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EXECUTIVE SUMMARY

The purpose of this project was to determine prefabrication and preassembly trends and effects on the construction workforce. Twenty-nine managers from across the United States were surveyed. Based on their responses, it was estimated that prefabrication and preassembly increased by approximately 86% from 1984 to 1999. For prefabrication and preassembly work, those surveyed generally agreed that productivity and safety levels are higher, skill levels are the same, and wage levels are lower. These results can be factored into future project and supply chain strategies.

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CHAPTER 1: INTRODUCTION

1.1 Problem Definition

Prefabrication, pre-assembly, and modularization are well-established strategies for construction. They have the potential to reduce project duration, improve productivity, reduce labor costs, and streamline the supply chain. Many changes have occurred however since the last significant study on these strategies (Tatum 1987). The internet has changed the way business is conducted, 3D CAD is commonplace, and automation continually advances. In addition, there is an ongoing skilled workforce shortage in construction. These changes and the lack of recent information have motivated the research described in this report.

1.2 Objectives

One objective of this research was to determine the impact of prefabrication and preassembly on the construction workforce. A second objective was to document of recent trends with respect to volume and area of activity of prefabrication and preassembly in the construction industry. A third objective was to find out how prefabrication and pre-assembly are used in the construction industry. This includes who performs which elements of the work, and on which tasks the work is normally performed. Records of this type of information are not maintained for most industry sectors. Even if a particular firm keeps them, they typically remain confidential. Since complete accounting is therefore infeasible, an attempt is made, based on expert judgment and assessment, to quantify overall trends over the past fifteen years.

1.3 Scope

The research reported herein is limited to the United States construction industry. The focus is on the industrial sector of construction. The survey excludes modularization and focuses on prefabrication and preassembly, since modularization is interpreted in the industry to refer to very large, multi-activity based units often requiring special transportation modes such as barges. All those interviewed expressed the opinion that the extent of modularization had not changed significantly in industrial construction over the last 15 to 20 years. Conversely, prefabrication and modularization have been steadily advancing in the housing sector of construction since its early days of inception. However, modular housing is beyond the scope of this work.

1.4 Methodology

A literature review was performed initially. It covered developments over the 20th century as well as research conducted within the last 40 years (Bibliography). Then, a series of interviews of leading construction industry professionals was conducted to gain further information. Based on the background research and personal interviews, a survey was developed to gather information. The survey was distributed to the project management-level and above of over 50 construction companies and organizations. Once the surveys were returned, the information was compiled and analyzed.

CHAPTER 2: BACKGROUND

Past research indicates that the definitions of modularization, prefabrication, and preassembly vary over time and by industry sector. There is no one entity tracking the use of all of these technologies. An exception is the Manufactured Housing Institute for the residential sector. Similar assessments for other sectors would be worthwhile.

While a historical analysis of the 20th century suggests a possible relationship between labor shortages, labor costs, demand for housing, and the level of manufactured housing activity, nothing in the literature substantially addresses this possible relationship. While causal links at the macroeconomic level may be impossible to determine, it may be possible and useful to identify relationships between such strategies as prefabrication and preassembly and their skill levels and wage rates for the labor required. This may impact, for example, choosing to import assemblies from other countries.

2.1 Definition of Terms

Partly because modularization, prefabrication, and preassembly are ill-defined, yet related terms, they are often collectively referred to in the industry as prework. Another related term that causes some confusion is "industrialization." These terms are defined below.

2.7.7 Modularization

Modularization is generally referred to as the preconstruction of a complete system away from the job site that is then transported to the site. The modules are large in size and possibly may need to be broken down into several smaller pieces for transport. Usually more than one trade is involved in the assembly of a module.

2.1.2 Prefabrication

Prefabrication normally involves one skill or trade, such as electrical, piping, or rebar. Prefabrication can be defined as "a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation" (Tatum, 1987). These prefabricated components often only involve the work of a single craft. Any component that is manufactured offsite and is not a complete system can be considered to be prefabricated.

2.1.3 Preassembly

A common definition for preassembly is "a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a unit" (Tatum 1987). The preassembly may be completed at the job site in a location other than the place of final installation. The preassembly process can involve adapting sequential activities into ones that are parallel. A preassembly often contains only portions of systems, and work from a variety of crafts is typically necessary.

Preassembly is generally considered to be a combination of prefabrication and modularization. It may use fabricated components made offsite and then assembled near the site. These units can then be installed at the site, similar to modules.

2.1.4 Industrialization

This term is used to attempt to describe and encompass all three aspects of offsite construction work: modularization, prefabrication, and preassembly. It is not widely used within the industry in the U.S. The industrialization process can be defined as an investment in equipment, facilities, and technology with the intent of increasing output, decreasing manual labor, and improving quality (Warszawski 1990). It uses the concepts of manufacturing and applies them to construction. To some extent it implies the use of fully integrated and automated project processes.

Industrialization is a term that was in common use in the 1970's to describe all forms of prework[1]. It has other meanings and connotations that can cause confusion. For example, when a third world country begins to improve its capital facilities in general and produce more goods, it is termed the process of industrialization. To minimize confusion, the term is not used again in this paper.

[1] The Industrialization Forum was a journal focused on issues of prefabrication, preassembly, and modularization. The Universite de Montreal published it five times a year from 1969-1977.

2.2 Prework Method Characteristics

Modularization, prefabrication, and preassembly each has advantages and disadvantages. The extent to which they are used is a function of many factors that are unique to each project and jobsite. The basic advantages and disadvantages of each strategy are reviewed below; however, the knowledgeable reader may wish to skip the remainder of this section. This review is derived from previous works, primarily (Deemer 1996) and (Tatum 1987).

2.2.1 Advantages

The overall cost for a project that uses offsite work can be less than a traditionally stick-built undertaking in certain instances. This can be caused by a variety of factors. The local labor for onsite work may be very expensive or inefficient. Severe onsite conditions and weather problems can lead to costly delays that can be avoided through prework. Also, onsite interference and worker congestion can be avoided, increasing productivity and lowering costs.

The onsite construction duration can be substantially shortened through the use of prework. More work for a project can be completed before going to the site so that the construction schedule is decreased. This can be an important factor for owners with compressed schedules.

Overall project safety can be improved through the use of offsite work. The risk to owners and contractors of worker accidents and lost time is reduced with construction work that is transferred away from the jobsite. Onsite work can be less safe due to ever-changing conditions, elevated work, and congestion. Manufacturing and offsite work reduce all of these factors to provide a safe and productive environment.

