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AN ANALYSIS OF THE INTEGRATION OF LEAN CONSTRUCTION PRINCIPLES IN THE BIM COORDINATION PROCESS

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Abstract

The concepts of Building Information Modeling (BIM) and Lean construction are increasingly popular and used for the purpose of improving the efficiency of construction projects. The Lean construction approach helps optimize the system, thereby minimizing the waste and increase the maximum amount of value for clients. This is in line with the effectiveness of BIM for the purpose of analyzing, evaluating, and managing projects based on the virtual information model before, during and after construction. The combination of BIM and Lean construction will certainly be the trend of the construction industry in the near future. This paper aims to analyze the integration of Lean construction principles in the BIM coordination process through a specific case study. The project management unit is responsible for managing and evaluating BIM models from consultants and contractors and serves as the project's BIM coordinator.

Keywords: building information modeling; BIM coordination process; Lean construction; Lean principles.

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1. Introduction

The Lean principle is an innovative approach to management based on the lesson learnt from the Toyota production system. This is a very typical example when Toyota has become the world's largest automobile manufacturer in overall sales, with success including increased sales and global market share [1]. This principle focuses on eliminating waste and at the same time creating more value for customers in the process of producing and providing services to an organization [1–3]. This helps to reduce costs, increase profitability, optimize the use of resources, shorten production cycles and respond flexibly to customer requirements. Thus, the scope and organization of Lean practices have moved beyond the boundaries of traditional manufacturing industries, to expand the areas of service delivery, health care, tourism, hospital and especially the construction industry.

The principles of Lean construction methodology are introduced to refine the construction process, to meet the requirements of the owner in more effective ways. Lean construction can be understood from the perspective of the owner, which is what the customer wants and how the requirements can be met. For this method, it needs to be done without wasting resources to ensure additional maximum gain value [3, 4]. Only items that are valuable to the owner will be implemented and all of these steps must be evaluated in a rigorous manner. Lean construction involves the pursuit of integrity, simultaneous and continuous throughout all stages of a construction project such as design, construction, operation, maintenance, renovation, and reconstruction. For a construction company, to reduce

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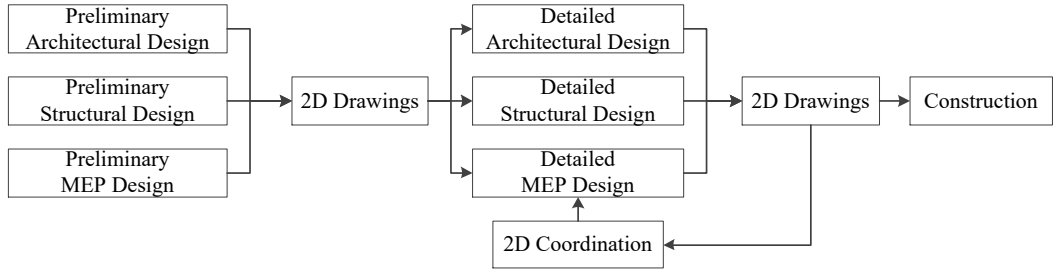
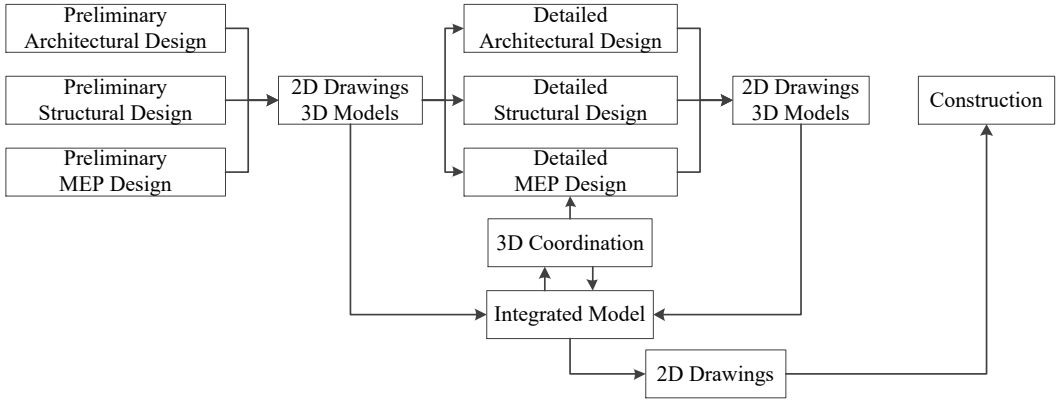
costs without compromising on quality, it is important to consider wasting time on site. Some examples include waiting due to unplanned machinery and equipment, redundant work items, improper handling techniques, lack of clarity lead to rework, the location is too far for material supply, etc. The elimination of such time-wasting activities should be made early from the initial design stage to the project delivery stage. Therefore, the BIM-based approach has been developed, which changed the way we work among project members.

