Modularization Critical Success Factors Accomplishment: Learning from Case Studies

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ABSTRACT
A well-known method of improving productivity in the construction industry is modularization, in which a portion of potential site-based work is carried out in fabrication/assembly shops. The construction industry as a whole, however, makes little use of modularization. Previous studies have identified how modularization is used now as well as the obstacles to applying it to projects. To help achieve wider and more effective use of modularization, the Construction Industry Institute’s (CII) Research Team 283 identified in 2013 21 critical success factors (CSFs). Information that is still missing, however, is the current level of CSF accomplishment on actual modular projects. This work collects such information and analyzes the general status of, degree of, and timing of CSFs accomplishment. This work finds that what appear to be challenging but valuable opportunities to increase modularization are higher degree of accomplishment in early completion recognition, investment in studies, and owner-delay avoidance. Moreover, this paper recommends earlier accomplishment on the following CSFs: module envelope limitations, alignment on drivers, module fabricator capability, and vendor involvement. This understanding of how well the industry accomplishes modularization CSFs should provide insight into how to achieve higher levels of modularization.

INTRODUCTION
Prior studies have established well modularization’s process and recognized its values and benefits. When modularization and related PPMOF (Prefabrication, Preassembly, Modularization, and Offsite Fabrication) techniques are properly used, they offer a great opportunity to improve project performance (Song et al. 2005; Tatum et al. 1987). Many past studies have also explored some of the barriers to its application.

However, the industry continues to struggle to achieve higher levels of modularization (Haas et al. 2000; Lu 2009; McGraw-Hill 2011). To deal with this issue, several studies have identified success factors for higher levels of modularization. In the building modular sector, Gibb and Isack (2003) identified, from the owner’s viewpoint, several success factors: early design freeze, reasonable lead times, sufficient time for pre-site prototyping, early vendors involvement, and owner’s understanding of its benefits and limitations. To help with achieving higher levels of modularization in the industrial sector, O’Connor et al. (2013) identified, by
surveying construction industry modular experts, the following 21 most influential CSFs.

- **CSF#1 - Module envelope limitations** (Impact score 3.83): Preliminary transportation evaluation should result in understanding module envelope limitations.
- **CSF#2 - Alignment on drivers** (3.79): Owner, consultants, and critical stakeholders should be aligned on important project drivers as early as possible in order to establish the foundation for a modular approach.
- **CSF#3 - Owner’s planning resources & processes** (3.58): As a potentially viable option to conventional stick building, early modular feasibility analysis is supported by owner’s front-end planning & decision support systems, work processes, and team resources support. Owner “comfort zones” are not limited to the stick-built approach.
- **CSF#4 - Timely design freeze** (3.58): Owner & Contractor are disciplined enough to effectively implement timely staged design freezes so that modularization can proceed as planned.
- **CSF#5 - Early completion recognition** (3.42): Modularization business case should recognize and incorporate the economic benefits from early project completion that result from modularization, and those resulting from minimal site presence and reduction of risk of schedule overrun.
- **CSF#6 - Preliminary module definition** (3.42): Front-end planners and designers need to know how to effectively define scope of modules in a timely fashion.
- **CSF#7 - Owner- furnished/long lead equipment specification** (3.42): Owner-furnished and long-lead equipment (OFE) specification and delivery lead time should support a Modular approach.
- **CSF#8 - Cost savings recognition** (3.42): Modularization business case should incorporate all cost savings that can accrue from the modular approach. Project teams should avoid the knee-jerk misperception that modularization always has a net cost increase.
- **CSF#9 - Contractor leadership** (3.39): Front-end Contractor(s) should be proactive - supporting the Modular approach on a timely basis and prompting Owner support, when owner has yet to initiate.
- **CSF#10 - Contractor experience** (3.37): Contractors (supporting all phases) have sufficient previous project experience with the modular approach.
- **CSF#11 - Module fabricator capability** (3.37): Available, well-equipped Module-Fabricators have adequate craft, skilled in high-quality/tight-tolerance Modular fabrication.
- **CSF#12 - Investment in studies** (3.32): Owner should be willing to invest in early studies into Modularization opportunities in order to capture full benefit.
- **CSF#13 - Heavy lift/site transport capabilities** (3.32): Needed heavy lift/site transport equipment and associated planning/execution skills are available and cost-competitive.
- **CSF#14 - Vendor involvement** (3.28): OEMs and technology partners need to be integrated into the Modularized solution process in order to maximize related beneficial opportunities.
CSF#15 - O&M provisions (3.26): Module detailed designs should incorporate and maintain established O&M space/access needs.

