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Use of BIM with Modular Construction in Future Construction Techniques

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ABSTRACT

Modular construction technology and applications are rapidly evolving. Modular construction is a process in which entire rooms or sections of rooms are built in a factory setting along with electrical, mechanical, and plumbing work and then transported to a final site for assembly. With modular construction, a building is built off-site, under controlled facility conditions, with the same materials and to the same codes and standards as conventionally built facilities, but in half the time. The modular construction method is used to build various types of buildings (whether they are apartment houses, office buildings, or hotels). This construction method is used for both permanent and relocatable projects. These projects can be built with two types of modules. These are 2D panels or 3D modules. These can be combined to form a third type, hybrid modular construction. Each has its advantages. 2D panels offer easy logistics and flexibility in building design and are mounted on site. Factory productivity is increased by using 3D volumetric solutions. They only need to be installed once they are delivered. The hybrid modular structure has the advantages of the previous two.

With the recent development of Building Information Modeling (BIM), the use of modular construction methods in conjunction with BIM becomes more common. As with any method, this one has advantages as well as disadvantages. Disadvantages of this method, such as a higher number of complex decisions, front-loaded design, etc., can be solved with BIM. Furthermore, the BIM platform can resolve the disadvantages of traditional construction methods, such as the difficulty of pre-project planning and coordination among members of interdisciplinary professions. With BIM and the modular construction method, physical conflicts between the structural system and its mechanical, electrical, and plumbing systems can be easily identified early in the design process, and resolution can be expedited. This article includes general information about the modular construction method, future application scenarios, use, and advantages of BIM. The document analysis method, one of the qualitative methods, was used, and in the light of the data obtained, comments and scenarios were tried to be created about the future of BIM and modular construction techniques. What distinguishes this study is that the concept of quality is examined in detail by using these two methods together.

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1. Introduction

The Industrial Revolution occurred between the 1750s and 1850s saw major and significant changes in art, design, and architecture. Design requirements have changed as a result of industrialization. Due to the uniqueness of the construction industry, it presents several challenges for the direct adaptation of technologies used in many other industries. However, the motivation to industrialize the construction process comes from reducing construction costs and time, improving building quality, and producing more energy-efficient buildings. Modular construction systems that provide these benefits have advanced as the industrial revolution ushered in the modern era. Therefore, the modular construction method creates a methodology for design, drawing, and production automation.

2. Background

2.1 Modular Construction Manufacturing (MCM)

Modular systems, also known as cells, are the most industrialized prefabricated construction systems, with all or most of the building's components produced in the factory and only assembled on the construction site. Modular building units have been used since the nineteenth century. A carpenter in London wanted to build a prefabricated structure to aid his final migration to Australia. He built the first prefabricated house in 1837 [7]. Despite the fact that the modular construction concept has been around for over 100 years, the opportunities for modular construction were largely untapped until the revival of modular solutions like modular apartment buildings, modular hotels, modular classrooms, and modular office buildings. Since then, modular construction has advanced significantly, and much more sustainable, long-lasting methods are now used. Modular construction manufacturing (MCM) is a process in which building units are manufactured in a factory and shipped to the construction site for assembly. This systematic methodology covers the entire construction process of a project, from the initial design stage to final delivery. Modular construction involves the use of prefabricated units known as modules, which are then transported to the construction site. The modular construction method complies with the same building codes, raw materials, and standards as traditional construction projects. Modular construction materials that are commonly used include concrete, fsteel, and wood. The modular construction process consists of specific steps (Figure 1). First, modules are built off-site under factory conditions. Typically, modules for construction projects are fully equipped with all electrical, plumbing, heating, and interior trims. The modules are then delivered to the site by a truck. Modules are placed on the site. They can be attached side-by-side or end-to-end, and they can be linked together to form multiple floors to create buildings of any scale or layout. Because modular structures are used in modular construction work, they can be used for almost any temporary or permanent, large or small application, from site huts to cutting-edge operating theaters.

There are different types of modular buildings. Permanent Modular Construction (PMC) prefabricates single or multi-story buildings in deliverable modules off-site. Unlike projects that only use site-built construction, integrating PMC modules improves quality control and reduces waste. Permanent modular structures are also ideal for mixed-use applications. A relocatable building (RB) is constructed using a modular construction process and is partially or completely assembled for reuse and transportation to different construction sites. Furthermore, the versatility of an RB makes it an excellent choice for emergency and natural disaster relief services.

Relocatable modular buildings are ideal for on-site offices, medical clinics, sales centers, restroom facilities, schools, and other similar applications.