Quality can also be improved through the use of offsite work. Controlled factory and production conditions and repetitive procedures and activities, along with automated machinery can lead to a higher level of quality than can be attained onsite. A positive side effect of using prework is potentially decreased environmental impact of the project. This is partly due to reduced jobsite construction duration and a decrease in field labor requirements. Labor availability can be an advantage as well for offsite work. There is generally a constant, employed workforce for offsite prefab plants.

Weather is less of a factor for prework, providing an additional advantage over stick-build sitework. The prefabrication and modularization shops take advantage of controlled environments that are not affected by harsh weather. Work is not interrupted and productivity can remain at a high level.

Simultaneous production, or parallel work, can be exploited with the use of prework. Instead of performing tasks in a strictly linear sequence onsite, construction activities can be broken up and completed simultaneously at multiple locations. This process shortens the construction duration and reduces onsite congestion by dispersing the workers.

2.2.2 Disadvantages and Impacts

There are also several impacts to the use of prework. Some of the impacts may be beneficial in the long run, such as pre-project planning. Transportation costs can be a disadvantage to offsite work (CII 1992). This is especially true for large modularized sections that must be transported over a long distance. Size constraints and limitations exist, based on the method of travel, which directly leads into cost and schedule considerations.

There is a need for increased engineering effort upfront (CII 1992). This means that design work and extensive planning must be completed before prework can begin. Interference analysis is required and lift planning, for example, must be completed well in advance. In practice, these activities can lead to a better performing project. While there may be a sense of inflexibility associated with prework, because it is much more difficult to make modifications after a project has begun, it may in fact lead to better scope control.

2.3 Historical Development

The history of modularization, prefabrication, and preassembly contains a variety of trends and complicated interactions that give rise to difficulties in documentation. It consists of a series of upswings and downswings centered on wars, economic shifts and housing booms. The following sections only summarize the history of the industry.

2.3.1 Beginnings

Several instances in history can be viewed as early forms of prework. A few significant instances stand out. Documented examples of prefabrication can be found as far back as the 1600's. As early as 1624, the English brought with them to Cape Ann a panelized house of wood for use by the fishing fleet (Peterson 1948). This house was subsequently disassembled, moved, and reassembled several times.

Another example of prefabrication by Europeans can be seen in the 1850's (Bhatt 1996). Britain's Great Exhibition of 1851 featured a building called the Crystal Palace. Joseph Paxton designed and oversaw the construction of this huge 1848-ft. by 454-ft. structure. Paxton's design, sketched out in less than two weeks, consisted of light and cheap materials: iron, wood, and glass. The dimensions of the building were based on 24-ft. intervals because this was the maximum size of a sheet of glass that could be manufactured at a reasonable cost. The construction period lasted only a few months and consisted of assembling the prefabricated components. After the Exhibition, the palace was taken apart, piece by piece, and moved to Sydenham. Broken glass was even remelted, providing some of the replacements.

There are numerous other examples of what could be considered very early uses of prefabrication or modularization, such as Stonehenge. Encyclopedia Britannica dates the modem form of prefabrication back to 1905 (Britannica Online 1998).

Modem prefabrication in the United States can be said to have started over 100 years ago, when the wooden frame house was developed. These houses introduced into home construction the first elements of prescheduled procedures upon which modem mass production is based (Bruce 1972). For the U.S., prework originated in the housing industry. This can also be seen in the very early 1900's with housing catalogs. Both Sears and Aladdin provided a ready-made "house-in-a-box" that could be purchased and delivered as an actual "mail order house." After it arrived, instructions were included for the purchaser to construct the house himself using standard tools. Every piece and component that would be necessary was provided and ready to be put in place. This technique is referred to as "scientific home building" by the catalogs (Aladdin 1917).

The post-World War I years brought a strong stimulus to prefabrication, but mainly in Europe. The U.S. continued to experiment with prefabrication, while Europe built with it. The Europeans promoted and advanced prefabrication as an industrial development during this time (Kelly 1951).

2.3.2 Peaks and Valleys

Modularization, prefabrication, and preassembly have not had a steady increase in use over time. Instead, use has fluctuated over time due to economic changes, population surges, wars, and other social and political factors (Bruce 1972). In addition to these factors, technological advances may also have an impact in the near future. Fluctuations also vary by construction sector, with the housing industry experiencing the greatest impact.

Prefabrication became a widely recognized movement in the early thirties (Kelly 1951). Interest in the idea spread beyond the initial groups of inventors and small companies first involved. The spread of the prefabrication concept can be attributed to a variety of economic, social, and technical factors. The underlying cause, however, was the Great Depression.

However, by 1940, there still were less than 30 companies that were manufacturing and selling prefabricated houses on a steady basis (Kelly 1951). The vast majority of home production involved comparatively little in the way of new materials or prefabrication. All in all, excluding precut houses, only 10,000 prefabricated units were produced between 1935 and 1940. This constituted less than 1% of all single-family homes built in non-farm areas during that period (Colean 1944).

Housing demand during times of war also caused increases in prefabricated housing. Prefabricated dwelling units for war workers during the early 1940's were a result of Federal housing agencies and their purchasing. The U.S. government has, at times, been prefabrication's best customer (Bruce 1972).

One sign of the industry's growth during the Second World War was the formation of the Prefabricated Home Manufacturers' Association in 1942. It was set up to disseminate information, establish industry standards, study distribution problems, improve manufacturing methods, make cost and accounting studies, and serve as a medium for the exchange of ideas (Kelly 1951).

The housing industry number for prefabrication production during World War II was approximately 200,000 units (Architectural Forum 1946). This relatively large number still represented a small part of the total war housing units, numbering 1.6 million. Even though the prefabrication method was on the incline, it did not become the preferred method.

2.3.3 Recent Evolution

The housing sector of construction, as described above, has been a key driver of prework. In times of drastic housing needs such as after wars and during economic booms, prework was used extensively as a quick solution. Even recently, fluctuations continue in the prefabricated housing market.

In the 1960's the U.S. government initiated Operation Breakthrough, a program intended to provide jobs, affordable housing, and a boost to the economy. The concept behind this program was prefabrication and modularization. The program was unsuccessful for numerous reasons, such as poor management, improper execution, and misguided goals. The program tarnished the public image of prework and the mention of prefabrication brought up images of the failed housing projects of Operation Breakthrough. This created a backlash and an eventual downturn in the use of prefabrication (Schodek 1975).

