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A Framework for BIM-enabled Life-cycle Information Management of Construction Project

Regular Paper

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Abstract BIM has been widely used in project management, but on the whole the applications have been scattered and the BIM models have not been deployed throughout the whole project life-cycle. Each participant builds their own BIM, so there is a major problem in how to integrate these dynamic and fragmented data together. In order to solve this problem, this paper focuses on BIM-based life-cycle information management and builds a framework for BIM-enabled life-cycle information management. To organize the life-cycle information well, the information components and information flow during the project life-cycle are defined. Then, the application of BIM in life-cycle information management is analysed. This framework will provide a unified platform for information management and ensure data integrity.

Keywords Life-cycle Management, Information Component, Information Flow, BIM Application

1. Introduction

Life-Cycle Management (LCM) has been developed as a business approach for managing the total life-cycle of products and services [1]. LCM has also been applied in the management of construction projects for many years in order to reduce whole life cost, time and risk, as well as to improve the service for owners [2]. Throughout the entire building life-cycle, building-related information should be captured and reused. Moreover, the importance of information has been emphasized for enhancing communication, so that the efficient management of construction information has emerged as an element determining the success of a project that involves many stakeholders. However, owing to a lack of effective information-sharing platforms, traditional approaches scatter the information in multiple products through the building life-cycle. Therefore the LCM of construction projects is not effectively used in the construction industry [3]. For example, during the design, shop drawing, fabrication and construction phases, nearly all required information is developed for a facility. Unfortunately it is typically not captured and stored for future use [4].

Building Information Modelling (BIM) is a new technique imitating buildings' actual information, through such tools as 3D geographic figures and non-geographic figures which include items such as the materials (for building components), weight, price, procedures, scale and size [5]. In order to enhance the information management process, BIM is proposed to enable and facilitate an integrated method of project flow and delivery by the collaborative use of semantically rich 3D digital building models at all stages of the project and building life-cycle. It utilizes the object-oriented concept to increase the efficiency of information management in the building life-cycle [6]. Furthermore, it provides the ability to see and analyse the construction project in near real-life fidelity. Consequently, one can formalize the facility's information relationships, which then yields analysis that could not previously be performed [7]. For example, if one captures information from the ordering and invoicing process, one has a very accurate model, not only for use during construction but also for its entire life-cycle.

There are many researches on life-cycle management, but most of them focus on quality, cost, environment and sustainability. Little attention has been paid to life-cycle information management [3, 8, 9]. BIM can be used for information management during the whole life-cycle of a construction project. As a technique, BIM has been used by different participants, but the potential of BIM in life-cycle information management has not been taken into full account [10]. Users may use BIM in every phase of a construction project, but the BIM model has not been delivered from one participant to another: each builds their own BIM [11]. For example, BIM can be used for parameter design and collision detection in the design phase, safety monitoring in the construction phase and building performance analysis in the operation phase. However, there is a development bottleneck of BIM in the construction and operation phase due to a lack of model-based information. That is to say, a great deal of information in these two phases has not been preserved in the building information model. This will lead to undesirable consequences [12]. For example, the exchange of information and documents with new partners often cannot be executed automatically or in electronic formats in those phases. Moreover, there are other difficulties for the development of BIM in the construction and operation phases [13], such as information type, input form, information format, etc.
It is, therefore, vital to organize this management support information into a standard framework. Consequently, it is important to establish a framework for model-based information management in order to ensure the information is retrievable and reusable. Succar has put forward a building information modelling framework [5] in which he divided a construction project into three major life-cycle phases: Design [D], Construction [C] and Operations [O] He proved that BIM implementation will change the relations, activities and tasks of life-cycle management, but he does not explain what this change would be.. Based on these studies, this paper builds a framework for BIM-enabled life-cycle information management to allow for its systematic investigation. In the information dimension, the information framework includes the information components, the information flow and the information function. The three dimensions in the framework are shown in Figure 1.

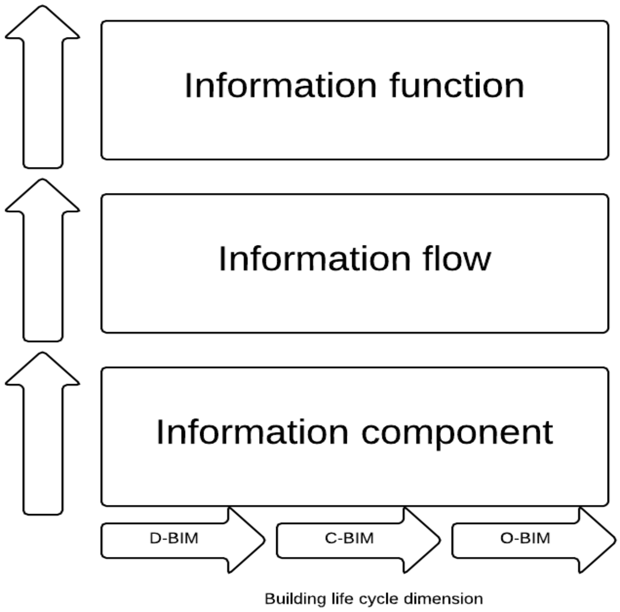

Figure 1. Information framework of BIM-enabled building life-cycle

2. Information components throughout project life-cycle

The information about the building life-cycle often includes different types and formats. BIM is regarded as an ideal tool for digitally representing the data repository of all information relating to the building life-cycle [14]. It enables us to manage and store the information according to the phase of the information, in order to make good use of the information in the future. This section describes the information components of each phase.

