



Modular Construction vs. Traditional Construction: Advantages and Limitations: A Comparative Study

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Abstract

Modular construction is a novel technique that has several advantages over traditional construction methods; however, along with the benefits, there are limitations that make it challenging. Various aspects of modular construction need to be studied in-depth to improve the construction process, and the aim of this study was to accomplish that by investigating its advantages and limitations and comparing them with traditional construction. The advantages were identified through a thorough literature review, and were classified into five categories: project schedule, project cost, labor safety, project quality and productivity, and environmental. The limitations were also investigated through the existing literature and classified into five categories: project planning, transportation, public and expert acceptance, establishment cost and cost due to complexity, and coordination. The results revealed that the advantages of modular construction outnumber its limitations; however, further technological development and research would lessen or mitigate the challenges. The results of this study highlight the main benefits and challenges associated with modular construction and will help project stakeholders choose between this method and conventional construction methods for their projects.

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1. Introduction

The Construction Industry Institute (CII) [2] defines modular construction as *"the use of offsite construction (including a segregated area onsite) and includes all work that represents substantial offsite construction and assembly of components and areas of the finished project."* Implementation of modular construction has notably increased throughout the past several decades [1]. Projects improve in several areas, such as cost, schedule, safety, etc. when this method is properly utilized. The experts broadly accept that modularization will lead to significantly enhanced productivity in the construction industry in the next 20 years [3]; nonetheless, several challenges and barriers to proper implementation limit its use in some cases [4].

During the past few decades, researchers have studied different aspects of modular construction. Pasquire and Gibb [5] studied the advantages and challenges of off-site production of construction components and revealed that experience plays the most important role in deciding whether to use modular or traditional construction. Song et al. [6] developed a tool with which the decision makers could evaluate the feasibility of modularization in their projects. Choi [7] investigated the relationship between the factors that may impact the success of a modular construction project and the project productivity and indicated that there

is a reasonable correlation between them. O'Connor et al. [8] revealed that when a construction project has a time constraint, modularization can be a useful method for completing the project in the allotted time. The most important challenges pertained to delays in the assembly of the components, overproduction, and long lead times.

Despite the fact that several researches have focused on different aspects of modular construction, few studies have compared the characteristics of traditional and modular construction to provide a guideline for deciding which method is best for a specific project. This study aims to identify the advantages and disadvantages of modular construction and compare them with those of traditional construction in a descriptive manner. The outputs of this research point will assist stakeholders in whether to use traditional or modular construction methods for a project.

2. Methodology

Relevant documents of different types were collected from the existing literature. The documents were obtained from four main databases: Google Scholar, ResearchGate, Scopus, and Science Direct. Keywords such as modularization, modular homes, modular vs traditional, prefab construction, off-site manufacturing, and others were used to explore various search engines. The content of the collected documents was analyzed with regard to title of the journal, nature of the study, year of research, need for modular construction, identification of factors contributing to the project success/failure, and data collection practices. The advantages associated with the implementation of the modular method of construction were identified and classified into categories of project schedule, project cost, labor safety, project quality and productivity, and environmental. The limitations of modularization in construction were identified and classified into categories of project planning, transportation, public and expert acceptance, establishment cost and cost due to complexity, and coordination.

3. Content analysis

The content of the documents used in this study was analyzed according to (1) title of the journal, (2) data collection practices, (3) research objectives, (4) year of research, and (5) need for modular construction. In the following, all of the content analysis stages are described.

3.1. Title of the journal

Over 80 journal articles, conference papers, dissertations, and research reports were examined. Approximately 50% of the documents were journal articles, followed by conference papers, guidebooks, dissertations, and project reports. Table 1 shows the list of journals and the number of collected articles from each.

