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From IKEA model to the lean construction concept: A solution to implementation

Abstract: The productivity of the construction industry worldwide has been declining over the past forty years. One approach to improving the situation is by the introduction of lean construction. The IKEA model has been shown to be beneficial when used in the construction context. A framework is developed in which the lean construction concept is embodied within the IKEA model by integrating Virtual Prototyping (VP) technology and its implementation is described and evaluated through a real-life case implementing the lean production philosophy. The operational flows of the IKEA model and lean construction are then compared to analyze the feasibility of IKEA-based lean construction. It is concluded that the successful application of the IKEA model in this context will promote the implementation of lean construction and improve the efficiency of the industry.

Keywords: Construction industry, lean construction, IKEA model, virtual prototyping.

1 Introduction

Construction management and technology are two key factors influencing the development of the construction industry. Over the past 40 years, although several

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new and advanced construction technologies have been applied to construction projects, the efficiency of the industry has remained quite low (Guo, 2009; Koushki et al, 2005; Sacks and Goldin, 2007). For example, the productivity of the USA construction industry has been declining since 1964 (Teicholz, 2004). A similar decline in construction productivity has also occurred in other countries. Japan, for example, decreased from 3714 to 2731 Yen/Man/Hours over the period of 1990 to 2004. The main reason for this appears to be that the new technologies cannot effectively reduce the cost of design and construction while, at the same time, improving the management of the construction process.

In order to improve this situation, many researchers and practitioners have attempted to introduce new management concepts, such as Supply Chain Management (SCM) (Cheng et al, 2010; Fernie and Thorpe, 2007; Love et al, 2004; Xue et al, 2007), Total Quality Management (TQM) (Kuo and Kuo, 2010; Lau and Tang, 2009; Love et al, 2000, 2004; Haupt and Whiteman, 2004; Zeng et al, 2003), and Lean Production (LP) (Eriksson, 2010; Garrett and Lee, 2010; Jørgensen and Emmitt, 2008; Meiling et al, 2012; McGrath-Champ and Rosewarne, 2009; Sage et al, 2012) to construction management. However, these management concepts have yet to be effectively applied in the construction industry. The most obvious reason for this is that the concepts originated from the manufacturing industry are, in many ways, profoundly different from the construction industry. Of major significance is the fragmented nature of the construction industry where, even with the aid of information technologies to support implementation, the technologies are not yet effectively integrated with the lean concepts (Breit et al, 2008; Sack et al, 2010; Shin et al, 2011; Tarantilis et al, 2008; Tommelein, 1998; Wang et al, 2007). Therefore, the application of both contemporary management concepts *and* appropriate information technology is likely to provide the solution needed.

This paper describes the use of the IKEA model and Virtual Prototyping (VP) technology for the management and control of construction processes needed for the effective implementation of the lean production concept. The well-known IKEA model, which already effectively incorporates the lean production ideal, is a proven efficient management and manufacturing system for home furnishings and has considerable potential for use in construction projects. The following sections provide a literature review of the lean construction concept and a framework is developed for an IKEA model-based lean construction for implementation through the Virtual Prototyping (VP) technology. The operational flows of the IKEA model and lean construction are also compared to assess the feasibility of the system.

2 Literature review

The lean production concept was created by Womack et al. (1990) based on the Toyota Production System in Japan. Due to the success of the concept in the manufacturing industry, researchers have recommended it for adoption in the construction industries of several countries, including UK (Green, 1999), Australia

(McGrath-Champ and Rosewarne, 2009) and Sweden (Meiling et al, 2012). *Lean construction* – a term coined by the International Group for Lean Construction in 1993 (Gleeson et al, 2007) - has been thoroughly investigated in recent years. This refers to the application of lean production principles and practices in design-construction processes to maximize value and to reduce waste (Alarcon, 1997; Howell and Ballard, 1998; Koskela, 1997, 2003).

Some successful experience in implementing lean construction has been achieved. Conte and Gransberg (2001), for example, examine the principles used in applying lean construction by over twenty construction companies in Brazil. Similarly, Wright (2000) presents several cases involving the use of lean construction and Garrett and Lee's (2010) case studies demonstrate that the application of lean concepts to the construction submittal review process can reduce or even eliminate the occurrence of non-value activities.

However, the application of lean construction is still in its initial stages. In order to improve the implementation of lean construction, Miller et al (2002) propose the "harmonization between main contractors and subcontractors" as a prerequisite, while Thomas et al (2002, 2003) propose "reducing variability to improve performance" and "improving labour flow reliability for better productivity" as lean construction principles.

