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Near optimum selection of module configuration for efficient modular construction

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ABSTRACT

Modular construction gained considerable momentum over the last decade due to its positive impact on project cost, schedule, quality, and safety. Current literature in this field focused on cranes selection and scheduling methods, without due consideration for optimum module configuration. This paper introduces a novel modular suitability indicator which utilizes five indices; 1) connections index (CI) to evaluate module connections using the matrix clustering technique, 2) transportation dimensions index (TDI) to evaluate module dimensions' effects on transportation, 3) transportation shipping distance index (TSDI) to evaluate the distance between manufacturing facility and the construction site, 4) crane cost penalty index (CCPI) to evaluate the crane cost relevant to the module placing rate, and 5) concrete volume index (CVI) to evaluate the project's foundation concrete quantities. Calculating the modular suitability index (MSI) provides a unified indicator to accomplish a near optimum selection of module configuration for efficient delivery in residential construction.

1. Introduction

Offsite construction systems vary depending on the size of prefabricated components which affect the need for onsite construction. These systems include many categories such as modular, panelized, prefabricated, and processed materials construction. Blending two or more of these categories results in a “hybrid” offsite construction system. Each category has its own unique configuration based on its own constraints such as transportation, manufacturing, and onsite lifting and positioning limitations. Choosing between the use of any offsite construction system depends on project characteristics and its targeted cost, schedule, and the scope of off-site manufacturing that can be used.

Modular construction provides a viable alternative to traditional (stick building) construction in view of enabling technologies developed earlier such as that used in the shipbuilding and automotive industries. The percentage of off- site manufacturing for modular construction ranges between 60 and 70%, comparing to 30 to 50% for hybrid construction and 15 to 25% for panelized construction [1].

This accounts for 50 to 60% of construction time reduction for modular construction compared to 30 to 40% for hybrid construction and 20 to 30% for panelized construction [1].

The advantages of modular construction were identified several decades ago [2] and more recently by O'Connor et al., [3]; investigating a set of critical success factors and enablers for optimum industrial modularization. Studying the critical success factors for modularization provided an overall idea highlighting needed changes in current engineering, procurement and construction (EPC) project delivery system to support optimal use of modularization. These studies, however, did not provide a systematic process to quantify the degree of modularity in construction projects. This quantification will enable the modular construction system to compete with the hybrid construction system. Since more manufacturers are beginning to use hybrid construction to eliminate some of the dimensional limitations that modular manufacturers currently face [4].

This paper provides a novel methodology for near optimum selection of module configuration. The methodology addresses the lack of knowledge by architects about the limitations of the manufacturing process of modules, which was identified in an earlier study [5]. In fact, architects should design modules as production designers to standardize the process of module manufacturing [6].

The developed methodology is accomplished by considering a set of practical constraints and factors that affect module configuration such as onsite connections limitation, transportation and weights limitations,

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crane cost limitation, and the required concrete quantities for project foundation.

2. Literature review

Modularization is a concept of mass customization for products that have been successfully adapted by various industries [7]. Product configuration focuses on structuring and standardizing products models to fulfill customer needs [8]. In the construction industry, the needs of customers have been identified based on building geometrical shapes; arranged in a manner that maximizes the Quality Function Deployment (QFD) in the design phase [9,10].

The QFD analysis requires the input of customer requirements. This is often evaluated in market surveys where different market segments are investigated using statistical methods and questionnaires [11]. However, standardized products considerably impact the design of buildings; especially when the design needs to be adapted to satisfy the customer requirements. Thus, such adaptation causes waste and quality problems in the production system [12]. The demand for customization compels the manufacturing industry to develop new methods for adaptation of their mass production to satisfy the individual needs of customers [7,8].

A method called MFD (Modular Function Deployment) was developed by Erixon [7] to investigate different strategies in product modularization. MFD utilizes the QFD for a product using a market survey and systematic analysis to find customer needs for any specific market.

Jensen et al. [13] developed another method to standardize the production and configuration processes by conducting functional requirement analysis to identify design parameters for modular construction of buildings. This method constrains the modularization of project using four views; 1) Customer view that controls the modular design according to customer requirements, 2) Engineering view which constrains the modular design according to deflection, strength, wind loads, fire, acoustics and national regulations, 3) Production view that identifies product dimensions and transportation constraints according to factory regulations and capacity, and 4) Site view for assembly constraints on site according to site plans.

Smith [6] presented a comprehensive description for modular configuration constraints and mass customization including transportation, assembly, craning, and tolerances limitation. Modular builders contributed to this study by identifying the optimum configuration of modules based on their experience. Another method was introduced by Jensen et al. [14] which integrates the rules and constraints of a modular building or product platform in a family of architectural CAD application such as; Revit structures. Lawson et al. [15] studied particular features and key design aspects for steel, concrete and timber modules in the UK, and provided several case studies for the dimensions of hybrid, panelized and modular construction. However, there was no systematic procedure for optimizing modular building designs.