BIM is the process of creating and utilizing the information model throughout the life cycle of a building project. It ensures a continuous process in design and construction, in which the flow of information is conveyed throughout the project participants. BIM not only change the visualization of the project and the way drawings are created but it also significantly changes the process of construction such as requirements from the owner to be collected for the development of future spatial plans; design analysis for many aspects such as energy, structure, cost, constructability; collaboration between project team members on one or more disciplines; fabrication and installation of components from the contractor; operation and maintenance of facilities after construction [5]. Traditional design and construction methods based on 2D drawings lead to fragmented information in the management, coordination, and project delivery. The information flow chart of traditional methodology and BIM is shown in Fig. 1. As a result, BIM is being developed as a platform to enhance coordination among stakeholders in a project to minimize errors and inadequacies throughout the construction process. BIM is considered one of the most effective tools for construction projects towards the lean construction approach.



(a) Traditional methodology



(b) BIM

Figure 1. The information flow chart

Some articles indicate the relationship between BIM and Lean construction [3]; responsibilities of BIM-based project partners [6, 7]; the effects of BIM and Lean construction on design management practices [8]. However, the integration of Lean construction principles in the BIM coordination process is not explicitly mentioned. This paper aims to analyze this issue through a suggested BIM coordination process and apply it to a specific case study during the planning, design and construction phase. In this case, the project management unit plays the role of coordinating BIM and controlling the BIM models from the consultants and contractors.

2. The process of BIM coordination

2.1. Principles of Lean construction

Lean construction is a project delivery system based on reliable workflows through the construction process. Some fundamental principles of Lean construction include [4]: generation of value, removal of waste, focus on process and flow, continuous improvement. Lean thinking defines values from owner's perspectives, thereby understanding the value stream to create the final product. It focuses on minimizing waste that does not create value for the owner such as a waste of materials, increased effort, waste of time as poor communication, decision making, re-design. Standardization of work processes is the most important principle that brings a large and sustainable value chain when referring to Lean construction. A reliable process helps the project to be completed faster than expected. This means that the project will be put into operation sooner without compromising the quality of the works. Having a reliable process minimizes the change in the design and construction process, thus reducing the bidding price and converting it into value for the owner. These processes continue to improve to cope with the change in construction projects.

Some of the tools for doing works in the Lean construction approach include Building Information Modeling, Integrated Project Delivery, Last Planner System, 5S, Kaizen Events. Among these options, BIM has emerged as a viable tool that meets the principles of Lean construction and demonstrates the application of new technologies to a long-standing construction industry. The process is one of four factors that determine the success of adopting BIM for a construction project, besides other factors such as people, technology and policies.

2.2. A suggested BIM coordination process

There are a lot of BIM tools from reputable companies such as Autodesk, Trimble, Graphisoft, Bentley, etc., which help users to create 3D models, deploy drawings, store and share information. However, the absence of a BIM coordination process makes the project stakeholders confused during the implementation of BIM leading to issues such as low efficiency, slow progress of construction, increased investment costs and disturbed personnel. There are some articles related to the BIM process such as developing the frameworks and standard operating procedures of BIM collaboration management special for the general contractor [9]; BIM-based collaborative design platforms [10, 11]. In this paper, a BIM coordination process is suggested (Fig. 2) for the BIM coordinator of the project management unit. Other units such as consultants, contractors, subcontractors must commit to following the process right from the beginning.

A coordination schedule including the scope of the BIM models and deadlines will be agreed between the parties. The clash report template, file naming convention and color code for the BIM models is also shared via a common data environment (CDE) [12]. This is the initial unification in order to facilitate smooth coordination, avoid duplication and loss of data. The separate BIM models