CSF#16 - Transport infrastructure (3.22): Needed local transport infrastructure is available or can be upgraded/modified in a timely fashion while remaining cost-competitive.

CSF#17 - Owner delay avoidance (3.16): Owner has sufficient resources and discipline to be able to avoid delays in commitments on commercial contracts, technical scope, and finance matters.

CSF#18 - Data for optimization (3.05): Owner and Pre-FEED/FEED contractor(s) need to have management tools/data to determine the optimal extent of modularization, i.e., maximum NPV (that considers early revenue streams) vs. % Modularization.

CSF#19 - Continuity through project phases (3.00): Disconnects should be avoided in any contractual transition between Assessment, Selection, Basic Design, or Detailed Design phases; their impacts can be amplified with Modularization.

CSF#20 - Management of execution risks (3.00): Project risk managers need to be prepared to deal with any risks shifted from the field to engineering/procurement functions.

CSF#21 - Transport delay avoidance (3.00): Environmental factors such as hurricanes, frozen seas, or lack of permafrost, in conjunction with fabrication shop schedules, do not result in any significant project delay.

By surveying modularization experts in the research team, earlier studies have identified the most impactful CSFs and quantified today’s frequency of each CSFs’ occurrences. What has yet to be identified is the accomplishment of modularization CSFs on current modular projects. Such information is critical to an exact understanding of current industry status and problems so as to provide better solutions to the construction industry.

OBJECTIVES

This study is aligned with CII Research Team 283’s primary research question: “What changes or adaptations in traditional project work processes are required to create an optimum environment for broader and more effective use of modularization?” The authors believe that one of the most critical studies that might provide appropriate solutions is one that provides a portrait of the current status of modular projects. This study addresses the issue by analyzing the industry status on modularization CSF accomplishment. The specific research questions are:

- What is current industry status on CSF accomplishments?
  - Total # of CSF accomplishments
  - Most commonly accomplished CSFs
  - Most commonly unfulfilled to accomplish CSFs
- What is the degree of CSF accomplishments according to each CSF?
- When is each CSF accomplished in current modular projects—and how do these square with the previous CII’s recommended timing?

The scope of the research concerns primarily the industrial sub-sector, including process and manufacturing facilities such as offshore facilities, petro-
chemical plants, power plants, and pharmaceutical plants, among others. Due to the limited number and type of case projects, the findings’ interpretations may be limited.

**ORGANIZATION OF PAPER**

After addressing this paper’s research methodology, this paper presents the following modularization CSF accomplishment from case studies: 1) general CSFs accomplishment, 2) degree of CSFs accomplishments by each CSF, 3) timing of CSF accomplishment, and 4) variations between CII’s recommendation and actual timing of CSF accomplishment. Later, the paper summarizes, in Conclusions and Contributions, what was learned from the analysis, research significance, and needs for future research.

**RESEARCH METHODOLOGY**

**Identify the Research Gaps**

First, the researcher identifies the gaps in the research and selects an appropriate research method. An extensive literature review is conducted focusing on the success factors for higher levels of modularization. The literature review facilitated a clear defining of the problem. Research questions were then formulated and variables and area of interest were defined.

**Develop Questionnaire**

Next, the study developed the research design and specific data collection procedure. The researcher, having selected the survey as the research instrumentation, developed a draft of a survey questionnaire. The authors would like to note that there are several risks associated with the survey method such as possibility of surveying only cooperative respondents, over/under-rated answers, biased respondents or questions, etc.

The survey questionnaire consists of four sections (with a total of 42 questions) and an appendix (21 CSFs). The four sections are: 1) project characteristics, 2) standardized module, 3) CSFs accomplishments, and 4) project performance. This paper uses for analysis only several questions regarding project characteristics and CSFs accomplishments sections’ questions. Project Characteristics section questions focus on examining the characteristics of a project. The questions in this section concern a project’s general information, fabrication and module assembly shop information, modularization information such as common module and modularization extent, advantages and impediments to the project, and project drivers. In the CSFs accomplishment section, the surveyees assessed, in terms of degree and timing, the accomplishing of modularization CSFs for the project. Most questions/statements were closed-ended, partially open-ended, and of the rating-scale type. To avoid burdening the respondents, the study limited its wholly open-ended questions.

