Decision Factors for the Feasibility Study of Developing Prefabrication Plants

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ABSTRACT
A feasibility study is one of the key phases for developing a prefabrication plant, which requires an analysis of many influencing factors. This research aims to identify the main decision factors for the feasibility study of developing a prefabrication plant. To this end, a thorough literature review and semi-structured interviews with the subject matter experts (SMEs) from different countries were conducted. Analyzing the findings, this study identified 20 decision factors for the feasibility study, such as upfront costs, operation and maintenance costs, market demands, government incentives, design flexibility, plant location, logistics management and costs, and technological constraints. The results of this study will help the industry practitioners, who are seeking to develop prefabrication plants, in their decision-making process during the feasibility study phase.

KEYWORDS
Prefabrication, Feasibility study, Conceptual framework, Off-site construction, Decision factors

INTRODUCTION
Fabrication, in the construction industry, is the formation of raw materials or products by cutting or bending and assembling them in a factory or at a manufacturing site (Eversmann et al., 2017; Bertram et al., 2019). Nowadays, prefabrication is becoming more attractive than traditional methods due to the need for rapid construction developments and innovation in construction. A decision for developing a prefabrication plant requires special consideration of many factors such as upfront costs, operation and maintenance costs, market demands, and technological constraints in the feasibility study phase. However, little research has been conducted to identify these factors. This research aims to investigate the feasibility study process for developing a prefabrication plant by identifying the decision factors and developing a conceptual framework for the decision-making process. This research focuses on worldwide perspectives on the decision factors through conducting a literature review and interviews with SMEs from different countries.

The paper consists of four sections. The next section discusses the literature review. From the literature review, some decision factors are identified and categorized. The next section describes the research methodology, where a qualitative approach is used to identify the decisive factors in the feasibility study phase for developing a prefabrication plant. The collected information is thoroughly analyzed in the subsequent section, and a conceptual framework for the decision-making process is developed. In the last section, the research concludes the results obtained in addition to the suggestion for possible future research in the field.

LITERATURE REVIEW

The use of prefabrication technology is gaining attraction amongst professionals in the construction industry by embracing emerging technologies such as Industry 4.0, Building Information Modelling (BIM), Design for Manufacturing and Assembly (DfMA), Digital Twin (DT), Computer Numeric Control (CNC) machines and robotics. The majority of the existing research in the field of construction prefabrication has focused on exploring these technologies for prefabrication and their benefits and barriers. Sorguc et al. (1970) is one of the earliest research on the feasibility study of prefabrication construction by formulating the cost factors for prefabricating low cost housing. Murtaza et al. (1993) identified five categories of factors including: i) plant location, ii) labor-related factors, iii) environmental and oraganizational factors, iv) project characteristics, and v) project risks for the feasibility study of modular construction in petrochemical or power plant. Verma et al. (2013) did a feasibility study for manufacturing lime-flyash cellular concrete blocks in India, and considered capital cost on land and building, capital cost on plant, equipment and machinery, and fixed capital investment as the main factors. These studies identified some of the factors to be considered in the feasibility study of prefabrication projects, but lack a framework identifiing key decision factors for the feasibility study of the prefabrication plants.

The next subsections discuss the major drivers that can impact the feasibility of developing a prefabrication plant.

Costs

High capital cost is considered to be one of the significant hindrances of adopting prefabrication (Xu et al., 2018). Generally, the upfront cost of the prefabrication production is more than conventional construction methods; however, prefabrication's assembly cost can be comparatively lower due to the material efficiency of prefabricated components produced off-site with extremely precise dimensions using advanced technologies. Hong et al. (2018) presented a basic cost-benefit analysis framework for quantifying savings of prefabricated buildings resulting from enhancing material quality, reducing labor requirements, and waste management. To minimize the capital cost, Xue et al. (2018) developed a factor analysis evaluation model (FAEM) and evaluated the effect of different factors such as management, material, design, and transportation on the cost performance of prefabrication projects.

