Life cycle management of construction projects based on Virtual Prototyping technology

H L Guo[1]; Heng Li[2]; and Martin Skitmore[3]

Abstract: Life Cycle Management (LCM) has been employed in the management of construction projects for many years in order to reduce whole life cost, time, risk and improve the service to owners. However, owing to lack of an effective information sharing platform, the current LCM of construction projects is not effectively used in the construction industry. Based upon the analysis of the information flow of LCM, a Virtual Prototyping (VP)-based communication and collaboration information platform is proposed. Following this, the platform is customized using DASSAULT software. The whole process of implementing the VP-based LCM of projects is analyzed via the application to a real life construction project. The advantages of implementing a VP-based LCM are also discussed and, from a simple case study, it is demonstrated that the VP-based communication and collaboration information platform is an effective tool to support the LCM of construction projects.

CE Database subject headings: Construction projects; Life cycle management; Information sharing; Virtual prototyping

[1] PhD, Construction Virtual Prototyping Lab, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong (corresponding author). E-mail: samuel.guo@polyu.edu.hk
[2] Professor, Construction Virtual Prototyping Lab, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. E-mail: bshengli@polyu.edu.hk
[3] Professor, Faculty of Built Environment and Engineering, Queensland University of Technology, Gardens Point, L404, Brisbane, Australia. E-mail: rm.skitmore@qut.edu.au

Introduction

Life Cycle Management (LCM) has been introduced into the management of construction projects in recent years (Gransberg and Ellicott 1997; Jaafari 2000) and it is believed that LCM can reduce the life-cycle cost of projects and improve the service to owners (Chalfant 2001; Xie and Simon 2006). Construction project management is traditionally separated into several independent and contiguous phases, e.g. planning, design, construction, commissioning, etc, and they are implemented respectively with almost no communication or interaction between participants in each phase (Gransberg and Ellicott 1997). This leads to many problems. For example, due to lack of communication and collaboration between designers and constructors, most of designs need to be modified or reworked during construction due to its unfeasibility; otherwise, these changes cannot be effectively supported by design personnel in that after a design is finished and then transferred to constructors, design personnel's tasks are over in the traditional project management method. As a result, time or cost overruns often occur and the rights (e.g. normal completion time, cost, etc) of owners are unable to be warranted (Ellicott 1994). The application of the LCM approach helps to solve these problems. LCM integrates each phase of project management from planning to close-out, making information sharing and coordination possible between owners, consultants, designers, contractors, etc (ISO 2002; Teresko 2004). All parties can communicate and collaborate with each other in real-time. On the one hand, this makes the holistic operation processes consistent so as to ensure a reasonable construction time and cost; on the other hand, it enables the owners' interests to be protected due to their ideas receiving due attention form the parties involved.

The effective implementation of LCM in construction projects relies strongly on a visual communication and collaboration information platform (Ameri and Dutta 2004; Garetti 2004) as information sharing is the key to implementing LCM (Schilli and Dai 2006). An effective information platform is needed to gather project information (Gross and Fleisch 2004) and furnish relevant information (from planning to decommissioning) to each participant (Krause and Kind 1998). At the same time, this allows information to be open, transparent, and otherwise easy to understand, especially for complex projects. However, no such information platform exists in the construction industry. Often, many shop drawings and Gantt charts provided by different parties are needed to conduct the LCM of construction projects as all parties, including owners, consultants, designers, contractors, etc, need them to discuss and make decisions on the planning, design, procurement, construction, commissioning, and decommissioning of projects. Due to the increasing complexity of projects, a great deal of information is needed (Love et al. 2002; Lee et al. 2006). This is usually provided in the form of 2D (dimensions) drawings that cannot be easily understood by each party. For example, owners find it difficult to understand the drawings provided by designers, while designers often cannot completely master the ideas of owners. As a result, the target of "information sharing" is rarely realized in the current LCM of construction projects.

As a result, some information systems and new technologies have been developed and employed for the LCM of construction projects. A representative prototype system, IFE

(Integrated Facility Engineering), developed by the University of Sydney, takes into consideration the information management of projects (Jaafari and Manivong 1998), visual management of design (Chaaya and Jaafari 1999), information management of construction (Jaafari et al. 2000), dynamic simulation modeling (Doloi and Jaafari 2000), etc. Although the system involves many modules, most of these are simply theoretical models and not applicable to real-life construction projects. Another representative commercial technology, AUTODESK® BLM, is a project LCM based on a BUZZSAW™ server, and provides online service to project management. REVIT®, one of software modules embedded in BUZZSAW™, can supply a visual design environment and facilitate communication and collaborative design, but focuses on the design phase only and not construction and operation.

