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COST CONTROL IN MODULAR CONSTRUCTION: A TAXONOMY FOR EFFECTIVE COST MANAGEMENT

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ABSTRACT

The cost effects of modular construction, which shares the same principles with lean construction, have been a subject of debate among researchers, with contrasting perspectives on how to control costs, compared to traditional construction cost management methods. Proponents of modular construction indicate that it can potentially be cost effective compared to traditional construction. As modular construction is gaining momentum in the construction industry, slowly replacing traditional on-site construction methods, there is a need for new cost control methods. The unique characteristics of modular construction create distinctive cost control difficulties. In this article, an attempt is made to showcase challenges and factors influencing costs in modular construction. The aim of the study is to propose a taxonomy of costs for modular construction processes. The study is ongoing and preliminary results presented in this article seek to understand the production process of modular construction, its associated costs and highlight potential cost control methods that align with the unique features of modular construction.

KEYWORDS

Modular construction, Cost control, Lean construction

INTRODUCTION

The construction industry is currently experiencing a substantial shift towards modular or off-site construction, steadily substituting traditional on-site construction methods in some market segments (Molavi & Barral, 2016). Modular construction utilizes building modules produced inside a controlled setting within manufacturing facilities to be conveyed and assembled on site. The concept of off-site construction has been known for a long time, but was not positively embraced until recently when the industry was subjected to pressure due to swelling labour costs and the need for sustainable buildings and processes (Zhang et al., 2016). In a study done by Assaad et al. (2022) in collaboration with the Construction Industry Institute (CII) in the USA, it was forecasted that off-site construction will grow from its current average percentage of 33.64% to an anticipated average of 54.9% in the future. This predicted increase will mark a substantial 4.33-fold industry growth in the USA over the coming decade. This significant increase indicates the acceptance and adoption of industrialized construction methods in the

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building industry, thus reflecting its potential to transform and restructure the construction methodologies and practices.

Modular construction attracts extensive attention from the construction industry because of its enormous benefits over traditional construction methods. Gibb (1999) states that the least desirable location one would want to construct a building is on a building site. Construction sites are burdened with inefficiency and different types of waste. By contrast, modular construction is usually faster, safer, and more reliable than traditional construction, as well as has reduced on-site labour requirements, improved quality, less wastage, and a lower environmental impact (Nazir et al., 2020). These benefits add to the increasing belief that modular construction successfully deals with the industry's needs for efficiency, sustainability, and value generation (Tsz Wai et al., 2023). However, despite the potential advantages offered by off- site construction, traditional on-site construction methods are still prevalent (Liew et al., 2019).

Modular construction shares the same principles and aims of waste reduction and enhanced efficiency with lean construction. The two approaches can complement each other in setting the pace for improvements in the construction industry. The fast speed construction of modular construction provides time-related cost savings for items such as site supervision, plant and equipment (Zhang et al., 2016). However, the unique features of modular construction, such as off-site manufacturing, transportation logistics, and assembly processes, create distinctive cost control difficulties. These challenges require innovative cost control methods throughout the lifecycle of modular construction projects. The application of lean construction concepts and methods in modular construction can contribute to streamline processes and the fostering of a culture of continuous improvement. This ultimately results in better cost management and project execution. By contrast, there is an ongoing argument that whilst volumetric modules can decrease the labour costs, it may simultaneously increase transportation costs.

This perspective article argues that relying on traditional cost control strategies is inadequate for delivering modular construction successfully. The study proposes a taxonomy of costs for modular construction processes and advocates for cost control approaches that align with the unique characteristics of modular construction, supported by empirical evidence and scholarly insights.

This investigation addresses a gap in knowledge, as little attention has been given in the literature on effective cost control strategies in modular construction. The development of such approaches is essential to ensure the implementation and delivery of modular construction projects in a cost-effective manner.

LITERATURE REVIEW

CHALLENGES OF TRADITIONAL COST MANAGEMENT

Cost management in construction generally involves monitoring the actual performance in comparison to the cost estimates and finding variances (Kern & Formoso, 2004). A major challenge of traditional cost management has been identified as the lack of accurate cost estimating and cost control processes, insufficient information modelling, and the absence of integrating cost management techniques and production management systems (Aziz, 2013).

