WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.151880
ARCHIVES OF CIVIL ENGINEERING
Vol. LXX ISSUE 4 2024

pp. 71 –83

Research paper

Research on reinforced concrete structure design of urban buildings by using BIM technology

Qianhong Bao[1]

Abstract: In order to improve the application of BIM technology in reinforced concrete structure design. Methods: This paper takes the housing project in District A of Guangzhou as the research object, and uses BIM technology to design the precast part of the reinforced concrete structure in the C household, including the deepening design of the reinforced concrete structure, production management of the precast components, tracking, address data modeling, hoisting and deployment, etc., which penetrates into all aspects of the design of the reinforced concrete structure. It was found that after the application of BIM technology, the construction period was reduced from the originally established 13 days per floor to 7 days per floor, and the on-site construction errors were reduced, the construction efficiency and construction quality were improved, and the project was successfully completed. It can be seen that the application of BIM technology in the design of reinforced concrete structures in urban buildings can shorten the construction period and ensure the construction quality at the same time. It is a favorable means to promote the development of urban construction industry and should be actively promoted.

Keywords: application, BIM technology, design, reinforced concrete structure, urban architecture

[1]MsC., Department of Construction Engineering and Art Design, Suzhou Vocational Institute of Industrial Technology, Jiangsu 215000, China, e-mail: baibao91009@yeah.net, ORCID: 0009-0009-8041-0635

1. Introduction

With the continuous development of modern science and technology, a variety of new technologies and new methods are constantly applied in various fields, which greatly promotes the progress and development of the industry. Among them, building information modeling (BIM) technology, with its unique advantages of information integration and collaborative work, has been widely used in the fields of construction, reinforced concrete and structural design, and has become an important force to promote the transformation and upgrading of the construction industry [1–5]. The application of BIM technology in the construction field is mainly reflected in the following aspects: building planning and design, construction and management, operation and maintenance [6–8]. In the design of reinforced concrete structure, BIM can realize the fine design and simulation of reinforced concrete structure in the model, so as to find and solve the problems in the design, improve the design quality and construction efficiency [9–11]. BIM can also be used for monitoring reinforced concrete structures. Using BIM technology, structural designers can perform accurate structural analysis and calculations. The BIM model is highly realistic and accurate, and can truly reflect the physical characteristics of the structure, thus providing the designer with reliable analysis data. In general, the application of BIM technology in the field of construction, reinforced concrete and structural design has far-reaching influence and broad prospects. By continuing to research and develop this technology, we can expect to achieve more efficient, precise and sustainable development in the construction industry in the future.

2. BIM model

Most of the urban buildings are concrete reinforced structures and masonry structures. In order to ensure the overall household design remains unchanged, a hybrid algorithm of comprehensive layer automatic recognition algorithm, optical character recognition technology and adaptive block algorithm is adopted to extract layer key data, re-arrange reinforced concrete structural components, and complete BIM modular components [12–14]. For urban architecture drawings are usually vector graphics files. Therefore, key layer information such as axis text and wall can be extracted with the help of automatic layer algorithm. When judging whether a certain layer is the target layer, check whether the necessary conditions (NC) of the layer's feature elements (FE) and related elements (RE) are met, then check the necessary conditions (SC) of FE and RE, calculate a single score according to Formula (2.1), and finally calculate the total score through Formula (2.2). The layer with the highest score is the target layer.

$$\text{Score} = \begin{cases} 0 \ (\exists \text{NC} == \text{False}) \\ \dfrac{\text{N(SC} == \text{True)} + 1}{\text{N(SC)} + 1} \ (\nexists \text{NC} == \text{False}) \end{cases} \tag{2.1}$$

$$\text{Total score} = \text{Score(FE)} + \sum_{i=1}^{n} \text{Score}(\text{RE}_i) \tag{2.2}$$

