# Using the IKEA model and Virtual Prototyping technology to improve construction process management

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**ABSTRACT**

Learning from manufacturing industries is a useful approach to improving the productivity of the construction industry and to solve problems arising from construction processes. Through the use of Virtual Prototyping (VP) technology, the lean production process engaged in the IKEA business model (IKEA model) is studied and implemented in a real-life construction project. Specifically, based on the analysis of the IKEA model, this paper presents how the IKEA model can be applied to optimize construction processes and simplify management activities. Finally, a case study is analyzed to demonstrate the improvement of construction process management through using the VP-IKEA approach.

**KEYWORDS**

IKEA model, site operations, virtual prototyping

## INTRODUCTION

Manufacturing companies have made many significant improvements in both productivity and management efficiency over the last century. This progress, however, has not been matched in the construction industry, which is still beset with a variety of long standing problems including time and schedule overruns, poor health and safety conditions as well as low quality and productivity (e.g. Xue *et al* 2007; Love *et al* 2004; Tserng *et al* 2006). Construction industry researchers and practitioners are increasingly seeking to apply the experience accumulated in the manufacturing industry (Bresnen and Marshall 2001) and to-date some management concepts have been adopted. For example, total quality management (TQM), supply chain management (SCM) and lean manufacturing (e.g. Wong and Fung 1999; Green 1998; Lapinski *et al* 2007) are now familiar management concepts in the construction industry.

Of particular interest has been the development of lean construction concepts arising out of Koskela's (1992) challenge to the traditional time-cost-quality trade-off paradigm and elaborated by Ballard and Howell (1994a, 1994b) as "a way to design production systems to minimize waste of materials, time, and effort" (Koskela and Howell 2002). This paper follows that tradition in presenting a construction management innovation based on a combination of the IKEA Group approach (termed here *the IKEA model*) and Virtual Prototyping (VP) technology. As the world's largest (and arguably most successful) furniture retailer, the IKEA Group and its methods have been studied by many researchers from several perspectives and its smart logistics system (Klevas 2005), revolutionary strategy (Barthelemy 2006) and management system (Weisbord and Jandoff 2005) have inspired other industry sectors. VP technology, on the other hand, which originated from the manufacturing industry, has been identified as having considerable potential for the design of structural steelwork (Slaughter and Eraso 1997), site planning (Tawfik and Fernando 2001) and construction project management in general (e.g. Sarshar *et al* 2004; Hobbs and Dawood 1999; Riese 2006).

The total cost of a construction project typically constitutes three major components: approximately 75% of it is spent on labour, material, plant and equipment; around 12% is wasted due to rework incurred by design errors and construction mistakes; and about 13% is used to cover management costs (payments to project management team), overheads and profits of the contracting firms (Love *et al* 1999). In other words, there is up to 25% of waste in the project cost. On the other hand, during the process of assembling a piece of IKEA furniture, there is no design error and constructability problem as the design is checked in a 3D environment and the assembling process is guided by a 3D easy-to-read instruction (Mather 1992). Moreover, because the assembler is given a detailed step-by-step instruction, there is no need to have any additional management personnel to supervise/manage the assembling process; thus the management cost is also nil. Recognising a construction process, especially when precast components are extensively used, has similarity with the assembly process of an IKEA future, this study aims to minimize construction cost by adapting the IKEA model in a project delivery process through the use of Virtual Prototyping technology.

In this study, the framework of the IKEA model is analyzed in section 2, and its application in construction process management is discussed in the section 3. Section 4 introduces a case study to demonstrate the use of VP technology in conjunction with the IKEA model to optimize the construction process and reduce management cost. Finally, the effectiveness of applying the VP-IKEA model in construction process management is demonstrated through a real-life design-build case study project.

## THE IKEA MODEL

IKEA is a privately-held, international home products retailer that sells competitive products, including furniture, accessories, bathrooms and kitchens at retail stores around the world. It became famous for the fact that the customers have to assemble many of the products. IKEA was founded in 1943 by Ingvar Kamprad in Sweden and it is owned by a Dutch-registered foundation controlled by the Kamprad family. IKEA is an acronym comprising the initials of the founder's name (**I**ngvar **K**amprad), farm where he grew up (**E**lmtaryd) and home village (**A**gunnaryd) (Wikipedia 2008).