The 1970's saw a separate resurgence in prework of sorts, evidenced by the short-lived, but important, Industrialization Forum. This publication ran from 1969 through 1977 and provided a wide variety of information. The early 1970's did see a slight upswing in prefabrication. This did not last long, however, as the end of the decade saw a fall once again and the journal ceased publication. This can also be seen in the housing data presented in Figure 2.1.

A new alternative to manufactured housing is the factory-built home industry (Henkenius 1999). These homes are built on factory floors and then transported to the building site for final assembly. They can be customized for individual tastes, yet take advantage of production facilities and their quality is often better than can be found for site-built houses. The various forms of factory-built houses are modular homes, panelized building systems, post-and-beam construction, and log houses.

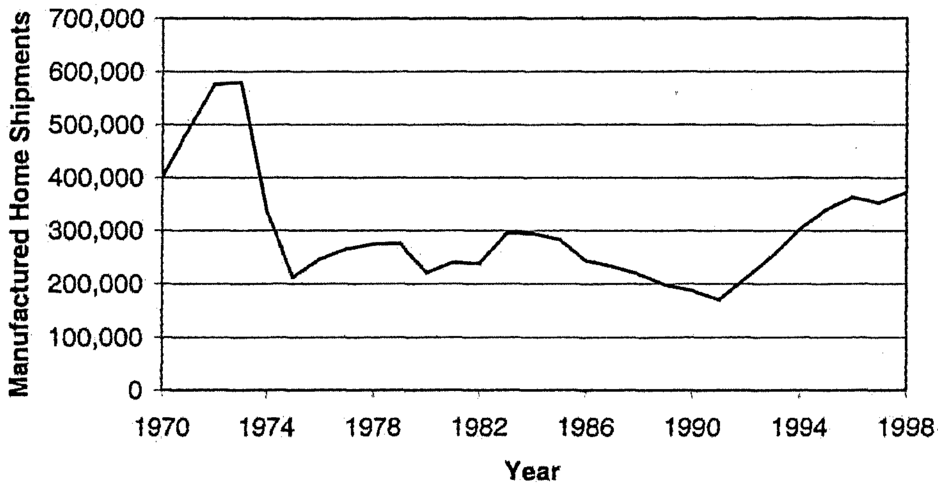

Figure 2.1 Manufactured Home Shipments Over the Last 30 Years

Data Sources: Elkridge & Levidge, Inc.; NCSBCS

While documentation of the use of prework in the housing industry is available, little information is available on the trends of the other sectors of construction. One of the goals of this research project was to provide some information about the industrial sector.

CHAPTER 3: METHODOLOGY

3.1 Interviews

To supplement the literature review, multiple experts at three prominent construction companies were interviewed. The interviews were carried out at the junior, middle management, and upper management levels in a formal manner using a prepared list of questions. The list of questions produced for these interviews to generate discussion is included in Appendix B.

3.2 Survey Design

The information from the interviews and the literature search helped in formulating an initial survey. This survey was intended to serve numerous purposes. No one interviewed was aware of shared or public records concerning the use of prefabrication and preassembly either by category of work or over time. While prefabrication and preassembly can be selected for the reasons identified earlier, it was not clear what were the key drivers of these two specific strategies and to what extent. The degree of application of these strategies to types of work was also not known for the industry in general, though each interviewee had a good sense of the extent of his or her own company's utilization. It became apparent during the interviews that there was disagreement as to which industry off site prefabrication workers are in; manufacturing or construction. Impediments to the use of these strategies were known but not in terms of their rank order of importance. Generally unknown were the impact on, and performance of, the various labor groups involved in prefabrication and preassembly, both onsite and offsite, including such factors as productivity, cost of labor, safety, and level of skills. These knowledge gaps identified in the interviews led to the design of a survey that might help fill some of the gaps.

CHAPTER 4: DATA COLLECTION

This chapter describes the data collected from the survey. The responses are included as well as an overview of what data was collected. An analysis is presented in the next chapter.

4.1 Response

Over fifty individuals were contacted and sent a survey. A total of 29 completed surveys were returned from 22 different companies in time to be included in the analysis. These companies are listed in Table 4.1, along with how many surveys each returned.

Table 4.1 Companies Completing Surveys

Alcoa	2	H&M Construction	2
BE&K	1	Phillips Petroleum	2
Bechtel	2	Rohm & Haas	1
Brady-Home	1	Rust Constructors	2
Burns & Roe	1	S&B	1
Celanese	1	S.M. Lawrence	1
Chevron	3	Sanders Brothers	1
Cianbro	1	Solutia	1
CII	1	Stone & Webster	1
Dick	1	Williams Steel	1
DuPont	1	WWL & Associates	1

4.2 Background Data

The average amount of construction experience for all the respondents is 25.9 years. The low is 20 and the high is 35. Most of the respondents have focused on heavy industrial construction in their careers (Figure 4.1).

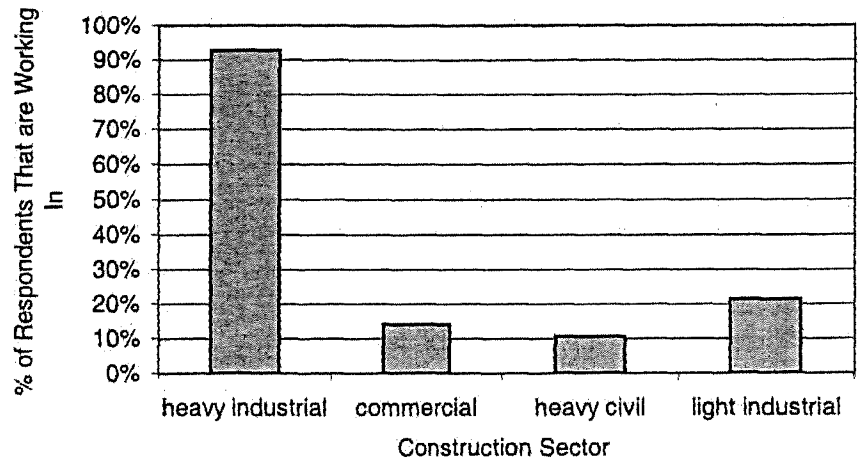

Figure 4.1 Construction Sector of Respondents

CHAPTER 5: DATA ANALYSIS

This chapter explores the data provided by the surveys in an in-depth manner. Each question is broken down and analyzed independently of the others. Then for each topic, the group of corresponding questions and their analyses are summarized. As a reminder, a blank survey for reference is provided in Appendix B.

