Performance Evaluation of Control Variables for the Development of a Blockchain Model for Construction Projects

Debasis Sarkar and Purvesh Raval

Abstract Many factors affect the progress and life cycle of a real-estate project. Therefore, evaluating such factors has become an indispensable and fundamental component of every firm operating in the real-estate industry. This paper aims at identifying and evaluating the control variables associated for the development of blockchain model applicable to construction projects. When a cutting-edge technology like blockchain is applied to this kind of job, it has the potential to become far more efficient. As a result, the purpose of this research is to develop a preliminary process framework that can direct users who are interested in utilising blockchain technology as a tool, as well as to identify the factors that influence the use of blockchain technology as a smart contract, supply chain management, and financing instrument tool by presenting them in the form of key performance indicators (KPIs). Eight major project factors like technology, organisation, finance, environment, BIM, data management and security, input–output, and project-process related have been identified. Subsequently significant KPIs have been identified under each category. Multi-criteria decision-making (MCDM) tool analytic network process (ANP) is used to establish the weights of the criterion based on the replies from three-stage questionnaire surveys performed among industry professionals working for prominent construction businesses in Ahmedabad, Gujarat, India. This study will reduce the possibility of time and cost overrun and enhance the probability of successful completion of a project within stipulated time and cost frame.

Keywords Building information modelling (BIM) · Key performance indicator (KPI) · Analytic network process (ANP) · Blockchain

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1 Introduction

The integrity and dependability of data may be significantly improved with blockchain technology, a system that links blocks of infThe industrial landscape is undergoing a rapid transformation due to the fourth industrial revolution (4IR), which is defined by the convergence of developing technologies. The construction industry is not an exception, and numerous convergence activities have taken place due to the integration of various emerging technologies. Some examples of these technologies include building information modelling (BIM), drones, augmented reality (AR), 3D printing, enterprise resource planning (ERP), virtual reality (VR), the Internet of Things (IoT), and blockchain technology, among others (Kim et al. 2020). This investigation focuses on the performance evaluation of control variables for developing the BIM-integrated blockchain model for construction projects. This new technology integration is one of the topics covered in this investigation.

ormation together like links in a chain. The article "Blockchain Technology Development Strategy" (Korea Institute of Science and Technology Information 2018) identifies blockchain technology as one of the emerging technologies that ensure data reliability and security while increasing efficiencies. Blockchain technology is one of the technologies expected to have a significant impact in the future. The technology behind blockchain makes it possible for members in a network to work together to record, validate, store, and extract information without the need for a centralised data middleman. Which of the following best describes a distributed ledger system that encourages decentralisation, openness, and data integrity? (Seo 2017). Blocks are connected in order of their creation sequence, and within each block is a collection of transaction records that each has their unique hash value. When opposed to a centralised database system, the fact that the identity of each block is determined by its hash value and that of the block that came before it makes it far more difficult for the data to get corrupted. Using blockchain technology has several significant benefits, such as lowering transaction costs, making it harder to fake or change data, and giving people more freedom.

In their research, Tezel et al. (2020) observed that the construction sector receives criticism for moving slowly to adopt new technologies. Real-time asset tracking, smart contracts, and crypto-currencies may improve commercial transactions in the construction sector. The major issues of construction sector are the lack of motivation to adopt and implement new technologies. Undergoing digital transformation by construction industry is also the need of the hour. There are lot of issues in the traditional procurement system, lack of coordination among the various hierarchy levels of the construction industry, lack of cooperation between the various stakeholders, poor management of resources, unhealthy competition and also very less profit margins are real concerns of the construction industry. The proposed blockchain model would definitely take care of most of these concerns of the construction sector.

2 Background

The technology behind blockchain is one of the most revolutionary developments of the past ten years. Its ability to record, enable, and secure a vast number of different types of transactions raises an intriguing question: can the same distributed ledger technology that powers bitcoin also enable better execution of strategic projects in a traditionally conservative industry like construction, which involves large teams of contractors and subcontractors as well as an abundance of building codes, safety regulations, and standards? According to David Bowcott, global director of development, innovation, and intelligence in Aon's Global Construction and Infrastructure Department, "Increasingly, we are thinking more carefully about when and where we need to compete and what can we share and collaborate on." Saving money, freeing up significant resources, and accelerating the completion of these complicated projects might all be accomplished by using blockchain technology to automate the contractual processes and paperwork that underpins them. (Quotes are taken, unless otherwise specified, from interviews that we did as part of our research). Genuine estate construction and development projects enabled by blockchain in the commercial real-estate sector, HerenBouw, based in Amsterdam, is utilising blockchain technology for an expansive development project in the city's harbour. According to Marc Minnee, the founder of Propulsion Consulting, HerenBouw's goal was to establish a project management system enabled by blockchain technology to make the building construction life cycle more efficient. The application Minnee developed for HerenBouw to employ blockchain technology focuses on registering transactions at legally critical moments, an area where precision and an audit trail are critical. "Blockchain provides a platform for visibly cascading work items down the chain and holding everyone accountable for accomplishing essential tasks," said Minnee. "Blockchain has the potential to revolutionise the way work gets done." Information prompt, clear communication, and fewer errors are some of the benefits offered by the system. According to Minnee, "Stakeholders have a clear and evenly distributed motivation to register these facts on-chain: Either you will not get what you purchased or get paid." They also build trust with one another, which helps to make their respective business processes run more smoothly. "Stakeholders spend more time exploring creative design and building process possibilities," according to the report. Launch of blockchain project pilots are currently under construction (Tapscott et al. 2019).

According to estimates provided by Aon, a worldwide risk adviser to the construction industry, 95% of the building construction data is lost when the building is handed over to the first owner. Briq, a blockchain company based in California, showcases the potential to capture and secure the documentation of a construction project in a blockchain ledger. This ledger is accessible to all parties involved in the project, and it can be given to the owner as a deliverable. Briq, a company based in Minneapolis, was hired by Gardner Builders to create a "Digital Twin" of a newly constructed office building. This "Digital Twin" included an inventory of every asset, broken down by room. According to Bassem Hamdy, CEO of Briq, "when a product or specification has to be discovered in a building, there is finally a location to search for what is actually in that building.