The CII Modularization Community of Practices (COP) is a formal venue for the exchange of knowledge that is useful in planning, designing, and executing modularization of varying levels of complexity on capital facility projects. The Modularization COP is composed of members that share a vision of guiding the capital projects industry to enhanced project performance through modularization. To elaborate the survey questionnaire, the authors asked the CII Modularization COP
team to review it and provide feedback. A pilot study was then conducted. Through these efforts, several revisions were progressively made to the questionnaire.

Identify Modular Case Projects
The next step was defining the population and target projects. In this process, the researchers aimed to contact the project manager or superintendent who actually executed the project. The CII Modularization COP and the Front-End-Planning COP supported searching for candidate modular projects and experts who were capable of answering the questionnaire. Also, previous CII RT 283 members and their reviewers were contacted for their participation in the survey. The population of the study is any recent project that implemented the modular technique. The population is not limited to a certain location (country) or company. Since surveying the entire population was infeasible, the researcher selected sample projects from the population and administered the survey to them.

Survey Distribution
In April 2013, the researcher began distributing the survey questionnaires. The surveys were sent via email and were collected likewise as well as through the traditional mail system. This approach generally produces less sampling bias—the tendency for one group to be overrepresented in a sample—than do phone surveys or personal interview. Furthermore, this approach eliminates the problem of interviewer bias—the tendency for the person asking the questions to influence the participants’ answers (Jackson 2003). Thus far, at end of July, the invitation emails were sent out to 91 possible candidates. Data collection will continue until the end of August 2013.

Assess CSFs Accomplishments
First, project characteristic was analyzed to understand the collected modular projects. From the case studies, this analysis covered the following: surveyee’s industry experience, their representatives, project type, TIC (Total installed cost), project duration, site location, current projects status, modularized types of units/sub-units, percent modularization, primary factor, site laydown space, quantity and quality of jobsite and fabrication shop, and use of standardized modules.

Second, detailed analyses on general CSFs accomplishment, degree of CSFs accomplishments by each CSF, timing of CSF accomplishment of each CSF, and variations between CII’s recommendation and actual timing of CSF accomplishment were conducted by studying collected case project information.

Since this conference paper had to be submitted by mid-August, the data analysis for this paper was conducted using six modular case projects, which the researchers had by the end of July. A full data analysis result with completed data collection will be presented at the 2013 CRC conference.

RESULTS AND ANALYSIS
The authors conducted the research analysis and present it in the following order: 1) characteristics of case projects, 2) general CSF accomplishment, 3) degree of CSF accomplishments by each CSF, 4) timing of CSF accomplishment, and 5) variations between CII’s recommendations and actual timing of accomplished CSFs.
Characteristic of Case Projects

The analysis selected a total of six case projects. Each surveyee who completed the survey had on average 23+ years of industry experience including some with modular techniques. The representation of surveyees included 2 owners, 3 contractors, and 1 OEM. All of the selected projects were in the heavy industrial sector and their subsector included: petro-chemical (mid-stream), chemical manufacturing, power, oil refining, and oil sands. The projects’ construction execution was begun between 2004 and 2012. The expected/determined TIC (total installed cost) of the projects (only facility cost) ranged from $0.1 billion to $7 billion. And the average of expected/determined project month number from start of site construction to actual or target mechanical completion was approximately 24 months. All sites were located in North America, from Mexico to Canada. When the survey was conducted, the current statuses of the projects were between EPC and In Operation. There were some variations by project, but the modularized types of units/sub-units include: process equipment, loaded piperacks, dressed up vessels, structural modules, utility equipment, dressed up vessels, power generation equipment, and remote instrument buildings. The average of the approximated percent modularization of the projects was 50.5% (Min. 33% & Max. 80%). Other characteristics are summarized in Table 1.

<table>
<thead>
<tr>
<th>Primary Factor</th>
<th>Project A</th>
<th>Project B</th>
<th>Project C</th>
<th>Project D</th>
<th>Project E</th>
<th>Project F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Laydown Space</td>
<td>Tight</td>
<td>Cost</td>
<td>Schedule</td>
<td>Cost and Schedule (Balanced)</td>
<td>Schedule</td>
<td></td>
</tr>
<tr>
<td>Quantity Jobsite</td>
<td>Inadequate or non-existent supply</td>
<td>Adequate supply</td>
<td>Inadequate or non-existent supply</td>
<td>Inadequate or non-existent supply</td>
<td>Adequate supply</td>
<td></td>
</tr>
<tr>
<td>Quality Jobsite</td>
<td>High quality</td>
<td>Adequate quality</td>
<td>Adequate quality</td>
<td>Low quality</td>
<td>Adequate quality</td>
<td>High quality</td>
</tr>
<tr>
<td>Quantity Fab-shop</td>
<td>Adequate supply</td>
<td>Adequate supply</td>
<td>Adequate supply</td>
<td>Adequate supply</td>
<td>Adequate supply</td>
<td>Adequate supply</td>
</tr>
<tr>
<td>Quality Fab-shop</td>
<td>High quality</td>
<td>Adequate quality</td>
<td>High quality</td>
<td>High quality</td>
<td>High quality</td>
<td>High quality</td>
</tr>
<tr>
<td>Use of Standardized modules</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