Where, Score is the score of the matching degree between the FE of each layer and the target layer; N (SC == True) indicates the number of SC that meet matching conditions. N (SC) is the number of sufficient conditions to identify the FE-RE structure of a figure; Total score is the total match score. In the process of building wall contour extraction, an adaptive block wall contour extraction algorithm is used for processing. The core idea of this method is to divide the discrete point data into grids of the same size, and the size of the grid is a dynamically changing value related to the best average number of coordinate points M in each grid, which can be calculated by the following Formula (2.3)–(2.6):

$$\begin{cases} W = X_{\max} - X_{\min} \\ H = Y_{\max} - Y_{\min} \end{cases} \tag{2.3}$$

$$\rho = \frac{n}{WH} \tag{2.4}$$

$$s = \frac{28A}{n\pi} \tag{2.5}$$

$$M = s\rho \tag{2.6}$$

In the above formula, $X_{\max}$, $X_{\min}$, $Y_{\max}$ and $Y_{\min}$ are the maximum and minimum values of the horizontal and vertical coordinates of the given fixed point. W and H are the width and height of the wall; ρ is the density expectation of the coordinate points; n is the number of all coordinate points in the given point set; s is the square area outside the search circle; A is the area of the region covered by the given fixed point set. Through the design of BIM model, lays the foundation for the subsequent collision detection, and also provides a positive impetus for the application of BIM technology in the design of reinforced concrete structures in urban buildings. In addition, the construction of BIM model is completed in Revit software, which operates in the same way as Autocad software and is well compatible with Autocad software [15–17]. Therefore, Revit software has gradually become the most widely used BIM basic model software in China.

3. Application of BIM technology in urban building structure

BIM technology, as a major auxiliary tool of urban architecture, has attracted much attention with the rapid development of urban architecture. The application of BIM technology in the construction stage of reinforced concrete structure engineering can effectively improve construction efficiency and reduce construction errors. Combined with the characteristics of reinforced concrete structure engineering, this paper focuses on the analysis of the integrated application of BIM technology in urban building structures, as shown in Fig. 1.

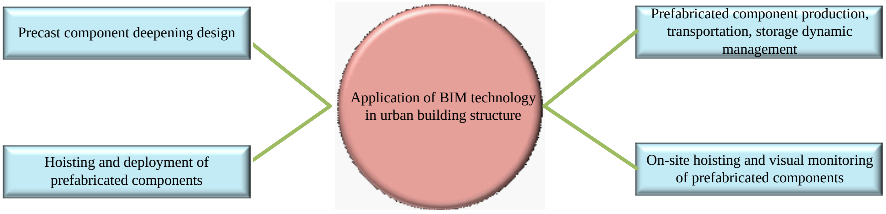

Fig. 1. Integrated application of BIM technology in urban building structures

3.1. Further design of prefabricated components

BIM technology realizes the opening and sharing of design information. Designers can upload the relevant design schemes and drawings of reinforced concrete structure projects to the BIM technology platform of the project, collect the specifications, sizes, materials and other information of the prefabricated components on the BIM technology cloud platform, and build the prefabricated component family library of various types of building prefabricated components (columns, walls, beams, plates, embedded parts). With the accumulation and enrichment of the family library in the BIM technology platform, BIM designers can compare and optimize the same type of prefabricated construction family, thus standardizing and modulating the prefabricated construction of reinforced concrete. In addition, the establishment of prefabricated component family library can promote the compilation of universal building design codes and standards. The in-depth design of prefabricated components also includes soft and hard collision detection between prefabricated components and between prefabricated components and other building construction to reduce problems during the later installation of prefabricated components, as shown in Fig. 2. With the help of BIM technology, the prefabricated component model can be further designed and directly connected to the prefabricated component manufacturer for the production of prefabricated components.

