

Modular v. Stick-Built Construction: Identification of Critical Decision-Making Factors

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This research study identifies critical decision-making factors that can help designers and constructors in selecting modular construction versus conventional "stick-built" technique for commercial building projects. The decision-making process of selecting one construction method over the other is complex and based on a number of factors some of which are site conditions, skilled labor availability, transportation conditions, organizational readiness, local codes, project schedule and budget, sustainability requirements and design complexity. The aim of this study is to identify the most critical factors that must be considered by the decision-makers for selecting modular or stick-built construction. The study employed a mixed methods research design and was divided into three phases. In the first phase, through an in-depth literature review and interviews with six industry professionals, ninety seven decision-making factors were identified. In the following phase, a questionnaire survey was conducted to determine quantitative rating and raking of these factors. In the final phase, with the help of a focus group of five industry professionals, twelve critical decision-making factors were shortlisted, validated and rank ordered. Moreover, the barriers that might be preventing the widespread use of modular construction were also identified. It is hoped that the presented findings will help project stakeholders in making more informed decisions about the appropriate construction method selection.

Key Words: Modular construction, Prefabrication, Manufactured construction, Fast track projects, Mixed methods research

Introduction and Background

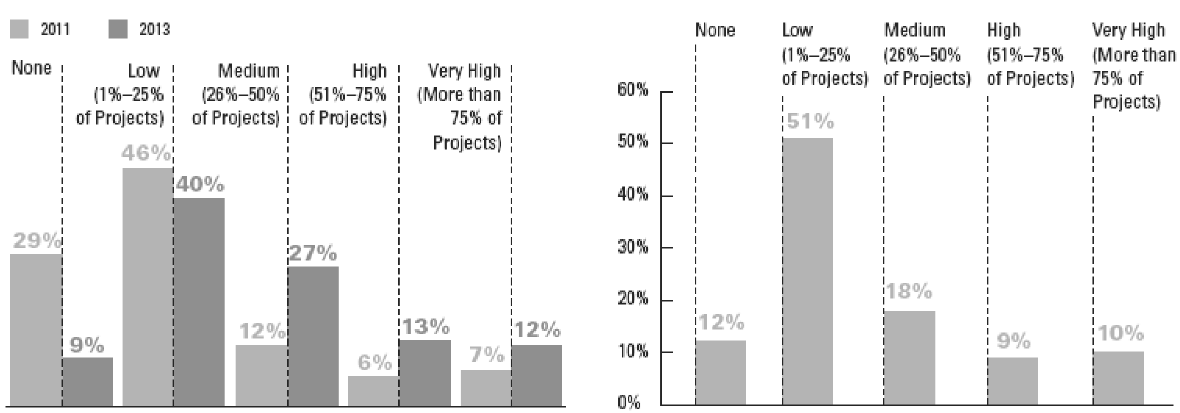
Research studies have suggested that the productivity of the construction industry has gradually declined over the past four decades at an average compound rate of -0.6% per year whereas productivity in all non-farm industries is increased at a rate of +1.8% per year over the same time period (Abdel-Wahab and Vogl, 2011; Teicholz, 2004). One of the reasons for this productivity decline is that the construction industry has been dominated by years with conventional design and construction practices. Conventional construction techniques are not only time consuming, but also require a significant amount of skilled field labor. In the complex building design and construction scenario of today, it is desirable to construct a facility that not only meets the functional and aesthetic requirements but also possess the following characteristics: (1) durability and high performance; (2) Speedy construction; (3) reduced cost; and (4) zero accidents and minimum waste at the jobsite. Therefore, to design and construct a building to meet the needs of clients and communities of future, a clear change in approach is required (SmartMarket Report, 2011).

One of the proposed strategies for improvement is to develop an efficient, innovative and productive industry by introducing a manufacturing approach to construction through the use of Modularization. Modular construction is a manufacturing process, generally conducted at a specialized facility, in which various materials are joined to form a component part of the final installation (CIRIA, 1999). The manufacturing process may be undertaken in a factory environment (factory prefabrication) or under the open sky at the site (site prefabrication). The term off-site fabrication is used when both prefabrication and pre-assembly are integrated (Gibb, 1999). Modular construction has been identified as the first degree of industrialization, followed by *mechanization*, *automation*, *robotics* and *reproduction*. The term "module" is defined in the literature as follows, "A module is a product resulting from a series of remote assembly operations. It is usually the largest transportable unit or component of a facility. A module consists of a volume fitted with all structural elements, finishes, and process components which, regardless of system, function or installing craft, are designed to occupy that space. Modules may contain prefabricated components or preassemblies and are frequently constructed away from the jobsite." (Tatum *et al.*, 1987). Modularization brings the advantages of the manufacturing process to the construction industry, such as a controlled environment, minimal waste, improved safety and quality control, low cost, faster completion and high productivity (CIDB, 2003).

