Chapter 4
Sustainable Construction Project Life-Cycle Management Based on Building Information Modeling

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Abstract Initial construction costs are overly concerned in traditional construction projects and the economic, social and environmental impacts are neglected during their whole life cycle. The application of Life Cycle Management (LCM) is fundamental in pursuing sustainability and improvements in the construction industry. Based on the current situation of LCM and Building Information Modeling (BIM), this paper proposes a theoretical model of BIM-based information integrated platform for sustainable construction projects. Process models for LCM and the design phase implementing BIM-based information integrated platform are built using IDEF0 modeling method. Then, the whole process of using BIM-based information integrated platform in sustainable construction projects is analyzed through its application in a real-life construction project in Shanghai. This paper analyzes the function and application methods of BIM to promote sustainability in each phase. Meanwhile, some important best practices are analyzed and discussed, which are significant to future projects. The results of applying BIM-based LCM method are evaluated through one-to-one expert evaluations interviews. The findings show that applying BIM-based information integrated platform to the full building life cycle is vital to reduce environmental loads and improve sustainability.

Keywords Building information modeling • Sustainable construction • Life cycle management • IDEF0

4.1 Introduction

The construction, operation and demolition of a building have tremendous impacts on the global energy and environment. With the facilities contributing 40 % of the carbon emissions to the atmosphere and 20 % of material waste to landfills, the

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construction industry has a responsibility to use the earth's resources as efficiently as possible [1]. Initial construction costs are overly concerned and the economic, social and environmental impacts are often neglected in traditional construction projects. It is much more cost-effective to design and build from the ground up rather than retrofit afterwards because of the long life of buildings. As such, advanced design and management tools are needed to justify the initial investment for sustainable construction.

LCM has been introduced into the management of construction projects in recent years [2]. It is believed that LCM can be applied to the whole construction process, thus making it possible to improve sustainability indicators and also minimize the environmental loads of the full building life cycle [3]. The application of LCM is fundamental in pursuing sustainability and improvements in the construction industry. However, the life cycle of construction projects is traditionally separated into several independent and contiguous phases, e.g., planning, design, construction, operation, etc., and there are almost no communication or interaction between participants in each phase [4]. This frequently leads to numerous reworks and changes during the construction and hence reducing the sustainability. LCM approach can integrate all phases of the project lifecycle and support information sharing and intra- and inter-organizational collaboration. On the one hand, this promotes realization of the three traditional objectives (time, cost and quality). On the other hand, it enhances the sustainability of construction products and processes.

BIM is a building lifecycle management tool of well understood information exchanges, workflows, and procedures used throughout the building lifecycle [1]. BIM can also fulfill new requirements which are brought by the interdisciplinary and hence complex nature of sustainable constructions. The increased complexity of the sustainable construction project results from the objective diversity and from inter-organization collaboration, where participants from different disciplines and different organizations need to work together to construct a sustainable product. Because of the complexity nature of sustainable project, a great deal of information should be managed and the information should be open, transparent, consistent, and easy to access. Two-dimensional (2D) drawings cannot fully meet the demands of information communication and cooperation among different parties. This challenge can be mastered by using BIM-based approach in the lifecycle of sustainable projects. To demonstrate this, a case study has been carried out based on the application of the BIM-based LCM approach.

4.2 BIM-Based Life-Cycle Information Integrated Platform

A construction project consists of several phases from planning to demolition. Succar [5] argues that construction projects pass through three major phases: Design, Construction and Operations. Focusing on the effects of BIM on various phases, this paper adopts a simplified subdivision and includes five major phases: Planning (P), Design (D), Construction (C), Operation and Maintenance (O&M), Demolition (De).