When a product or standard needs to be found in a structure," the specs stored in blockchain are very comprehensive. They include paint colours, ceiling fittings, LED bulbs, and door hardware. Additionally, they include user manuals, warranties, and a countdown clock that building owners can monitor. "Any improvements and refurbishments to the building can be documented, and the whole repository can be transferred to new owners if the asset is put up for sale," said Ellis Talton, Briq's director of growth marketing. "If the asset is put up for sale, the repository can be transferred to the new owners," said Talton. To put it another way, the building owners are provided with a living ledger that details everything that has occurred with the building, overcoming cultural obstacles (Tapscott et al. 2019).

Established procedures in the building industry may slow down the general deployment of blockchain technology. "The construction business is technologically advanced in many facets of it does," said Talton. "The industry as a whole is very innovative." However, a strong emphasis is placed on personal connections in this field. Many businesses are privately held and owned by families. Relationships that have existed for decades can be considered when choosing general contractors and subcontractors. Talton further mentioned that very little money, less than one percent of revenues, is put into up-front contracting and IT infrastructure for managing complicated building projects (whereas in aerospace and automotive, this amount ranges from 3.5% to 4.5%). According to him, "the building process, including the people and materials, accounts for the great majority of the costs associated with the project." According to Scott Nelson, CEO of Sweetbridge, blockchain-based project management might work particularly well in the construction industry: "Projects are well-structured, and their foundation is in contracts". The goals are crystal clear: complete the task on schedule, according to specification, and without rework. Traditional project management methods are still effective, but some projects could benefit from a more decentralised and agile approach. In such an approach, transparency is prioritised, and participants can be reimbursed for labour performed and for results achieved. The potential applications of blockchain technology in project management has been explored and implemented by Tapscott et al. 2019).

Blockchain technology will eventually have game-changing applications in the field of project management. We strongly recommend that organisations investigate and make the most of this potential. Here are a few steps that come next. Determine the various applications that could benefit from using blockchain. Look for places where the endeavour's success depends on mobilising resources outside the organisation's limits, where identities, contracts, and payments must be audited and protected, and where the provenance and ownership of assets must be tracked.

Build prototypes and get the first feedback from pilot programmes. Carry out a first investigation: Audit the systems that are now being used to talk to the people who are already utilising them, and think about who would need to be engaged in determining feasible solutions, selecting one to prototype, creating the pilot, and engaging in testing. Develop a rationale for why investing in blockchain will benefit your company. Find ways how blockchain can improve project success, such as increasing procedures and organisational ability to identify and exchange vast volumes of data with specified persons and entities. According to David Bowcott of Aon, "Collectively, we are all better off if we encourage data collaboration and use blockchain and machine learning to help us establish longer-term industry road maps for investments and technologies that can boost productivity and efficiency and lessen risk." Even while project management principles will continue to be essential, blockchain technology makes it possible for managers to concentrate their efforts on finding solutions to challenges and improving the quality of the project's deliverables (Tapscott et al. 2019).

3 Objectives and Problem Statement

The primary objectives of the research are as follows:

1. To perform bibliometric analysis for significant keywords of this research.
2. To study the control variables for the development of a blockchain model and to evaluate the performance variables through a multi-criteria decision-making (MCDM) tool for construction projects.

4 Literature Review

4.1 Performance Evaluation of Control Variables for the Development of a Blockchain Model

There is a chance that the model for the information flow computation of seven key performance indicators will be able to eliminate the slowdowns in project performance caused by the wrong structure and measurement of information (Bapat et al. 2021).

According to Coates et al. (2010), it has come to light that key performance indicators (KPIs) make it possible to organise and display information in a systemic manner, which is necessary for reliable assessment and monitoring of business benefits brought about by BIM adoption. As a consequence of this, KPIs can serve as a method for comparing the success of various BIM adoptions about the following objectives: measuring the quality of projects; standardising information and measurement processes throughout the community; setting appropriate benchmarking targets, and recording the effectiveness of action. (Demediuk et al. 2021).

To prioritise KPI using factor analysis, Sarkar (Tapscott et al. 2019) conducted a questionnaire survey with 69 different respondents. There are 41 KPIs, and 15 of them have been determined to be the most important. Additionally, the process flow for effectively using BIM in facility management has been outlined in a sequence that makes logical sense. Since only a few years ago, the use of BIM in the offsite building has been increasing significantly, a barrier that prevents the varied output formats of BIM software from being interoperable has emerged due to the lack of widespread adoption of universal BIM standards. In order to facilitate the dissemination of information, Nawari (2012) produced the "Model View Definition" handbook. According to Becerik-Gerber et al. (2012), traditional construction engineering and management have been unsuccessful in resolving the challenges that have arisen due to incorrect communication flows between members of the project team and inefficient management in the AEC industry. They have also implemented a remote construction monitoring system in addition to the virtual collaboration technique that they are using for this project. Sarkar (2011) created the conceptual framework for incorporating risk management into BIM. Because of this integration, risk can be evaluated stage-by-stage throughout the project (Becerik-Gerber et al. 2012).

Additionally, BIM is in charge of risk management on the floor above it, which can improve project performance through planning the project and monitoring it at a more granular level. A safety risk management strategy may be valuable to a project if the project manager can properly combine safety management with building information modelling (BIM). According to Sarkar (Tapscott et al. 2019), early clash detection of MEP services can acquire the targeted project performance increase for urban transportation projects in India, such as mass rapid transit systems (MRTS). This research has also helped the architecture, engineering, and construction (AEC) industry by making an excellent framework for integrating BIM and risk management (Sarkar and Gujar 2021).

The analytic hierarchy process (AHP) and the analytic network process (ANP) are two similar decision-making multi-criteria decision-making (MCDM) procedures that Saaty first presented in 1980, 1996, and 2006.

5 Bibliometric Analysis

The VOS viewer incorporates not one, not two, but three distinct methods of analysis: network visualisation, overlay visualisation, and density visualisation. The magnitude of each circle depicts the significance of the corresponding term. The proximity of two circles represents the connection that exists between the two circles. When the affinity is more robust, the distance between the two places is shorter, and when the affinity is weaker, the distance between the two places is greater. The circle's colour indicates the cluster that the circle is a part of, and there are several different clusters, each of which is represented by a unique hue.