Other research by Meiling et al (2012) measures the degree to which lean management principles are applied and implemented in off-site construction, while Eriksson (2010) develops the understanding of lean construction and its influence on SCM in general. Sage et al (2012), on the other hand, explore the implementation of lean construction through a "Strategy-as-Practice" perspective; Bashford et al (2005) introduce the production management model into residential construction; and Sacks and Goldin (2007) present a lean management model for the construction of high-rise apartment buildings complete with simulation methods for its validation. Further work by Jørgensen and Emmitt (2008) also explores the lost-in-transfer from lean production to lean construction.

In summary, therefore, lean construction is still waiting to be fully introduced, with the main barriers being that

- lean construction cannot be understood easily since it lacks intuitive appeal;
- a primary principle of lean construction is to make production planning accurate and detailed and reduce planning variability, but in current practice, the separation of design and construction makes planning difficult; and
- lean construction needs efficient communication between the different participants (e.g. main contractors and subcontractors) and it is difficult to harmonize their relationships sufficiently to structure the work and realize “production control”.

One approach to overcoming these problems is in the use of computerized simulation. Sacks et al (2007), for instance, analyze and evaluate lean construction models using living and computerized simulation; Tommelein (1998) use discrete event simulation to describe the concept of lean construction; Breit et al (2008) present an initial conceptual framework for the use of 3D/4D and simulation technologies to support lean construction; and Sacks et al (2010) propose a conceptual building information modelling (BIM)-based lean production management model and analysis of its requirements. This paper extends the simulation approach by embodying the lean construction concept within the IKEA model.

3 IKEA model-based lean construction

3.1 The IKEA model and lean construction

IKEA is a famous brand of home furnishings, with the vision that it "**…** offers a wide range of well-designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them" (IKEA website). The function of the IKEA model then is to provide high-quality home furnishings at the lowest cost (Barthelemy 2006; Mather 1992). For IKEA, the designers work with the manufacturers to find smart ways of making furniture with existing production processes. Customers then choose an item of furniture themselves, collect it at a self-serve warehouse, transport it home and assemble and install using the 3D instructions provided (an example shown in Figure 1, IKEA website) without the need for any additional technical assistance. This considerably reduces IKEA's costs as most of the post-manufacture work is done by the customer and not IKEA.

The lean production concept is obviously embodied in the IKEA model. On the one hand, it adequately takes into account the distinguishing features of lean production, for example zero faults, zero time delivery, zero inventory of finished products, long-term partnerships with customers and suppliers, concurrent design of the product and manufacturing process, high production planning reliability and stability, etc (Kumar et al, 2000). On the other hand, it reduces manufacturing sequences. As Figure 1 shows, the 3D instructions for customers are very clear and intuitive for assembling furniture so that no other operations are needed between design and installation (Barthelemy 2006). This reduces total time and cost - clearly an application of the lean production ideal. IKEA model, therefore, provides a visual representation of the lean production ideal.

To some extent, manufacturing home furniture is similar to constructing a building, especially a simple "Design-Build" (D/B) project. In addition, the features of the IKEA model appear to provide a solution to the three problems of implementation of lean construction mentioned earlier. This suggests that some suitably modified version of the IKEA model may be suitable for construction projects, especially D/B projects, and can be employed to achieve a lean construction solution.

3.2 IKEA model-based lean construction

In considering the development of IKEA model-based lean construction, three main aspects are immediately apparent:

- *Concurrency of the design and construction process planning*. Design and construction are the two main activities in the construction industry. In order to realize the lean goal of zero time delivery from design to construction, the design and construction processes should be conducted concurrently as far as possible. In other words, when the design is finished the construction plan is also finished. There is no idle time involved between production process design and construction. This needs the collaboration of multi-participants, i.e. architects, engineers, contractors, subcontractors, and clients. The IKEA model is simple to carry this out since it only has to take designers and manufacturers into account. For the construction industry, more collaborative work is needed due to the many participants involved in its projects.
- *Reduction of the construction 'middle links' and optimized construction sequence*. The reduction of the 'middle link' is an important means of saving time and cost and reducing inventories. In the same way as the IKEA approach discards assembly services to reduce costs, the construction industry also needs to eliminate some middle links, such as the need for technicians to instruct the workers. This can be done by the use of 3D construction instructions provided directly to the workers (Li et al, 2008). In addition, reducing the middle links can

improve the reliability of the whole system as well as benefit production control and minimise inventories. As IKEA aims to optimize the assembly process to reduce assembly time, the construction industry can also optimize the construction process to provide workers with appropriate and efficient 3D construction instructions.

- *Strengthened communication among different participants*. Communication between owners, designers, contractors, subcontractors, and suppliers is the basis for implementing lean construction. This helps ensure the whole project is continuous and reliable, which is the precondition for zero time delivery and zero inventories. IKEA provides a good means of communication for designers, manufacturers, customers, and suppliers, making it possible to provide good quality, low cost, furnishings.