The essence of the IKEA spirit is “offering a wide range of well-designed, functional home furnishing products at prices that are so low that as many people as possible will be able to afford them” (Mather 1992). In the manufacturing industry, the decomposition and assembly of a product are two basic activities which determine its cost. The decomposition of a product is *the* precondition of standardized production, and assembly of standardized parts is closely related to logistics and marketing. Costs are reduced by controlling these two basic activities. To do this, IKEA extends the traditional principle of “DFM, or design for manufacturability” to “DFL, or design for logistics” (Mather 1992), by considering both the function and manufacturability, and the convenience of packaging, transporting and assembling of the product. The IKEA model also incorporates customer self-service, which means that customers are themselves responsible for locating, collecting, transporting and assembling the purchased furniture. IKEA’s combination of careful design decomposition, collaboration with the cheapest suppliers and customer self-service, result in substantial cost savings (Barthelemy 2006). These are passed on to customers in the form of competitive price which, together with the consequent high sales volumes, gradually increases the company’s profitability.

To support customer self-service, IKEA provides an attractive catalogue and set of 3D assembly instructions. The catalogue contains abundant information, with the product name, price, size, composition, possible usage and alternative decorating style and even an introduction to the designer. It also serves as a type of functional advertisement to attract customer attention and induce consumption through its high-quality Scandinavian design style. Customers obtain all the information required for product selection and purchase without the need for sales personnel. Likewise, the vivid 3D instruction leaflet clearly demonstrates the assembly method and sequence – obviating the need for professional input. Figure 1 illustrates the concept, the main benefits of which are:

- *Optimizing the process from design to ultimate consumers*. As the consequence of DFL, the simplicity of assembling becomes one of the significant aspects of design. Unassembled furniture also enables flat packaging, which reduces the logistics costs involved and allows customers to provide there own transportation.
- *Simplifying management activities*. The management activities and personnel required for marketing, selling, delivering and assembling are minimised, requiring only a simple management organization and which helps to form the IKEA's flat organizational structure.

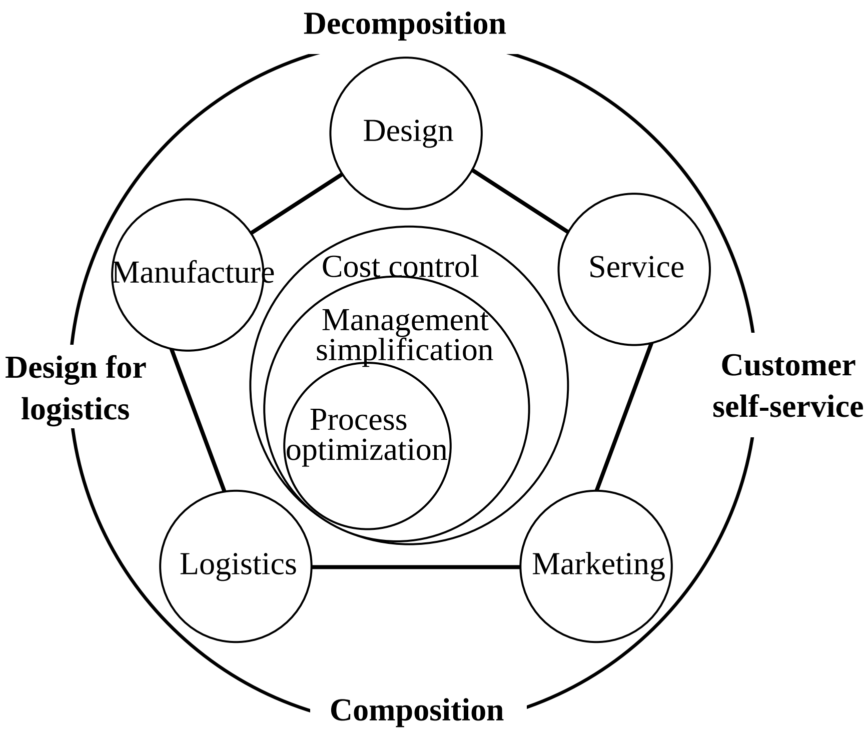


**Figure 1:** IKEA model

In recent times, the IKEA model has come to denote a broader and ideological form, often associated with popular culture in a negative sense, with its cheap and quick, low quality, disposable image. Its do-it –yourself philosophy (Wall 1999:159-162), for example, has been identified with “politics where you make the wished-for changes yourself … a political model of direct action, where the citizen herself is equipped with accessible tools to affect desired effects by herself” (Vinthagen 2006). Likewise, the 'IKEA model of medical advance', in doing “the basic science in the laboratory and self-assemble in the clinic”, is said to be damaging clinic advance (Rees 2001). Even further education (FE) has been said to be suffering from an IKEA mentality (Scaife 2004). From a production process viewpoint, however, the IKEA model clearly has much in its favour and the next section considers its feasibility for use in construction project management.