As an alternative, this paper describes the use of Virtual Prototyping (VP) for the LCM of construction projects. VP technology is a computer-aided design process concerned with the construction of a digital mock-up and realistic graphical simulation to address the broad issues of physical layout, operational concept, functional specifications and dynamics analysis under various virtual operating environments (Shen et al. 2005; Xiang et al. 2004; Pratt 1995). Although VP technology has been extensively and successfully applied to the automobile and aerospace fields (Choi and Chan 2004), its development and application in the construction industry (i.e. construction process simulation) has been limited to date. This is due to construction projects being unique in terms of their conditions, requirements, and constraints. The Construction Virtual Prototyping Laboratory (CVPL) of the Hong Kong

Polytechnic University has conducted much research into the application of VP to real-life construction projects in Hong Kong, e.g. (Huang et al. 2007). This has shown VP technology to be a useful tool and effective visual communication and collaboration platform for owners, consultants, designers, contractors, subcontractors or other participants in the design, construction and management of construction projects.

Based upon CVPL research, the VP technology is presented as a key technique to establishing a visual communication and collaboration information platform for the LCM of construction projects (building projects). Its theoretical structure is elaborated and the implementation process of VP-based LCM is examined into through a real-life construction project in Hong Kong - the Tseung Kwan O (TKO) Sports Ground.

A VP-based information platform for construction project LCM

LCM of construction projects

Life Cycle Management (LCM) has been developed as a business approach for managing the total life cycle of products and services (Garetti 2004; Kovacs et al. 2006). It has been discussed and applied widely in the manufacturing industry (Hayes and Wheelwright 1979a,b; Labuschagne and Brent 2005). Its potential application in the construction industry has also been examined in recent years and various project life cycle approaches have been discussed, e.g. control-oriented models, quality-oriented models, risk-oriented models, etc., (Bonnal et al. 2002). In addition, it has been noted that, owing to the different characteristics of projects or industries, the phases of project life cycle are different from each other. As a result, it has been proposed that the available life cycle phases of Conceptual, Planning, Testing, Implementation and Closure (Kerzner 2001) should be applied to projects. Based on the features of construction projects, the following life cycle phases are adopted here (see Figure 1).

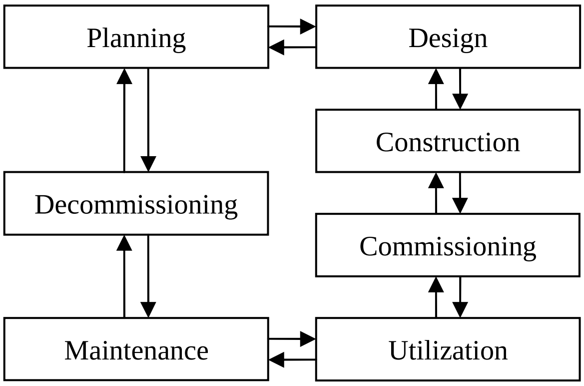

Fig. 1. The life cycle of a construction project

Note that *Planning* includes conception design, preliminary evaluation, etc.; *Design* involves initial design and detail design; *Utilization* refers to the owners' or tenants' use or operation of buildings; and *Decommissioning* consists of demolition and recycle of buildings or material.

Information flow for the LCM of construction projects

The LCM of construction projects can be described as a management system for all the processes of a project (An 2003), from planning, design, and construction to the commissioning, utilization, maintenance, and otherwise decommissioning of the project. Its information flows should therefore involve information concerning all these phases. As shown in Figure 2, this includes a great deal of information relating to planning, design, construction, commissioning, utilization, maintenance and decommissioning. The information is integrated into the VP-based communication and collaboration information platform.