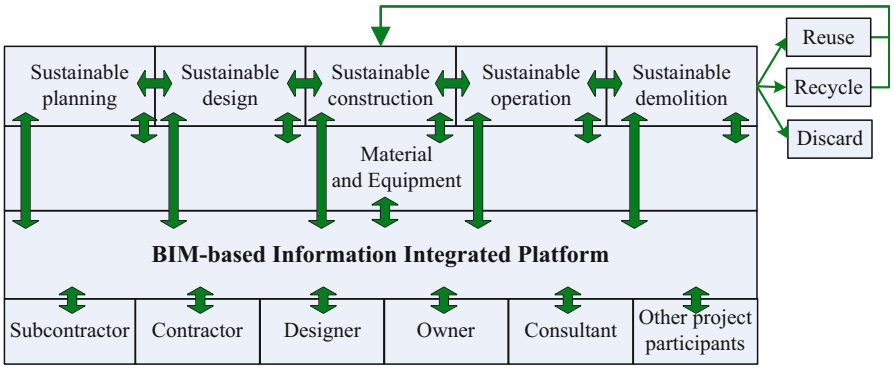

Fig. 4.1 Model of BIM-based information integrated platform

Despite a wide range of positions and opinions on the subject of sustainability, there is a general agreement that the current paradigm of linear development, which disregards constraints to material or energy consumption, is unsustainable. The life cycle of traditional project is an unsustainable linear process and the material and waste in the demolition phase are discarded. The life cycle of sustainable project presented in Fig. 4.1 highlights a cyclic sustainable process. In order to produce a sustainable project, LCM is useful as an overall planning, co-ordination and control approach. A theoretical model of BIM-based information integrated platform for sustainable construction project is developed as shown in Fig. 4.1. Through this information platform, inter-organization communication and collaboration would be more efficient.

Based on the model in Fig. 4.1, process model of the BIM-based information platform for sustainable construction project is developed using IDEF0 modeling method. The IDEF0 modeling method is employed to develop a visual representation of the processes in the modeled system. For this research, IDEF0 diagrams are used to give a formal representation of the processes of BIM-based LCM for sustainable project. IDEF0 diagram includes the FUNCTION component which represents the main activity that is taking place and is used to transform the INPUT, which is an object or data, into the OUTPUT. The CONTROL component represents the constraints on the system and the MECHANISM is the means of which the activity can take place [6].

The process model show clearly, in a readable and understandable format, the processes that BIM is implemented in different lifecycle phases (see Fig. 4.2). Also, these diagrams allow project participants to visualize the important constraints and mechanism in each phase. Meanwhile, the outputs can easily be modified and stored on the BIM-based information integrated platform. The cooperative practices among various organizations in the building sector to produce sustainable products, can be modeled as an inter-organizational collaboration process. The team can be called an inter-organization and multidisciplinary collaboration team (see Figs. 4.2 and 4.3). It is formed around the goal of producing sustainable building. Owner, BIM consultant, sustainable building consultant, designer, general contractor and