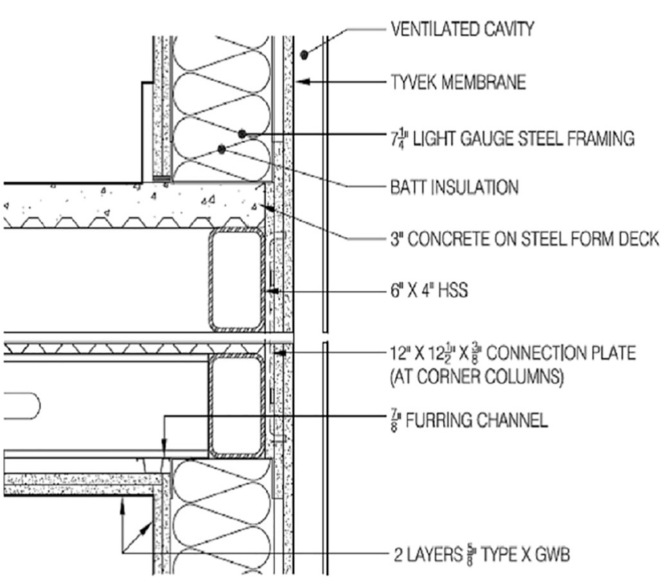

Fig. 1. External connection side view [16].

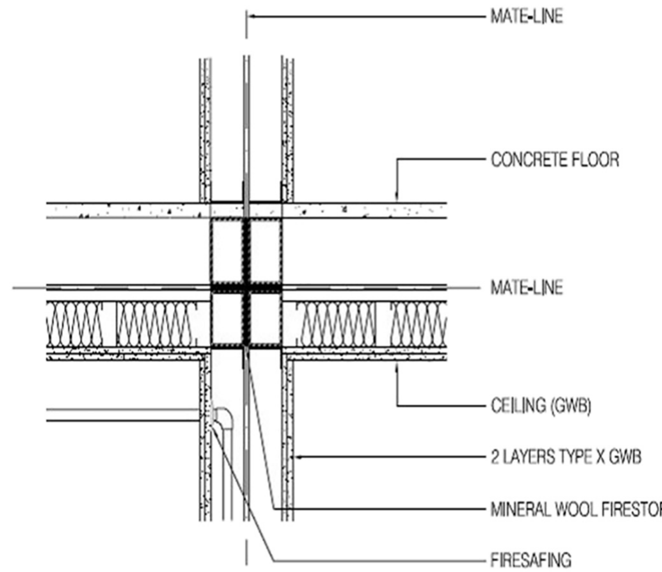

Fig. 2. Internal connection plan view [16].

3. Methodology

The developed methodology utilizes five indices, which accounts for connections of modules onsite (CI), transportation of fabricated modules to construction jobsite (TDI and TSDI), crane operating condition and related cost (CCPI) and project concrete foundation (CVI). These five indices are integrated into one indicator (MSI) measuring the relative suitability of competing modular designs. These indices are described below.

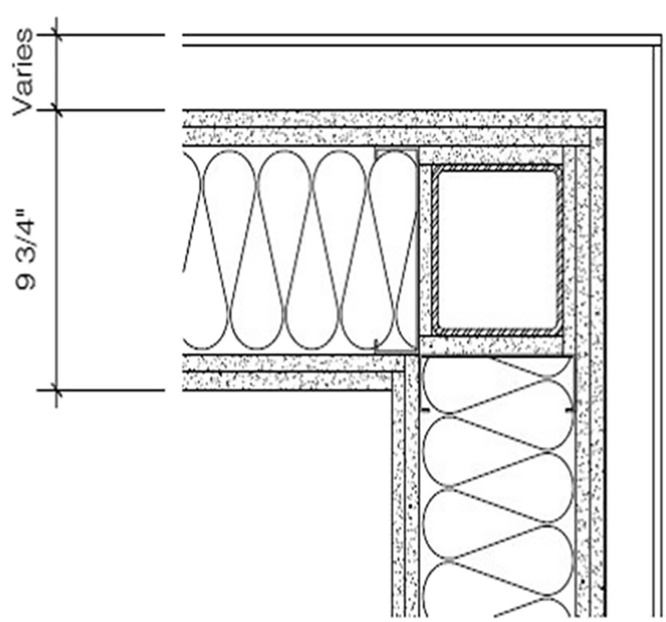

Fig. 3. Corner connection details [16].

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