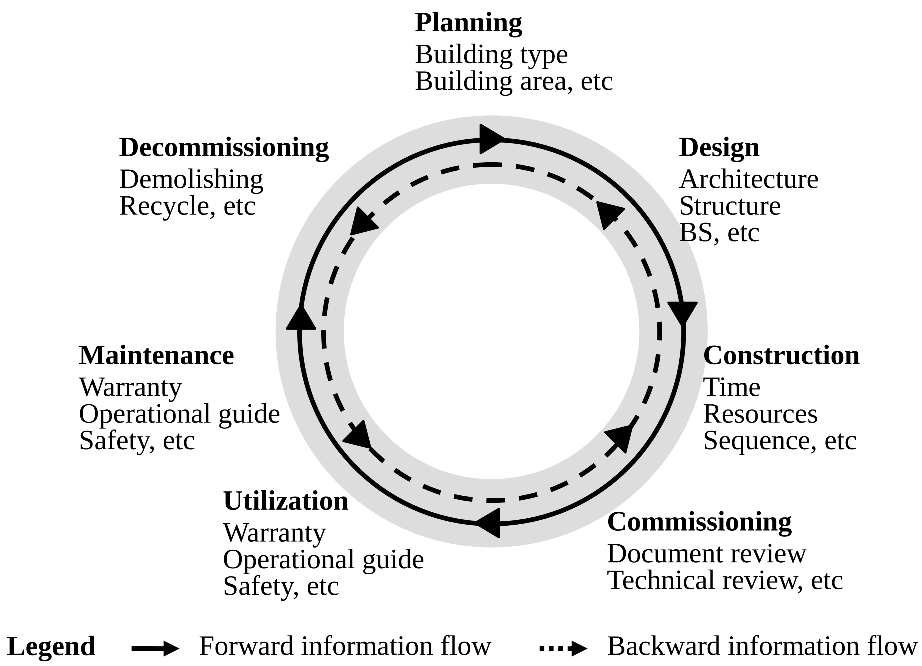

Fig. 2. The information flow of LCM of construction projects

The information flow has both a forward influence and a backward impact, that is, the information of a phase both influences, and is influenced by, its successive phases. When a decision is made, its impact on predecessors or successors, even the whole life cycle, must be taken into account. This is explained in detail in the next section.

VP-based information platform for LCM

Based on LCM model of a construction project and its information flows, the theoretical model of a VP-based LCM communication and collaboration platform is developed as shown in Figure 3. The information platform provides a virtual environment that includes two main modules, i.e. a *main model module* and *process simulation module*. The *main model module* is used to build the digital mock-up of the project, the so-called main model, which consists of static information from the life cycle phases of the project, e.g. planning, design; and the *process simulation module* focuses on the dynamic information of projects, e.g. the construction process and methods, and space analysis. In this way, all the information concerning the life cycle phases is integrated into the platform.

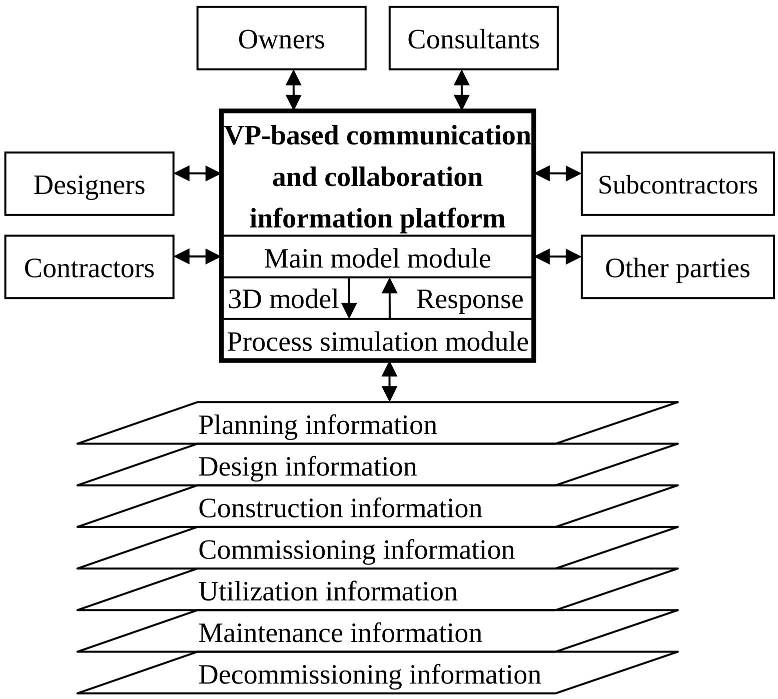

Fig. 3. Model of VP-based communication and collaboration information platform

Through the platform, all project participants share the relevant information presented above and communicate with each other in real-time. The main model is a 3D digital model, which visually shows all the static information needed for a project. Each participant can understand it easily, and therefore the model allows all participants to conveniently communicate and collaborate with each other. On the other hand, the process module offers a virtual environment to all parties to “try before actually building”. As we know, often the construction process is complex and irreversible and before actual construction is commenced, the construction schedule and methods must be checked and approved by owners or consultants in order to ensure a smooth construction process. Despite this, rework is inevitable as the traditional construction statement cannot be prepared in enough detail and many problems cannot be anticipated prior to actual construction. The process simulation module assists owners, consultants, even constructors to understand, discuss and modify the construction methods before actual construction so as to reduce rework or risks. It can also help with the maintenance and demolition of a building. From the point of view of LCM, the design of the building not only takes into consideration its construction, but also considers its maintenance and demolition in order to reduce the life-cycle cost and risks. That is the design should fit to maintenance and demolition as well as construction. The maintenance and demolition processes and methods of the building can be tried and tested by using the information platform to ensure that the design and maintenance and demolition methods are available for maintenance and demolition. This will also provide a 3D instruction for maintenance and demolition in the future.