The following sections investigate these three aspects further in the development of an IKEA model-based lean construction system.

4 Concurrent design and process planning

Construction process planning is the consideration of how the work is to be done; it structures the flow of work. It includes decisions concerning how the project is to be divided into smaller activities and how the work involved in each of these activities is to be coordinated within and between activities. The design of a building is the basis of the construction process plan. When the design is modified, the process is also conducted simultaneously so they both finish at the same time. In addition, taking into account the validity of the design and process, two premises must be met to maintain concurrency: design without errors and an appropriate construction sequence. If design errors cannot be eliminated, the plan has no validity. Based on a design without errors, the construction process should also be planned and checked to provide an appropriate sequence which assures it can be conducted smoothly. Therefore, to achieve concurrency of design and process planning involves a platform to maintain concurrent real time and enable the design and process to be linked together.

Of course, construction projects are different from home furnishings. In some cases, their designs and construction sequences are totally different. In other words, construction projects can have no fixed design plans and construction sequences. Thus it is impossible to check the design or construction sequence of each project in the same way as that of furniture (for example a dining table) in a real environment. To do this involves the provision of a *virtual environment* in which design plans and construction sequences can be tried again and again to eliminate design errors and obtain an appropriate construction sequence. Virtual prototyping technology offers such a means of support for the platform and to check the design and process.

4.1 Virtual prototyping

Virtual Prototyping (VP) is a computer-aided design and planning process concerned with the construction of digital product models and realistic graphical simulations that address the broad issues of physical layout, operational concept, functional specifications, and dynamics analysis under various operating environments (Shen et al, 2005; Xiang et al., 2004; Pratt, 1995). Dedicated VP technology has been extensively and successfully applied to the automobile and aerospace fields (Choi and Chan, 2004). For instance, an automobile can be fabricated virtually via the VP technology, allowing various team members to view the 3D image of the finished product, evaluate the design, and identify the production problems prior to the actual start of mass production. There have also been several applications of VP technology in the construction industry (i.e. construction process simulation), for example, the Construction Virtual Prototyping Laboratory (CVPL) of Hong Kong Polytechnic University (Li et al, 2011; Guo et al, 2010; Li et al, 2008; Huang et al, 2007). These suggest that VP can be used to check design errors efficiently, modify them rapidly, and then simulate the construction process in a virtual environment so as to present clear and easily-operated 3D construction instructions.

4.2 Design error checking

As introduced earlier, the design of a construction project involves many participants and collaborative design among different participants can effectively detect and eliminate design errors. The detection process involves two stages:

1) Constructing a 3D main model which integrates architecture, structure and building services (BS) using VP technology, and
2) Automatically detecting clashes between all components in the model.

Then, once detected, all participants can discuss and modify the design errors in the 3D main model. In this way, all the participants can work collaboratively to remove any design errors through the 3D main model of a project.

4.3 Modification of design

In order to improve the efficiency of design, all the detected design errors must be modified rapidly. The process of design modification is illustrated in Figure 2. This is a simple task in the virtual environment provided by VP technology. Also, the 3D main model can be updated automatically when any element is modified. This enables the final design plan to be produced after several cycles of design-modification and is the basis for maintaining the concurrency of the design and construction process planning of the project.

4.4 Construction process simulation

For a construction project, its sequence of construction activities cannot be repeated in a real environment. Therefore, in order to devise an appropriate sequence, it must be tested in a virtual environment. This is the aim of the construction process simulation and its procedure is shown in Figure 3. By simulating different construction sequences using VP technology, their feasibility can be analyzed - including collisions, conflicts, safety, etc. These problems can then be solved in time through the collaboration and communication among the different participants, and re-simulated. By continual repetition of this process, the construction sequences concerned are modified until all problems are solved and an appropriate construction plan is evolved. This provides another guarantee of the concurrency of the design and process planning.

5 Reduction of construction middle links

As with the IKEA model, the middle links are reduced through adopting the 3D instruction method. This kind of instruction is presented in a very clear step-by-step form. By referring to the 3D instruction, workers are able to work smoothly without any additional technical support and thereby reducing the traditional ‘middle links’ involved. This eliminates the need that occurs in the traditional construction process for intermediate technicians or subcontractors to instruct the workers involved. Note that the removal of construction middle links is achieved through the compilation of a set of 3D instructions for each project. These 3D instructions can be compiled using the VP technology (Li et al, 2008).

6 Strengthening of communication among different participants

In order to strengthen communication among the different participants, an efficient communication platform is needed. The VP technology supports the collaboration of design and construction process planning, reduction of middle links, and provides a communication platform for the different participants. In other words, the communication among the different participants is strengthened due to the collaborative effort demanded by the process. This improved communication not only provides support for collaborative design and construction process planning, but also enables the construction to take place smoothly. As a result, the improved communication enhances the reliability of the construction system and reduces the idle time, inventories and cost, in addition to assuring the successful implementation of lean construction.

