

Comparative Study on Offsite Construction Techniques in the U.S. Building Construction

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This study's objective was to 1) investigate the current level of using offsite construction techniques in the building sector of the U.S. residential, commercial, and industrial construction sectors, 2) compare the benefits and challenges of using these techniques as perceived by Architects/Engineers (A/Es) and General Contractors (GCs) operating in the U.S. residential, commercial, and industrial construction sectors and 3) compare the attitudes toward using offsite construction techniques by experienced users and non-experienced users. The study sample included 1,200 randomly selected architects/engineers, and general contractors from a nationwide database. Several statistical methods including t-tests and regression tests were used in this study to process data using the SAS program. The findings indicate that the current level of use of offsite construction techniques comprise around 23% in the U.S. construction industry. Data from the study supports the assertion that residential, commercial, and industrial contractors have significantly different perceptions regarding the impact that these techniques have on project cost and building component quality. The findings show that experienced industry practitioners had a more positive attitude towards these techniques than those who had minimal, or no, experience with offsite construction techniques. Three approaches have been proposed in this study to increase the usage of these techniques, including: increasing R& D investment in offsite techniques, improve awareness training by manufactures, construction institutions/associations, etc.

Keywords: offsite construction techniques, preassembly techniques, modular buildings, panelized building systems, construction research.

Problem Statement

A large portion of construction research conducted in the United States and globally submits that the use of offsite construction techniques provides significant advantages, including: 1) the reduction of overall project schedules, 2) the improvement of product quality, 3) increased onsite safety performance, 4) a reduction in the need for onsite skilled workers, and 5) a decrease in the negative environmental impact caused by construction operations (Gann, 1996; Hsieh, 1997; CII, 2002; Edge, 2002; Gibb, 2003; Venables, 2004; Lu, 2007). However, the current level of utilization of offsite techniques in the United States construction industry remains limited (Lu, 2007; CII, 2002; Beliveau, 2000). Therefore, it would be beneficial to investigate the challenges and the benefits of using these techniques in the U.S. construction industry, and to identify the opportunities to increase the level of uses.

Research Objectives

The purposes of this study were to: 1) investigate the current level of utilization of offsite construction techniques in the building sector of the U.S. construction industry, 2) compare the perceived benefits and challenges of using these techniques by Architects/Engineers (A/Es) and General Contractors (GCs) in U.S. residential, commercial, and industrial construction sectors, 3) compare the attitude towards the use of offsite construction techniques by experienced users and non-experienced users, and 4) determine if a correlation exists between A/Es' or GCs' satisfaction of using these techniques and the percentage of use.

Research Scope

The offsite construction techniques in this study are defined as those construction techniques that accomplish offsite applications where building systems or assemblies are manufactured or fabricated away from the building site prior to installation. Those techniques include:

- *Offsite Preassembly*: Offsite preassembly refers to a process by which various building materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation. It is generally focused on a system, rather than a product. For example: roof trusses; preassembled vessels complete with insulation, platforms, piping, and ladders (Tatum et al, 1986).
- *Hybrid Systems*: Hybrid systems are prefabricated building facilities – a fully factory finished building unit with completed internal furnishes and building services. For example: factory finished bathrooms with interior finishing, plumbing, electrical service, and factory completed office rooms (Gibb, 2005).
- *Panelized Building Systems*: Panelized building systems consist of the construction of the structural frame, or building envelop, using building panels manufactured in a factory. It consists of factory-built components instead of completed modules that are transported to the site, assembled and secured in a permanent location. Typically it includes factory based fabrication, such as finished wall panels with cladding, insulation, internal finishes, doors and windows.
- *Modular Buildings*: Modular buildings refer to factory-built homes of one or more units completely assembled or fabricated in a manufacturing plant away from the jobsite. Subsequent to fabrication, they are transported and assembled on site. Modular buildings normally consist of multi-rooms with three-dimensional units, which are constructed and pre-assembled complete with trim work, electrical, mechanical, and plumbing installed.

Research Instrument

Because of the geographic dispersion of the subjects, the utilization of a self-administered questionnaire with a well-defined scope was determined to be the most feasible approach to gather data for this study. To enhance the validity and reliability of the survey instrument, a pilot study was conducted using 10 representatives from each of the A/E & GC groups. Feedback from the respondents regarding the content, scope, question structure, and response scales was used to improve validity and reliability of the survey questionnaire.

The survey instrument consisted of 4 sections: Section I asked for general information about the respondent and the degree of utilization of offsite construction techniques. Questions included the respondent's job title, company size and market sectors, the percent utilization of offsite construction techniques, and past experience with offsite construction techniques.