## APPLICATION OF THE IKEA MODEL AND VP IN CONSTRUCTION PROCESS MANAGEMENT

Process management in the construction and furniture industries faces similar problems: both industries are traditionally of a bespoke nature, highly fragmented and with low productivity; furniture manufacturers deal with various suppliers while construction firms work with a range of subcontractors and consultants; and cost, quality, and assembleblity/buildability are important concerns. Table 1 summarises the major similarities involved.

These similarities indicate that it may be beneficial for the construction industry to adopt some of the furniture industry’s more modern practices as exemplified by the IKEA model of optimizing the project processes involved, simplifying the management tasks required and using VP technology (Mather 1992).

**Table 1:** The similarity between construction process and IKEA's manufacturing

| Item | Construction project | IKEA |
|---|---|---|
| Industry trait | Fragmental, low productivity | Fragmental, slow growing |
| Process | Project-oriented, customized | Customer-oriented, cost-driven |
| Partnership | Complex, teamwork | Complex, collaborated with suppliers |
| Objective | Low cost, high quality, safe, timely | Low cost, high quality, in time |

*Optimization of construction processes*

Construction processes are characterised by their uncertainty and complexity, and many problems are caused by design errors and a mismatch of planned and actually needed resources. The complexity of the construction product makes design errors inevitable and difficult to identify prior to the project commencement. Construction process control on the other hand seldom provides sufficiently  timely coordination of labour, material and equipment from different providers and a mismatch occurs frequently. It is well known that design errors and mismatch of resources generate reworking, change orders and disturbance of construction plans and schedules, thereby increasing costs (Park and Pena-Mora 2003). Therefore, the objective of optimizing the construction process management is to eliminate design errors and provide a reasonable construction sequence prior to the commencement of construction works.

*Simplification of management activities*

Empirical data indicates that construction cost increases exponentially with the increasing degree of complexity and scale of a project (Love, Pundal and Li 1999**)**. Larger and complex projects involve more management activities and hence need more personnel to prevent, control and solve problems such as design changes, resource mismatches and conflicts among project participants. Simplifying management activities through eliminating non-value-adding processes and/or amalgamating activities enables the reduction of management personnel and costs.

*Provision of VP technology*

The VP technology adopted in this study comprises a set of computer software developed by the Construction Virtual Prototyping Lab at the Hong Kong Polytechnic University (see www.cvptl.com for more information). Through customizing two software systems, Catia V5© and Delmia V5© of the Dassault Systems, and adding construction specific functions, the virtual prototyping technology provides a digital mock-up of construction processes and activities. It extends current technologies, such as 4D CAD, by providing the capacity to simulate not only 3 dimensions and time, by all important dimensions of a construction project such as safety, logistics, and productivity.

Specifically, the current 4D model does not convey all the information required to evaluate the schedule. Building components and construction equipment are usually modeled in the 3D images and linked with schedule. These 4D CAD systems lack construction-specific components such as scaffolding and other temporary works integrated in the 3D model. Such 4D models do not show the space needs and corresponding potential congestion of temporary works (Koo and Fischer, 2000; Chau et al 2005). However, temporary works are a critical element of the overall construction plan. Failure in planning appropriate temporary structures affects safety, quality, and productivity adversely (Chini and Genauer 1997). A detailed comparison of VP and other similar technologies is available in (Huang *et al* 2007).

The use of VP enables a ‘try before build’ simulation. To validate the assemblebility of its products, the process of assembling process of a IKEA product needs to be tested in a VP system to ensure that customers can conveniently ‘build’ the product ‘on-site’. Similarly, VP technology can be adapted and applied to improve the buildability of construction projects. VP is a computer-aided design process concerned with the construction of digital product models (virtual prototypes) and realistic graphical simulations that address the broad issues of physical layout, operational concept, functional specifications, and dynamic analysis under various operating environments (Shen *et al* 2005; Xiang *et al* 2004). The application of VP technology in the construction industry can fulfil the function of checking design errors efficiently, modifying those rapidly, and then simulating the construction process in a virtual environment so as to present a clear and easily-operated 3D construction instruction (Huang *et al* 2007). Therefore, VP technology can provide a virtual experimentation platform for the implementation of process optimization and management simplification of construction process.

The subsequent sections further elaborate how construction processes can be optimized and management activities simplified with a VP-IKEA approach.

## Construction process optimization

The optimization of the construction processes focuses on the elimination of non-value-added and unnecessary cost-added activities, including change orders for design errors, reworking caused by inappropriate planning and inappropriate operations, information misunderstanding among construction partners, and inefficiency due to the lack of skilled crafts people.

Through constructing 3D models from 2D drawings of a construction project, many design errors such as missing or inconsistent dimensions can be easily identified. In addition, the collision detection technique embedded in the VP technology will help identify conflicts of components.