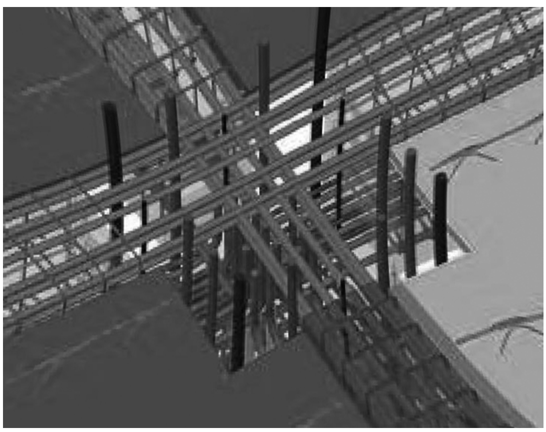

Fig. 2. Steel bar collision test

3.2. Hoisting and deployment of prefabricated components

The hoisting of precast concrete component is the key and difficult point in the construction of reinforced concrete structure engineering, and also directly related to the success or failure of the project. The BIM 3D model can dynamically simulate the hoisting process of each prefabricated component, so as to plan in advance the model and positioning parameters of hoisting equipment, the number of relevant operators and materials, adjust the layout of the construction site, optimize the relevant construction technology and equipment, and finally store and determine the hoisting position and hoisting sequence of all prefabricated components, as shown in Fig. 3. The 4D dynamic simulation model is combined with the construction schedule plan to form a 5D model, and the planned schedule is compared with the actual schedule, and the corresponding measures and schemes are proposed according to the project situation.

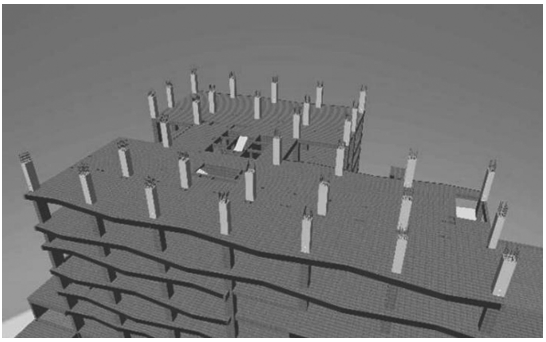

Fig. 3. Construction simulation of prefabricated column hoisting

3.3. Application in dynamic management of prefabricated component production, transportation and storage

The production, transportation and storage of prefabricated components need to be dynamically adjusted according to the conditions of the construction site. With the help of BIM technology, the demand plan of prefabricated components can be reasonably adjusted according to the production situation of prefabricated components factory, the scheduling situation of transport vehicles and the on-site demand. The production and transportation plan of prefabricated components factory and transport vehicles can be adjusted in real time according to the demand plan. Thus, the purpose of transporting prefabricated components to the site for direct lifting after the completion of production is achieved, reducing the storage of prefabricated components in the factory and construction site. Through the combination of BIM technology, RFID technology and two-dimensional code technology, each prefabricated component has a unique code, and its production, transportation, storage and installation information are recorded on the cloud platform [18]. It can be viewed at any time through the mobile terminal to control the relevant component information in real time, as shown in Fig. 4.

Fig. 4. Two-dimensional code display of prefabricated components

3.4. Application in on-site hoisting and visual monitoring of prefabricated components

After the hoisting construction plan is determined, BIM technology can store the hoisting positioning, hoisting sequence, hoisting attention points and other information of all prefabricated components in the BIM model, and then transmit it to the handheld terminal through the cloud platform. The project construction site operators can accurately view the detailed construction scheme and construction status of each prefabricated component according to the BIM model, and realize the visualization and paperless hoisting of prefabricated components. The construction site operators scan the prefabricated components before hoisting, check and input their status information, check the hoisting construction plan after accurately identifying the threshold component information, check the location and other details of the prefabricated components after hoisting, and confirm the information of the completed hoisting of the prefabricated components by scanning the component chip/two-dimensional code after passing the inspection. At the same time record the prefabricated component lifting process, the actual device and the construction time, so as to check. In this way, the occurrence of construction errors is reduced and the construction efficiency is improved.

4. Case analysis

4.1. Project overview

In order to test the practical application of BIM technology in urban building structures, an empirical study is carried out with the housing project in Guangzhou District A as the research object. The construction area of the project is about 160,000 square meters, divided into A, B, C three units, a total of 6 towers. The basement is 2 floors, the basement construction area is about 50,000 square meters, the total number of households is 1932, and the comprehensive plot ratio is 3.00. The construction period is 1064 days, the total number of prefabricated square is about 6650 cubic meters, among which, the average horizontal structure of unit C is prefabricated, and the vertical structure is poured. The basic situation of the project is shown in Table 1.