While the concept of using modularization for projects perhaps can be traced back to Egyptian pyramids and Greek temples, the modern construction industry has only recently started to take significant advantage of this construction approach. The demand was at its peak in the 1950s, 1960s and the early 1970s in Eastern and Western Europe for the construction of new towns, suburbs, and large scale public housing developments (Warszawski, 1999). During this period, various precast concrete building systems were developed. In the early 1970s, the construction firms in the United States also explored several modular building systems. An example being the Hilton Palacio del Rio hotel in San Antonio, Texas. Built for the Texas World's Exposition of 1968, the 500-room deluxe hotel was designed, completed and occupied in an unprecedented period of 202 working days. All of the rooms were placed by cranes in 46 days. Still in use, the hotel is believed to be the tallest modularly constructed facility in the United States (SmartMarket Report, 2011).

Modularization has not had a steady growth over time; instead, it has fluctuated based on the level of demand during war and economic booms. However recent technological advancements have dramatically increased the scope of modularization. The reemergence of modular construction as a "new" trend can be tied to the rise of BIM and green projects, as reported in the SmartMarket report of 2011 published by the McGraw-Hill Construction (SmartMarket Report, 2011). Based on a survey of 800 architecture, engineering and contracting (AEC) professionals conducted between February and March of 2011; it is found that Model-driven prefabrication, where BIM models are provided to building product manufacturers to prefabricate building elements off-site, is projected to increase dramatically in the next two years. Similarly, it is reported that 88 percent of the respondents are using modularization on at least one green project whereas 19 percent of them are using it on half of their green projects. These trends are shown in Figure 1. The survey results also reported the following additional trends:

- 66% respondents reported that project schedules are decreased–35% indicated a decrease of 4 weeks or more.
- 65% respondents reported that project budgets are decreased – 41% indicated a decrease of 6% or more.
- 77% respondents reported that construction site waste is decreased–44% indicated a decrease of 5% or more.
- 70% of architects and 66% of engineers believe that prefabrication and modularization will result in measurably high quality in future projects.
- By 2013, 38% of architects and 48% of engineers that use prefabrication and modularization today expect to be using it on more than 50% of their projects.



(a) Use of model-driven (BIM) prefabrication (b) Percent of green projects using modulaization

Figure 1: Survey results of McGrawHill Construction indicating BIM and Sustainability as key drivers to promote modularization concept among AEC firms (Source: SmartMarket Report, 2011).

Research Aim, Objectives and Scope

There has always been a strong interest and desire towards modularization in the construction industry. However, due to the lack of expertise in the area of modularization decision-making, numerous firms opted for stick-built construction (Murtaza *et al.*, 1993). One of the major problems is determining the project characteristics that make modularization the best choice. In most cases, the decisions are made based on the experience and gut-feelings of modularization experts. Modular construction is a complex combination of philosophy, system and techniques, and there is always a risk that a wrong decision may result in poor implementation or even in project failure (Koskela and Ballard, 2003).

The aim of this research is to examine all critical factors that help decide adaption of modular construction over conventional “stick-built” construction. The research objectives are as follows:

- To identify and rank-order critical factors leading to successful implementation of modular construction over conventional construction while achieving cost and time savings and better quality.
- To identify the barriers that typically prevents the widespread use of modular construction.

The scope of this study is limited to commercial building projects only, however, most of the findings can also be applied to residential, healthcare and industrial projects.

Research Design

It was determined that both quantitative and qualitative data would be required to fully answer the research objectives. Hence it was decided to employ a mixed methods research methodology. Mixed methods research is an approach where the researcher mixes or combines quantitative and qualitative research techniques, methods or concepts into a single study (Johnson and Onwuegbuzie, 2004). The research methodology was divided into three phases which are illustrated in Figure 2.