Section II investigated the perceived benefits and barriers of using offsite construction techniques. Participants were asked to evaluate the benefits and barriers of using offsite construction techniques by their level of agreement or disagreement with responses based upon a seven-point Lickert scale. Possible response selections included: 1 (strongly disagree), 2 (moderately disagree), 3 (slightly disagree), 4 (neither disagree nor agree), 5 (slightly agree), 6 (moderately agree), and 7 (strongly agree).

Section III asked the respondents to identify the top three reasons for using offsite construction techniques. Section IV asked the respondents to identify the top three challenges of using offsite construction techniques. Participants were asked to select the top 3 reasons/challenges of using offsite construction techniques from a list of options provided.

Sample Design

The population for this study were architects/engineers (A/Es) and general contractors (GCs) in the U.S. construction industry with their majority of work concentrated in the residential, commercial, and/or industrial sectors. The sampling frame for general contractors was a composite listing from the Dun & Bradstreet (D&B) list of general contractors whose annual volume was more than \$1 million U.S. dollars. Six hundred (600) general contractors were randomly selected from a total of 11,000. The sample frame for architects/engineers was the

American Institute of Architects (AIA) 2006 national membership list. Six hundred (600) design firms were randomly selected from a total of 49,595.

Findings

Data Analysis

Data collected from the questionnaires were analyzed by using the SAS computer program. Descriptive statistics were used to examine and summarize the data for each survey question. A series of 2 tail *T*-tests were used to analyze the interval data. Lastly, regression tests were used to determine if there was a linear relationship between respondents' satisfaction level of using offsite construction techniques and the percentage of their use.

General Information of participants

Of the 1,200 questionnaires distributed, 138 questionnaires (11.5%) were returned. Seven returned questionnaires were not usable. Therefore, 131 respondents (11%) were used in this study. 67 (51%) of these respondents were architects/engineers, and 64 (49%) were general contractors. The average annual revenue of the architect/engineer respondents was \$21.43 million with a range from \$0.1 million to \$300 million, and the average annual revenue of the general contractor respondents in 2005 was \$290.364 million U.S dollars, with a range from \$1.3 million to \$ 12 billion. The distribution is tabulated in Table 1.

	Residential	Commercial	Industrial	Institutional	Total
A/Es	13 (19.4%)	35 (52.2%)	1 (1.5%)	18 (26.9%)	67
GCs	14 (21.8%)	32 (50%)	7 (10.9%)	11 (17.3%)	64

Table 1 Respondents' market sectors

Current utilization of offsite construction techniques

The A/E respondents reported that 26.75% of their design work incorporated the use of one or more types of offsite construction techniques. The breakdown indicated the use was 19.57% for offsite preassembly, 1.6% for hybrid systems, 4.88% for panelized systems, and modular buildings were used 0.72% of the time. GC respondents reported that 19.62% of their work used one or more types of offsite construction techniques. Preassembly techniques were used 12.32% of the time, hybrid systems had a 0.09% utilization rate, panelized systems 6.17%, and 1.04% of the time modular buildings were utilized, as presented in Table 2.

	Preassembly	Hybrid systems	Panelized Systems	Modular	Total
A/Es	19.57%	1.58%	4.88%	0.72%	26.75%
GCs	12.32%	0.09%	6.17%	1.04%	19.62%

Table 2 The current degree of using offsite construction techniques in the building sector of US in 2006

Satisfaction level with the offsite construction techniques

In this study, each respondent was asked to indicate their level of satisfaction with each offsite construction technique. Satisfaction was measured using a 7-point Lickert scale that ranged from 1 (very unsatisfied) to 7 (very satisfied). Respondents were asked to select '0' if they had no experience with the offsite construction technique. The statistical means for all four techniques are presented in Table 3.

	A/Es	G/Cs
Offsite preassembly	5.69	5.74
Hybrid systems	4	5.23
Panelized systems	5.71	5.55
Modular systems	4.4	4.4

Table 3 The average satisfaction level of using offsite construction techniques

Relationship between satisfaction level and frequency of use

Four regression tests were conducted with this study to examine if there was a linear relationship between the A/Es' and GCs' satisfaction level with preassembly techniques and panelized systems and frequency of use. The results of the regression tests yielded the model of $Y = 18.08 + 8.20X$ for the A/Es' satisfaction levels of preassembly technique with their frequency of use. This result suggested that if A/Es' satisfaction level of preassembly technique increases 1 point (on the seven point scale), the frequency of specifying this technique for their projects would increase 8.2%.

