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**DOI**
10.1016/j.egyr.2022.05.008

**Publication date**
2022

**Document Version**
Final published version

**Published in**
Energy Reports

Energy Reports 8 (2022) 7107–7126

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Review article

# Policies, applications, barriers and future trends of building information modeling technology for building sustainability and informatization in China

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A R T I C L E I N F O

*Article history:*
Received 10 April 2022
Received in revised form 3 May 2022
Accepted 5 May 2022
Available online xxxx

*Keywords:*
Building informatization
Building information modeling
Building sustainability
Engineering management
Sustainable development

A B S T R A C T

The application of building information modeling (BIM) technology has effectively supported the high-quality development of building sustainability and informatization in China. However, few studies comprehensively analyzed the enacted policies, prevalent applications, and existing barriers of the latest application and development of BIM technology in building industry from building sustainability and informatization perspectives to provide effective consultation and guidelines for its rational scale application in China. This paper firstly made a statistical analysis on the policies and standards of BIM technology issued from 2011 to 2021 in China. Moreover, the latest application, development and existing issues of BIM technology in building sustainability and informatization were also comprehensively discussed and analyzed. The main conclusions indicated that the application status of BIM technology for building sustainability and informatization in China was large in quantity, wide in scope, but low in level. The existing issue and limitation in terms of BIM application in China was mainly due to the lack of standards and domestic-oriented tools. Finally, the future outlook and recommendations of BIM technology for building sustainability and informatization in China were also presented as avenues for upcoming research.



**Contents**



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https://doi.org/10.1016/j.egyr.2022.05.008

## 1. Introduction

In the past few decades, building information modeling (BIM) technology has been widely used worldwide in various industries, such as building engineering, bridge engineering, highway engineering, airport engineering and power engineering (Costin et al., 2018). Concerning the building engineering, BIM technology has been extensively applied for designing commercial buildings, industrial buildings, office buildings and residential buildings by integrated with various technologies (Darko et al., 2020; Deng et al., 2021). BIM technology facilitates the amendments to the original building design scheme, and thus effectively storing updated building projects (Atazadeh et al., 2017; Isikdag et al., 2013). Abanda et al. (2015) had enumerated and inspected other advantages of BIM applications covering all stages of the building life-cycle. In general, the significances of BIM application in building engineering can be summarized as follows: (i) presenting the 3-dimensional (3D) visualization of buildings; (ii) integrating different disciplines and improving efficiencies, coordination and communication between each party; (iii) simulating the pre-construction process to minimize mistakes during construction (Zhuang et al., 2021; Tam et al., 2022).

As previously mentioned, BIM has been integrated with different technologies for building engineering. For instance, Yang et al. (2021) developed a new modeling paradigm based on combing BIM, geographic information system (GIS) and domain-specific computational engines (DCEs) for assessing the vulnerability of interdisciplinary infrastructures. Zhang et al. (2020b) developed a new construction tool by integrating BIM with GIS for hydropower project construction, which provided a satisfactory solution to address the issues of inconsistencies in storage, accuracy and operational speed of the combined BIM and GIS models. Tang et al. (2019) conducted a comprehensive review of BIM and internet of things (IoT) devices integration aimed at determining frequently emerging application domains and common design patterns in approaches to address BIM-IoT device integration. Results indicated that BIM and IoT integration in the cloud could be one of the prominent future research directions. Some researchers had investigated the BIM with 3D laser scanning for assessing the surface quality of concrete (Guo et al., 2020; Kim et al., 2015). Furthermore, with the development of big data and virtual reality (VR), they had been integrated with BIM for online geometry computing services (Zhou et al., 2019b) and data exchange (Khalili, 2021). In recent years, several researches had studied BIM-based smart city planning and design (Marzouk and Othman, 2020; Heaton and Parlikad, 2019). These studies analyzed the implemented functionalities and the application advantages with other coupling technologies.

In China, BIM technology is increasingly widely used in building industrialization and building informatization. The accelerated development of BIM technology largely depends on the guidance of the Chinese government and the release of mandatory normative treaties by some relevant institutions (Yang and Chou, 2018), e.g., design standards, drawing standards, charging standards and responsibility division of subsequent issues (Al-reshidi et al., 2017; Qian and Leng, 2021). These measures provide the basis for different departments (e.g., the company of BIM software, design department and construction department) with respect to their responsibilities, making BIM technology in accordance with the requirements of practical project and effectively avoiding unnecessary disputes (Gao and Pishdad-Bozorgi, 2019; Cerovsek, 2011).

Although BIM technology has developed rapidly in recent years in China, a plenty of issues need to be solved for its effective application (Tan et al., 2019a; Ding et al., 2020b; Li et al., 2021b). For example, Shanghai, Beijing and other first-tier cities have the majority of BIM engineering projects, especially its application rate in government projects exceeds 85%. However, the development of BIM in third- and fourth-tier cities in China is still not enough, which is less than 50% (Ministry of Housing and Urban-Rural Development, 2019). The reason can be related to local policies, BIM teams, and developers' motivation, etc. (Huang et al., 2021). In the past decade, a large number of studies analyzed the application of BIM in building engineering in China (Li et al., 2020), reported on the corresponding barriers and issues encountered in the BIM application in China (Tan et al., 2019a). For example, Ma et al. (2020) had classified 14 critical barriers, of which the top barrier was interoperability issues of information and data. Concerning the application of BIM in building sustainability and informatization, Pereira et al. (2021) presented a scientometric and systematic review on improving building energy efficiency using BIM, which could determine some areas where BIM technology played an essential role in improving building efficiency, thereby assisting stakeholders in the architecture, engineering, construction and operations sector in global energy consumption and related environmental impacts. Santos et al. (2019a) investigated the contribution of BIM in sustainable building in terms of environmental, economic, and social dimensions through informetric analysis and literature review, which indicted that BIM is a reliable approach for sustainable construction. Wang et al. (2019) comprehensively reviewed researches of the integration of BIM and GIS applications in sustainable built environments, which presented that BIM-GIS integration need to be applied in a large-scale area. Although the above-mentioned studies make significant contributions to mapping BIM for building and its integration with other advanced technologies within this field, rarely of them summarize and analyze the impediments to the application of BIM in building engineering from a perspective in China, especially driven by the general circumstances of China's BIM policies. Under the unique system of Chinese government, the government is usually given more power and important role in BIM promotion. However, there are few current compendium and in-depth dissection of the BIM policies promulgated by national and local governments of China in recent years. In addition, most of the current BIM-related reviews focus on a certain type of application scenario and overemphasize the BIM's value in such application scenarios. And few studies summarize and discuss the issues and challenges encountered building sustainability and informatization, and then derive from them the specific issues associated with promoting BIM application in specific fields.

To solve the above-mentioned research gaps in previous studies, the contributions of this study conduct a comprehensive critical analysis on the enacted policies, prevalent applications and existing barriers of BIM technology in buildings from different perspectives to provide effective consultation and guidelines for its high-quality development and rational scale application in China. The novelty of this study can be summarized as: (i) a series of enacted standards and policies of BIM application at the national and local level in the last decade had been introduced and comparatively analyzed by using statistical methods, which cover from trial implementation of BIM application in different building industries in China; (ii) the state-of-art applications and research status of BIM technology for building sustainability and informatization are summarized, and corresponding application obstacles are also discussed in this study; (iii) the crucial issues and some advanced foresighted perspectives of BIM application are systematically analyzed and explored to facilitate its future high-quality application in China's building sector.

This paper is organized as follows: Section 2 shows the related literature review for the building sustainability and informatization from different perspectives; the relevant enacted policies

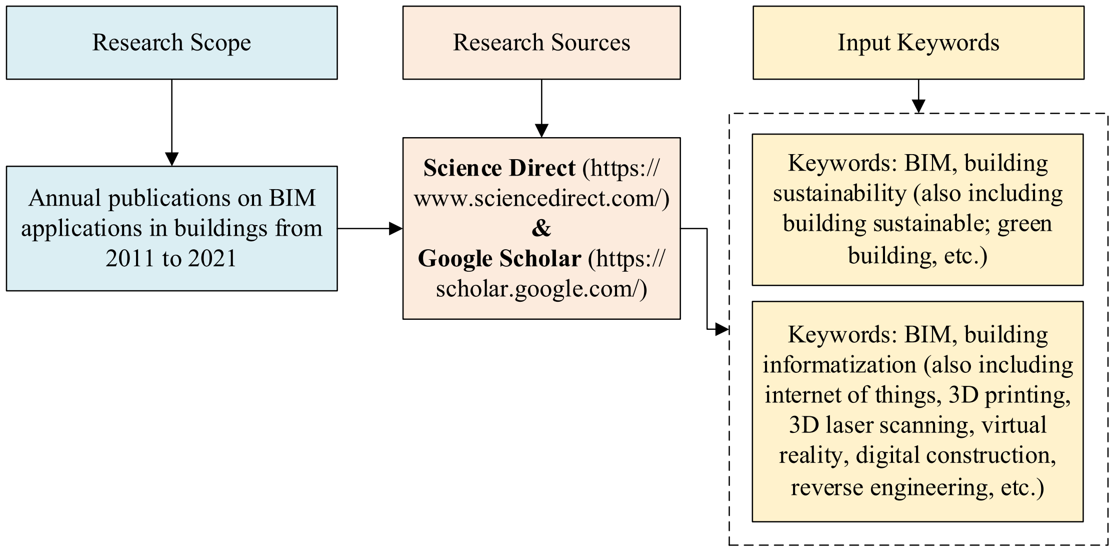


**Fig. 1.** The review flowchart of this study.

and standards of BIM technology issued from 2011 to 2022 are summarized and analyzed in Section 3; Section 4 discusses the latest application and development of BIM technology in the building sustainability and building informatization, as well as the existing issues and realization barriers of BIM application in these specific scenarios; Section 5 presents some existing issues, limitations, and recommendations of BIM application and studies in China's building sector, and Section 6 concludes this paper and proposes some future work perspectives.

## 2. Literature review

In recent years, building sustainability and informatization are the most discussed and currently key areas that are being comprehensively promoted in China's building industry (Carvalho et al., 2019; Liu et al., 2021; Ahmad and Thaheem, 2018). Therefore, this paper mainly focuses on the application and development of BIM technology in these two fields. Fig. 1 shows the flowchart of review process. In this Section, the authors reviewed and summarized annual publications on the BIM application in buildings from 2011 to 2021 to further analyze the research trends on the BIM application in different building fields. In the first step, the keywords were selected based on the above areas. Thus, "BIM, building sustainability (also including building sustainable, green building, etc.)", and "BIM, building informatization (also including IoT, 3D printing, 3D laser scanning, VR, digital construction, reverse engineering (RE), etc.)" were entered in the search box for the title, abstract, or author-specified keywords using the advanced search function based on the ScienceDirect and Google Scholar website. Then, the application and development status of BIM technology in sustainability and informatization were also studied based on the search results.