Design and Engineering

The design and engineering phase has significant impacts on prefabricated products' performance and production efficiency. BIM and DfMA have been the main areas of research to improve design and engineering in prefabrication. Staub-French et al. (2018) investigated how BIM and DfMA can improve mass timber construction in British Columbia (BC), Canada. Sustainability enhancement (Fatima et al., 2018) and time and cost reduction (Selvaraj et al., 2009) can be achieved through DfMA. Yoo et al. (2019) proposed a BIM-based approach throughout the pre-construction, fabrication, and construction phases of the prefabricated steel framework. Chen et al. (2020) developed a system for improving the seismic performance of the prefabricated modular mass timber construction in high seismic zones.

Technology

Technology and innovation in prefabrication are necessary to improve the prefabrication processes by addressing some challenges. Supply chain management is one of the challenging processes in prefabrication. Tiwari et al. (2018) proposed a cloud-based solution to improve and ease the communication for supply chain management of prefabricated components, which can lead to a better production control, reduced waste material, and a smooth flow of communication throughout the prefab process. Using robots and automating the fabrication processes can improve productivity, reduce production costs, and provide more design flexibility. Robot systems can provide more flexibility in design changes. Eversmann et al. (2017) analyzed the robotic fabrication technologies and evaluated their efficiency and structural and functional capabilities. Kasperzyk et al. (2017) developed Robotic Prefabrication System (RPS) to increase the design flexibility of prefabrication. BIM and lean construction are other techniques to improve the efficiency of the planning and design processes for prefabrication (Bortolini, 2019).

Logistics

Transportation is a process that can largely affect the time and cost-efficiency of prefabrication construction. Li et al. (2015) proposed a technical framework introducing BIM and RFID technologies to facilitate the logistics company in transporting prefabricated products effectively and efficiently. Li et al. (2016) showed that the logistic cost for cross-border transportation could take up to 15% to 20% of overall prefab construction cost.

Productivity

Productivity of prefabrication is a major driver of prefabrication efficiency. Forsythe and Sepasgozar (2019) have measured prefab timber panel installation productivity and suggested improving practices. Simulation has been used to model repetitive fabrication operations and measure productivity in different scenarios. Altaf et al. (2015) developed an online simulation model of prefabricated wall panel production incorporating real-time data from RFID to evaluate the production productivity in different scenarios.

Environment and Sustainability

Prefabrication can reduce wastage generation up to 100% (Tam et al., 2007). A comparative study of environmental performance between prefabricated and traditional residential buildings in China showed that prefabricated residential building construction could reduce energy use by 20.49%, resource depletion by 35.82%, health damage by 6.61%, and ecosystem damage by 3.47% (Cao et al, 2015). Michael et al. (2020) proposed a green (eco-friendly) prefabricated building concept that can save up to 30-55% more energy than the traditional construction of buildings.

Quality

Prefabrication can improve the quality of the products due to precise measuring, cutting, and assembling of materials through software-based automated machinery (Kyjanek et al., 2019). Durability is another quality aspect that can be improved by prefabrication. D'orazio et al. (2020) showed the durability of a novel lightweight prefabricated product, namely HOME DONE, which is used for affordable construction and temporary housing.

Market Demand

Despite the advantages of prefabrication, its market share has been limited in the construction industry. Some governments are promoting prefabrication as a solution for affordable housing. Li et al. (2019) stated that the Singapore government actively promotes prefabrication construction. An aggregate annual growth rate of the modular construction (prefabrication construction with repeated parts of products as a whole structure) was 5.69%, with estimated spending of £8.5 trillion in 2018 and is forecasted to be increased by approximately £115.8 million by the end of 2023 (Nabi & Asce, 2020).

Regulatory

Zhao and Riffat (2007) suggested that appropriate codes and regulations are required to broaden the prefabrication. Government and research institutes can contribute to developing and updating the codes and regulations for prefabricated products.