2.1 Information components in design phase

The D-BIM includes the information that comes into being in the design phase, which depends to a large extent on the activities in the design phase. The design phase is intended to demonstrate the clients' construction intentions, including the functional requirements and standards of the proposed project through an implementation model. The design works require a multi-disciplinary collaborative working method in order to ensure the maximization of owners' intentions.

The main activities in the design stage include those in which owners organize, design and sign the bidding and contract documents with designers, consultants, supervisors, contractors and other parties. The owners commission the survey and design company to carry out the hydrogeological investigations and to prepare the design specification, schedule and design estimates. They also audit the preliminary design and technical design as well as organizing contractors and supervisors to perform a construction drawing review. They then obtain the approval of the government department in charge of construction plans [15].

It is important to ensure that the information can be used by multiple users to enable interdisciplinary collaboration, as well as to improve operational efficiency. We group the information in the design phase into six categories according to the design content, namely: public information about the project, information related to similar projects; location information about the proposed project; survey and design information; bidding and contract information and economic information. The detailed information for each phase is shown in Table 1.

2.2 Information components in construction phase

The C-BIM contains information produced in construction activities. The information in the C-BIM is more abundant since control and management of construction is a dynamic process. It is also a long-lasting and complicated work, which involves the owner, design company, supervision company, general contractor, subcontractors, material suppliers, equipment suppliers and relevant government departments. In addition, a great deal of human and material resources should be prepared for use in the construction phase [16].

<table>
<tr><td rowspan="33">Information in design phase</td><td rowspan="5">Public information about the project</td><td>National and local policies</td></tr>
<tr><td>Laws and regulations</td></tr>
<tr><td>Specifications and procedures</td></tr>
<tr><td>Environmental policy</td></tr>
<tr><td>Government services and limitations</td></tr>
<tr><td rowspan="8">Information related to similar projects</td><td>Construction scale</td></tr>
<tr><td>Structure form</td></tr>
<tr><td>Cost structure</td></tr>
<tr><td>Technology</td></tr>
<tr><td>Geological conditions and the effect of treatment</td></tr>
<tr><td>Construction period</td></tr>
<tr><td>Usage of new materials and new technology</td></tr>
<tr><td>Economic and technical indicators</td></tr>
<tr><td rowspan="4">Location Information about the proposed project</td><td>Geology hydrology and topography</td></tr>
<tr><td>The demolition and resettlement situation</td></tr>
<tr><td>Access points for water, electricity and gas</td></tr>
<tr><td>Surrounding building information</td></tr>
<tr><td rowspan="6">Survey and design information</td><td>Hydrological investigation data</td></tr>
<tr><td>Design depth and technical documents</td></tr>
<tr><td>Design specification and schedule</td></tr>
<tr><td>Audit information about preliminary design and technical design</td></tr>
<tr><td>Information about construction drawing review</td></tr>
<tr><td>Various professional design drawings</td></tr>
<tr><td rowspan="4">Bidding & contract information</td><td>Prequalification documents</td></tr>
<tr><td>Survey and design tenders</td></tr>
<tr><td>Letter of acceptance</td></tr>
<tr><td>Survey and design contract</td></tr>
<tr><td rowspan="4">Economic information</td><td>Labour quota</td></tr>
<tr><td>The market price on human, material and machine resources</td></tr>
<tr><td>Design estimates</td></tr>
<tr><td>Construction budget</td></tr>
</table>

Table 1. Information framework of the design phase

Information in construction phase	General information	Project public information	Laws, regulations and department rules
			Technical standards
			New technology and new Process information
			Natural environment information
	Project -specific information	General situation information	Engineering situation
			Drawings (architectural, structural, plumbing, electrical, etc.)
			Bidding documents & contracts
		Technology information	Construction log, quality inspection records
			Construction organization design
			Supervision engineer reply notice
			Technical disclosure
			Construction management plan
			Quality inspection certification and test report of main materials, components and equipment
			Construction technology, construction standard
			Detection and assessment of construction quality
		Construction management information	Construction plan and site layout
			Meeting notice and meeting summary
			Negotiation records
			Construction schedule
			Contract cost, actual cost
			Cost control plan
			Cost analysis documents
			Security clarification
			Acceptance of safety facilities
			Safety education, safety inspection, safety precautions
		Resource information	Demand and allocation schedule for employment
			Supply schedule for materials and equipment
			Material consumption records and payment information
			The price of labour, materials and equipment
		Environmental information	Physical environment
			Political environment
			Legal environment
			Economic environment
			Cultural environment
			Resource environment
	Organization -specific information	Information related to similar projects	Construction scale, structure form
			Cost structure
			Geological conditions and the effect of treatment
			Construction period
			Usage of new materials and new technology
			Economic and technical indicators