With the demands of achieving more sustainable buildings, researchers are increasingly exploring effective solutions to minimize the environmental impact and energy consumption of buildings. Using BIM and its integrated technologies for building sustainability design, application and assessment has been an increasing attention in recent studies. Carvalho et al. (2020) reviewed the significance of BIM in three building sustainability assessment methods, namely, Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) and Sustainable Building Tool (SBTool). The results demonstrated that the SBTool was the most attractive approach for enhancing building sustainability in the future. In their another study (Carvalho et al., 2019), BIM technology was used to optimize building sustainability assessment (BSA) methods by focusing on the SBTool $^{PT}$-H. Indeed, BIM could provide detailed information to designers in order to compare the efficiency of various sustainable solutions and evaluate the building's sustainability at the early stages of projects (Carvalho et al., 2020). However, despite these benefits, there are still some limitations/barriers in building sustainability that need to be further addressed. To assess building sustainability, one of the significant issues is the lack of tools and platforms (Azhar et al., 2011; Liu et al., 2015b). Furthermore, Wong and Zhou (2015) had indicated that three R's concept (reduce, reuse and recycle) needed to be included in future green BIM tools for analyzing sustainability in terms of new development and/or retrofitting projects. Chong et al. (2017) indicated that building sustainability assessment requirements needed to be entirely considered in the future BIM standards. Sanhudo and Martins (2018) indicated that building sustainability and its assessment were still challenging, and new automated BIM-based software needed to be developed. Other literatures regarding the BIM technology for building sustainability and the major contributions are summarized in Table 1.

Besides building sustainability, another critical role of the BIM application concerns building informatization, which the whole life cycle of a building project can be achieved with the help of BIM technology. Building informatization schemes, as sustainable construction technologies, have been widely promoted in the last decade contributes to the clean built environments and improve quality performance (Shen et al., 2017; Tan et al., 2018). Ma et al. (2019) reviewed the application of BIM technology in building informatization, and they found the development of the digital technology and IoT technology was beneficial for promoting the civil building sector. For the purpose of supporting the energy management throughout the life cycle of buildings, the BIM technology is needed to be further applied and developed (Francisco et al., 2018; Sanhudo et al., 2018). Other literatures regarding the BIM technology for building informatization and the related major contributions are summarized in Table 2.

In fact, although China is one of the countries that promote BIM application in the architecture, engineering, and construction (AEC) industry, the application of BIM technology still has some limitations (Deng et al., 2020). Liu et al. (2013) summarized a series of limitations of BIM technology application and development in China, including the value of using BIM technology in

**Table 1**
BIM technology for building sustainability and the related major contributions.

| Ref. | Research topic | Main findings/contributions |
|---|---|---|
| Yung and Wang (2014) | Automatic assessment of building sustainability | This study proposed and developed a model for automatically assessing the sustainability lifecycle of buildings using BIM approach and its supporting technologies. The model can automatically derive quantities, calculate economic, environmental and social impacts, and evaluate the sustainability performance of alternative design options. |
| Azhar et al. (2011) | Sustainable design and LEED® rating analysis | This study developed a conceptual framework to establish the relationship between BIM-based sustainability analysis and LEED® certification process. The validated framework could streamline the LEED® certification process and generate significant time and resource savings. |
| Wong and Fan (2013) | Sustainable building design | This study investigated the contributions of BIM to sustainable buildings in terms of design performance and improving communication and coordination. |
| Matos et al. (2021) | Building condition assessment | This study used BIM as a supporting tool for building condition assessment, with key performance indicators to prioritize maintenance actions. It involved building data collection, building life-cycle cost estimation, and automated calculation of building performance metrics. |
| Jalaei et al. (2020) | Automate sustainable design assessment | This study described an integrated approach to automate the process sustainability assessment of a proposed building by integrating a BIM and LEED certification system. It also provided a framework to calculate the possible scores of the building at the concept stage. |
| Galiano-Garrigós et al. (2019) | Energy performance and $CO_2$ emissions assessment | This study evaluated the accuracy of BIM environment software and how the database and simplification affected the decision-making process for building design. Computational examples were performed with various tools as well as compared to real building performance data. |
| Jalaei and Jrade (2015) | Conceptual design stage of sustainable buildings | This study presented an integrated approach of BIM with the Canada Green Building Certification System (LEED©). Using BIM in this approach would help designers to easily and efficiently invent and animate sustainable buildings in 3D mode during the conceptual stage. |
| Zhang et al. (2019b) | Real-time green building rating in BIM-based design | This study proposed an intelligent green building rating (iGBR) framework supported by semantic and social approaches to achieve real-time rating in building design. Also, a prototype iGBR system was developed to validate the framework based on the Evaluation Standard for Green Buildings in China. |
| Olawumi and Chan (2021) | Assessment framework for building sustainability performance | This study utilized conceptual framework design, expert surveys, and case studies to identify and build the different components of the Greater Bay Area framework. The developed green-BIM assessment framework adopted the building sustainability assessment method scheme as its primary green building rating system. |
| Ilhan and Yaman (2016) | Green building assessment tool | This study proposed a framework for an integrated BIM and sustainability data model in the life-cycle design stage. It also proposed the Green Building Assessment Tool (GBAT), which implemented the proposed model and helped the design team to achieve green building certification. |

the AEC industry was not quantified, BIM professional software needed to be developed, and a lack of government promotion and relevant standards. Boya et al. (2014) studied the BIM technology application in China with the help of the game model between government and enterprise. They found that the slow development of BIM technology in China was strongly related to the government's economic policy. In addition, Sun and Wang (2015) indicated that the interest conflict between project owners and contractors was a primary factor hindering the BIM technology development in China. Li et al. (2017) found the reasons for the slow promotion of BIM technology in China by combining literature review, questionnaire survey and interviews. They demonstrated that the main obstacle in terms of BIM promotion in China was a lack of understanding of the BIM value by the owners. Zhou et al. (2019a) indicated that insufficient government leadership, legal issues, and high BIM application costs were the main barriers to the current BIM application in China. These summarized barriers are similar to the founding by Zhang et al. (2019a). Dong et al. (2020) discussed the barriers and the possible improvement measures concerning the application of BIM technology in project cost by combining decision-making test and evaluation laboratory methods. They pointed out that the most significant factor concerning BIM application in China was the lack of policy support from industry authorities and the government.

Based on these previous studies, the development and application of BIM technology in China still have many limitations and barriers. It is noticeable that most of the existing studies exploring the barriers/limitations to BIM technology application in China adopted a literature review and questionnaire survey. Compared with previous studies, this study explores the policies, applications, barriers and future trends of BIM from a comprehensive perspective combined with a statistical analysis of BIM policies and standards in China, which contributes to its high-quality development in various practical applications.

## 3. Statistical analysis of building information modeling policies and standards in China

The research framework used for the statistical analysis of BIM policies and standards can be seen in Fig. 2. In order to perform this statistical analysis, the first step is to collect and review the recent national and local BIM policies and standards. Then, the local policies and standards are reorganized based on the geographical regions of China. After, the linear regression is carried out to analyze the relationship between the national and local BIM policies and standards. Finally, the open-source text-mining tool Gephi 0.9.3 (https://gephi.org/features/) is used to select the keywords for these policies and standards to investigate the main policy direction of BIM in China.

In this study, the national BIM policies and standards are obtained from the Ministry of Housing and Urban-Rural Development of the People's Republic of China (http://www.mohurd.gov.cn/) and the local BIM policies and standards are obtained from the Housing and Urban-Rural Construction Departments of each province (e.g., Hunan Provincial Department of Urban-Rural

**Table 2**
BIM technology for building informatization and the related major contributions.

| Ref. | Research topic | Main findings/contributions |
|---|---|---|
| Li et al. (2018c) | On-site assembly services in prefabricated construction | This study combined IoT and BIM to design a platform for prefabricated public housing projects. The IoT-enabled BIM platform could provide various decision support tools and services to different stakeholders to improve the effectiveness of daily operations, decision-making, collaboration and monitoring. |
| Shahinmoghadam et al. (2021) | Real-time thermal comfort assessment in building enclosures | This study investigated the synergistic benefits of BIM, IoT, and VR in developing immersive VR applications for real-time monitoring of thermal comfort conditions. A system framework was proposed for computing predicted mean vote (PMV)/predicted percentage of dissatisfied (PPD) indices in real-time. |
| Valinejadshoubi et al. (2021) | Automated alert system for thermal comfort monitoring in buildings | This study proposed an integrated solution based on the BIM platform and IoT to improve the performance of environmental monitoring management in smart city buildings. The proposed system was an effective monitoring system for environmental monitoring management. |
| Cheng et al. (2020) | Data-driven predictive maintenance planning framework | This paper discussed how BIM and IoT could facilitate the implementation of predictive maintenance and improve the feasibility of adopting long-term and dynamic maintenance strategies in facility maintenance management processes. |
| Wang et al. (2021) | Automated generation of parametric BIM for MEP scenes | This study proposed a fully automated method to convert ground laser scan data into well-connected as-built BIM for mechanical, electrical and plumbing (MEP) scenes. |
| Getuli et al. (2020) | BIM-based immersive VR for construction workspace planning | This study aimed to enhance the usual manual workspace planning process by simulating construction activities using immersive VR and BIM techniques. Workspace planning could be improved by capturing the knowledge of experienced workers and combining it with the knowledge of construction managers. |
| Du et al. (2018) | BVRS for collaborative decision-making | This study introduced a BIM-VR Real-time Synchronization (BVRS), which was based on an innovative cloud-based approach to BIM metadata interpretation and communication. |
| Pan and Zhang (2021) | BIM-data mining integrated digital twin framework | This paper proposed a closed-loop digital twin framework that integrated BIM, IoT, and data mining (DM) technologies with an emphasis on intelligent construction project management. |
| Lee et al. (2019) | Automated building occupancy authorization | This study conducted an automatic inspection of building occupancy authorization using the unmanned aerial vehicle (UAV). RE was also performed, including digital photography and data post-processing. The obtained spatial information was used for building occupancy inspection authorization in the BIM platform to analyze the effectiveness and applicability of the UAV-based inspection. |
| Sun and Liu (2022) | Intelligent dispatching system management platform | This study proposed a hybrid model of digital twin BIM (DT-BIM). This model accomplished the process of identifying resource shortages, analyzing requirements, executing decisions, scheduling resources, and updating all processes in the database with the support of artificial intelligence (AI). |

and Construction: http://zjt.hunan.gov.cn/). In total, this study collected and reviewed 77 national policies and standards, and 687 local policies and standards associated with BIM technology in China from 2011 to 2021. The reason for collecting the policies and standards from 2011 is that the Ministry of Science and Technology of the People's Republic of China (MOST) announced BIM technology as a national key research and application project in the "12th Five-Year" Science and Technology Development Planning. Hence, the year 2011 is considered as "The First Year of China's BIM" (Ministry of Science and Technology of the People's Republic of China, 2018).

