Research on Computer Aided Architectural Design and Construction Management Based on BIM

Zhao Dong, Qing Liu*, Qingling Qiu, Min Li, Li Zhou

School of mechanical and electrical engineering, Wuhan Business University, Wuhan, Hubei, 430056, China

Abstract: In the dynamic landscape of the construction industry, the integration of computer-aided design (CAD) technology has become commonplace. However, as architectural demands evolve, so do the complexities in design and management. Consequently, Building Information Modeling (BIM) technology has emerged as a pivotal tool, progressively transforming the business landscape. This paper aims to elucidate the distinctive features and advantages of BIM technology through a comparative analysis of five key characteristics. Additionally, it delves into the practical applications of BIM in both architectural design and construction management. The foundational section of the paper illuminates the principles, concepts, and inherent characteristics of BIM technology. A comprehensive exploration of the technology's evolution in the construction industry is undertaken, highlighting its pivotal role. Subsequently, the paper offers an insightful overview of how BIM is applied in architectural design and construction management. By providing a concise analysis, this paper endeavors to instill an awareness among professionals in the construction industry about the critical aspects of information management and the unique features of BIM technology. The ultimate goal is to enhance the efficiency of architectural design and construction management practices, fostering tangible advancements in China's construction industry.

1. Introduction

Building information modeling (BIM) is an architectural design and management method based on digital technology. It is based on all kinds of relevant information and data of construction projects, and shows the information such as geometric shape, spatial relationship, structural system and material properties of buildings by establishing models. Compared with the traditional two-dimensional vector drawing, BIM model has more information and functions. BIM model covers the whole life cycle of a building from design, construction, completion to operation. Through the simulation of digital information, it can provide visual effect display in the design stage and help the design team to better understand and communicate the design intent. In the construction stage, BIM model can support collision detection, time arrangement and resource management, and improve construction efficiency and quality. In the operation stage, BIM model can be used for equipment maintenance management, energy efficiency analysis, etc., to realize the optimal operation of buildings. BIM technology has the following five main characteristics: (1) Visualization. BIM model can present the exterior and interior space of a building in three dimensions, so that designers, architects, engineers and customers can understand and evaluate the design scheme more intuitively. (2) Coordination: BIM model can integrate design information of different disciplines, automatically carry out collision detection and conflict resolution, find and solve design problems in advance, and reduce conflicts and mistakes in construction. (3) Simulation, BIM model can carry out various simulation analysis, such as structural analysis, energy analysis and sunshine analysis, to help the design team make more scientific decisions. (4) Optimality: BIM model can improve the performance and efficiency of buildings, including energy efficiency and space utilization, through optimization and comparative analysis of design schemes. (5) Graphability, BIM model can generate various types of drawings and reports, which is convenient for project exchange and cooperation at all stages. In a word, BIM technology, through the establishment and application of Building Information Modeling, realizes the digitalization and accuracy of architectural design, construction and operation, improves design efficiency, reduces construction errors, and provides better support for building maintenance and management [1].

2. Research on the application of BIM in construction management

2.1Traditional design technology construction management analysis

Issues with time management often stem from deficiencies in the initial drawings. The conventional design workflow involves generating numerous drawings

liuq1118@126.com*

essential for the construction process, ranging from a dozen to even hundreds. The challenge arises as inspectors and architects attempt to sift through this extensive design information, making errors inevitable in the process of organizing and extracting relevant details from such an abundance of drawings. In addition, because the design work of each major is completed independently, there will be some contradictions between the drawings designed by each major. If the above problems are not found in time, they will be exposed in the construction stage, which will affect the construction of the project[2]. When we represent our buildings in two-dimensional (2D) and three-dimensional (3D) views, we essentially provide flattened, vertical, and side perspectives of real-life structures. The challenge lies in the fact that this representation differs from the familiar length-based understanding, making it difficult for individuals to comprehend these drawings without specialized training and education. As the design industry continues to advance and demands for more sophisticated designs increase, the limitations of two-dimensional CAD design become evident. It struggles to meet evolving needs, address design complexities effectively, and lacks a comprehensive visual perspective. Enter Building Information Modeling (BIM) technology, which serves as a remedy for the drawbacks associated with traditional two-dimensional and three-dimensional visualization methods [3]. BIM not only addresses these shortcomings but also provides a more holistic and intuitive approach to design. The utilization of BIM technology bridges the gap between traditional methods and contemporary design requirements. Table 1 offers a comparative summary, outlining the similarities and distinctions between conventional design and construction management approaches and those based on BIM. This underscores the transformative impact of BIM technology in overcoming the limitations of traditional practices.