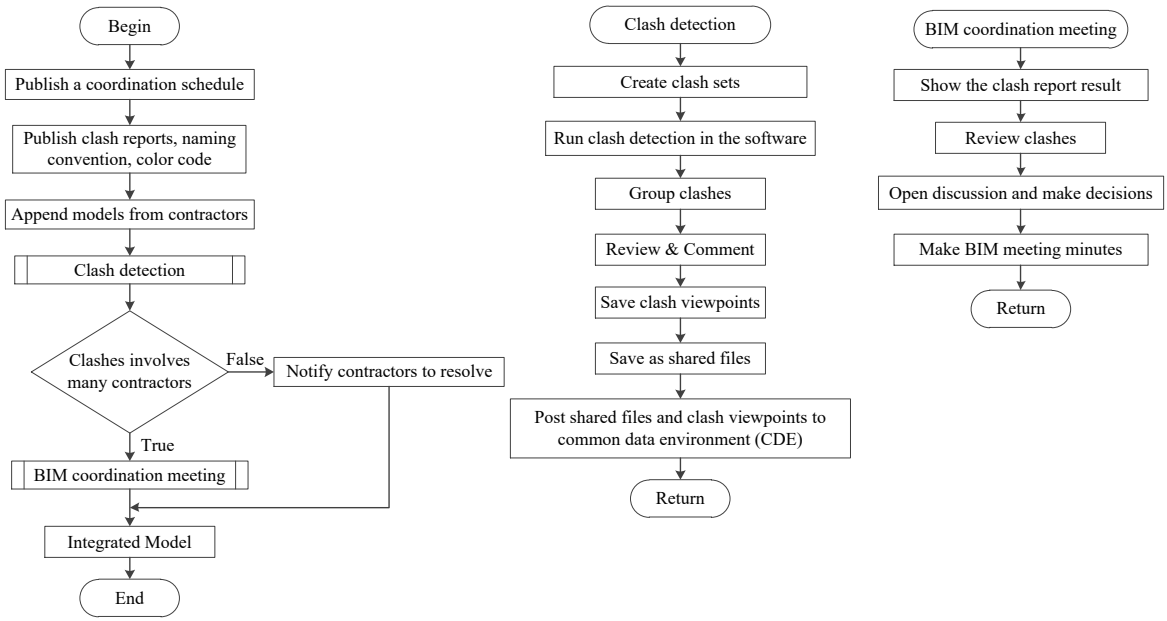


Figure 2. BIM coordination process

for each discipline are provided by contractors or consultants is requested to be submitted to the BIM coordinator on time. The suggested process for creating these separate models is shown in Fig. 3. After receiving the model files, the BIM coordinator will append the models and perform clash detection process. The types of clashes to be considered include hard clashes (objects cross each other), soft clashes (without the guarantee of clearance distance), and clashes over progress. The BIM coordinator will request a BIM coordination meeting to resolve the issue when significant conflicts are identified involving many contractors.

Some specialized software that helps run clash detection such as Autodesk Navisworks, Solibri, Adoddle cBIM, etc. However, it is important to filter and prioritize critical issues, while ignoring minor clashes that can be addressed at the site. Clash images and shared files will be posted to the CDE to help other parties update information, capture changes as quickly as possible, and also serve as data for BIM meetings. At each BIM coordination meeting, the BIM coordinator and the parties will discuss the issues to evaluate the design and find the optimal solution and the BIM model is used as a connection between the parties. Finally, the responsibility for handling the problem will be clearly indicated for each consultant or contractor involved.

3. Analysis of the integration through a case study

This is a complex building developed based on the principles of lean construction using BIM in the design and construction phase. The building is located at 174 Thai Ha street, Dong Da district, Hanoi, Vietnam with a scale of 13 stories & 3 basements and a gross floor area of 10000 m^2. This project was assigned to BIM from the project management unit at an early stage. Based on the actual capacity of design consultants and contractors, the BIM objective for this project mainly focuses on two main solutions including Design Authoring and 3D Coordination [13] and is based on the suggested process. Design Authoring uses the BIM model to visualize, develop and understand the design of the project. 3D Coordination uses manual checks or clash detection software when coordinating