The national and local policies and standards regarding BIM technology in China from 2011 to 2021 have been displayed in Fig. 3. In general, a linear growth can be found for these standards and policies, which are increased year by year. At the national level, the highest record of the number of policies is found in the year 2017 with the value of 17. However, it is noticed that a decreasing trend can be found since 2020. The reason can be strongly related to the COVID-19 pandemic, resulting in the government paying more attention to coping with the pandemic. As shown in Fig. 4, the policies and standards of each province have been organized by the geographical regions of China. It noticed that the number of policies and standards issued in each year of provinces generally follows the national ones' trend, which indicates that the national policies have strong impacts on the local ones. Furthermore, it is also found that the northern and eastern provinces in China have issued more standards and policies than that of the other regions. The reason can be related to the northern provinces being close to the administrative centre of China (Beijing), and the eastern provinces are near the economic centre of China (Shanghai). These two regions are highly developed. Concerning Hong Kong and Macao, the policies and standards are issued much less than that of the other regions, which can be related to Hong Kong and Macao as the special administrative region of China, thereby making their own policies based on the local market environment. Hence the national level policies have fewer impacts on these regions.

Regarding the southwest of China, Sichuan and Guizhou have issued more standards and policies than the other provinces. For the northwest of China, the difference between each province is more negligible, but Qinghai province has issued much more policies in 2020 and 2021 than other provinces. For the northeast region, Jilin province has issued policies and standards much higher than the provinces of Liaoning and Heilongjiang. Concerning the south-central regions, Hunan province is the highest, which can be related to many advanced architecture companies

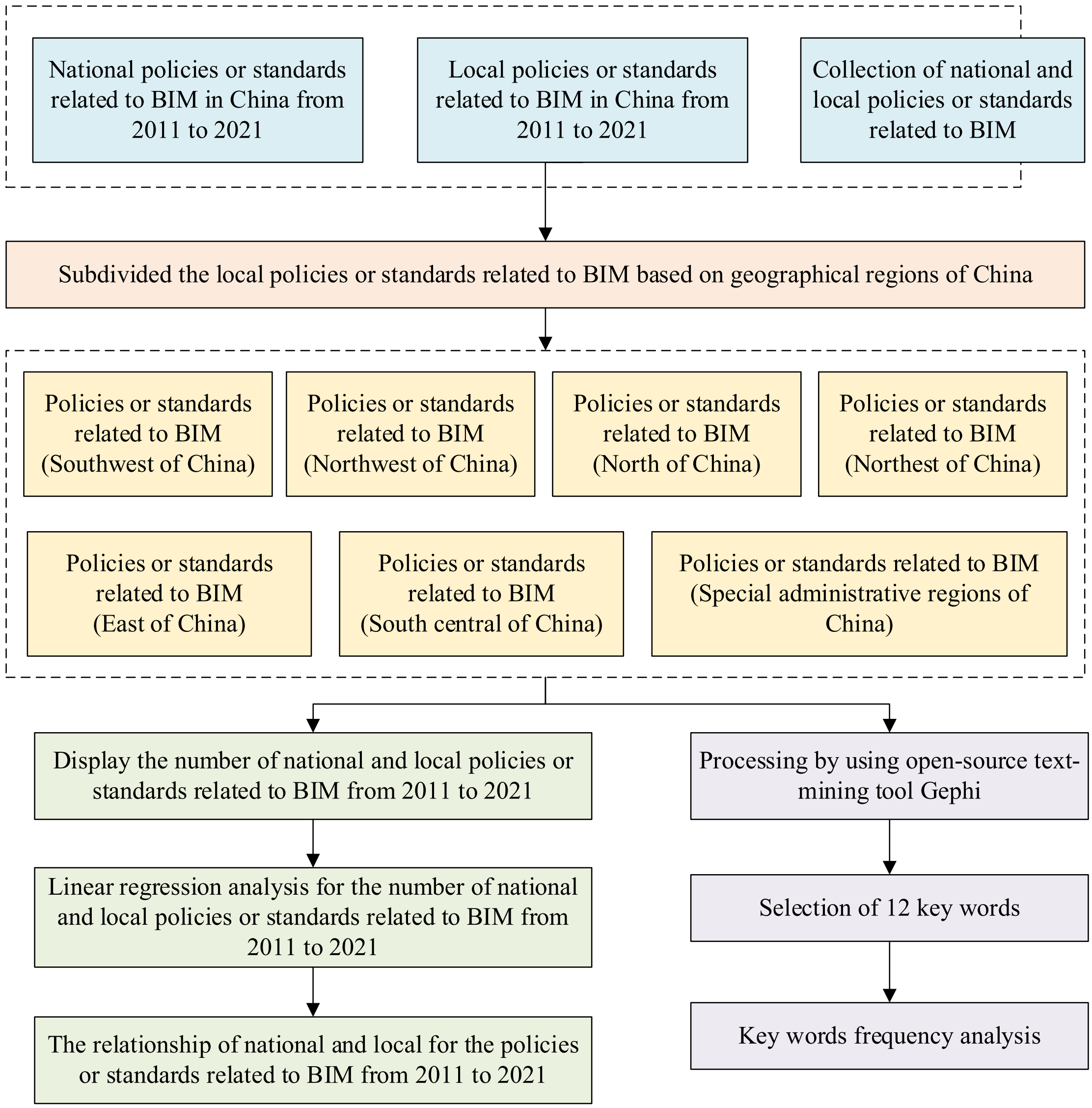


**Fig. 2.** The flowchart of research methodology of in Section 3.

located in Hunan (e.g., China Grand Enterprises, China Construction Fifth Engineering Division Corp., and Hunan Construction Engineering Group).

In order to analyze the relationship between the number of issued national policies and the number of issued local policies from 2011 to 2021 in China, a linear regression is performed. The linear regression equation is expressed as follows (Belsley et al., 2005):

$$Y = a + bX \tag{1}$$

where $X$ and $Y$ refer to the independent variable the dependent variable, respectively. $b$ is the slope of the line, and $a$ is the intercept.

Here, the Pearson correlation coefficient (Pearson's r) is used to measure the strength of the relationship between the relative movements of two variables as follows (Benesty et al., 2008):

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]} \tag{2}$$

where $r$ is the Pearson correlation coefficient, $n$ is the sample size, $x$ and $y$ are the individual sample points. The value of Person's r ranges between −1 and 1. A perfect positive correlation corresponds to the value of 1, while the value of −1 indicates a perfect negative correlation. The value of 0 shows that no linear relationship is found between the movement of the two variables.

As displayed in Fig. 4, a strong positive correlation has been found for the provinces in the northern and eastern of China, which indicates that the national policies have a significant impact on this region. As the above-mentioned analysis, these regions are highly developed and strongly influenced by the administrative and economic centre of China. For the other regions, this relationship is less obvious. For instance, there is almost no correlation between the number of issued national policies and standards and the number of issued policies and standards in Chongqing, with Pearson's r around 0.07. This can be related to the fact that Chongqing is the municipality being able to make self-governance regulations. Furthermore, the special geographical conditions (hilly areas) make the BIM technology not fully applied. Liu et al. (2019) had also indicated that Chongqing was one of the less BIM-developed metropolitan cities in China. Similar to Chongqing, Macao is also a special case. The reason for this may be related to the fact that Macao generally follows the policies of Guangdong province and therefore is less likely to promulgate its own policies (Luo et al., 2021).

To further analyze these policies and standards, 12 keywords are selected by using the open-source text-mining tool Gephi.

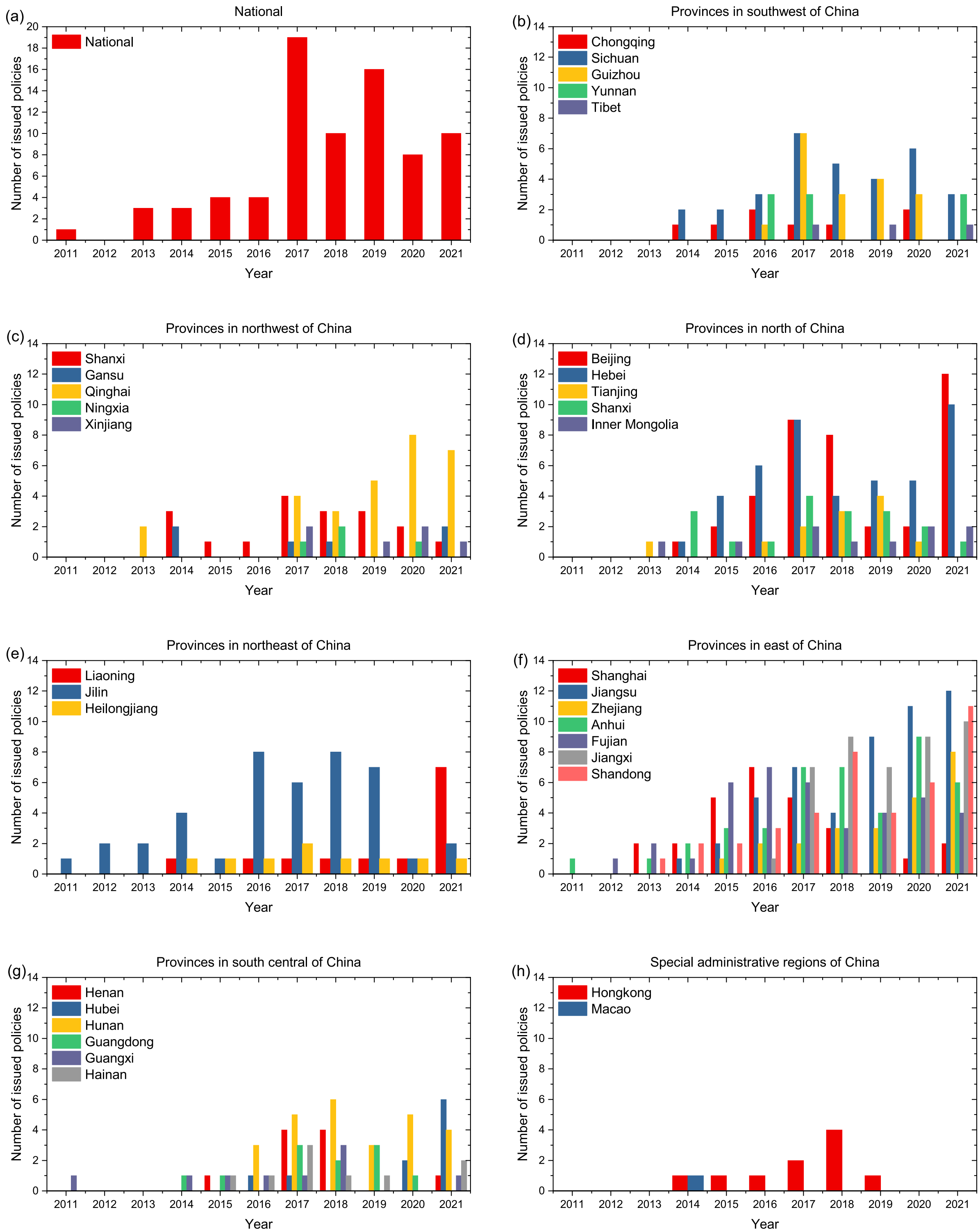


**Fig. 3.** The number of national and local standards and policies of BIM technology in China and each province from 2011 to 2021: (a) national; (b) provinces in southwest of China; (c) provinces in northwest of China; (d) provinces in north of China; (e) provinces in northeast of China; (f) provinces in east of China; (g) provinces in south central of China; (h) special administrative regions of China.