According to Forgues et al. (2012) the cost estimates are often carried out when the conceptual design is at an advanced level or even finished, making it too late for relevant stakeholders to make informed decisions. Therefore, cost management can play a key role not only in terms of reducing costs but also in the analysis of trade-offs that affect functionality, quality and the long term performance of the building.

Koskela (2000) criticizes most of the cost management methods utilized in the industry for following a standard cost method, strongly based on mass production ideas, which associates most cost items to a finished element derived from design drawings, for example, walls (m2) and windows (units). Koskela further contends that traditional cost management disregards the nature of the product and the production process in question due to its insufficiency of the conceptual base. Kaplan (1984) concurs that it is improbable that any cost accounting system can sufficiently summarize a company's manufacturing operation.

COST IMPLICATIONS OF MODULAR CONSTRUCTION

Previous studies have explored the cost performance of modular construction, discussing the cost effects from contrasting perspectives on the overall cost compared to traditional construction methods. Some of them have explored how some lean principles and methods can improve efficiency and cost effectiveness in modular construction.

Zhang et al. (2016) state that the cost of industrialized construction can exceed the cost of a building delivered through traditional methods. The high costs in modular construction are often attributed to the initial investment in equipment and land for module production, the complexity of the design and materials used (Nahmens & Ikuma, 2012). However, advocates of modular construction argue that while upfront costs may be substantial, they can be offset by reduced labour costs, waste and reduced overhead costs, and potential time savings.

The installation of ready-made module units on-site requires less labour, resulting in decreased labour costs compared to traditional construction, which heavily relies on labour-intensive techniques (Nazir et al., 2020). In this context the application of the concept of standardized work can result in the synchronization of work processes and in higher productivity of the workforce (Bataglin et al., 2020).

Modular construction contributes to improved environmental performance by incorporating lean principles such as reducing construction waste and improving energy efficiency resulting in optimized costs (Nahmens & Ikuma, 2012). Material recycling and inventory control that happen in controlled factory environments align with lean goals of value generation and waste minimisation.

Gibb (1999) suggests that cost reductions can also be achieved through factors such as on-site overhead reduction, stemming from potential time savings due to shorter durations and increased installation efficiency. Pull planning and value stream mapping can assist in identifying and discarding activities that do not add value while incorporating activities that add value like efficient utilisation of resources (Bataglin et al., 2020). This leads to improved project predictability and decreased overhead costs.

While there are no generalised figures on the improved performance of modular construction, some studies have found that modular construction can reduce overall waste weight by 83.2% in large structures and 81.3% in small structures (Loizou et al., 2021); 35% reduction for on-site labour and an overall cost benefit of 8.62% for a hospital development (Court et al., 2009); savings on rework costs that can be as high as 2% in conventional construction (Lawson et al., 2012); and produce 40% less greenhouse gases emission than conventional construction (Quale et al., 2012).

In overall, pull production and Just in Time (JIT) production play a key role in the integration between on-site and off-site processes in modular construction (Innella et al., 2019). Pull production is important for planning and controlling production in the manufacturing plant so it is possible to cope with variability in the project. Construction site production of modularity must pull the delivery of pre-fabricated components from the manufacturing plant to the site for assembly. JIT means production considers only what is necessary, when it is necessary and where it is necessary.

Tam et al. (2005) highlight that savings in modular and prefabrication can be fully realised when the construction process is fully mechanised, changing construction into an assembly industry, and using recycling materials for prefabricated components.

CHALLENGES AND FACTORS INFLUENCING COST CONTROL IN MODULARITY

The cost of transportation has emerged as a primary challenge in modular construction. The high cost emanates from transporting large volumetric modules to the site where they will be assembled (Shahtaheri et al., 2017). The transportation costs increase if the project site and manufacturing facility exist in different countries or far away from each other. Court et al. (2009) advocate for setting up an assembly workshop on the construction site if the space permits or setting up adjacent to the construction site for cost reduction. However, during the transportation and installation, risks related to breakage of modules may be encountered, thus leading to even higher costs (Shahtaheri et al., 2017).

The storage capacity of the manufacturing plants is usually limited and can give rise to costs related to inventories (Nazir et al., 2020). High inventory due to excessive production and non-movement of modules can have a financial bearing in the organisation as storage costs have to be paid. Therefore, a cost effective inventory control of work in progress (WIP) of modules is essential. The use of the JIT approach can potentially promote continuous flow of modules with the aim of precisely matching the demand of the modules with the supply as produced by the factory (Balkhi et al., 2022).