Table 2. Information framework of construction phase

In the construction phase, which is the implementation process of construction, projects can be grouped into three sub-phases: preparation sub-phase, construction sub-phase, as well as the handover and defective obligation sub-phase. The major activities in the preparation sub-phase include obtaining construction permits and information on regulation and technical standards, choosing supervision unit and sub-contractors, signing construction contracts, organizing and examining drawings, programming, operating and explaining design and technical aspects, etc. The implementation management of the construction is the critical work in the construction phase, which involves site management, resource management, schedule management, cost management, quality management, as well as generally ensuring safe and civilized management. The main works of the handover and defective obligation sub-phase are project delivery, commissioning of equipment and facilities, acceptance of completion materials and preparation for property handover. Therefore, the information generated in these activities is diverse and complex and can mainly be grouped into three categories: general information, organization-specific information and project-specific information [17].

The general information category defines publicly-available information concerning construction products, regulations, standard procedures, natural environment, etc.

The organization-specific information categorizes all information available to a specific organization, such as standard solutions to design-construction problems, often in the form of a library of previously completed projects that are used as reference cases within the organization. This may include information related to similar projects.

The project-specific information is tied to one specific construction project or project type, but shared by several organizations that make up the supply chain. This study is concerned with management of project-specific information at the actual construction stage of the project on site. Project-specific information includes general situational information, organizational information, construction management information, technical information, resource information and environmental information.

The main information in the construction phase is shown in Table 2.

2.3 Information components in operation phase

Operation management is the operation maintenance of construction projects. A good operation management will not only provide users with an elegant and comfortable environment, but also ensure the performance of buildings' facilities and achieve sustainable applications.

The main work included in the operation phase includes: maintaining buildings and facilities; daily maintenance and management of construction equipment (electricity, heating, ventilation, air conditioning, elevators, etc.); operations management units signing a contract with the user; keeping buildings in the surrounding environment clean and green; public security management; personnel file management; the formulation of rules and regulations; and maintaining the rent and sale situation of the buildings and facilities [18].

Operation phase information can be grouped into three categories: general information, project-related information and facilities management information. The general information category defines public information concerning national and local policies and regulations, such as the various regulations issued by the relevant department. The project-related information contains takeover information, contract documents and record information and the project situation. The facilities management information categorizes all information available to the facilities' management in the operation phase, such as user information, environmental information, building information, equipment information, economic information, public security, disaster protection information, etc. The main operation information is shown in Table 3.

3. Information flow throughout project life-cycle

Information is related to numerous departments and participants from the design phase to the operation phase and the information in the BIM keeps circulating and updating. Therefore, it is necessary to know how the information flows and is exchanged in the BIM.

3.1 Information flow map in design process

Generally, the design process is divided into three departments: architectural design, structural design and facility engineering design. Meanwhile, facility engineering design contains electrical design, water supply and drainage design, HVAC design and thermal power system design [19].

Architectural design includes graphic design, shape and design of the facade, profile design, etc.

Structure design provides the structural scheme of architectural design, in an attempt to have harmonious and unified structure and construction. Preliminary estimates of overall structure are made on this basis.

Building electrical design mainly provides design for the construction of all electrical equipment and lighting power, as well as the design of lightning protection grounding and weak current provision.

Water supply and drainage design generally includes a building's internal water supply system design, a building's internal drainage system design and the construction of a rainwater drainage system design.

Information in operation phase	General information	Public information	National and local policies and regulations
			Regulations issued by the relevant department
	Project-related information	Takeover information	Information on property and technology from contractor
		Contract documents and record information	Property management contract, rental agreement
			Conventions files for the payment of various fees
			Meeting record, complaint record
			Personnel records, other documents
		Project situation	Building's geometrical size, structure, performance, construction analysis data, spatial and general layout
	Facilities management information	User Information	User profiles, service demand
			The owners' congress, committee member information
			degree filled
		Environmental information	The internal environment of the building facilities
			Residential facilities, vehicle management information
		Building information	Building maintenance information
		Equipment information	Equipment layout, parameters and operation plans and performance information
		Economic information	Daily maintenance and management of equipment, facilities plan
			Daily maintenance plan of the building
			Property rental and sale situation
			Building maintenance plan
			Facilities, equipment and assets appraisal
			Property payment, receipt and cost information
		Public security, disaster protection information	Public security management regulations, security schedule plan
			Escape routes and fire channel information