Specifically, the optimization of construction process is obtained from five perspectives:

*Design check and constructability evaluation*

Design is a process to translate the owner's desire to physical facilities. Typically architects and engineers from different disciplines produce separate designs which contain errors, such as dimensional inconsistencies and missing information, that directly lead to rework (Love *et al* 2004). Prior to the availability of VP technology, it was not possible to test the completeness and correctness of design as this required physical mockup, which was both costly and risky to produce (Akintoye *et al.* 2000). Design errors are then identified and solved through remedial work on site. The application of VP technology requires developing 3D models of the project from 2D drawings. This process enables many design errors to be detected automatically and the construction sequence can be simulated and improved.

*Translating the construction schedule into 3D step-by-step instructions*

Through simulating and improving the construction sequence, the construction schedule can be translated into a series of 3D step-by-step instructions that are easier for project participants to understand and follow. Traditionally, project managers use bulky construction documents -

typically including 2D drawings, written specifications and manuals - to manage projects. A major task of project managers is to understand these documents and derive executable actions from them. However, understanding the documents is never a trivial task as it is both time-consuming and easy to make mistakes. To translate construction documents into executable actions, project managers need to mentally construct construction sequences based on their understanding of the documents. Again, this often leads to misinterpretations, risks and uncertainties. The provision of 3D step-by-step construction sequences to project managers should substantially relieve project managers of this task and trim down the size of project management team.

*Identification of unsafe zones and quality problems*

Quality and safety are critical objectives to project management as they can reduce project time and cost. Project managers need to ensure that all materials, equipment and operations achieve the required quality in a safe project environment. The traditional approach to quality and safety management is mainly reactive: waiting for problems to occur and then taking on-site remedial actions. This practice is inefficient and costly (Akintoye *et al* 2000). The use of VP technology makes it possible to identify quality problems and unsafe zones in advance. By navigating through virtual construction sites, quality problems and unsafe zones can be pre-determined and detected. These include locations for possible human-machine interactions, missing or incomplete safety nets, and narrow or insufficient workspaces. In other words, the use of VP technology can transform construction project management from a reactive to proactive management style.

*Effective communication platform for all project participants*

The current practice is for the general contractor to be responsible for process planning, control and coordination. However, there are often inconsistencies and conflicts in the project information generated by the various parties involved in projects. VP technology represents project information in virtually realistic forms and provides a focal point to host and exchange project information. Project participants can therefore obtain direct and unequivocal information simultaneously. This thus eliminates the bottleneck problem in communication among project participants (Elliman and Orange 2000).

*Construction knowledge management*

Construction process simulation can provide a visual platform to demonstrate complicated construction techniques and procedures to craft workers. Using VP technology, construction techniques can be vividly and visually demonstrated and recorded. The recorded visual information captures construction knowledge in a direct and informationally rich format that is easy to understand and follow. The accumulation of visual information in this format may be re-used in future projects and for educational purposes.

**Simplification of construction activities**

As stated previously, the management cost of a construction project can amount to 13% of the total cost, while in an IKEA assembly process the management cost is nil. The reason for IKEA to achieve zero management cost is that its assembly process is guided by a step-by-step 3D instruction which is easy to understand, unlike a construction plan and schedule which is often difficult to follow. In order to reduce the management cost of a construction project, this study applies the Virtual Prototyping technology to simulate construction processes. The simulated processes can be presented in step-by-step instructions which are easy to follow by on-site operatives. Because of this, on-site management personnel can be reduced and the associated management activities simplified.

The application of VP technology to the construction process creates a new project participant, the process simulator, in project delivery. With this new participant, the functions and roles of existing project participants can be re-arranged and the construction process simplified. Specifically, the follow aspects of the construction process can be changed.

*Simplification of the document submission process*

Design and planning documents are exchanged among project participants. For example, many documents, including design drawings, product data and samples need to be submitted by subcontractors to the architect, engineer and general contractor for approval (see Figure 2). This is important because it is closely related to the quality, schedule and even the success of the overall project. However, the submission and approval process is complex and time consuming because:

- project information is prepared in various formats such as 2D drawings, tables and texts; which may lead to misunderstandings among project participants; and
- comments or changes cannot be included in the submitted document.