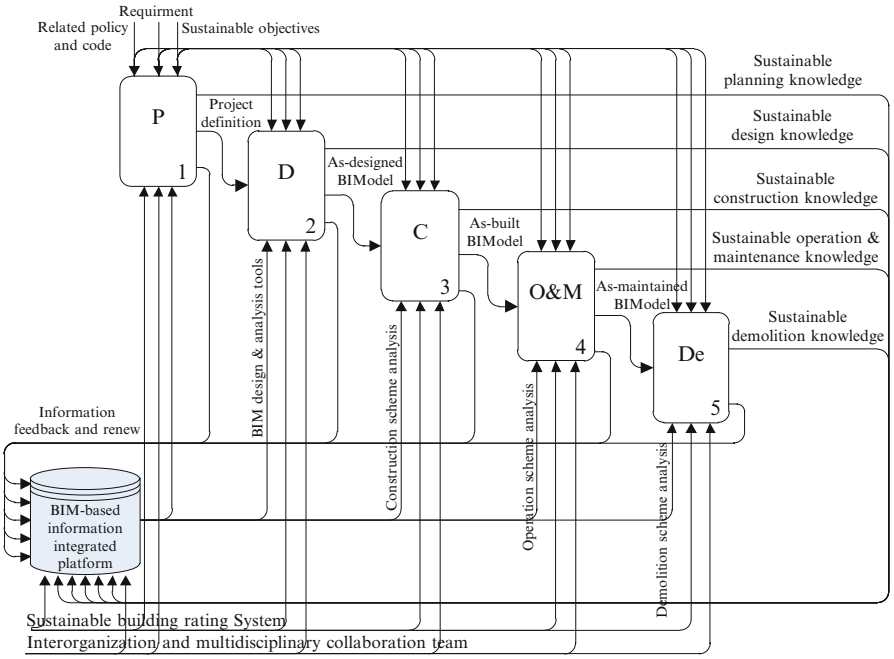

Fig. 4.2 Process model of the BIM-based LCM for sustainable construction project

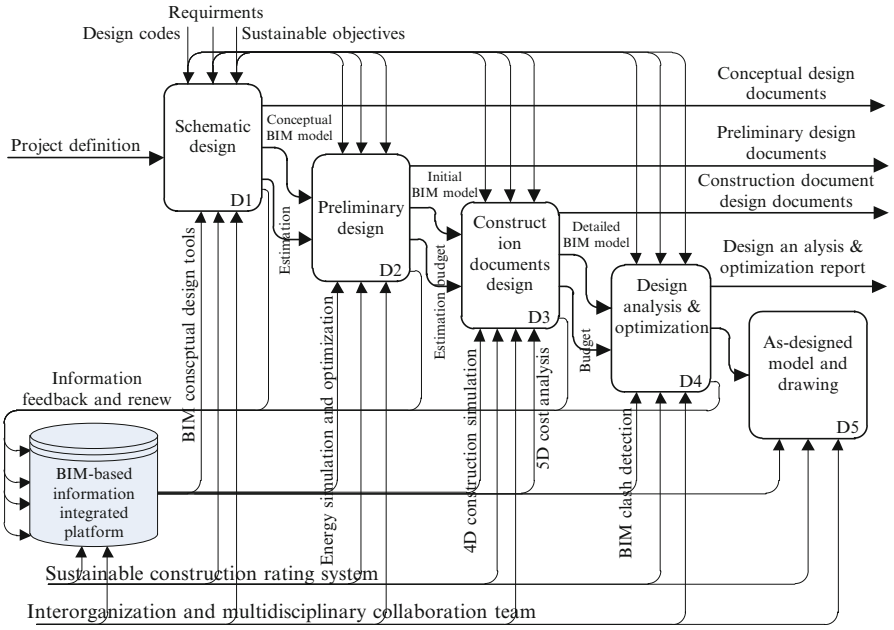

Fig. 4.3 Process model of BIM-based sustainable design

the key subcontractors work together. The inter-organization collaboration results in the sharing of critical resources and facilitates sustainable knowledge transfer among organizations. It also facilitates the creation of new knowledge and produce synergistic solutions [7]. The knowledge of the sustainable best practices generated in each lifecycle phase can be shared among the inter-organization and multidisciplinary collaboration team (see Fig. 4.2). This is the key to the success of a sustainable project.

4.3 Process of Using BIM-Based LCM: A Case Study

The whole process of using BIM-based LCM platform in sustainable construction projects is analyzed through its application to a real-life construction project in Shanghai–South Underground Plaza and North–south Corridor project (SUPNSC) of Shanghai West Railway Station Transportation Hub. This project is a mega project in Shanghai. The owner (Putuo district government) plays the leading role in promoting sustainability of the project and committed to constructing green building by applying BIM at the beginning of the project. Research institutions of sustainable building formulated 'sustainable construction standards' for the owner at the beginning of the project. Following this, they made the 'sustainable construction guidelines' based on the standards to make it more easily used in the project life cycle management process. Both the standards and the guidelines provide a detailed plan for keeping sustainability in whole process of project implementation, including design, construction and operation. Based on the commitment of sustainability, the owner establishes an inter-organization collaboration mechanism and the key participants designate the related field experts to work in this team, like a multidisciplinary organization. Life cycle management thinking is implemented in each project decision-making process. The project adopts a General Contract Management mode.