Table 3. Information framework of the operation phase

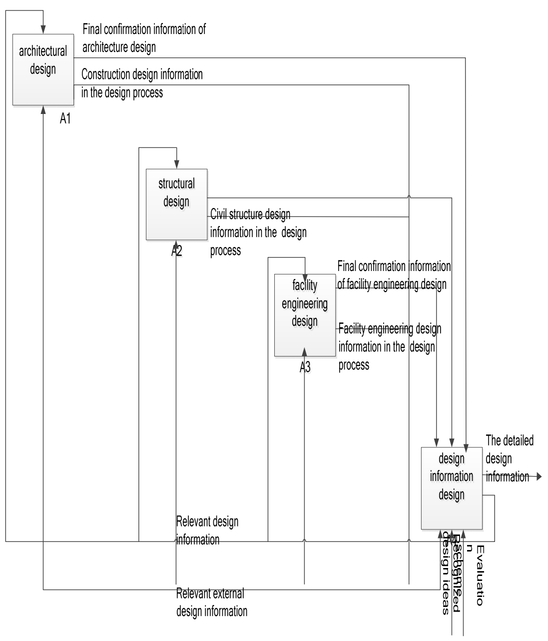

Figure 2. Model A-0 information flow map in design process

HVAC design generally includes design of the heating system, design of the air conditioning system and design of the ventilation and smoke control system.

Thermal power design for residential buildings is mainly the gas system design. Its chief design elements include: the amount of gas required, the pipe network layout and the gas pipe network's hydraulic calculation.

Through the co-ordination between these six professionals, the design of the building can be constantly enriched in the architectural design process. The information flow system required is shown in Figure 2.

The construction process includes two main stages: (i) construction and structural engineering and (ii) building equipment installation engineering. The construction process information flow is shown in Figure 3.

3.2 Information flow map in the construction process

The architectural and structural engineering stage has been divided into four divisions: foundation engineering, main structure engineering, waterproof engineering and building decoration engineering [19]. The construction and structural engineering stage information flow is summarized in Figure 4.

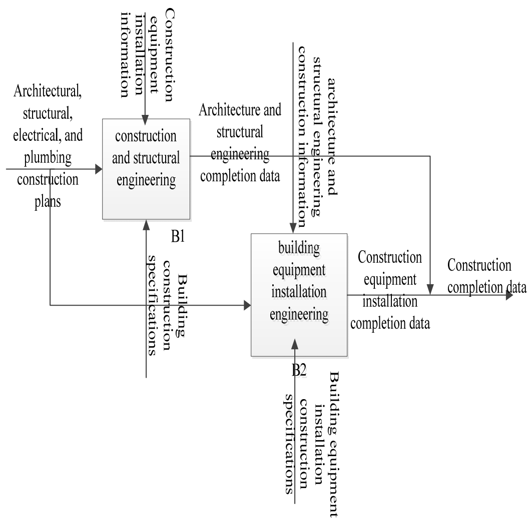

Figure 3. Model B-0 information flow map in construction process

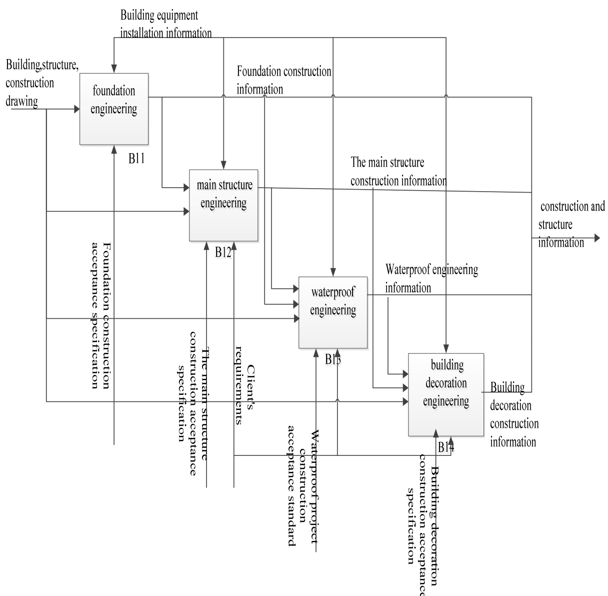

Figure 4. Model B-1 information flow map of architecture and structure engineering

Foundation engineering for architecture and structure includes the relative elevation 0.000 mm below the building foundation, foundation, underground waterproofing and the protection of foundation pit engineering. Through analysis, we can draw an information flow model for foundation engineering, as shown in Figure 5.