The factory's demand is another important factor for considering opportunity costs. Opportunity cost is related to production time and refers to the potential benefit lost due to one choice (or necessity/obligation) over another (Windheim et al., 2017). In instances of high demand of specific modules, a delay in production can mean increasing the cost associated with the production of certain modules and reducing the company profit. The opportunity to produce more modules is lost at the expense of finalising the required modules (in this case, not by choice, but by the emerging situation).

Another noteworthy challenge is the management of dimensional and geometric variability in modular construction (Shahtaheri et al., 2017). It is expensive to accommodate plant changes during design and construction.

Molavi & Barral (2016) state that there is a high scarcity of skilled workers in the production of modular and prefabricated components. Skilled workers are needed to carry out complex techniques, and intricate designs in the production and installation of components.

The design stage also plays a critical role in cost control. While the actual expenditures associated with the design may be small because each module require a small number of changes each instance, the level of influence on cost control is the greatest during this stage (Gilbert III et al., 2013). Thus, efforts to reduce and control costs should be reinforced at the design stage.

During the production stage, costs arise from materials, labour, and indirect costs of the manufacturing plant. Since production is done in a factory-controlled environment the production of waste is minimal hence reduced cost of production (Nazir et al., 2020). However, the literature does not provide information on the range of costs related to rebuilding components due to damages, transport costs, inventory costs, labour costs and factory costs in modular construction.

The literature review presented in this sub-section pointed out several opportunities to improve the way costs are modelled in modular construction, by considering the nature of the production processes. Therefore, some key cost categories emerge, and should be considered in the proposed taxonomy: logistics costs, opportunity costs, inventory, time-related costs, fixed costs, etc.

POTENTIAL STRATEGIES FOR COST MANAGEMENT IN MODULAR CONSTRUCTION

Clients always expect that the construction work should be done within the budgeted amount, specified quality and on time (Aziz, 2013). Therefore, modular construction requires cost control methods that can achieve the expectations and requirements of the customers.

LEAN CONSTRUCTION

Lean construction is rooted in the removal of wasteful activities from construction processes. Lean construction uses different methodologies and techniques like JIT, pull planning, target costing, value stream mapping among others for the removal of waste in processes. Therefore, it is important to have a cost management system that clearly identifies and highlights the cost of non-value adding activities. A study by Nahmens & Ikuma (2012) done in the USA which applied lean construction for the construction of industrialized housing, construction material waste was reduced by 64% and the production hours were reduced by 31%.

USE OF TECHNOLOGY

According to Sergei & Gennady (2016) the best technology for constructing modular buildings must be able to recognize and understand the factors and features that allow the reduction of the stated costs, labour inputs and work duration.

The support that Building Information Modelling (BIM) provides to off-site construction in managing design risks and improved documentation, has been well documented in the literature (Zhang et al., 2016). The visualisation capabilities of BIM allows early clash detection, speed and accuracy of cost estimation, and enhanced coordination. The use of 5D BIM model allows accurate materials quantities take offs. The benefits of virtual design and construction are evident and cannot be overstated (Zhang et al., 2016). However, the main shortcoming of 5D BIM is its inability to capture time-related costs which are not dependent on quantity take offs.

STANDARDIZATION AND MODULARITY

Standardization is a concept that involves the extensive use of components, methods with regularity and repetition (Viana et al., 2017). Standardization provides better conditions for implementing modular systems efficiently as modularity focuses on standard modules and standard processes. The central idea of modularity is the possibility of decomposing a product into manageable parts (modules) that have standardized forms of interactions (Gibb, 1999). Modularity has been pointed out as a key concept in modular construction, especially when there is a need to customize products according to customer requirements. It enables the development of flexible production systems and has shown to be effective in dealing with complexity in different types of systems (Viana et al., 2017). The literature further indicates that the adoption of modularity brings several benefits that are enhanced when this strategy is related to concepts of industrialized construction such as standardization.

