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Investigation of Designers' and General Contractors' Perceptions of Offsite Construction Techniques in the United States Construction Industry

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INVESTIGATION OF THE DESGINERS' AND GENERAL CONTRATORS' PERCEPTIONS OF OFFSITE CONSTRUCTION TECHNIQUES IN THE UNITED STATES CONSTRUCTION INDUSTRY

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ABSTRACT

This study aimed to examine the current utilization of offsite construction techniques in the building sector of the U.S. construction industry, and to investigate the architects'/engineers' (A/Es') and general contractors' (GCs') perceptions of benefits and barriers of using these techniques, and also to identify the motivations and barriers of using these techniques by A/Es' and GCs' responses.

A self-administrated survey questionnaire was developed as primary research methodology. 1200 A/Es and GCs were randomly selected as research subjects, and T-tests and regression tests were utilized in the study to achieve the research objectives.

The study found that both A/Es and GCs identified that using offsite construction techniques would increase product quality, overall labor productivity, and onsite safety performance. The use of these techniques also reduces the overall project schedule, onsite disruption of other adjunct operations and negative environmental impact of construction operations. The transportation restraints, the inability of making changes onsite, and limited design options appeared to be most significant challenges of using offsite construction techniques based on the findings. In addition, this study found that the residential, commercial and industrial respondents perceived the benefits and barriers to the use of offsite construction techniques differently regarding to the impact of product quality, design options, jobsite management efficiency, overall project cost, and local building regulations. The finding also indicated that the people

who had used these techniques before had more positive attitude towards these techniques than those never utilized these techniques. Majority respondents in this study believed the use of these techniques would increase in the next 5-10 years.

Several practical recommendations were proposed in this study to overcome the barriers to the use of offsite construction techniques including eliminating transportation restraints, inability to make onsite changes and increasing the design options.

DEDICATION

TO MY BELOVED PARENTS

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The shortage of skilled craft workers and the declining number of new entrants present significant challenges for the United States construction industry according to a study conducted by the Construction Industry Institute (CII) in 1997. Many other studies have reported that labor availability is becoming a significant challenge in the United States construction industry as well (Liska & Piper, 1999; CII, 1998 & 2000, 2002; Hass, 2000; Eickman, 1999).

The United States Department of Labor predicted the potential shortage of skilled workers in the construction industry in its Workforce 2000 study. According to a study by the Construction Financial Management Association (CFMA) , the lack of skilled craft labor was one of the top five greatest challenges to today's construction industry (CFMA, 2005). In addition, a study by the Construction Industry Institute (CII) predicted there would be an alarming rate of craft worker turnover regionally and by trade (CII, 2005).

On the other hand, owners (buyers of construction) are demanding their projects be completed faster, be less expensive, and be completed without sacrificing quality and safety performance. In 2005, the Construction Management Association of America (CMAA) conducted its sixth annual survey of owners and found that more than 40% had experienced construction schedule overruns due to the shortage of skilled craft workers onsite which resulted in the escalation of materials, labor and other associated costs (CMAA, 2005).

To overcome the shortage of skilled craft workers and meet owner's expectations, construction companies are looking for ways to deliver projects more efficiently. Offsite construction techniques, including offsite preassembly, hybrid building systems, panelized systems and modular buildings appear to be one approach to overcome the above mentioned challenges.

In the United States, the CII conducted a series of studies on offsite construction techniques and identified a wide range of benefits including reducing overall project duration, improving labor productivity, reducing the quantity of field labor, and improving efficiency of jobsite management through the creation of more predictable work processes and shop environment (CII, 2002). T. C. Haas, in the Center for Construction Industry Studies at the University of Texas at Austin, found that prefabrication and preassembly greatly reduced the need for construction craft workers onsite and also improved labor productivity (Hass, 2000).

Research conducted overseas has consistently found that offsite construction techniques offer numerous advantages such as reducing construction schedules, reducing the number of skilled craft workers onsite, increasing project quality and improving onsite safety performance. Studies in the United Kingdom (UK) reported many similar benefits of utilizing offsite construction techniques in terms of improving quality, schedule, safety, labor productivity and reduction in the number of onsite craft workers. These researchers also found that using offsite construction techniques resulted in potential cost savings due to shortened project schedules, less on-site work, improved labor productivity, and more efficient equipment utilization (Neale,1993; Gibb, 2000). German researchers identified another benefit of offsite construction techniques, the reduction of negative environmental impacts (Venables et al., 2004). In Japan, Gann found many similar benefits in his study comparing industrialized residential construction with automobile manufacturing (Gann, 1996). Similar studies were conducted in many other countries including Sweden, Scotland, Norway, Netherlands, Singapore, Hong Kong and P.R. China, all of which identified many benefits of using offsite construction techniques (Bergstrom & Stehn, 2005; Lu & Fox, 2001; Wang & Havadi & Krizek, 2006; Hui, 2005; Barlow & Ball, 1998)

1.2 Problem Statement

Offsite construction techniques have not been utilized widely in the United States construction industry even though current automation technology and transportation modes provide great opportunities for using these techniques to improve overall project performance (Hass, 2000 & O'Brien, 2000).

In the United States, conventional construction techniques still dominate the industry. For example, in 1998, in the residential sector of the U.S. construction industry, 75% of 1.2 million new residential houses were built on-site. Factory built housing represented approximately 25 percent in both 1998 and 1999 and approximately 20 percent over the last 20 years (Manufactured Housing Institute, 2000).

Several reasons could explain why offsite construction techniques have not been widely accepted in the U.S construction industry. First, there are various challenges to using offsite construction techniques including limited design options, less onsite change flexibility, transportation restraints of building systems (structure strength, modular size, etc), increased transportation cost, and less construction error tolerance (Gibb, 1999). In addition, construction industry practitioner's negative perceptions of using offsite construction techniques have always been considered as one of the most significant challenges, in both the United States as the United Kingdom (Barlow, 1999; Gibb, 2002; Hass, 2000; Sawyer, 2006).

The purpose of this study therefore was to determine to what degree offsite construction techniques were being used in the building sector of the U.S. construction industry in 2005. This study also aimed to identify architects'/engineers' (A/Es') and general contractors' (GCs') perceived benefits and barriers of using those techniques.

1.3 Research Objectives

The objectives of this research effort were to:

1) Investigate the current degree of utilization of offsite construction techniques including offsite preassembly, hybrid systems, panelized systems and modular buildings in the building sector of the U.S. construction industry.

2) Identify architects'/engineers' and general contractors' perceived benefits and barriers of using offsite construction techniques in the building sector of the U.S. construction industry.

3) Determine the reasons why or why not offsite construction techniques were being used by architects/engineers and general contractors in the building sector of the U.S. construction industry.

4) Examine whether architects'/engineers' and general contractors' higher satisfaction level of offsite construction techniques would result in a higher percentage of using these techniques in the building sector of the U.S construction industry.

1.4 Significance of Study

Although numerous studies have been conducted by different institutions and/or individuals on offsite construction techniques in the US construction industry, the majority of previous studies concentrated on building methods, building materials, strategy development or market trend analysis (CII, 1997; & 2000; Clark, 1996; Eickmann, 1996; Walter, 2001; O' Brien, 2000). The CII conducted a series of studies on the use of offsite construction techniques in terms of constructability and developing a strategy for decision making. The National Association of Home Builders (NAHB) conducted many studies on prefabricated housing regarding market trends, technology improvement, means and methods, and management improvement.

A 2002 study conducted in the U.K. was titled "Overcoming Client and Market Resistance to Prefabrication and Standardization in Housing". That study examined the attitudes towards various prefabricated houses through a series of interviews with representatives of general contractors, developers, financial institutions, and housing associations. The result of the study greatly contributed to the increased utilization of offsite construction techniques in the United Kingdom (Edge et al., 2002).

This research also aimed to examine the architects'/engineers' and general contractors' perceptions of using offsite construction techniques, and to identify reasons why these techniques have or have not been used in the U.S. construction industry.

1.5 Research Questions

The following questions were investigated in this study:

1) To what degree were offsite construction techniques being used in the building sector of the United States construction industry in 2005?

2) What did the architects/engineers, and general contractors perceive to be the benefits and barriers of using offsite construction techniques in the building sector of the United States construction industry? Did they perceive each benefit or barrier statistically different from each other at the 0.05 level of significance?

3) What were the top 3 reasons that would motivate general contractors to use offsite construction techniques in the building sector of the U.S. construction industry?

4) What were the top 3 reasons that would motivate architects/engineers to specify offsite construction techniques in the building sector of the U.S. construction industry?

5) What were the top 3 challenges that would restrain general contractors from using offsite construction techniques in the building sector of the U.S. construction industry?

6) What were the top 3 challenges that would restrain architects/engineers from specifying offsite construction techniques in the building sector of the U.S. construction industry?

7) Was there any linear relationship between architects/engineers and general contractors' levels of satisfaction with using offsite construction techniques with the percentages of their use in the building sector of the U.S. construction industry?

8) What did architects/engineers and general contractors forecast the utilization of offsite construction techniques in next 5-10 years?

1. 6 Hypotheses

The statistical analysis in this study consisted of three sections: 1) architects'/engineers' relating to the use of offsite construction techniques; 2) general contractors' responses relating to the us of offsite construction techniques; and 3) comparing whether the two groups' responses were statistically different with each other.

Hypothesis statement 1

The use of offsite construction techniques reduces the overall project schedule.

Hypothesis statement 2

The use of offsite construction techniques reduces the need for skilled craft workers onsite.

Hypothesis statement 3

The use of offsite construction techniques reduces the project construction cost.

Hypothesis statement 4

The use of offsite construction techniques increases project product quality.

Hypothesis statement 5

The use of offsite construction techniques increases overall onsite labor productivity.

Hypothesis statement 6

The use of offsite construction techniques limits design options.

Hypothesis statement 7

The use of offsite construction techniques increases safety performance.

Hypothesis statement 8

The use of offsite construction techniques reduces onsite disruption of other adjacent operations.

Hypothesis statement 9

The use of offsite construction techniques reduces the negative environmental impact of construction operations.

Hypothesis statement 10

The use of offsite construction techniques increases the overall project cost.

Hypothesis statement 11

Transportation restraints (i.e. size constraints, transportation cost, and impact on building structures) limit the use of offsite construction techniques.

Hypothesis statement 12

Owners' negative perception of offsite construction techniques limits their use.

Hypothesis statement 13

The use of offsite construction techniques limits the ability to make changes to work onsite.

Hypothesis statement 14

The use of offsite construction techniques increases design efficiency

Hypothesis statement 15

The use of offsite construction techniques increases design cost

Hypothesis statement 16

Complicated computer software for designing offsite construction techniques limits their use.

Hypothesis statement 17

The use of offsite construction techniques increases jobsite management efficiency

Hypothesis statement 18

Local building regulations restrict the use of offsite construction techniques.

Hypothesis statement 19

Lack of skilled offsite assembly craft workers limits the use of offsite construction techniques.

1.7 Research Scope

This study focused on the degree of the current level of utilization of offsite construction techniques in the building sector of the U.S. construction industry, and the architects'/engineers' (A/Es') and general contractors (GCs') perceptions of using these techniques. The research scope included the market segments of single and multi-family residential, commercial, institutional and industrial buildings in the U.S. construction industry. Manufactured houses (mobile homes), highway construction and civil work were not included in the scope of this study.

1.8 Limitations of Study

The following limitations were inherent to this study due to the availability of funds, respondents, and research resources.

1) The population in this study was limited to the A/Es and GCS firms in the building sectors in the U.S construction industry. Highway and civil construction contractors and designers were not included in this study.

2) Manufactured homes were not included in the study.

3) Highway and civil work were not included in this study.

4) The sample frame for general contractors was the Dun & Bradstreet 2005 list. The GCS sample was randomly selected from those construction companies whose annual revenue was more than one (1) million U.S dollars in 2005. The sample frame for architects/engineers was those firms listed in the American Institute of Architects (AIA) 2005 National Membership Profile.

1.9 Definition of Terms

1.9.1 Offsite Construction

According to Gibb A., & Pendlebury M., offsite construction is a term used to describe the spectrum of applications where buildings, structures or parts are manufactured and assembled remote from the building site prior to installation in their final position, which included offsite pre-assembly, hybrid building systems (PODS), panelized building systems, and modular buildings.

1.9.2 Offsite Pre-assembly

Offsite pre-assembly 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, for example: roof trusses; pre-assembled vessels complete with insulation, platforms, piping and ladders (Tatum et al, 1986).

1.9.3 Hybrid Systems (Pod)

Hybrid systems were 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 and electrical service, factory completed office room.

1.9.4 Panelized Building Systems

Panelized building systems consisted of the construction of the structural frame using building panels manufactured in a factory. It also consists of factory-built structural components instead of completed modules, transported to the site, assembled and secured to a permanent foundation, typically including additional factory based fabrication, such as finished wall panel with cladding, insulation, internal finishes, doors and windows (NAHB, 2004).

1.9.5 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, then transported and assembled on site. Modular building normally consists of multi-rooms with three-dimensional units, which are constructed and pre-assembled complete with trim work, electrical, mechanical, and plumbing installed (O'Brien, 2000).

1.9.6 Improving Jobsite Management Efficiency

In this study, improving jobsite management efficiency refers to the use of offsite construction techniques to reduce the amount of onsite work, optimize the construction schedule and improve jobsite safety performance.

1.9.7 Construction Cost

Construction cost refers to the expense of all labor, materials, equipment, overhead and construction company's profit.

1.9.8 Overall Project Cost

In this study, overall project cost includes the entire expenses associated with the design and construction of the buildings.

1.10 Organization of the study

Chapter 2 provides a comprehensive literature review of the use of offsite construction techniques by the U.S. and overseas construction industries. The benefits and barriers to the utilization of these techniques identified by previous studies have also been included in this chapter. This chapter also presents two case studies conducted by the researchers and the interviews with the representatives with the manufacturers.

Chapter 3 presents the methodology and procedures of the research. It begins with the research questions and hypotheses for this study, followed by a description of the development of the self-administrated survey, and a pilot study conducted to test validity and reliability. This chapter also identifies the population, sampling frame and sampling methods and along with the statistical methods utilized in this study.

Chapter 4 presents the findings from survey respondents and a summary of statistical analysis for each hypothesis statement and research question.

Chapter 5 presents the conclusions drawn from the data analyses and statistical testing of each hypothesis. This chapter also provides conclusions derived from the study and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews the forms of offsite construction techniques being studied in this research, presents a comprehensive literature review of the use of offsite construction techniques by the U.S. and overseas construction industries. It also provides several examples of current utilization of offsite construction techniques in the U.S. residential, commercial, industrial and institutional construction sectors. In addition this chapter reports two cased studies conducted by the researcher and the interviews with the representatives from the manufacturers from the case studies.

2.1 Forms of offsite construction techniques

2.1.1 Offsite pre-assembly

Offsite pre-assembly is 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, for example: roof trusses; pre-assembled vessels completed with insulation, platforms, piping and ladders (Tatum et al, 1986). Figure 2.1 presented an example of offsite preassembled roof truss.

Figure 2.1 Offsite Preassembled Roof Trusses
(Courtesy of Timer Engineering, UK)

2.1.2 Hybrid Systems (Pod)

Hybrid systems consist of prefabricated fully factory-finished building facilities, including completed bathrooms with all the furnishings installed, completed office washrooms and plant rooms, etc, as Figure 2.2 presented.

