Application of BIM Technology in Whole Process Cost management of Hospital Construction Projects: An Analysis from the Hospital Engineering Investment Perspective

Ning You, Qingkun Zhao, Bin Zhang*, Huihui Yan

The Affiliated Hospital of Qingdao University, Qingdao, Shandong 266003

2789798359@qq.com

Abstract. The construction of hospitals presents significant challenges in investment control and management due to their large-scale nature, extensive deployment of heavy equipment, and specialized medical systems. These complexities are further compounded by multiple participating entities, intricate construction processes, and coordination difficulties inherent in the building phase. This combination of factors creates substantial obstacles for effective capital allocation and cost containment in healthcare facility development. This paper takes a hospital construction project as an example. From the perspective of whole-process investment management, it analyzes the application of BIM technology across various stages including pre-construction, bidding and tendering, design, construction, and operation and maintenance phases. It can be observed that the application of BIM technology not only effectively addresses project coordination and communication challenges, but also enables accurate and detailed investment management throughout the entire project lifecycle. Furthermore, it enhances post-commissioning operation and maintenance management standards, significantly reduces hospital operational costs, and achieves effective control over capital utilization.

Keywords: BIM Technology, Management, Hospital Construction Projects, Whole Process Investment Control.

1 Introduction

Capital construction investment is a major expense for hospitals and is related to the smooth and efficient economic operation of hospitals. Adopting precise and detailed whole-process investment control management in the process of hospital construction is an important means of controlling capital investment. The level of management will have a direct impact on the investment effectiveness of the entire project [1].

The emerging BIM technology realizes shared digital information at different stages of a construction project, such as preproject, design, bidding, construction, operation

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and maintenance, with advantages of visualization, simulation, and dynamic monitoring. The data showed that 93.94% of the respondents were willing to apply BIM Technology in the construction process [2]. One of the important indicators was that the application of BIM technology could optimize the construction plan and better carry out the progress, quality, cost and safety management in the implementation phase. BIM technology is considered by the construction industry as one of the key technologies targeting the full-cycle management of construction projects.

With the development of BIM Technology, BIM4D, 5D and 7D technologies have emerged one after another, which cover time schedule, cost, energy consumption analysis, assets and other data, so as to realize the refinement, informatization, intelligence and coordination of cost management [3,4]. When our hospital was building the second-phase comprehensive ward building project, BIM technology was introduced for the first time. Compared with traditional construction projects, this BIM-implemented ward building achieved a cost reduction exceeding RMB 1,000 per square meter in construction and installation costs, demonstrating significant economic benefits.

Therefore, to strengthen construction investment management, BIM technology is introduced during the initial phase of the International Medical Center project. This initiative closely integrates the characteristics of BIM technology with each stage of the construction process. A management team composes of personnel from all participating units is established to implement whole-process investment control throughout the entire construction cycle. The application of BIM technology aims to achieve refined investment control and precise management throughout the entire life cycle of hospital projects. By optimizing resource allocation and operational efficiency, this approach enhances the economic performance of healthcare facilities [5,6]. The whole process of investment control management in the construction of the International Medical Center is shown in Fig. 1.