A representation of a network is shown in Fig. 1. Within the red region, BIM serves as the central focus, and the degree to which the phrases "facility management (FM)," "construction process," and "design phase" are related to one another begins to recede. The majority of the publications are focused on facilities management (FM), whereas the construction and design sections are lacking. The phrase "life cycle" serves as a bridge between the red and green sides. According to the study of the data visualisation, the terms in the green region have "production" at their centre, with "Sustainable Development" and "life cycle assessment" related to it. However, the phrases "construction industry" and "BIM" are located at a significant distance from the phrase "Sustainable Development," which indicates that it is of lower relevance. The association with the entire life cycle is also meaningless to consider. This circumstance, or the lack of progress in the construction sector, is mirrored in the development of sustainable building practices (Nawari 2012).

The depiction of the research trend with time as the criterion is shown in Fig. 2. The terms related to BIM as the core are highlighted since this has been the primary focus of study over the last five years. As a result, the following present picture of the field may be disclosed based on the bibliometric study, which is described in Figs. 1 and 2.

It is currently in the preliminary and intermediate stage, but the integration of BIM and network systems can support the improvement of the construction and operation phases of the architecture, engineering, and construction (AEC). This integration makes it easier to retrieve and manage information, and it is currently taking place.

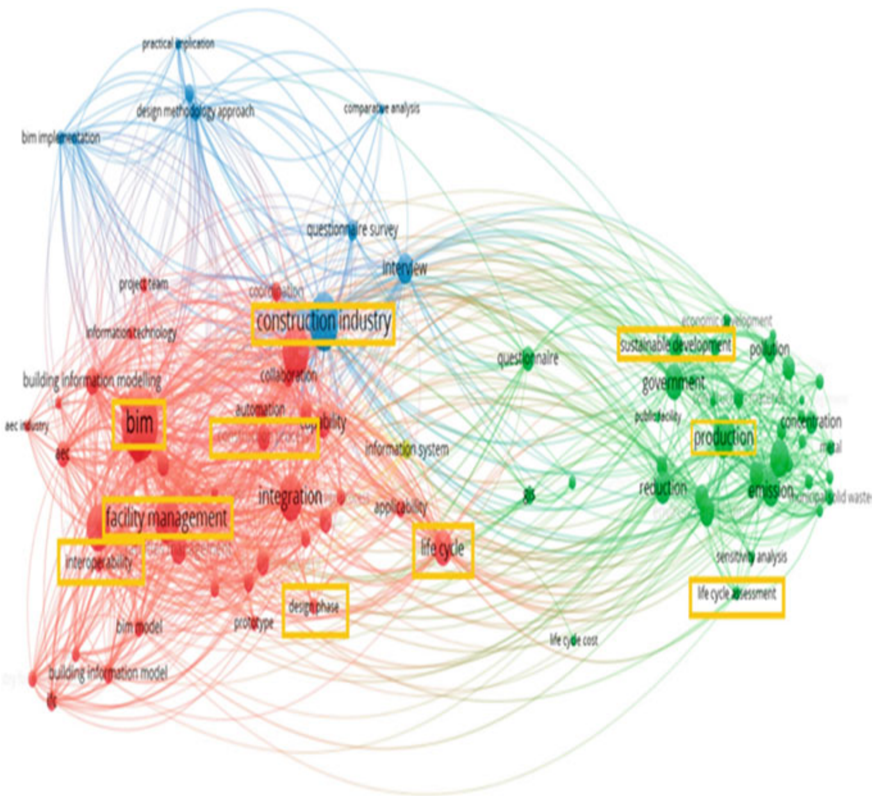

Fig. 1 Visualisation of research hotspot or major cluster sets and keywords in the construction industry via VOS viewer

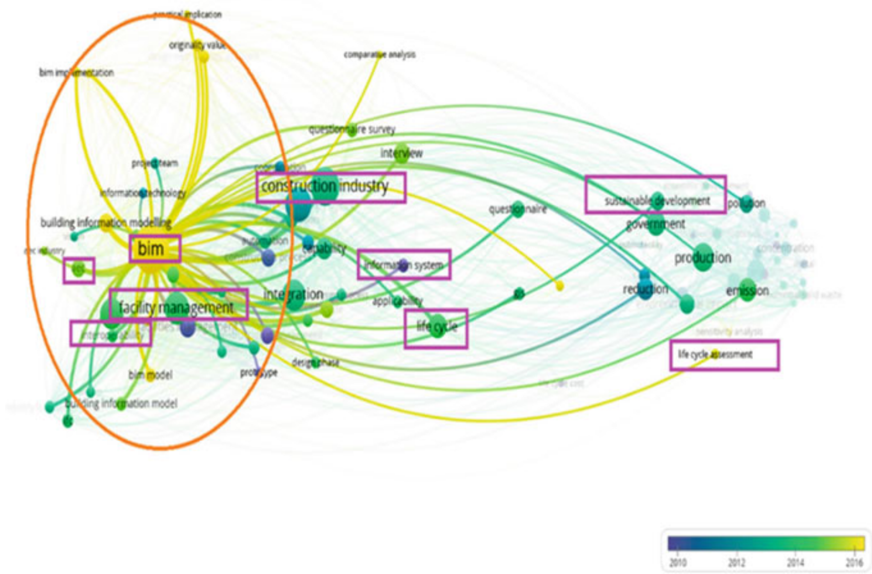

Fig. 2 Visualisation of research hotspots in the construction industry

The utilisation of BIM over the entirety of a building's life cycle presents both opportunities and challenges. There is still more work to ensure the interoperability of data information across the building life cycle.

The facility management phase attracted more attention than the building design, construction, and maintenance stages throughout the study into the construction industry and BIM. The concept that problems with the life cycle should be addressed early on has received much attention in recent years.

As shown in Fig. 3, the construction sector has undergone a digital transition in recent years, which may be considered an emerging trend. This will become the dominant development trend in the construction business in the foreseeable future, and it is worthwhile to investigate the application of blockchain technology in the construction sector (Nawari 2012).