As can be seen in Table 1, the most common primary factor for collected modular case projects was schedule. Their site laydown space adequacy was close to half generous and half tight. With respect to characteristics of jobsite and fabrication shop, clear differences were identified. On average, labor quantity at jobsites was inadequate or non-existent and labor quality at jobsites was adequate. This is in contrast to the fabrication shops, which on average had sufficient labor supply as well as high quality. This shows that one of the significant benefits of transferring site
work to fabrication shops is gaining higher labor quality and quantity. However, consistent labor productivity characteristic was not identified either jobsites or fabrication shops.

**General CSFs Accomplishment**

Without considering degree of CSFs accomplishment, an average of nearly 80% of CSFs were accomplished partially, mostly, or fully (Min. = 59% - Project A & Max. = 95% – Projects 5 & 6). Among the six case projects, the most commonly unfulfilled CSFs were #3–timely design freeze—and #4–early completion recognition (unfulfilled 3/6). The next most commonly unfulfilled were CSF# 7–owner-furnished/long lead equipment specification, CSF#12–investment in studies, CSF#17–owner delay avoidance, CSF#18–data for optimization, and CSF#19–continuity through project phases (unfulfilled 2/6).

**Degree of CSFs Accomplishments by each CSF**

To measure more precise CSFs accomplishments, degree of CSFs accomplishments were measured by each CSF and their results are presented in Table 2.

<table>
<thead>
<tr>
<th>CSF #</th>
<th>Avg. Accomplishment</th>
<th>CSF #</th>
<th>Avg. Accomplishment</th>
<th>CSF #</th>
<th>Avg. Accomplishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85%</td>
<td>8</td>
<td>60%</td>
<td>15</td>
<td>68%</td>
</tr>
<tr>
<td>2</td>
<td>68%</td>
<td>9</td>
<td>73%</td>
<td>16</td>
<td>68%</td>
</tr>
<tr>
<td>3</td>
<td>52%</td>
<td>10</td>
<td>78%</td>
<td>17</td>
<td>38%</td>
</tr>
<tr>
<td>4</td>
<td>35%</td>
<td>11</td>
<td>100%</td>
<td>18</td>
<td>47%</td>
</tr>
<tr>
<td>5</td>
<td>40%</td>
<td>12</td>
<td>32%</td>
<td>19</td>
<td>47%</td>
</tr>
<tr>
<td>6</td>
<td>62%</td>
<td>13</td>
<td>90%</td>
<td>20</td>
<td>68%</td>
</tr>
<tr>
<td>7</td>
<td>45%</td>
<td>14</td>
<td>67%</td>
<td>21</td>
<td>78%</td>
</tr>
</tbody>
</table>

High degree of CSFs accomplishments (bolded) were identified in CSF#1–module envelop limitations (85%), CSF#11–module fabricator capability (100%), and CSF#13–heavy lift/site transport capabilities (90%). Interestingly, CSF#11–module fabricator capability accomplished 100%. Compared to that, CSF#4–timely design freeze (35%), CSF#12–investment in studies (32%), and CSF#17–owner delay avoidance (38%) showed a low degree of CSFs accomplishments (underlined). With these results, the authors concluded that to achieve even higher levels of modularization, CSFs with low degrees of accomplishment (CSF#s 4, 12, and 17) would have been required for the case projects.

**Timing of CSF accomplishment**

An important factor to measure their accomplishment on CSFs is not only CSF’s degree of accomplishment but the projects’ timing of CSF accomplishment. The surveyees were asked to assess the modularization CSFs accomplishment for their case project by project phase: 1) Opportunity Framing, 2) Assessment (FEL1),
3) Selection (FEL2), 4) Basic Design (FEL3), and 5) EPC (Execution). The results of each project’s timing of accomplishments by each CSF are laid out in Table 3.

