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Process, productivity, and economic analyses of BIM–based multi-trade prefabrication—A case study

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ABSTRACT

Previous studies yielded contradicting results regarding the benefits of multi-trade prefabrication (MTP) based on building information modeling (BIM). This study investigates the causes of the contradicting results by analyzing the process, productivity, and economic benefits of BIM-based MTP through a case study. The process analysis results indicate that coordinating mechanical, electrical, and plumbing (MEP) systems took longer in MTP than in the conventional method because of the newly added offsite coordination activities. Nevertheless, the overall project duration was reduced because of the parallel execution of MTP and concrete work. The productivity analysis shows that the newly added MTP activities also increased person-hours. However, as the assembly process was repeated, the required person-hours decreased by 40% from that of the initial stage because of the learning effect. The case study revealed that the management of coordination activities and the selection of projects were critical for the successful implementation of BIM-based MTP.

1. Introduction

Prefabrication, which was first introduced in the manufacturing industry (e.g., the automobile industry), is being increasingly applied in construction projects [4]. Compared with conventional onsite fabrication, prefabrication is reported to shorten the overall project schedule, improve product quality, increase onsite safety, and reduce the need for skilled onsite workers, waste, and carbon emissions [23,33,46,49]. Conversely, prefabrication also has the potential to increase the overall project duration and cost due to high production, transportation, and installation time and costs [2] and difficulties in implementation, particularly when prefabrication details are not reflected in the design or workers are unfamiliar with the prefabrication processes [27].

Advances in design and construction technologies, such as building information modeling (BIM), design for manufacture and assembly (DfMA), and laser scanning, can help overcome the aforementioned drawbacks [4,18]. For example, BIM can be used to efficiently detail each building trade [25] and detect and correct the interferences between trades to obtain precise and fully coordinated geometric models. Such BIM environments improve the applicability of prefabrication to construction projects [48]. Furthermore, these technological developments support the expansion of prefabrication from single-trade prefabrication (e.g., curtain walls, precast concrete, and prefabricated pipes) to multi-trade prefabrication (MTP), wherein various trades must be coordinated in the same space [15].

Yet, some studies have expressed concerns regarding the practicability of MTP in the construction industry [8,24,27] and claimed that prefabrication is not economically effective despite the shortened project durations [2,13,45]. The present study investigates the causes that resulted in the contradicting views of previous studies on the benefits of MTP in BIM projects. Several previous studies discussed the potential economic benefits of prefabrication but only on a high level (i.e., final reduction values or perceived savings) [7,17,27,28]. This study conducts detailed process, productivity, and economic analyses of a case project of multi-trade corridor racks in an exhibition complex.

The rest of this paper is organized as follows: Section 2 reviews the current literature on prefabrication in the construction industry and highlights relevant issues; Section 3 describes the research methodology; Section 4 introduces the case project; Sections 5 to 7 report the results of the process, productivity, and economic analyses, respectively; and Section 8 summarizes the study's findings and limitations, presents the industry implications of the results, and discusses the scope for future work.

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2. Literature review

Prefabrication was initially applied in the construction industry to reduce cycle time and costs and improve construction quality [46] and recently to reduce waste and carbon emissions [23,49]. Prefabrication technologies are applied in various contexts to meet different objectives. For example, as housing demand exceeds supply in the UK, prefabrication has been increasingly used since the 1990s to improve construction speed [33]. The prefabrication technology was also applied in the Graves Avenue Bridge renewal project in Florida, in the US to minimize bridge downtime [9]. Meanwhile, the Morgantown Coal Unloader Pier construction project in Maryland (US) adopted prefabrication to reduce worker exposure to cold temperatures outside and improve productivity, which decreased the project duration [37]. Similarly, a plant construction project deployed prefabrication during the engineering and fabrication phases to improve productivity through design standardization, modularization, and recycling [31].

Prefabrication technologies for various trades have gradually advanced. With the development of prefabricated housing frames in the 1620s [3], the prefabrication for housing buildings is among the earliest and most explored technologies [6]. The main prefabricated elements in these early structures, which were not as extensively prefabricated as the current structures, were timber frames and complex joints [38]. The costs of timber and plywood increased, and with the increasing acceptance of concrete as a building material, precast concrete work were attempted in the 1850s [12]. With various reinforcement technologies, precast concrete is currently used to manufacture linear and curved members [41].

Conventional prefabrication technologies focus on single-trade prefabrication, such as precast concrete products, facade panels, and window frames. However, the demand for MTP, wherein various trades must be coordinated in the same space, is rapidly growing [15,17,27]. Bathroom pods (Fig. 1), which are commonly known as unit bathrooms, or UBRs in Asia, are among the oldest and most well-known examples of MTP that include MEP, tiling, interior finishing, and door installation. These bathroom pods were introduced in the 1960s when Korea and Japan were striving for economic revitalization. They have been widely implemented in apartment units and hotels since the 1980s [11].

Modern buildings tend to have heavy MEP systems [27], for which contractors tend to use prefabrication [40,47]. MTP has recently been applied to MEP corridor racks with complex MEP components (Fig. 2)—the coordination, manufacturing, and assembly of which are much more challenging than those of relatively simpler MTP components (e.g., bathroom pods) because of the higher MEP density.

BIM-based DfMA, coordination, and laser scanning technologies help overcome some of the complex coordination, manufacturing, and assembly issues. For example, the BIM-enhanced prefabrication of precast concrete and structural elements through the automation of detailing and the utilization of computer numerical control machines [5,14,39] has facilitated the prefabrication of complex structures, including irregular facade panels and MEP systems [22,26]. A BIM-based design process and a model view definition for prefabricated buildings were also specified [36,42]. In addition, the use of the Internet of Things in prefabrication is being explored to improve data exchange and communication during prefabrication and assembly [43,52]. As a result, the adoption of prefabrication has been recently accelerated [1,4,18,50].

Despite many successful cases of BIM-based MTP [1,4,18,50], several studies have expressed concerns about the effectiveness of prefabrication [8,21,24]. A survey conducted by Goodier and Gibb [8] identified the cost increase as the main barrier to the adoption of prefabrication in the UK. Lu [24] reports that the top three challenges in prefabrication in the US are the inability to make changes onsite, transportation constraints, and limited design options. Lawson et al. [21] argued that MTP increases onsite risks if the geometric differences between the prefabricated components and the structural frames of the building are not controlled.

Several industry reports have analyzed the economic impact of MTP and have also revealed contradicting results. Among the industry reports, the most documented are the Miami Valley Hospital project by Skanska US, wherein MTP was applied to corridor racks and bathroom pods [7,20], and the Saint Joseph Heritage project by Mortenson

Fig. 1. Bathroom pod (UBR) (photographed by Sejun Jang).