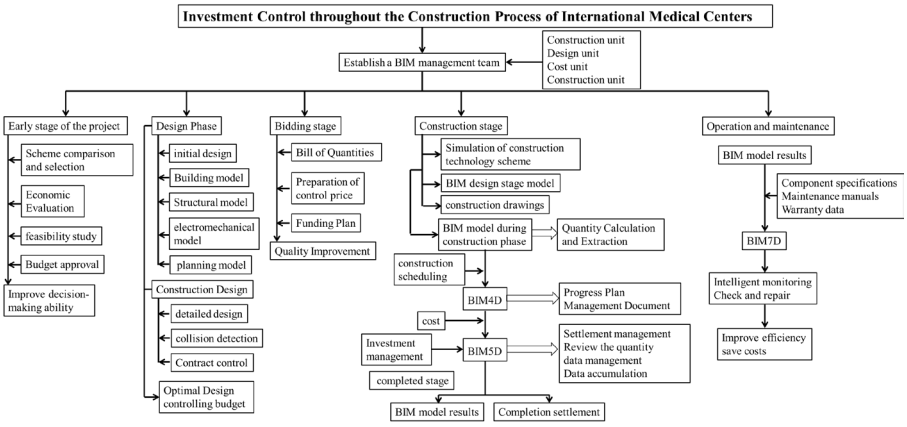


Fig. 1. Whole process of investment control management in the construction of the International Medical Center.

2 Case Study

2.1 Project Profile

The International Medical Center is the first international hospital project in Shandong Province. The hospital is fully aligned with international standards in terms of setup, management, quality, environment and services. The project is in the financial center of Laoshan District, covering an area of only 5,000 square meters, with a building area of 663 million square meters, 23 floors above ground, 3 floors underground, a total building height of 98.45 meters, ultra-limited building, frame-shear wall structure, seismic intensity of 7 levels.

The complex surrounding environment, narrow construction site, and complicated functional areas all add to the difficulty of constructing the entire project. With the support of BIM technology, precise and detailed whole-process investment control management is implemented for this project in the personnel management, project decision-making phase, design phase, bidding phase, and construction phase. The total investment amount of the project was RMB 739 million, and the cost per square meter is about RMB 11,000, realizing a high investment efficiency. Fig. 2 is an aerial view of the International Medical Center.

Fig. 2. Aerial view of the International Medical Center.

2.2 Establishment of an investment control management team based on BIM technology

Based on the construction characteristics of the International Medical Center and the features of BIM such as visualization, three-dimensionality, integration and sharing, an investment control management team is established. The project team is composed of professionals from cost management, construction, design, agency representation, and the client side, with a representative from the client serving as the team leader. Through a BIM model-based collaborative platform provided by the design institute, they implement integrated management of whole-process investment control. This approach

facilitates efficient communication and enables decision-makers to make rapid, well-informed judgments. The BIM management platform architecture is shown in Fig. 3.

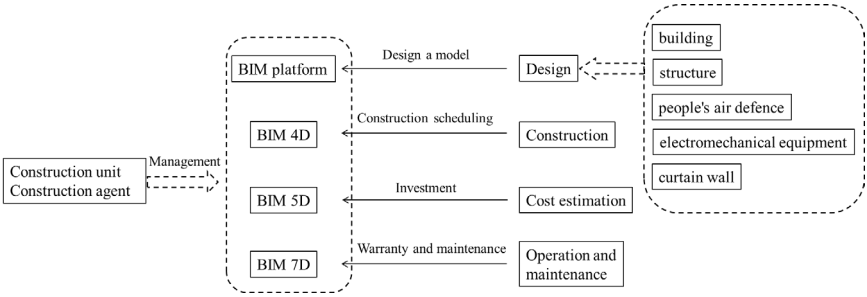


Fig. 3. BIM management platform architecture.

2.3 Application of BIM technology at the pre-project stage to improve the decision-making ability of project investment control

In the pre-decision stage of the project, the hospital management confirm the project construction program based on the investment requirements and the development direction of the hospital, including medical procedures, functions, processes, equipment, construction standards, etc., which are the key elements affecting the total investment of the project. Because hospital decision makers come from a medical background, they often lack the ability to visualize construction projects in three dimensions and the knowledge of material prices. The three-dimensional and visual characteristics of BIM Technology provide it with an intuitive understanding of the feasibility of the project. The BIM team utilizes the BIM modeling scheme for the preparation of investment estimates for feasibility studies and the approval of economic evaluations of projects. And according to the market situation, prices and selection of materials are recommended, so that investors clear decision-making direction, to avoid major design changes and improve the decision-making ability of investors in the early stages of the project.