Figure 2.2 Hybrid System- Completed Shower Room
(Courtesy of Architecture Week)

2.1.3 Panelized Systems

Panelized systems refer to the construction of the structural frame of the building by using panels manufactured in a factory. It consists of factory-built structural components instead of completed modules, transported to the site, assembled and secured to a permanent foundation, typically including additional factory based fabrication, such as cladding, insulation, internal finishes, doors and windows (NAHB, 2004). Figure 2.3 presented an example of a panelized wall with all the cladding, interior and exterior finishing installed.

Figure 2.3 Panelized wall with cladding, interior and exterior finishing
(*Courtesy of Pulte Home Sciences)*

2.1.4 Modular Buildings

Modular buildings normally have multi-rooms with three-dimensional units, which are constructed and pre-assembled complete with trim work, electrical, mechanical, and plumbing installed (O'Brien, 2000). Upon the completion by the manufacture, these units are shipped to the site for installation on permanent foundations.

The modular building process eliminates the possibility of damage from weather and provides for all materials to be assembled in a protected climate-controlled environment. Therefore, modular building provides superior building quality compared to conventional building. It eliminates the possibility of any water infiltrating the house during the construction phase. Refer to an example of modular buildings showed in Figure 2.4.

Figure 2.4 Modular building at Lafayette Street, New York City, United States
(Courtesy of Urban Space Management, Inc.)

2.2 The Use of Offsite Construction Techniques

2.2.1 Introduction

This section examines the use of offsite construction techniques in several international construction industries including those in the United Kingdom, Japan, Germany, Asia and other European countries. The development of the use of offsite construction techniques in the international construction market may have implications for the use of these techniques in the U.S. In addition, the uses of offsite construction techniques in United States are also discussed.

2.2.2 Overseas Applications

Offsite Construction Techniques Applications in United Kingdom

Utilization of offsite construction techniques in England can be traced back to 1624 when the English brought with them to Cape Ann a panelized house made of wood for use by the fishing fleet. Since then, this house was subsequently disassembled, moved, and reassembled several times (Peterson, 1948).

In the early part of the 20th century, major activity in mass prefabrication systems for buildings occurred in the United Kingdom. The impetus was a huge market demand for new housing after World War I. The traditional building approach could not provide enough houses due to the construction duration and the lack of availability of skilled workers. The low production of traditional methods and destruction caused by the war created a climate for innovative construction methods and processes (Waskett, 2001).

However, offsite construction techniques were not consistently developed in the United Kingdom after World War I because much of the early effort focused on the development and use of alternative construction materials other than masonry and concrete. Therefore, at the time there was no significant change in the approach to building that would move the technology forward (Waskett 2001).

Following the destruction caused by World War II, the UK government was pressured to provide homes for soldiers returning from abroad, which also matched the need to find employment opportunities for them. In September 1942, the U.K. Interdepartmental Committee on House Construction was formed to take charge of developing alternative construction materials and methods in terms of improving efficiency, economy, and construction speed (Waskett 2001). The Committee significantly promoted the development of offsite construction techniques.

Another great impetus of the use of offsite construction techniques was the innovation of timber framing systems that occurred from 1927 to 1941. The fact that timber has always been easy to form into panels provided the possibility of fabricating accommodation units in the factory and then assembling them on site. In addition, the innovation of Large Panel Systems (LPS) in 1948 significantly pushed the development of prefabrication and preassembly techniques.

Within the last few years there has been a great increase in the use of offsite construction techniques for buildings, driven by a range of factors including demands for faster construction and shortages of skilled craft workers (BRE, 2003). The implementation of offsite construction techniques in the United Kingdom construction industry has been dominated by large construction companies whose incentive for using prefabrication and standardization techniques was to improve productivity and reduce construction time. Often these techniques have been utilized in large urban areas on very congested jobsites. Modularization or modular design has been described as the key to offsite construction techniques in UK because it offers customers distinctive advantages over traditional construction techniques in terms of labor productivity, project schedule, product quality and a safer working environment (Gibb, 2001).

In the UK, the use of offsite construction techniques are more widely accepted in the commercial sector than the residential and industrial sectors, due to the fact that in England and Wales masonry systems are used for the majority of the residential buildings. Rapid commercial development in London in the late 1980's created a great opportunity for increasing the use of offsite construction techniques. Commercial clients demanded a better quality product, faster delivery, and at a reasonable cost. The use of offsite construction techniques was one of effective approaches to meet their needs. Increased labor costs and decreased availability of skilled labor at the worksite were two contributing factors of the development of offsite construction techniques in the late 1980's. Prefabrication has been identified as a way of achieving faster completion on commercial premises. For example, McDonald's restaurants use prefabrication technology to build their new outlets. Recently they set a record of a completed outlet being built and opened for business within 13 hours of starting construction on a prepared building site (Blismas, 2006). Currently, in the UK, offsite construction techniques have considerable commercial implications for businesses and a range of clients from hotels to retail outlets are using some forms of prefabricated procurement.

In addition, offsite construction techniques have been applied in the UK industrial construction sector as well, predominately for assembling heating and cooling equipment and other building services. Traditionally the installation of building services is time consuming and labor intensive, while prefabricated modular construction can overcome these challenges and meet aggressive schedules (Blismas, 2006).

Despite many well-documented benefits that can be derived from the use of offsite construction techniques, the applications of these approaches are still limited. In 2004, offsite construction techniques comprised 2.1% of the construction work in the UK, including new building, refurbishment, repair, and civil engineering work (Goodier, 2004). A major reason was reluctance of clients to accept innovated building techniques in that they have difficulty ascertaining the benefits that by offsite construction techniques added to a project (Pasquire & Gibb, 2002). For many of those involved in the construction process, the benefits of using offsite construction techniques were not well understood. A study by Pasquire and Gibb (2002) demonstrated that the decision of using offsite construction techniques in the UK is largely based on anecdotal evidence rather than rigorous data. No formal measurement procedures or strategies are available to compare the results of using offsite construction with conventional construction. Decisions regarding the use of offsite construction techniques are consequently unclear and complex due to interdependencies between construction trades and resources. These complexities make the derivation and inclusive evaluations very difficult. The uniqueness of each project made it very difficult to develop a comprehensive evaluation system comparing the use of offsite construction techniques with conventional approaches. It should be pointed out that a large part of the resistance to innovation came from the construction companies themselves rather than from the clients, according to a research report conducted by the Robert Gordon University, U.K. (Edge 2002).

Another big challenge to the use of offsite construction techniques in the UK was the unclear impact of the construction costs. Industry sources indicated that using offsite construction techniques increased costs around 7-10%, but the reason for the higher costs has not been identified yet due to many contributing variables such as: unavailability of confidential project financial information, higher factory overhead costs, and using modern construction equipment (BRE, 2003).

A shortage of skilled assembling workers is another contributing barrier to the use of offsite construction techniques in the UK. Compared to conventional construction techniques, offsite construction techniques require highly skilled labor for precise onsite assembly of factory-made building components. Some of problems with prefabricated building methods stemmed from poor onsite assembly workers' skills rather than defects of building materials, components or structures.

Other than the factors mentioned above, researchers in the UK insisted that insufficient industry capacity of producing building modules may also be a barrier to increased use of offsite construction techniques (Gibb, 2004).

In order to examine the current utilization of offsite construction techniques and identify the benefits and challenges, UK government, researchers and other professional institutions have conducted a considerable amount of research in this field. One of the most influential research projects was conducted in the 1998. This research which was titled “Rethinking Construction” examined the construction process and building methods in the UK construction industry. It gained a great deal of attention from both the UK government agencies and the construction industry (Egan, 1998).

Dr. Martin Edge, a leading scholar in the UK construction industry, conducted another significant study in 2002 to investigate where resistance to the use of offsite construction techniques existed and examined approaches to overcome it. This research was undertaken over a 30 month period, and included interviewing representatives from 100 major construction companies and manufacturers, hundreds of developers, construction professionals, and house buyers. This research found that home buyers are not resistant to new forms of offsite construction techniques, but partially resistant to new building materials. In addition, this study found that there was a strong niche market for innovative forms of housing which are potentially affordable, sustainable and flexible (Edge, 2002).

Offsite Construction Techniques Applications in Japan

The Japanese residential construction industry has a long tradition of craft production based on woodworking skills (Gann, 1996). In the late 1950s, the Japanese housing market began to utilize offsite construction techniques because of the shortage of skilled carpenters, depletion of indigenous supplies of timber, low-quantity housing production, and rapid economic growth. This large market demand triggered a need to modernize conventional construction methods and adopt the efficient production methods from Japanese manufacturing industries (Brock & Brown, 2003).

By 1955 the Japanese government acknowledged that productivity growth in housing production was low relative to other manufacturing industries. The Japan Housing Corporation (JHC) was founded in 1955 and focused mainly on developing medium-rise reinforced concrete apartments. This organization developed standardized concrete panel systems. However, early forms of houses incorporating these panelized systems could not compete with conventional timber buildings because they failed to provide enough various designs to meet the homeowners' needs (Gann, 1996).

By 1970 the housing market, in terms of quantity, had been satisfied. Therefore, the JHC shifted its focus to improve the housing quality and reduce project costs. Meanwhile, industrialized housing producers invested heavily in improving the flexibility of designs to satisfy each individual consumer's choices, which doubled the market share for prefabricated wood panel housing between 1980 and 1992. By 1995 industrialized housing accounted for almost one quarter of all new dwellings (Coaldrake, 1996). Industrialized housing market growth in Japan was also associated with the high density housing in urban areas, where customers had positive attitudes towards factory-made products developed by manufacturers who were increasing their efforts to satisfy consumer preferences (Gann, 1996). In 1994, panel and modular housing systems were widely adopted in the Japanese housing industry and accounted for over 10% of the total housing output (Gann, 1996).

Currently, offsite construction techniques are predominately used in the building sectors in Japan, notably in the residential sector (Matsumura, 1994). In 2003, prefabricated single-family housing accounted for $16 Billion US dollars in the Japanese construction market (Takabatake, 2004). Offsite construction techniques combine different levels of factory and site-based activities. The major prefabricated structural systems include: timber-frames, 2×4 wood frame, factory-made light-gauge welded panels, module steel-frame systems and prefabricated reinforced concrete systems. Among them, 50%-80% of manufactured houses were using steel-framing techniques (Ward et la, 1995).

Unlike construction markets in other countries, which construction markets were shared by many companies, the Japanese industrialized construction market was dominated by five major companies with a combined 80% market share. Those companies are: Sekisui House, Misawa Homes, Daiwa House, Sekisui Heim, and National House. All of these companies aimed to produce high-quality reliable houses for middle and luxury markets, offering a wide range of design options to provide flexibility for customer choice (Gann, 1996)

None of the above mentioned companies, with the exception of Misawa, evolved from traditional wood framing residential firms. In order to exploit the new market for their old business they heavily invested in factory facilities and research & development (R&D). Each of these companies employed several hundred scientists, technologists, architects, and engineers. They are structured with varying degrees of vertical integration from design, marketing, sales, materials fabrication, assembly, and erection on site. These initial steps greatly improved the popularity and acceptance of offsite produced houses by homeowners in Japan. For instance, Sekisui House and Daiwa House offer sophisticated design services to engage customer preferences with computer-aided design (CAD) systems which generally provide good-quality three dimensional (3D) presentations of design work. Each customized design is developed through a series of stages which include visits by sales and design staff to apprise the customer of all costs, time, and quality implications relating to their choices. They also provide samples of materials, fittings, and furnishings. Even though the negotiation process normally takes 3 months, the construction company generally offers a detailed estimate and a completion date within 2 days of achieving agreement on the final design.

Misawa Homes, National Houses, and Toyota Homes have used franchise sales networks, separating sales from in-house design work. Toyota's sales system is similar to their car production; it heavily relies on a franchised dealer network or subsidiaries of car dealers. In 1994 Toyota had 28 sales agencies and 121 show houses. A salesperson could sell cars this year and then homes the next year all focused in one region (Gann, 1996)

Sekisui House, the largest industrialized housing producer, makes prefabricated steel and timber-framed housing panels in five factories. They utilize computer controlled machines in manufacturing and assembly processes including frame-welding robotics. Every component is marked with the customer's name to identify particular work. One factory-produced home typically contains 30,000 items, comprising 700 different component types. Sekisui House has more than 2 million different kind of parts needed to satisfy all design options (Mastodon, 1990).

Sekisui House produces approximately 70-80% of the value of each house in its factories, including all structural and panel work, electrical, plumbing and furnishing, such as telephone, TV and video outlets. On-site work, accounting for around 20-30% of total value, only involves site preparation, joining units and hooking up permanent services. Labor costs were reduced 25% by using the modular systems compared to the panel systems by Sekisui House (Coaldrake, 1996).

Sekisui House began fabrication begins 3 days before units placed on site. Just in Time (JIT) delivery systems are used to ship units to the site on the day of placement. The production line operates in 24 stages, completing a module every 3 minutes. Work begins with cutting steel members for framing the units and continues through the zinc coating process, which is an automatic coating technology developed by Ford Corp. Fabrication of the frame includes automatic welding by robots. Workers are responsible for installing all necessary panels, windows, doors, staircases, services, bathrooms, kitchens, and fittings by using the JIT system, which is similar to the system utilized in the Japanese automobile industry. It takes approximately 3 hours to complete one unit, and a house can be completed approximately in 3 days (Gann, 1996).

Several critical aspects of the Japanese construction industry have been identified in the literature. They include:

- Utilizing electronic data models of building processes and products to provide distinctive designs.

- A distinct framework for innovation supported by government and industry; including regulations, investment in R&D, customer satisfaction and quality control.
- Cross-industry learning from the automobile industry-particularly in design, engineering, research and development, coordination of supply chains, JIT delivery systems, quality circles and the automation of transfer and storage of parts.
- Most of the customers have positive attitudes towards factory-made products developed by manufactures to satisfy consumers' preferences.
- National sales networks employing specially trained design and sales professionals who also act as market researchers to ensure closer links between producers and users.
- Government provided financial and legal support for technical development aimed at solving housing storages and the encouragement of more effective use of land.
- A willingness to exchange ideas that help develops the construction industry.

Offsite Construction Techniques Applications in Germany

Offsite construction techniques have been utilized in Germany for about 70-80 years. In the late 1920s and early 1930s, the first industrially produced home was made as a symbol of modernism and progress (Venables, et al, 2004). In 1947, an exhibition of eighteen (18) prefabricated houses was held in Stuttgart-Zuffenhuasen by an American construction company, six of them still exist today (Samstag, 2003).

In the 1950s and 1960s, the German timber industry and home builders heavily invested in the use of offsite construction techniques, notably in the residential sector. In 2002, over 23,000 light framed prefabricated homes were completed in Germany, equivalent to 13% of the new residential construction volume for that year. In Eastern Germany, the use of offsite construction techniques was around 20% (DFV, 2004).

Currently, offsite construction techniques have been widely adopted in Germany. These techniques are most commonly used in the construction of new detached housing. There are more than 100 manufacturers in Germany with capacities ranging from 50 to 3,000 units annually. The majority of the firms are small family-owned. However, similar to the Japanese construction industry, the offsite construction market has been dominated by five large firms. They are Massa, Elk-Bien-Zenker, Kampa, WeberHaus and Schworehaus. Each of them produces 1,000 to 3,000 homes per year and together account for more than half of the market (Venables, et al, 2004).