4.3.1 Planning

At the beginning of the planning phase of the SUPNSC project, BIM is a powerful tool in Sunken Plaza planning. Figure 4.4 shows the final layout of south plaza ground. As shown in Fig. 4.4, Sunken Plaza is to sink the plaza and then decorate the sunken level with mosaic floors, fountains, flowers in an attempt to make the area as attractive as possible. Such an arrangement will increase natural ventilation and lighting, and hence reduce energy consumption. BIM model provides a platform for the designer to obtain the requirements and ideas of the owners quickly, while the owners find it easy to understand the digital model provided by the designer. The digital model improves communication among consultant, designer and owner. The information captured in the planning phase will guide the following design activities.

Fig. 4.4 Planning of the South Underground Plaza

4.3.2 Design

Figure 4.3 shows the general design process based on BIM, which is not a fixed process. The design of SUPNSC project uses products from Autodesk Inc. The BIM-based information integrated platform is customized using the software, such as Autodesk Revit Architecture, Autodesk Revit Structure, Autodesk Revit MEP and Autodesk Navisworks. Revit is the best known and current leader for the use of BIM in building design and was introduced by Autodesk in 2002. Owing to the feature of the design software, architecture model, structure model and MEP/FP model are separately developed in SUPNSC project (see Figs. 4.5, 4.6 and 4.7). This method will lead to conflicts between different systems. As such, an integrated model is produced by combining sub-models into a single model for whole-project review. Inter-organization collaboration is very important to a sustainable project in design review and analysis. Through the BIM-based information platform, the clash and interface detection activities are carried out to find any clashes and interferences before the construction process. As shown in Fig. 4.8, Autodesk Navisworks is used to identify the clashes based upon the integrated model, e.g. the clash between air duct and two beams in the SUPNSC project (see Fig. 4.8).

Sustainable building rating system guides every design processes. Green building research institute worked with designer to do energy simulation analysis and main equipment selection analysis, e.g. air conditioner and air blower, etc. The virtual building is built and tested in the computer and many design errors and constructability issues are identified and solved. Reworks and unsustainable plans are reduced or eliminated because of the application of BIM. Additionally, the final simulation can capture and save much knowledge for future projects and support future maintenance [4].

The green building standard and guideline developed in the planning phase guide the whole design and design analysis process. For example, under these guidelines of sustainability, this project also adopts rainwater harvesting technology. The rainwater will be used to irrigate the landscape plants and flush toilets in SUPNSC project,