2.4 Maximize investment benefits by applying BIM technology in the design phase

According to statistics, the impact of project decision-making and design stage on project cost can be as high as 75%. The introduction of BIM technology for design is the most effective means to realize investment control.

The International Medical Center is located in a location with complex pipelines, many medical functional areas, and high hospitality requirements. Complex designs are brought about by complex functional requirements, air-conditioning, including centralized air-conditioning, independent air-conditioning, purification air-conditioning; vertical transportation, including medical and patient elevators, a total of 14; logistics and transportation, including pneumatic logistics and box logistics, and so on. The curved shape of the building is peculiar, and the installation pipelines are intricate. However,

each floor of the building have an area of only 2,000 square meters and a floor height of 4m. To meet complex functional requirements in a limited space, errors are inevitable in the design process under the traditional two-dimensional design model, increasing the risk of over-profiling. BIM includes design software, calculation software and pricing software, which can be applied to structural design, volume statistics and pricing management respectively. The application of BIM have a positive impact on cost control during the design phase.

(1) Limit design based on BIM.

The cost personnel utilized the BIM collaborative work platform to measure the budget estimates from the whole aspects of materials, functions and construction technology. Comparison of BIM models is carried out according to the limitation indexes. The visibility and information sharing of BIM improve the accuracy and efficiency of project cost measurement, and could intervene and report on deviations in a timely manner, allowing managers to do a better job of investment planning and forecasting.

(2) BIM-based deepening design.

As the design enterd the construction drawing stage, the contents of each specialty are gradually refined. All personnel fully understand the project characteristics and design intentions through 3D models, timely provide opinions and suggestions, reduce the probability of rework during the construction process, and played a positive role in achieving cost control goal.

At the same time, it have positive help to design collision detection. The layout standards for air conditioning, water supply and drainage, fire protection, logistics, strong and weak electricity, earthquake resistance and other pipelines in hospitals are high, with complex and intersecting distributions. Conventional two-dimensional drawings can no longer be reasonable layout of the pipeline, seriously affecting the correctness of the construction, and rework phenomenon is serious. BIM-based collision detection solve these problems well. In this project, a three-dimensional building model is provided by BIM technology, and various pipelines can be identified by line types, colors, and other information, and pipeline laying can be simulated 1:1. All pipelines, cable trays, air ducts, units, valves, etc. have various types of models, and the dimensions are completely consistent with the actual component dimensions. By selecting different types of pipeline fittings, real spatial layout and positional relationships can be achieved in simulated space. A total of 346 intersections are inspected during the testing process, and the designers make timely modifications to them, which eliminate rework during construction due to this problem, and cost was also effectively reduced.

As shown in the layout diagram of the pneumatic logistics pipeline in Fig. 4, the system is located above the north lane of the B01 garage. Pneumatic logistics systems required large round corners of R1300 for turning and steering, which take up a large area both in the plane and in the vertical range. But the height of the space that can be utilized is only 1 meter, and there are other pipes interspersed with it. In order to avoid collision with other pipelines, the pipelines are rearranged to achieve design optimization after many repeated tests and a comprehensive consideration of the installed pipelines. According to the analysis, the application of BIM Technology has saved about 20% of the construction cost.

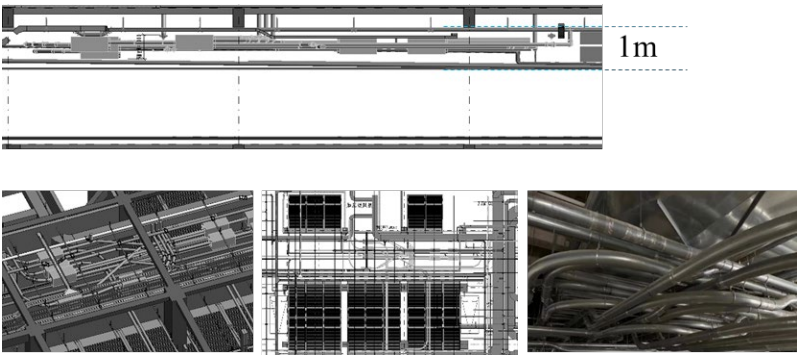


Fig. 4. Pneumatic logistics pipeline layout.