Residential vs Commercial A/Es' Perceptions

The findings indicated that A/Es in the residential market had different perceptions regarding the use of offsite construction techniques when compared to A/Es primarily in the commercial market. Statistically significant differences include the following:

- 1) Residential A/Es perceive the utilization of offsite construction techniques as less restrictive on design options.
- 2) Commercial A/Es perceive that an owner's negative perception of offsite construction techniques has less influence on their use.
- 3) Commercial A/Es perceive that the complicated software necessary for designing offsite construction is a greater deterrence to using these techniques.

The results are tabulated in Table 5.

Perceptions	Residential N=12	Commercial N=55	Sig. diff.
The use of offsite construction techniques reduces the overall project schedule.	4.55	5.23	No
The use of offsite construction techniques reduces the need for skilled craft workers onsite.	4.00	4.20	No
The use of offsite construction techniques reduces the project construction cost.	4.09	4.30	No
The use of offsite construction techniques increases product quality.	4.27	4.70	No
The use of offsite construction techniques increases overall labor productivity.	4.64	4.98	No
The use of offsite construction techniques limits design options.	3.27	4.11	YES
The use of offsite construction techniques increases safety performance.	4.09	4.43	No
The use of offsite construction techniques reduces onsite disruption of other adjacent operations.	4.36	4.42	No
The use of offsite construction techniques reduces environmental impact of construction operations.	4.36	4.61	No
The use of offsite construction techniques increases project design efficiency.	3.90	3.88	No
The use of offsite construction techniques increases design cost.	3.64	3.44	No
The use of offsite construction techniques increases the overall project cost.	3.00	2.89	No
Transportation restraints limit the use of offsite construction techniques.	4.91	4.77	No
The owner's negative perception of offsite construction techniques limits the use of those techniques.	4.00	3.53	Yes
Offsite construction techniques limit the ability to make change onsite work.	5.45	4.88	No

Complicated computer software for designing offsite construction techniques limits their uses.	3.55	3.07	Yes
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Table 5 Comparing A/Es' perceptions by market segments

GCs' Perceptions: Residential vs. Commercial vs. Industrial

The result of the comparative study on GCs subgroup indicated that the residential, commercial and industrial GCs had different perspectives of using these techniques as follows:

- 1) Compared to the two (2) other subgroups, industrial GCs believe that the use of offsite construction techniques had a more favorable impact on product quality.
- 2) Commercial and residential GCs agreed that using these techniques would limit design options, while industrial GCs felt it had no impact.
- 3) Industrial GCs perceive offsite techniques as having a greater influence on the reduction of negative environmental impacts.
- 4) Only commercial GCs perceived that an owner's negative perceptions limited the use of these techniques. Conversely, industrial GCs believe that negative owner perception did not impact use.

A comprehensive listing of the mean responses is presented in Table 6.

Perceptions	Residential	Commercial	Ind.
	N=14	N=43	N=7
The use of offsite construction techniques reduces the overall project schedule.	5.15	5.32	5.71
The use of offsite construction techniques reduces the need for skilled craft workers onsite.	4.92	4.79	5.14
The use of offsite construction techniques reduces the project construction cost.	4.38	4.47	4.29
The use of offsite construction techniques increases product quality.	4.38	4.26	5.57
The use of offsite construction techniques increases overall labor productivity.	5.31	5.17	5.86
The use of offsite construction techniques limits design options.	4.46	4.64	4.00
The use of offsite construction techniques increases safety performance.	4.69	4.66	5.00
The use of offsite construction techniques reduces onsite disruption of other adjacent operations.	4.85	4.77	5.86
The use of offsite construction techniques reduces environmental impact of construction operations.	4.69	4.30	5.00
The use of offsite construction techniques increases jobsite management efficiency.	4.68	4.29	5.86
The use of offsite construction techniques increases overall project cost.	3.46	3.53	1.86
Transportation restraints limit the use of offsite construction techniques.	5.15	5.09	5.29
The owner's negative perception of offsite construction techniques limits their uses.	4.15	4.62	3.14
The local building regulations restrict the use of offsite construction techniques.	3.15	3.81	2.43
The use of offsite construction techniques limits the ability to make change onsite work.	5.23	5.02	4.86
Lack of skilled assembly craft workers limits the use of offsite construction techniques.	2.92	3.19	3.14

Table 6 GCs' perception comparison by market segments

A/Es' Users vs. Non-users

The findings indicate that A/Es who have specified offsite construction techniques (Users) had different perceptions of using these techniques with those who had no experience (Non-users) with regard to the following aspects:

- 1) Users agreed that using these techniques reduced project cost.
- 2) Users agreed that using these techniques would improve onsite safety performance.
- 3) Users believe that an owner's negative perceptions are not a barrier to using these techniques.

A comprehensive listing is shown in Table 7.