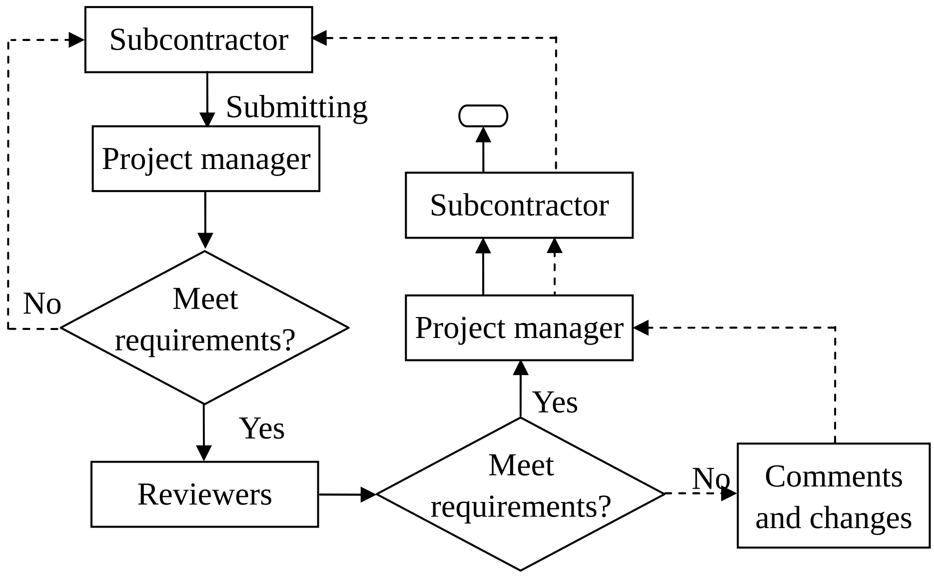


**Figure 2**: Traditional document submission process

Using VP technology, the submission process can be improved as illustrated in Figure 3. Here, the submitted documents are simulated and translated into visual models and sequences inform which feasibility may be evaluated. Design errors from 2D drawings are revealed and detected automatically and the impact of alternative construction methods can also be analyzed.

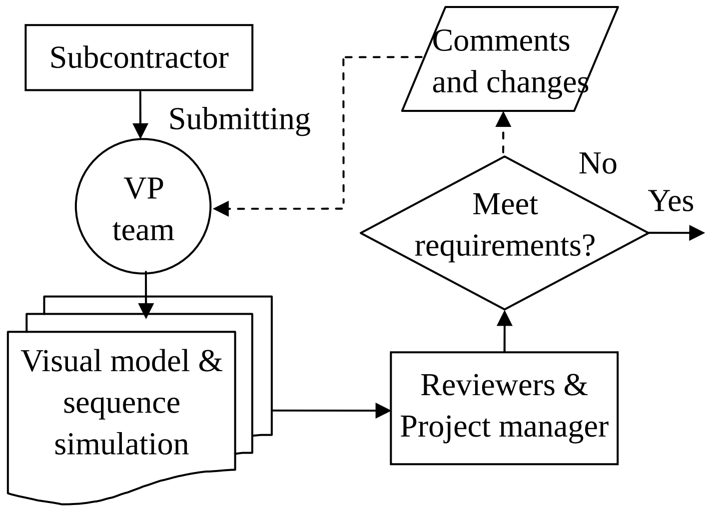


**Figure 3:** VP-based document submission process

*Re-arrangement of the roles and responsibilities of project managers*

The application of VP technology in construction process management transforms project management from a reactive and remedial approach to a proactive approach. Generally, project management can be divided into five phases (Park and Pena-Mora2003): project initiating, project planning, project executing, project controlling and project closing, as shown in Figure 4.

Existing planning tools, such as the critical path method (CPM) and Gantt charts, can only allow planners to represent time, activities and their interdependences and resources of a project, whereas important information such as site layout, dynamic spatial relationships between plant, materials and operatives cannot be represented. This directly leads to inappropriate and un-executable construction plans, and disputes and rework arise. This also explains the existence of multiple ‘Executing’ and ‘Controlling’ phases, as indicated in Figure 4.