Some of the German offsite prefabrication manufacturers have extended their operations to other European countries. In 2002, exports of prefabricated homes accounted for 5% of the total German housing industry business. Major export markets included the UK, Switzerland and Austria. Prefabricated homes were also exported to other European countries, and also to Russian and Japan (Venables, et al, 2004).

As happened in the UK, prefabricated homes in Germany used to be perceived as lower quality than traditional site-built homes. The first generation of manufactured houses in Germany was referred to as "cardboard houses" due to poor quality. However, currently the image of prefabricated houses has changed significantly due to increased quality. The industry has improved its image through the development of standardization, certification schemes, and consistent promotion of the merits of using offsite construction techniques. In 2003, LBS Inc., a large German mortgage bank, conducted a survey to investigate current perceptions about the acceptance of prefabricated houses. The study revealed that 95% of the respondents perceived offsite construction techniques as trustworthy and a practical approach, and 82% of the respondents would consider buying a factory built home (BDF, 2003).

The reasons for the high acceptance of offsite construction techniques in Germany are attributed to the continuous innovation supported by in-house R& D, training and quality assurance processes provided by manufacturers (Venables, et al, 2004).

German construction associations have consistently provided many training opportunities for the manufacturers and onsite assembly workers (Venables, et al, 2004). Professional associations such as the Bundedverband Deutscher Fertigbau (BDF) and the Deutscher Fertigbau Verband (DFV) in Germany have played a crucial role in achieving higher acceptance for the use of offsite constructions techniques. In addition, those associations also emphasized on training, which resulted in an increase of 6% manufacturing members and 7% of employment in offsite construction in 2002 (Venables, 2004).

In Germany, offsite construction techniques have been used in building construction with a variety of building materials. Timber-based offsite construction systems take the form of post–beam construction, and structural insulated panels (SIP), or a combination of both. External finishes normally consist of rendering or cladding. The specifications for the timber construction in Germany set higher standards than those in the UK, with greater concern for the final quality of the finished product. Post-and-beam systems are aimed at the upper end of the housing market and application is still very limited. Concrete and masonry systems are used for building panels and roofing elements. In addition, modular concrete housing and automated production of concrete panels for walls and basements are also utilized in the German construction industry (Barlow 2004).

Offsite Construction Techniques Applications in Other European Countries

Most European countries have used offsite construction techniques in various forms for many years, and each of them developed a system that fits their own culture and construction technology. In the Netherlands, most homes are built by a hybrid method of concrete shells and a few exceptions of timber frames. The main applications of offsite construction techniques in the Netherlands were for roof and wall panels. The method is called rationalized fast-tracking housing techniques. This method utilizes steel tunnel formworks with cast-in-place concrete to complete a building with 50 units or more, due to the economical scale (Gibb, 2002).

In the Netherlands, the structural walls of buildings are prefabricated and insulated, using timber cavity inner leaves incorporating windows and doors. The inner leaves of cavity walls are prefabricated timber-framed construction, consisting of timber panels, a plasterboard inner skin, insulation, vapor barriers, damp-roof courses, windows, and door frames (either PVC or timber framed). Smooth-faced gypsum blocks are used in the building for non-load-bearing internal walls, which provide layout design flexibility, and better sound and fire resistance. Roofs are prefabricated with hinged timber elements incorporating roof-lights and vents. The prefabricated timber hinged roof elements are designed to sit on wall plates on the eaves and gable walls (Waskett, 2001).

Compared to conventional construction technology in the Netherlands, offsite construction approaches reduce construction time from 21 months to 12 months, with 33% more usable floor area. They also reduce the building cost up to 17%. Most dominate contractors are taking advantage of these methods and materials. It has been successfully applied in the industry for more than 25 years (Waskett, 2001).

Offsite Construction Techniques Applications in Asia

In Asia, offsite construction technologies are not as widely utilized as they are in the western countries. Singapore along with several other developed countries in Asia have developed effective methods for offsite construction, especially in using precast reinforced concrete technology to construct multi-story buildings.

Singapore relies heavily on imported labor for its construction industry. The Housing Development Board (HDB) has developed two basic approaches to solve the shortage of skilled labor; the fully prefabricated reinforced concrete building system and the semi-precast reinforced concrete building system. HDB learned from European experience of the importance of quality control of the panel connections and on-site workmanship. They emphasized the need for careful pre-project planning beginning with conceptual design (Gibb, 2001).

In HDB’s semi-precast reinforced concrete system, the main building components, such as beams and columns are all made cast-in-place. All other reinforce concrete components are pre-cast in factories, including staircases, parapets, internal non-load-bearing partition walls. HDB also developed two different fully precast reinforced concrete systems: pre-cast column-beam-slab system (PCBS) and post-tensioned flat plate floor system. Pre-cast reinforced concrete column and beams are connected together using bolts and anchors. Post-tensioned reinforced concrete flat plate floor systems are comprised of three story precast columns with onsite concrete flat slab with no supporting beams.

HDB also developed a volumetric bathroom unit based on a European system. The unit is fully furnished in the factory and is comprised of a fiber-glass or concrete base with lightweight framing for the walls and ceiling. This keeps the weight to a minimum making for easy installation and on-site handling (Gann, 1993).

According to Singapore’s experience, the standardization of building components is the key to successful utilization of offsite construction technologies. This standardization greatly reduces the number of modules needed to precast the concrete components and thus speed up the erection work.

In Korea, the leading construction company in the field of offsite construction is Daewoo Corp, which developed a multi-room modular construction system used for multi-story buildings. Daewoo Construction typically has a prefabricating facility set up on the project site. Because the preassembly is completed onsite, the construction company does not have to deal with the transportation issues. All of the precast concrete modules are manufactured onsite and then lifted into position by a crane at the rate of one floor per day. Daewoo states that their system is three times faster than conventional methods because all the factory-built panelized walls incorporate all of the mechanical and electrical systems. Like most other Asian countries, Korea's large population provides a great opportunity for using offsite construction techniques which have been widely adopted in constructing high-rise buildings that exceeded fifteen floors (Gibb, 2004)

2.2.3 Application of offsite construction techniques in United States

History of the use of offsite construction techniques in the United States

The use of offsite construction techniques in the United States (U.S.) construction industry originated about 100 years ago with the development of the wood frame house (Bruce 1972). One of the major benefits of these houses was that every piece and component could be manufactured in the factory, transported and then assembled on-site. During the mid-1800's prefabricated components were shipped from the east coast of the United States to California during the gold rush, as were army field barracks during the American Civil War (O'Brien, 2000).

In 1908, Sears Roebuck & Company began selling kit homes through its popular catalog. This was called the Modern Homes program. From 1908–1940 Sears Roebuck & Company sold more than 100,000 homes. Over that time Sears designed 447 different housing styles.

Home owners could also modify houses according to their own needs based on Sears' popular home designs. Individuals could even design their own homes and submit the working drawings to Sears who would then ship the appropriate precut and fitted materials, including standard 2×4" studs or 2×8" studs for framing, precut timber, fitted pieces, and even nails. Sears Modern Homes Program offered distinct advantages with mass-customized construction methods which greatly reduced purchase costs and shortened construction time up to 40%.

During the 1920's and 1930's many prominent architects and engineers began to construct mass-produced housing. Steel, sheet metal, tubular pipe, aluminum, wire, and glass were considered as the appropriate materials for manufactured housing. In the 1930s Howard T. Fisher, in an effort to make homebuilding friendly to the average homeowner, pioneered the system of prefabricated wood-stud panels which are still used today. Following Fisher' idea in the 1940's house trailers were developed which were constructed based on current aircraft manufacturing techniques (Colean, 1944)

Historically, the use of offsite construction techniques were not significantly increased in the US during World War I due to economic fluctuations. By 1940 there still were less than 30 companies that were manufacturing and selling prefabricated houses on a regular basis (Kelly 1951).

In 1942 the Prefabricated Home Manufacturers Association was established in the US due to a great demand for housing products. This association was established to disseminate information, develop industry standards, study distribution problems, improve manufacturing methods, conduct cost and accounting studies, and serve as a forum for the exchange of ideas (Kelly 1951). Over the years, this association has made significant contributions to the development of offsite construction techniques (Arch. Forum 1946).

In the 1950s, to meet the steady demand for new homes following World War II, companies began to produce homes in factories. These homes were equivalent to today's Housing and Urban Development (HUD) code or mobile homes. When a home manufacturer first produced a two-section home conforming to an applicable building code in 1958, the modular housing industry was formally born. Even though great production increases were seen at that time, offsite construction techniques were still not competitive with traditional methods.

As had happened in Europe, the U.S. housing industry itself has been a key-driving factor in the use of offsite construction techniques, in that these techniques were used as efficient solutions to meet increasing housing demands. In 1960 the Operation Breakthrough program was began to provide jobs, affordable housing, and to boost the economy. This program unexpectedly created the eventual downturn in the use of prefabrication (Schodek 1975).

In 1970 the reemergence of offsite construction techniques was promoted by the Industrialization Forum. This organization provided a wide variety of information to the construction industry and greatly improved methods. At present, a powerful housing market is driving homebuilders to consolidate and invest in technology for prefabrication and supply chain integration (ENR 2006). The factory-built home industry is becoming an important alternative to housing industry in the U.S. These homes can be customized for individual needs with better quality compared to conventional-built homes. The various forms of factory-built houses include modular homes, panelized building systems, post-and-beam construction, and log houses. (Haas 2000)

Recent application of offsite construction techniques in the residential construction of the United States

A review of the current utilization of offsite construction techniques included five different types of prefabricated building products. They are offsite preassembly, precut housing, manufactured housing, panelized building systems and modular building systems. Each of them is different in design, on-site installation, and code requirements. The site-built home, often called "stick-built", dominates the market with over 75% of the 1.2 million annual new homes built in the United States in the year of 2000. Prefabricated housing represented approximately 25% of new single-family housing, in both 1998 and 1999, and approximately 20% over the last 20 years (Manufactured Housing Institute 2000).

- Precut Housing

Precut housing, which was originated by Sears Roebuck & Company in 1908, consisted of factory-built kits that have been manufactured at the plant with components shipped to the site for assembly on a permanent foundation. The homeowner could order their desired design from the manufacturer's catalog, or provide working drawings to the manufacturer. The components would be delivered with an assembly manual. These kit homes included traditional houses, log cabins, and dome homes, all of which must comply with the local codes in the jurisdiction where they are being physically assembled (O'Brien, 2000).

- Manufactured Housing

In 1954, Marshfield Homes introduced prototypical manufactured housing. The homes were constructed without any building regulatory approval during the 1950's to the mid-1970s. This type of home is often called "mobile homes" and is considered to be of inferior quality by most consumers (Obiso 1998).

In 1974 the United States Department of Housing and Urban Development (HUD) received congressional approval to enforce a construction code on the mobile home industry. By 1976 a nationwide standard was in effect governing the construction of mobile homes. In 1979 the term "mobile homes" was replaced by "manufactured housing" and now referred to as "HUD code housing".

Currently manufactured housing refers to a particular type of factory-built home with one or more units assembled, transported on wheels to the site, and often installed on nonpermanent foundations. This type of housing must comply with the manufactured housing codes within the jurisdiction of a plant's location, which are "HUD codes" (O'Brien, 2000).

- Panelized Building Systems

Panelized building systems consist of factory-built housing components instead of completed modules that are transported and assembled to a permanent foundation. These houses must comply to the local building codes where the house will be assembled. The building panels consist of open-wall, floor joists, closed-wall with doors and windows, and structurally insulated panels. Open-wall panels are traditional 2' stud framing at 16" or 24" on center with the open cut for window and doors assembling onsite. These interior and/or exterior wall panels are cut and assembled in a plant and then shipped to the site for field assembly in the conventional manner. Closed-wall panels are similar to open-wall panels except that the exterior sheathing is fastened to the studs in the factory before shipping to the site.

Structured insulated panels (SIP) are 2" to 12" thick cores of rigid foam insulation that has wood sheathing bonded to both surfaces which provides the homeowner a durable, low-cost, energy-efficient house with significant energy saving advantages. The windows are pre-assembled at the factory and openings for doors are precut in the factory.

- Modular Housing

Modular housing was originated in the 1980's. Contrary to conventionally built housing, modular housing is constructed in segments called "modules" (or "boxes") in a factory setting. Modular housing normally has multi-room, three-dimensional units, which are constructed and pre-assembled complete with trim work, electrical, mechanical, and plumbing installed in the factory instead of onsite (O'Brien, 2000). Upon the completion, units are shipped to the site for installation on permanent foundations. Modular housing must comply with the same local building codes used for conventional housing within the respective jurisdiction.

Since the modules are built in the factory, the possibility of damage from inclement weather onsite is reduced, and also the possibility of water infiltration during the construction phase is eliminated. Therefore, modular housing provides better building quality compared to conventional site buildings (O'Brien, 2000).

Recent application of offsite construction techniques in the commercial, institutional and industrial constructions of the United States

In the commercial sector, H.B. Zachry Construction Company is one of the pioneers using offsite construction techniques. In 1968 the company constructed the Hilton Hotel in San Antonio, Texas. It was the most sophisticated modular building in the world by then. The construction started 7 miles away at the 6 acres of factory yard, where all hotel rooms were constructed. Each room was finished with concrete structure, drywall, plumbing, interior and exterior finishing, windows, doors, and balconies, and then delivered to site by train. All the modular rooms were put into place by using lifting cranes, and then assembled together by welding pre-structured steel bars. A helicopter was used to assure that each room was assembled within designed horizontal and vertical dimensions. The construction work was finished in 202 days, breaking the previously conventional construction record far ahead. After that, Zachry construction company used this "Zachry modular system" for building and installing 1,600 rooms for Holiday Inn in Texas in six months, and eight story nursing rooms in Texas within in 45 days, and a metropolitan hospital in Texas in 15 months (Zarchry, 2000).

One of examples for the use of offsite construction techniques in the commercial sector is precast prison and jail cell modules, which invented by Tindall Corp. Tindall Corp. is a family-owned company headquartered in Spartanburg, South Carolina. Started from 1963, it has emerged as one of the largest U.S. precast concrete producers, with upwards of 800 employees and five plants occupying more than 350,000 sq.ft. of manufacturing area (Tindall website).

The company's strengths lie in prison and jail construction, heavy industrial structures with replacing a considerable amount of filed construction work with manufactured components. This company manufactured and erected precast cell units with high strength concrete. The cells are completed produced and furnished in factory with completed plumbing, mechanical and electrical services. Once the modules are delivered and erected onsite, the mechanical systems can be connected by site contractors. By using TindallCast building system, 10 to 15 housing modules or 20 to 30 prison cells can be erected in a day. It offers exceptional fast project schedules, superior quality, and competitive project cost for the owners. Besides manufactured cell modules, Tindall also offer the customized building modules for other institutional buildings including classroom, church building and office rooms (Tindall, 2007)

Flour Corp. is one of the industry leaders in using offsite construction techniques in the industrial projects. Flour Corp is one of the world's largest construction companies, with 35,000 employees, based at Irving, TX. This company offers design, construction, engineering and maintenance services all over the world by a network of offices in more than 25 countries across 6 continents (Flour website)

The under construction project of biotech manufacturing facility in Puerto Rico by Flour Corp is an example of industrial projects incorporated the use of offsite construction techniques. This plant is the largest modular constructed biologics manufacturing in the world, which involves more than 600 modules from five module fabrication facilities in four countries. Flour's Greenville, South Carolina, and San Juan, Puerto Rico are working as a team in executing the design phase of this project because it involves complex trafficking logistics and site logistic.