Aside from the types mentioned, a thorough examination of modular construction identifies additional categories based on the modular construction method. Closed modular construction (3D Modules) entails off-site design, development, and construction of entire rooms, including electrical wiring, plumbing, and HVAC. This prefabrication process, before delivering the completed module to the job site, installs and "closes up" all components in the manufacturing facility. Because building components can be expanded, downsized, relocated, and visually inspected on the job site while maintaining quality and engineering integrity, open modular construction (two-dimensional modules) adds versatility and simplifies the inspection process.

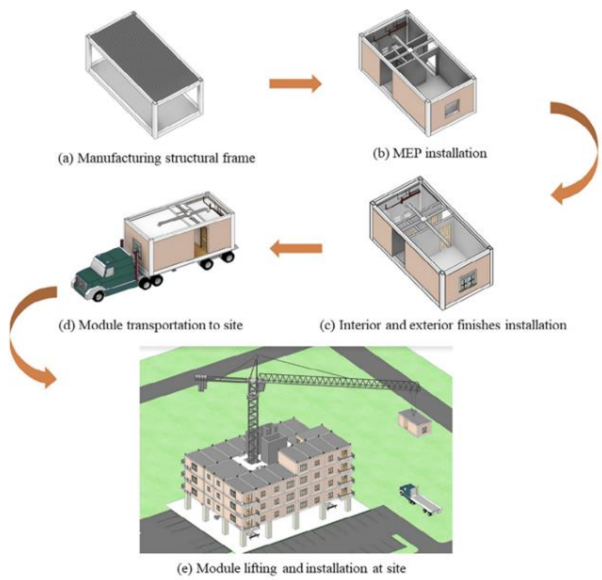

Figure 1: Modular construction – from manufacturing to site installation [7]

3. Materials and methods

3.1 Automation with BIM in Modular Construction

The first pillar of the industrialization or modularization of the building construction process is the automation of the design and drawing process. Managing the design and drawing process is an important issue in the architect/engineer/contractor (AEC) industry [5]. Automating the design and drawing process reduces unnecessary design activities, provides an infinite number of solutions, eliminates assumptions and design errors, and shortens the time required for any change.

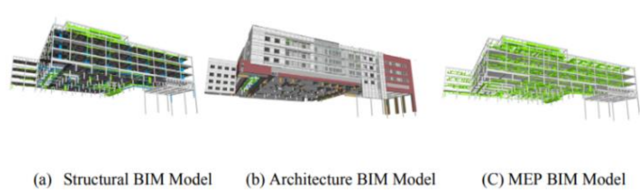

Figure 2: BIM Models in Healthcare Expansion Project [8]

Automation through modularization will have significant benefits for the construction industry, with benefits such as reducing overall project schedules, improving product quality, increasing on-site safety performance, reducing the need for skilled workers on-site, and decreasing in the negative environmental impact of construction operations [8]. One of the most difficult tasks faced in the modular construction delivery process has always been the coordination and manufacture of mechanical, electrical, and plumbing (MEP) systems. Three main factors contribute to the challenges of modular MEP fabrication. To begin with, the process is pretty split between design and construction firms. Second, the level of technology used in the various coordination scenarios varies widely between engineers and building contractors. Third, the process is to provide a model for private contractors' prefabrication plans [6]. The use of Building Information Modeling (BIM) for coordinating, documenting, fabricating, designing, and drawing MEP systems in modular structures seems to be a viable solution to these problems.

3.2 Building Information Modeling (BIM) Application in Construction

BIM is commonly defined as the process of developing an intelligent and computable three-dimensional (3D) data set and sharing it with the various types of professionals on the design and construction team. BIM technology creates an accurate virtual model of a building with precise geometry and relevant data to support procurement, fabrication, and on-site installation activities. To support automated production operations in factory settings, industrialization of the building construction process requires special methods of manufacturing and specific design criteria. Therefore, integration of the Building Information Model (BIM) with modular construction is required to support the manufacturer's needs for design and drafting in construction. The multidisciplinary nature of modular construction manufacturing makes BIM the right technology for the construction industry. BIM provides a core model loaded with project data that facilitates the data transfer process between different project stakeholders. The implementation of BIM systems in modular structures includes visualization of the designed structure; modeling; code reviews; manufacturing/factory drawings; communication; cost estimation; construction sequences; 4D model (3D models + timing information); conflict, interference, and collision detection processes; 5D BIM (cost estimation) [7]. Through this single information platform, BIM fosters collaboration between the design team, consultant, builders, and customers. It is aimed to achieve optimum efficiency and quality in the construction industry by using the technology of BIM to integrate architectural and structural design and modularity concepts into a model.