2.5 Application of BIM technology at the bidding stage to improve the accuracy of control price preparation

The bidding management of BIM is an important link in the application of BIM in cost management. BIM can be considered as a means of quantifying drawings. Cost engineers can quickly export effective content such as engineering quantities and project characteristics through BIM, eliminating the tedious calculation process, avoiding calculation errors, and providing convenient and efficient assistance to both parties in preparing engineering quantity lists and bidding quotations. Fig. 5 shows the extraction of engineering quantities and the preparation of preliminary budgets.

Detailed List of Air Ducts

A	B	C	D
System Type	System Classification	Size	Sum
B air-makeup system	Air supply	400×400	18
B air-makeup system	Air supply	1300×160	4
H return air system	Return air	106×346	33
H return air system	Return air	130×600	8
H return air system	Return air	130×150	74

Summary Table of Construction Costs for Above Ground Parts

Number	Item	Value (ten thousand yuan)	Proportion of Cost (%)
1	Total of Sub-unit Project	2245.26	42
2	Total of Measure Project	1350.24	26
3	Total of Other Project	1351.25	25
4	Stipulated Fees	231.53	4
5	Taxs	185.62	3
6	Project Cost	5363.91	——

Project Cost and Name	Project Budget (ten thousand yuan)				Sum (ten thousand yuan)	Technical and Economic Index (yuan/m²)
	Construction Work	Installation Works	Construction Work	Other Fees		
Construction and Installation Engineering Cost					141603.77	5067
(1)International Medical Center					68257.1	4896
1.Civil Engineering	6951.98				6951.98	499
2.Steel Structure Work	18123.96				18123.96	1300
3.Curtain Wall Work	5401.5				5401.5	387
4.Decoration Work	18814.87				18814.87	1350
5.High Current Work		3172.41			3172.41	228
6.Weak Current Work		6532.72			6532.72	460
7.Water Supply and Sewerage Work		2694.74			2694.74	193
8.Heating Ventilation Work		6007.25			6007.24	431

Fig. 5. Extraction of engineering quantities and preparation of preliminary budget.

2.6 Application of BIM5D technology during the construction phase to realize investment control

As the actual implementation stage of the project, the construction phase, with capital investment accounting for more than 75% of the total investment, is the core link of the whole life cycle of the construction project and the key link for the technology to realize its application value.

In order to accomplish the construction goal, a construction BIM team is formed and a BIM technology application process is developed during the early stages of construction. Afterward, proceed with the development of discipline-specific models, integrate them through a collaborative platform, manage the application of stage-specific use cases, and maintain the integrated models. Finally, refine the model data based on as-built conditions and deliver the finalized model.

The construction BIM team consist mainly of designers, construction technicians, builder's managers, and agency managers. The four parties work closely together, using BIM technology to conduct operations such as drawing reviews, visualization simulations of the construction process or key complex nodes. Errors, omissions, bumps, and deficiencies in the design can be detected in time for early design adjustments. Construction technicians can deeply understand and feel the project implementation effect through BIM technology before construction.

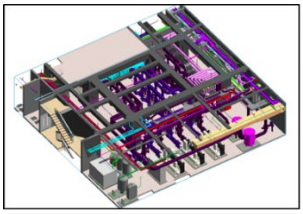
For example: during the construction coordination process, the construction team identify a 60-centimeter elevation discrepancy between outdoor and indoor floor levels in the plaza area through BIM-based design validation. Collaborative resolution through design optimization effectively mitigated potential rework risks, resulting in cost savings of approximately RMB 1.8 million. This case demonstrates the critical role of BIM technology in design conflict detection and collaborative problem-solving during the construction phase.