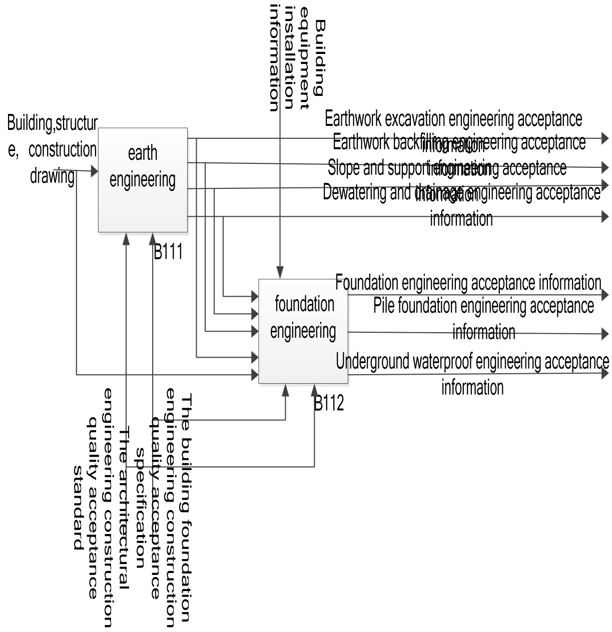

Figure 5. Model B-11 information flow map of foundation engineering

3.3 Information flow in operation phase

The operation phase consists of property reception, property use, property maintenance and property demolition. In this phase, the right of property management is transferred from a construction firm to a property management firm. Therefore, the first task of the operation phase is property reception. According to property management regulations and service contracts, a property management firm organizes reception work [20]. All of the information relating to this work will be inherited from C-BIM, such as project approval documents, all contracts and agreements, facilities and equipment operating instructions, as well as information relating to property management. The main work of property use, which is the second task of the operation phase, is to manage the property in normal use. In this way, we can acquire information at the operational level, the living level, as well as property management data, etc. The function of property management is to support facilities and equipment to work normally. To realize this target, records should be checked and maintenance and recondition records carefully preserved. The last work in the life-cycle is property demolition. The demolition work should comply with the laws and regulations and be carefully recorded.

3.4 Integration of life-cycle information

Through the analysis of information flow in different stages, the task of information exchange is clearly complicated by different stakeholders. It encompasses vast volumes, complex types, diverse sources, scattered storage and dynamic processes of information.

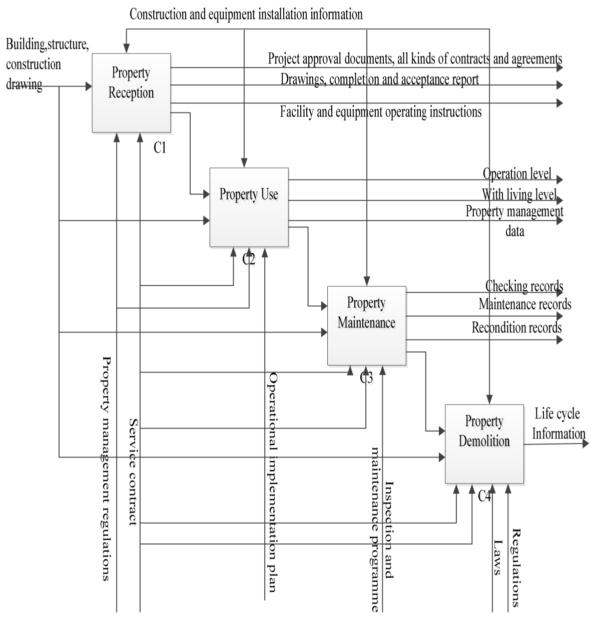

Figure 6. Model C-1 information flow map of operation process

Furthermore, today, information systems in construction are mainly designed for a specific phase, which creates a lack of life-cycle information and the accumulation of experience. In other words, the construction phase cannot use the information of the design phase, while the operation phase cannot use the information of the construction and design phases [21].

BIM is an effective tool to integrate information from different stages to promote information communication and reuse. Also, it is the key element for realizing life-cycle management in construction. Meanwhile, information value is greatly enhanced by using BIM.

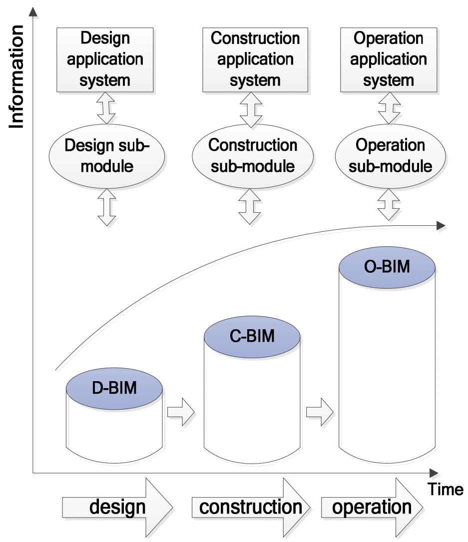

Figure 7. Model C-1 information flow map of D-BIM, C-BIM and O-BIM

The D-BIM, C-BIM and O-BIM are different portions of the BIM, but the information within them is not isolated. The sub-BIM can establish information by extracting, extending and integrating the previous sub-BIM, as well as adding new information. In this way, the whole BIM gradually comes into being in the whole life-cycle, as shown in Figure 7.

From the design stage to the construction stage and then the operation stage, engineering information gradually integrates and finally forms an engineering information set completely describing the life-cycle of buildings. Each of the stages and the software systems in each stage exchange demands according to their own information, thus defining the stage and the information exchange sub-models for specific applications. The application system can realize the integration and sharing of data by extracting and integrating sub-models. For instance, when conducting the design of architecture, structure, electric, water supply, drainage, HVAC and thermal power on the basis of relevant information in the design stage, numerous geometrical data will be produced along with the existing requirements for collaborative data access. The sub-model interacting with the BIM can satisfy such requirements. Therefore, the construction phase can extract part of the information from the design phase, then apply it to application software. Similarly, the operation phase can extract part of the information from the design phase and the construction phase, then apply that information to operation application software. Owing to the information preservation and integration by BIM, the problems of information loss and faults are resolved.