Figure 4 shows the operational flow chart of the VP-based information platform. Note that V-Construction means virtual construction; A-Construction means actual construction; and the Pro modeler means the process modeler - which may be looked upon as a new career involving the use of VP technology for the product and process modeling of construction projects.

Beginning with the owner’s conception, a construction project is commenced. In the planning phase, with the consultant’s guidance, the designer develops a rough design from which the process modeler builds an initial digital model. This enables the owner, consultant and designer to check the rough design together and modify the design and model until it is feasible. This is followed by the design phase, in which the rough design is developed into an initial and detailed design by the designers. The relevant digital model is established by the process modeler and is used to check the constructability of design by the owner, consultant, designer, and constructor. They work together to solve any problems using the digital model. Especially, based on the platform, owner’s concerns not only ensure that owner’s ideas can be realized in the design, but also make the design more feasible and efficient than before through eliminating some unfeasible ideas in time. For the construction phase, construction methods and construction schedule provided by the contractor or subcontractor are transferred into a virtual simulation process, and the process simulation will be continuously updated as long as construction methods or schedule are changed and approved. The owner, consultants and contractor work together using the virtual process until a feasible construction method or sequence of work is obtained. When this is satisfactorily competed,

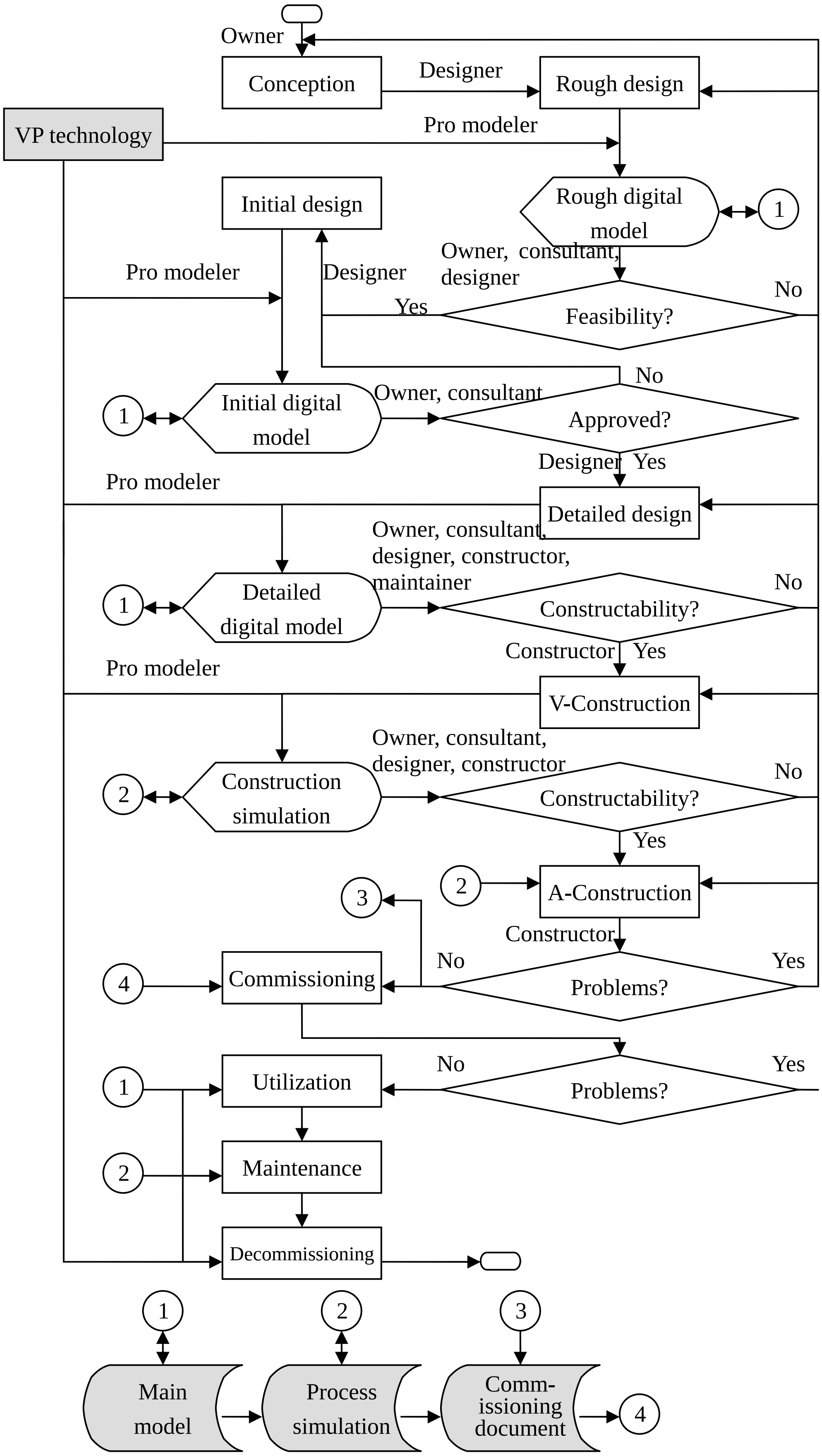

Fig. 4. Operational flow chart of the VP-based information platform