2.3 Cases studies of the use of offsite construction techniques

As part of the literature search, the researcher conducted 2 case studies of visiting two highly reputable offsite manufacturing facilities. The following section presents a summary of the information obtained from the tour and interviews.

Case Study 1--- the Visit of Pulte Science

Pulte Home Science is a division of Pulte Homes, Inc. America's second largest homebuilding company. Pulte Homes, Inc. was founded in 1960 in Bloomfield Hills, Michigan. After 57 years, the company currently has operations in 27 states in the U.S. In 2006, Pulte Homes produced 41,487 homes and generated the annual volume of $14.3 billion (Pulte Homes, 2007)

Pulte Home Science (PHS) manufacture facilities located at Manassas, Virginia, was established in 2003. At this facility, PHS produces factory-built housing components instead of completed building components. The housing components include structural insulated panels (SIP) exterior walls with assembled windows and pre-cut door opens, the steel stud interior walls, the laminated wood floor joists, and the foundation walls. Structured insulated panels (SIP) are fabricated by laminating a polystyrene foam between two sheets of 7/16" thick Oriented Strand Board (OSB).

SIP walls provide better energy efficiency by delivering a whole wall with a R-14 rating allowing for a tighter envelope with less air filtration.

A tour of the PHS plant was conducted by the chief plant engineer. During the tour, questions about the manufacturing process were asked. No structured interview questions were used in this interview, the information listed below are the observations of the tour and interview at PHS plant.

In PHS, the customized panelized building component systems are developed with modern technologies incorporating CAD design and computer numerical control (CNC) cutting machine. The drawings of each panel are developed by CAD software, then all digital design data are transferred into a control computer, which operates the CNC cutting machine. Therefore, each section of SIP wall via a cut routine derived directly from the engineering drawings, which produces building components with accurate dimensions, and greatly reduces the design to construction period. In addition, using computerized modern technology greatly improves the stability, strength, energy efficiency and architectural aesthetics of panelized building systems. It resulted in precisely cut components, stiff floor, wide spans, and higher R-Value compared to conventional building methods (PHS Website, 2007).

Furthermore, the computerized modern technology provides variety design options. There were no two PHS homes were being built exactly same according to the chief plant engineer of PHS, because PHS provided the homeowners a wide variety of house plans developed by their in-house engineer with CAD system. The homeowners can select any plans and modify the design to meet their own needs. Once final design was completed, the PHS engineer developed engineering drawings by using PHS developed design software, which connected with the CNC cutting machines. All the building components are cut by the computer controlled CNC machine with 100% precision and quality stability, which also result in the reduction of construction time.

However, the public's negative perceptions of offsite construction techniques included panelized systems have always been one of the significant barriers to increase their application (Blismas, 2006).

"Producing the panelized component is the easy part", said Mr. Chief Plant Engineer, "the entire construction industry is in favor of conventional construction method is the biggest challenge we are facing on daily basis". The contractors are reluctant to accept these techniques due to a variety of reasons, including negative perceptions of these techniques, previous experience with lower quality, lack of qualified assembling workers, and unwilling to change their means and methods.

Skeptical code officials are other challenges to the offsite construction techniques according to the findings from personal interviews. To overcome this challenge, PHS developed a model of their panelized building systems to educate the code officials. "We invited the code officials come to the plant and explained what we are doing during their visit", says Mr. Chief Plant Engineer. In response, most code officials are more open to accept these methods after the detailed explanation with all the supporting data.

Not surprisingly, some architects and engineers are also reluctant to accept these systems because the computerized design system normally took more to comprehend. As the Chief Plant Engineer explained that an experienced architects normally need to spend a year to comprehend the design software utilized in the PHS plant.

Case Study 2--- the Visit of Crestline Homes

Crestline Homes, Inc. is an industry leader of manufacturing modular buildings. The company is located at Laurinburg, NC, and established in 1984. Since then, it has produced more than 10,000 home.

Crestline Homes has 2 manufacturing facilities to produce modular buildings. The primary markets are North Carolina, South Carolina, Virginia, Tennesseans, and Georgia. In response to the increased demand, the company's operations are expanding to Florida and Mississippi.

Similar to PHS plant, In Crestline Homes, all homes are designed using CAD technology. Once the drawings are approved by homeowner and the permit is secured, the construction process begins in a climate-controlled factory by skilled craftsman using precise machinery and advance technology. All of the manufactured building plans must be reviewed and approved by the local building officials to compliance with the local building codes, where the home will be installed. The construction process is inspected at every stage by independent third party inspectors, those are licensed by the states to perform in-plant inspections. When the modules are approved by the inspections, the third party places a certifying label assured that modules have been pre-engineered in conformance with the approved plans and the local building codes (Modular Report, 2004).

Contrary to conventionally-built homes, which are assembled on the jobsite piece by piece from floor to roof, modular homes are construction in segments (called modules) in the factory. After construction, the separate modules are transported to jobsite. To reimbursement the rigors of shipping and vibrations during the transportation, each module has been constructed with 20-30% more structural strengths than conventional buildings. For instance, drywall is typically glued with a special adhesive and then screwed to the framing. All the modules are constructed with 2"×4"or 2"×6" wall studs, 2"×8"or 2"×10" floor-joists, 2"×4"and 2"×6" rafters with 8" or 10" bottom cords, all constructed on 16" centers. Additional structural strengths of homes provided a rigid system with better performance than conventional buildings. In Crestline Homes, all the modules are built to withstand the winds up to 120 mph to ensure the structural integrity during the transportations from factory to jobsite.

Final assembly phase normally began with constructing foundations onsite by the modular builders. As soon as the foundation was completed, the assembly process started with the supervision of experienced project engineers trained and certified by the manufacturers. It typically took experienced modular builders less than two hours to place one unit. The finish work normally included securing remaining roof shingles, attaching siding, electrical connections, plumbing completion, mechanical joints, and miscellanies finishes.

Once completed, modular building is virtually indistinguishable from conventional building. In addition, it offers many advantages to both homebuilder and homeowner. For instance, fabricating building components in factory improves quality and precision, eliminates weather impact on the construction phase, reduces material costs, onsite manpower and on-site construction time significantly. According to the study conducted by the Partnership for Advancing Technology in Housing (PATH), modular housing can greatly reduce the construction cycle, from site preparation to finishing construction, it normally take 20-25 days compared to the average 6-9 months for constructing a conventional studs-truss house. In Crestline Homes, a single-family house with 25, 00 sq.ft. normally takes 2 weeks or less to finish.

The information gathered from the personal interviews supported that offsite construction techniques incorporated certain degree of onsite work, which normally completed by an independent general contractor, who is responsible for determining the type and design of finish product with owners, and ordered the building components from the manufacturers. The onsite construction work included constructing garage, patios, balconies, sidings and titled up pre-engineered steep roofs at the site.

Compared to conventional on-site construction, the modular buildings provide many benefits for the owners included faster speed of construction, higher product quality, more cost-efficient, less waste and more energy efficient.

As expected, misconceptions of modular building systems from homeowners are one of the most significant challenges in the industry. Most interviews had mentioned these factors during the discussion. People are always confused the modular buildings with the manufactured housing. An interviewed modular builder shared with the researcher a classical story. A developer in South Carolina changed his mind of using modular building system in his new project as soon as the building modules were delivered by trucks, even though he was very satisfied with previously completed buildings with modular systems. Similar cases have been happened In PHS and many other offsite construction contractors everyday.

2.4 Benefits of using offsite construction techniques

Many literature studies have analyzed the benefits of prefabrication, preassembly and modularization processes. These approaches have greatly contributed to the improvement of the construction industry in terms of construction duration, construction costs, product performance, onsite safety, productivity, customization, and environmental issues. The benefits of offsite construction techniques are summarized below.

2.4.1 Schedule

Saving in time is one of the most substantial benefits of the prefabrication, preassembly, and modularization processes used in the construction industry. Reducing onsite production time has a great impact on shortening overall project schedules. The site work is traditionally vulnerable to disruption from extremes of weather, which is one of the main variables of the construction schedule. The use of prefabricated components on-site reduces the risks of delay and protection requirements in a given project. At present scheduling problems causing a large number of residential construction companies can cause huge productivity problems. Prefabrication technology is one answer to shortening the schedule and improving efficiency (ENR 2006). In addition to housing, some major retail clients are actively involved in prefabrication methods in the continual reduction of construction time in the commercial sector of the industry. Overall, prefabrication, preassembly, and modularization play an active part of schedule savings.

2.4.2 Cost

The use of prefabrication techniques at a project allows cost savings at every stage of the production chain due to mass production, for instance, material savings at the procurement stage and labor savings at the construction stage. A CII study of industrial projects found that in some cases costs were reduced by as much as 10% of overall project costs and 25% of onsite labor costs (Tatum 1987). Cost reductions were largely attributed to the lower cost of offsite labor. In addition, savings may be associated with site overhead reduction, installation efficiencies, and the standardization of design (CII 2002). Cost reductions can also be explained in terms of craft productivity increasing and labor rates decreasing on site.

2.4.3 Onsite Safety Performance

Prefabrication can increase the on-site safety record by reducing the exposure of workers to inclement weather, height, hazardous operations, and onsite working time. Workers in a fabrication shop are not affected by inclement weather. Prefabricated components also provide more working space to alleviate the potential possibility of accidents onsite (Ball, 1998).

2.4.4 Product Quality

Higher product quality through the use of prefabricated components can be achieved by precise design and close supervision on-site, which reduces the amount and scope of change. The more accurate profiles and standardized dimensions of components lead to better quality control on the project. At present, Construction IT software helps ensure alignment and precision of a given project are maintained both onsite and in the factory. Computer-assisted manufacturing technology allows each product in the line to vary from each other. Software integrates design practice with manufacturing to provide mass customized production (Russell, 1981).

2.4.5 Workmanship

Prefabrication can offer opportunities to alleviate the problem of skilled labor shortages. In factory environments the quality of the finished product is much easier to assure than on-site. All that remains is to ensure that the on-site assembly meets the required standards to allow the product to perform as designed. Compared to the traditional construction approach, prefabrication has lower workmanship requirements on-site owing to simplified work content (Blismas, 2006).

2.4.6 Environmental Impact

Careful quality control of the manufacturing process enables construction waste to be controlled and minimized through appropriate design and recycling opportunities. Negative environmental impact can be alleviated by reduced onsite construction time, less noise, and less waste produced on-site. In addition, industrialized construction processes can greatly increase material inputs and reduce costs. One specific scheme being developed with European Community (EC) funding has been quoted as having the following anticipated benefits (Blismas, 2006).

- 50% reduction in the amount of water used for the construction of a typical house
- 50% reduction in the use of quarried materials in the construction
- At least 50% reduction in the energy consumption

2.5 Challenges of using offsite construction techniques

However, the literature studies also found several challenges of using offsite construction technique, which are summarized as follows.

2.5.1 Project Planning and Coordination

The biggest disadvantage of prefabrication, preassembly, and modularization in construction is the increase of pre-project planning stage. There is a need for increased engineering effort upfront (CII, 2002). Therefore, design work and extensive planning must be precisely conducted before fabrication. In addition, coordination of design, transportation, and onsite installation are critical components for successful implementation.

2.5.2 Transportation Restraints

Transportation logistics plays a large role in determining offsite construction feasibility. The method and route of transportation impose size and weight limitations as well as width and height restrictions during transit (CII, 2002). Roadway transport, as the most common method utilized, usually restricts the size of modular building or preassembled building components to 12-14 feet in width, and 50-55 feet in length. In addition, and their weight also restricted by the capacity of lifting equipment usually between 10 to 30 tons. In addition, there exist the U.S. highway restraints along with lifting capacity of crane. Manufactured building components have to be overly designed to alleviate possible damage during transit, which likely to increase design and construction cost (Pendlebury, 2004)

2.5.3 Negative Perceptions

Based on the literature studied, the general negative perceptions of offsite construction techniques was one of the most significant challenges in both the U.S. and overseas with the exceptions of in Germany and Japan. In the U.S., prefabricated buildings have always been confused with manufacture houses, "mobile homes", even though there is a big different between these two types of buildings (Hass, 2000; O'Brien, 2000)

2.5.4 Flexibility to make changes onsite

The inability to make changes onsite during construction may decrease the use of offsite construction techniques. Offsite construction techniques, in particular for modular buildings, require a well-defined scope early the project planning stages (CII, 2002).

CHAPTER 3

RESEARCH METHODOLOGY

This chapter addresses the research design, sample design, research procedures, survey instrument along with statistical methods used in this study.

3.1 Restatement of Research Questions & Hypotheses

The following questions were examined in this study:

1) To what degree were offsite construction techniques being used in the building sector of the United States construction industry in 2005?

2) What did architects/engineers and general contractors perceive to be the benefits and barriers of using offsite construction techniques in the building sector of the United States construction industry? Did they perceive each benefit and barrier differently at the 0.05 level of significance?

3) What were the top 3 reasons that would motivate general contractors to use offsite construction techniques in the building sector of the U.S. construction industry?

4) What were the top 3 reasons that would motivate architects/engineers to specify offsite construction techniques in the building sector of the U.S. construction industry?

5) What were the top 3 challenges that restrain general contractors from using offsite construction techniques in the building sector of the U.S. construction industry?

6) What were the top 3 challenges that restrain architects/engineers from using offsite construction techniques in the building sector of the U.S. construction industry?

7) Was there a linear relationship between architects/engineers and general contractors' levels of satisfaction in using offsite construction techniques with the percentages of their uses in the building sector of the U.S. construction industry?

8) What did architects/engineers and general contractors forecast as to the future of using offsite construction techniques in the next 5-10 years?

The statistical analysis used to examine hypotheses in this study consisted of three sections: 1) architects'/engineers' response relating to the use of offsite construction techniques; 2) general contractors' responses relating to the use of offsite construction techniques; and 3) comparing whether the two groups' responses were statistically different with each other.

Hypothesis statement 1

The use of offsite construction techniques reduces the overall project schedule.

Hypothesis statement 2

The use of offsite construction techniques reduces the need for skilled craft workers onsite.

Hypothesis statement 3

The use of offsite construction techniques reduces the project construction cost.

Hypothesis statement 4

The use of offsite construction techniques increases project product quality.

Hypothesis statement 5

The use of offsite construction techniques increases overall onsite labor productivity.

Hypothesis statement 6

The use of offsite construction techniques limits design options.

Hypothesis statement 7

The use of offsite construction techniques increases safety performance.

Hypothesis statement 8

The use of offsite construction techniques reduces onsite disruption of other adjacent operations.

Hypothesis statement 9

The use of offsite construction techniques reduces the negative environmental impact of construction operations.

Hypothesis statement 10

The use of offsite construction techniques increases the overall project cost.

Hypothesis statement 11

Transportation restraints (i.e. size constraints, transportation cost, and impact on building structures) limit the use of offsite construction techniques.

Hypothesis statement 12

The owners’ negative perception of offsite construction techniques limits their use.

Hypothesis statement 13

The use of offsite construction techniques limits the ability to make changes to work onsite.