Despite the fact that modular building technologies offer significant benefits to the construction industry, the current construction delivery model does not support them due to the extensive project planning and MEP coordination required (Figure 2). With more BIM integration in construction projects, incorporating modular building technologies into projects becomes more effective and desirable because the entire planning, design, shop drawing development, manufacturing, and construction process can be streamlined. Physical conflicts between the structure and mechanical, electrical, and plumbing systems can be easily identified early in the design process and resolved.

It is predicted that optimum efficiency and quality will be achieved in the construction industry when the concepts of architecture, structural design, and modularity are integrated into a model using BIM technology.

4. Results and discussion

4.1 The Quality Provided by The Combination of BIM and Modular Construction

Construction product quality can be defined as the extent to which the needs expressed or implied during the construction process are guaranteed. Examples such as schedule performance, construction costs, and project completion on time are also included in the definition of quality. Technological advances are critical to improving the quality of a product in terms of its function. Modular construction is a method that architects and clients can use to improve the quality of their buildings, especially when used in conjunction with BIM. The PDCA circle in Figure 3 shows how the modular construction technique and BIM can improve quality when used effectively.

With modular construction method, the quality of the buildings will be much higher because the elements of the modules will be built to the desired size and shape, which will aid in meeting the quality standards. Moreover, the controlled environment of a manufacturing plant will lend itself to more thorough quality testing and traceability of components that enable the team to correct problems before the unit or system arrives at the work site. Also, BIM improves the quality and interoperability of design information. The use of BIM modeling services in modular construction increases the use of prefabricated modules while also resolving all potential issues during the design stage, saving time and money and improving project quality. By using BIM, thinking ahead of how the prefabricated product to be produced will look, how it will behave, or what kind of construction process it will go through will affect the quality of the construction. It can be integrated into the modular construction system of BIM at certain stages. For each phase of manufacturing, studies on the performance of the BIM library, system development for supporting BIM design, and the applicability of BIM for quantity take-off can be conducted using BIM. Creating virtual and simulation environments that support the design and assembly of prefabricated components and allow construction to be simulated can become standard practice. Production management for off-site production, process simulation for process management, and studies to reduce production errors can all be done using BIM. In the production process of modular elements, clash detection and resolution in 3D models can be achieved with BIM. Finally, for the on-site construction phase, BIM can be used for lifting and on-site construction planning by visualizing lifting equipment. In addition, at all stages, studies to define the BIM implementation process and tasks can be conducted for improve product quality.

Through the use of BIM, controlled off-site production and 5D BIM cost estimation (modelling scheduling information to model construction sequences and adding financial cost) reduce costs. The modular structure integrated with 4D BIM (modelling scheduling information to model construction sequences) improves program performance. Detailed model-based shop drawings improve fabrication and construction quality. Resolving conflicts in the pre-construction phase saves rework, cost, and time. It improves site safety with modular building elements, 3D BIM visualization, and accurate drawing sets. Integrating BIM into the process makes modular construction workflows more beneficial and successful, with higher margins and higher product quality. Construction efficiency is increased by standardizing prefabricated modules with an integrated BIM repository and 3D visualization of relevant information.