Table 1. Basic information of the project

Number	**Building height (m)**	**Number of floors**	**Precast site**	**Structural form**	**Assembly rate (%)**
Building A5/A6	84.8	29	Bay Windows, stairs	Shear wall structure	15.20
Building A7/A8	96.1	33	Bay Windows, stairs	Shear wall structure	15.20
Building B	87.6	30	Bay window, stairs, laminated floor, air conditioning board, beam wall integrated component	Shear wall structure	34.25
Building C	83.8	28	External wall panels, main beams, secondary beams, laminated panels, stairs	Shear wall structure	57.9

From the overall situation of the project, there are the following aspects of the construction difficulties: First, the forms of PC components are diverse, PC components and the pre-cast structure connection parts are many and complex, and it is necessary to consider the connection between the construction PC components and aluminum alloy templates, and the production accuracy of components is high. Second, the number of PC components is large, and there are many types of PC components, and the management of transportation, approach, stacking and hoisting of PC components is difficult. Third, the amount of karst cave engineering needs to be treated is large, the buried depth of the karst cave reaches 46 m, the height of the cave reaches 11.3 m, and the karst cave is mostly filled or semi-filled flow and soft plastic clay, which is difficult to deal with. In addition, the working face of the project needs to be expanded in a large area, more pile machines need to be invested, and the supporting facilities of the punching drill require more, which increases the difficulty of management. After the construction period is divided into local control nodes, the construction period is tight. Fourth, the surrounding environment is complex, there are farmland in the northeast, and civil houses in the village in the east and south, with large construction surface and large engineering volume, and high requirements for green environmental protection, safety and civilization on the construction site. Fifth, mechanical and electrical installation of more internal motion, including weak current system, pipeline is more complex, pipeline comprehensive balance and optimization is difficult.

4.2. Experimental Setup

During the construction period, BIM technology was used for on-site construction guidance, and an EMPC big data cloud platform based on BIM technology was established. The specific Settings of BIM technology on the platform were shown in Fig. 5.

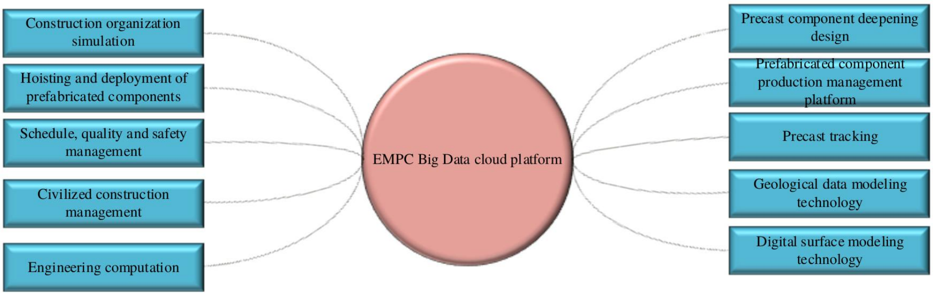

Fig. 5. Specific Settings of BIM technology on EMPC big data cloud platform

Firstly, precast deepening design and collision integrated coordination technology can deepen the design of reinforced concrete structure, which is the key to the implementation of concrete structure engineering. The in-depth design based on BIM technology adopts the concept from whole to detailed component, combined with the continuous accumulation of prefabricated component library, and carries out the rapid modeling and in-depth design of components. Then the automatic check function of BIM technology is used for error checking and collision detection, as shown in Fig. 6. Then, all the prefabricated components were assembled to test their correctness and constructability, so as to solve the problems of various forms of prefabricated components, many and complex connection parts between prefabricated components and cast-in-place structures, connections between prefabricated components and aluminum alloy formwork, and many and complex mechanical and electrical installation contents, as shown in Fig. 7.

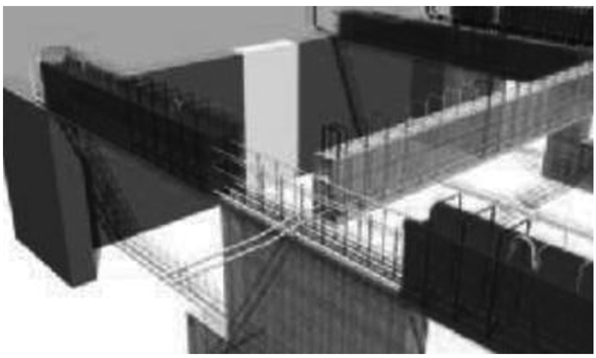

Fig. 6. Collision detection of prefabricated wall, beam and reinforcement

Second, the prefabricated component production management platform. After the BIM model of the prefabricated component is established, the BIM model information can be directly imported into the central control system of the factory with the help of BIM technology, computer-aided processing technology of building components and the prefabricated component production management platform of the component production management system, and the BIM model information can be connected with the production and processing equipment to realize the sharing of design information and processing information. Solve the problem that