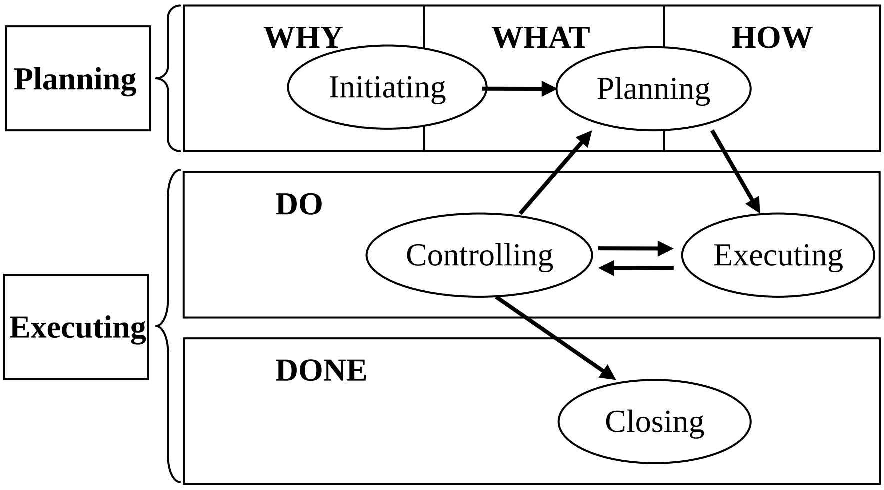

**Figure 4:** The construction project management process

As a powerful construction planning technique, VP can be used to prepare and verify the feasibility of the design and construction plan. In a VP environment, the planner is provided with a virtual construction site with all the necessary information needed to develop a realistic construction plan. Within this environment, planners can conduct ‘what-if’ analyses to ensure the feasibility and constructability of all details of the construction plan. After this process, it is unlikely that rework due to inappropriate planning will occur, and ‘Executing’ and ‘Controlling’ becomes unambiguous and non-repetitive, as shown in Figure 5. Thus the management personnel and cost configured to these two phases can be reduced.

## CASE STUDY

Hong Kong Tseung Kwan O Sports Ground is a design and build (DandB) project contracted to China Overseas Holdings Limited for the 5th East Asian games, to be held in Hong Kong in 2009. It is the first stadium project in Hong Kong adopting the VP technology. As the general contractor, the project team from China Overseas Holdings Limited decided to use VP technology to optimize the construction process and reduce risk and project cost.

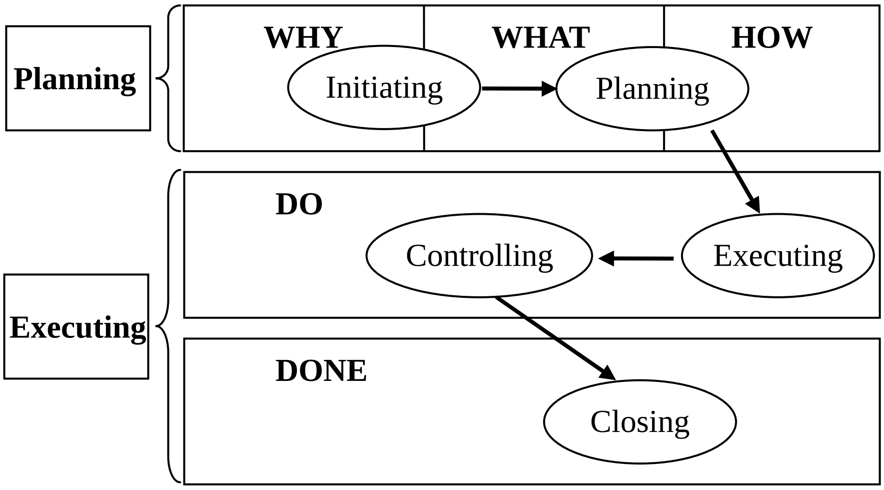


**Figure5:** Construction project management process based on VP

The Hong Kong Polytechnic University, including the first and second authors, prepared the BIM (Building Information Model) for the project.

During the preparation of BIM model of the Tseung Kwan O Sports Ground project, 84 design errors were identified. By integrating the preliminary planning information, site layout, plant and equipment, members of the Construction Virtual Prototyping Lab conducted the simulation of the construction processes. Once the simulation model is established, project management personnel from the main contractor were invited to evaluate the feasibility of the simulated construction process and to explore ways of improve the processes. Recommendations and suggestions from the project management personnel were then used to update the simulation model. This process of evaluation has been iterative until all parties were satisfied with the simulation results.

The simulation model was then offered to site management team to guide the construction process. In order to ensure to deal with the discrepancies between the simulation model and site reality, 2 members of the Lab were seconded to the site office to work side-by-side with project management team. Discrepancies, once detected, would be incorporated into the computer model to update the simulated construction processes so that subsequent construction activities could be guided by the simulation model.

The whole period of construction process simulation and model updating has been approximately 8 months. The construction project was completed in March 2008. Along with the 84 design errors detected, the simulation enabled the project to be completed 25 days ahead of schedule and the total cost was reduced by approximately 8% due to the elimination of rework and reduced size of on-site project management team. Details of these are presented in subsequent sections.

**Optimizing the *V-column* installation Process**

*Visualization of the construction documents*

A 3D model was developed based on the design drawings of the *V-column* structure prepared by the nominated subcontractor. This was used as a basis of further analysis including design error check, sequence simulation, safety and quality appraisal etc., was developed.

*Checking design errors*

The *V-column* structure is a reinforced concrete superstructure composed of columns, slab, partition, etc. Design errors in the form of dimensional inconsistencies and collision of objects are automatically detected by the VP system.