The Scopus database was searched to get the articles that were analysed. Scopus provides a more diverse selection of articles (Echchakoui 2020) In addition, Scopus is among the most exhaustive databases of journals that have been subjected to peer review. In April of 2022, a search for published works on the Internet was carried out using the terms "building information modelling" (BIM) and "blockchain" as the beginning keywords. It was determined to search for certain types of literature, including journals, conference proceedings, title terms, and years. During the preliminary investigation, 127 publications about scientific literacy were discovered, 89 of which were engineering-related. The Scopus database's indexed copies of the articles that matched the criteria were culled. This data does not contain newspaper articles, books, book references, or book chapters. A total of 89 items were selected from the

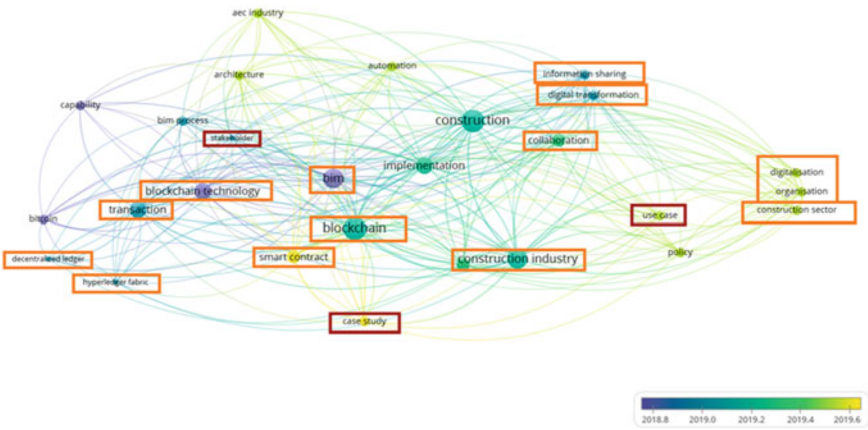

Fig. 3 Visualisation of research hotspots in the application of blockchain in the construction industry

total of 127 that were mentioned. The paper had been downloaded in CSV format before it could be processed using the VOS viewer. This would allow for the patterns in the bibliometric form to be shown and analysed (Jan et al. 2009). The number of keywords utilised may be changed according to one's preferences, and less important keywords can be eliminated. Using the VOS viewer programme, it is possible to mine data, create maps, and organise the articles that have been obtained from the database. The overlay of BIM and blockchain in Fig. 4, made with the VOS viewer, shows how important both are in the real world. (Echchakoui 2020).

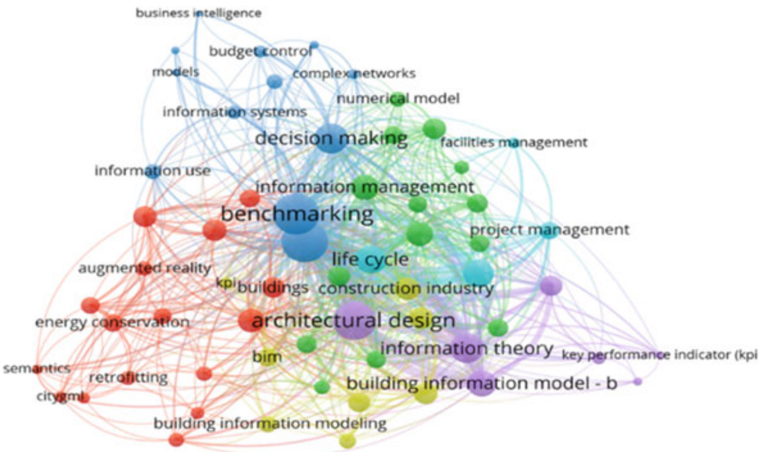

Fig. 4 Overlay visualisation of BIM and KPIs

For a more in-depth bibliometric study, see here. KPIs have been substituted for the blockchain term. A total of 82 papers have been recognised as having some study on KPIs associated with BIM. This term has been used a total of 141 times in research articles, and it is used three times in each study. It provides an overlay representation of BIM and KPIs-related papers studied in the VOS viewer programme, as seen in Fig. 2. This demonstrates how vital key performance indicators are about building information modelling (BIM).

As part of the ongoing bibliometric research, the term "blockchain" was included in the list of keywords alongside "BIM" and "KPIs." This returns the result that there were no documents discovered. This suggests that most academics are attempting to connect BIM with other types of technology but that no one has begun research to determine key performance indicators for the integration of BIM with blockchain. Based on these data, identifying key performance indicators (KPIs) for any new technology is shown to be significant. Also, this kind of identification is essential for the future of realistic development and to help researchers work in this direction so that BIM and blockchain can be used together (Nawari 2012) (Fig. 5).