5.1 Recent Trends

The first aim of the survey was to find out what are the recent trends of prefabrication and preassembly in the construction industry. Question 1 of the survey states, "What is the average use of prefabrication and preassembly for projects you are familiar with **today,** in terms of % of overall project work?" Respondents reported that they use prefabrication and preassembly for 27% of overall project work. However, since the term modularization was not included in the question, it is not certain how much overlap there may have been with modularization.

The second question is a direct comparison with question 1. It seeks to find out how much prefabrication and preassembly were used at some arbitrary point in the past. It states, "Now, think back 15 years, what was the average use of prefabrication and preassembly for projects you were familiar with at that time, in terms of % of overall project work?" Respondents reported that 15 years ago, use of prefabrication and preassembly involved about 14% of overall project work. Since then, a significant increase of roughly 86% has occurred. It indicates more intense industry use of these strategies.

The range of 15 years was chosen for three reasons. A long enough period was required for observable changes to have occurred. It was necessary that the respondents had been working in the industry at the beginning of the period. Finally, significant research was published in the mid-1980's on prefabrication, preassembly, and modularization. Changes occurring since that research could thereby be observed.

5.2 Use of Prefabrication and Preassembly

Understanding that many of the reasons for performing prefabrication and preassembly are well known, it was of interest to determine if one factor dominates the others, or if new technology drivers were beginning to emerge. Question #4 states, "Of all the factors that are currently driving the use of prefabrication and preassembly, what single factor is the most important?" When forced to choose a single driving factor in prefabrication and preassembly, the respondents collectively chose cost and schedule as the most critical factors (Figure 5.1). A number of respondents also indicated that shop labor is cheaper. Additionally, productivity was indicated to be higher in shop work than field work. The third driving factor is workforce, in terms of prefabrication and preassembly as a way to deal with the shortage of skilled construction workers. The fourth and fifth most important factors chosen are safety and quality, respectively.

Despite what past research has shown, respondents did not identify technology as a critical driver for the use of prefabrication and preassembly. It is apparent that, although technology might well facilitate the use of these techniques through 3D-CAD, new materials, internet based purchasing and improved cranes, it is not a driving factor in the minds of the survey's participants.

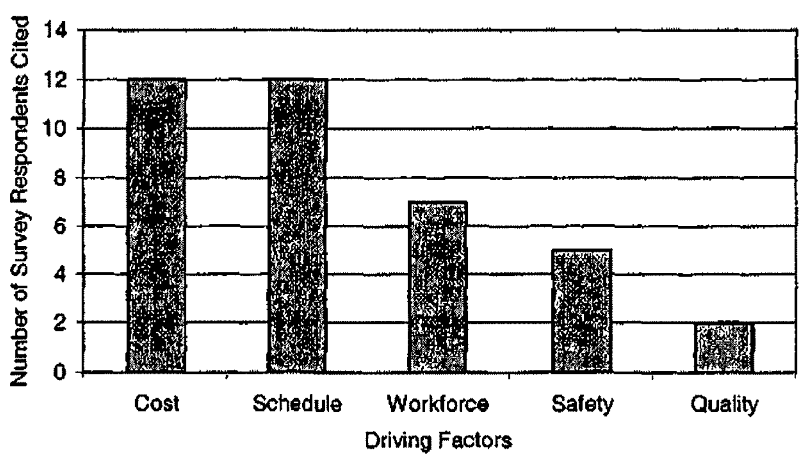

Figure 5.1. Driving Factors of Prefabrication and Preassembly

The research also identified how prefabrication and preassembly was being performed by the project participants (Figure 5.2). Question #5 states, "How are the following techniques typically performed at your company?" With prefabrication, most

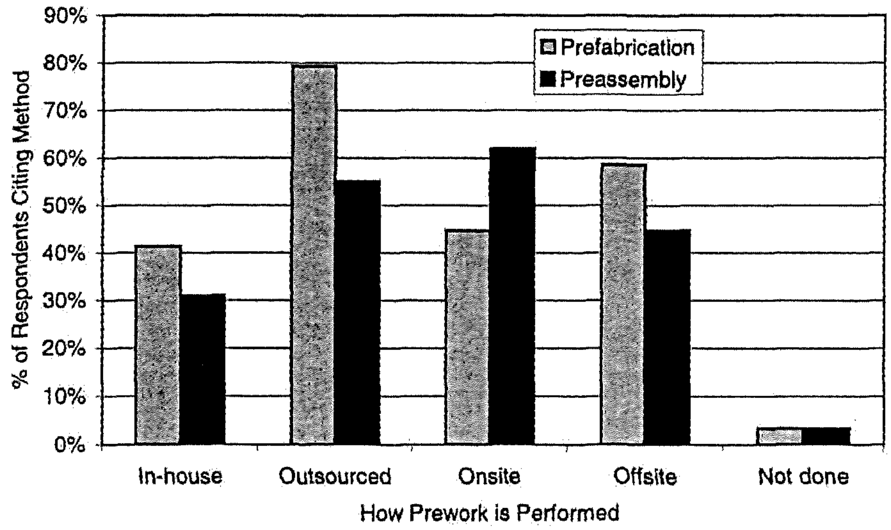

Figure 5.2. Prework Methods

contractors outsource, some do the work in-house, and a smaller percentage combines the strategies (which is why the numbers add up to more than 100% in some cases). The same is true, but less so, with preassembly work. Similar observations can be made for onsite versus offsite work. In fact, prefabrication is often done in a shop away from the construction site while preassembly is usually performed onsite adjacent to the stick build work. One company responded that it performs no prefabrication or preassembly whatsoever.

It is important to have some sense of the relative importance of the advantages of prefabrication and preassembly. Question #7 states, "Rate the following possible advantages of prefabrication and preassembly as compared to traditional stick-built construction." For the study, survey participants were asked to rank twelve known advantages of prefabrication and preassembly as compared to traditional stick-built construction. Each advantage was rated on a 5 point Likert scale with 3 being the same as stick-built, 1 much worse, and 5 much better. The results are shown in Figure 5.3.