the simulation results are applied to instructing the actual construction work. In the remaining phases, the digital model and process simulation is used with the VP technology to explain the design and construction and help identify and solve further problems. In addition, previous phases may be revisited and reinvestigated as needed.

It can be seen from Figure 4 that the VP technology plays an important role in the LCM of a construction project. Both the main model and process simulation arising from the VP provide an effective communication and collaboration information platform for all participants for each phase of the project. During the process of LCM, the planning/design/construction methods may be changed according to the needs of all parties until the final LCM method is defined

Customization of VP-based information platform

The VP technology developed by CVPL is mainly based on software from DASSAULT® SYSTEMES CORP. Thus the VP-based LCM information platform is also customized using the software, i.e. PROCESS ENGINEER, CATIA V5, and DELMIA V5. Its theoretical model is shown in Figure 5.

The holistic platform is supported by PPR HUB, which integrates Process, Product, and Resources modules. PROCESS ENGINEER helps the owner/consultant test their ideas in a virtual platform or environment and assists in planning decisions; CATIA V5 allows the owner, architect, structure engineer, BS engineer, finishing engineer, contractor, or other users to create and check the design of a building, including a digital mock-up of the building, temporary works and construction equipments; and DELMIA V5 provides a virtual environment for the contractor or subcontractor to define and simulate construction processes and evaluate different construction methods so as to check problems, e.g. collisions between machine and building, safety, time waste. All of these form the LCM information platform and all the digital models are provided by CATIA V5.

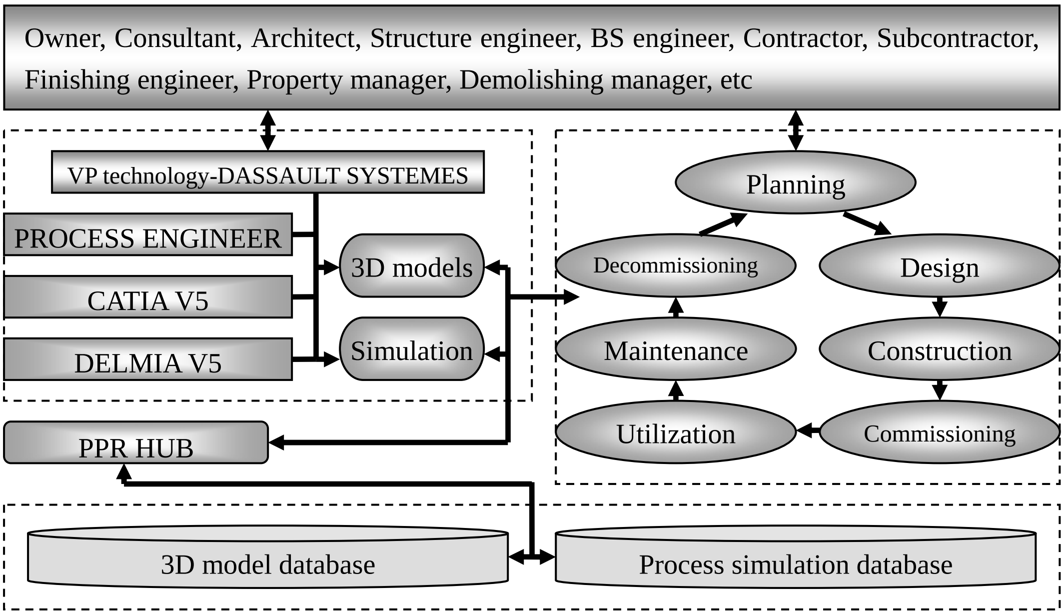

Fig. 5. The VP-based LCM information platform customized

The following section provides a detailed description of the process of implementing the LCM for construction projects via the VP-based information platform.