Perceptions	Users	Non-users	Sig. diff.
	N=44	N=23	
The use of offsite construction techniques reduces the project construction cost.	4.32	4.17	Different
The use of offsite construction techniques increases product quality	4.66	4.57	Same
The use of offsite construction techniques increases overall labor productivity	5.07	4.65	Same
The use of offsite construction techniques limits design options	3.91	4.09	Same
The use of offsite construction techniques reduces onsite disruption of other adjacent operations.	4.45	4.35	Same
The use of offsite construction techniques reduces environmental impact of construction operations	4.57	4.61	Same
The use of offsite construction techniques increases project design efficiency.	3.84	3.96	Same
The use of offsite construction techniques increases design cost.	3.41	3.57	Same
The use of offsite construction techniques increases the overall project cost.	2.82	3.04	Same
Transportation restraints (i.e. size constraints, transportation cost, and impact on building structures) limits the use of offsite construction techniques.	4.75	4.78	Same
The owner's negative perception of offsite construction techniques limits the use of these techniques	3.34	4.09	Different
The use of offsite construction techniques limits the ability to make change onsite work.	5.05	4.83	Same
Complicated computer software for designing offsite construction techniques limit their uses.	3.23	3.00	Same

Table 7 Comparing A/Es' perceptions by past experience with using offsite construction technique

GC's: User vs. Non-user Perceptions

The findings indicate that GCs who have specified offsite construction techniques (Users) had different perceptions of using these techniques with those who had no experience (Non-users) with regard to the following aspects:

- 1) Users believed that using these techniques improved product quality.
- 2) Users felt that using these techniques would increase onsite management efficiency.
- 3) Users believe that using these techniques will not increase overall project cost.
- 4) The Non-user group felt that using these techniques would limit design options, while Users felt their use would not limit design options.

A summary of the findings is presented in Table 8.

Perceptions	Users	Non-User	Significant
	N=41	N=23	Difference

The use of offsite construction techniques reduces the overall project schedule.	5.49	5.30	Same
The use of offsite construction techniques reduces the need for skilled craft workers onsite.	4.93	5.09	Same
The use of offsite construction techniques reduces the project construction cost.	4.44	4.48	Same
The use of offsite construction techniques increases product quality.	4.68	4.09	Different
The use of offsite construction techniques increases overall labor productivity.	5.27	5.35	Same
The use of offsite construction techniques limits design options.	4.34	5.13	Different
The use of offsite construction techniques increases safety performance.	4.68	4.83	Same
The use of offsite construction techniques reduces onsite disruption of other adjacent operations.	5.05	4.87	Same
The use of offsite construction techniques reduces environmental impact of construction.	4.59	4.22	Same
The use of offsite construction techniques increases jobsite management efficiency.	4.83	4.17	Different
The use of offsite construction techniques increases overall project cost.	3.24	3.78	Different
Transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of offsite construction techniques.	5.20	5.13	Same
The owner's negative perception of offsite construction techniques limits the use of those techniques.	4.02	4.96	Different
The local building regulations restrict the use of offsite construction techniques.	3.54	3.57	Same
The use of offsite construction techniques limits the ability to make change onsite work.	5.12	5.30	Same
Lack of skilled assembly craft workers limits the use of offsite construction techniques.	3.24	3.04	Same

Table 8 Comparing GCs' perceptions by past experiences with using offsite construction techniques

Conclusion

The findings of this study indicated offsite construction techniques are incorporated into 23% of new building construction, in 2006. Use of offsite construction techniques was predominately limited to offsite preassembly techniques, such as precast concrete products and preassembled trusses. The results from the regression tests showed a positive relationship between the A/Es' satisfaction levels with preassembly techniques and their percent utilization.

This study found that residential A/Es versus commercial A/Es perceive the contributing factors to the use of these techniques regarding limited design options, owner's perspectives, and computer software as being significantly different from each other. In addition, residential, commercial, and industrial contractors perceive the impact of these techniques on building product quality and overall project cost as being significantly different from each other. The findings also indicated that practitioners in industry sectors had a stronger positive attitude towards using offsite construction techniques, which presented an enhanced opportunity to increase the level of utilization of these techniques in this sector.

The finding show that among both the A/Es and GCs groups experienced users had a more positive attitude towards these techniques than those having no experience.

Recommendations

Based on the findings of this study, three (3) major recommendations to increase the use of these techniques in the U.S construction industry are proposed as follows:

- 1) Construction companies and professional organizations should invest more in research and development in the area of customized design and alternative materials.
- 2) Awareness training regarding the use of offsite construction techniques should be developed and provided to manufacturers, general contractors, and designers.
- 3) Owners, designers, and general contractors should collaborate with each other on pre-project planning, to overcome the fact that using offsite construction techniques would limit the flexibility of onsite changes.

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