Gephi has been used widely for graph and network analysis, which is developed with a flexible and multi-task architecture in order to manage complex data sets and produce valuable visual results (Bastian et al., 2009). The occurrence frequency of the keywords of these policies and standards are displayed in Fig. 5. Concerning the national policies and standards, a high occurrence frequency can be found for the keywords of 'application', 'housing', 'urban and rural construction', 'architecture design', 'construction industry' and 'standard', which is higher than 10%. Namely, the Chinese government attaches great importance to the BIM application, especially in the field of housing, urban and rural construction, and architecture design. Furthermore, it is noticed that the national BIM standard has been established. For instance, 'the unified standard', 'the classification and coding

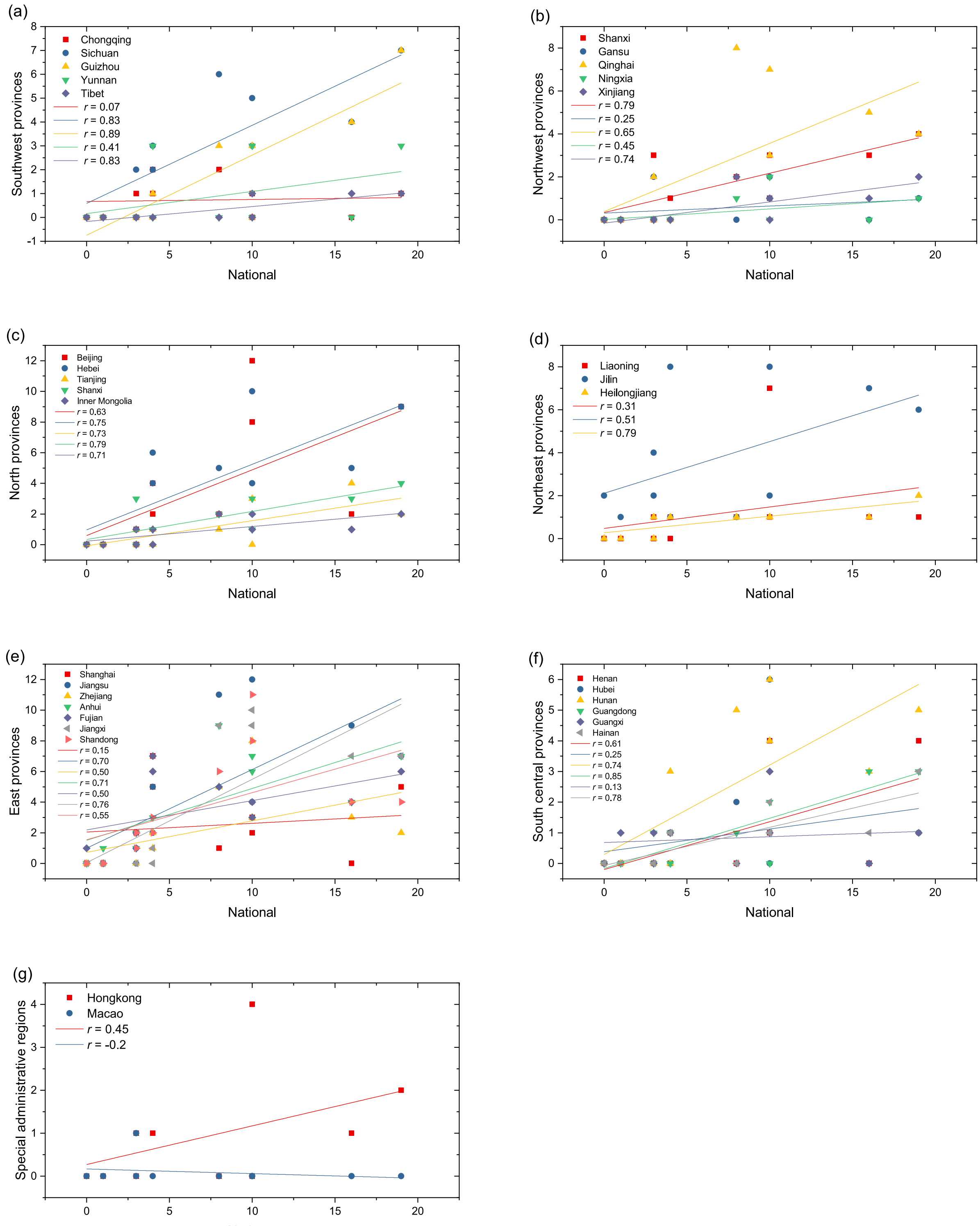


**Fig. 4.** The relationship between the number of national standards and policies of BIM technology and the number of local standards and policies of BIM technology in China from 2011 to 2021: (a) southwest provinces; (b) northwest provinces; (c) north provinces; (d) northeast provinces; (e) east provinces; (f) southcentral provinces; (g) special administrative regions.

standard', 'the design standard, and 'the construction application standard' for BIM have been issued from 2011 to 2021. The keywords 'construction industry', 'green building', 'guidance', 'building energy efficiency', and 'industrialization of construction' have a relatively low frequency, which is less than 4%. The occurrence frequency of keywords of 'prefabricated building' and 'building information' is about 7.02% and 8.77%, respectively. These results indicate that the Chinese government has paid greater attention to applying BIM technology in prefabricated building and building information than the construction industry, green building, building energy efficiency and industrialization of construction.

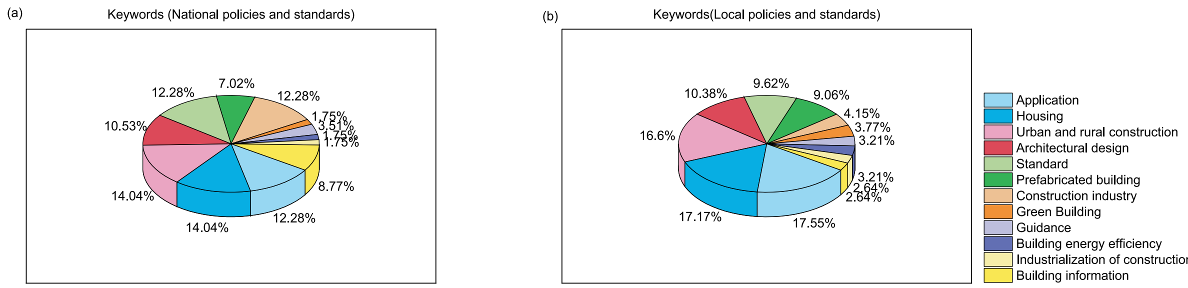


**Fig. 5.** The occurrence frequency of the keywords of the national and local policies and standards on BIM technology in China from 2011 to 2021: (a) national policies and standards; (b) local policies and standards.

Regarding the local policies and standards of provinces, the results are consistent with the national ones. The 'application', 'housing', 'urban and rural construction', and 'architecture design' are the keywords that have a high occurrence frequency, which is higher than 10%. The keyword 'application' has the highest frequency, about 17.55%. These results indicate that national policies have a strong impact on the local governments' decisions on BIM application. The keywords 'construction industry', 'green building', 'guidance', 'building energy efficiency', 'industrialization of construction' and 'building information' have relatively lower frequencies, which are less than 5%. These results indicate that the local policies and standards on the application of BIM technology in the construction industry, green building, building energy efficiency, industrialization of construction and building information may be still insufficient. Different from the national policies and standards, the lowest frequency keyword is found for 'building information' in local policies and standards, only 2.64%. This suggests that local policies and standards may follow local conditions, and are not necessarily based exclusively on national policies. The keywords 'standard' and 'prefabricated building' have an occurrence frequency of around 9.62% and 9.06%, respectively. For these two keywords, the local policies and standards are consistent with the national ones. Overall, the local governments have generally followed the national policies and standards. Indeed, these national policies and standards are considered the guidelines for promoting BIM application in some provinces

## 4. Application, development and research status of building information modeling technology for building sustainability and informatization

### *4.1. Building information modeling technology for building sustainability*

In recent years, BIM technology has become a popular method for sustainable building design (Jalaei and Jrade, 2015; Lim et al., 2021). It can effectively simulate the building information in a virtual and visible environment, including geometry, spatial relationship and geographic information, etc. (Wong and Zhou, 2015; Jalaei et al., 2020; Gan et al., 2018). The BIM can store the building information in its model, and then perform the simulation to verify the performance of design scheme. Designers can use BIM to improve their design efficiency and choose the optimal solution (Darko et al., 2020; Eleftheriadis et al., 2017). For instance, Liu et al. (2015a) indicated the optimization of building design based on BIM, which was proposed to improve the sustainability of buildings. In that study, they achieved the goal through the integration of a BIM-based simulation system and particle swarm optimization (PSO) based optimization system. Compared with the traditional design method (Zhou et al., 2021), the multi-objective problem of life cycle cost (LCC) minimization and life cycle cost estimate (LCCE) minimization had been considered, as shown in Fig. 6.

Huang et al. (2021) conducted in-depth interviews and surveys with 300 stakeholders of BIM and green sustainable building design (including architects, construction company managers, and green building certifiers). The results showed that BIM played an essential role in energy saving, material saving, land saving, and improving the indoor/outdoor environment, as shown in Fig. 7. BIM is capable of facilitating the interrogation of equipment performance parameters, calculating reusable building materials, and reducing building energy consumption. In the design stage, BIM can reasonably utilize the underground space, prioritize the construction of abandoned land, and increase the green space percentage. Meanwhile, BIM can also contribute to increase the opening area of exterior windows and facilitate accurate simulation of sunlight analysis. BIM can realize the requirements of collecting and analyzing data information required for green buildings, centralized demonstration and rapid calculation (Wong and Zhou, 2015; Carvalho et al., 2021; Llatas et al., 2020). In addition, the assessment process of a green building could be significantly optimized due to BIM's visualization and simulation features. The evaluation results of green buildings could also be more conveniently recorded and monitored using BIM (Chong et al., 2017; Edwards et al., 2019).

The concept of sustainable building integrating BIM technology has been widely spread and practiced in many practical projects worldwide (Fadeyi, 2017). While considering the implementation of BIM-driven building sustainability practices, despite there being strong synergies between them, the organizations are still finding difficulties with integration. The literature demonstrates that the implementation of both of them is consistently underdeveloped and delayed (Ametepey et al., 2015; Ng et al., 2015). The sustainability-driven projects are also more complicated than conventional approaches due to more specialized and customized processes resulting in more complicated construction (Ochoa, 2014). Although many projects have proved the actual energy-saving effect of sustainable building technology, the final applied effects in the whole life cycle of buildings are still not predictable by designers and engineers (Sadafi et al., 2011; Munaro et al., 2020). The main reasons are as follows: (i) most design methods only focus on one goal, such as thermal performance or carbon emission reduction. However, cost-saving is the main purpose for the customers (Santos et al., 2019b; Rad et al., 2021); (ii) it is inevitable to pursue the best design scheme with higher accuracy, which requires a lot of computation. For the current design improvement method, heavy workload and time consumption are two common shortcomings, which make designers expect to adopt higher efficiency and accuracy.