Hypothesis statement 14

The use of offsite construction techniques increases design efficiency

Hypothesis statement 15

The use of offsite construction techniques increases design cost

Hypothesis statement 16

Complicated computer software for designing offsite construction techniques limits their use.

Hypothesis statement 17

The use of offsite construction techniques increases jobsite management efficiency

Hypothesis statement 18

Local building regulations restrict the use of offsite construction techniques.

Hypothesis statement 19

Lack of skilled offsite assembly craft workers limits the use of offsite construction techniques.

3.2 Research Design

A stratified random sample design was used for this study, because stratification of sample may produce a smaller bound on the error of estimation than by a simple random sample of the same size (Scheaffer & Mendenhall & Otto, 2006). The general contractors with the majority of their work in the building segment of the U.S construction industry was selected as one stratum. The other stratum was architects/engineers whose design work concentrated in the building segment of the U.S construction industry was selected as research subjects. A simple random sample was selected from each stratum.

Two self-administrated survey questionnaires were developed as primary research methodology for data collection to examine the above mentioned research questions and hypotheses test, because the geographical dispersion of the subjects makes the collecting data by interviews or case studies cost prohibitive and time consuming (Edum-Fotwe et. Al., 1994). Therefore, the utilization of self-administered survey questionnaires with a well-defined scope was determined the most feasible approach to gather data for this study. In addition, the use of a self-administered survey questionnaire with a randomly selected sample group reduced interviewer bias and improved validity by using anonymous respondents.

However, self-administered surveys have several significant limitations such as non-respondent error, limitation of the "depth" of gathered information, and researcher's inability to confirm the respondents understanding of the questions. These limitations can be minimized by using targeted respondents, conducting a pilot study of the survey instrument, and enlarging the sample group.

3.2.1 Targeted Respondents

The selected survey respondents must be able to provide reliable and valid data concerning the research constructs under the study (Bausman, 2002). To support valid measurement of industry practitioner's perceptions and utilization of offsite construction techniques it is essential that the survey respondents have knowledge and experience in this field. They should have a great understanding of offsite construction techniques and extensive knowledge of the utilization of these techniques in their own firm.

In general contractor's companies, the individual(s) eligible for this study were the owner, president, vice president, Chief Executive Officer (CEO), project manager, or job superintendent. In architect/engineer firms, the individual(s) who meet the requirements were president, directors, registered architects or engineers.

3.2.2 Pilot-study

To enhance the validity and reliability of the survey instrument, a pilot study was conducted using 5 representatives of each of the two stratums. Feedback from the pilot-study respondents regarding the content, scope, question structure, and response scales was solicited and used to make improvements to the survey questionnaire.

The survey questionnaires were mailed to the randomly selected research subjects and were required to be return within two weeks. A self-addressed business reply envelope was provided for ease of return.

3.3. Sample Design

3.3.1 Population

The population of this study comprised of two stratums: architects/engineers (A/Es) and general contractors (GCs) and in the building sector of the U.S construction industry.

3.3.2 Sample Frame

1) Architects/Engineers (A/Es)

The sampling frame for Architects/Engineers was the American Institute of Architects (AIA) 2005 national membership list, which includes 49,595 firms, from which 600 design firms were randomly selected with 12 firms from each state.

2) General Contractors (GCs)

The sampling frame for general contractors in this study was a composite listing from the Dun & Bradstreet (D&B) utilizing general contractors whose annual volume was more than $1 million U.S. dollars in 2005. Since there is no one comprehensive list of general contractors in the U.S. construction industry, the D&B list is the most comprehensive one that could be found for the sample frame in this study. There was a total of 11,000 general contractors eligible, 600 GCs were randomly selected from this list.

3.3.3 Sample

This study used a stratified random sampling design to conduct the self-administrated survey. Two simple random samples were selected from each above mentioned group.

Estimated total sample size for each group was determined by the formula:

$N = (t\alpha * \sigma)^2 / E^2$

This study was designed at the 95% of confidence interval. For the conservative estimate, σ was 3.5, and E was assumed to be 0.2. Based on the calculation, estimated total sample size was 1177. In this study, the sample size of 1200 was used to ease of study.

3.4 Survey instrument

Two self-administrated survey questionnaires were developed for each sample based on the findings from the comprehensive literature review, tour of offsite manufacture facilities, and a series of interviews. The objectives of these surveys were to investigate architects'/engineers' (A/Es') and general contractors' (GCs') perceptions of the benefits and barriers of using offsite construction techniques and determine the current degree of utilization of these techniques in their project. All surveys included four sections: Section I-general information about the respondent and the degree of using offsite construction techniques; Section II- the perceptions of using offsite construction techniques. Section I & II were designed to be measured by seven-point lickert scales; Section III- the identification of top three reasons for using offsite construction techniques, and Section IV-the identification of the top three reasons for not using offsite construction techniques. Each respondent was also asked to circle three (3) reasons for using or not using the offsite construction techniques from the given options in the section III & IV.

The survey given to architects/engineers can be found as appendix A. The survey given to general contractors can be found as appendix B, and an open-ended interview questionnaire to facilitate developing research instrument can be found as appendix C.

In order to improve the response rate, a personalized cover letter addressed directly to the president of each company was developed and sent with the questionnaires (Appendix D). The respondent right as a volunteer in this study was addressed, and their information would be remaining anonymous.

The survey instruments and cover letter were reviewed and approved by Institutional Review Board at Clemson University Office of Research Compliance by December, 2006, as shown in Appendix E.

The surveys were mailed to a sample of A/Es and GCs in January, 2007 with noted return date deadlines within two weeks.

3.5 Research Procedures

The following procedures were utilized subsequently to collect data and examine the research questions.

First, the present study began with a comprehensive literature review included the use of offsite construction techniques in the building sector of the United States and Overseas construction. Second, the researcher conducted a case study to visit two industry-leader offsite manufacturing facilities and interviewed representatives from those two factories.

Third, Based on the information gathered from the literature review and the factory tours, the researcher conducted a series of in-depth open-ended interviews with selected industry practitioners. Developers, architects, general contractors, and manufacturers were selected to obtain sufficient insight and understanding of the benefits and challenges of using offsite construction techniques in the U.S. building construction sectors. All of these interviews were based on a structured interview questionnaire developed by the researcher. (See appendix C). Prior to the interview each participant was provided a copy of the structured questions by email. The majority of interviews were conducted by telephone, with several were done by face-to-face due to the short distance involved. The interviews ranged from 45 minutes to one and half hours long, with the average being approximately one hour. The results of the interviews were used to develop these two self-administered questionnaires.

Fourth, the researcher mailed 1,200 self-administrated survey questionnaires to the randomly selected sample of A/Es and GCs, with noted return date within 2 weeks.

Fifth, within two (2) weeks of the initial mailing one hundred and thirty eight (138) respondents were received. The researcher recorded all the survey responses on an EXCEL spreadsheet for analysis, and coded as the follows.

3.5.1 Data Entry and Coding

In this research data entry and coding was accomplished by a three step process: 1) coding the questionnaire, 2) initial data entry and output and 3) verification of the data by comparing the initial data with a hard copy print of entered data.

3.5.2 Coding the Questionnaire

The research questions were designed to investigate the respondent's perceptions by using seven point lickert scales. The response for each statement was coded to the numerical options from 1-7 with 1 indicating "strongly disagree", 2 "moderately disagree", 3 "slightly disagree", 4 "neither disagree nor agree", 5 "slightly agree", 6 "moderately agree", and 7 "strongly agree".

The satisfaction level of past experience using offsite construction techniques by the respondent were also measured by seven point lickert scales. The responses for this section were coded to the numerical options from 0-7 on the questionnaire. 0 was "never used the followed offsite construction techniques in the past". 1 indicating "highly unsatisfied", 2 "moderately unsatisfied", 3 "slightly unsatisfied", 4 "neither unsatisfied or satisfied", 5 "slightly satisfied", 6 "moderately satisfied" and 7 "strongly satisfied".

Each response for top three barriers and motivations of using offsite construction techniques was also numerically coded. The three circled reasons were coded as "1", with the reasons not circled coded as "blank".

3.5.3 Initial Data Entry and Verification

After finishing the initial data entering process, a hard copy of the spreadsheet was printed. The verification process with emphasis on controlling data entry error was implemented by comparing the hard copy with the raw data on each questionnaire.

3.6 Statistical Methods

Several statistical methods were utilized in this study which included 1) a series of single t-test for examining the hypotheses of A/Es' and GCs' responses of the benefits and barriers in using offsite construction techniques. A single t-test was used for examining hypothesis because the researcher intended to compare the mean of the respondents with the known mean (4), which indicated "neutral".

2) T-tests for comparing 2 samples assuming equal variances were used in this study to compare whether A/Es' responses were different with GCs' at the 0.05 level of significance.

3) Regression tests were used to determining the linear relationship between the A/Es' and GCs' satisfaction levels for the use of offsite construction techniques with the percentages of their use.

CHAPTER 4

FINDINGS AND ANALYSIS

This chapter reports the findings of the study and discusses the results of the data analysis.

4.1 Survey Samples

The self-administrated survey questionnaire were mailed to 600 architects/engineers (A/Es) and 600 general contractors (GCs). 86 (7.5%) of the questionnaires were returned with no forwarding address. Among those 86 firms, 61 firms (71%) were A/Es and 25 firms (29%) were GCs. Therefore, the final sample numbered 1114 with 539 (48%) architects/engineers and 575 (52%) being general contractors.

4.1.1 Survey Responses Rate

135 firms had responded to the survey by the deadline, and 2 firms responded within the following two weeks. Therefore, a total of 138 (12.3%) out the 1114 firms had participants in this research; of which 71 (51%) were architects/engineers firms and 67 (49%) were general contractor firms. Four (4) A/Es' respondents and three (3) GCs' respondents were not used due to the incomplete answers, or completed by the untargeted respondents, as Table 4.1 presents.

	Initial mail	*Undelivered*	*Respondent*	*Unusable*	*Net Respondent*
A/Es	600 (50%)	61 (71%)	71 (51%)	4	67 (51%)
GCs	600 (50%)	25 (29%)	67 (49%)	3	64 (49%)
Total	1200	86 (7.2%)	138 (100%)	7	131 (100%)

Table 4.1 Summary of respondents

4.1.2 Respondents Analysis

1) Annual revenue of responding firms

The average annual revenue in the fiscal year 2005 of the respondents in the architects/engineers group was $21.43 million, with design fees ranging from $100,000 to $300,000,000. The average annual revenue in 2005 of the usable respondents in the general contractor group was $290,364,655, with a range from $1,300,000 to $ 12 billion. The majority of respondents reported annual revenue was from $20 million to $60 million U.S. dollars. More than 90% of respondents reported annual revenue of less than $500 million in 2005, as presented in Table 4.2.

	Range	*Average*
A/Es' Respondents	$ 0.1 million-$ 300 million	$21.43 million
GCs' Respondents	$1.3 million-$12 billion	$ 290.364 million

Table 4.2 A/Es and GCs respondents' Annual volume for 2005

2) Market segments of respondents

For the architects/engineers sample group, 13 (19.4%) firms out of 67 respondents concentrated in the residential sector, 35 (52.2%) firms focused on the commercial, 1 (1.5%) firm was heavily involved in the industrial design, and 18 (26.9%) firms worked in the institutional sector as presented in Table 4.3.

14 (21.8%) of the 64 GCs' respondents concentrated their work in the residential sector, 32 (50%) of them were commercial general contractors, 7(10.9%) companies concentrated their work in the industrial sector, and 11 (17.2%) firms were institutional contractors.

	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 (17.2%)	64

Table 4.3 Market Segments of the Respondents

4.2 Findings

The following is the summary of A/Es' and GCs' responses for each survey question.

Section I: Company Information of Using Offsite Construction Techniques

Question 1: please indicate your job title

1) GCs' respondents' job title

CEO	*Contractor Administrator*	*S. Int.*	*Owner*	*President*	*PM*	*VP*
8 (12.5%)	1 (1.6%)	3 (4.7%)	6 (9.4%)	27 (42.2%)	8 (12.5%)	11 (17.1%)

Table 4.4 GCs' responses on job title S. Int. indicates superintendent, PM indicates project manage, VP indicated vice president

2) A/Es' Respondents' job title

Architect	*Director*	*Owner*	*Partner*	*President*	*Principal*
35 (52.2%)	3 (4.5%)	7 (10.4%)	3 (4.5%)	9 (13.5%)	10 (14.9%)

Table 4.5 A/Es' responses on job title

Question 4: The majority of your company's work is performed on a _______ basis?

	International	*National*	*Regional*	*State-wide*	*Total*
A/Es	0 (0%)	2 (3%)	36 (54%)	29 (43%)	67
GCs	3 (5%)	8 (13%)	27 (42%)	26 (40%)	64

Table 4.6 the respondents' operation area

Question 5: For 2005, please indicate what percentage of your company's total volume incorporated the use of offsite construction techniques?

	Preassembly	*Hybrid system*	*Panelized*	*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 4.7 the respondents' percentages of using offsite construction techniques in 2005

Question 6: please indicate your satisfaction level of past experience of using offsite construction techniques, on a scale of 0 to 7 with 1 being very unsatisfied to 7 being very satisfied, and 0 indicating have never used offsite construction techniques.

Offsite preassembly techniques

	N/A	Very Unsatisfied			Neutral			Very Satisfied	Avg. Rating
	0	1	2	3	4	5	6	7	
A/Es	(29.85%)	(1.48%)	(2.99%)	(1.49%)	(10.45%)	(3%)	(37.31%)	(13.43%)	5.69
	0	1	2	3	4	5	6	7	
GCs	(28.13%)	(1.56%)	(3.13%)	(3.10%)	(3.13%)	(4.69%)	(34.38%)	(21.88%)	5.74

Hybrid Systems

	N/A	Very Unsatisfied			Neutral			Very Satisfied	Avg. Rating
	0	1	2	3	4	5	6	7	
A/Es	(88.06%)	(1.49%)	(0%)	(1.49%)	(2.99%)	(5.97%)	(0%)	(0%)	4
	0	1	2	3	4	5	6	7	
GCs	(79.69%)	(0%)	(0%)	(0%)	(9.38%)	(3.13%)	(1.55%)	(6.25%)	5.23

Panelized Systems

	N/A	Very Unsatisfied			Neutral			Very Satisfied	Avg. Rating
	0	1	2	3	4	5	6	7	
A/Es	(53.73%)	(0%)	(0%)	(1.49%)	(5.97%)	(7.46%)	(20.90%)	(10.45%)	5.71
	0	1	2	3	4	5	6	7	
GCs	(34.38%)	(4.69%)	(4.69%)	(1.56%)	(1.56%)	(4.69%)	(23.44%)	(25%)	5.55

Modular Buildings

	N/A	Very Unsatisfied			Neutral			Very Satisfied	Avg. Rating
	0	1	2	3	4	5	6	7	
A/Es	(77.61%)	(0%)	(4.48%)	(1.49%)	(4.48%)	(4.48%)	(7.46%)	(0%)	4.4
	0	1	2	3	4	5	6	7	
GCs	(60.94%)	(3.13%)	(4.69%)	(6.25%)	(4.69%)	(7.81%)	(4.69%)	(7.81%)	4.4

Section II: Perceptions of using offsite construction techniques

Survey question: please circle one number that most closely represent your level of agreement or disagreement with each statement on a scale of 1 to 7 with 1 being strongly disagree to 7 being strongly agree.

