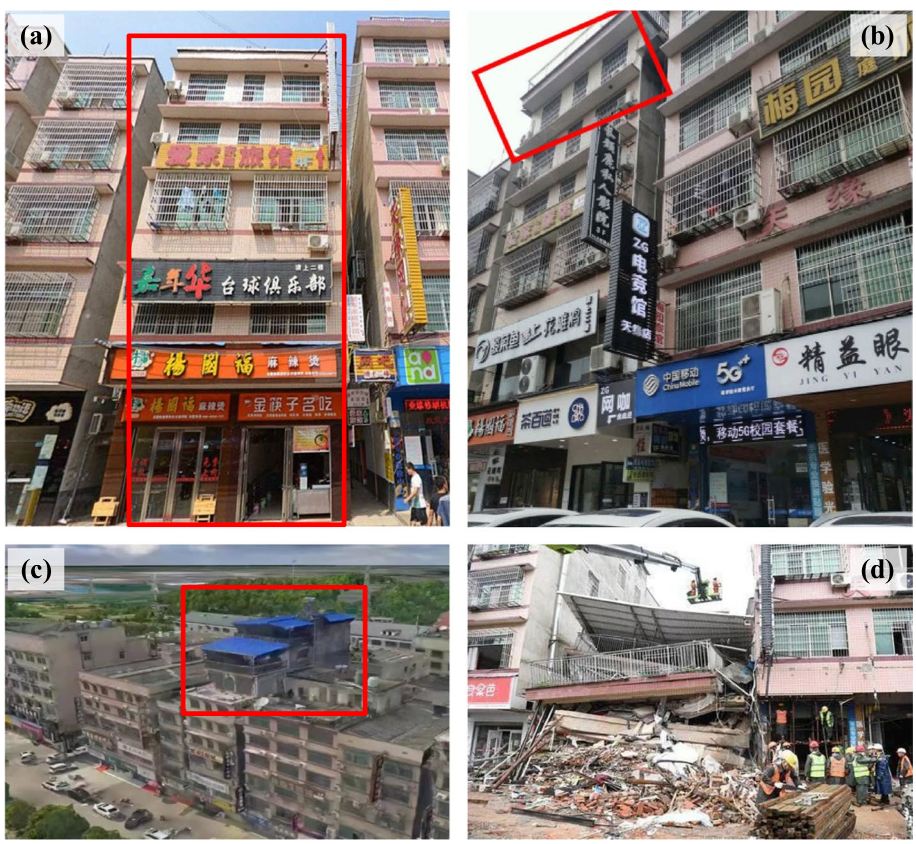

Fig. 5 Street view of the self-built house (**a**) in 2020 (original design); (**b**) in 2022 (with an added floor); (**c**) few days before the collapse accident (with additional floors), and (**d**) collapsed building. (source:https://m.sohu.com/a/542748839_121194189?scm=&spm=smwp.topic_146.spmc-feed-2-sub.8.1651452871152LMoCJGJ_56481)

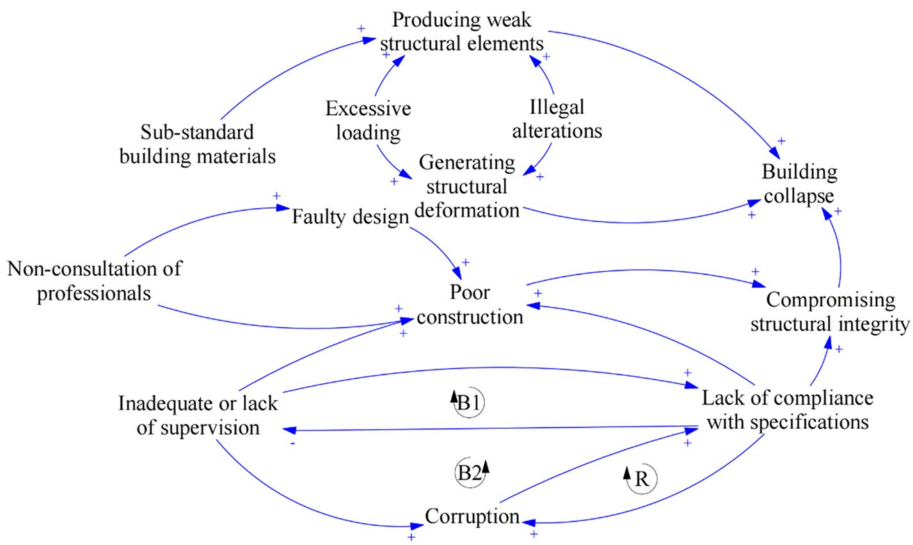

Fig. 6 Causal loop diagram for building collapse in Changsha

that was responsible for the house safety appraisal of the self-built family hotel (4th to 6th floor) issued a false house safety appraisal report. Legal representatives of the company were suspected of providing false certification documents. After the investigation, two workers who participated in the illegal renovation of the self-built house were suspected of major liability in the accident. Sadly, only ten persons were rescued alive while 53 were killed.