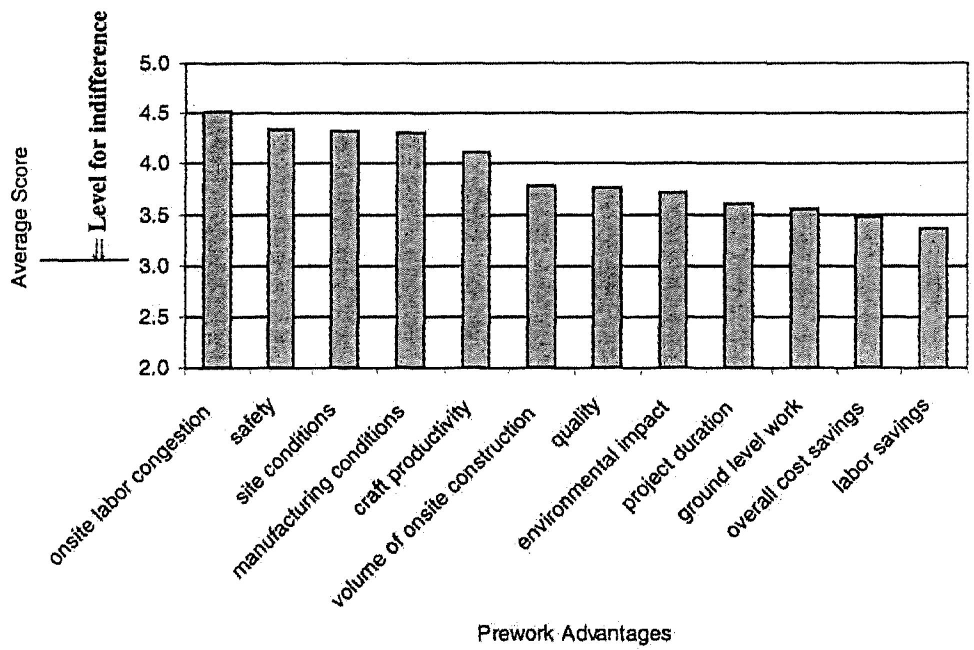

Figure 5.3. The Relative Impact of Prework Advantages

Reducing onsite labor congestion, with a score of 4.5, is indicated to have the biggest relative advantage over stick-built work. It should be remembered however that the absolute dollar value of "overall cost savings" for example, might be greater than "site conditions", which is considered to have a higher relative advantage. The ranking of the remaining advantages is worth examining.

Question #8 states, "Rate the significance of possible impediments to the use of prefabrication and preassembly." Six impediments that restrict the use of prefabrication and preassembly were identified in the study. Survey respondents used a 5 point Likert scale to quantify their impact, with 3 being neutral with respect to the conventional approach, 5 very significant, and 1 very insignificant, as shown in Figure 5.4. The most significant impediment to prework, with a score of 4.2, is the amount of pre-planning involved. Right behind pre-planning is the amount of project coordination (4.1). The next three impediments are all significant and grouped closely with their scores: transportation (3.8), inflexibility (3.7), and procurement (3.5). The sixth possible impediment, change in project risk, was found to not be an impediment.

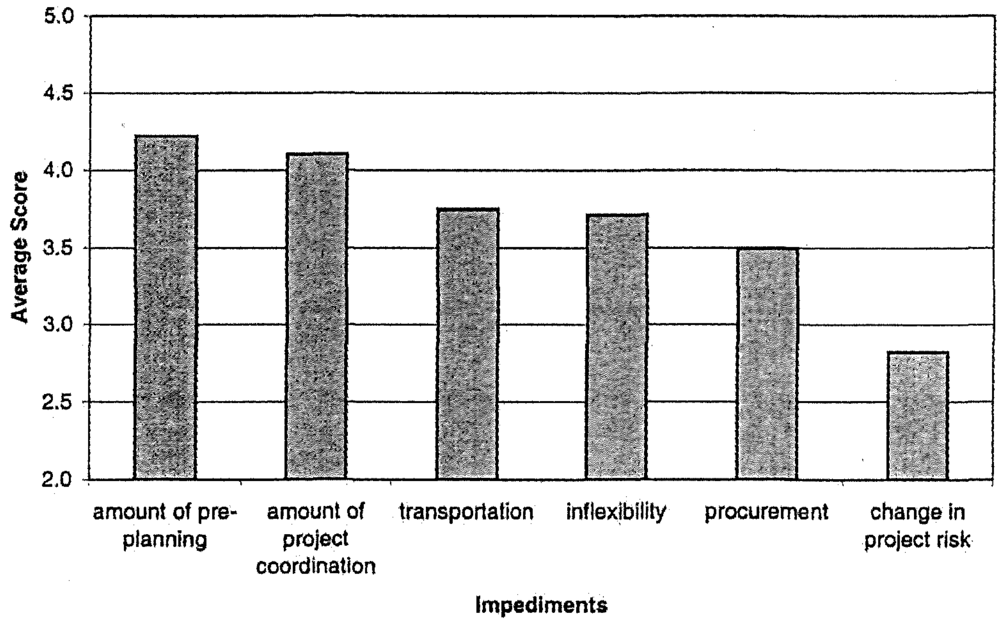

Figure 5.4. The Relative Significance of Prework Impediments

Question #10 asks, "Which construction activities do you use these techniques on?" Prefabrication and preassembly are used on a variety of techniques in construction, (Figure 5.5). Keeping in mind that the survey focused on industrial construction, the most active construction activity for prework is piping. At least some piping is prefabricated by 90% of the respondents and preassembled by 69%. The next highest ranked activities are structural assembly, mechanical, and equipment. Other important activities for prework are instrumentation and welding. It is interesting to observe that in every activity, prefabrication is equal to or greater than preassembly in the percentage used for prework.