1) The use of offsite construction techniques reduces the overall project schedule

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (2.99%)	3 (7.46%)	4 (11.94%)	5 (25.37%)	6 (35.82%)	7 (13.43%)	5.11
GCs	1 (1.56%)	2 (0%)	3 (9.38%)	4 (15.63%)	5 (20.31%)	6 (23.44%)	7 (29.69%)	5.42

2) The use of offsite construction techniques reduces the need for skilled craft workers onsite.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (1.49%)	2 (10.45%)	3 (10.45%)	4 (32.84%)	5 (23.88%)	6 (13.43%)	7 (4.48%)	4.16
GCs	1 (4.69%)	2 (9.38%)	3 (4.69%)	4 (12.5%)	5 (23.44%)	6 (23.44%)	7 (21.88%)	4.98

3) The use of offsite construction techniques reduces the project construction cost

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (4.48%)	2 (4.48%)	3 (11.94%)	4 (32.84%)	5 (23.88%)	6 (17.91%)	7 (4.48%)	4.27
GCs	1 (4.69%)	2 (7.81%)	3 (14.06%)	4 (21.88%)	5 (23.44%)	6 (18.75%)	7 (9.38%)	4.45

4) The use of offsite construction techniques increase product quality

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (1.49%)	3 (10.45%)	4 (29.85%)	5 (28.36%)	6 (19.4%)	7 (7.46%)	4.63
GCs	1 (6.25%)	2 (7.81%)	3 (9.38%)	4 (31.25%)	5 (12.5%)	6 (20.31%)	7 (12.5%)	4.47

5) The use of offsite construction techniques increases overall labor productivity.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (0%)	3 (5.97%)	4 (25.37%)	5 (26.87%)	6 (32.84%)	7 (5.97%)	4.93
GCs	1 (0%)	2 (3.13%)	3 (4.69%)	4 (14.06%)	5 (28.13%)	6 (37.5%)	7 (12.5%)	5.29

6) The use of offsite construction techniques limits design options

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (5.97%)	2 (14.93%)	3 (17.91%)	4 (20.9%)	5 (8.96%)	6 (28.36%)	7 (2.99%)	3.97
GCs	1 (3.13%)	2 (14.06%)	3 (10.94%)	4 (14.06%)	5 (17.19%)	6 (28.13%)	7 (12.5%)	4.62

7) The use of offsite construction techniques increases safety performance.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (1.49%)	3 (7.46%)	4 (46.27%)	5 (25.37%)	6 (16.42%)	7 (0%)	4.36
GCs	1 (1.56%)	2 (3.13%)	3 (3.13%)	4 (37.5%)	5 (25%)	6 (26.56%)	7 (3.13%)	4.73

8) The use of offsite construction techniques reduces onsite disruption of other adjacent operations.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (1.49%)	3 (10.45%)	4 (41.79%)	5 (20.9%)	6 (19.4%)	7 (2.99%)	4.42
GCs	1 (1.56%)	2 (0%)	3 (0%)	4 (29.69%)	5 (39.06%)	6 (25%)	7 (4.69%)	4.98

9) The use of offsite construction techniques reduces negative environmental impact of construction operations.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (2.99%)	2 (1.49%)	3 (8.96%)	4 (32.84%)	5 (28.36%)	6 (22.39%)	7 (2.99%)	4.58
GCs	1 (3.13%)	2 (6.25%)	3 (9.38%)	4 (32.81%)	5 (23.44%)	6 (21.88%)	7 (3.13%)	4.45

10) The use of offsite construction techniques increase the overall project cost

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (8.96%)	2 (17.91%)	3 (38.81%)	4 (22.39%)	5 (5.97%)	6 (1.49%)	7 (4.48%)	2.89
GCs	1 (9.38%)	2 (18.75%)	3 (20.31%)	4 (29.69%)	5 (15.63%)	6 (4.69%)	7 (1.56%)	3.44

11) The use of offsite construction techniques limits the ability to make change onsite work

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
A/Es	1 (0%)	2 (4.48%)	3 (4.48%)	4 (17.91%)	5 (37.31%)	6 (25.37%)	7 (10.45%)	4.97
GCs	1 (0%)	2 (6.25%)	3 (4.69%)	4 (20.31%)	5 (15.63%)	6 (39.06%)	7 (14.06%)	5.19

12) Transportation restraints (size constraints, transportation cost, and impact on the building structures) limit the use of offsite construction techniques.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
A/Es	(4.48%)	(2.99%)	(4.48%)	(22.39%)	(34.33%)	(23.88%)	(7.46%)	4.76
	1	2	3	4	5	6	7	
GCs	(0%)	(3.13%)	(9.38%)	(12.5%)	(31.25%)	(29.69%)	(14.06%)	5.17

13) The owner's negative perception of offsite construction techniques limits the use of offsite construction techniques.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
A/Es	(4.48%)	(11.94%)	(22.39%)	(35.82%)	(16.42%)	(5.97%)	(2.99%)	3.59
	1	2	3	4	5	6	7	
GCs	(3.13%)	(9.38%)	(20.31%)	(21.88%)	(15.63%)	(20.31%)	(9.38%)	4.36

14) The use of offsite construction techniques increase project design efficiency

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
A/Es	(2.99%)	(10.45%)	(16.42%)	(43.28%)	(19.4%)	(4.48%)	(2.99%)	3.88

15) The use of offsite construction techniques increases design cost

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
A/Es	(4.48%)	(11.94%)	(20.9%)	(40.3%)	(13.43%)	(4.48%)	(4.48%)	3.46

16) Complicated computer software for designing offsite construction techniques limits their uses.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
A/Es	(4.48%)	(13.43%)	(34.33%)	(38.81%)	(1.49%)	(2.99%)	(4.48%)	3.15

17) The use of offsite construction techniques increase jobsite management efficiency

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
GCs	(3.13%)	(6.25%)	(9.38%)	(26.56%)	(21.88%)	(29.69%)	(3.13%)	4.59

18) The local building regulations restrict the use of offsite construction techniques.

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
GCs	(9.38%)	(21.88%)	(15.63%)	(26.56%)	(15.63%)	(6.25%)	(4.69%)	3.55

19) Lack of skilled assembly craft workers limits using offsite construction techniques

	Strongly Disagree			Neutral			Strongly Agree	Avg. Rating
	1	2	3	4	5	6	7	
GCs	(7.81%)	(18.75%)	(35.94%)	(29.69%)	(1.56%)	(6.25%)	(0%)	3.17

20) Question: Please provide any other benefits or barriers of using offsite construction techniques.

Several other benefits were mentioned by respondents, included 1) to compensate for the local weather, 2) to compensate for increasing labor costs, and 3) to increase GCs' competency.

Other barriers of using offsite construction techniques mentioned by respondents were: 1) union boycott, 2) increased fuel cost and other costs associated with transportation, 3) challenges from banking or financing institutions, and 4) several general contractors emphasized that design teams tend to lack confidence in offsite construction techniques except for the precast reinforced concrete and fabricated trusses.

21) Question: Do you anticipate the use of offsite construction techniques will increase in the next 5-10 years?

82% of A/Es' respondents believed that the use of offsite construction techniques would increase in the next 5-10 years, 7% of the A/Es' respondents believed the use of these techniques would decrease while the rest of group expressed no opinion.

81.4% of GCs' respondents believed that use of offsite construction techniques would increase in the next 5-10 years. 15.6% believed the use of these techniques would decrease, and 3% expressed no opinion.

Section III the reasons for using offsite construction techniques

Survey question: Please circle the top 3 reasons why your company uses offsite construction techniques.

1) Findings from A/Es' responses

Categories	**Frequency**	**Percentage**
To reduce construction duration.	29	43.28%
To reduce overall project cost.	24	35.82%
To reduce project overall schedule.	24	35.8%
To increase product quality.	20	29.85%
To compensate for the shortage of skilled craft workers.	13	19.40%
To compensate for the local weather conditions.	10	14.93%
To reduce environmental impact	10	14.93%
To increase overall labor productivity	7	10.45%
To increase overall labor productivity	7	10.45%
Project owners require using off-site construction techniques	5	7.46%
To reduce design duration.	4	5.97%
To compensate for the restricted working space onsite.	4	5.97%
Any other reasons	2	2.99%
To enhance your company's reputation	0	0%
To improve project safety performance	0	0%

Table 4.8 the top 3 reasons for using offsite construction techniques by A/Es' respondents

2) Findings from GCs’ responses

Categories	Frequency	Percentage
To reduce project overall schedule.	21	32.81%
To reduce construction duration.	20	31.25%
To compensate for the local weather conditions.	11	17.19%
To reduce overall project cost.	11	17.19%
To increase overall labor productivity	10	15.63%
To compensate for the shortage of skilled craft workers.	10	15.63%
To increase product quality.	10	15.63%
To increase product quality.	10	15.63%
To increase overall labor productivity	10	15.63%
Project owners require using off-site construction techniques	7	10.94%
To compensate for the restricted working space onsite.	7	10.94%
To reduce design duration.	5	7.81%
To increase your company’s profit margin	4	6.25%
To reduce environmental impact	2	3.13%
To improve project safety performance	2	3.13%
To enhance your company’s reputation	0	0%
Any other reasons	0	0%

Table 4.9 the top 3 reasons for using offsite construction techniques by GCs’ respondents

Section IV the challenges of using offsite construction techniques

Survey question: Please circle the top 3 reasons that restrain your company from using offsite construction techniques.

1) A/Es' responses

Categories	**Frequency**	**Percentage**
Inability to make changes in the field by using offsite construction techniques	35	54.69%
Transportation restraints	34	53.13%
Limited design options of using offsite construction techniques	31	48.44%
General contractors do not have expertise of assembling prefabricated building components onsite.	22	34.38%
Lack of skilled assembly craft works locally.	10	15.63%
The project owners do not allow using offsite construction techniques	10	15.63%
Using offsite construction techniques will increase the construction cost	8	12.50%
Any other reasons	8	12.5%
The local building regulation restricts the use of off-site construction techniques	6	9.38%
The local zoning ordinance restricts the use of offsite construction techniques	5	7.81%
Designing offsite construction components requires special computer software.	4	6.25%
Using offsite construction techniques will increase the design cost	3	4.69%
The financial institution restricts the use of offsite construction techniques.	0	0%

Table 4.10 the top 3 challenges of using offsite construction techniques by A/Es

2) GCs' responses

Categories	Frequency	Percentage
Transportation restraints	30	46.88%
Limited design options of using offsite construction techniques	29	45.31%
Inability to make changes in the field by using offsite construction technique	26	40.63%
The project owners do not allow using offsite construction techniques	11	17.19%
The financial institution restricts the use of offsite construction techniques.	9	14.06%
Using offsite construction techniques will increase the design cost	7	10.94%
The local zoning ordinance restricts the use of offsite construction techniques	7	10.94%
Using offsite construction techniques will increase the design cost	7	10.94%
Using offsite construction techniques will increase the construction cost	6	9.38%
Any other reasons	5	7.8%
The local building regulation restricts the use of offsite construction techniques	4	6.25%
General contractors do not have expertise of assembling prefabricated building components onsite.	1	1.56%

Table 4.11 the top 3 challenges of using offsite construction techniques by GCs

4.3 Analysis

The following is the summary of statistical analysis for each of the research questions.

4.3.1 Data Analysis for Research Question No. 1

Research question 1: To what degree are offsite construction techniques being used in the building sector of the United States construction industry in 2005?

1) Overall percentage of using offsite construction techniques by A/Es & GCs

	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 4.12 Overall percentages of using offsite construction techniques

As Table 4.12 shows, in 2005 A/Es had specified the use of offsite preassembly 19.57%, and incorporated hybrid systems in 1.6% of their work, also they specified the use of panelized systems 4.88% of their work, while modular buildings in 0.72%.

For GCs' group, 12.32% of their total volume was accomplished by using offsite preassembly techniques, and 0.09% was completed by using hybrid systems, 6.17% of their work was finished by panelized systems and 1.04% by modular buildings.

Overall, in 2005, 26.75% of architect/engineer's design work incorporated offsite construction techniques, and 19.62% of general contractor's total volume incorporated using offsite construction techniques.

2) Percentage of A/Es' using offsite construction technique by different market

	Preassembly	*Hybrid Systems*	*Panelized Systems*	*Modular*
Residential	22.45%	0%	5.36%	0%
Commercial	19%	1.89%	4.79%	0.86%

Table 4.13 Percentages of A/Es' specifying offsite construction techniques by markets

The researcher also analyzed the residential and commercial (including institutional) A/Es' percentages of using offsite construction techniques. In this study, the residential A/Es refer to the firms with 50% or more of their design work concentrated in residential sector, while the commercial A/Es refer to the firms with 50% or more of their design work concentrated in commercial and/or institutional construction sector. As a result of the very limited sample of industrial (N=1) designers, it would be inappropriate to analyze the percentage of using these techniques in the industrial sector. Therefore, only the residential and commercial A/Es' responses have been analyzed in this section.

As Table 4.13 presents, the A/Es' respondents specified preassembly techniques in 22.45% and panelized systems in 5.36% of their projects in 2005. None of them had specified hybrid systems or modular buildings. Also A/Es' respondents specified panelized systems in 5.36% of their work.

As for commercial A/Es, preassembly had been specified in 19% of their work, hybrid systems accounted for 1.89%, panelized systems accounted for 4.79%, and modular buildings accounted for 0.86%.

However, because of very limited sample size, statistical analysis indicated that there was no significant difference in the percentages of using offsite construction techniques in different markets.

3) Percentage of GCs' using offsite construction technique by different market

	Preassembly	*Hybrid systems*	*Panelized Systems*	*Modular*
Residential	20%	0%	10.77%	0.77%
Commercial	8.2%	0.04%	5.20%	0.98%
Industrial	11.14%	0.54%	8.57%	0.82%

Table 4.14 Percentages of GCs'using offsite construction techniques by market segments

In addition, this study also examined the residential, commercial and industrial GCs' percentage of using offsite construction techniques in 2005. The residential GCs refer to the firms with 50% or more of their construction work concentrated in residential sector, the commercial GCs refer to the firms with 50% or more of their construction work concentrated in commercial and/or institutional sectors, and the industrial GCs refer to the firms with 50% or more of their construction work concentrated in the industrial sector.

Data in Table 4.14 indicates that in 2005, the residential GCs incorporated offsite preassembly techniques in 20% of their work, incorporated panelized systems in 10.77% of their work, and modular building systems in 0.77%. None of the residential contractors reported having used hybrid systems in their projects.

For the commercial GCs, 8.2% of their total construction volume was accomplished using offsite preassembly, 0.04% by hybrid systems, 5.2% by panelized systems, and 0.98% by modular building systems.

The industrial GCs incorporated offsite preassembly techniques in 11.14% of their work, incorporated hybrid systems in 0.54% of their work, panelized building systems in 8.57% and the modular building systems in 0.82%.

However, because of very limited sample size, statistical analysis indicated that there was no significant difference in the percentages of using offsite construction techniques in different markets.

4.3.2 Statistical Analysis for Research Question No.2

Research questions No. 2: What did architects/engineers, and general contractors perceive to be the benefits and barriers of using offsite construction techniques in the building sector of the United States construction industry? Did A/Es and GCs perceive each benefit or barrier significantly different with each other at the 0.05 level of significance?