4.3 System thinking approach setup

This study capitalizes on a set of building collapse case histories from China and around the world to improve the selection of potential variables of collapse for the case investigated. The classification of these causes comprises primary and secondary categories, each of which is associated with the element or component(s) that failed under each cause and the area of specialty/stakeholder(s) responsible for the collapse. To further understand how various triggers interacted and lead to the collapse of the building, causal relationships amongst the different causes were established and analyzed. The factors adopted for this analysis are summarized in Table 3.

4.4 SEA method framework

This study conducted a questionnaire survey on 15 experts, compared the management methods formulated by the Hunan Provincial People's Government with the on-site implementation one by one, and conducted a quantitative test of the above management methods based on the six principles of SEA.

Table 3 Summary of factors delineated in the present case study

Factors	Description
Sub- standard building materials	Materials that do not meet the requirements of relevant specifications
Weak structural elements	Easily damageable structural element of the building
Excessive loading	Exceeding the maximum load that the building can withstand
Illegal alterations	Changes to the main body and load-bearing structure of the building without approval of legal services
Structural deformation	Deformation of structural components under external forces
Faulty design	Design that does not align with the provisions of laws and administrative regulations
Non-consultation of professionals	No professionals involvement in design, construction, and rehabilitation works
Inadequate or lack of supervision	Lack of reasonable supervision by relevant departments
Lack of compliance with specifications	Non-compliance with relevant specifications
Poor construction	Non-respect of building construction norms leading to building structures failure
Structural integrity	Cracks, fractures, and other phenomena occurring in buildings

5 Results

5.1 System thinking assessment results

The system-thinking software Vensim was utilizes to model the interaction amongst the collapse causes delineated in the previous section. Figures 6 and 7 provide the cause-and-effect cycle diagram and cause tree diagram of the model, respectively. The former was constructed in the Vensim software, while the cause tree diagram was subsequently generated according to the results of the cause-and-effect cycle diagram. In this diagram, B stands for balancing and R represents the reinforcing loops. In addition, numbers are used to label feedback loops. For example, B1 represents the first balanced feedback loop, and so on. The analysis of these results show that four main reasons underlined the collapse of the self-house building in this case.

(1) *Poor construction quality of self-built houses.* It is estimated that at the time of the building construction, the quality control process was not strictly followed. It was reported that the residents themselves mixed the concrete, providing no guaranties with regard to standards for buildings of this type. For instance, the quantity and bonding quality of floor reinforcements were determined by experience. Another example of this construction negligence is the poor loads lowering system. For example, a central load-bearing wall above the fourth floor was completely misaligned with the ones of the three floors below it.

(2) *Illegal alterations.* The creation of a medical school in the neighborhood brought about new business opportunities. It is suspected that the owner remodeled the original building (including alteration in load-bearing walls, adding of new floors and walls) to take advantage of this new economic ecosystem and satisfy his business needs. Indeed, first the construction of an additional floor transformed the building into a six-storeyed structure. Then, right after the accident, two more floors were built on the roof (see Fig. 4c), not only with brick-concrete structures but also with iron sheds, which significantly increased the structural load. Apart from that, this building that was originally designed as a residential building was illegally converted into a commercial building (hotel and restaurant). This contribute notablely increasing the live loads of the building to an extent that did not correspond to its original design.

(3) *Lack of monitoring and regulations enforcement.* In some remote areas of China, many self-built houses have not yet embraced the state-of-the-art application of design specifications, construction approval and quality inspection. The supervision, management, and enforcement of regulations for buildings in rural areas are yet to be strengthen by the local government.

5.2 SEA analysis results

Table 4 shows the results of the SEA assessment. Specifically, it shows that the self-built house lacks proper safety management mechanism, such as proper emergency inspection, strong administrative law enforcement and criminal justice. At the same time, self-built houses also lack a complete and systematic system to consider the sustainability principle and assess the environmental carrying capacity.