METHODOLOGY

DESCRIPTION OF THE EMPIRICAL STUDY

The study adopted a Design Science Research (DSR) approach, which combines descriptive and prescriptive research to close the gap between practice and theory (Holmström et al., 2009). The objective of DSR is to develop solution concepts, also known as artefacts for classes of complex and relevant problems, considering a certain context, and, in general, have a multidisciplinary character (Voordijk, 2009). DSR was selected because it is oriented towards the creation of new knowledge through design and action rather than just description.

The main artefact to be developed in this investigation is a conceptual model, i.e. a taxonomy of costs for modular construction processes. This taxonomy can support the development of design propositions for the development of cost management systems for modular construction, which can be regarded as a recommendation for action to be taken in a specific circumstance with the aim of achieving a certain result (Voordijk, 2009).

This study has an exploratory nature that sought to get an in-depth understanding of the problem, which is the starting point for developing propositions. The investigation was focused on cost of manufacturing, transportation and the installation of prefabricated modules. The conventional construction activities, often involved in project delivery, were out of the scope of the investigation. The study was developed through three phases; problem definition and comprehension, development of the solution, and analyses and reflection. The three phases were broken into six stages as shown in Figure 1.

(i) Stage 1: sought to identify a gap in knowledge through an in-depth analysis of a practical problem and review of existing literature.

(ii) Stage 2: involved an in-depth theoretical exploration of the identified problem and its specific characteristics. During this stage there was a deep practical involvement with the aim to: understand the production process of the company; understand the flow of information related to costs; and understand how the company estimates and controls costs.

(iii) Stage 3: consisted of collecting and analysing data and understanding the nature of modular construction costs from documents and through observations.

(iv) Stage 4: involved discussions and validation of information with relevant managers. The research artefact was developed, which is the taxonomy of costs for modular construction based on understanding the phenomenon of production.

(v) Stage 5: involved presenting and discussing with company representatives the research products, analysis and diagnosis developed in the previous stages.

(vi) Stage 6: consisted of a qualitative analysis of the contributions of the main research products.

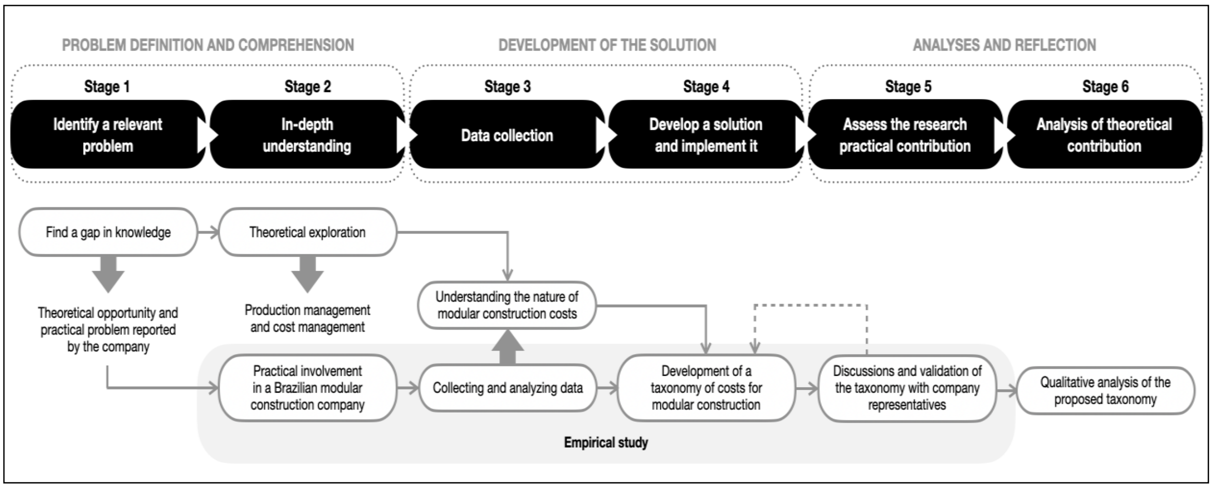

Figure 1: Stages of the Research Design and Development

The empirical study was developed in a Brazilian modular construction company, which develops and delivers complete modular components solutions for projects in different segments (e.g. education, security, residential). The company is responsible for all production, transportation and installation of volumetric modules, project development, execution of on-site installation and management of both factory production and construction work.