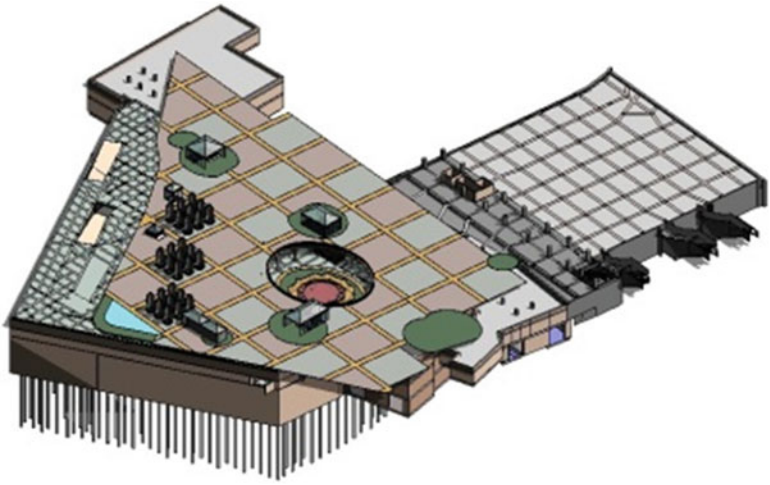

Fig. 4.5 Architecture model of SUPNSC

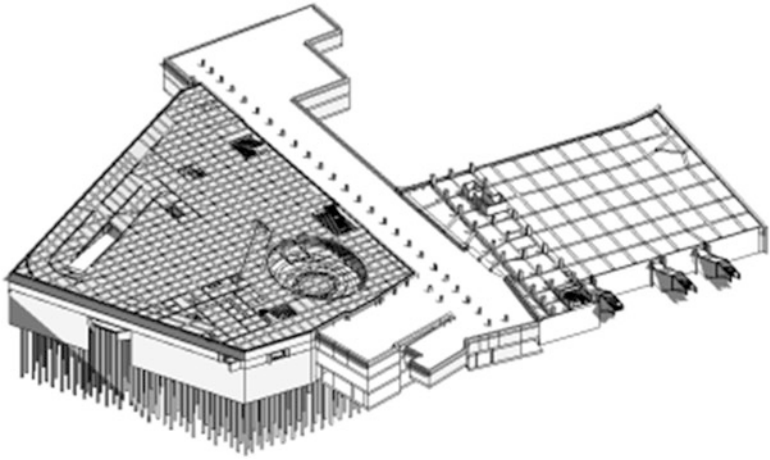

Fig. 4.6 Structure model of SUPNSC

which will help to achieve an excellent rating of sustainable building rating system in terms of water conservation. The pipeline design of the rainwater gathering system will use Autodesk Revit MEP.

4.3.3 Construction

In the construction phase, the focus of the BIM-based LCM is on constructability analysis and sustainable construction analysis. 4D construction simulation and 5D