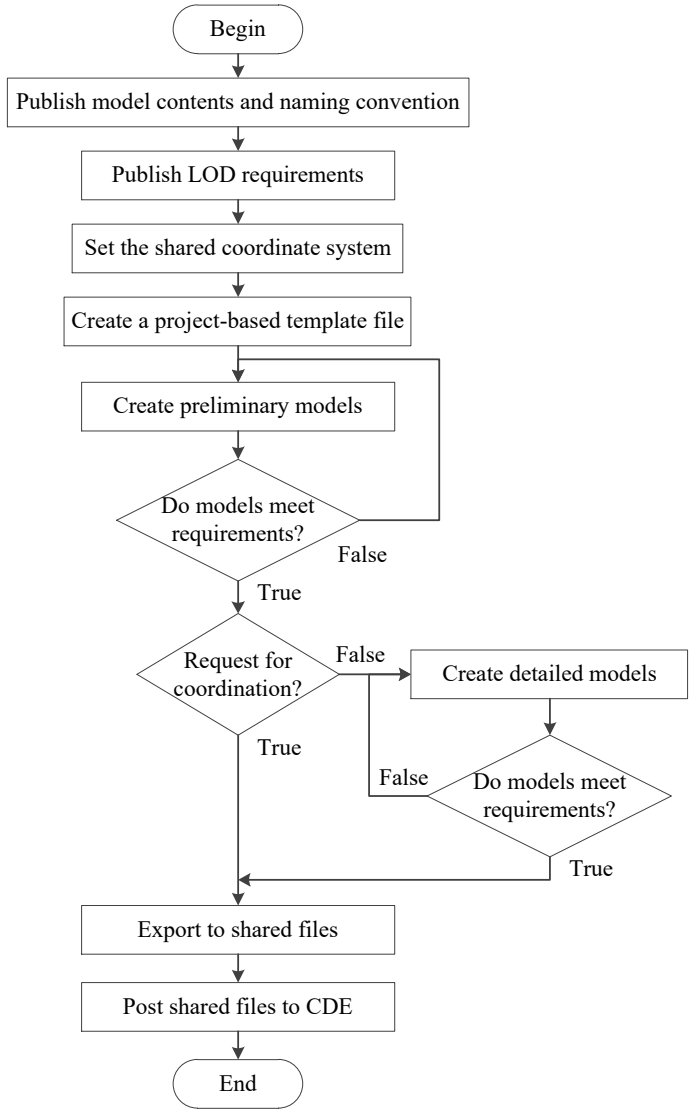


Figure 3. BIM modeling process for consultants and contractors

various disciplines with the purpose of pointing out critical conflicts. Through this coordination process, a fully integrated BIM model from disciplines is created at an earlier stage, and the owner can adjust the requirements, limits, and progress of the project in a timely. As a result, the owner can realize greater returns from investment through integrated design that increases the value of project information in each phase and increases the efficiency of the project team.

In this case study, Autodesk BIM 360 Docs application is used to exchange, share and store information for the entire project. It is considered as a CDE with functions like store information in a cloud platform with high security and accessible at any location and time; access permission to information for the company and project members; allows quick search of data; track and compare revisions to keep up to date with the latest information; view 2D and 3D data files directly on the cloud platform; comments and markup tools, issues, and submissions creation, data extraction to ex-

change information among project participants [12, 14]. BIM models as a shared data source for the purpose of discussing design issues, constructability assessments, and as well as safe and effective construction measures. During the BIM coordination, some software has been used such as Autodesk Revit, Navisworks Manage to help coordinators and contractors detect conflicts and quickly extract viewpoints. All 3D models from various disciplines for the BIM coordination meeting are shown in Fig. 4.