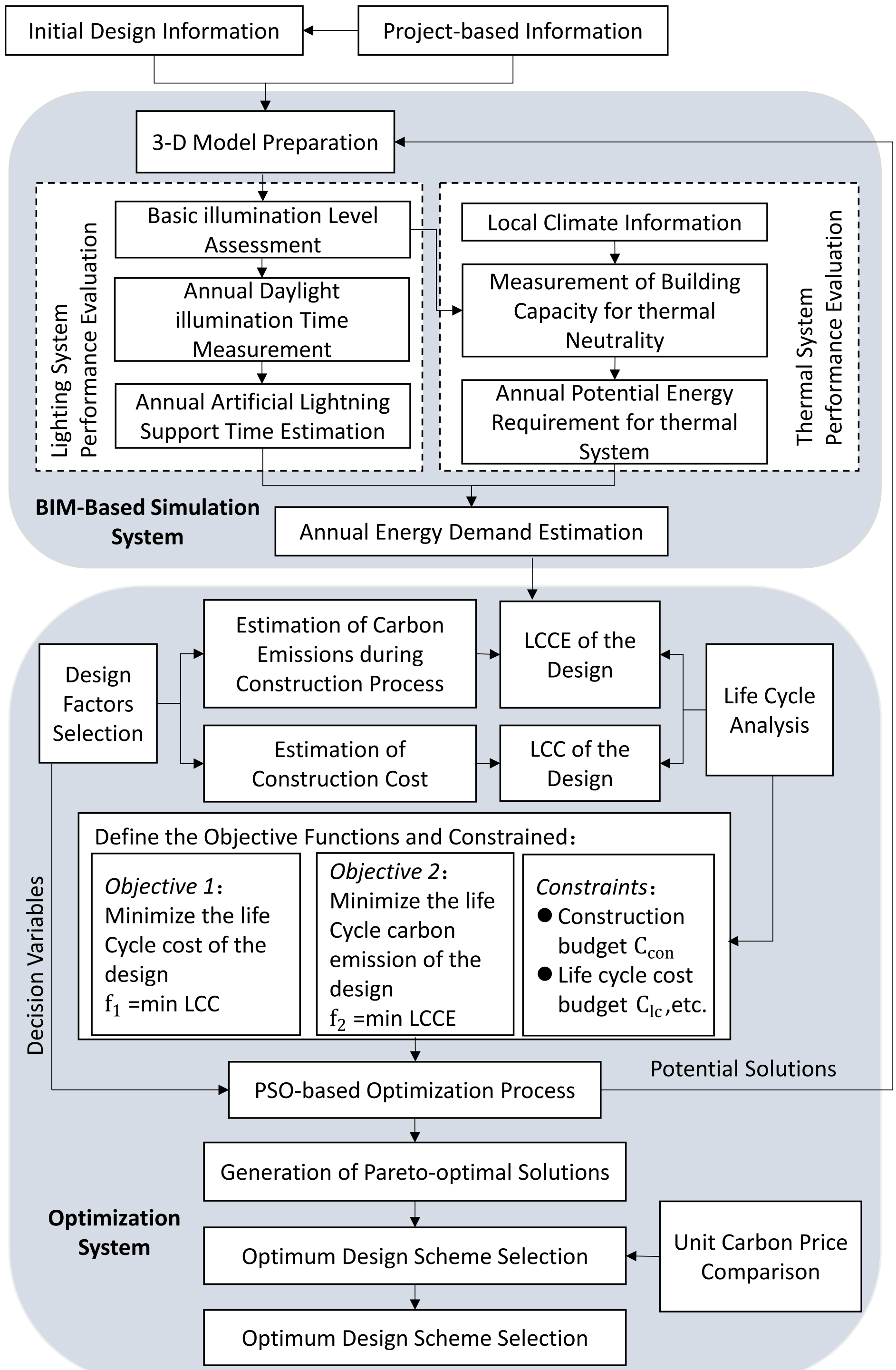


**Fig. 6.** Optimization scheme for sustainable building based on the BIM technology (Reprinted from Liu et al. (2015a). Copyright with permission from Elsevier).

The effective sustainable design of buildings largely depends on the successful cooperation among all participants. However, the increasing complexity of modern buildings increases the challenge and complicates of their collaborations (Jalaei et al., 2020; Palomar et al., 2020). In conventional sustainable design, the degree of integration among different participants is limited, which is regarded as some different independent disciplines. For example, architects start with conceptual design to provide the architectural shape and layout to meet the functional and aesthetic requirements. Then, structural engineers build structural systems and skeletons to meet safety, structural performance and cost standards (Liu et al., 2017). The cooling and heating of a building are generally the responsibility of a heating, ventilation, and air conditioning (HVAC) engineer. The automatically integrated design based on BIM technology can bridge the gap among different participants, reduce design time, and provide feasible automatic optimization solutions, which is beneficial for integrating different disciplines (Matos et al., 2021; Shadram et al., 2016). However, the existing views are in the preliminary research stage, and the application is still in the blank stage. Moreover, BIM automation integrated sustainable design will put forward higher requirements for future design professionals, who need to have

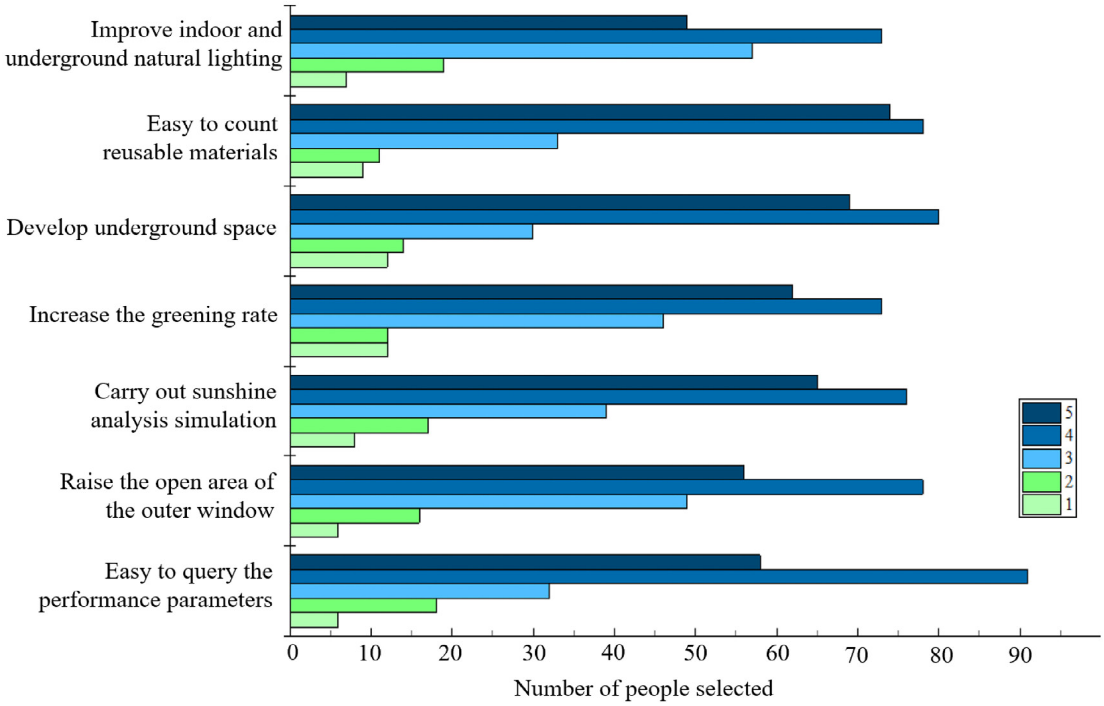


**Fig. 7.** Results of BIM's contribution to building energy saving, material saving, land saving, indoor/outdoor environment:1-almost no contribution; 2-limited contribution; 3-some contribution; 4-much contribution; 5-great contribution (Reprinted from Huang et al. (2021). Copyright with permission from Elsevier).

extensive knowledge, skills and ability. In addition, researchers need to further develop BIM software to expand its operability for building sustainability, so as to realize the automatic synergy between building design, analysis, optimization and evaluation (Li et al., 2021a; Najjar et al., 2019).

### 4.2. Building information modeling technology for building informatization

Building informatization refers to the use of information technology, which includes IoT technology, 3D printing technology, 3D laser scanning technology, VR technology, digital construction technology, RE technology and other information technologies (Xu-Dong et al., 2006; Yunyi et al., 2018). BIM technology is the specific application of building informatization, and it describes the computer-aided design, which is mainly based on three-dimensional graphics, object-oriented and architecture to help realize the integration of building information (Howard and Björk, 2008; Li et al., 2018a). BIM is integrated with more advanced technologies in order to create a greater comprehensive value (Fadeyi, 2017; Santos et al., 2019b; Rad et al., 2021).

Nowadays, with the gradual and in-depth development of BIM application, a plenty of information projects are combined with BIM technology (Li et al., 2018d). The integrated application of BIM and IoT is essentially the fusion of the whole process of building information. With the development of BIM application, many BIM projects have been combined with IoT (Lei et al., 2020; Wong et al., 2018). For instance, some researchers examined and prospected the application strategy and value of BIM-based IoT technology in the construction stage (Huang et al., 2018). Some researches focused on the specific engineering forms of construction engineering and municipal engineering, and discussed the integrated application scenarios of BIM and IoT technology (Liu, 2019; Zhong et al., 2017). BIM plays the role of information integration, interaction, display and management in the upper layer, while the IoT technology undertakes the functions of information perception, collection, transmission and monitoring in the lower layer. The integrated application of the two technologies can realize the "information flow closed-loop" in the whole building process and realize the organic integration between virtual information management and physical environment hardware (Tang et al., 2019). Zhai et al. (2019) developed the IoT-enabled BIM platform, as shown in Fig. 8. By combining advanced IoT technologies and BIM, barriers that hinder the possible functionality of BIM could be addressed. Using an application scenario of a modular building project in Hong Kong as an example, this study demonstrated how the coupled platform could solve the issues of inconvenient data collections, lack of automated decision support, and incomplete information encountered by independent stakeholders.