Table 3 Timing of CSF Accomplishment

<table>
<thead>
<tr>
<th>CSF Recommendation</th>
<th>Project A</th>
<th>Project B</th>
<th>Project C</th>
<th>Project D</th>
<th>Project E</th>
<th>Project F</th>
<th>% Later</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSF #1</td>
<td>Opportunity Framing</td>
<td>EPC</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>Basic Design</td>
<td>Opportunity Framing</td>
<td>Assessment 5/6</td>
</tr>
<tr>
<td>CSF #2</td>
<td>Opportunity Framing</td>
<td>Basic Design</td>
<td>Opportunity Framing</td>
<td>Selection</td>
<td>Assessment</td>
<td>Opportunity Framing</td>
<td>Assessment 4/6</td>
</tr>
<tr>
<td>CSF #3</td>
<td>Opportunity Framing</td>
<td>N/A</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>-</td>
<td>Opportunity Framing</td>
<td>Assessment 3/3</td>
</tr>
<tr>
<td>CSF #4</td>
<td>Early to Mid</td>
<td>Basic Design</td>
<td>-</td>
<td>Selection</td>
<td>Basic Design</td>
<td>-</td>
<td>Basic Design 0/6</td>
</tr>
<tr>
<td>CSF #5</td>
<td>Assessment</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>EPC</td>
<td>Assessment</td>
<td>Selection 2/6</td>
</tr>
<tr>
<td>CSF #6</td>
<td>Starting in Assessment</td>
<td>N/A</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>Selection</td>
<td>Assessment</td>
<td>Assessment 2/6</td>
</tr>
<tr>
<td>CSF #7</td>
<td>Starting in Assessment</td>
<td>EPC</td>
<td>Assessment</td>
<td>-</td>
<td>-</td>
<td>Selection</td>
<td>Assessment 2/6</td>
</tr>
<tr>
<td>CSF #8</td>
<td>Starting in Assessment</td>
<td>-</td>
<td>Opportunity Framing</td>
<td>Selection</td>
<td>Selection</td>
<td>Assessment</td>
<td>Selection 3/6</td>
</tr>
<tr>
<td>CSF #9</td>
<td>Assessment</td>
<td>EPC</td>
<td>Assessment</td>
<td>EPC</td>
<td>-</td>
<td>Basic Design</td>
<td>Assessment 3/6</td>
</tr>
<tr>
<td>CSF #10</td>
<td>Assessment thru Detailed Design</td>
<td>EPC</td>
<td>Selection</td>
<td>EPC</td>
<td>-</td>
<td>Basic Design</td>
<td>Assessment 2/6</td>
</tr>
<tr>
<td>CSF #11</td>
<td>Selection</td>
<td>EPC</td>
<td>Selection</td>
<td>EPC</td>
<td>Basic Design</td>
<td>Basic Design</td>
<td>Selection 4/6</td>
</tr>
<tr>
<td>CSF #12</td>
<td>Assessment and Selection</td>
<td>N/A</td>
<td>Opportunity Framing</td>
<td>-</td>
<td>-</td>
<td>Assessment</td>
<td>Assessment 0/6</td>
</tr>
<tr>
<td>CSF #13</td>
<td>Basic Design</td>
<td>EPC</td>
<td>Assessment</td>
<td>EPC</td>
<td>Selection</td>
<td>Basic Design</td>
<td>Basic Design 2/6</td>
</tr>
<tr>
<td>CSF #14</td>
<td>Starting in Assessment</td>
<td>EPC</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>Basic Design</td>
<td>Basic Design</td>
<td>-</td>
</tr>
<tr>
<td>CSF #15</td>
<td>Basic Design</td>
<td>N/A</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>Basic Design</td>
<td>EPC</td>
<td>Assessment 1/6</td>
</tr>
<tr>
<td>CSF #16</td>
<td>Assessment</td>
<td>-</td>
<td>Assessment</td>
<td>EPC</td>
<td>Basic Design</td>
<td>Assessment</td>
<td>Assessment 2/6</td>
</tr>
<tr>
<td>CSF #17</td>
<td>Late in Selection</td>
<td>-</td>
<td>Assessment</td>
<td>EPC</td>
<td>-</td>
<td>Basic Design</td>
<td>Selection 1/6</td>
</tr>
<tr>
<td>CSF #18</td>
<td>Early in Selection</td>
<td>-</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>-</td>
<td>Selection</td>
<td>Selection 1/6</td>
</tr>
<tr>
<td>CSF #19</td>
<td>All Phases</td>
<td>-</td>
<td>Assessment</td>
<td>Basic Design</td>
<td>-</td>
<td>Basic Design; EPC</td>
<td>Assessment; Selection; Basic Design 0/6</td>
</tr>
<tr>
<td>CSF #20</td>
<td>EPC</td>
<td>EPC</td>
<td>Assessment</td>
<td>EPC</td>
<td>Selection</td>
<td>EPC</td>
<td>Basic Design 0/6</td>
</tr>
<tr>
<td>CSF #21</td>
<td>EPC</td>
<td>EPC</td>
<td>Assessment</td>
<td>EPC</td>
<td>Selection</td>
<td>EPC</td>
<td>EPC</td>
</tr>
</tbody>
</table>