7 Case study

A construction project in Hong Kong, TKO Sports Ground, that adopted the lean production ideal by combining the IKEA model with VP technology, was taken to demonstrate the implementation of the IKEA model-based lean construction system and evaluate its performance. This was a D/B project and the focus of the case study was on the three story spectator stand of the sports ground. The three main aspects of the IKEA model-based lean construction follow.

7.1 Concurrency of design and process planning

- 3D modelling of the spectator stand

3D modelling is the prerequisite for concurrent design and process planning. Based on the shop drawings of the spectator stand, the 3D main model was built using the VP technology and it included architectural, structural, and building services (BS) (see Figure 4). As the VP technology has not been widely used in the construction industry, the 3D modelling was undertaken by professional modellers. During the modelling process, all the consultants - architects, structural engineers, BS engineers - and contractors provided suggestions to the modellers to enable the main model to fully represent the different disciplines involved.

- Design error checking

In order to effectively and efficiently detect design errors before the real construction begins and therefore avoid or reduce the occurrence of design-related construction problems, the 3D models were used to automatically identify design errors or clashes in advance through the VP technology (see Figure 5). The clashes found included those occurring within architectural, structural and BS components. For example, Figure 6 shows two clashes between the roof and partition walls. Through such clash checking, over 100 design errors were found and eventually removed through the collaboration of different participants to ensure complete design constructability.

- Modification of design errors

The correction of design errors is another important function of collaborative design. This involves design revisions based on the suggestions from the different professions involved. The revision process is very fast and convenient. Once the errors are detected, the design is rapidly and easily modified using the VP technology. Figure 7 shows an example involving the modification of a column. In order to modify the length of the column, the user simply edited the property "length" of the column. The VP technology then automatically modified all the same kind of columns in the 3D main model to ensure design consistency.

- Construction process planning and simulation

The final objective is to achieve an appropriate construction process plan. During the course of checking and removing design errors, the foremen and subcontractors developed different construction process plans and, with the help of the modellers, simulated them in the virtual environment. Based on the simulations, the process plans were effectively analyzed and compared, and relevant problems identified. For example, Figure 8 shows the simulation of the construction sequence of a V-column installation. This indicates quite clearly that the temporary support is outside the first-floor slab and that the construction sequence is therefore not feasible. By using such simulations and rectification work, an appropriate error-free installation process was finally achieved. As a result, when the design of the project was completed, most of construction process planning (especially for the V-column and roof truss) was also finished.

7.2 Reduction of construction middle links

In order to reduce construction middle links in the project, many 3D construction instructions were developed as a result of the construction process simulations. That is, the production of the instructions was based on the simulation of the appropriate construction process plan. The instructions are represented in the form of videos or printed materials. For example, Figure 9 briefly demonstrates the 3D construction instruction for “the installation of V-columns”, in which the installation process is clearly shown step by step. Normally, the workers were given training on the nature of the work to be done and its *modus operandi* by use of the 3D instructions prior to performing the actual task. They could also check the 3D instructions when actually carrying out the work. To a great extent, the 3D instructions successfully instructed the workers directly in completing their tasks correctly. Significantly, this resulted in the project manager identifying an approximately 50% reduction in the intermediate technicians (e.g. assistant foremen) that would normally have been needed to carry out the work.

7.3 Strengthening of communication among different participants

By utilizing the 3D model and associated process simulation, the VP technology was found to provide an effective and efficient communication platform for the different participants involved, i.e. designers (e.g. P&T), main contractor (China State Construction Engineering Ltd), subcontractors (e.g. Genetron Engineering Co., Ltd), consultants, etc. They used the main model to identify design errors and communicate with each other to solve the problems in real-time. At the same time, the construction process plans were also developed and simulated by the main contractor and subcontractors using the VP technology. Through the visual simulation, they analyzed the feasibility of the construction plans, identified possible problems that could occur and communicated in real-time to solve the problems. Moreover, the application of the VP technology made it possible and practicable to communicate directly with the workers involved – strengthening communication among the different participants in the project in addition to saving a great amount of intermediary time.

7.4 Performance evaluation

In order to evaluate the performance of the IKEA model-based lean construction in the case study project, an interview with the project manager with overall responsibility for the project was conducted. This indicted quite clearly that the implementation of the IKEA model-based lean construction system enabled the project cost (including design and construction) to be reduced by approximately 2.5 million HKD, with a concomitant time reduction of approximately one month.

8 Comparative analysis of the IKEA model and lean construction

As was demonstrated in the case study, the IKEA model has considerable potential for the implementation of the lean construction philosophy. Its feasibility can be further analyzed by comparing the IKEA model and the IKEA model-based lean construction method described and illustrated above.