Table 1. List of journals and the number of collected articles from each

Journal Title	Frequency	Percentage
Journal of Construction Engineering and Management	8	12
Journal of Cleaner Production	3	5
Journal of Management in Engineering	3	5
Project Management Journal	3	5
Journal of Engineering, Design and Technology.	3	5
Automation in Construction	2	3
Procedia Engineering	2	3
Journal of Injury Control and Safety Promotion	2	3
Journal of Architectural Engineering	2	3
Other Journals and papers	34	55
Total	62	100

*Distribution of studied literature based on data collection method
 (Combination means that the paper has used more than one methodology for writing. For example,
 Interview and questionnaire, literature review and case study, etc.)*

3.2. Data collection practices

Figure 1 shows the distribution of the studied literature, based on data collection method used. As is shown in the figure, the data collection method most often used (48%) was exclusively from a literature review. Twenty-one percent (21%) of the data was from case studies, 9% was from surveys, and the remaining 22% combined the three methods to collect data.

3.3. Research objectives

Figure 2 illustrates the distribution of the studied documents according to their objective. Sixty-two percent (62%) of the studied literature focused on determining the advantages and promoted the wide use of modular construction. Eighteen percent (18%) of the documents concentrated on finding and discussing the limitations, and twenty percent (20%) of them examined both the advantages and limitations and suggested further research due to unavailability of data.

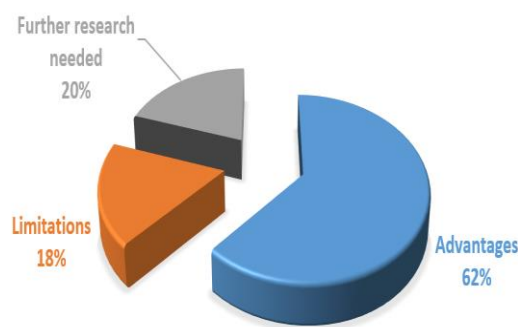


Figure 2. Distribution of documents according to their objective

3.4. Year of study

As shown in Figure 3, the number of journal articles published on the advantages of modular construction from 1995 to 2020 increased exponentially, which conveys that the need for modular housing has become more critical during the past two decades. Between 2015 and 2020, 36 journal articles were published on this topic, which was the highest number of studies among all five-year targeted intervals.

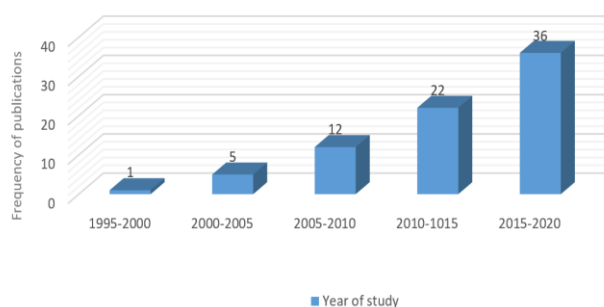


Figure 3. Distribution of publications on modular house based on year and frequency

3.5. Need for modular construction

After a careful review of the journal articles, it was found that two key factors influence the need for modular construction: (1) population growth, and (2) a high rate of deaths resulting from construction work.

3.5.1 Population growth and need for affordable housing

Data provided by the U.S. Census projects that the population in the United States is expected to grow from 300 million people today to over 350 million people by the end of 2025. Based on the average household (2.59 people per household), 19.3 million homes will be needed to accommodate the extra 50 million people. Many studies indicate that urbanization is influenced by housing factors [13]. Cities are not growing proportionately with the economy, and there is a gap between the upper and lower classes. This division

can be addressed with proper housing for every class of people, which includes living in an environment that is healthy, affordable, and feasible [14]. Based on a survey in 2005, every third person in cities live in inconvenient and unsanitary conditions [15].

3.5.2 High rate of deaths in traditional construction

The construction industry has a higher rate of death than all of other sectors of work. In the U.S, nearly 20% of deaths result from the construction sector (OSHA). Klakegg [16] espoused that construction jobs at off-site plants are safer than on-site operations, as the majority of accidents occur on the construction premises. All of the information available in the Safety Hazards to Workers in Modular Home Construction video pertains to residential construction and does not differentiate between modular and mobile homes [17]. With the same deficiencies in data, [14] the Occupational Safety and Health Administration database contains reports of 125 accidents related to modular building construction, most of which occurred during installation processes and were caused by falls from roofs [16]. It is estimated that 80% fewer accidents occur from modular construction than from traditional construction [16]. Responses from a survey conducted by Becker [18] showed that 50% of the responders believed that modularization is safer than traditional construction.