* indicates later CSFs accomplishment than that recommended by CII
*(-) indicates Not Accomplished
In general, Projects A and C showed late CSF accomplishment compared to other projects—most of their CSFs were accomplished between Basic design and EPC. Project B showed good accomplishment timing compared to other projects.

**Variations between CII’s Recommendation and Actual Timing of CSF Accomplishment**

The CII Research Team established the optimal timing in addition to identifying CSFs. They asserted that CSFs are necessary to deploy organizational resources at the optimal timing to address each CSF and maximize its impact. Their recommendations are presented in Table 3, second column. To better understand how the case projects did on timing, each CSF was compared in terms of CII’s recommendation on Modularization CSFs accomplishment timing and case projects’ accomplishment. Shaded in gray are the CSFs that were accomplished later than that recommended by CII.

To increase modularization, what appear to be challenging but valuable opportunities are CSF#1–Module envelope limitations, CSF#2–Alignment on drivers, CSF#11–Module fabricator capability, and CSF#14–Vendor involvement. The most unfulfilled CSF was in Opportunity framing with understanding module envelope limitations from preliminary transportation evaluation (CSF#1). It turned out that most case projects accomplished it later than Opportunity framing. Other commonly unfulfilled CSFs which showed some variation between CII’s recommendation and actual timing of CSF accomplishment were CSF#s 1, 2, 11, and 14; see Table 3.

**CONCLUSIONS AND CONTRIBUTIONS**

**Summary of What Was Learned**

The previous CII research team identified 21 of the most important CSFs ranked according to impact. To provide enhanced solutions for higher levels of modularization, this study, in addition to analyzing general CSF accomplishment, also analyzed the degree and timing of CSF accomplishment.

In the general CSF accomplishment analysis, frequently unfulfilled CSFs were identified: CSF#3–timely design freeze, CSF#4–early completion recognition, CSF#7–owner-furnished/long lead equipment specification, CSF#12–investment in studies, CSF#17–owner delay avoidance, CSF#18–data for optimization, and CSF#19–continuity through project phases. In the analysis of degree of CSFs accomplishment by each CSF, CSF#s 4, 12, and 17 showed low degree of accomplishment. What are needed to increase modularization are achievement in non-accomplished CSFs and higher accomplishments in low degree of CSFs.

CSFs that were frequently accomplished later than CII’s recommendations included CSF#1–module envelope limitations, CSF#2–alignment on drivers, CSF#11–module fabricator capability, and CSF#14–vendor involvement. Accomplishing these CSFs early represent valuable opportunities to increase modularization.

**Research Significance**

This study tried to answer one primary question: “What changes or adaptations are required to create an optimum environment for broader and more effective use of modularization?” The previous study identified the most impactful CSFs by surveying industry experts. However, what lay beyond the scope of the
previous study was modularization CSF accomplishments on current modular projects. Such information is critical, it would seem, to understanding the current industry status and problems and provide better solutions to the construction industry.

This study, by collecting actual modular case project information, assessed the current industry’s status on modularization. The study assessed the following: 1) total # of CSF accomplishments, 2) most commonly accomplished CSFs, 3) most commonly unfulfilled CSFs, 4) degree of CSFs accomplishment according to each CSF, and 5) timing of CSF accomplishment. The findings from the study are useful in understanding the current status of modular projects and should provide insight into how to achieve higher levels of modularization.

**Needs for Future Research**

From the results, the authors provide solutions for the collected projects. These solutions, however, are limited in their generalizability to the industry. If more case projects could be collected, this could lead to solutions that provide higher levels of modularization in the industry. Furthermore, from the collected data, we should be able to characterize current industrial modularization (advantages, disadvantages, drivers, etc.) and examine quantitative links between modularization CSFs, modularization extent, and project performance. The identified findings can be extend to other industries such as commercial building, residential, or infrastructure sectors.

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**REFERENCES**