Level of Prefabrication

Despite the benefits of prefabrication, high level of prefabrication is not neccessariliy the most suitable approach for construction. Traditional construction has some benefits such as more flexibility for building customized products, lower upfront costs, and less efforts required for coordinating on-site and off-site activities. Lu et al. (2018) developed a framework for the optimal level of prefabrication adoption in a certain political, economic, social and technological background by considering 13 factors such as policy, supply, labor, social attitude, site logistics, and user acceptance.

RESEARCH METHODOLOGY

A qualitative approach was adopted for this research. The methodology includes identifying decision factors and other variables for a feasibility study of the prefabrication plant development from the literature review and interviews with subject matter experts. Initially, information was collected from the literature review, and based on that, a list of questions was prepared for the semi-structured interview. All the information collected from the interviewees was analyzed to identify the main decision factors. The identified decision factors are presented in the subsequent section, based on which a conceptual model for developing a prefab plant is created.

In this research, six experts (three were CEO, one was a founder, one was a co-founder, and one was an associate technical project manager of a prefabrication company) were interviewed. The interviewees were from the United Kingdom, United States, Italy, Spain, and Canada, and some of them had global experience. The experts were asked about their company and their background in the field, the factors and risks they considered in the feasibility study, how they do market analysis, and other related factors for developing a prefabrication plant. The interviews were completed in November 2020.

FINDINGS AND PROPOSED FRAMEWORK

All the decision factors suggested in the literature, and identified during interviews, were categorized, prioritized and presented in Table 1, where "L" refers to the data obtained from the literature review, and "I" refers to the data obtained during the interviews.

Table 1. Identified decision factors from the literature review and interviews

L	I	Decision Factors	Description	Priority
			Cost factors	
*	*	Labor cost	Direct payments to the workers working on off-site and on-site construction.	Low
	*	Equipment cost	Costs of purchasing technical and non-technical machinery and technology depend on the size of the plan.	High
*	*	Land cost	Cost of land for building the plant and storage facilities.	High
*	*	Facility costs	Advance investment for the development of a plant and other facilities is generally higher than conventional construction.	High
*		Maintenance costs	Costs for maintaining the plant. Better maintenance can lead to higher productivity.	Medium
	*	Operation costs	Costs for operating or running the plant during production.	High
*	*	Transportation costs	Costs for transporting products from off-site to the construction site.	High
*	*	Automation technology costs	Costs of advanced technologies (e.g., robotics) for automating the operation depend on the size of a plant.	High
*	*	Design costs	Costs for designing the products.	Medium
*	*	Installation costs	Costs for on-site assembly of components	Medium
	*	Miscellaneous costs	Costs related to the waste, error, miscommunication fault, etc.	Low
			Design and Engineering factor	
*	*	Design flexibility and changes	Costs for the design change according to what the client wants and being flexible in the market to deliver products	High
			Skilled worker factor	
*	*	Skilled workers	Availability of skilled workers with previous experience in prefabrication construction in the proximity area of the plant	Medium
			Plant	
	*	Plant Size	The size of the plant and facilities needs to be sufficient for a safe and efficient workspace	High
*	*	Plant Location	The location of the plant considering market demands and transportation costs.	High
			Sustainability	
*	*	Green practices	Using sustainable design and production processes without harming the environment, the health of workers, and economic viability	Medium
			Market	

*	*	Market demands	Local or regional demands for prefabricated products and buildings can affect where to build a prefabrication plant and what product should be produced.	High
			Public and Regulatory	
	*	Society perspective	The society's point of view and their attention and interest in a prefabrication construction can support the project.	Low
*	*	Government incentives and regulation	Availability of government incentives, permits, product codes and standards, environmental regulations, import/export regulations, and road restrictions for transporting goods.	Medium
	*	Regularity	Regularity related to prefabricated products	Medium

Analyzing the outcome of the literature review and the interviews, cost factors, including upfront cost, operation and maintenance costs, and transportation costs have been considered as one of the major categories for decision making. Logistics management is another critical factor since transportation is required for delivering prefab structures on-site for the installation. Therefore, effective logistics management is needed to avoid delays and extra costs. Design flexibility and changes, plant location, government incentives, and regulation have been among other important factors identified in this research.