The combination of BIM and 3D printing technology is very effective for energy saving, decrease of cost, isolation of structural and beneficial for building design (Zhang et al., 2020a; Pessoa et al., 2021). In addition, the combination of BIM and 3D printing technology can effectively increase the project coordination and communication with multiple industries to provide better final products for users. Meanwhile, BIM is the core of 3D printing architecture by providing software to manage the design and construction process (Sakin and Kiroglu, 2017). Some researchers consider that BIM is just a little more complicated than 3D animation, 3D design, or 3D computer-aided design (CAD) (Xue et al., 2019; Ding et al., 2020a). However, BIM is different from other model-based processes, which can evaluate every step in the construction process. Even after the construction is completed, BIM can guide the project business (MehmetSakin and Canerkiroglu, 2017). He et al. (2021) proposed a BIM approach to support the detailed geometric design and digital fabrication of modular buildings, and discussed its ability to generate geometric details of 3D printed modules, as shown in Fig. 9. In addition, a robotic simulation of 3D printing was performed to explore flexible schedules for producing 3D printed modules or assemblies. This study illustrated that this coupling technology could assist practitioners in improving the quality of modular building construction management and further increase productivity and cost-effectiveness.

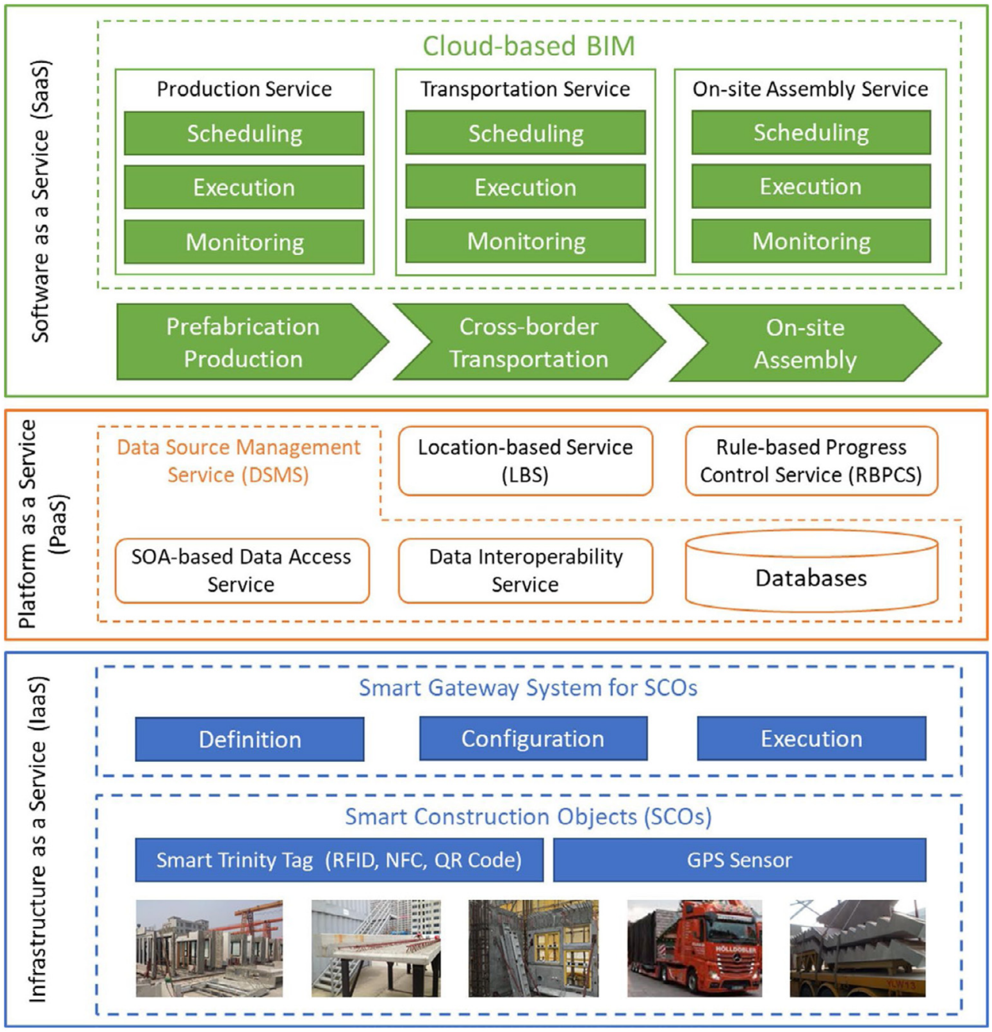


**Fig. 8.** The application of IoT-enabled BIM platform for modular integrated construction (Reprinted from Zhai et al. (2019). Copyright with permission from Elsevier).

The studies on the combination of BIM technology and 3D laser scanning have been widely analyzed in previous studies. For the construction status, it is difficult to modify on site, the real information of the site can be obtained through 3D laser scanning technology. The creation of a BIM from 3D laser scanning is by default the capturing of the data (Mahdjoubi et al., 2013), as shown in Fig. 10. The integration of BIM and 3D laser scanning is to compare, transform and coordinate the BIM model with the corresponding 3D scanning model in order to achieve the purpose of assisting engineering quality inspection, rapid modeling and reducing rework, and this combination technology can solve many problems that cannot be solved by traditional methods (Mahdjoubi et al., 2013; Bosché, 2012; Bosché et al., 2015). In addition, BIM and 3D laser scanning of RE technology have been applied in many construction cases, which can improve the information utilization and communication among the main stakeholders in each stage. In the past decade, RE has been widely recognized because it can promote the secondary design in the renovation process of old buildings and help stakeholders better understand the design and construction. RE can collect the 3D coordinates of the existing buildings to be reconstructed through advanced scanning technology, and accurately restore the original building information to the 3D model. The combination of 3D laser scanning and BIM can produce significant advantages, especially in the existing conditions (Ding et al., 2019a). Through laser scanning, the changes in construction conditions and operation stages can be recorded to ensure the accuracy of BIM processing information.

The research on the combination of BIM and VR technology has been widely investigated in previous studies. VR is a technology that uses a computer to generate a simulation environment, enabling the users to “immerse” in the environment through a variety of sensor devices (Lin et al., 2018; Motamedi et al., 2017). It makes the designers who apply BIM feel personally in the environment, and naturally interact with the computer-generated environment (Getuli et al., 2020; Hou et al., 2003). The combination of BIM and VR technology can make the field personnel of the reconstruction project, especially those who have limited experience in using formal design documents to understand the meaning of the designer better, and effectively speed up the construction activities and avoid the rework (Chen et al., 2021). Through the BIM model, the designer checks the architecture design, engineering model, specification and constructability in the VR environment (Khalili, 2021), as shown in Fig. 11. This enables field workers to visualize design models with detailed objects and attributes directly before construction, especially those complex models. In addition, the design database would automatically update any changes and generate all representations and visualizations for these field workers to avoid misunderstandings and help them fully understand the impact of changes on construction (Yang et al., 2019).

A digital construction system refers to establishing a digital geographic basic platform, geographic information system,

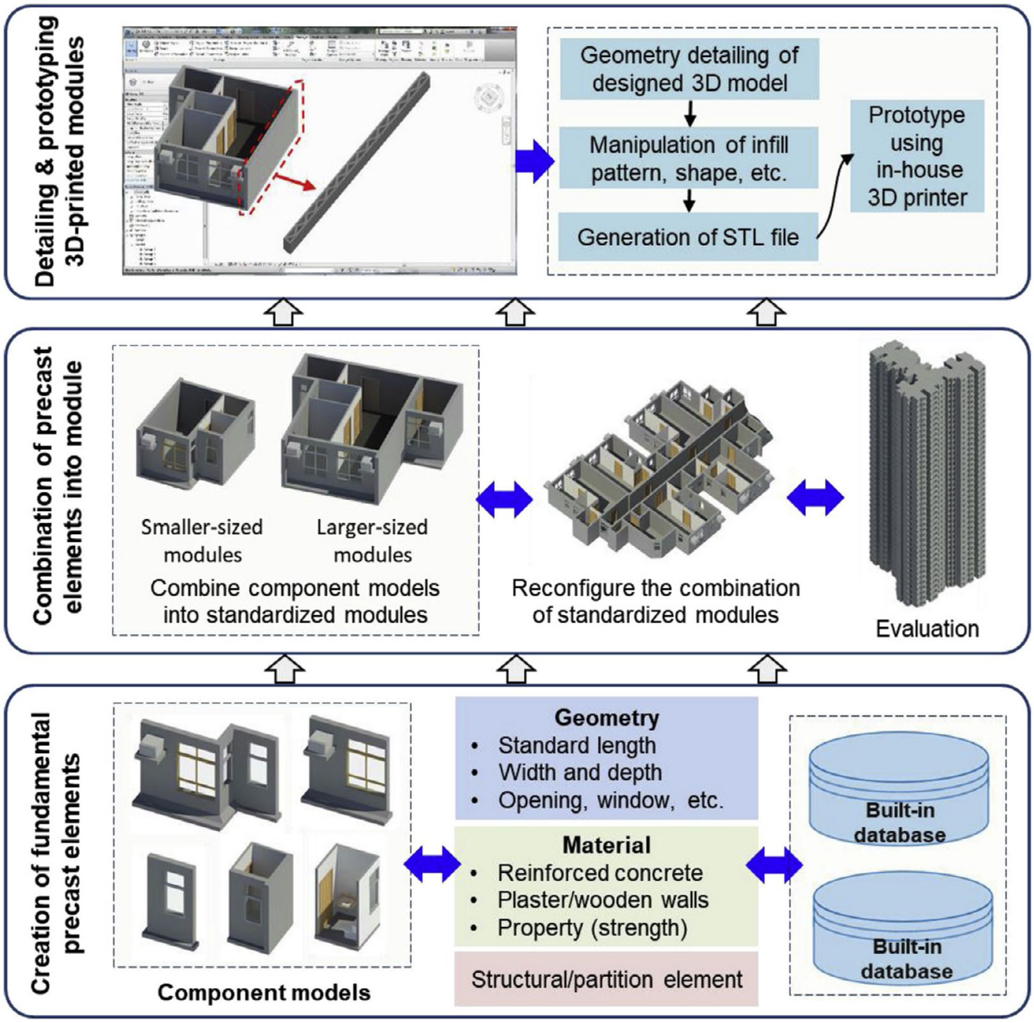


**Fig. 9.** BIM-enabled computerized design including the detailing/prototyping of 3D-printed modules (Reprinted from He et al. (2021). Copyright with permission from Elsevier).