Table 1. Similarities and differences between traditional design and construction management and BIM-based construction management

Traditional Design and Construction Management	Characteristics of construction management based on BIM	Advantages of BIM-based construction management
There is a lot of engineering information, and manual sorting errors are usually unavoidable.	It adopts virtual construction mode and has object-oriented characteristics.	Design interaction is natural, and design mode is top-down.
Visibility in two dimensions and three dimensions is poor	Engineering data and component model are highly integrated.	The attributes of the component model can be accessed and adjusted. Two-dimensional drawings can be asked and adjusted.
Restricted to geometry data model, not restricted to geometry data model, not	Adopt parametric model	The modification is highly intelligent and automatic, which facilitates the analysis of building performance.
Not conducive to refinement and standardization.	Engineering data faces different stages. Engineering data faces different stages.	Electronic engineering documents

2.2BIM based construction project design process

In contrast to the traditional architectural design approach, the BIM-based architectural design method revolutionizes the role of professional engineers in project development. Instead of grappling with the challenge of envisioning and constructing a three-dimensional drawing from an array of simple yet numerous two-dimensional plans, engineers utilizing BIM need not engage in repetitive comparisons and calculations of architectural design information. The BIM methodology empowers professionals to organize components and design architectural information seamlessly within a virtual three-dimensional space, leveraging the capabilities of computer software technology. Drawing insights from the current BIM platform software, this paper endeavors to outline the BIM building structure design process during the design stage. The core of this process involves the creation of a BIM structural 3D model. This entails constructing an information model that embodies the properties of structural components, achieved through different component families, classes, and elements. In the specific context of this project, characterized by a frame-supported shear wall structure, the BIM model is crafted by considering fundamental structural elements such as beams, structural columns, and structural plates. Subsequent adjustments to the BIM model configuration lead to the visualization and display of the refined BIM pattern. This transformative approach enhances the efficiency and precision of structural design within the BIM framework[4].

Modal analysis serves as a fundamental technique for scrutinizing the inherent properties of a structure. It stands out as a prevalent and efficient method, particularly in the seismic response analysis of structures that can be treated as either uncoupled linear or decoupled linear systems. Notably, structural modal analysis serves as the foundational analysis for subsequent response spectrum analysis and time history analysis.

Applying D'Alembert's principle, the dynamic equilibrium equation governing a structural system subjected to seismic forces can be expressed as:

$$F_I(t) + F_D(t) + F_S(t) = F(t) \quad (1)$$

Where: $F_I(t)$—— Inertial force vector acting on node mass;

$F_D(t)$——Viscous damping force vector or energy dispersive force vector;

$F_S(t)$——Internal force vector borne by structure;

$F(t)$——The load vector imposed on the structure by the outside world.

In the context of seismic forces, if the external load F(t) in Equation (1) becomes zero, and the structure lacks damping, the resulting expression transforms into a second-order differential equation (Equation 2).

$$MX''(t) + KX(t) = 0 \quad (2)$$

Here, M and K denote the mass matrix and stiffness matrix of the structural system, respectively. The vectors X" and X(t) represent the acceleration and displacement of the structure, respectively.

Making an assumption that each particle undergoes vibration with the same frequency, shares the same phase angle φ, and experiences different amplitudes represented by X:

$$X(t)=X\sin(\omega t+\varphi) \quad (3)$$

Substitute (3) into the natural vibration equation (4)

$$[K]X\sin(\omega t + \varphi) - \omega^2[M]\{X\}\sin(\omega t+ \varphi) = 0 \quad (4)$$

The above formula holds for any time, so there is a characteristic equation

$$([K] - \omega^2[M])\{X\} = 0 \quad (5)$$

Obtaining the vector {X} directly from the vibration coefficients of individual nodes within the determinant proves unfeasible. Therefore, it is imperative that Equation (5) be equated to zero.

$$[K] - \omega^2[M]=0 \quad (6)$$

Using the finite element software SATWE and yingjianke, calculations were conducted for two distinct structural models. Specifically, the analysis focused on the 18th order vibration mode. The results were then scrutinized by extracting the first 6 vibration modes from the calculation output file. The structural natural vibration periods corresponding to each vibration mode are detailed in Table 2. In structural design, a common practice to enhance torsional resistance involves indirectly gauging the overall torsional deformation resistance of the structure. This is accomplished by examining the period ratio, signifying the ratio of the first natural vibration period Tt associated with torsional motion to the first natural vibration period T1 primarily dominated by translational motion[5].