*Simulation of the installation sequence*

After the design errors were completely eliminated, the construction sequence was simulated in the virtual environment through allocating and testing appropriate materials, equipment and other resources for all construction activities.

*Nominated subcontractor involvement*

Before commencement of the *V-column* construction, the nominated subcontractor was invited to participate in the VP simulation process. The subcontractor was in charge of submitting design drawings to the main contractor for approval. Once design errors were detected, the subcontractor and the main contractor discussed the design, based on the 3D model, to confirm the modifications. Moreover, the sequence simulation enabled the subcontractor to verify the coordination with other holistic on-site activities.

*Quality and safety control*

The VP technology provides an economical and risk-free visual platform to check the design and construction process conform to specifications. For example, in the initial installation process, no temporary support is designed to hold the *V-column* once it is hoisted to position. After viewing the simulation of construction sequence, the safety officer proposes that temporary wires should be attached to the *V-column* and the roof top to ensure the stability of the column.

*Training of craft workers*

The simulation process of *V-column* installation is also used to train craft workers before the real construction is started to assure the applicability of the physical operation as not all workers are familiar with the techniques, materials and equipment employed in the project. Craft workers are provided with vivid and easy-to-understand instructions of the working procedure and learn operational methods through the virtual simulation environment. This reduces the amount of rework caused by operational mistakes of workers.

**Simplification of management activities**

In order to complete the project objectives, the contractor assigns management personnel to control different aspects of construction. The initial organizational structure of the project management team is shown in Figure 6. Using the VP-IKEA model, the organizational structure is simplified and improved in two ways: (1) Removing positions that become redundant after the use of VP technology and (2) combining functions and responsibilities.

*Removing abundant management personnel*

The use of VP technology makes it much easier to plan and control the construction process, with project management practice now being more a proactive than reactive process. In addition, as workers are given 3D instructions, less on-site supervision and monitoring personnel are required. As a result, the amount of management personnel, especially those in charge of on-site supervision, is reduced by approximately 50 percent. For example, the positions of Foreman and Assistant Foreman are removed from the project organization, and the responsibilities reassigned to the General Foreman (see Figure 7).