4. BIM application throughout project life-cycle

The fragmented nature of a construction project has led to the separated application of BIM in different stages of the project life-cycle. Many researches have been done on the application of BIM on individual components of construction projects. Many people can benefit from the application of BIM; the cost reduction and control benefits were often seen in the BIM-based project [22]. However, the potential value of BIM in life-cycle management is routinely underutilized.

This paper discusses information life-cycle management methodology and presents an approach to managing construction life-cycle information efficiently by modelling building's information life-cycle. Building Information Modelling (BIM) allows for multi-disciplinary information to be superimposed within one model. It creates an opportunity to conduct these analyses accurately and efficiently when compared with the traditional methods. The integration and interoperability strategies of construction life-cycle data have a primary and secondary effect. Primary effects are those where the use of BIM makes information activities (creation, retrieval, delivery and communication) more efficient. Secondary effects are where the use of BIM in information-processing activities makes material-handling activities more efficient [23].

BIM is a digital representation of the physical and functional characteristics of a facility. It serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle from inception onward. The application of BIM is detailed in Figure 8.

4.1 Application: design phase

According to the VE (Value Engineering) process in the building life-cycle, it is far easier and cheaper to change an electron in the design phase than it is to use a jack hammer to remove a wall. BIM-enabled projects could make greater energy savings by enabling easier interactive feedback on design-decision consequences. For example, lighting designers could quickly see the effect an added skylight might have on resulting lumen levels, while architects could optimize the angle of exterior louvers to minimize heat gain without sacrificing natural light.

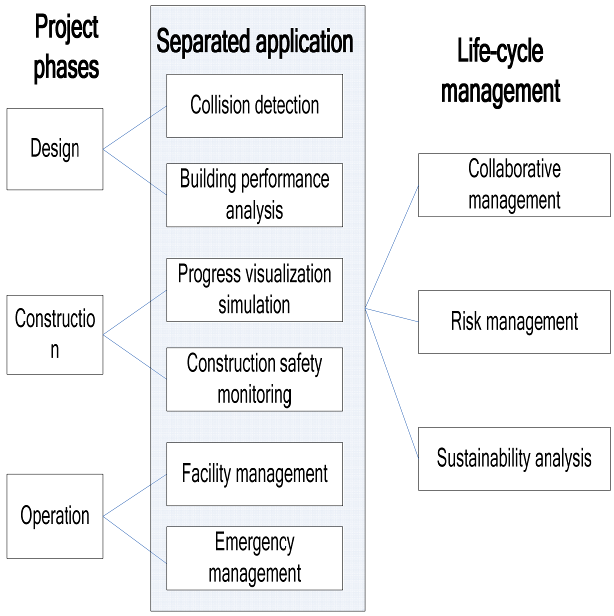

Figure 8. Detailed application of BIM in life-cycle information management

BIM provides all the virtual-walkthrough capabilities of current advanced 3D designs. Many construction projects have been improved via the relatively simple change of incorporating scheduling information into a BIM database. With this, a fourth dimension—time—is incorporated into the model.

In the design phase, the advantage of using BIM is the provision of an electronic model which can be mathematically analysed for compliance with codes. In this article, two typical applications of BIM-based information are described: the collision detection model and building performance analysis.

(1) Collision detection model
BIM allows the elimination of conflicts which would turn into change orders by a pipeline collision detection model. In the formation process of collision detection, design information plays a key role. First, it obtains the spatial data required by the collision detection, as well as geometrical data such as the size, coordinates, types of building components, structural components, equipment, pipelines, connections, etc. Then the extracted data is combined into a single subsystem. Based on this subsystem, the appropriate detection indicators, regulatory requirements, or empirical data are entered, finally forming a sub-model for collision detection. In the detection process, the conflict will give the corresponding display to ensure the designer makes timely adjustments. The pipeline collision model is created on the basis of the design information model. This model achieves associated modifications to ensure the timely transmission of information on design changes. It also contains more information on the entity objects in the parametric 3D model, so that the conflicts among components, equipment and pipelines are intuitively presented. This ensures that the engineers are able to accurately identify problems and make changes in a timely manner. Exposing problems for solution helps shorten the construction period, improve project quality and lower construction costs [24].

The application process of the collision detection model based on BIM is shown in Figure 8.

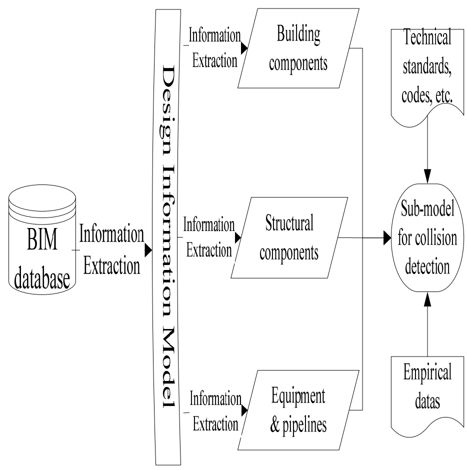

Figure 9. Application process of collision detection model based on BIM

(2) Building performance analysis
One of the biggest potential advantages BIM could provide to environmentally-conscious designers is the ability to predict energy performance quickly and accurately, without the need for complicated calculations. Instead, the modelling software itself will be able to provide this information and quickly recalculate the effects alternative strategies could have on overall efficiency. Due to the augmented information in BIM, the Environmental Impact Assessment (EIA), Whole Life -Cycle Cost Assessment (WLCCA) and Life-Cycle Assessment (LCA) approaches can be integrated into the sustainability analysis of BIM-enabled projects. BIM-based building performance analysis process is shown in Figure 9.