4. Advantages and limitations of modular construction

Modular construction has several advantages and disadvantages that need to be considered while using this method [19]. Many of the advantages are related to improvements in costs, schedules, safety, quality, productivity, environmental performance, etc. [20], while the disadvantages are associated with project planning, transportation and site limitations, initiation costs, lack of knowledge, etc. [10]. These considerations are discussed in the following, based upon information derived from the literature.

4.1. Advantages

The advantages of modularization and the sources of the information are summarized in Table 2 and discussed in the following. In general, by carefully implementing modular construction methods, there are several advantages in broad areas such as quality, labor, cost, speed of construction, and environmental impacts.

Table 2. List of the advantages of modularization in construction and the sources of information

Advantage	Source(s)
Speedy	[10]; [19]; [20]; [21]; [22]
Cost effective	[2];[23]; [24]; [25]; [26]; [27]
Highly Safe	[28], [29], [30], [31], [32]
Highly Productive	[33]; [34]; [35]
Environmentally Friendly	[21]; [36]; [37]; [38]; [39]; [40]

Speedy: Two Important benefits of the modularization method for construction are that several activities can be performed simultaneously [21], and weather conditions have little effect on the schedule [19]. As a result, the time required to complete a modular construction project is usually 40% less than that of traditional construction methods [19], which can be very important for projects with a need for a quick turnaround [41], such as such as post-disaster reconstruction of infrastructures, hospitals, etc. [42]. Ramaji and Memari [20] indicated that the complexity of a project considerably affects the time-saving feature of modularization, due to the increased need for communication and on-site work [22].

Cost Effectiveness: CII [2] revealed that a 10%-25% decrease in the construction cost of projects is expected when modularization is implemented. Several factors contribute to the lower cost [15,16], such as reduced material transportation for on-site labor [17], the highly efficient installation of construction components produced off-site, and the lack of vulnerability to weather extremes [18]. Cartwright [19] emphasized that modular construction leads to lower costs because the design procedure is standardized and requires less time and engineering than the traditional design process.

Highly Safe: Working on-site often involves activities that threaten the safety of the workers [28,43], and the increasing number of fatalities and non-fatal injuries have led many researchers to look for solutions [29]. Several studies have investigated the effects of modularization on the safety of the laborers and revealed that it results in a significant decrease in the number of safety problems [30]. The rate of accidents occurring in construction projects reduces by 80% when the modular construction method is used [31]. Even though modularization usually decreases the rate of injuries at job sites, safety frameworks need to be established for this method as well [31]. Thus, the Occupational Safety and Health Administration (OSHA), which monitors the on-site injuries in the U.S., provided requirements for the safety of the laborers who work on projects that implement modular construction [32].

Highly Productive: The production of prefabricated components for modular construction is tightly controlled and mostly automated [33]. The laborers who produce the components are skillful if for no other reason than they repeatedly perform the same procedure [44, 45]. In addition, the components are not subjected to weather conditions that might affect the quality of the materials [34]. In summary, the modular products have the potential to be of higher quality, less expensive, and produced in higher quantities in a smaller time period than those produced at the construction site [35].

Environmentally Friendly: The amount of waste generated by traditional construction methods has always been an environmental challenge for project managers and stakeholders [36]. Modular construction generates less waste than traditional construction [21], the products are easy to reuse and recycle, the waste is easy to dispose of [38], the components may be detached when their lifecycle ends [39], they don't produce on-site dust, greenhouse gases, or noise [40], etc. Thus, modular construction is a sufficient solution to the need for reducing the volume of waste [36,37].

4.2. Limitations

The limitations of modularization in construction and the sources of the information are summarized in Table 3 and discussed in the following.