Process of implementing VP-based LCM

Planning

At the beginning of the planning phase of a construction project, the LCM can be implemented through the VP-based information platform. The owners describe their conception of the construction project, the consultant/designer can easily communicate with owners and rapidly and accurately get their opinions on the basis of the information platform. Also many ideas can be easily tried with a very low cost using VP technology until a suitable conception is created. As an example, Figure 6 shows the final layout of the TKO sports ground project in Hong Kong. This is the rough digital model of the project, including a spectator stand, a main soccer field, and a subsidiary soccer field, which are built and analyzed using PROCESS ENGINEER and CATIA V5. Through the digital model, the owner and consultant discussed the general planning of the sports ground and modified it until it satisfied the owner’s needs. It can be seen that the planning model is very clear and easily understood, especially for the design of the spectator stand.

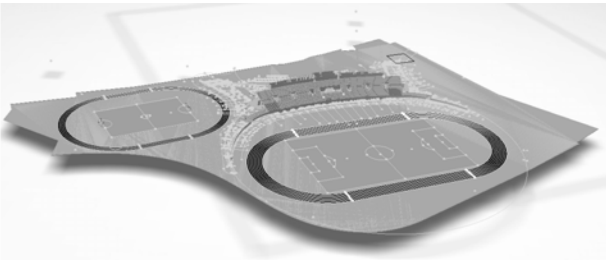

Fig. 6. Planning the TKO sports ground project

LCM is not a fixed process but an iterative one. Unlike traditional project management, some changes continuously occur in the holistic process of LCM so as to meet the requirement of all parties. For instance, when some problems appear in the construction or design phase, the conception of projects needs to be reinvestigated and changed many times. The platform also can provide a virtual environment for convenient and rapid reinvestigation or modification. Otherwise it can make these changes easily understood by the owner as sometimes owners cannot understand shop drawings or their changes. After the visual planning is finished, the relevant information may be saved to guide the design.

Design

Following the visual planning, designers, i.e. architect, structure engineer, and BS&EM engineer, may conduct collaborative design via the visual platform and this forms the digital mock-up of the project, namely the Main Model, using CATIA V5. Figure 7 shows the main model of the TKO project built by CVPL and which underpins the following phases. When the design of the architecture, structure and building services is separately conducted in the traditional method, conflicts between these separate designs often occur. The collaborative design process identifies these conflicts, for example between a pile cap and an underground pipe in the TKO project (see Figure 8), and enables them to be modified as soon as possible.

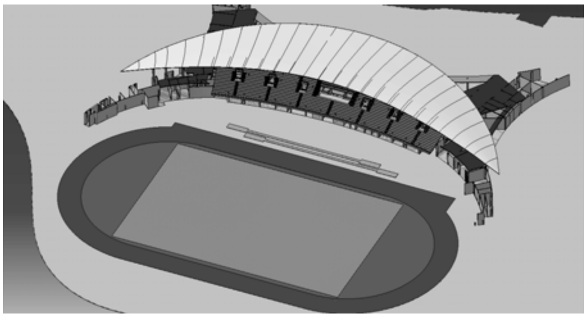

Fig. 7. The main model of TKO sports ground project

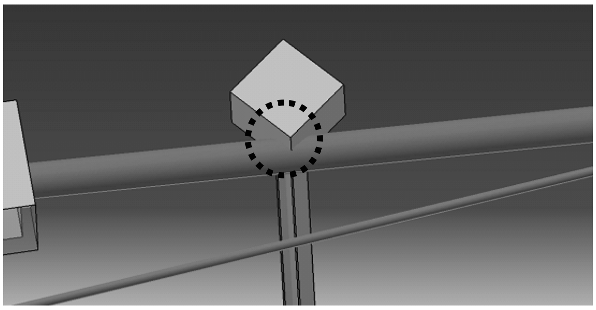

Fig. 8. Conflict between pile cap and pipe in the TKO project

At the same time, the constructor (e.g. a consultant or a project engineer) involved in the phase identifies the constructability of the design so that the process of construction can be smooth. Rework therefore is reduced or eliminated further to reduce the whole life-cycle cost and time. The owner and consultant also have early knowledge of the design and are able to offer their comments, so that the design is easily and rapidly approved.

Although many design errors and constructability issues are identified before construction, some problems still occur in the process of actual construction. These also need the support of the platform to analyze the design. Thus the main model of the project is an important information entity of the VP-based LCM information platform. It provides a great deal of information for the construction, commissioning and maintenance of the project.