4.2 Application: construction phase

In the construction phase, a BIM with this scheduling information can help all those involved in a project (architects, engineers, general contractors and subcontractors) to visualize the day-by-day progress of a given project. With this, the building team can monitor - in advance - an animated version of the planned construction process.

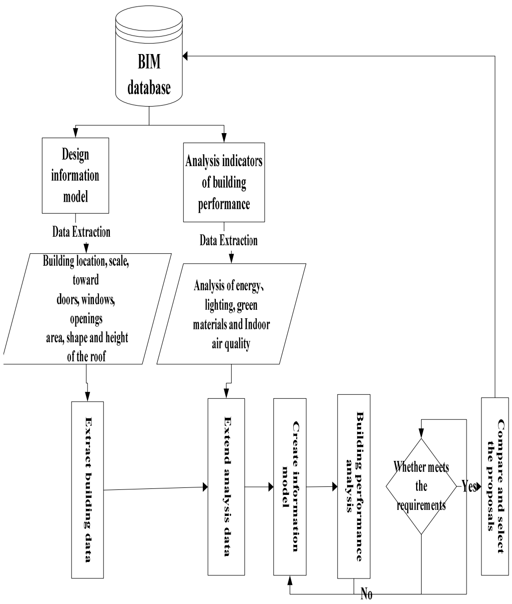

Figure 10. Building performance analysis process based on BIM

As the design of buildings has become more complex, it is very difficult for project managers to compute the time of construction planning and scheduling accurately. There is a pressing need for high level computer-assisted technologies to develop a comprehensive construction planning and schedule before a project is actually built.

In this article, two typical applications of BIM-based information in the construction phase are described: progress visualization simulation and construction safety monitoring.

(1)Progress visualization simulation
In the construction phase, the BIM-based schedule management is implemented by increasing the time dimension, based on the design information model. Then a sub-information model is established which can reflect the progress of the construction intuitively and accurately. That sub-information model can achieve the construction progress simulation, that is, pre-establish a construction schedule based on building information modelling. It can compare this to the actual construction schedule and the planned construction schedule to find the gap,, find out the reason for it and finally adjust and control the gap to ensure timely completion of the tasks. The scheduling information integrated into the BIM also helps to optimize construction planning and scheduling [6]. The schedule management module function is shown in Figure 10.

(2)Construction safety monitoring
Furthermore, one of the biggest potential advantages BIM could provide in the direction of ensuring safety in construction is the facility for construction safety monitoring. In the construction phase, the construction security sub-model is formed by extending the construction safety information into the construction information model, which can realize the analysis and monitoring of the whole process of construction safety. It can analyse the security of the construction process and the project itself in a timely and dynamic way. Meanwhile, it is able to monitor, analyse and evaluate the safety of the construction process in real time and give early warning of security risks. Moreover, it can provide appropriate solutions for managers through the security knowledge base included in the BIM database. Construction safety testing module functions are shown in Figure 11.