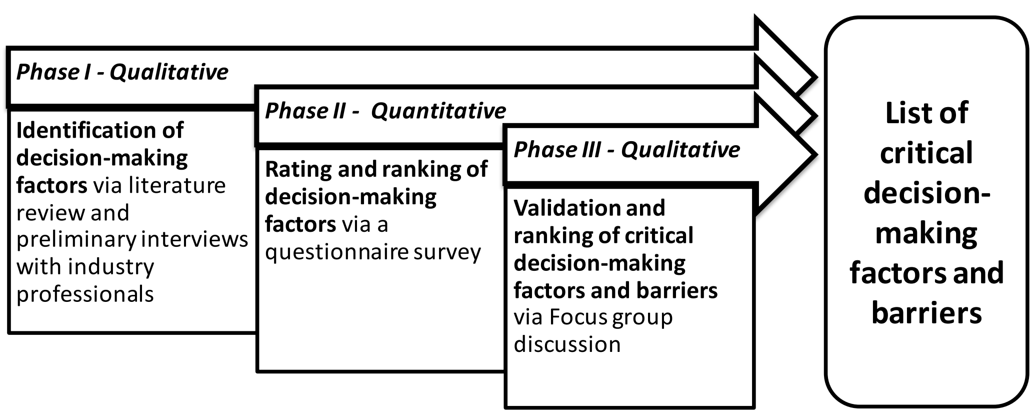


Figure 2: Roadmap of research design.

In the first phase, through an in-depth literature review and interviews with six industry professionals, 97 decision-making factors were identified. In the following phase, a questionnaire survey was conducted to determine quantitative rating and raking of these factors. In the final phase, with the help of a focus group of five industry professionals, 12 critical decision-making factors were shortlisted, validated and rank ordered. Moreover, the barriers that prevent the widespread use of modular construction were also identified. More details about each phase of the research and associated results are discussed in the following section.

Methodology and Main Findings

Phase I: Identification of Decision-Making Factors

The purpose of this phase was to identify all factors that could be considered in the decision-making process of selecting modular construction over the conventional stick-built method. Through an in-depth literature review and internet search, a list of 76 factors was prepared. After that, open-end interviews were conducted with six industry professionals who were involved in the decision-making process of ten or more modular construction projects over the last twenty years. These professionals were identified through referrals of industry contacts. The list of 76 factors was sent to each interviewee at least a week before the interview to provide adequate time for review. They were asked to add, delete or combine any factors. Based on their suggestions, a final list of 97 factors (see Table 1) was prepared which were divided into 13 categories as follows:

- Design-related factors
- Labor considerations
- Organization's readiness
- Owner's perspective
- Finance-related factors
- Module-related factors
- Manufacturing unit
- Codes, permits, and submittals
- Project risk factors
- Site attributes
- Transportation and equipment
- Technology-related factors
- Sustainability requirements

The final list was again sent to all interviewees for validation and feedback. Based on their comments, minor adjustments were made.

Phase II: Rating and Ranking of Decision-Making Factors

In this phase, a questionnaire survey was conducted to determine the rating and ranking of 97 decision-making factors which were identified in Phase I. The questionnaire was divided into three sections as follows:

- Section 1: Organization's and respondent's profile (e.g. organization type, annual revenue, work experience of the respondent in modular construction, number of modular projects worked on, etc.)

- Section 2: Rating of decision-making factors: The respondents were asked to rate each factor on a Likert scale of 1 to 10 where:
    - 1: not important factor
    - 2 to 4: slightly important factor
    - 5 to 6: important factor
    - 7 to 9: very important factor
    - 10: most important factor

  The respondents were also given a choice to add additional factors in each of the 13 categories.

- Section 3: Additional comments and contact information (optional)

Since the questionnaire was designed for individuals having strong experience in modular construction, the survey sample was selected using *judgment sampling*. Judgment sample is a type of nonrandom sample, which is selected based on the judgment of the researcher (and/or other experts involved in the research). The sample consisted of the members of Modular Building Institute (MBI), contacts provided by the interviewees of Phase-I and AEC firms identified through *Engineering News Record* and other trade magazines. The Modular Building Institute (MBI) is the international non-profit trade association serving modular construction. Members are manufacturers, contractors, and dealers in two distinct segments of the industry - permanent modular construction (PMC) and relocatable buildings (RB). More details about MBI can be found at: http://www.modular.org. All together the questionnaire was sent to 110 individuals/organizations during October to November of 2010. The recipients were provided 6 weeks time to submit their responses.