The operational flows of the IKEA model and lean construction are illustrated in Figures 10 and 11. As can be seen, their flows are very similar - both have concurrent design and construction planning and employ 3D instructions to reduce the middle links (assembly service or instruction of technicians). The only differences are that:

- the assembly of IKEA furniture can be tested in a real environment while the construction process must be tested in a virtual environment; and
- the production process of IKEA already exists while the plan for the production process of a building depends on the essentially bespoke nature of the building design and the planning process has therefore to wait until the building design process is completed.

The virtual environment eliminates these differences. In addition, the virtual environment provides a platform for communication between the different participants.

9 Conclusions

The three main barriers to the implementation of lean construction are identified here as the lack of (1) understanding of the concept, (2) integration of design and construction and (3) efficient communication between different participants involved. In order to overcome these barriers, a modified version of the IKEA model is presented which incorporates the use of VP technology. The main features of this IKEA model-based lean construction approach are its concurrent design and construction process planning, reduction of construction middle links, and enhanced communication between different participants. These are discussed and demonstrated through a real-life case. The operational flows of the IKEA model and lean construction are also compared – indicating the suitability of the IKEA model for construction projects and the implementation of lean construction.

It is shown that the application of the IKEA model has considerable potential to make the lean construction concept clearer and more easily understood. Significantly, considerable improvements in the efficiency of the construction process are also apparent through an enhanced facility to detect design errors and improve constructability. Other opportunities also appear to exist in enhancing the safety of the workers involved by simulation of working conditions and inclusion of further guidance in the 3D instructions provided.

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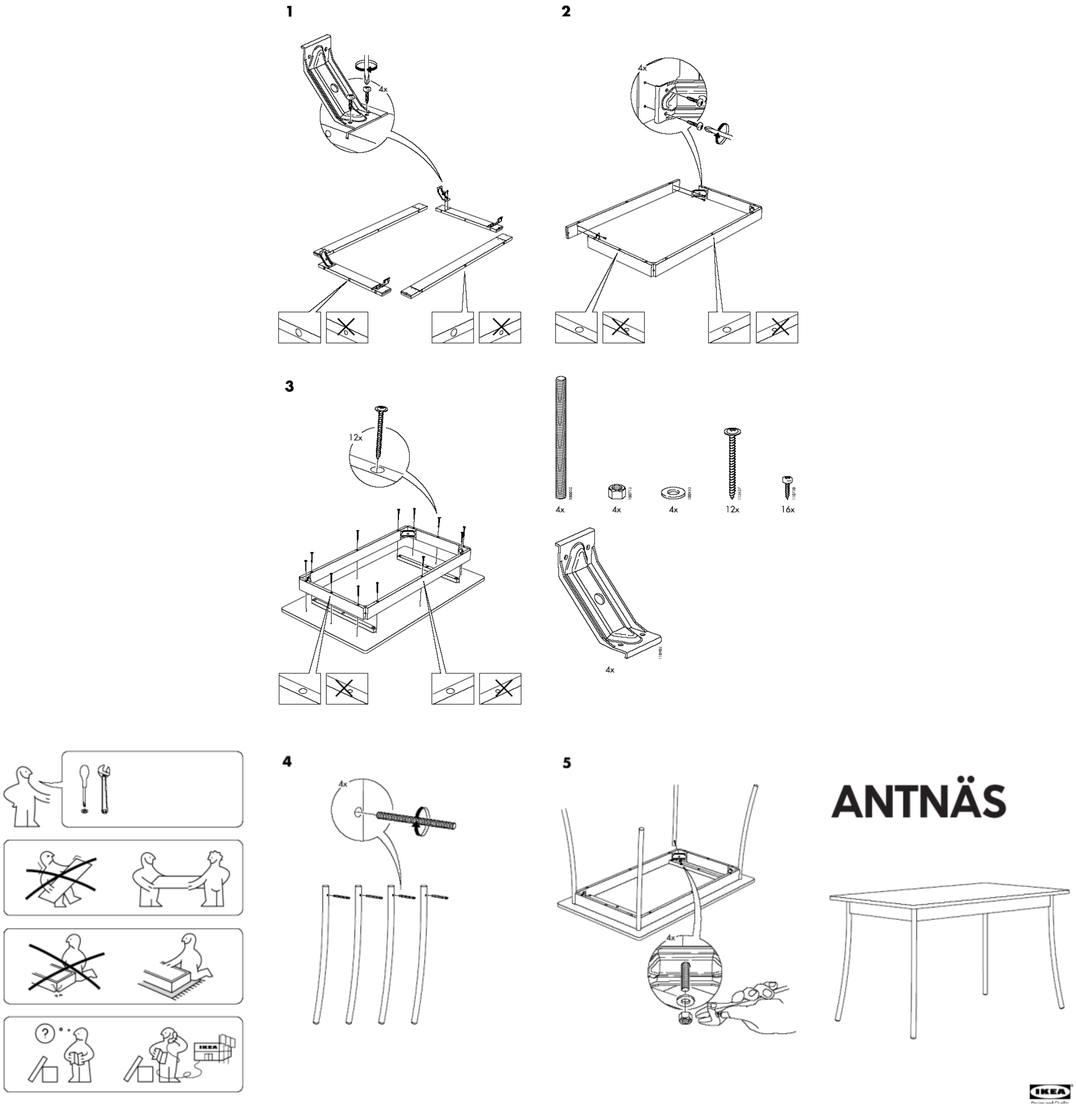