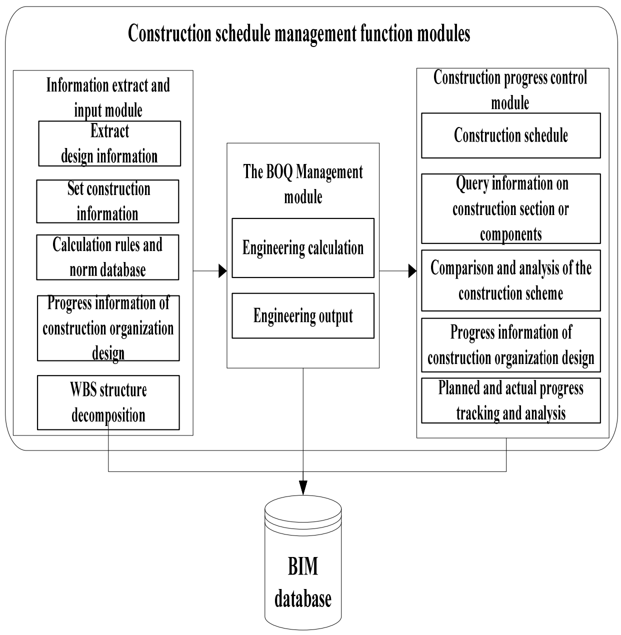

Figure 11. Schedule management modules functions

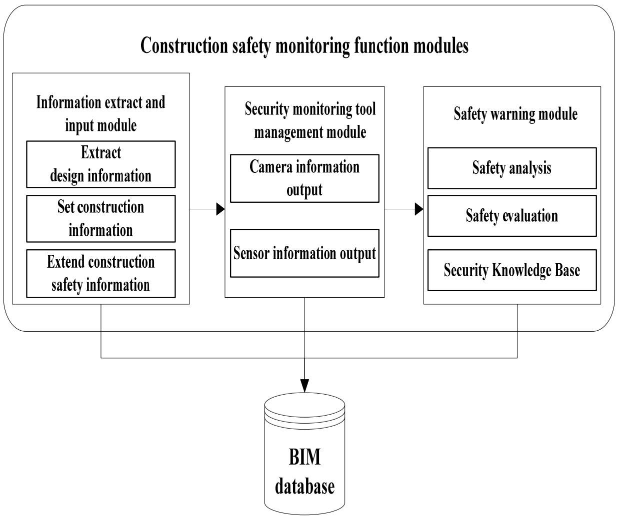

Figure 12. Construction safety testing functional modules

4.3 Application: operation phase

In the operation phase, a fully BIM-enabled project will incorporate information about each piece of equipment and system within the building. Then, facility managers will be able to update the virtual model as the actual building is modified, so the 3D "virtual" building remains an exact replica of the actual structure. Consequently, the use of a BIM could mean significant savings for facilities' owners over time. Getting the right replacement part for a failed HVAC component, for example, could be as simple as clicking on an image of the part within a BIM to find out manufacturer and model information.

According to studies focusing on BIM application in operation phases, BIM can be used for facility management and emergency management.

(1) Facility management
According to a study focusing on leveraging BIM in facilities management, BIM could be beneficial in various FM application areas, such as locating building components, checking maintainability, facilitating real-time data access, space management, emergency management and controlling and monitoring energy. The potential FM application areas based on BIM can be divided into three categories: tracking building performance; building maintenance; and emergency management.

Tracking building performance includes space management, controlling and monitoring energy and facilitating real-time data access. Building maintenance includes locating building components and checking maintainability. Emergency management is used to prevent the occurrence of an emergency, such as a fire or other disaster [18].

(2) Emergency management
Prior to the occurrence of disasters, virtual reality, roaming technology and related disaster analysis software based on BIM can simulate the process of the disaster, analyse the causes of the disasters and work out the disaster protection plan as well as the best evacuation and protection program. Due to the visual presentation of the information, customers can easily understand the disaster contingency plans of the building and rescue personnel.

When the disaster occurs, BIM can provide complete and detailed information on the part affected by the, including spatial information, components and equipment status, as well as giving performance information and the best escape route. Based on this information, rescue personnel can immediately make the proper response to the disaster to improve the effectiveness of rescue and resolution.

4.4 Life-cycle management

We benefit from the scattered application of BIM in different phases, but would benefit much more from BIM-based life-cycle management. Some of these benefits include collaborative management, risk management and sustainability analysis for a more effective reaction [25]. The benefit of BIM in life-cycle management is shown in Table 4.

Application	Function	Requirement
Collaborative management	Negotiate between different participants and different software	Complete information of different phases and unified standard
Risk management	Increase the probability and impact of positive events and decrease the probability and impact of adverse events	Data of similar projects' experiences and the critical data of this project
Sustainability analysis	Perform complex building performance analyses to ensure an optimized sustainable building design	Information of all phases are needed, planning information for cost analysis, MEP design for energy analysis and other information for life-cycle assessment

Table 4. The application of BIM in life-cycle management

5. Conclusion

There is an increasing demand for the application of integrated information technology to the building life-cycle in China. In pre-BIM projects, stakeholders all work on their own piece of the project, with their own applications, to accomplish their own outcome. While in the BIM-enabled projects, stakeholders in the building life-cycle process all contribute to the BIM. Each receives and creates value through their participation. The BIM-based models are expanding to provide a virtual database of almost all the information relating to a building's construction and performance. This paper has put forward a framework for BIM-based life-cycle information management. The main contributions of this paper are summarized as follows:

1) From the point of life-cycle management, information produced in different phases is different, as is information demand in different phases. To meet the different management demands of different phases, the specific BIM of each phase is needed. Therefore, this paper proposed new categories of BIM, D-BIM, C-BIM and O-BIM, in order to effectively manage construction information throughout the project life-cycle.
2) Computers cannot recognize messy, disorganized information automatically. This paper has analysed the information flow of life-cycle management, which has laid a foundation for automatic information automatic.
3) The BIM is not only a single, large database; it is also an information management tool. The information recorded in BIM does not only help realize collaborative design; it also assists construction management by providing construction information using a kanban system. The integrated information of the project can also provide construction experience for further use.
4) This paper has analysed the framework of BIM-enabled information management, which has laid a solid foundation for the production of information, which is playing a more and more important role in project management. This framework can provide a platform for information integration and modification.

In conclusion, even though the application of BIM in information management has been studied by many researchers, the potential of BIM in life-cycle management has not been taken into full account. It demands more attention. This paper has laid a foundation for life-cycle information management.

6. References

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