Within the given time frame, 25 valid responses were received yielding a response rate of 23%. This response rate is very typical for construction industry surveys and therefore the findings can be considered as reportable. Baker (1998) mentioned that statistically reliable conclusion can be obtained from a sample size of 20 or more. However, the readers must be aware that the low or high response rates in non-probabilistic samples do not guarantee that the survey results would be representative of the population of interest.

To further investigate the reliability of the responses, the Cronbach's alpha coefficient was used. This coefficient is commonly used as a measure of the internal consistency of the data. A value of 0.70 or more typically represents interrelated data (Pallant, 2001). In this study, the alpha coefficient came out to be 0.875 which represents highly interrelated responses and consistency of the scale with the sample size.

The questionnaires were completed by top management in the organizations (mainly vice presidents and senior project managers). Almost all of them had over 15 years of modular construction experience. Two-third of the respondents had worked on 10 or more modular construction projects. On the basis of their position and work experience, it can be inferred that the respondents have adequate knowledge of the activities associated with modular construction.

After evaluating all responses, it was decided to divide decision-making factors into three categories based on their mean rating scores. These three categories are as follows:

- Major factors (having a mean rating score of 6.5 or higher)
- Moderate factors (having a mean rating score between 3.5 to 6.5)
- Minor factors (having a mean rating score below 3.5)

Table 1 illustrates all 97 decision-making factors which are sub-divided into major, moderate and minor factors. These factors are also rank-ordered based on their mean rating score. As shown in the table, there are 16 major, 66 moderate and 15 minor factors. It is important to note that few outliers were identified in the reported data and were not included in computing mean rating scores.

Phase III: Validation and ranking of critical decision-making factors and identification of barriers

In the final phase of this research, the findings of the questionnaire survey were reported to a focus group of five industry professionals. A *focus group* is a form of qualitative research in which a group of experts are asked about their perceptions, opinions, beliefs and attitudes towards a product, concept or theory. Questions are asked in an interactive group setting where participants are free to talk with other group members. Focus groups can provide accurate information, and are less expensive than other forms of traditional qualitative research instruments. They are a very useful tool in validating research findings or reaching a consensus (Marshall and Gretchen, 1999).

Three members of this focus group were chosen from Phase I of this research while the remaining two were selected from the pool of questionnaire respondents. All had over 20 years of experience in modularization and had worked on 15 or more modular construction projects. They participated in a 90 minute moderated discussion. The survey findings were provided to them and each member was asked to prepare their list of most critical factors. They were given the choice to even pick moderate or minor factors (as reported by the questionnaire respondents) if they consider them critical. After collecting their lists of critical factors, the final results were compiled and shared with all members. It was found that there were a total of 12 critical decision-making factors picked by the focus group members. All 12 belong to "major" factors category. After that, open discussion was made to validate these critical factors with consensus. During this discussion, the participants also provided their opinions about possible barriers that might be preventing the widespread use of modular construction.

The final list of twelve critical decision-making factors is as follows:

1. Owner's receptivity and willingness to accept modular construction.
2. Need for expediting the schedule.
3. Early upfront involvement of top management in the project.
4. Suitability of design for modularization.
5. Use of Repetitive components in design.
6. Organization's familiarity with modularization.

7. Well defined scope and ultimate project budget parameters.
8. Integration of a well-versed team and collaboration among players.
9. Structural stability of individual and assembled modules.
10. Getting complete product submittals, shop drawings, and co-ordination drawings ahead of decision-making.
11. Competitive edge on bidding (i.e. if owner favors modularization).
12. Site accessibility.