The use of BIM technology can do a good job of controlling the procurement of materials and the amount of work settlement control. The specifications, models and quantities of materials required for the project are statistically refined in advance through BIM to reduce the waste of materials. Through the analysis of 3D models and the inspection of node positions, unreasonable problems can be identified in advance during the construction process and resolved in a timely manner. Not only does it ensure the quality of construction, but it also enables meticulous and standardized completion of construction nodes.

Process delivery using BIM 3D modeling. Before construction, the graphical method shall be adopted to carry out construction technical disclosure for important complex node positions and complex processes. In the explanation of the text at the same time the 3D model of the team to explain the process node modeling form and notes through the 3D model to show the construction personnel.

Comprehensive pre-construction pipeline layout and collision checking. The hospital installation project is complex and have multiple pipelines. Although the construction drawings have been arranged according to the physical objects during the construction phase, secondary deepening modifications still need to be made based on the actual situation of the special project before construction to avoid major construction errors. Especially, it is necessary to conduct sub item research on the problems existing in collision intersections and make secondary modifications and adjustments. After adjustment, 13 intersections are detected during the collision check again. All collision crossings are finally resolved through final research and program validation, providing solid assurance for on-site pipeline installation, and laying a good foundation for the smooth implementation of the project and the creation of high-quality projects.

For example: during the design process of the chiller room, construction personnel conducted detail design based on their construction experience, including the arrangement of elevations, layout of units, and routing of pipelines. BIM guided construction has been achieved, integrating BIM into construction to avoid rework, material misuse, and other issues, thereby significantly saving investment. An example of collision in the field of electromechanical engineering is shown in Fig. 6.



Collision Report of Engineering Electromechanical Specialty in International Medical Center of Affiliated Hospital of Qingdao University

Test 1	Common Difference	Collision	New-built	Active	Reviewed	Approved	Resolved	Type	State
	0.100m	806	806	0	0	0	0	Hard collision	Define

							Project 1				Project 2			
Graphic	Collision name	State	Distance	Description	Date Found	Collision Point	Project ID	Level	Project Name	Project Type	Project ID	Level	Project Name	Project Type
1	Collision 1	New-built	-0.432	Hard Collision	2022/10/14 6:54:00	x:7.227, y:-32.601, z:23.700	Element ID: 2640336	AR_F06	AR_PF Exhaust System	Line	Element ID: 2364020	AR_F05	AC_SF Air supply system	Line
2	Collision 2	New-built	-0.429	Hard Collision	2022/10/15 6:54:00	x:6.827, y:-32.904, z:23.700	Element ID: 2640355	AR_F06	AR_PF Exhaust System	Line	Element ID: 2364020	AR_F05	AC_SF Air supply system	Line
3	Collision 3	New-built	-0.362	Hard Collision	2022/10/16 6:54:00	x:-4.164, y:-53.449, z:23.600	Element ID: 2383486	AR_F06	AR_HF Exhaust System	Line	Element ID: 2622607	AR_F06	AC_HF Air supply system	Line
4	Collision 4	New-built	-0.346	Hard Collision	2022/10/17 6:54:00	x:8.651, y:-41.250, z:25.200	Element ID: 2619079	AR_F06	17500CMH	Synthesis Part	Element ID: 2623646	AR_F06	AC_X Fresh air system	Line
5	Collision 5	New-built	-0.331	Hard Collision	2022/10/18 6:54:00	x:7.227, y:-32.601, z:23.400	Element ID: 2640326	AR_F06	AR_PF Exhaust System	Line	Element ID: 2364020	AR_F05	AC_SF Air supply system	Line

Fig. 6. Examples of collisions in the field of electromechanical engineering.