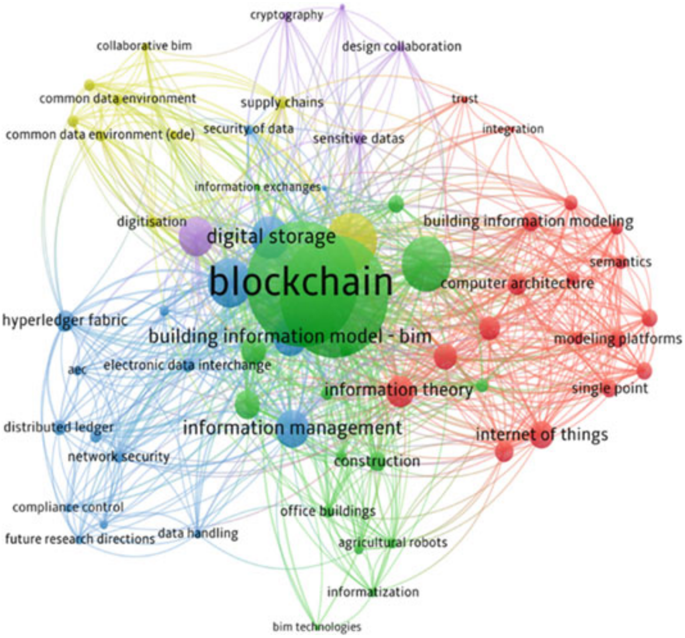

Fig. 5 Overlay visualisation of BIM and blockchain

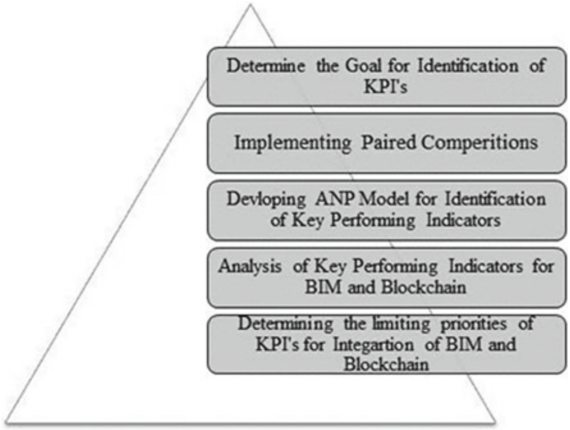

Fig. 6 Algorithm of ANP model for identification of control variables

6 Conceptual Framework

It is necessary to evaluate various control variables to develop the blockchain model by identifying the key performance indicators (KPIs). Because of this, it is first necessary to list out all potential variables related to the development of integrated BIM and blockchain technology. This will allow for improved performance of construction projects that use blockchain technology. The fundamental framework, which Gongbo and Shun (2011) made effective use of, has been chosen. Based on these essential control variables, which comprise 201 in total, the process of determining key performance indicators (KPIs) will be carried out to construct a complete framework. The key performance metrics were generally broken down into eight different categories, which are (i) associated with technology; (ii) associated with organisations; (iii) associated with finances; (iv) associated with the environment; (v) associated with building information modelling; (vi) associated with data management and security; (vii) associated with input and output, and (viii) associated with projects and processes (Gongbo and Shun 2011) (Fig. 6).

7 Methodology

This section describes the process taken to perform the systematic literature review and describes its results, including the extensive list of challenges and opportunities compiled from the literature that informed the development of the framework and bibliometric indicators that describe the body of literature reviewed. In addition, the remaining research methods used to develop the framework are explained, namely a focus group discussion, an in-depth interview, and the socio-technical systems approach adopted.

A preliminary survey was carried out with the use of these possible markers. A well-structured questionnaire was developed to investigate the use of BIM and blockchain technologies once the building phase is complete. The questionnaire was divided into three distinct parts when it was constructed. In the initial part of the survey, we gathered some basic information about the respondents, and we also asked them a few questions to better determine their level of technological savvy. In the second and third sections of the pilot survey, the respondent is asked to rate the significance of the indicators that have been discussed thus far on a scale that ranges from five (extremely important), four (very strongly important), three (strongly important), two (moderately critical), and one (not at all important). In Ahmedabad, Gujarat, those individuals who had some kind of direct or indirect connection to the building information modelling (BIM) business were the focus of the inquiry. The group of people who used BIM comprised professionals from various fields, such as architects, structural engineers, electrical engineers, plumbing experts, HVAC experts, project management consultants, and other BIM service providers. Around 15 industry people from Ahmedabad and the surrounding area in Gujarat who were directly or indirectly involved with BIM technology were handed the questionnaire. There were 12 "yes" answers from these people who were asked to be respondents.

In Annexure 1, the key performance indicators (KPIs) associated with the performance evaluation of control variables for the development of the blockchain model are listed, beginning with F1 and ending with F201, together with the reference.

8 Case Study and Analysis

Building information modelling (BIM) is one of the most exciting innovations to emerge in recent years in design, engineering, and construction. Even though its use is still relatively new and there is much to learn about it, it is altering how contractors and engineers conduct business. Observing the implementation of BIM by other companies and their successes and failures along the road is one method for gaining knowledge in this area. BIM was initially developed more than a decade ago to differentiate the information-packed architectural 3D modelling from the conventional 2D sketch. It is being lauded as a saviour for complex projects by those who support it due to its capacity to repair problems early on in the design stage and precisely schedule construction. This ability is the primary reason for this praise.

BIM has seen a surge in popularity in recent years, there is still no consensus over how to define it. "BIM is the virtual representation of the physical and functional aspects of a facility from its origin onward," said Patrick Suermann, PE, a testing team leader for the National Building Information Model Standard (NBIMS). As such, it functions as a shared information repository for cooperation across the whole life cycle of a facility. According to the National Institute of Building Sciences (NIBS), it is "a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle, defined as existing from its earliest conception to its demolition." [citation needed] In general, however, building information modelling (BIM) technology enables the digital construction of an accurate virtual model of a structure. The finished computer-generated models contain precise and well-defined geometry and relevant data required to aid the construction, manufacturing, and procurement processes necessary to materialise the final building. These models may be found on the computer (Nawari 2012).

BIM is a desktop computer environment that includes 3D modelling concepts, information database technology, and interoperable software. This environment can be used by architects, engineers, and contractors to design a facility and simulate its construction. BIM is the primary component of building information modelling (BIM). Because of this technology, members of the project team can develop a virtual model of the building and all of its systems in three dimensions, which can communicate the information they have generated. The building geometry, spatial linkages, quantitative characteristics of building components, and geographic information are some of the aspects that are included in the model. Similarly, the drawings, specifications, and construction details are vital to the model. The project team can swiftly identify design and construction concerns and find solutions to those issues in a virtual environment far before the construction phase in the physical world.

Therefore, BIM is a procedure that you use to collect and manage building data throughout the life cycle of a project. Building design and construction often benefit from utilising three-dimensional, real-time, and dynamic software. This helps to control and improve overall efficiency. The process results in the production of the building information model, which incorporates all of the pertinent data relating to the geometry of the building, the spatial relationships within the building, the geographic information, and the quantities and properties of the building components. Contractors, architects, engineers, and others in the construction industry are continually looking for new methods to enhance the BIM process, causing construction technology to continue to advance over time. According to Chuck Eastman, director of Digital Building Laboratory, one of the many significant advantages that may be gained from making use of modern BIM design tools is that it: at this point, they define objects using parameters. That is to say, and the objects are described in terms of parameters and relations to other objects so that if a change is made to a related object, this one will likewise be updated to reflect the new state. Objects that use parameters can automatically re-build themselves by the rules that are inherent in them. The requirements may be straightforward, such as requiring a window to be entirely contained within a wall and moving the window along with the wall, or they may be intricate, specifying size ranges and addressing aspects such as the actual link between a steel beam and column (Nawari 2012).