Table 3. List of the limitations of modularization in construction and the sources

Limitation	Source(s)
Required Accurate Planning	[46]; [47];[48]
Transportation Challenges	[46]; [49]; [50]
Negative Public and Expert Perception	[51]; [52]
Establishment Cost and Cost Due to Complexity	[4]; [19]; [10]; [51]; [53]
Excessive Coordination Needed	[54]; [55]

Require Accurate Planning: O'Connor et al. [46] indicated that the project planning process of modular construction differs approximately 37% from the project planning of conventional construction. The differences might include the overall planning, cost estimation, scoping, design, etc. [46], which lead to considerable limitations. In addition, the planning process is especially challenging because of the complex components that have to be produced and assembled during the prefabrication process [47]. Thus, accurate planning with explicit scope and design details is required prior to the start of the project [48].

Transportation Challenges: An adequate number of vehicles is required to deliver the manufactured components to the jobsite for modular construction [49]. Oversized components need specific transportation considerations and cause delays, incur extra costs, and add complexity to the construction process [50]. The transportation limitations of modular construction are barriers to the timeliness and cost effectiveness of such projects [46].

Negative Public and Expert Perception: Overall, the concept of modular construction is viewed negatively by the public and even some of the construction experts [51]. This will have to change before it is widely used, and for this change to occur, the public will need to be made aware of its positive aspects [52].

Establishment Cost and Cost Due to Complexity: Even though the cost of construction is less for an off-site construction method, it requires the establishment of a fabrication plant [19]. Therefore, in areas where the labor and other requirements for traditional construction cost less than establishing a manufacturing plant for modular construction, on-site construction is more popular with the project stakeholders [51]. Modular construction requires suppliers, contractors, designers, and engineers who are experienced in and knowledgeable about prefabricated construction [4], and the lack of such experts is a considerable constraint to implementing this method [19]. Since many financial documents cannot be accessed, some researchers have expressed doubts about the positive impact of modularization on the cost of the construction projects [53]. For example, Kamali and Hewage [10] espoused that since modular construction is a relatively new and complex construction method, a wide range of studies need to be conducted to determine the costs. In addition, the modularization process needs to be monitored appropriately to correlate the timesaving factors with cost effectiveness.

Excessive Coordination Needed: In any construction project, establishing coordination and transitioning from one stage of construction to the next is key to completing the project on schedule and cost effectively [56,57,58,59,60,61]. Presumably, since the procedure in modular construction is different, the need for coordination will be a greater challenge [54, 55].

5. Discussion

Among the five major advantages of modular construction over traditional construction, the cost and schedule, which determine the productivity of a project [61], are interrelated. Saving time in construction activities equates to reducing the cost of the project [10]. Some aspects of these factors, however, such as the cost of materials, which is estimated to be lower than those used in traditional construction because they can be bought in bulk, independently impact modular construction [2,62,63]. Another example is the time that is required to design a modular project, which is significantly less than for traditional construction, because the designs are typically used for multiple similar projects [46, 64].

Safety is of high importance in any construction project, and data shows that modular construction is safer than traditional construction methods [65]. Much of the improved safety is due to the reduced environmental hazards in off-site manufacturing [2]. The safe and less hazardous environment also enhances productivity and the quality of the products [54].

The planning, cost estimation, scoping, and design in modular construction are different from those of traditional construction and have their own challenges and limitations that are likely to affect the whole planning process [47, 66]. In addition, the prefabricated components need special consideration when being delivered to the jobsite, which can affect the timeliness and cost effectiveness of a project [48]. In traditional construction, however, such challenges are not observed [67]. The probable extra costs incurred by using modular construction are the initial setup cost, lack of available skilled workers, and the complexity of the process [4,68]. The general disagreement about modularization [69] and the difficulties of coordinating the staff remain as impediments to this method being used more broadly. In summary, according to the studied literature on modular construction, although there have been improvements in several of the features of this technique, there are still opportunities for more [25,69].

6. Conclusion

Various aspects of modular construction technique were investigated in this study, and the positive and negative features were discussed as advantages and limitations. The major advantages discussed included project schedules, project costs, safety of the laborers, project quality and productivity, and environmental. The major limitations included project planning, transportation, public and expert acceptance, establishment cost and cost due to complexity, and coordination.

The results revealed that although modular construction has more advantages than limitations, further research is needed to mitigate or eliminate the challenges. The outputs of this study will be of benefit to project stakeholders who are trying to decide whether to use modular or traditional construction methods for their projects.

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