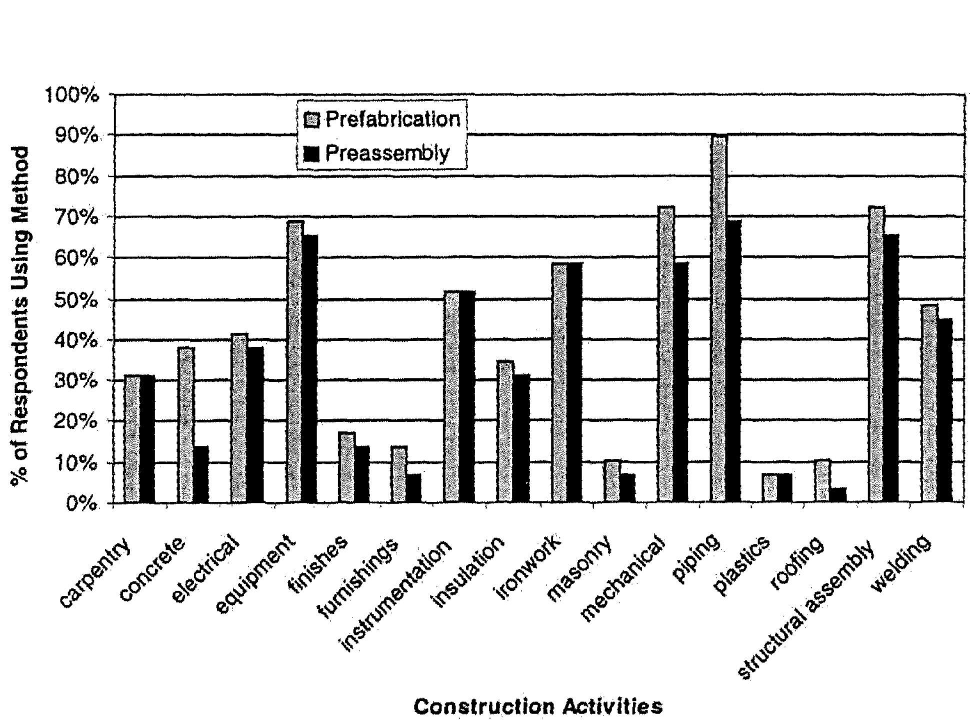

Figure 5.5. Prework and Construction Activities

5.3 Impact on the Workforce

One of the main goals of this research project was to measure how prefabrication and preassembly affect the construction workforce. The impact on labor is not easily established; yet such information may still be useful for effective workforce utilization. Many factors could have been studied. Four labor factors were chosen consistently as both important and quantifiable: productivity, wages, safety, and skill level.

All four of these factors are scored based on the same 5 point Likert scale as used earlier. Productivity here is defined as cost per unit output, with 3 being the same as stick-built work, 5 much higher, and 1 much lower. The labor wage rate factor is based on an identical scale as productivity. Safety is based on a similar scale, except that 5 is much better and 1 much worse. Finally, skill level uses an identical scale to productivity.

Since impact may vary by category of workers involved in prework, four categories were identified. They include offsite shop prefabricators, onsite prefabricators, onsite preassembly crew, and in-place installers. The offsite shop prefabricators are the permanently located workers situated in a manufacturing-type environment. Onsite prefabricators are used when a temporary fabrication facility is set up next to the construction site. The onsite preassembly crew performs preassembly on or directly adjacent to the site. The in-place installers are the onsite workers that install the final prefabricated or preassembled section into its final position.

Survey respondents were asked to compare how these various labor groups compared to standard stick-built workers in terms of: productivity (cost/unit output), cost of labor/wage rate, safety level, and skill level required.

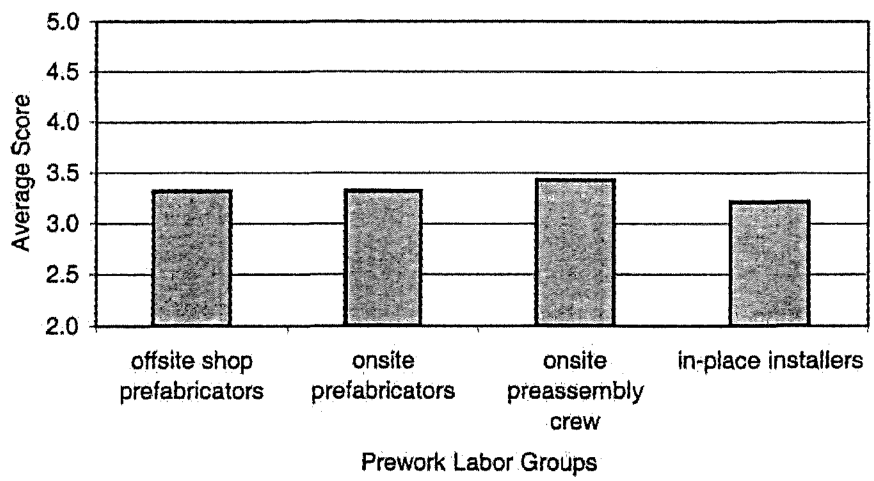

Figure 5.6. Productivity of Prework Compared to Conventional Productivity

Question #9 states, "Rate the various labor groups below as they compare to the standard stick-build worker in terms of: productivity (cost/unit output), cost of labor/wage rate, safety level, and skill level required." The first factor is productivity and the results are shown in Figure 5.6. The group considered to show the highest productivity is the onsite preassembly crew with a value of 3.4. Next highest are the prefabricators, both onsite and off, with scores of 3.3 each. Finally, in-place installers show marginal improvement in productivity with a 3.2. It is apparent that productivity is likely to be improved slightly in all areas of prework.

The second factor is wage rate (Figure 5.7). The lowest wages are experienced by the offsite shop prefabricators (2.5). This may be offset by an annual income advantage if they are working continuously throughout the year and receiving uninterrupted benefits. Onsite prefabricators (2.8) also receive lower than traditional wages. Both the onsite preassembly crew (3.0) and the onsite installers (3.0) have relatively no change in pay compared to traditional onsite work.

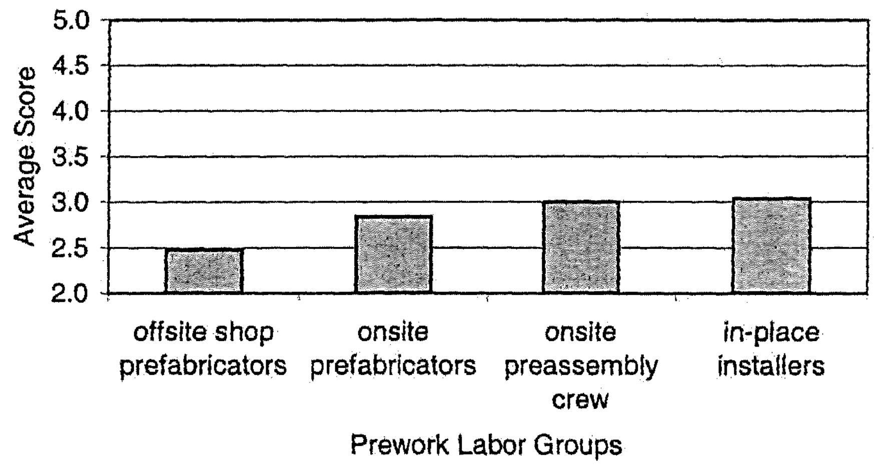

Figure 5.7. Labor Cost of Prework Compared to Conventional Rates

The third factor is the safety level of prework. This data can be seen in Figure 5.8. Offsite shop prefabricators are considered to have the highest safety level, significantly better than stick-built work, with a score of 3.6. Both the onsite preassembly crew (3.3) and onsite prefabricators (3.3) have higher safety levels than traditional construction. In-place installers have the lowest safety of the four groups (3.2), but are still better than traditional work. Generally prework is considered safer than conventional work, perhaps because it is mostly performed at grade and in areas with reduced congestion.