The questionnaire includes two essential topics: blockchain technology and BIM. Participants were asked to rate how interested they were in adopting blockchain technology for supply chain management and smart contracts on a scale from one to five. This was part of the inquiry that asked respondents about their interest in using blockchain technology (from extremely interested to not at all interested). The outcome was dominated by weighting (3) being interested, at 44.44% of the total. Other rank distributions were as follows: (4) highly interested for 29.63% of respondents; (2) moderately interested for 22.22% of respondents; (1) somewhat interested for 3.7% of respondents; and (0) not at all interested for 0% of respondents. This demonstrates that individuals are interested in using blockchain for BIM, even though there is not currently a substantial available framework.

9 Result Interpretation

The findings of the ANP as a whole demonstrate that technologically linked aspects have gotten the highest amount of attention out of all of the KPIs. This is measured in terms of the relative relevance of each KPI compared with the others. The following is a list of the additional aspects in descending order of how important they are: BIM, the environment, data management and security, organisation, project-process, financial considerations, and input–output relationships. This result is supported by the fact that the weight given to the technology-related factor is 0.265, which is much higher than the weights given to any of the other factors when those factors are evaluated to make an integrated model that combines BIM and blockchain (Table 1).

Table 1 Ranking of major factors based upon normalisation

Sr. No	KPIs	Normalised	Idealised	Rank based on the calculated weight from the study
1	Technology related factors	0.265	1.000	1
2	Organisation related factors	0.125	0.472	5
3	Finance related factors	0.048	0.181	7
4	Environment related factors	0.143	0.540	3
5	BIM related factors	0.182	0.687	2
6	Data management and security related factors	0.137	0.517	4
7	Input–Output related factors	0.039	0.147	8
8	Project-Process related factors	0.061	0.230	6

10 Discussion

The findings of this study demonstrate how well the ANP approach works for examining the KPIs for the use of blockchain technology in the construction sectors. It has been noted that eight important components have been grouped together from the 201 discovered KPIs. The most crucial aspects may be determined by prioritising and ranking these eight factors using the various MCDM approaches. For effective project implementation without significant schedule and expense overruns, the project authorities might apply corrective and preventative mitigation measures.

By integrating blockchain and building information modelling (BIM), a construction project may have a single source of truth for all of its details (Kim et al. 2020). A trustworthy digital twin of the asset, such a model may assist with its design, development, operation, and maintenance throughout its existence, to make a model of the blockchain and building information model used in the infrastructure project that is being studied right now.

11 Conclusion

Following the completion of this research work, it is possible to conclude that, according to the ranking of significant factors based upon normalisation, the technological related factors weightage of 0.265 and the building information modelling related factors weightage of 0.182 are, among other factors, the highest and second-highest, respectively, in terms of importance when it comes to the development of a blockchain model for use in construction projects. It is possible to conclude from this that the significance of technology and BIM will play a key part in creating a blockchain model for the construction sector, while the finance related factors weightage of 0.048 and the input–output related factors weightage of 0.039 don't add much to building a blockchain model for construction projects based on these ANP-based results.

Disclosure Statement The authors reported no potential conflict of interest.

Annexure 1

See Table 2.

Table 2 Key performance indicators (KPIs) related to performance evaluation of control variables for the development of the blockchain model