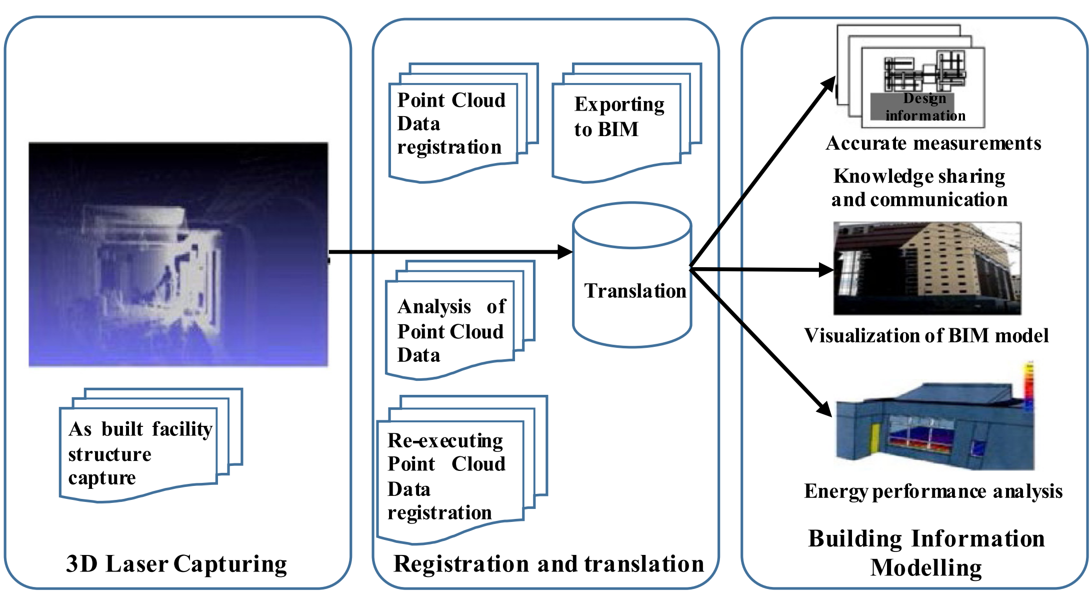


**Fig. 10.** The integration model of BIM and 3D laser scanning (Reprinted from Mahdjoubi et al. (2013). Copyright with permission from Elsevier).

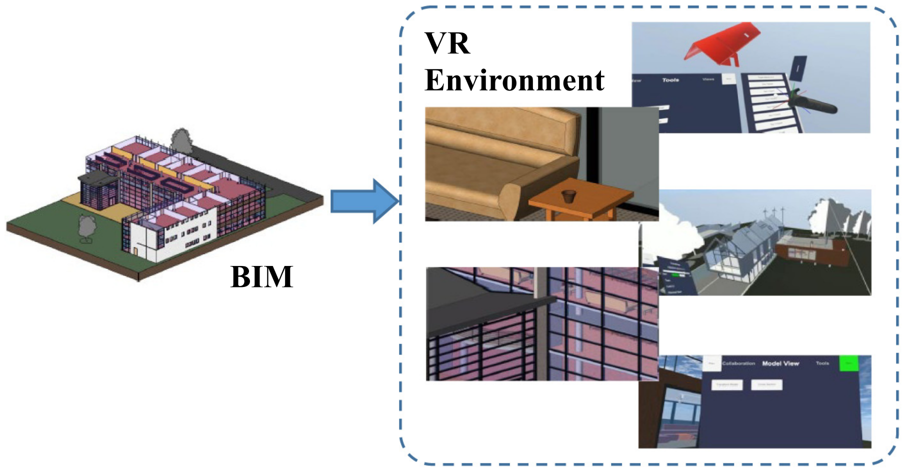


**Fig. 11.** The application of BIM integrating with VR technology.
*Source:* Modified from Khalili (2021).

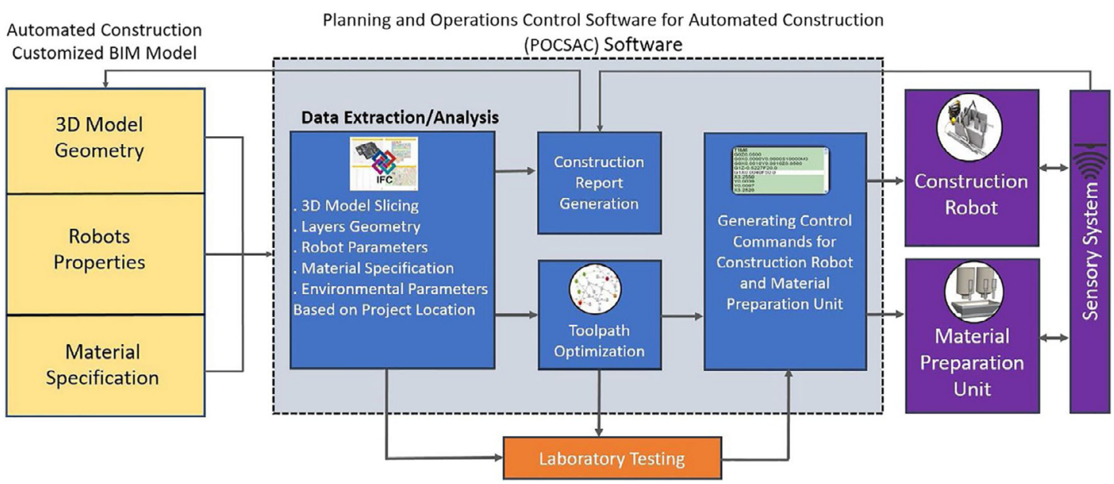


**Fig. 12.** The framework flow of BIM integrating with robotic construction (Reprinted from Davtalab et al. (2018). Copyright with permission from Elsevier).

remote sensing technology, site data acquisition system, global positioning system and other basic platforms (Ding et al., 2019a; Merschbrock and Munkvold, 2015). It can effectively integrate the site information resources, break through the limitations of time and space, and then establish an open information environment to make the construction project of each participant, which is more effective for exchanging real-time information with other parties. Davtalab et al. (2018) proposed a framework for integrating BIM into an automated construction system, as shown in Fig. 12. The proposed framework provided a solution for interoperability between different components of the automated construction system and the BIM integration software platform, thus achieving maximum benefits through the synergistic effect of these two technologies. Some studies have also found that integrating these advanced technologies into the BIM platform can enhance information sharing among different stakeholders by visualizing the construction process. Simultaneously, the limited space monitoring system is designed and integrated into the BIM platform to improve the visualization and safety of the construction site (Li et al., 2018b).

At present, many enterprises have applied the digital framework of BIM combined with RE to improve the utilization rate of information in different stages, which can reduce the mistakes and rework of reconstruction projects in the process of urban renewal (Ding et al., 2019b). Ding et al. (2019a) proposed an integrated framework with effective information and organizational management that integrates BIM, RE, and other supporting technologies, as shown in Fig. 13. This framework combined supporting technologies (VR, 3D laser scanning, 3D printing and prefabrication) to understand better design and construction, and it also combined the tools (work breakdown structure and model breakdown structure) to improve the quality of organization and management (Volk et al., 2014).

The above-mentioned framework has been successfully implemented in the renovation project of a shopping mall in Hainan, China, which improved the renovation efficiency by 15%, reduced the design changes by 30% and reworked by 25%, and finally saved two months and 7.41% of the cost for the steel canopy (Ding et al., 2019b). Therefore, this framework could actively reduce the mistakes and rework in the process of transformation, and significantly improve the effectiveness of urban renewal. Especially in this reconstruction project, the accuracy of the original building information is essential for the secondary design. Therefore, based on the 3D coordinate data collected by 3D laser scanning, the original building structure is restored. Secondly, according to the secondary design model, it is still difficult for the field workers to understand the design intention and determine the installation location. The combination of BIM and VR technology can help workers better understand the meaning of design and construction (MehmetSakin and Canerkiroglu, 2017).

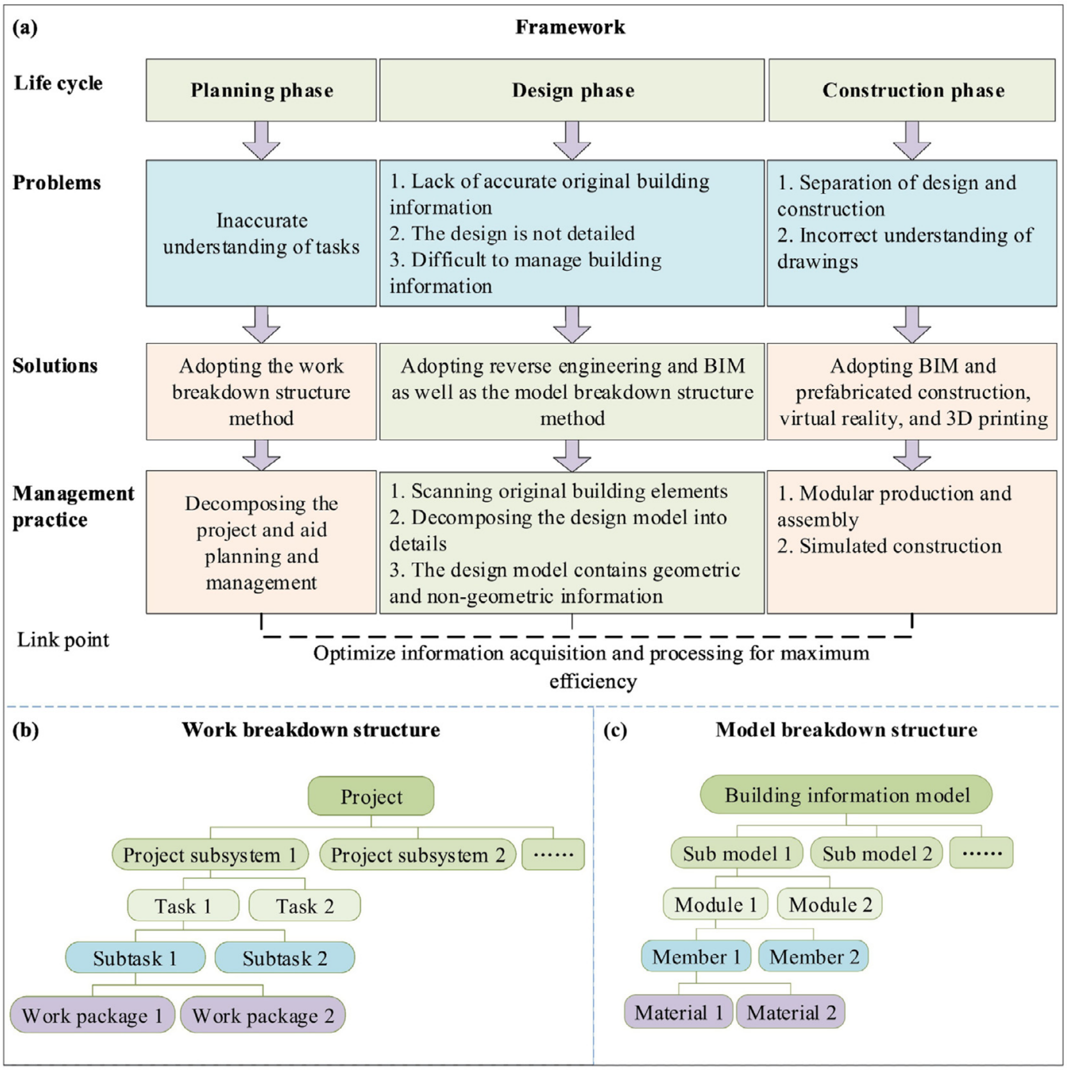


**Fig. 13.** Framework for implementing BIM integrated RE, and other supporting technologies in renovation projects (Reprinted from Ding et al. (2019a). Copyright with permission from Elsevier).