6 Discussion

The poor construction quality, illegal alteration, and control deficiencies are the three main aspects responsible for the accident. As self-built houses are built by farmers themselves to save money. The construction of self-built houses lacks specific design. During construction or renovation, the quality control process is not strictly followed. Moreover, rural housing construction is generally

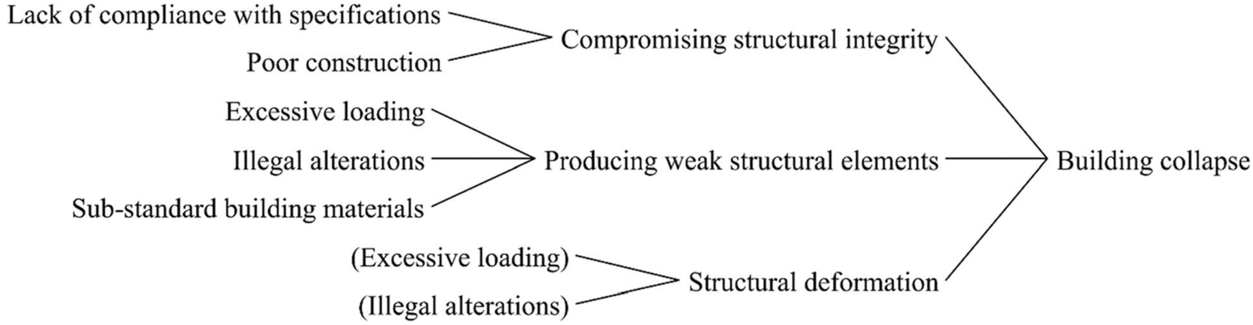

Fig. 7 Cause tree diagram for building collapse in Changsha

Table 4 Itemized evaluation of the management of rural housing construction in Hunan Province using strategic environmental assessment (SEA) principles

SEA Principle	Management of Rural Housing Construction	Score out of 5
1	Not perfect: there is no sufficiently complete and systematic system to consider the principles of sustainability	1
2	Not perfect: mostly considered before the project start	0
3	Not perfect: lack of proper emergency inspection, powerful administrative law enforcement and criminal justice	1
4	Not perfect: lack of assessment of the environmental bearing capacity	1
5	Yes: monitoring of environment during construction	1
6	Not perfect: no public involvement or appraisal	0
Total score		4

carried out secretly without approval from the government's technical and quality departments.

The case of hotel collapse accident in Suzhou substantiates the influence of weak construction quality and illegal alterations on building collapse [6]. Furthermore, the insights gathered from results analysis allow delineating some prevention measures for addressing the aforementioned deleterious aspects. These measures relate primarily to the enhancement of building safety management via ensuring quality assurance and quality control, risk assessment and structural health monitoring.

6.1 Quality assurance and quality control

In the case discussed herein, the building did not undergo a systematic inspection by the entities in charge of quality control throughout its construction and renovations processes. Yet, it is suspected that when the last operation of this type occurred, false certification documents were produced by the party in charge of the building safety appraisal. This accident, hence, underscores the urgency of tightening the construction control of self-built houses.

Moreover, raising awareness on the quality of materials as well as construction quality is critical for reducing hazard risks. Self-built houses must be able to effectively withstand various types of natural disasters, such as floods or storms, and simultaneously avoid adverse environmental phenomenon [7]. The choice of the building structure must be closely linked to construction technology.

6.2 Risk assessment of self-built houses

Risk assessment is widely adopted as an effective approach for predicting potential hazards in many engineering projects [2]. As such, it appears as a powerful management tool for self-built houses safety [43]. Many efforts have been carried out in recent years for developing effective risk assessment technologies. Methods based on multi-criteria decision making (MCDM) models such as, analytic hierarchy process (AHP), the technique for order preference by similarity to an ideal solution (TOPSIS) [21], the decision-making and trial evaluation laboratory (DEMATEL) [8, 47], have particularly become popular. Nevertheless, there is a great demand for assessment frameworks that evaluate the risk levels associated with building system's dynamic based on a robust metric (risk index). Such system should consider not only the extent and impact of each potential building collapse factor locally, but also the benchmarks (various levels) of building structural integrity in the construction of the risk index. It is also recommended to suitably map (e.g., geographical information system (GIS)) the whole system risk status to enable a real-time management and timely responses.

6.3 Structural health monitoring and AI warning system

The structural health monitoring of old buildings is urgently needed for reducing collapse risks. Unlike newly built buildings, old buildings were not equipped with monitoring devices at the time of construction, resulting in structural health monitoring difficulties. However, nowadays with the advance of technology, AI offers new opportunities for efficiently achieving this monitoring task [42]. AI methods are more and more performant in civil engineering (e.g., high dimensionality, non-linearity) with good prediction outcomes [41]. Besides, AI can rely on the collection of previous collapse cases or health monitoring data [11, 15] to establish a strong physics-informed model for improving the understanding of failure mechanism of buildings and provides a reference for future health monitoring. Building collapse is related to the building's age, structural transformation history, and material properties [35]. Therefore, when using an AI algorithm to predict a building structure [29], these influencing factors should be wisely represented for increasing the accuracy of the AI model [5]. Figure 8 proposes an indicative framework on how AI can be used to achieve/ enhance a warning system for building hazards.