Figure 1: 3D assembly instruction for IKEA home furnishing (dining table)

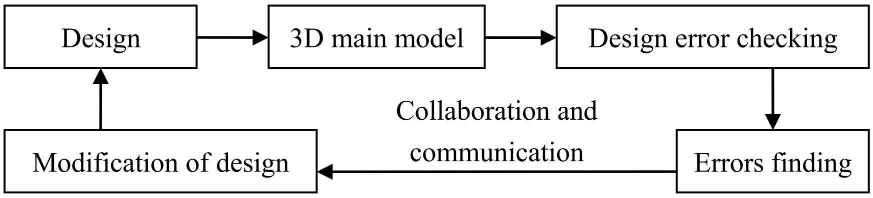

Figure 2: The process of design-modification

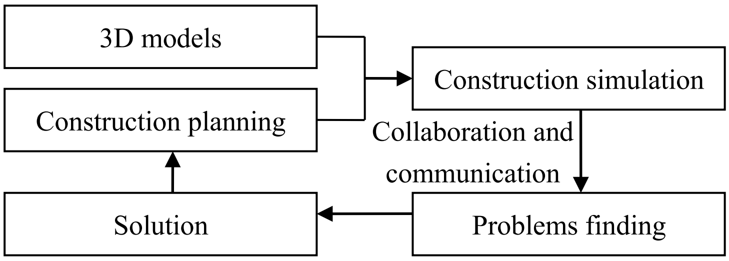

Figure 3: The process of construction planning-simulation

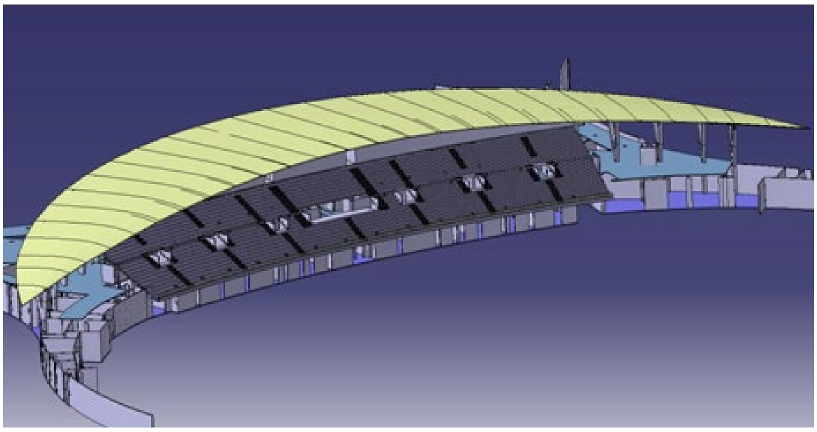

Figure 4: 3D model of the spectator stand