The company offers two volumetric modular solutions that differ in terms of the technology used and service to the business segments. This research focuses on the Y modular solution for the education market segment, whose volumetric unit has a standard dimension of 3x6x3m and is formed by a steel structure module (chassis) combined with slabs and external cladding (various types and number of panels). The modules were diverse and involved personal customization combined with pure customization. There was limited repetition of the same module. The structural module is delivered with finishing with hydro-sanitary and electrical installations and internal and external floor and wall finishings.

The family of modular products for schools consists of 46 standard products made up of several volumetric modules. Standard products are used for both new projects and expansions of existing schools.

The company was selected mainly because of its long experience and relevance in the Brazilian modular construction sector. The company was also involved in an improvement program based on the principles of Lean Production.

The strategy that was adopted in order to improve the reliability of the findings is triangulation. Triangulation allows the use of multiple data sources for a deeper comprehension of the subject of study (Farquhar et al., 2020). Data was collected through open-ended interviews, direct observation and the independent analysis of different drawings and documents. In total, more than 20 hours of interviews and meetings were held, 4 visits to two construction sites and approximately 13 hours of observations of the production process of the modules in the factories. Interviews were conducted with multiple company representatives. The study commenced in July 2022. The development of the taxonomy was based not only on the analysis of the data collected, but also on the literature review about cost management challenges in the context of modular construction (see literature review). Table 1 displays the sources of evidence utilized for the study for the respective phases and stages.

Table 1: Sources of Evidence

Phases	Stages	Main Activity	Details of activities	Sources of evidence
Problem Identification and Comprehension	Stage 1	Exploring gap opportunity	Understanding a relevant problem from practical and theory point of view	Literature review; Participant observation (planning meetings)
	Stage 2	In-depth exploration	Understanding the production process at the factory and modular products	Direct observation (manufacturing plant)
Development of the Solution	Stage 3	Collecting and analyzing data	Understanding the budgeting process and information flow; Analyzing factory production, cost control and challenges; Exploring logistics costs and factory costs with other sectors; In-depth understanding of the budget process for modular solution Y; Analysis of various budgets for modular solution Y, cost breakdown and material spreadsheets; Analysis of design drawings	Open ended interviews (cost management system); Document Analysis (cost estimates, design); Direct observation (manufacturing plant)
	Stage 4	Development of a taxonomy of costs	Discussion and validation of information	Open ended interviews (cost management system)
Analyses and Reflection	Stage 5	Presenting and discussing the product	Discussions with company representatives; Validation of the taxonomy	Participant feedback (cost management system)
	Stage 6	Qualitative analysis	Using literature and previous stages to qualitatively analyze the research product	Open ended interviews (cost management system) Literature review

RESULTS

This paper presents the preliminary results of this investigation. The company prepared a cost estimate by using a spreadsheet, in which the costs of each modular product was calculated, through accounting data and standard cost of raw materials and the standard time of production for each product or product family. The cost management system employed by the company can be classified as the traditional standard costing method. The changes were monitored by costing by apportionment of the transformation cost categories. The change in specification cost and the total hours for incorporating the changes in manufacturing the unit were recorded. The cost of different Y solution modules categorized according to their complexity, direct material cost and estimated production time with its own labour. Four categories were used for generating and controlling costs associated with different types of modular solution Y; (i) complex, (ii) medium complex, (iii) simple, and (iv) circulation or the most simple. The analysis of the estimated costs and production cost control suggested that cost estimates were developed with some form of logic aimed at aligning them closely to the production cost, especially indirect manufacturing cost. Some modules were stored in an open space at the manufacturing plant before being transported to their respective construction sites.

The nature of the production process led to the categorization of the main phenomena that generates costs. The taxonomy of cost categories followed five distinct key stages of manufacturing and assembling the modules as shown in Figure 2; (i) design process, (ii) production of volumetric units, (iii) logistics process at manufacturing plant, (iv) transportation process and, (v) assembly of pre-finished volumetric units.