At present, BIM has been promoted and applied in many countries globally, and the mature standards or systems have been established. However, there are still many obstacles in the large-scale BIM application for building informatization (Li et al., 2018a), mainly including: (i) through the actual investigation, it is found that all parties have their own systems to operate due to the core demands of construction industry participants (i.e., owners, supervisors, construction, survey and design) are not the same; (ii) the formation of information island has a long history, and the protection of their interests leads to the formation of untrue information, non-synchronization and non-intercommunication, which results in the collaboration office is difficult to be realized; (iii) at present, BIM software still has a deviation for the informatization of the construction industry. The informatization of the construction industry is a highly professional industry, and ''management standardization, standard form, form informatization, and information intensification'' are the urgent problems to be solved; (iv) the metadata collection of construction informatization has not been recognized by relevant personnel, and the awareness of informatization is not strong; (v) the hardware facilities on the construction site are not in place, and the quality of personnel needs to be improved.

Overall, the development of building informatization in the industry is significantly uneven, and the application of an integrated information management system is rare. Some enterprises only use independent software, such as a financial system, material management system and personnel management system. It is impossible to unify the daily information exchange, market operation management, project process management, procurement process management, and human resource management on the platform of enterprise informatization. Thus, the information island hinders the overall level of enterprise informatization. The building informatization should consider the different demands of each participant, focus on the whole process management of the project process, and break the information island to let each participant share data.

## 5. Existing issues, limitations, and recommendations of building information modeling application and studies

Based on the above discussion, it is noticed that BIM has been widely used in various industries and different stages of the building industry. However, the research and application of BIM in China are relatively late, and many issues still exist, which would lead to the limited BIM application in building sustainability and informatization (Das et al., 2021; Kamel and Memari, 2019; Antwi-Afari et al., 2018). In previous studies, besides the research on the advantages of BIM application, many researchers have studied the obstacles of BIM implementation in buildings (Lu et al., 2021). Overall, the lack of both standards and domestic-oriented tools for BIM implementation is the biggest practical obstacle, thereby affecting BIM application in building sustainability and informatization in China (Tan et al., 2019b). Some organizations in the United States, Australia and other developed countries have issued a series of BIM standards to guide the implementation. However, the development of BIM standards in China is still in its infancy, and there is no unique BIM standard for building sustainability and informatization. In addition, most used BIM software is independent, and there are different implementation obstacles for different application scenarios. For example, the customized functions for the prefabricated structure and sustainable design cannot be provided by Autodesk Revit (Zhou and Shi, 2018). The software is difficult to meet the requirements of all parties in terms of function, especially in the aspects of materials, cost and operation and maintenance management. The lack of BIM software not only causes many professional technologies and applications, but also restricts the BIM development in China (Li et al., 2018a). As researchers have indicated, the lack of standards and domestic-oriented tools makes the BIM development more difficult in China, and practitioners still adopt a wait-and-see attitude toward the BIM application (Li et al., 2018b). Therefore, the application and development of BIM technology in building sustainability and informatization still have a long-term arduous task.

Several researchers have also investigated the seriousness of the barriers in various ways for different stakeholders of BIM applications (Huang et al., 2021). Their findings can be subdivided into three aspects. In terms of technological aspects, the biggest barrier is the weak interaction amongst software as perceived by owners, while the lack of uniform BIM standards is perceived as the most serious barrier by architects and constructors. In terms of managerial aspects, both owners and designers ranked the government's failure to transform the traditional two-dimensional management model as the primary barrier, while the lack of management awareness of BIM for construction project works. In terms of the social environment, the lack of policy guidance and guarantee, corresponding standards, and BIM experts are the biggest barrier to the owners, designers, and builders, respectively.

Some researchers concluded that the most major barriers to BIM implementation are associated with project stakeholders and the technology's usage (Chan et al., 2019). Consequently, dynamic variations in the attitudes, efforts, and policies from construction companies and project teams will mitigate the influences of these barriers to BIM implementation. More importantly, the notable benefits to be gained from BIM adoption by key construction project stakeholders are primarily related to the effectiveness of delivering cost, time, and quantity-related project objectives. Prominent benefits could be strengthened and obtained when the building industry's current collaborative work environment is improved as well as interoperability issues with computer software are addressed.

The BIM application in China's existing design institutes mainly focuses on auxiliary design aspects, such as drawing turnaround, pipeline collision detection and related analysis. In accordance with the current preliminary BIM application, the workload is frequently over two times of the traditional design practices within the design stages, resulting in a verifiable increase in design costs. However, the combination of BIM with new technologies such as big data, IoT, smart manufacturing, and smart construction sites has not been applied maturely enough, and their practical implementation has been relatively rare in the building sector (Huang et al., 2021; Shi and Xu, 2021). Notwithstanding that the costs of BIM application are high, the adoption of BIM in design institutes and other sectors remains widespread, as some local governments' policies stipulate that new public buildings reaching a certain area are required to use BIM. After the construction of many building projects is completed, the value of BIM deployment is fundamentally extinguished in construction projects. Therefore, BIM would not be enthusiastically adopted in building projects with high one-time investment costs and low-return benefits (Migilinskas et al., 2013).

To make BIM technology more reasonable and fully used in building sustainability and informatization and achieve high-quality development, some effectiveness measures and application recommendations should be carried out in the following practice-based works. The non-consistency of BIM standards has been a primary barrier to BIM development, especially since individual provinces in China have formulated standards for BIM applications. Considering the distinct institutional and cultural background of China, a government-led promotional policy is a prerequisite for BIM implementation. It is recommended that the governments should jointly with authoritative departments or enterprises, take multiple opinions and progressively formulate a consistent and applicable BIM standard. In China, the governments could play a leadership and promotional role by jointly inviting authoritative industry associations such as the China Construction Association with powerful institutions and the China Academy of Building Sciences to negotiate and develop standards. The governments should also conduct questionnaires to stakeholders such as architects and constructors who are most concerned about the barriers of inconsistency for BIM standards and sufficiently consult their viewpoints. The compilation of standards should be combined with China's national circumstances. Simultaneously it should be formulated with reference to international BIM standards or some construction industry codes that have been promulgated in China. In addition, more standards, including design standards (Zhou et al., 2020), documentation deliverability standards, and tariff standards also require to be promulgated to transform the BIM application in the building industries thoroughly. The formulation and promotion of BIM technology policies need to consider the regional characteristics, project categories, and application direction. It is essential to investigate the market demand and development situation of BIM technology, such as software development enterprises, design enterprises, construction contractors, real estate development enterprises, government and universities.

In order to overcome the specific barriers of BIM in promoting building sustainability and informatization, software developers are expected to more conveniently realize data sharing and information transmission between BIM platforms and corresponding evaluation systems. By enhancing the interoperability of BIM data under multi-systems, BIM could be more easily used in the building operation and maintenance stages. For example, integrating a security monitoring system into BIM would contribute to managers' real-time observation of equipment status in green buildings. If BIM could be integrated with the energy management system (Zhou, 2022), it would also enable better surveillance of the building's energy consumption. In addition, various BIM authorization and analytical tools should be assessed, including the utilization of visual programming to increase the automatization of data management. A collaborative effort among BIM software developers, building sector stakeholders, and relevant researchers should be undertaken to address identified gaps and prospective requests to provide a more comprehensive BIM-based green and sustainability ecosystem (Lim et al., 2021).

BIM application in the operation and maintenance stage of various construction projects should be expanded in future studies. It is an excellent phenomenon to expand the BIM technology by integrating city information modeling (CIM) application in the operation and maintenance stage (Peng et al., 2020). In addition, for the restoration and protection of ancient buildings, BIM technology can also be actively used, such as establishing the BIM model combined with RE technology. The integration of BIM and new technologies should also be increased. In recent years, new network and communication technologies, cloud technology, mobile technology, IoT and other new generation of information technology continue to emerge, which indeed bring new impetus and impacts to the development of project management information (Heigermoser et al., 2019).

It is time-consuming and labor-intensive to gather and process data and model information "in-situ" for existing buildings. Because most existing buildings may be available only in 2-Dimensional drawings, and generally without complete documentation of as-built information or developed BIM models. To generate in-situ BIM for existing buildings, future studies should improve the data acquisition process associated with in-situ BIM modeling. To achieve this objective, an approach integrating BIM with realistic-capturing techniques, including photogrammetry and laser scanning, would be required. Although image-based techniques are recognized as a feasible and cost-effective approach to constructing in-situ BIMs, existing data extraction remains error-prone. Using cluttered point clouds to automatically or efficiently extract information remains a challenging aspect of in-situ BIM modeling. Future studies should be concentrated on improving the reliability and accurateness of point cloud data in complicated environments. Future studies are also required to explore efficient and practical algorithms for constructing object detection and identification. Therefore, it is possible to achieve completely automated development of in-situ BIM generation processes.

## 6. Conclusions and future works

This paper summarizes the latest application and development of BIM technology for building sustainability and informatization in China. Firstly, a statistical analysis is performed on the relevant policies and standards of BIM technology issued from 2011 to 2021 in China. Based on this analysis, this study points out that national policies and standards show a stronger impact than the local ones. Then, this study analyzes the latest application and development of BIM technology for building sustainability and informatization. Existing issues in building sustainability and informatization are also discussed. The main conclusion can be summarized as that the application of BIM technology for building sustainability and informatization in China is in a large quantity, with a wide range of scope, but the level still needs to be improved. The main reasons can be summarized as the unreasonable management practices of both governments and enterprises, and the lack of reasonable top-level planning, and the lack of standards and domestic-oriented tools for BIM implementation. In view of the aforementioned issues, this paper proposes rationalized suggestions, countermeasures and future recommendations to provide assistance and reference for governments and enterprises to boost BIM usage rate in engineering projects.

Although this study has analyzed BIM policies and standards of national and individual provinces through statistical analysis approaches, covering policy development trends and existing issues. Future research work should provide more quantitative recommendations for the governments to improve and reformulate building sustainability and building informatization policies. In addition, BIM technology in building sustainability and building informatization is the concentrated discussions in this study. However, in other related highly emphasized areas, such as Industry 4.0 and intelligent buildings, there are likewise considerable problematic and implementation barriers to their application in China, which requires more in-depth investigations in future studies. Nevertheless, it is appreciated that the vast majority of studies in this paper considered English-language literature sources from two mainstream search engines, including journal papers, and conference papers with the exception of policy analysis. These statistical results may be affected, however, the impacts of these set boundaries on characterizing critical analysis and thematic discussions are probably minimal. Future works will provide more general insights by expanding the scope of the literature to different databases and languages to further fully analyze the thematic discussions in this paper.

## Acknowledgments

This work was supported by the Hong Kong University of Science and Technology (Guangzhou) startup grant (G0101000059). This work was supported in part by the Project of Hetao Shenzhen-Hong Kong Science and Technology Innovation Cooperation Zone (HZQB-KCZYB-2020083).

## Declaration of competing interest

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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