Sr. no.	Description of KPIs	References
Technology-related		
F1	Complexity in development of integration of building information modelling with blockchain technology	Li et al. (2018)
F2	Complexity in the selection of specific blockchain platform	Hamledari and Fischer (2021)
F3	Compatibility of building information modelling with blockchain technology	Li et al. (2018)
F4	Compatibility of the integrated model with the existing market	Shojaei et al. (2019)
F5	Cost of development of blockchain technology	Hamledari and Fischer (2021)
F6	Cost of implementation of an integrated model	Ye et al. (2020)
F7	Operational and maintenance cost of blockchain technology	Shojaei et al. (2019)
F8	Relative advantages of blockchain technology	Hamledari and Fischer (2021)
F9	Privacy of data exchange between stakeholders	Hamledari and Fischer (2021)
F10	Scalability of blockchain tool	Akhavan et al. (2021)
F11	Availability of specific blockchain tool	Li et al. (2018)
F12	Trialability of an integrated model	Hargaden et al. (2019)
F13	Observability of data in blockchain model	Hamledari and Fischer (2021)
F14	Immutability of information stored in blockchain	Li et al. (2018)
F15	The perceived novelty of the integrated model	Ye et al. (2020)
F16	Level of integration of the Internet of things and cloud computing	Li et al. (2018)
F17	Disintermediation of existing centralised banking	Ye et al. (2020)
F18	Perceived benefits of payment automation	Hamledari and Fischer (2021)
F19	Computability of devices used in integrated model	Sarkar et al. (2015)
F20	Infrastructural facility	Alizadeh Salehi and Yitmen (2018)
F21	Increase in data availability	Pradeep et al. (2020)
F22	Reduction of information asymmetry	Akhavan et al. (2021)
F23	Reliability of blockchain technology	Hamledari and Fischer (2021)
F24	Exclusion of false information from contractual information	Kim et al. (2020)
F25	Hacking attempts system denials	Ye et al. (2020)
F26	High-security encryption	Li et al. (2018)
F27	Contract conclusion with a reasonable fee	Hargaden et al. (2019)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F28	Transparency of payment process	Li et al. (2018)
F29	The integrity of blockchain technology	Hunhevicz and Hall (2020)
F30	Confidentiality of data shared in the developed model	Sarkar et al. (2015)
F31	Interoperability of blockchain with other technology	Akhavan et al. (2021)
F32	Perceived challenges for adopting blockchain in the payment process	Li et al. (2018)
F33	The hype of the developed model	Li et al. (2018)
F34	Trust in the blockchain technology	Pradeep et al. (2020)
F35	Storage capacity of computers	Pradeep et al. (2020)
F36	Decentralisation of the existing banking system	Shojaei et al. (2019)
F37	Inclusiveness of blockchain tool	Kim et al. (2020)
F38	Maturity of blockchain technique in the market	Hamledari and Fischer (2021)
Organisation related		
F39	Top management support	Iyer and Jha (2004)
F40	Top management knowledge/awareness	Lokshina et al. (2019)
F41	Firm size in terms of staff	Hamledari and Fischer (2021)
F42	The capability of human resources	Hamledari and Fischer (2021)
F43	Financial resources of the company	Iyer and Jha (2004)
F44	Presence of training facilities	Shojaei et al. (2019)
F45	Organisational culture	Hargaden et al. (2019)
F46	Supportive technological environment	Akhavan et al. (2021)
F47	Perceived risk of vendor lock-in	Kim et al. (2020)
F48	Perceived efforts in collaboration	Hamledari and Fischer (2021)
F49	Organisation learning capability	Iyer and Jha (2004)
F50	Organisation innovativeness	Lokshina et al. (2019)
F51	Information technology governance	Hunhevicz and Hall (2020)
F52	Enormous resources (energy, infrastructure)	Iyer and Jha (2004)
F53	High need for process harmonisation	Ye et al. (2020)
F54	Well-defined scope of organisation	Hunhevicz and Hall (2020)
F55	Existing infrastructure for the adoption of blockchain and BIM	Li et al. (2018)
F56	Learning culture of nontechnical staff	Akhavan et al. (2021)
F57	Data management of organisation	Hamledari and Fischer (2021)
F58	Organisational security	Hamledari and Fischer (2021)
F59	Privacy of organisation	Hargaden et al. (2019)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F60	Coordination problem	Hamledari and Fischer (2021)
F61	Specific guidelines for BIM and Blockchain adoption	Kim et al. (2020)
F62	Organisational relationship	Iyer and Jha (2004)
F63	Organisational readiness	Das et al. (2021)
F64	Training and skill development policy	Hunhevicz and Hall (2020)
F65	The reputation of the blockchain platform provider	Das et al. (2021)
F66	The social network of organisation	Pradeep et al. (2020)
F67	Customer response	Akhavan et al. (2021)
F68	The demand of clients to use BIM and blockchain	Lokshina et al. (2019)
F69	The leadership of the BIM manager	Iyer and Jha (2004)
F70	Availability of initial investment	Iyer and Jha (2004)
Finance related		
F71	Transaction's speed	Hamledari and Fischer (2021)
F72	Comprehensibility of the transactions	Hargaden et al. (2019)
F73	Easy verification of transactions	Hamledari and Fischer (2021)
F74	Transparency in transaction	Hamledari and Fischer (2021)
F75	Capitalisation—Ease of the conversion of income or assets into capital	Ye et al. (2020)
F76	Ease in money usage	Shojaei et al. (2019)
F77	Reduction of usage of currency	Hamledari and Fischer (2021)
F78	Removal of economic barriers	Das et al. (2021)
F79	Reduction in inventory problems	Ye et al. (2020)
F80	Increase in sales of real estate	Shojaei et al. (2019)
F81	Ease invalidation of transaction	Hamledari and Fischer (2021)
F82	Increase in net income	Hamledari and Fischer (2021)
F83	Peer-to-peer transaction	Hamledari and Fischer (2021)
F84	Reduction in corruption	Hamledari and Fischer (2021)
F85	Immutability of transactions—It cannot be altered once inserted into the blockchain	Hamledari and Fischer (2021)
F86	Permanent availability of the transactions data	Hamledari and Fischer (2021)
F87	Chronological order of transactions data	Lokshina et al. (2019)
F88	Decreased delays and errors in transactions	Ye et al. (2020)
F89	Instant and digitally recorded money transfer	Akhavan et al. (2021)
F90	Increased revenue in procurement by secured loans	Pradeep et al. (2020)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F91	Real-time tracking of transaction and decreased costs	Kim et al. (2020)
F92	Auditing system which examines and evaluates the financial statement of organisation	Hamledari and Fischer (2021)
F93	Accountability structure serves as the foundation for establishing effective financial processes	Hamledari and Fischer (2021)
F94	Level of financial awareness in stakeholders	Shojaei et al. (2019)
F95	Type of currency utilised in project especially in foreign direct investment	Ye et al. (2020)
F96	Level of dependency on centralised banking system	Hamledari and Fischer (2021)
F97	Type of financial model for cash-in and cash-out flow	Hamledari and Fischer (2021)
Environment related		
F98	Regulations regarding new technology	Li et al. (2018)
F99	Competitive pressure	Shojaei et al. (2019)
F100	Government policy	Shojaei et al. (2019)
F101	Government support	Akhavan et al. (2021)
F102	Stakeholder pressure	Li et al. (2018)
F103	Customer pressure	Hunhevicz and Hall (2020)
F104	Trading partner readiness	Li et al. (2018)
F105	Legal/standards uncertainties	Lokshina et al. (2019)