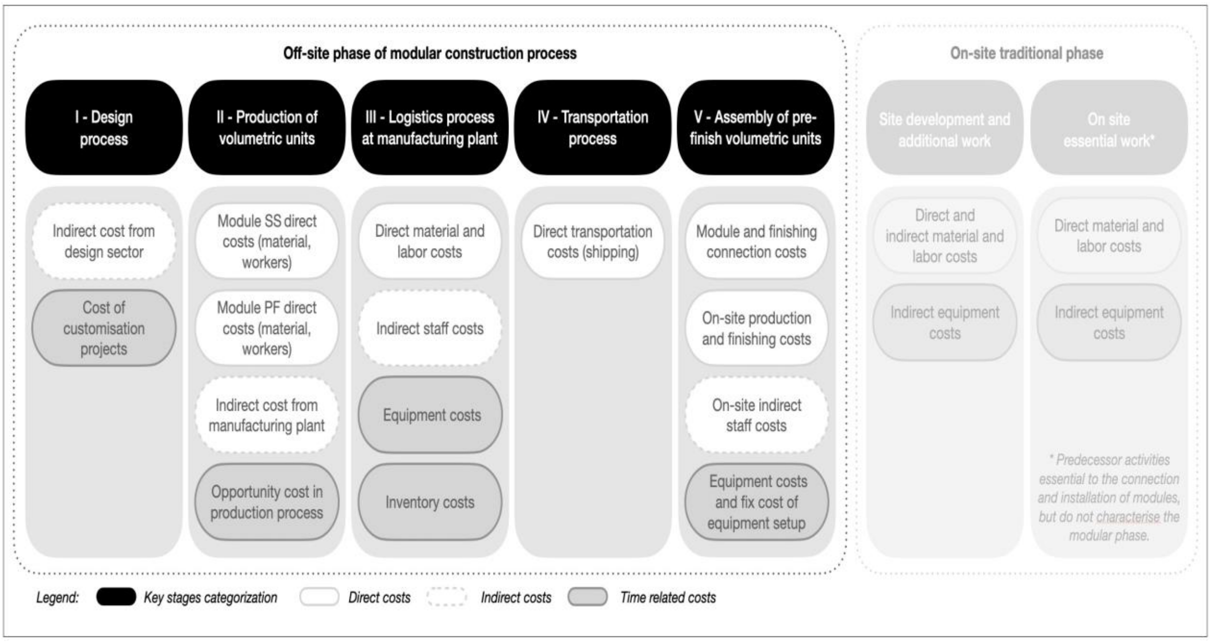

Figure 2: The Nature of Modular Construction Process and Associated Costs

Costs related to the design process can be divided into two main categories: indirect costs related to the design team, and project customization costs. During the production stage, costs arise from materials and labour of the structural shell (SS) and the pre-finished (PF) modules, indirect costs of the manufacturing plant, and opportunity costs in the manufacturing plant. Manufacturing indirect costs refer to transformation costs and other industrial costs such as indirect costs of energy, water, maintenance, rent and depreciation. The logistics process at the manufacturing plant incurs indirect and direct costs from the workers, equipment and inventory. The transportation process essentially includes the costs directly associated with freighting volumetric units and are estimated from the potential supplier or freighting company. The transportation costs depend on the number of modules and the distance to be travelled to the delivery point. The assembly of pre-finished volumetric units involves costs associated with materials used for connecting the modules, plant and equipment used during the assembly, and costs of the workforce.

DISCUSSIONS

The study has provided insights into the various stages of modular construction and the associated costs at each phase. It has shed light on the complexities of cost management in modular construction, emphasizing the need for innovative cost management solutions and the application of some lean methods to overcome the specific challenges posed by each stage of the process.

TAXONOMY OF MODULAR CONSTRUCTION PHASES

The reviewed literature does not provide an explicit description of the different stages that modular development goes through. Providing a taxonomy of the different phases of modular construction provides a point of departure for understanding different costs associated with modular construction. Taxonomy provides a good foundation for calculating operational costs for each category, which is usually disregarded when preparing cost estimates. Moreover, taxonomy provides a structured conceptualization and common language for communication among construction team members, aiding clarity. The structured conceptualisation makes it possible and easy to identify sources of cost deviations in case of cost overruns. Production planning can also be improved as the appropriate efforts and resources for cost control can be dispatched according to the requirements of any category.

REPETITION AND STANDARDIZATION OF COMPONENTS

Modularity allows repetition, which facilitates cost management. This repetition can lead to more accurate cost estimates and better cost control throughout project delivery. In addition, modularity provides opportunities for customization whilst maintaining cost effectiveness. The use of components that can be customized and combined in numerous ways provide opportunities to achieve cost advantages through repetition and standardization. This balance between repetition for cost efficiency and customization provides evidences of the potential positive impact of modular construction in improving project cost control.