Table 1

Rating and ranking of decision-making factors for modular construction

1. Design-related factors	**2. Module-related factors**	**3. Site attributes**	**4. Labor considerations**	**5. Manufacturing unit**	**6. Transportation and equipment**
Suitability of design	Structural stability	Site accessibility	Labor availability	Inspection/ supervision	Available transportation infrastructure
Repetitive components	Standardization of connections	Space constraints	Available labor skill level	Capability and productivity rate	Delivery distance
Standardization of components	Local codes	Weather conditions	Comparative labor productivity	Transportation accessibility	Availability of transportation vehicles and supporting equipment
Design flexibility	Workability	Availability of suitable trades	Comparative labor wage rate	Manufacturer's knowledge of state and local codes	Logistics of transporting material and equipment to site
MEP coordination	Durability	Environmentally sensitive site	Impact of labor force reduction	Efficiency	Required construction equipment availability and cost
Design status at the time of decision-making	Ease of fabrication	Site location	Labor fringes and support cost	Experience	Freight rates and taxes
Complexity of project design	Module size and weight	Safety and site security	Jurisdictional restrictions	Warranty/ insurance coverage	
Project scope, size and height	Maintenance	Site topography	Union presence and opposition	Location of the plant	
Foundation design	Reusability and relocatability	Bulk commodity availability		Material used approved by the environmental agencies	
Assembly joints		Available utilities		Security/ proprietary issues	
Ergonomic considerations					

Major factors | Moderate factors | Minor factors

Table 1 (continue…)

Rating and ranking of decision-making factors for modular construction

7. Organizations' readiness	8. Codes, permits and submittals	10. Owner's perspective	11. Project risk factors	12. Sustainability requirements	13. Finance related factors
Early upfront involvement of top management	Getting product submittals, shop drawings, co-ordination drawings	Owner's receptivity and willingness to accept modular construction	Lead time for materials, fabricated modules, etc.	Manufacturer's availability within 500 miles	Availability of preliminary finance feasibility study
Organization's familiarity with modularization	Meeting local codes and pertinent regulation requirements	Need of expediting the schedule	Testing, commissioning, inspection	LEED® certification	Savings on interest cost
Integration and collaboration among players	Obtaining approval, permits from all authorities	Well defined scope and project budget	Increased planning and engineering	Reduction in waste generation	Cost escalation
Competitive edge on bidding	Meeting transportation requirements and regulations	Owner's insistence on relocation and reusability in the future	High initial capital cost	Reduced construction pollutants at site	Allocation of financial resources
Effective cross-functional communications	**9. Technology-related factors**	Impact of construction on local business	Onsite maintainability issues	Reduced disturbance at the jobsite	Cost of liability, insurance and bonding
Willingness to work with design constraints	Use of BIM		Sharing risks, costs and rewards	Recycle material usage	Consideration of taxes/interim financing
Ability to adapt to new methods and processes	Use of advanced tracking technologies		Less control over overall construction processes	Building module reuse with relocation	
Number of projects in-hand	Use of advanced construction equipment				Available federal financing program
Willingness to fund modularization training package	Use of automated data handling technologies				

Major factors Moderate factors Minor factors

Similarly, the list of identified barriers (or constraints) that might be preventing the use of modular construction is as follows:

1. Key decisions about construction method made by the designers (i.e. design do not support modularization).
2. Owner's wrong conception about modularity (i.e. owner do not want prefabrication).
3. Non-availability of prefabrication unit in the project vicinity.
4. Restricted site layout (i.e. hard to transport large modules).
5. Decreased flexibility for design changes later in the project.
6. Carrying out late changes and on-site modifications in design is difficult.

Concluding Remarks

Currently modular construction is used to some degree in all forms of construction. The future applications of modularization are expected to increase at a fast pace due to increased use of BIM among project stakeholders, advancements in manufacturing methods, increased demand of green projects and heavy focus on productivity increase. Modularization has the potential to address many recurring industry challenges, including skilled work force availability, tight budgets, schedule compression, and reduced site risk by reducing onsite labor. It is noticed that information technologies are effectively helping to overcome the extra requirements of design, coordination, communication, and organization associated with modularization.

The decision-making process of selecting modular construction over the conventional stick-built construction is complex and based on a number of factors such as owner's willingness to accept modularization, early involvement of top management in the decision-making process, suitability of design for modularization, construction schedule, cost, and site characteristics. A key factor is the effective collaboration among project stakeholders in the early project stages. In this regard, the *Integrated Project Delivery* (IPD) system can play a vital role. If all stakeholders are onboard in the early project planning phase, it would be easier to plan and implement modularization concept.

Some of the barriers preventing the widespread use of modularization include lack of modularization provisions in typical project design, lack of awareness of the benefits of modular construction among owners, the non-availability of prefabrication units in the project vicinity, restricted site layout, and modular design rigidity. It is recommended that related organizations like Modular Building Institute (MBI) should play a more active role in educating owners, designers, and contractors about the benefits and implementation of modularization concepts. It is hoped that the findings of this study will help project stakeholders in making more informed decisions about the appropriate construction method selection.

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