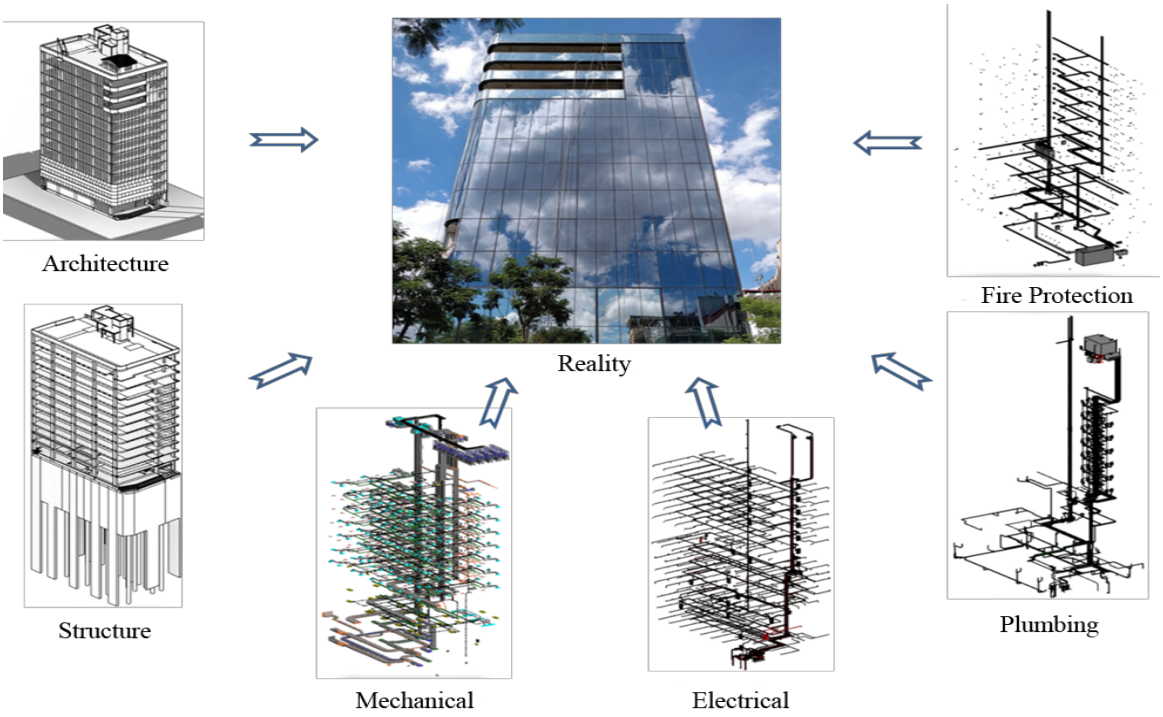


Figure 4. 3D models for the BIM coordination meeting

A clash report template is created by the BIM coordinator, which facilitates smooth coordination and ensure accountability between contractors involved. Some conflicts and locations that do not guarantee the clearance height such as the basement or ramp are shown in Fig. 5.

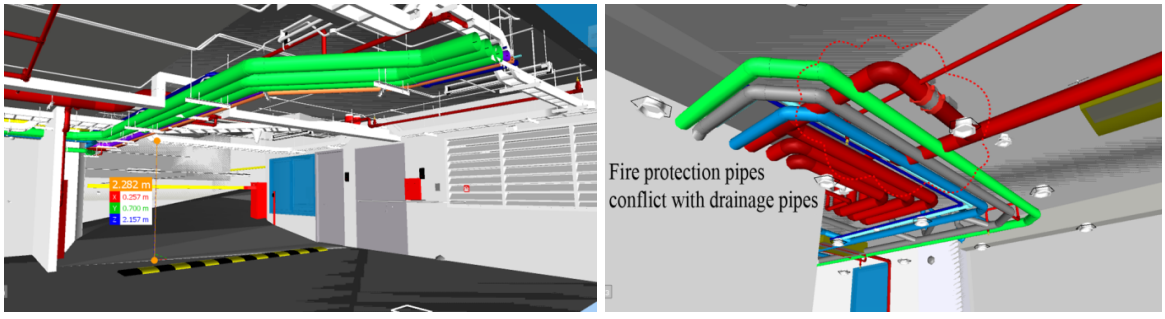


Figure 5. Some design errors in the BIM model

After combining 3D models, handling conflicts, and simultaneously detecting design errors, the creation of construction drawings and quantity take-offs are carried out. This new approach helps

avoid unpredictable errors that lead to time and costs incurred at the site, thereby increasing value for the owner. The effectiveness of using the BIM coordination process for this case study during the planning, design and construction phase to achieve lean construction principles is shown in Table 1. BIM promises to be more effective for further stages such as finishing, handover, operation, renovation, and demolition.

Table 1. The effectiveness of using the BIM coordination process

Stage	The effectiveness	Lean construction principles
Planning	Choosing investment plans and making capital plans. Assess the return on investment of the project. Spatial planning.	Generation of value.
Design	Rapid assessment of design options through 3D models. Assess the suitability of the design with owner's requirements. Analyze and predict the performance of the building to minimize energy consumption, towards sustainable design. Design coordination across disciplines through integrated BIM models. Detect conflicts and design errors based on 3D models prior to construction. Supports 2D drawing deployment. Management units, contractors, suppliers can participate from an early stage to create intent 3D models.	Generation of value. Removal of waste. Focus on process and flow. Continuous improvement.
Construction	Automatically connect to create components. Strengthen cooperation and communication between contractors. Estimate the volume and cost accurately. Connect with technology devices to exchange and update information between the design office and off-site. Integration with partner databases.	

4. Conclusions

In this paper, an analysis of the effectiveness of using the BIM coordination process during the planning, design and construction phase is addressed to achieve lean construction principles. These basic principles including generation of value, removal of waste, focus on process and flow, continuous improvement and are considered as project criteria. Through the BIM coordination process, a fully integrated BIM model is created from stakeholders and used right from the early stage. This helps to overcome the major design errors in the construction project and brings clear benefits to owners. The application of this process is suitable for projects with complex engineering systems

that really need 3D coordination. Finally, it is necessary to clarify the responsibility for BIM models according to project progress, avoiding the disadvantages to the overall BIM coordination.

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