The final factor that was examined concerning the workforce is the worker skill level (Figure 5.9). Onsite prefabricators (3.1), in-place installers (3.1), and offsite shop prefabricators (3.1) are all considered to be at about the same skill level, just slightly more skilled than traditional construction workers. The onsite preassembly crew (3.0) is considered to be at the same skill level as stick-build workers. This makes sense, considering they are likely drawn from the same labor pool.

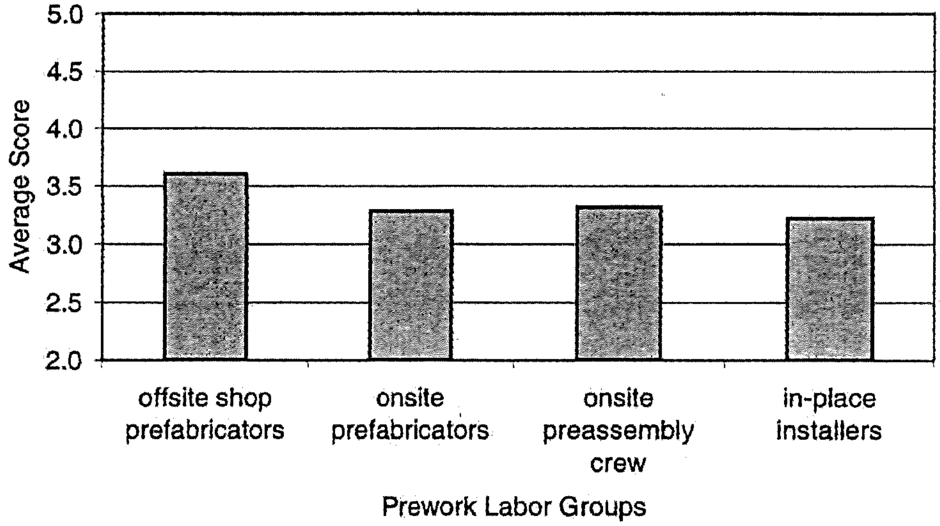

Figure 5.8. Safety of Prework Compared to Conventional Construction Safety Rates

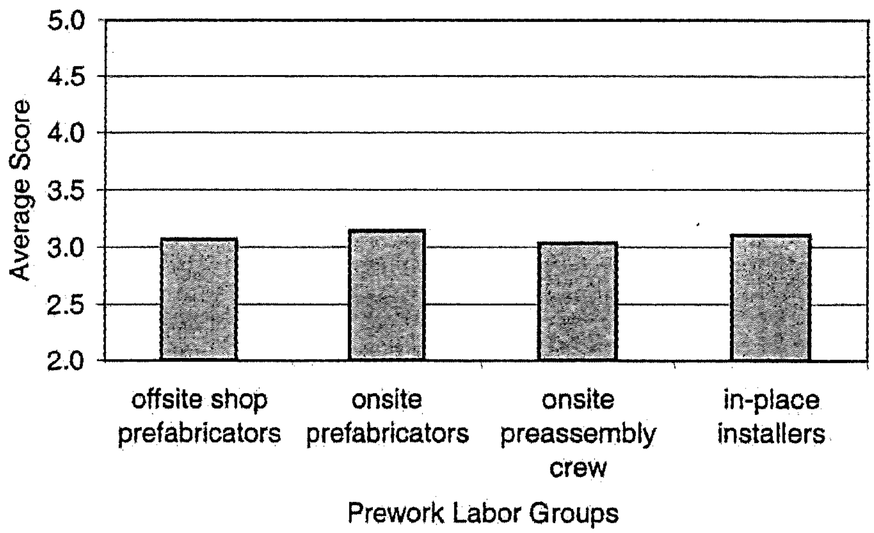

Figure 5.9. Skill Level Required for Prework Compared to Conventional Construction

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

The main goals of the research have been achieved. Recent trends of construction prefabrication and preassembly have been determined. The methods in use today in industrial construction have been identified. Also, the research has revealed the relative weight of the drivers, advantages, and impediments. The impact of technology, specifically prefabrication and preassembly, on the workforce has also been identified.

6.1 Conclusions

The most important findings derived from the survey are reiterated here:

- The use of prefabrication and preassembly is estimated to have almost doubled in the last 15 years, increasing by 86%;
- The three main drivers of the use of prefabrication and preassembly today are schedule, workforce issues, and economic factors, with schedule being the most important;
- Prefabrication is performed for more activities than preassembly, however their relative dollar impacts are unknown;
- Prefabrication and preassembly are almost twice as likely to be outsourced than done in-house;
- Prefabrication is more likely to performed offsite, while preassembly is mostly done onsite;
- Prefabrication and preassembly take advantage of controlled manufacturing conditions to improve the onsite conditions, reduce onsite labor congestion, increase the amount of ground level work, and reduce the overall amount of onsite construction;
- Prefabrication and preassembly usually shorten the project duration and may reduce the overall project cost, while increasing craft productivity, improving quality, and reducing labor rates;
- Prefabrication and preassembly may reduce the environmental impact of construction and increase worker safety;

- The added amount of pre-planning and project coordination required for prefabrication and preassembly can act as impediments;
- Other impediments to prefabrication and preassembly are increased transportation difficulties, greater inflexibility, and more advanced procurement requirements;
- The construction activities that prefabrication and preassembly are most often applied to industrial construction are piping, mechanical, equipment, and structural assembly;
- Productivity is considered better than conventional levels in all labor groups involved in prefabrication and preassembly;
- The cost of labor is lower for prefabrication workers;
- The safety level is considered better than conventional levels for all labor groups involved in prefabrication and preassembly, especially offsite shop prefabricators;
- The skill level required for prefabrication and preassembly workers is no different than traditional stick-build construction;
- It is unclear as to which industry, construction or manufacturing, offsite prefabrication workers are members.

6.2 Recommendations for Future Work

One option worth considering is the development of a comprehensive history of the use of prefabrication and preassembly over the past century. Such a study should examine the expansion and contraction cycles of the various types of prework in order to try to understand the broader economic and social forces behind these changes. However, it should also examine the role technological developments have played. Understanding these forces would help to facilitate more effective use of prework in the future.