Construction

In the construction phase, the focus of the LCM is on construction methods, construction techniques, the utilization and allocation of resources in order to control construction time, cost and quality. Different projects require different construction methods, that is, the construction method for the project is usually unique. Contractors or subcontractors can use the VP-based information platform to freely simulate and discuss the process of construction to decide the optimal construction method, construction sequence, and resource leveling and test new construction techniques before actual construction is commenced. Figure 9 shows the optimization process of roof truss installation method in the TKO project identified as a result of many iterations in the platform. The platform can also be adopted to simulate the planning of construction, make the whole process smooth in the virtual environment, and provide working guides for workmen. This reduces or eliminates the rework of construction, lowers the construction cost and time, and improves the quality of projects. The holistic simulation process is conducted using DELMIA V5.

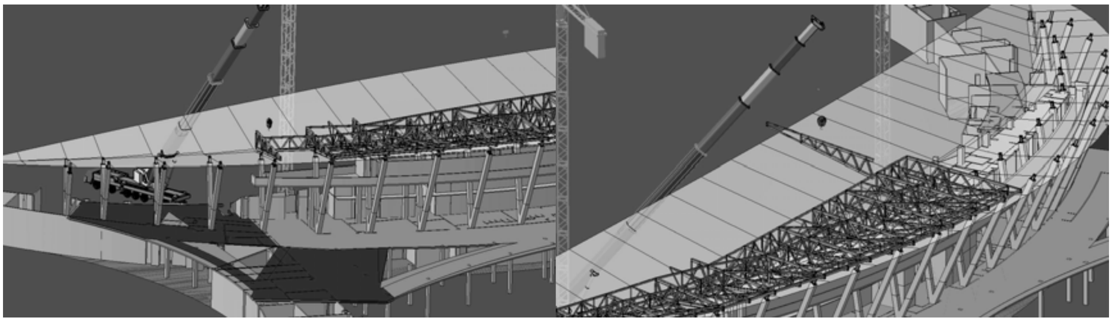

Fig. 9. Simulation of roof truss installation in the TKO project

By using the simulation, owners or consultants may conveniently communicate with contractors or subcontractors and know enough about the construction process and methods for the construction statements to be efficiently approved. For traditional LCM or project management approaches, it is very difficult for owners or consultants to know about the construction process and therefore much more time is spent on the approval of construction statements. Additionally, the final simulation can capture and save much knowledge for future projects and support future maintenance.

Commissioning

All documents arising from above several phases help in commissioning the construction project. In addition to technical documentation, the VP-based information platform supplies visual documents to support the commissioning process. As with the design/construction phase, the owner and tenant can understand the whole project using these visual documents before or after project delivery. This facilitates the commissioning process and saves time.

As an example, the performance evaluation of the design of the spectator stand in the TKO project is presented as follows. As the spectator stand of a sports ground, it must ensure that the audiences' sightline is not hindered. In practice, traditional methods area available to test the sightline, but these are not very accurate. In this project, the VP technology is used and the performance is shown easily and clearly (see Figure 10). This is a test result at a key point, showing that the handrail has little influence on sightline. Therefore, when the project is delivered, a useful video can be provided to assist the contractor and client in explaining this.

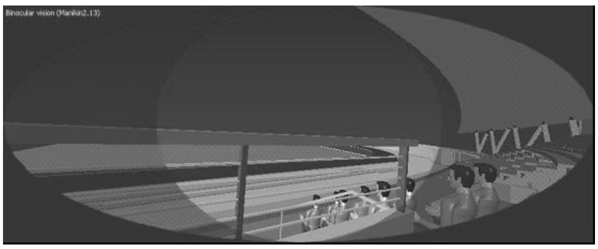

Fig. 10. Performance evaluation of audiences' sightline

Utilization

After commissioning, the platform provides a digital mock-up for the owners or tenants to organise the operation/utilization of a building. Conventionally, owners or tenants only have a conception about the project but know little of the characteristics of the final product (the building). They do not know how to operate or utilize some devices in the building. The digital mock-up supplies them with a visual document to help them do this. To some extent, this saves time and money, which can be spent on teaching or learning. Also the service to the owner is improved. Note that the digital mock-up (main model) is often created in the design phase and it is updated with the change of the design at the time these operations are considered.

The main model of the buildings established using the VP technology also offers a management platform for property management. At present, many buildings have been managed via employing management information systems, and most of them adopt the plan, elevation or section of a building to manage inhabitants or assist in fire control. However, only professionals can understand all of these drawings. Although some of management information systems introduce 3D models of buildings, the relevant model needs to be post-developed, which is time-and-cost waste. Thus it is useful and economical to construct and apply the main model using the VP-based LCM approach to the management of buildings. This not only reduces management costs but also ensures adequate safety.