There are some opportunities for improving cost estimating and control related to the use of digital technologies, such as the improvement of the existing cost database, and the use of 5D-BIM for quantity takes-offs. Through BIM, adjustments to the designs can be made at any given point in time and BIM can show real time changes and visual representation of cost data of different components of the modules. However, the impact of digital technologies tends to be very limited if traditional cost modelling, based on the standard cost method, is still used.

SYNCHRONIZATION OF ACTIVITIES

The management of inventories to avoid storage cost by the company is also a key change. The adoption of lean production techniques such as JIT and pull planning, are important for synchronising not only with the construction site but with the suppliers of materials for producing modules. As suggested by Bataglin et al. (2020), confirmation points (triggers) can be used as a mechanism for pulling components from manufacturing plants, according to the status of the system. Therefore, the implementation of lean techniques will reduce different types of waste as only necessary modules will be produced, workflows streamlined, as well as aligning on-site and off-site operations, ultimately reducing lead times and saving cost.

STRENGTHENED LOGISTICS SYSTEM

The transportation of modules from the manufacturing plant to different schools spread across the country may also impact the overall expenses of producing modules. Several strategies can be utilized to reduce those costs. Space utilization of the trucks used for transportation can be maximized through efficient loading processes, and leveraging economies of scale through bulk transportation and reducing the number of trips. The selection of transportation modes can also assist in controlling transport costs: an effective, adapted and strengthened logistics system is critical for cutting transportation costs incurred by the company (Hsu et al., 2017).

In overall, modular construction offers opportunities for reducing lead time, and consequently time-related costs, and also can improve reliability of cost estimates. The complexities associated with off-site manufacturing, transportation logistics, and on-site assembly require a re-evaluation of traditional cost control methods. The dynamic nature of modular construction projects needs proactive approaches that consider the intricacies of supply chain coordination, production scheduling, and site integration.

CONCLUSIONS

Modular construction is known for its efficiency and predictability. The streamlined processes of modular construction allows for waste reduction and shorter project lead times. Modularity also provides an opportunity for operational costs to be reduced as assembly line activities are much simpler. It allows for customisation while still maintaining cost effectiveness, making it possible to achieve cost advantages through standardization and the repeated use of components. This balance between repetition for cost efficiency and customization highlights the effectiveness of modular construction in managing costs in projects.

However, to a large extent, the unique characteristics of modular construction create distinctive cost control difficulties. The high costs in modular construction often stem from the initial investment in equipment and land for module production, the complexity of design and materials used. The primary cost drivers in modular construction emanate from transportation, warping and damage during transportation, and a shortage of specialised skilled workers. To address cost control in modular construction, it is crucial to use cost control methods that align with the unique features of modular construction.

The main conceptual contribution of this study is the development of a taxonomy outlining the different phases of modular construction. A structured framework for determining costs associated with each phase of modular development is provided through taxonomy, aiding better cost management custom-made to the requirements of each phase. The taxonomy of cost categories followed five distinct key stages of manufacturing and assembling the modules; (i) design process, (ii) production of volumetric units, (iii) logistics process at manufacturing plant, (iv) transportation process and, (v) assembly of pre-finished volumetric units. The development of this taxonomy is strongly related to some lean principles, such as elimination of the share of non-value adding activities, reduction of variability, pull production, synchronisation and takt time, and simplification by the reduction of the number of steps and parts.

Whilst this perspective paper sheds light on valuable insights and reflections on the current subject, there are a few notable limitations of the study that needs to be acknowledged. As this is an on-going study, the results of the study are partial thus limiting the depth of analysis of some aspects which have been explored comprehensively and in detail. Moreover, the lack of previously published information about the different stages of modular construction made it impossible to draw comparisons with prior studies thus making it difficult to build upon existing knowledge. Finally, there were some limitations related to the research method as the findings of the study are based on a specific company, and thus cannot be generalised to other situations because of the unique context and conditions.

Regarding future studies, the following suggestions emerged from this investigation: to develop additional prescriptive knowledge (e.g. principles and prescriptions) for designing cost management systems for modular construction, and to test the taxonomy of cost management categories by applying in the development or testing of cost management systems.

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