It would also be worthwhile to try to qualitatively verify some of the key observations of this study. For example, corporate records could be examined. This raises confidentiality concerns however, and in practice most industry benchmarking data is acquired in the same ways as this study; from reliable reporters.

Future research should also examine the impact of 3D CAD, 4D CAD, the internet, and other advanced technologies. Supply chains, management approaches, design methods, and other project elements will be impacted by these technologies. Opportunities also exist for development of algorithms and intelligent agents to facilitate the use of prework in the domain of high technology.

APPENDIX A: BIBLIOGRAPHY

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APPENDIX B: INTERVIEW QUESTIONS

1. What do the terms modularization, preassembly, and prefabrication mean to you?
2. Compare the status of prefabrication (amount of use in contracts, research, innovations, etc.) now vs. 20 years ago, both in your company and the construction industry.
3. In your opinion, what are the benefits of prefabrication, both overall and when applied to certain jobs and/or situations?
4. What are the disadvantages of prefabrication?
5. Are there any specific impediments that are restricting the use of prefabrication?
6. For your company, explain the distribution of union vs. non-union labor on the construction site and at a prefabricating plant.
7. Have you initiated any programs, agendas, or activities to facilitate the use of prefabrication on construction projects?
8. Have you received any feedback regarding whether the workers are in favor of prefabrication or not?
9. How does your company make the decision to initiate offsite work/prefabrication?
10. Do you have a set of implementation procedures for prefabrication?
11. Do you actively use multiskilling? If so, what is its relation to stick-build construction as opposed to prefabrication?
12. What is the cost of labor/wage rate for stick-build vs. prefabrication?
13. How would you compare the status of safety for stick-build vs. prefabrication?
14. How is prefabrication work organized compared to stick-build work?
15. How is productivity affected by the use of prefabrication?
16. Are any different skills required of prefabrication workers as compared with traditional construction work?
17. How much training or education is needed for the skills of prefabrication as opposed to that of stick-build work?
18. Explain mobility requirements for prefabrication compared to stick-build workers.
19. Do the workers experience any more or less job diversification in prefabrication work as opposed to stick-build construction?

20. Is there a general level of status or superiority/inferiority concerning prefabrication work compared to traditional construction?

APPENDIX C: PREFABRICATE AND PREASSEMBLY SURVEY

1. What is the average use of prefabrication and preassembly for projects you are familiar with **today,** in terms of % of overall project work?

% Prefab and Preassembly

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

2. Now, think back **15 years,** what was the average use of prefabrication and preassembly for projects you were familiar with at that time, in terms of % of overall project work?

% Prefab and Preassembly

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

3. What factors are driving the use of prefabrication and preassembly **today?** (Mark all that apply)

   Schedule constraints

   Technology advances (3D CAD, materials, cranes, computers, etc.)

   Economic factors (please specify) ______________________________

   Workforce issues (please specify) ______________________________

   Other ____

4. Of all the factors that are currently driving the use of prefabrication and preassembly, what single factor is the most important?

____

5. How are the following techniques typically performed at your company? (Mark all that apply)

Prefabdication

In-house Outsourced Onsite Offsite Not done

Preassembly

In-house Outsourced Onsite Offsite Not done

6. In what industry do you consider offsite prefabrication workers to be working?

Manufacturing/production Construction

Other ______________________

7. Rate the following possible advantages of prefabrication and preassembly as compared to traditional stick-build construction (stick-build work = 3):

	Much worse	Worse	Same	Better	Much better
Quality	1	2	3	4	5
Environmental impact	1	2	3	4	5
Onsite labor congestion	1	2	3	4	5
Safety	1	2	3	4	5
Site conditions	1	2	3	4	5
Manufacturing conditions	1	2	3	4	5
Other ______________	1	2	3	4	5

	Much lower	Lower	Same	Higher	Much higher
Craft productivity	1	2	3	4	5
Labor rates	1	2	3	4	5
Overall cost	1	2	3	4	5
Other ________	1	2	3	4	5

	Much less	Less	Same	More	Much more
Project duration	1	2	3	4	5
Ground level work	1	2	3	4	5
Onsite construction	1	2	3	4	5
Other ________	1	2	3	4	5

8. Rate the significance of possible impediments to the use of prefabrication and preassembly:

	Very Insignificant	Insignificant	Neutral	Significant	Very significant
Amount of pre-planning	1	2	3	4	5
Inflexibility	1	2	3	4	5
Transportation	1	2	3	4	5
Change in project risk	1	2	3	4	5
Amount of project coordination	1	2	3	4	5
Procurement	1	2	3	4	5
Other ________	1	2	3	4	5

9. Rate the various labor groups below as they compare to the standard stick-build worker (stick-build work = 3) in terms of:

Productivity (cost/unit output)	Much lower	Lower	Same	Higher	Much higher
Offsite shop prefabricators	1	2	3	4	5
Onsite prefabricators	1	2	3	4	5
Onsite preassembly crew	1	2	3	4	5
In-place installers	1	2	3	4	5

Cost of labor/wage rate	Much lower	Lower	Same	Higher	Much higher
Offsite shop prefabricators	1	2	3	4	5
Onsite prefabricators	1	2	3	4	5
Onsite preassembly crew	1	2	3	4	5
In-place installers	1	2	3	4	5

Safety level	Much worse	Worse	Same	Better	Much better
Offsite shop prefabricators	1	2	3	4	5
Onsite prefabricators	1	2	3	4	5
Onsite preassembly crew	1	2	3	4	5
In-place installers	1	2	3	4	5

Skill level required	Much lower	Lower	Same	Higher	Much higher
Offsite shop prefabricators	1	2	3	4	5
Onsite prefabricators	1	2	3	4	5
Onsite preassembly crew	1	2	3	4	5
In-place installers	1	2	3	4	5

10. Which construction activities do you use these techniques on?

	Prefabrication	Preassembly
Carpentry		
Concrete		
Electrical		
Equipment		
Finishes		
Furnishings		
Instrumentation		
Insulation		
Ironwork		
Masonry		
Mechanical		
Piping		
Plastics		
Roofing		
Structural assembly		
Welding		
Other____________________________		

Personal Information

11. Name: ______________________________

12. Job title: ______________________________

13. Company: ______________________________

14. What sector of construction do you work in?

Heavy industrial	Commercial	Heavy civil
Light industrial	Residential	Other ____________

15. Within this construction sector, what types of projects do you typically work on?

____

16. How many years of experience do you have in the construction industry?

____

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