As discussed in an earlier chapter, hypothesis tests in this study consisted three sections: 1) determining architects/engineers' responses of each hypothesis statement of using offsite construction techniques; 2) determining general contractors' responses of each hypothesis statement of using offsite construction techniques; and 3) comparing whether the responses of these 2 groups were significantly different from each other by using a t-test for 2 samples assuming equal variances. The overall level of significance used in this study was 0.05.

Examining Hypothesis Statement 1

The use of offsite construction techniques reduce the overall project schedule

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*Stand. Dev.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	5.11	1.53	8.80	1.98	0.37
GCs	64	5.42	1.53	7.90	1.98	0.36

Table 4.15 Hypothesis Test for Perceptions on Overall Project Schedule

As Table 4.15 shows, the t-value for the architects/engineers (A/Es) was 8.80, which is greater than t critical value for two-tail test (1.978). Therefore, there is sufficient evidence to reject the null hypothesis. The mean of 5.11, being greater than neutral number (4), indicates that the A/Es "moderately agreed" that the use of offsite construction techniques reduces the overall project schedule.

The t-value for the general contractors was 7.90, which is greater than t critical value for two-tail test (1.978). Therefore, there is sufficient evidence to reject the null hypothesis. The mean of 5.42, being greater than neutral number (4), indicates GCs "moderately agreed" that the use of offsite construction techniques reduces the overall project schedule.

Comparison of the A/Es' & GCs' responses on the impact of overall schedule

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

T-Test: Two-Sample Assuming Equal Variances		
	A/Es Schedule	*GCs Schedule*
Mean	5.12	5.42
Variance	2.35	2.06
Observations	67	64
Pooled Variance	2.21	
Hypothesized Mean Difference	0	
df	129	
t Stat	-1.16	
P(T<=t) two-tail	0.25	
t Critical two-tail	1.98	

Table 4.16 T-test for comparing A/Es' & GCs' perceptions on schedule

As Table 4.16 shows, the P-value was greater than 0.05, indicating that there was not enough evidence to reject the null hypothesis.

Examining Hypothesis Statement 2

The use of offsite construction techniques reduce the need for skilled craft workers onsite

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.16	1.52	0.88	1.98	0.37
GCs	64	4.98	1.75	4.49	1.98	0.43

Table 4.17 Hypothesis test of perceptions of A/Es & GCs on onsite workmanship

As Table 4.17 shows, the t-value for the architects/engineers group was 0.88, which is less than t critical value for two-tail test (1.978). Therefore, there was insufficient evidence to reject the null hypothesis.

The t-value for general contractor group was 4.49, which is greater than t critical value for two-tail test (1.978). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.98 being greater than neutral number (4), indicated that GCs "slightly agreed" that the use of offsite construction techniques reduce the need for skilled craft workers onsite.

Comparison of the A/Es' & GCs' responses on the impact of workmanship

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es Perception	*GCs Perception*
Mean	4.16	4.98
Variance	2.32	3.06
Observations	67	64
Pooled Variance	2.68	
Hypothesized Mean Difference	0	
df	129	
t Stat	-2.86	
P(T<=t) two-tail	0.004	
t Critical two-tail	1.97	

Table 4.18 T-test for comparing A/Es' & GCs' perceptions on workmanship

As Table 4.18 shows, P-value for two-tail test equaled to 0.004, which is less than 0.05. Therefore, there was sufficient evidence to reject the null hypothesis. The general contractors' group had different perceptions with architects/engineers' group.

Examining Hypothesis Statement 3

The use of offsite construction techniques reduces the project construction cost

Alternative hypothesis: μ ≠ 4

Null Hypothesis: μ = 4

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.27	1.58	1.39	1.98	0.38
GCs	64	4.45	1.59	2.28	1.98	0.39

Table 4.19 Hypothesis test for perceptions on construction cost

As Table 4.19 shows, the t-value for architects/engineers (A/Es) was 1.39, which is less than t critical value for two-tail test (1.98). Therefore, there was insufficient evidence to reject the null hypothesis.

The t-value for general contractors (GCs) group was 2.28, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.45 being greater than neutral number (4), indicates GCs "slightly agreed" that the use of offsite construction techniques reduces the project construction cost.

Comparison of the A/Es' & GCs' responses on the impact of construction cost

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es' Perception	*GCs' perceptions*
Mean	4.27	4.45
Variance	2.50	2.54
Observations	67	64
Pooled Variance	2.52	
Hypothesized Mean Difference	0	
df	129	
t Stat	-0.66	
P(T<=t) two-tail	0.51	
t Critical two-tail	1.98	

Table 4.20 T -test for comparing A/Es' & GCs' perceptions on construction cost

As Table 4.20 presents, the P-value for two-tail test was 0.51, which is greater than 0.05, there was insufficient evidence to reject the null hypothesis.

Examining Hypothesis Statement 4

The use of offsite construction techniques increases product quality

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.63	1.44	3.56	1.98	0.35
GCs	64	4.47	1.69	2.22	1.98	0.42

Table 4.21 Hypothesis testing for perceptions on product quality

As Table 4.21 shows, the t-value for architects/engineers (A/Es) group was 3.56, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.63 being greater than 4, indicates that the A/Es "slightly agreed" that the use of offsite construction techniques improve product quality.

The t-value for the general contractors (GCs) group was 2.22, which is greater than t-critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.47 being greater than neutral number (4), indicated that GCs "slightly agreed" that the use of offsite construction techniques improve the product quality.

Comparison of the A/Es' & GCs' responses on the impact of product quality

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es' Perception	*GCs' perception*
Mean	4.62	4.67
Variance	2.08	1.81
Observations	67	64
Pooled Variance	1.95	
Hypothesized Mean Difference	0	
df	129	
t Stat	-0.18	
P(T<=t) two-tail	0.85	
t Critical two-tail	1.98	

Table 4.22 T-test for comparing A/Es' & GCs' perceptions on product quality

As Table 4.22 presents, the P-value for two-tail test was 0.854, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis.

Examining Hypothesis Statement 5

The use of offsite construction techniques increase overall labor productivity

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.93	1.35	5.61	1.98	0.33
GCs	64	5.30	1.19	8.65	1.98	0.30

Table 4.23 Hypothesis test for perceptions on labor productivity

As Table 4.23 shows, the t-value for architects/engineers (A/Es) group was 5.61, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.93 being greater than

4, indicates that A/Es "slightly agreed" that the use of offsite construction techniques improve the overall labor productivity.

The t-value for general contractors (GCs) group was 8.65, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 5.30 being greater than 4, indicated that GCs "moderately agreed" that the use of offsite construction techniques improve the overall labor productivity.

Comparison of the A/Es' & GCs' perceptions on the impact of labor productivity

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es	*GCs*
Mean	4.92	5.29
Variance	1.82	1.41
Observations	67	64
Pooled Variance	1.62	
Hypothesized Mean Difference	0	
df	129	
t Stat	-1.66	
P(T<=t) two-tail	0.09	

Table 4.24 T-test for comparing A/Es' & GCs' perceptions on labor productivity

As Table 4.24 shows, the P-value for two-tail test was 0.09, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis.

Examining Hypothesis Statement 6

The use of offsite construction techniques limits the design options

Alternative hypothesis: μ ≠ 4

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	3.97	1.83	-0.14	-1.98	0.45
GCs	64	4.63	1.74	2.87	1.98	0.43

Table 4.25 Hypothesis test for Perceptions of design options

As Table 4.25 shows, the t-value for architects/engineers (A/Es) was -0.14, which is greater than t-critical value for two-tail test (-1.98). Therefore, there was insufficient evidence to reject the null hypothesis.

The t-value for general contractors (GCs) was 2.872, which is greater than t critical value for two-tail test (1.978). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.63 being greater 4, indicated that GCs agreed that the use of offsite construction techniques limit the design options.

Comparison of the A/Es & GCs' perception on the impact of design options

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es	*GCs*
Mean	3.97	4.62
Variance	3.33	3.03
Observations	67	64
Pooled Variance	3.18	
Hypothesized Mean Difference	0	
df	129	
t Stat	-2.09	
P(T<=t) two-tail	0.03	
t Critical two-tail	1.97	

Table 4.26 T-test for comparing A/Es' & GCs' perceptions on design options

As Table 4.26 shows, the P-value for two-tail test was 0.037, which is less than 0.05. Therefore, there was sufficient evidence to reject the null hypothesis, and determined that architects/engineers and general contractors have different opinions on the impact of design options caused by using offsite construction techniques.

Examining Hypothesis Statement 7

The use of offsite construction techniques increases the safety performances

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.36	1.19	2.48	1.98	0.29
GCs	64	4.73	1.17	5.01	1.98	0.29

Table 4.27 Hypothesis test for perceptions on safety performance

As Table 4.27 presents, the t-value for architects/engineers (A/Es) group was 2.48, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.36 being greater than neutral number (4), indicated that A/Es "slightly agreed" that the use of offsite construction techniques improved the safety performance.

The t-value for general contractors (GCs) group was 5.01, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.73, being greater than neutral number (4) indicated that GCs "slightly agreed" that the use of offsite construction techniques improved the safety performance.

Comparison of the A/Es' & GCs' Perceptions on safety performance

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances		
	A/Es safety	*GCs safety*
Mean	4.35	4.73
Variance	1.41	1.37
Observations	67	64
Pooled Variance	1.39	
Hypothesized Mean Difference	0	
df	129	
t Stat	-1.82	
P(T<=t) two-tail	0.07	
t Critical two-tail	1.97	

Table 4.28 T-test for comparison A/Es' & GCs' perception on safety performance

As Table 4.28 shows, the P-value was 0.07, which is greater than 0.05. Therefore, there was not enough evidence to reject the null hypothesis.

Examining Hypothesis Statement 8

The use of offsite construction techniques reduce onsite disruption

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.41	1.35	2.54	1.98	0.33
GCs	64	4.98	0.99	7.84	1.98	0.25

Table 4.29 Hypothesis test for Perceptions on reducing onsite disruption

As Table 4.29 shows, the t-value for architects/engineers (A/Es) group was 2.54, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.41 being greater than

4, indicated that A/Es “slightly agree” that the use of offsite construction techniques reduce the onsite disruption of the other adjunct operations.

The t-value for general contractors (GCs) group was 7.84, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.98 being greater than 4, indicated that GCs “slightly agreed” that the use of offsite construction techniques reduce the onsite disruption of the other adjunct operations.

Comparison of the A/Es’ & GCs’ perception on the impact of onsite disruption

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	A/Es	*reduce disruption*
Mean	4.98	4.42
Variance	0.99	1.82
Observations	64	67
Pooled Variance	1.42	
Hypothesized Mean Difference	0	
df	129	
t Stat	2.72	
P(T<=t) two-tail	0.007	
t Critical two-tail	1.97	

Table 4.30 T-test for comparing A/Es’ & GCs’ perceptions on onsite disruption

As Table 4.30 shows, the P-value for two-tail test was 0.007, which is less than 0.05. Therefore, there was sufficient evidence to reject the null hypothesis, and determined that architects/engineers have the different opinion on that using offsite construction techniques reduce onsite disruption of other adjacent operations with the general contractors.

Examining Hypothesis Statement 9

The use of offsite construction techniques reduces environmental impact of construction operations.

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.58	1.33	3.59	1.98	0.32
GCs	64	4.45	1.36	2.65	1.98	0.34

Table 4.31 Hypothesis test for perceptions on environmental impact

As Table 4.31 shows, the t-value for architects/engineers (A/Es) group was 3.59, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.58 being greater than 4, indicated that A/Es “slightly agree” that the use of offsite construction techniques reduce the negative environmental impact of construction operations.

The t-value for general contractors (GCs) group was 2.56, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.45 being greater than 4, indicated that GCs “slightly agreed” that the use of offsite construction techniques reduce the negative environmental impact of construction operations.

Comparison of the A/Es’ & GCs’ perceptions on environmental impact

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances		
	A/Es	*GCs' Environmental*
Mean	4.45	4.58
Variance	1.83	1.76
Observations	64	67
Pooled Variance	1.79	
Hypothesized Mean Difference	0	
df	129	
t Stat	-0.55	
P(T<=t) two-tail	0.58	
t Critical two-tail	1.97	

Table 4.32 T-test for comparing A/Es' & GCs' perceptions on environmental impact

As Table 4.32 shows, the P-value for two-tail test was 0.58, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis.

Examining Hypothesis Statement 10

The use of offsite construction techniques increases overall project cost

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	2.89	1.24	-7.28	-1.98	0.30
GCs	64	3.44	1.41	-3.19	-1.98	0.35

Table 4.33 Hypothesis test for perceptions on overall construction cost

As Table 4.33 shows, the t-value for architects/engineers (A/Es) was -7.28, which is less than t-critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 2.89 being less than 4, indicated that A/Es "moderately disagreed" that the use of offsite construction techniques increase overall project cost.

The t-value for general contractor (GCs) was -3.19, which is less than t critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.44 being less than 4, indicated that GCs "slightly disagreed" that the use of offsite construction techniques increase overall project cost.

Comparison of the A/Es' & GCs' perceptions on the impact of overall cost

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	AE overall cost	*GCs overall cost*
Mean	2.89	3.43
Variance	1.54	1.99
Observations	67	64
Pooled Variance	1.76	
t Stat	-2.33	
P(T<=t) two-tail	0.02	
t Critical two-tail	1.97	

Table 4.34 T-test for comparison A/Es & GCs' perceptions on overall cost

As Table 4.34 presents, the P-value for two-tail test was 0.02, which is less than 0.05. Therefore, there was sufficient evidence to reject the null hypothesis. Architects/engineers had a stronger disagreement on the use of offsite construction techniques increase overall project cost.

Examining Hypothesis Statement 11

Transportation restraints limit the use of offsite construction techniques.

Alternative hypothesis: μ ≠ 4

Null Hypothesis: μ = 4

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.76	1.52	4.11	1.98	0.37
GCs	64	5.17	1.28	7.31	1.98	0.31

Table 4.35 hypothesis test for perceptions on transportation restraints

As Table 4.35 shows, the t-value for architects/engineers (A/Es) was 4.11, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.76 being greater than 4, indicated that A/Es "slightly agreed" that transportation restraints limit the use of offsite construction techniques.

The t-value for general contractors (GCs) was 2.872, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 5.17 being greater than 4, indicated that GCs "moderately agreed" that transportation restraints limit the use of offsite construction techniques.

Comparison of the A/Es & GCs' perceptions on transportation impact

Alternative Hypothesis: μ-GCs $\neq$ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	AE transportation	*GCs transportation*
Mean	4.76	5.17
Variance	2.31	1.64
Observations	67	64
Pooled Variance	1.97	
Hypothesized Mean Difference	0	
df	129	
t Stat	-1.67	
P(T<=t) two-tail	0.09	
t Critical two-tail	1.97	

Table 4.36 T-test for comparing A/Es & GCs' perceptions on transportation restraints

As Table 4.36 shows, the P-value for two-tail test was 0.09, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis.

Examining Hypothesis Statement 12

The owner's negative perception of offsite construction techniques limits the use of offsite construction techniques.

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	3.59	1.54	-2.18	-1.98	0.37
GCs	64	4.36	1.60	1.72	1.98	0.40

Table 4.37 Hypothesis test for Perceptions on owner's negative perception

As Table 4.37 shows, the t-value for architects/engineers (A/Es) was -2.18, which is less than t-critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.59 being less than 4, indicated that A/Es "slightly disagreed" that owner's negative perception of offsite construction techniques limits their uses.