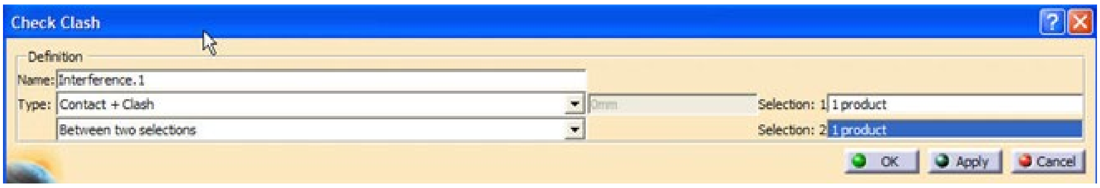

Figure 5: Automatic design error detection

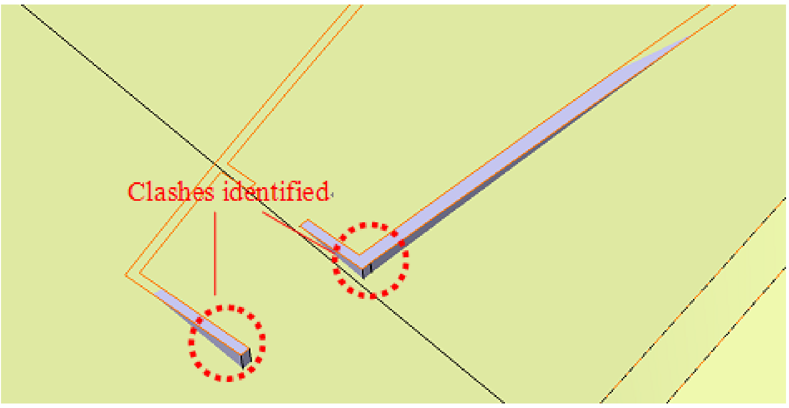

Figure 6: Clashes between the roof and partition walls

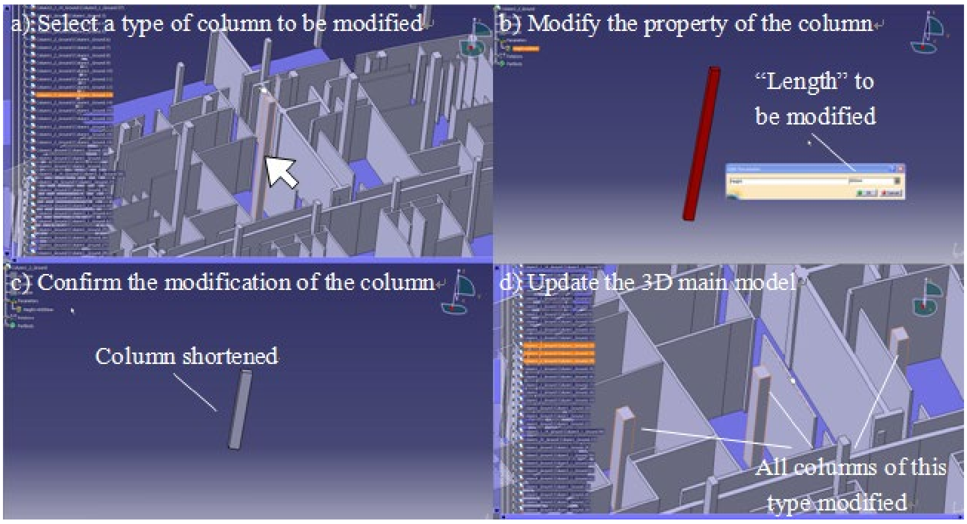

Figure 7: Rapid modification of design errors

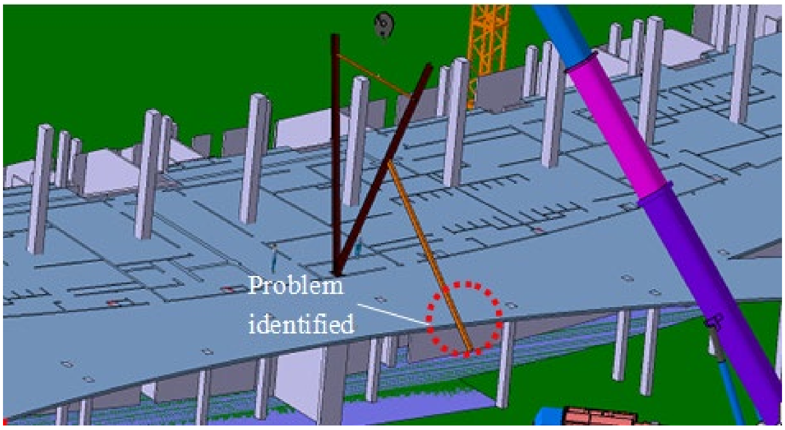