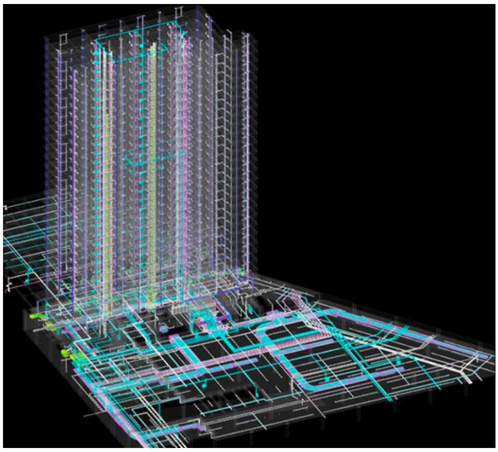

Fig. 7. Electromechanical deepening model of the project

the production of threshold components requires high precision. The production information imported by the BIM model is combined with the requirements of the project duration to formulate a production scheduling plan, refine the production of threshold components, the supply of various materials and the supply of labor, improve the production efficiency of components, and ensure that the construction schedule requirements are met.

Thirdly, the tracking of prefabricated components based on BIM, RFID/ QR code and Internet technology will be based on BIM design model and integrate radio frequency (RFID)/QR code and Internet technology. Before the prefabricated components leave the factory, the information of RFID chips or QR code will be associated with the on-site component assembly plan. During the assembly of component products, Realize the sharing of design information, production information, transportation information and assembly information, According to the system of installation scheme, the production, loading, transportation and storage plans of corresponding components are clearly defined. At the same time, the APP client based on the field intelligent terminal connects to the prefabricated component generation management system to realize real-time extraction, invocation and change of component information, so that the whole process of component management is orderly and efficient. Through the module to solve the number of prefabricated components, models, 0 transportation, approach, stacking, lifting management difficulties and other problems.

Fourthly, BIM-based geological data modeling, that is, intelligent geological modeling based on advanced drilling geological data with the help of BIM technology, can more accurately display the distribution of various geological layers and karst caves. Then, measures and schemes of karst cave treatment are proposed with the help of 3D geological model, and construction schemes of different karst cave treatment schemes are simulated with the help of BIM technology, so as to improve the efficiency of karst cave treatment and greatly reduce the construction cost. The modeling of karst cave distribution is shown in Fig. 8.

Fifth, the data surface model based on BIM and UAV, that is, the UAV tilt photography technology and the ContextCapture software of Bentley were used to generate the data surface model for real-time monitoring and dynamic adjustment of the construction site,

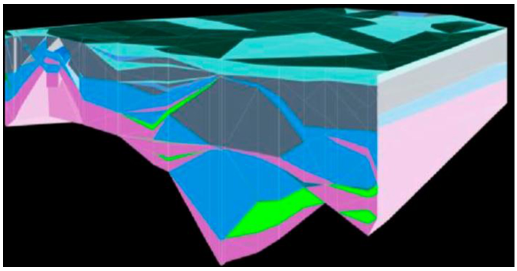

Fig. 8. Modeling of karst cave distribution

which effectively realized the establishment of the construction site model in a short time. Distance, area and elevation can be measured on the model to provide data basis for project commencement preparation. Site layout planning based on the digital surface model can be carried out in an intuitive way to measure site elevation and earthwork excavation and filling, and can also be planned for layout, drainage direction, transportation routes, material stacking, traffic relief, etc. Reduce the problems such as construction disturbance, poor transportation and water accumulation, improve the construction efficiency and shorten the construction period.

Sixth, construction organization simulation, that is, using BIM technology to conduct construction organization simulation of the entire project, guide and adjust the construction process and site construction layout, coordinate the relationship between various construction units, types of work and resources in the process of delivery, so as to make the site layout more reasonable and smooth, and improve construction efficiency.