Maintenance

The main model of the building provides visual information for maintainers to maintain or change some parts of building or devices. This is especially important for some non-typical buildings, e.g. sports grounds. The drawings related to the building are in such great quantity that they are difficult to preserve. Often after 5-10 years, they are lost or destroyed. When maintaining the building, relevant drawings are not available. Although some of electronic drawings, e.g. CAD drawings, are currently stored in computers, these 2D drawings are usually difficult to be understood by maintainers. The 3D main model can help maintainers do this conveniently and clearly. Also, the main model includes much manufactures' information, for example name, telephone, address, etc, and the information of devices or material, e.g. name, type, etc. This information integrated with the main model can aid maintainers to select relevant material, devices, etc. Maintainers only need to click on an item to get its relevant information and therefore it is easy to use the platform.

Furthermore, for some projects difficult to be maintained or modified, maintenance solutions can be tested via the VP technology. This informs maintainers on how to conduct maintenance in the future and can lower maintenance costs and risks. Note that all information can be easily managed by owner's own staffs in the system and therefore it is convenient for the owner to use this information.

Decommissioning

At the end of the building's useful life, the main model can be used to inform its demolition. At that time, based on the main model some key structures can be identified, the procedure for demolition determined, and the material or components to be reutilized identified and protected. This will reduce the risk and cost of demolishing the building and is not possible with traditional methods.

Additionally, many demolishing methods can been tried and checked in the VP-based platform until a suitable method is found. This also makes the demolition process smooth and safe, and reduces time and cost. From the view point of the LCM, these have been taken into account in the design and construction phase.

This section presents the process of implementing LCM for construction projects using the VP-based communication and collaboration platform. The following section will discuss the performance of the implementation of VP-based LCM.

Discussion

Advantages of implementing a VP-based LCM

From the analysis of the implementation of the VP-based LCM, it is clear that the VP technology makes a surprising contribution to the LCM of construction projects. VP-based

LCM appears to have a great number of advantages, e.g. reducing the risk, time, and cost of operating a project and improving the service level to owners/tenants during the whole life cycle. The detailed advantages of the VP-based information platform in different phases of life cycle of projects are summarized in Table 1. It is obvious that the VP technology makes an important improvement to the LCM of projects, especially in the design and construction phases, while from experiences, the time and cost of implementing the VP technology is much less than the time and cost savings. Such a level of performance is impossible to be realized in the traditional LCM of construction projects.

Table 1. Contribution of VP technology to the LCM of construction projects

Phase of LCM	VP technology	Time saving	Cost saving	Service improvement
Planning	Initial main model	Much	Little	More
Design	Main model	More	More	Much
Construction	Main model and process simulation	More	More	Much
Commissioning	Main model and process simulation	Much	Little	Much
Utilization	Main model and process simulation	Much	Little	More
Maintenance	Main model and process simulation	More	much	More
Decommissioning	Main model and process simulation	More	More	Less

Note: Less, Little, Much, and More denote the degree of contribution of VP technology to the LCM of construction projects and the degree from Less to More increases.

Case study of cost and time saving in the construction phase

As a simple case study of the use of VP-based LCM, the cost and time saving in the construction phase is summarized for several real-life construction projects in Hong Kong and Macau (see Table 2). All data are collected from relevant contractors, that is, these data are empirical. In some cases the situation is unclear due to lack of data.

Table 2. Cost and time savings in the construction phases of real-life projects in Hong Kong

Project name	**Cost saving**	**Time saving**
Kwai Chung Public Housing	Unclear	About 17%
HKCC	Unclear	Unclear
Ho Tung Lau	About 12%	About 5%
Venetian Macau Hotel	About 5%	Unclear
TKO Sports Ground	About 250HKD	About 1 month

From the data provided in Table 2, although not including all data from the holistic life cycles of projects, it is clear that the VP technology can make the LCM much useful and effective.

Conclusions

LCM has been a needed feature of the construction industry for many years, but has not been successful in its application as yet. This is because it lacks an effective communication and collaboration information platform to support information sharing between different parties. This paper describes a new information sharing platform using VP technology via analyzing the information flow of LCM of construction projects and customizing the platform using DASSAULT software. The process of implementing LCM of projects is presented on the basis of the VP-based information platform. The advantages of implementing VP-based LCM are further discussed and it is shown that the VP technology can provide useful support to implementing the LCM of construction projects. However, VP-based LCM of construction projects is still in its infancy and much further research is still needed. For example, the delivery approach (e.g. Design-build) of a project has an impact on the implementation of VP-based LCM since it affects the participants during different phases; although this paper presents the advantages of the VP-based LCM platform for the construction phase, these data are empirical, and a quantitative method is needed to quantitatively analyse the advantages of the platform. These all need to be further studied.

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