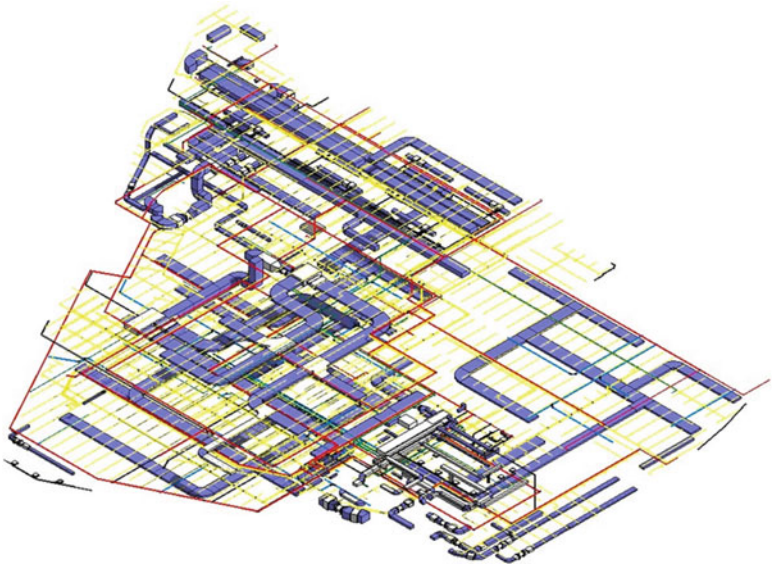

Fig. 4.7 MEP model of SUPNSC

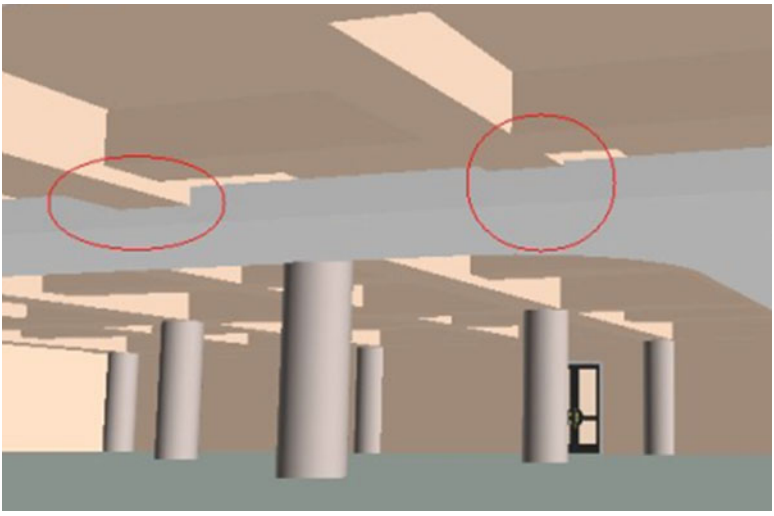

Fig. 4.8 Collision between air duct and beams

cost analysis are conducted to find the optimal construction method in the SUPNSC project which uses an inverse sequence construction approach. Instead of adopting bottom-up construction method, the project employs a top-down construction method. The primary purpose of this method is to ensure the safety of surrounding buildings and facilities, such as Metro Line 11, Railway Line and Shanghai west

Railway Station. As the project is located in the downtown area and the space of the construction site is limited, there is not enough space for the building material and construction equipment. The top-down construction method can solve the construction site layout problem as well. The General Contractor Manager and the key sub-contractors work with designer using 4D construction simulation method to analyze constructability. This cross-organization collaboration mode can reduce the rework and the number of request for information (RFI).

4.3.4 Operation and Maintenance

After the delivery of the project, the platform provides an as-built BIM model for the operation and maintenance of the building (see Fig. 4.2). The as-built model is a 'digital makeup' of the project and provides visual information for facility manager to organize the operation and maintenance of the building. Contrast with traditional 2D drawings, the digital model is easy to be understood by facility manager. It also can help facility manager to make a reasonable operation and maintenance plan. BIM-based facility management software is already developed. At the same time, the as-built model stores the parameters and production information of equipment, such as performance parameter, manufacturer's name, contact information, etc. The facility manager can easily access the relevant information.

Regarding the operation and maintenance phase, this part takes into account the activities needed to keep the building in good condition during the occupation phase. Proper plan of operation and maintenance can increase the service life of a building, reduce the material and energy consumption, and enhance the sustainability of the building.

4.3.5 Demolition

The demolition phase often results in waste disposal or recycling of building materials such as concrete, wood, drywall and metal. At the end of building lifecycle, based on the as-maintained model (see Fig. 4.2), the key structures, materials and equipment can be identified and can be fully reused or recycled. Although the cost could be higher because of the extra effort required in selecting the materials for reuse or recycle, the negative impacts to the environment will be effectively reduced. The 'sustainable construction standards' and 'sustainable construction guideline' have made a detailed plan and provide a meaningful guide to the demolition. From the view point of the LCM, these have been taken into account in the design and construction phase. Although this phase generates a lot of environment effects, the demolition phase is not usually significant considering the implementation scope of BIM.

4.4 Questionnaire Survey and Analysis Based on SUPNSC Project

The LCM research of sustainable construction project is a longitudinal study, which needs several years from implementation to results. This project was in progress at the time of writing; therefore a complete evaluation of the sustainable benefits of the BIM-based LCM is not feasible. The results of applied BIM-based LCM are evaluated through a questionnaire survey (see Table 4.1) during the construction process. After completing the questionnaire survey, five experts from each organization are chosen for an one-to-one expert evaluations interviews. The experience of the respondents in the construction industry is quite respectable. Thirty-eight percent of survey respondents have more than 10 years' experience in sustainable construction and the others have more than 5 years' experience. All the respondents are from the inter-organization team of the SUPNSC project and take part in the process of using BIM. So, opinions and views on the relevance of BIM-based LCM approach obtained through the survey can be regarded as important and reliable.

Since the Brundtland Report, the concept of sustainability has been further developed to include three aspects, or pillars: the environmental, economic and social pillars [8, 9]. Based on Triple Bottom Line (social, environmental and economics)) of sustainable development, China's Evaluation standard for green building (GBT50378-2006), LEED and related research literature and evaluation indicators are developed (see Table 4.2). Likert-scale items are commonly used to investigate the attitudes of respondents to a series of written or verbal statements (items). The response scales represent the contribution of BIM-based LCM to the sustainable project and are defined by endpoints such as 'extremely important' to 'least important'. Severity index analysis is selected in this study to rank the criteria according to their relative importance. The following formula is used to determine the severity index [10]:

$$\text{Severity Index}(\text{S. I.}) = \frac{1}{5}\left(\sum_{i=1}^{5} \omega_i \frac{f_i}{n}\right) \times 100\% \tag{4.1}$$

where i is the point given to each criterion by the respondent, ranging from 1 to 5; ωi is the weight for each point (=rating in scale of points, which "1" is the least important and "5" is the extremely important); fi is the frequency of the point i by all respondents; n is the total number of responses. Four important levels are transformed from S.I. values: More ($0.75 \leq$ S.I. ≤ 1), Much ($0.4 \leq$ S.I. < 0.75), Little ($0.2 \leq$ S. I. < 0.5), and Less ($0 \leq$ S.I. < 0.25). More, Much, Little and Less represent the degree of contribution of BIM-based LCM approach to SUPNSC project.

As a simple questionnaire survey of using BIM-based LCM approach, the contribution to the sustainability is analyzed (see Table 4.2). The results show that BIM is a powerful technology to promote the sustainability of the project during the entire life cycle. As shown in Table 4.2, BIM-based LCM approach has a tremendous impact on the three traditional objectives (time, quality and cost). Meanwhile, it also has many advantages to En-KPIs and So-KPIs. The five experts

Table 4.1 Questionnaires and responses

	Number of questionnaires		Percentage	Response rate
Respondents	Final sent-out	Valid responses	(%)	(%)
Owners/Developers	6	3	18.75 %	50.00 %
Designers	8	4	25.00 %	50.00 %
Contractors	10	4	25.00 %	40.00 %
Key subcontractors	6	2	12.50 %	33.30 %
Green building consultants	8	3	18.75 %	37.50 %
Total	38	16	100.00 %	42.11 %

Table 4.2 Contribution of BIM-base LCM approach to the sustainable project

Key performance indicators (KPIs) Based on TBL	Sub-indicators	Severity index	Impact
Environmental Indicators group (En-KPIs)	En1: Energy effciency	0.775	More
	En:2 Water consumption and water conservation	0.788	More
	En3: Materials consumption	0.525	Much
	En4: Land use and site selection	0.575	Much
	En5: Pollution generation	0.638	Much
	En6: Resuable/recycle elements	0.363	Little
Socio-Cultural Indicators group (So-KPIs)	So1: Workers' health and security	0.613	Much
	So2: Functionality, usability and aesthetic aspects	0.600	Much
	So3: Labor availability	0.238	Less
	So4: Indoor environmental quality	0.575	Much
	So5: Architectural considerations – cultural heritage integration and the compatibility with local heritage value	0.225	Less
	So6: Innovation and design process	0.763	More
Economic Indicators group (Ec- KPIs)	Ec1: Construction time	0.563	Much
	Ec2: Initial construction cost	0.663	Much
	Ec3: Maintenance cost	0.500	Much
	Ec4: Disposal cost	0.363	Little
	Ec5: Whole lifecycle value	0.613	Much

participated in the interview quite agree with the findings and propose that BIM is a mega trend and will play crucial roles in improving sustainability in the construction industry.

4.5 Conclusions

LCM has not been successful in its applications as yet. That is because it lacks an effective information platform to support information sharing between different participants [4]. This paper proposes a model of BIM-based information integrated

platform and its application is presented via process models using IDEF0 modeling method. Through a real-life project, the application processes of BIM-based LCM are demonstrated. The detailed sustainable advantages of the BIM-based LCM are tested using questionnaire survey and interview method. These models are developed toward sustainable projects, but can also benefit the traditional construction projects.

The SUPNSC project demonstrates a unique, yet successful example of BIM technology. Inter-organization collaboration team is composed of experts from well-known corporations in SUPNSC project and the owner plays a leading role in the team. Although this is a single case study, the five experts' strong agreement with the survey results is sufficient to partly validate that a BIM-based LCM approach can improve the sustainability indicators of construction project. To further validate BIM-based modeling approach, additional research is required to use multiple case study method.

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