Seventh, the hoisting and deployment of prefabricated components mainly simulated the construction process of hoisting and assembling prefabricated components of the project C building, rationally arranged the positions of construction cranes, construction elevators, and prefabricated components storage yards. Optimize shear wall construction, beam wall integrated hoisting, beam hoisting, KT board hoisting, balcony hoisting, floor panel cast-in-place layer construction and stair strip construction process and construction sequence, store and record the hidden rotation sequence of all prefabricated components, and carry out construction information to improve construction efficiency and safety.

Eighth, progress, quality and safety management based on BIM technology. Under the role of big data cloud platform, with the help of BIM technology integrated project construction progress, quality and safety management platform, project managers and site operators can then view and update project information according to the mobile terminal information, and raise relevant progress, quality and safety issues according to the site construction situation. After the relevant personnel understand and deal with the problem, the myopia feedback and tracking record form a construction closed loop and improve the communication efficiency.

Ninth, civilized construction management based on BIM technology. After modeling the project site and surrounding buildings with BIM technology, deployment is carried out according to the relevant requirements of safe and civilized construction, reducing the impact on the surrounding environment and promoting standardized construction of the project.

Fig. 9. Semi-finished steel yard

Tenth, engineering calculation based on BIM technology, that is, directly obtain BIM cost related information from the established BIM model, use effective software or conversion plug-in, convert into the data information required for cost measurement, and apply the calculation rules of rated engineering quantity to calculate the engineering quantity.

4.3. Experimental results

The BIM technology is adopted in the urban construction housing project according to the actual engineering situation, which reduces the on-site construction errors, improves the construction efficiency and construction quality, and makes the project successfully completed. Compared with traditional construction methods, the construction period of reinforced concrete housing in urban buildings based on BIM technology has dropped from 13 days/floor to 7 days/floor. At the same time, the construction cost has been saved at least 2 million yuan per unit, and the assembly rate and hoisting time of Building C have been improved. The relevant results are shown in Tables 2 and 3.

Table 2. Comparison of assembly rate before and after BIM technology application

Number	**Building height (m)**	**Number of floors**	**Assembly rate under traditional construction method**	**Assembly rate after BIM technology application (%)**
Building A5/A6	84.8	29	15.20%	62.5
Building A7/A8	96.1	33	15.20%	65.6
Building B	87.6	30	34.25%	60.5
Building C	83.8	28	57.9%	66.4

In summary, after the application of BIM technology, construction efficiency, quality, schedule, cost and other aspects can be improved to varying degrees, which is a high-quality choice for the current urban construction development.

Table 3. Comparison of hoisting time of Building C

Component form	Traditional mode single component lifting time (h)	Building C				
		Quantity	Tower crane	Total time required	BIM technology intervention time for lifting of single order components (h)	Total time required
Column	0.5	23	2	5.75	0.3	3.45
Kingbeam	0.5	42	2	10.5	0.3	6.3
Secondary beam	0.5	15	2	3.75	0.3	2.25
Outer wall	0.5	68	2	17	0.3	10.2
Beam wall	0.5	26	2	6.5	0.3	3.9
KT board caisson	0.2	125	2	12.5	0.1	6.25
Total		299		56		32.35

5. Conclusions

In summary, this paper first analyzes the basic overview of BIM technology, laying a solid theoretical foundation for later application. Secondly, the application of BIM technology in urban building structure is discussed, including the deepening design of prefabricated components, hoisting deployment and visual monitoring. Finally, taking the housing project in Guangzhou District A as the research object, an empirical study was carried out to comprehensively apply BIM technology from the in-depth design of reinforced concrete structures, production management platform of prefabricated components, tracking of prefabricated components, data surface model, and simulation of construction organization. The application of BIM technology in the design of reinforced concrete structures in urban buildings is understood through this comprehensive application method. The final result indicates that the application of BIM technology has greatly shortened the construction period of the housing project in Guangzhou District A from the established 13 days per floor to the current 7 days per floor, while improving the overall construction quality. To bring the project to a successful completion.

References

[1] R. Kontrimovicius, L. Ustinovicius, C. Miedziałowski, and M. Vaišnoras, "The initial prototype BIM system for the optimization of integrated construction processes", *Archives of Civil Engineering*, vol. 68, no. 3, pp. 617–631, 2022, doi: 10.24425/ace.2022.141906.