Figure 8: Simulation and analysis of the V-column installation

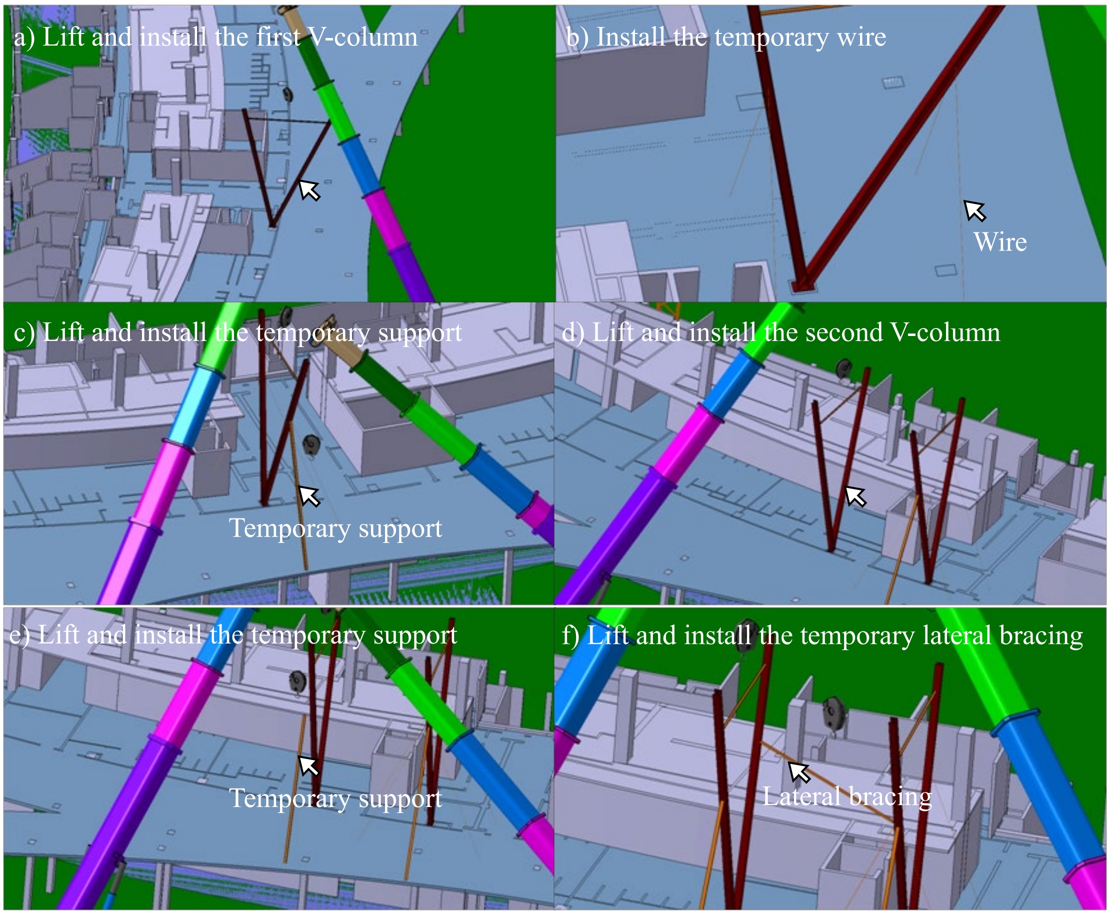

Figure 9: 3D instruction of the V-column installation

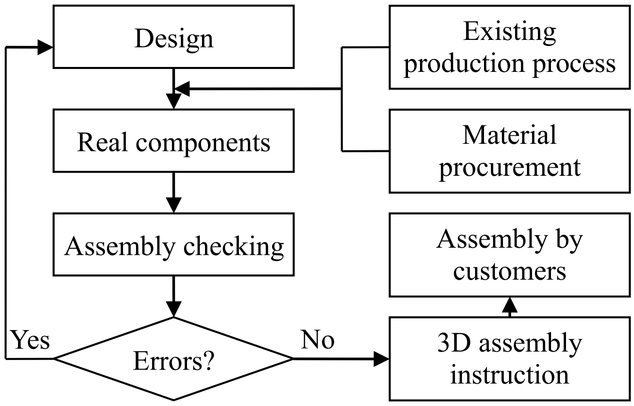

Figure 10: Operational flow of the IKEA model

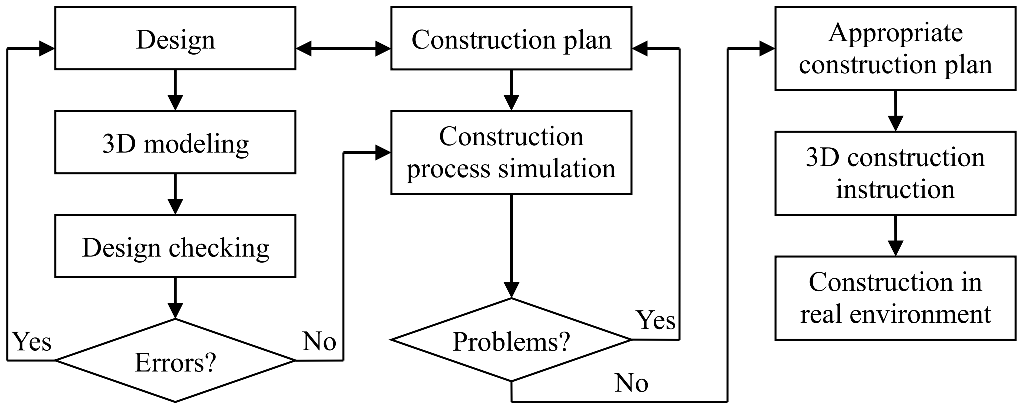

Figure 11: Operational flow of the IKEA model-based lean construction