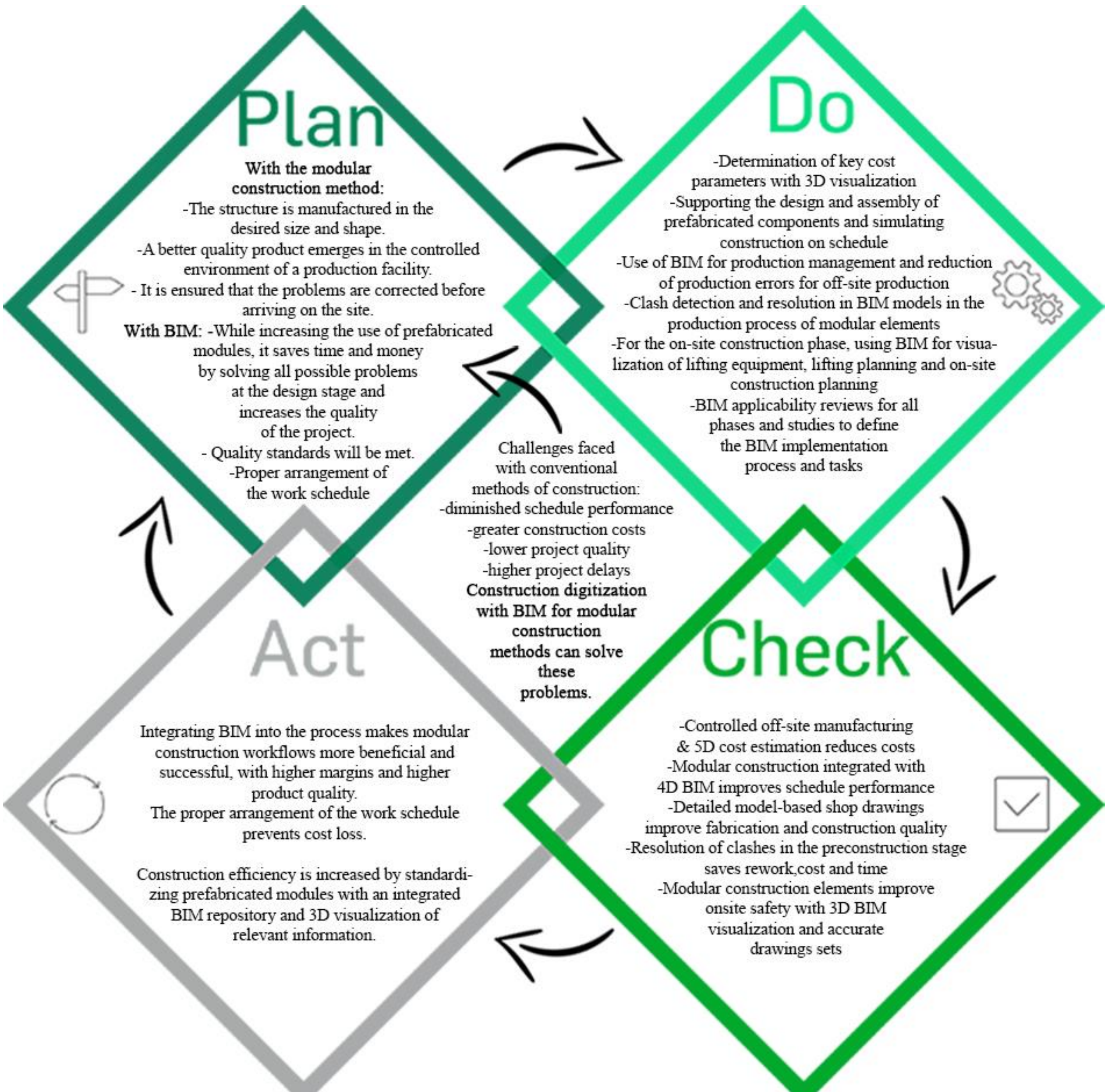

Figure 3: PDCA cycle* for the quality provided by the combination of BIM and modular construction (Prepared by Authors) *PDCA cycle is a management methodology that aims to continuously improve processes. The stages of this cycle are as follows: plan, do, check, and act.

4.2 Distinctions from Previous Studies

This study distinguishes itself from previous research in two key ways. Firstly, it goes beyond simply exploring the impact of the combined use of modular construction and BIM on quality. Instead, it implements the PDCA method as a comprehensive framework to systematically plan, execute, evaluate, and continuously improve the entire construction process. This iterative approach ensures that quality is not only measured but actively enhanced through ongoing refinement and adaptation.

Secondly, while existing literature may offer isolated studies on individual aspects of modular construction, BIM, or their combined impact on quality, this study bridges the gap by incorporating the PDCA method into the evaluation. This structured approach provides a rigorous and transparent framework for assessing and improving quality throughout the project lifecycle, setting it apart from less systematic investigations.

4.3 Recent Research and Research Gaps

While the literature lacks comprehensive comparative analyses, this study incorporates the PDCA method into the evaluation, providing a structured approach to assess and improve quality. Limited studies delve deeply into the impact of the combined use of modular construction and BIM on quality. The use of BIM has the potential to significantly improve the quality of construction projects.

6. Conclusion

Building information modeling (BIM) and modular construction are acknowledged as important technologies for resolving the current crisis in the construction sector. BIM and modular technology have a close relationship and can be used in conjunction to increase construction quality. BIM and modular building have been recommended as essential components of technology to advance the construction sector. Considering the quality-enhancing effect in the construction industry, the modular construction system and the use of BIM in modular construction are suggested as a future construction method. Consequently, it is advised that BIM and a modular approach be combined to raise the standard of the construction industry.

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