F106	Institutional-based trust	Hargaden et al. (2019)
F107	Technology progress in the industry	Alizadeh Salehi and Yitmen (2018)
F108	Support from the community	Kim et al. (2020)
F109	Professional consultation	Das et al. (2021)
F110	Expert assistance	Akhavan et al. (2021)
F111	Perceived constraint of infrastructure	Sarkar et al. (2015)
F112	Market turbulence	Ye et al. (2020)
F113	Market power	Ye et al. (2020)
F114	Market dynamics	Sarkar et al. (2015)
F115	Customer readiness	Shojaei et al. (2019)
F116	Consensus among trading partners	Hargaden et al. (2019)
F117	Characteristics of industry	Li et al. (2018)
F118	Industry standards for BIM and blockchain	Shojaei et al. (2019)
F119	Environmentally friendly system	Pradeep et al. (2020)
F120	Ease in operating environment	Pradeep et al. (2020)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
BIM related		
F121	Man, hours spent per project	Das et al. (2021)
F122	Speed of development	Chin et al. (2008)
F123	Revenue per head	Pradeep et al. (2020)
F124	IT investment per unit of revenue	Hamledari and Fischer (2021)
F125	Cash flow monitoring	Ye et al. (2020)
F126	Better architecture	Li et al. (2018)
F127	A better product	Chin et al. (2008)
F128	Reduced costs, travel, printing, document shipping	Ye et al. (2020)
F129	Bids won or win percentage	Shojaei et al. (2019)
F130	Client satisfaction and retention	Pradeep et al. (2020)
F131	Employee skills and knowledge development	Shojaei et al. (2019)
F132	Ease of usability/BIM interface	Chin et al. (2008)
F133	Parametric nature of BIM elements	Lokshina et al. (2019)
F134	Feature of "customizable schedule" and "shared parameters"	Chin et al. (2008)
F135	Coordinated 2D (plan) views, 3D views, data attributes and schedules in BIM	Shojaei et al. (2019)
F136	Ease of navigation, search, and highlight elements within BIM	Chin et al. (2008)
F137	Type of software used for 2D-3D modelling and structural modelling	Hamledari and Fischer (2021)
F138	Dependency on service provider of software	Hamledari and Fischer (2021)
F139	Cost of adoption of building information modelling	Hamledari and Fischer (2021)
F140	Cost of implementation of building information modelling along with progress monitoring	Chin et al. (2008)
F141	Operation and maintenance cost of building information modelling	Sarkar et al. (2015)
Data management & Security related		
F142	Data accuracy in integrated model	Shojaei et al. (2019)
F143	Level data security in building information modelling	Hamledari and Fischer (2021)
F144	Complexity of data available at site	Lokshina et al. (2019)
F145	Data transparency in blockchain	Hamledari and Fischer (2021)
F146	Data processing and exploration system	Das et al. (2021)
F147	Data transparency in computer aided design	Akhavan et al. (2021)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F148	System for modification of entered data in blockchain	Das et al. (2021)
F149	Extensive data exchange through wireless technology	Lokshina et al. (2019)
F150	Data storage facility and its implementation cost	Chin et al. (2008)
F151	System for data collection from deployed sensors	Alizadeh Salehi and Yitmen (2018)
F152	Data acquisition system for BIM	Alizadeh Salehi and Yitmen (2018)
F153	System of data auditing and modification	Das et al. (2021)
F154	Method of data communication	Ye et al. (2020)
F155	Internet protocol selection	Hamledari and Fischer (2021)
F156	Data backup and recovery	Shojaei et al. (2019)
F157	System for checking accuracy of collected data of progress	Sarkar et al. (2015)
Input–output related		
F158	Collection of as-built data for the facility	Sarkar et al. (2015)
F159	Data accuracy of collected data for progress monitoring	Hamledari and Fischer (2021)
F160	Availability of infrastructural facility for proper implementation of progress tracking	Sarkar et al. (2015)
F161	Availability of specific progress monitoring tool	Alizadeh Salehi and Yitmen (2018)
F162	Complexity in selection of progress monitoring system	Alizadeh Salehi and Yitmen (2018)
F163	Cost of information gathering	Sarkar et al. (2015)
F164	Cost of information improvisation	Shojaei et al. (2019)
F165	Cost of development of progress monitoring system	Alizadeh Salehi and Yitmen (2018)
F166	Cost of implementation of input devices for progress monitoring	Alizadeh Salehi and Yitmen (2018)
F167	Operational and maintenance cost of progress monitoring system	Sarkar et al. (2015)
F168	Availability of as-built BIM (model) from consultants	Das et al. (2021)
F169	Clarity of facility management (FM) functions to be accomplished using BIM	Sarkar et al. (2015)
F170	Standardisation of formats for collected data	Hamledari and Fischer (2021)
F171	Defined required attributes for each discipline and element of facility	Ye et al. (2020)
F172	Reliability of collected as-built data	Chin et al. (2008)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F173	Quick / in advance decision-making	Sarkar et al. (2015)
F174	Complexity in selection of data analysis and improvisation tool for collected data from site	Hamledari and Fischer (2021)
F175	Potentiality of direct and indirect cost savings in using BIM as FM tool	Shojaei et al. (2019)
F176	Reduced response time to user complain	Sarkar et al. (2015)
F177	Reduced error/improved quality of FM service	Shojaei et al. (2019)
F178	Facilitating access to real-time data	Sarkar et al. (2015)
F179	Improved and standardised record keeping	Hamledari and Fischer (2021)
F180	Asset management and data tracking	Sarkar et al. (2015)
F181	Emergency performance planning	Sarkar et al. (2015)
F182	Improved space management and reduced vacancy	Akhavan et al. (2021)
F183	Analysing and reporting energy efficiency	Sarkar et al. (2015)
F184	Accelerated decision-making for preventive and corrective maintenance	Lokshina et al. (2019)
F185	Better visualisation of design options for retrofit, renovation, or demolition of existing facility	Sarkar et al.(2015)
Project process related		
F186	Size of the project/facility	Hamledari and Fischer (2021)
F187	Type of the project/facility	Sarkar et al. (2015)
F188	Complexity (no. of utilities) of the project/ facility	Sarkar et al. (2015)
F189	Duration of project	Das et al. (2021)
F190	Availability of resources at site	Shojaei et al. (2019)
F191	Location of project	Sarkar et al. (2015)
F192	Existing facilities of project	Sarkar et al. (2015)
F193	Access to the database	Hamledari and Fischer (2021)
F194	Standardisation of process and frequency of updating the BIM and database	Sarkar et al. (2015)
F195	Standardisation of data in blockchain	Hamledari and Fischer (2021)
F196	Interoperability of BIM, facility management systems and other database tools	Hamledari and Fischer (2021)
F197	Interoperability of BIM, blockchain and progress monitoring tool	Sarkar et al. (2015)
F198	Effective collaboration between project stack holders	Chin et al. (2008)

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Table 2 (continued)

Sr. no.	Description of KPIs	References
F199	Involvement of expertise person in design phase and other strategic decisions	Sarkar et al. (2015)
F200	Existing process for approval of bills	Hamledari and Fischer (2021)
F201	Project management process at site and at office	Hamledari and Fischer (2021)

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