2.7 BIM technology for as-built settlement

After the completion of the project, the BIM results can be directly applied in the settlement calculation, which not only saves a lot of human labor and avoids the phenomenon of incomplete drawings, but also prevents double counting and omission. The establishment of BIM-based project settlement information and cost database can improve the accuracy and efficiency of settlement.

The application of BIM technology across multiple phases, including preliminary planning and design, tendering, construction, and final settlement, ensured the high-quality completion and delivery of this project. This integrated implementation generated significant time efficiency and economic benefits, aligning with the high-quality development requirements for modern healthcare facilities. The adoption of BIM technology has yielded substantial improvements in construction duration, conflict resolution efficiency, cost control, and information sharing when compared with conventional schemes lacking BIM implementation. This technology demonstrates measurable advantages in optimizing project timelines, enhancing collaborative problem-solving capabilities, maintaining budgetary discipline, and facilitating data interoperability. Table 1 shows the list of BIM Technology benefit evaluation.

Table 1. List of BIM Technology benefit evaluation.

Item	Lacking BIM	Applying BIM	Evaluation results
Construction duration	48 months	42 months	Efficiency increased by 12.5%
Conflict resolution efficiency	Cost increase due to design change and repeated construction	The acceleration of conflict resolution minimizes design changes and repetitive construction	Increase conflict resolution rate by 40%

Cost control	The inability to predict and control costs at various construction phases leads to severe cost overruns	Identify cost risks at an early stage to prevent budget overruns	Save about 7% of construction cost
Information sharing	Lack of sharing, information Fragmentation, and low communication efficiency	BIM model sharing and smooth communication	Improve work efficiency and teamwork

3 Prospect of BIM Technology Application in Hospital Operation and Maintenance Stage

The phenomenon of "reconstruction without maintenance" is common in domestic buildings. Throughout the entire lifecycle of a building, 80% of the costs occur in the operations phase, and two-thirds of the losses in the operations phase are due to low efficiency. Therefore, hospital administrators should not only focus on the cost control in the pre-investment decision, design and construction phases of the project, but also focus on the cost management in the operation and maintenance phase after the project is completed. According to the literature summary [7,8], we look forward to the cost management of hospital buildings based on BIM Technology in the operation and maintenance phase.

The functional areas of hospitals are complex, with a high flow of people and logistics traffic, and systems such as electromechanical, air-conditioning, ventilation, water supply and drainage, fire protection, and medical gases all need to be managed and maintained. Currently, the problems faced by the project after commissioning are:

(1) Traditional operations management is very passive and lacks safety hazard foresight. The ability is poor to quickly respond to emergencies in hospitals.

(2) The maintenance work of each profession is closed and isolated, lacking a unified collaborative work platform, resulting in low work efficiency and serious waste of manpower and material resources.

(3) Traditional paper drawing data is difficult to preserve completely, causing difficulties for hospital decoration, equipment updates, and system upgrades in the later stage.

The emergence of BIM has made it possible to address these challenges. By leveraging BIM's visibility and collaborative applications to enhance data quality and operational efficiency, it can transform traditional facility management models. This enables the operation of information within models and the manipulation of models through information, effectively improving the integration level of building operation management. The implementation of a BIM-based visual operation and maintenance management system shifts passive management to preventive management, achieving comprehensive optimization in architectural operations. This improves the overall operation and maintenance management level of the hospital, enables it to realize the full life cycle management of the building, and significantly reduces the operation and maintenance cost of the hospital.

4 Conclusion

In this paper, through the application practice of BIM technology in the whole process of investment control of international medical center, we summarize the application of BIM technology in each period of construction and put forward the corresponding outlook on the role in the operation and maintenance stage. BIM technology can highly integrate the information resources in the construction process, improve the communication efficiency of the participants, and realize the seamless integration of decision-making, design, bidding, construction, completion, and operation and maintenance phases. By utilizing its visual and collaborative features, it provides excellent assistance for the investment control of the entire construction process, and serves as a reference for the future investment control and management work of hospitals.

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