Based on these findings, a conceptual framework presented in Figure 1 was developed to assist practitioners in the feasibility study of a prefabrication plant development by highlighting the most important factors to be considered in decision making.

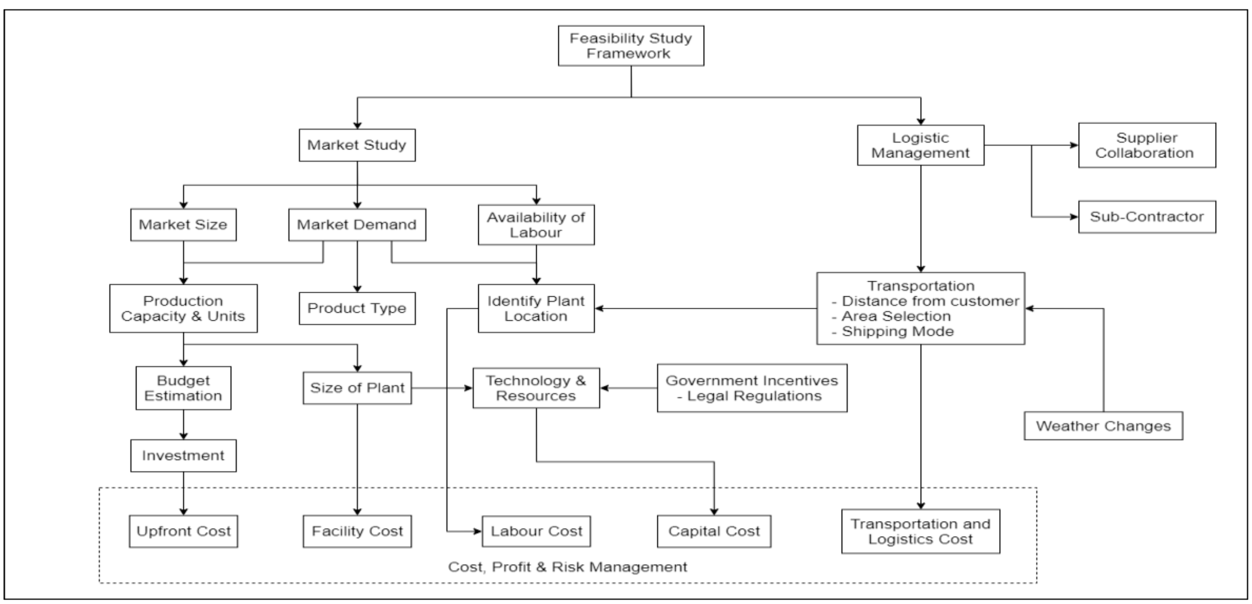

Figure 1. Conceptual framework model for developing a prefabrication plant

CONCLUSIONS AND FUTURE RESEARCH

This research identified 20 factors for a feasibility study of a prevarication plant development through literature review and interviews with SMEs. In addition, a conceptual framework for decision-making in the feasibility study phase was developed. The findings of this research can help industry practitioners in their decision-making and reduce the risk of failure for prefabrication plants, due to inadequate feasibility studies, at the early stage of the project.

This research was attempted to be generic and universal. However, some factors such as the business model, the geographical location of the plant, and the product type can significantly impact the feasibility study. Therefore, future research can focus on a specific location/country and specific prefabricated product type to achieve more practical results. In addition, the developed farmewrok can be implemented in a case study to demonstrate applicability of the farmewrok.

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