[2] A.N. Haddad, A.B. Silva, A.W.A. Hammad, M. Najjar, E.G. Vazquez, and V.W. Tam, "An integrated approach of building information modelling and life cycle assessment (BIM-LCA) for gas and solar water heating systems", *International Journal of Construction Management*, vol. 23, no. 14, pp. 1–17, 2023,doi: 10.24425/ace.2022.141906.

[3] A.B. Mohammed, "Process Map for Accessing Automatization of Life Cycle Assessment Utilizing Building Information Modeling", *Journal of Architectural Engineering*, vol. 29, no. 3, 2023, doi: 10.1061/JAEIED.AEENG-1449.

[4] N.H.K. Anuar, N. Ishak, and N.S. Shohime, "The Integration of Critical Risk with Building Information Modelling (BIM) Application Strategies in Building Refurbishment Project Lifecycle", *IOP Conference Series: Earth and Environmental Science*, vol. 1238, no. 1, pp. 1–9, 2023, doi: 10.1088/1755-1315/1238/1/012004.

[5] P. Peng, "Application of Building Information Model BIM technology in intelligent civil engineering", *Integrated Circuit Applications*, vol. 40, no. 8, pp. 212–213, 2023.

[6] Y. Bai, "The application of BIM technology in construction project management", *Real Estate World*, vol. 2023, no. 16, pp. 106–108, 2023.

[7] C.Y. Zhang, "Design of building engineering information Model based on BIM technology", *Electronic Technology*, vol. 52, no. 07, pp. 78–80, 2019.

[8] Q. Zhang, "Application of BIM Information Technology in Building engineering Design", *Electronic Technology*, vol. 52, no. 07, pp. 121–123, 2023.

[9] L.N. An, "BIM Modeling Analysis Based on Quantitative durability of Reinforced Concrete Structures", *The Comprehensive Utilization of Fly Ash*, vol. 37, no. 02, pp. 135–140, 2023.

[10] Z.T. Wu, "Research on joint assembly method and application of prefabricated reinforced concrete and wood mixed structures based on BIM technology", Northwest University for Nationalities, Gansu Province, China, 2021.

[11] L.R. Xiao, W.Y. Zhou, and J.H. Gao, "BIM design method and analysis for prefabricated structure of a reinforced concrete dormitory building", *Shanxi Architecture*, vol. 45, no. 07, pp. 57–60, 2019.

[12] J. Wang, "An image encryption algorithm based on block scrambling and Mixed chaos", *Changjiang Information and Communication*, vol. 34, no. 10, pp. 64-66, 2021.

[13] Q.Q. Wang, X.Z. Yang, and Y.P. Lin, "Research on BIM structure model generation method based on Layer Automatic Recognition algorithm", *Civil Engineering Information Technology*, vol. 14, no. 03, pp. 80–88, 2022.

[14] Q. Wang, and M. Qi, "Research on Fuzzy Low quality optical Character Recognition Technology", *Proceedings of the 14th National Conference on Signal and Intelligent Information Processing and Application*, vol. 2021, pp. 223–226, 2021.

[15] Y.J. Chen, "Research on the application of Revit Secondary Development in BIM Forward Design of Subway cable laying", *Building Energy Efficiency (Chinese and English)*, vol. 51, no. 07, pp. 139–144, 2019.

[16] S.L. Zhang, H.Z. Zhang, and J. Li, "Differences between Revit and AutoCAD and 3dsMAX in nuclear power plant design", *Water Supply and Drainage*, vol. 53, no. S2, pp. 175–177, 2017.

[17] J.S. Yao, and Z.W. Hou, "Application practice of BIM and AR in the operation and maintenance of existing hospitals: Practice and exploration of information transformation of existing buildings in the old hospital district of Huashan Hospital Affiliated to Fudan University", *Chinese Hospital Architecture and Equipment*, vol. 24, no. 07, pp. 59–63, 2019.

[18] L.J. Hou, W. Li, J.F. Zhang, Z.Y. Wang, Z.Q. Yuan, and Y. Xiang, "Reinforcement calculation technology for BIM model of ship lock engineering based on Revit secondary development", *Port & Waterway Engineering*, vol. 2022, no. 11, pp. 197–201+221, 2022.

Received: 2024-02-20, Revised: 2024-03-29