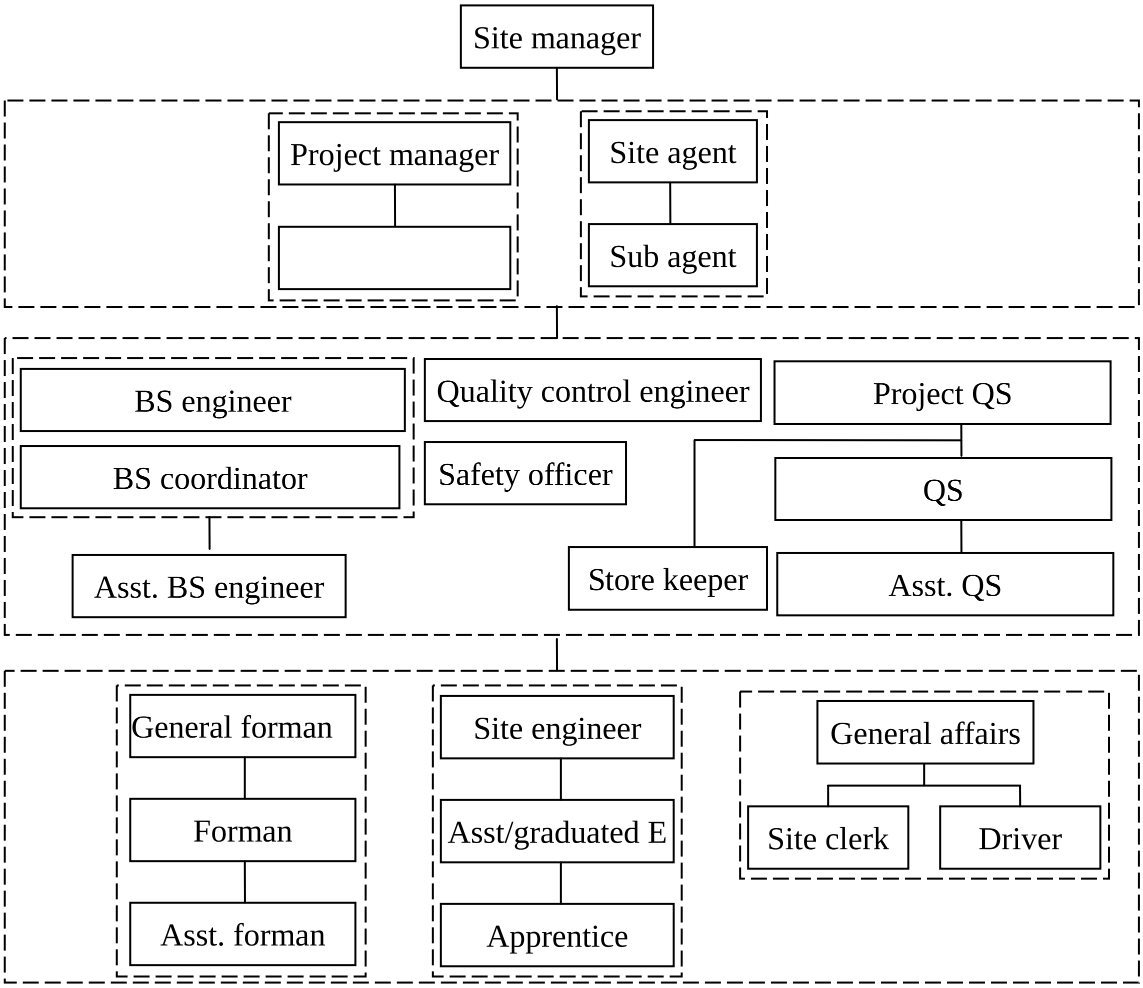


**Figure 6:** The project organization

*Reduction of management size*

In the initial organizational structure, there is a Quality Control Engineer (QCE) and Safety Officer (SO). Since the VP Technology simulates the construction process prior to the real construction, many of the potential quality and safety problems are detected and resolved in the virtual environment. As a result, the scope of QCE and SO work is reduced to the point where it is combined into just one position, as shown in Figure 8.

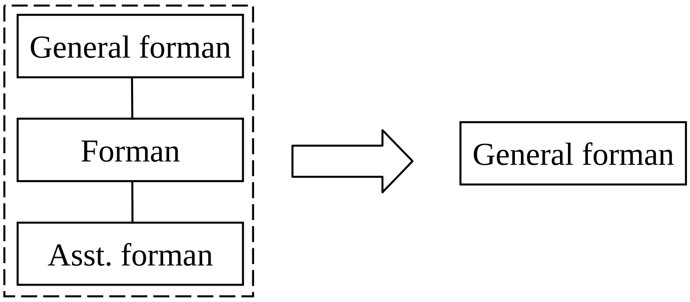


**Figure 7:** The trimmed organization

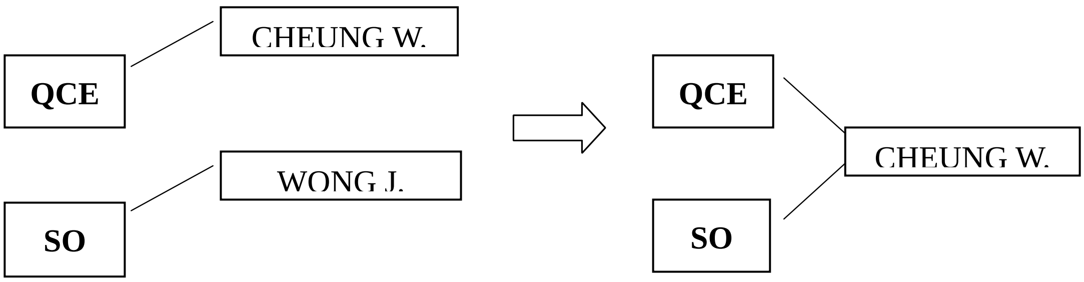


**Figure 8:** Functional combination

## CONCLUSION

The IKEA model, based on customer-assembly of products, has been successfully used in the car manufacturing industry to improve productivity and reduce costs and prices and has some potential for application in the construction industry. Likewise, VP offers a means of testing out production processes in advance of actual construction – a vital aspect for construction projects, which are often of a bespoke nature. This paper presents an application to the construction industry using the VP-IKEA combination with 3D instructions. A case study is described in which both efficiency and productivity were considerably improved.

The implications of using the VP-IKEA model are that, in addition to significant time and cost/price reductions, a radically simplified management structure is possible and one that is more closely aligned to that of manufacturing. If adopted on a large scale, therefore, it is likely that the construction industry itself will become organised much more along the lines of manufacturing, with a greater use of prefabricated components, standardised assembly processes and concomitant reduction in risk and uncertainty over time, price and quality levels achievable in the industry.

It is necessary to note that the focus of this study is to explore the use of the VP-IKEA model to reduce rework and management cost of a construction project. Further research is needed to explore the possibility of adopting the cost-control mechanisms of the IKEA model into a construction project delivery process. Many other issues, such as the difficulties and barriers to the adoption of VP technology, have been elaborated in Huang *et al* (2007).

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