6.4 Synopsis

Overall, the management of self-built houses requires the participation of local construction safety management departments and local government department to formulate a suitable safety management framework [16]. In particular, the investigation of construction conditions and improvement of the professionalism of the construction team are essential for ensuring the safety of self-built houses. Increasing and improving safety awareness of houses construction in rural areas is essential. Further, it is necessary to clarify the scope and objectives of safety management, scientifically eliminate potential safety hazards, and improve the safety level of self-built houses [35].

7 Conclusions

This study proposed an analytical procedure to evaluate the risk of self-built buildings. The proposed approach that combines system thinking and SEA approaches was tested through a building collapsed case in Hunan province. The lessons learned from this accident were delineated and chirurgical responses proposed. The mains conclusions are drawn as follows:

(1) The proposed combinatory approach allowed a comprehensive overview of the causes of building collapse, which can provide a way for urban management department to do decision. For instance, the score of 4/30 obtained via SEA analysis indicate the need to reinforce building management from various perspectives.
(2) The causes of the collapse are primarily anthropogenic, and include the poor construction quality, illegal alterations, and lack of regulations enforcement. Artificial intelligence offers AI offers promising opportunities for efficiently achieving this structural health monitoring and early warning system for building at risk in remote areas.
(3) The key prevention measures for abating the risk of building collapse in rural area involve reinforcing regulations/management for ensuring quality assurance/quality control, efficiently assessing safety risk, and timely performing structural health monitoring.

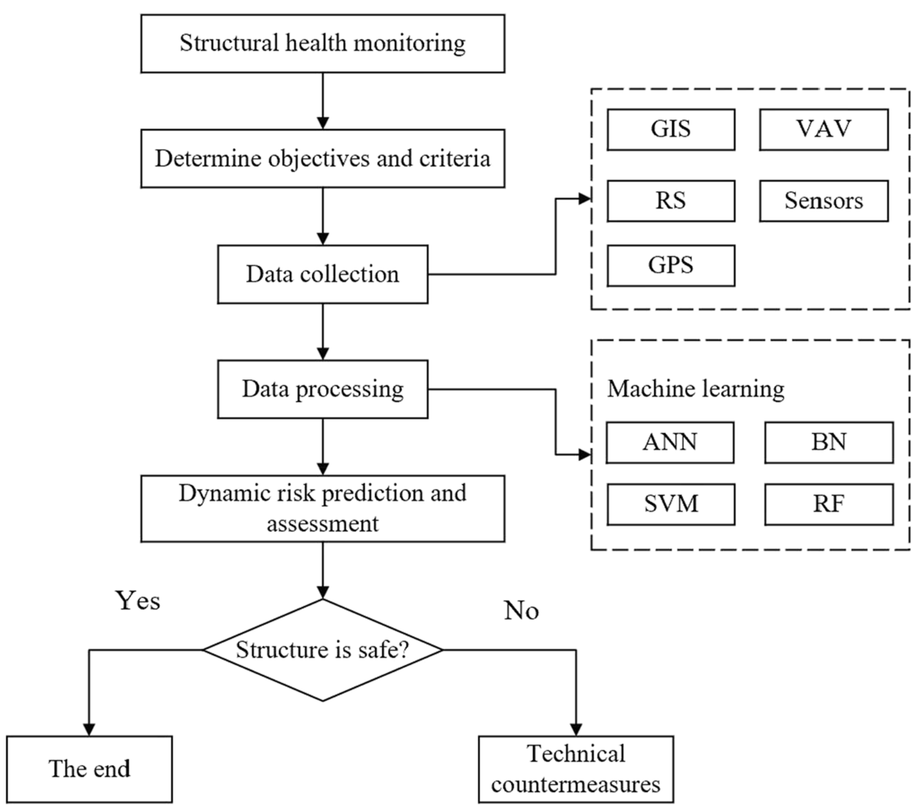

Fig. 8 Proposed framework for using of AI technology in structural health monitoring

(4) Structural health monitoring and AI warning systems are viable strategies for reducing collapse risks. Yet, they are bound to enhance the current status of self-built houses in Hunan.

The proposed study is essentially qualitative, which may limit its robustness. Future studies shall incorporate quantitative parameters and or sophisticated fuzzy systems to enhance the performance of the proposed approach. Moreover, prevention and risk abatement measures is bound to be improved by AI and novel information technologies.

Authors' contributions
Yu-Ting He: Investigation, Data curation, Methodology, Writing-Original draft preparation. Pierre Guy Atangana Njock: Conceptualization, Supervision, Visualization, Reviewing and Editing.

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Availability of data and materials
No data was used for the research described in the article.

Declarations

Competing interests
Pierre Guy Atangana Njock is an editorial board member for Smart Construction and Sustainable Cities and was not involved in the editorial review, or the decision to publish, this article. All authors declare that there are no other competing interests.

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