Table 2. Natural vibration period and vibration mode characteristics of structure

Vibration mode	SATWE		YJK	
	Cycle	Torsion coefficient	Cycle	Torsion coefficient
1	3.041	0.00	3.004	0.00
2	2.812	0.08	2.803	0.06
3	2.420	0.81	2.248	0.92
4	0.852	0.01	0.787	0.02
5	0.676	0.00	0.641	0.00
6	0.556	0.87	0.511	0.95

The yingjianke software yielded 18 vibration modes in line with the calculations. Notably, the effective mass coefficients in both the X and Y directions were found to be 92.01% and 94.21%, respectively. Both of these coefficients surpass the 90% threshold, thereby meeting the specified requirements. This alignment underscores the consistency between the results obtained through the BIM structure model imported into the yingjianke software and those derived from conventional calculation methods.

3. BIM application case in construction management

Considering cost implications, the distribution of BIM-managed buildings varies for different building types. Figure 1 illustrates the diverse distribution of main building types managed through BIM construction. Examining the data in the table reveals that, within the past 12 months, respondents applied BIM to a range of projects, with commercial buildings accounting for 25% of feedback from customers and 50% from architects. The figure also depicts the proportional usage in residential, educational, and sanitary buildings. Based on this data, it becomes evident that BIM construction management is predominantly employed in the context of commercial buildings[6].

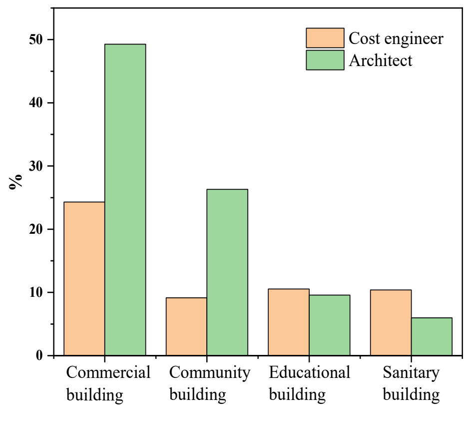

Fig 1. Proportion of various types of projects mainly applying BIM

In general, the use of BIM in different stages of a construction project is as follows: 1. Design check and feasibility analysis before construction; 2. Used for the coordination of subcontractors; 3. Segmenting of construction[7].

For example, there is a museum project completed in 2012, which is mainly steel structure, covers an area of more than 20,000 square meters, and has 14 exhibition halls and 12-story residential buildings, with a total cost of nearly 450 million RMB. In this project, BIM was used in the construction stage. The traditional workflow includes the application of two-dimensional drawings, the use of drawings to coordinate space, and the coordination of installation between MEPs, and this workflow is repeatedly used to reduce the incidence of contradictions in construction[8]. According to the survey, generally speaking, a floor needs 10-12 cycles of coordination. However, in the new process, BIM is used to refine the models of the components, which are all responsible, need to be installed in time and approved by engineers and architects. The whole work is divided into different areas to be coordinated, in addition, it also includes additional components added by corresponding subcontractors to each area according to the basic model provided by the general contractor[9]. When modeling the components to be installed, the dimensioning (explicit or ambiguous) of the models established by each subcontractor is helpful to the basic coordination arrangement of the work. The dimensions required by standard specifications or manufacturers belong to explicit dimensions, such as the height of walls, the width of doors, etc. The requirement of being able to make a single piece of equipment pass, that is, installing a single piece of equipment, belongs to ambiguous dimensioning (also called channel dimensioning). Unclear dimensioning can simulate some potential problems in advance to avoid these problems appearing in the construction process and affecting the project progress[10].

4. Conclusion

The integration of BIM computer-aided technology into contemporary architectural design and construction management systems presents evident advantages. As modern information technology continues to advance, and architectural design technology undergoes continuous updates, BIM technology stands out as a catalyst for inspiring designers' creative thinking. It not only provides technical support for crafting superior architectural schemes but also becomes imperative to elucidate the practical functions of computer-aided design technology based on BIM. Effectively merging BIM technology with architectural design and construction management is crucial for advancing and developing the field. This integration not only streamlines customs clearance work but also ensures the maximum benefits derived from architectural engineering endeavors. In essence, the synergy between BIM technology and the architectural design and construction management process serves as a driving force for progress in the industry.

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