The t-value for general contractor (GCs) group equaled to 1.72, less than t critical value for two-tail test (1.98). Therefore, there is insufficient evidence to reject the null hypothesis.

Comparison of the A/Es' & GCs' perceptions on the owner's negative perceptions

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

T-Test: Two-Sample Assuming Equal Variances

	AE owner's per	*GCs owner's per*
Mean	3.59	4.35
Variance	2.36	2.58
Observations	67	64
Pooled Variance	2.47	
Hypothesized Mean Difference	0	
df	129	
t Stat	-2.77	
P(T<=t) two-tail	0.03	
t Critical two-tail	1.65	

Table 4.38 T-test for comparing A/Es' & GCs' perceptions on owner's perceptions

As Table 4.38 shows, P-value for two-tail test was 0.03, which is less than 0.05. Therefore, there was sufficient evidence to reject the null hypothesis. Architects/engineers disagreed that owner's negative perceptions limit their uses, while general contractors neither agreed nor disagreed that statement.

Examining Hypothesis Statement 13

Offsite construction techniques limit the ability to make change on site.

Alternative hypothesis: μ ≠ 4

Null Hypothesis: μ = 4

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	4.97	1.48	5.39	1.98	0.36
GCs	64	5.19	1.38	6.89	1.98	0.34

Table 4.39 Hypothesis test for A/Es' & GCs' perceptions on onsite change

As Table 4.39 shows, the t-value for architects/engineers (A/Es) was 5.39, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.97 being greater than 4, indicated that A/Es "slightly agreed" the use of offsite construction techniques limits the ability to make change onsite work.

The t-value for general contractors (GCs) was 6.89, which is greater than t critical value for two-tail test (1.978). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 5.19 being greater than 4 indicated that GCs "moderately agreed" that the use of offsite construction techniques limit the ability to make change onsite work.

3) Comparison of the A/Es' & GCs' perception on the inability to make change

Alternative Hypothesis: μ-GCs ≠ μ-A/Es

Null Hypothesis: μ-GCs = μ- A/Es

t-Test: Two-Sample Assuming Equal Variances

	AE inadaptable to change	*GCs inadaptable*
Mean	4.97	5.18
Variance	2.18	1.90
Observations	67	64
Pooled Variance	2.04	
Hypothesized Mean Difference	0	
df	129	
t Stat	-0.86	
P(T<=t) two-tail	0.38	
t Critical two-tail	1.65	

Table 4.40 T-test for comparing A/Es & GCs' perceptions on onsite change

As Table 4.40 shows, P-value for two-tail test was 0.38, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis.

Testing Hypothesis Statement 14

The use of offsite construction techniques increase project design efficiency

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	3.88	1.31	-0.75	-1.98	0.32

Table 4.41 Hypothesis test for A/Es' perceptions on design efficiency

As Table 4.41 shows, the t-value for architects/engineers (A/Es) was -0.75, which is greater than t critical value for two-tail test (-1.98). Therefore, there was insufficient evidence to reject the null hypothesis.

Testing Hypothesis Statement 15

The use of offsite construction techniques increases design cost

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	3.46	1.36	-3.23	-1.98	0.33

Table 4.42 Hypothesis test for A/Es' perceptions on design cost impact

As Table 4.42 shows, t-value for architects/engineers (A/Es) was -3.23, which is less than t critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.46 being less than 4, indicated that A/Es "slightly disagreed" that the use of offsite construction techniques increase the design cost.

Testing Hypothesis Statement 16

Complicated computer software for designing offsite construction limits their uses.

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
A/Es	67	3.15	1.19	-5.86	-1.98	0.29

Table 4.43 Hypothesis test for A/Es' perceptions on computer software

As Table 4.43 shows, the t-value was -5.864, which is less than t critical value for two-tail test (-1.978). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.15 less than 4, indicated that A/Es "moderately disagreed" that complicated computer software for designing the offsite construction techniques limits their uses.

Testing Hypothesis Statement 17

The use of offsite construction techniques increase jobsite management efficiency

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*S. D.*	*t-obs*	*t-critical*	*Margin of Error*
GCs	64	4.59	1.41	3.367	1.98	0.35

Table 4.44 Hypothesis test for GCs' perceptions on jobsite management efficiency

As Table 4.44 shows, the t-value was 3.367, which is greater than t critical value for two-tail test (1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 4.59 being greater than 4, indicated that GCs "slightly agreed" that the use of offsite construction techniques increase jobsite management efficiency.

Testing Hypothesis Statement 18

Local building regulations restrict the use of offsite construction techniques

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*Std. D.*	*t-obs*	*t-critical*	*Margin of Error*
GCs	64	3.55	1.59	-2.28	-1.98	0.39

Table 4.45 Hypothesis test for GCs' perceptions on local building regulations

As Table 4.45 shows, t-value was -2.28, which is less than t critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.55 being less than 4, indicated that GCs "slightly disagreed" that local building regulations restrict the use of offsite construction techniques.

Testing Hypothesis Statement 19

Lack of skilled assembly craft workers limits the use of offsite construction techniques.

Alternative hypothesis: $\mu \neq 4$

Null Hypothesis: $\mu = 4$

	Sample Size	*Mean*	*Std D.*	*t-obs*	*t-critical*	*Margin of Error*
GCs	64	3.17	1.18	-5.59	-1.98	0.29

Table 4.46 Hypothesis test for GCs' perceptions on skilled assembly craft workers

As Table 4.46 shows, t-value was -5.59, which is less than t-critical value for two-tail test (-1.98). Therefore, there was sufficient evidence to reject the null hypothesis. The mean of 3.17 being less than 4, indicated that GCs "slightly disagreed" that lack of skilled assembly craft workers limits the use of offsite construction techniques.

Summary of the result of hypothesis tests in this section is presented in Table 4.47

Hypothesis Statement	*A/Es*	*GCs*	*diff.*
The use of offsite construction techniques reduces the overall project schedule.	Moderately Agree	Agree	No
The use of offsite construction techniques reduces the need for skilled craft workers onsite.	Fail to reject	Slightly Agree	Yes
The use of offsite construction techniques reduces the project construction cost.	Fail to reject	Slightly Agree	No
The use of offsite construction techniques increases product quality	Slightly Agree	Slightly Agree	No
The use of offsite construction techniques increases overall labor productivity.	Slightly Agree	Moderately Agree	No
The use of offsite construction techniques limits design options	Fail to reject	Slightly Agree	Yes

The use of offsite construction techniques increases safety performance	Slightly Agree	Slightly Agree	No
The use of offsite construction techniques reduces onsite disruption of other adjacent operations	Slightly Agree	Slightly Agree	Yes
The use of 0ffsite construction techniques reduces environmental impact of construction operations	Slightly Agree	Slightly Agree	No
The use of offsite construction techniques increases jobsite management efficiency	N/A	Slightly Agree	N/A
The use of offsite construction techniques increases the overall project cost	Moderately Disagree	Slightly Disagree	Yes
Transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of offsite construction techniques.	Slightly Agree	Moderately Agree	No
The owner's negative perception of offsite construction techniques limits the use of those techniques.	Slightly Disagree	Fail to reject	Yes
The local building regulations restrict the use of offsite construction techniques	N/A	Slightly Disagree	N/A
The use of offsite construction techniques limits the ability to make change onsite work.	Slightly Agree	Moderately Agree	No
The use of offsite construction techniques increase design efficiency	Fail to reject	N/A	N/A
The use of offsite construction techniques increase design cost	Slightly Disagree	N/A	N/A
Complicated software for designing offsite construction techniques limit their use	Moderately Disagree	N/A	N/A
Lack of skilled assembly craft workers limits the use of offsite construction techniques.	N/A	Slightly Disagree	N/A

Table 4.47 Summary of hypothesis test for A/Es and GCs' responses

4.3.3 Data Analysis for Research Questions No. 3, 4, 5, 6

The purpose of the data analysis in follows was to answer the research questions No.3, 4, 5, and No. 6, those were to identify the top three (3) reasons for using or not using offsite construction techniques by A/Es and GCs' responses.

1) Top three (3) motivations for A/Es

The top three (3) motivations for architects/engineers to use offsite construction techniques in rank order were 1) to reduce the construction duration, 2) to reduce the overall schedule and 3) to reduce the overall project cost. In addition, almost 30% of respondents mentioned another reason- to improve the product quality.

2) Top three (3) challenges for A/Es

The top three (3) challenges in rank order were 1) the transportation restraints, 2) limited design options and 3) inability to make changes in the field.

3) Top three (3) motivations for GCs

The top three (3) motivations for general contractors to use offsite construction techniques in rank order were 1) to reduce the construction duration, 2) reduce the overall schedule, 3) to reduce the overall project cost and 3) to compensate for local weather conditions.

4) Top three (3) challenges for GCs

The top three challenges for general contractors in rank order were 1) transportation restraints, 2) limited design options and 3) inability to make changes in the field. About 8% of contractors discussed other reasons included the subcontractors did not want to use offsite construction techniques, the long lead-time (materials procurement time) and architects were struggle with offsite construction techniques, contractors did not want to change the means and methods.

4.3.4 Regression Tests for Research Question No.7

Research question No7: was there a linear relationship between the A/Es' and GCs' satisfaction levels of using offsite construction techniques with the percentages of their uses? Four (4) regression tests were conducted in this section to test the preassembly techniques and the panelized systems. The hybrid system and modular buildings were not been tested due to the very limited sample size.

1) A/Es' satisfaction level of preassembly with percentage of their uses

A linear relationship between the satisfactions levels of preassembly with the percentage of specify assumed existed. That meant the higher level of satisfaction of preassembly by A/Es would lead to a higher percentage of specifying preassembly techniques in their projects.

$Y = a + bX$

Y indicated the percentage of specifying preassembly techniques

X indicated the level of satisfaction of preassembly techniques

Alternative hypothesis: $b \neq o$

Null Hypothesis: $b = 0$

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*	
Regression	1.00	4925.72	4925.72	6.27	0.02	
Residual	45.00	35346.15	785.47			
Total	46.00	40271.87				

	Coefficients	*Std. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	18.08	18.77	-0.96	0.34	-55.87	19.72
Preassembly	8.20	3.27	2.50	0.02	1.60	14.79

Table 4.48 Regression Test of Preassembly for A/Es Group

As Table 4.48 shows, at the 0.05 level of significance, the regression test rejected the null hypothesis because the p-value was 0.02, which is less than 0.05. It indicated that A/Es' higher level of satisfaction of preassembly techniques would result in the higher percentage of specifying these techniques in their projects.

Y= 18.08 + 8.20 X

This equation indicates that A/Es' satisfaction level of preassembly techniques increase 1 degree, the percentage of specifying preassembly techniques in their project will increase 8.2%.

2) GCs' satisfaction level of preassembly with percentage of their uses

A linear relationship between the satisfaction levels of preassembly with the percentage of utilization was assumed existed. In other word, the higher level of satisfaction of preassembly by GCs would result in higher percentage of using preassembly techniques in their projects.

Y = a + bX

Y indicated the percentage of utilization of preassembly

X indicated the level of satisfaction of preassembly

Alternative hypothesis: $b \neq o$

Null Hypothesis: $b = 0$

	df	*SS*	*MS*	*F*	*Sig. F*	
Regression	1	1048.20	1048.20	1.60	0.211	
Residual	44	28735.03	653.06			
Total	45	29783.23				
	Coefficients	*Std. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95.0%*
Intercept	-2.07	15.37	-0.13	0.89	-33.05	28.90
Preassembly	3.28	2.59	1.26	0.21	-1.94	8.522

Table 4.49 Regression Test of Preassembly for GCs Group

As Table 4.49 shows, the P-value for regression test was 0.21, which is greater than 0.05. Therefore, there was insufficient evidence to reject the null hypothesis. Regression test suggested that there was no linear relationship between the general contractor's levels of satisfaction of preassembly with the percentage of this technique incorporated in GCs' projects.

3) A/Es' satisfaction level of panelized systems with the percentage of their uses.

A linear relationship between the satisfactions levels of panelized systems with the percentage of their uses was assumed existed.

$Y = a + bX$

Y indicated the percentage of specifying preassembly techniques

X indicated the level of satisfaction of preassembly techniques

Alternative hypothesis: $b \neq o$

Null Hypothesis: $b = 0$

	df	*SS*	*MS*	*F*	*Sig. F*	
Regression	1.00	20.88	20.88	0.21	0.65	
Residual	22.00	2193.62	99.71			
Total	23.00	2214.50				
	Coefficients	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.72	12.25	0.39	0.70	-20.68	30.13
7.00	0.98	2.15	0.46	0.65	-3.47	5.44

Table 4.50 Regression Test of Panelized Building Systems for A/Es Group

As Table 4.50 shows, the P-value was 0.65, which is greater than 0.05. Therefore there was insufficient evidence to reject the null hypothesis. Regression test indicated that there was no linear relationship between A/Es' satisfaction levels of panelized building systems with the percentage of their uses.

4) GCs' satisfaction level of panelized systems with the percentages of their uses

A linear relationship between GCs' satisfaction levels of panelized systems with the percentage of their uses was assumed existed.

$Y = a + bX$

Y indicated the percentage of utilization of panelized building systems

X indicated the level of satisfaction of panelized building systems

Alternative hypothesis: $b \neq 0$

Null Hypothesis: $b = 0$

ANOVA

	df	*SS*	*MS*	*F*	*Sig. F*	
Regression	1.00	258.90	258.90	1.29	0.26	
Residual	40.00	8040.72	201.02			
Total	41.00	8299.62				
	Coefficients	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.03	6.86	0.30	0.77	-11.83	15.89
Panelized	1.33	1.17	1.13	0.26	-1.04	3.70

Table 4.51 Regression Test of Panelized Building Systems for GCs Group

As Table 4.51 shows, the P-value was 0.26, which is greater than 0.05. Therefore there was insufficient evidence to reject the null hypothesis. Regression test indicated that there was no linear relationship between GCs' satisfaction levels of panelized building systems with the percentage of their uses.

4.3.5 Data Analysis for Research Question No. 8

Research question No.8: what do architects/engineers and general contractors perceive the future of offsite construction techniques in the next 5-10 years?

82% of A/Es' respondents believed that using offsite construction techniques would increase in the next 5-10 years, 7% of them believed using these techniques would decrease, and the rest of group had no opinion.

While, 81.25% of general contractors believed that use of offsite construction techniques would increase in the next 5-10 years, 15.6% believed using these techniques would decrease, and 3% had no opinion.

4.4 Subgroups' Perceptions Comparison

In order to get a better understanding of contributing factors to offsite construction techniques, this study divided each sample group (A/Es and GCs) into 2 subgroups according to market segments and having past experience with offsite construction techniques or not. T-test for two sample assuming equal variances were used to investigate, at the 0.05 level of significance, whether there was a statistical difference on the respondents' perceptions of using offsite construction techniques between different subgroups.

Comparing the Residential vs. Commercial A/Es' Perceptions

In this section, the respondents in A/Es' group were divided into 2 subgroups by majority of their work in each market segment: residential and commercial. The respondents who had more than 50% of work in residential were treated as the residential subgroup, total 12 in this study. The respondents who had more than 50% of work in commercial or institutional were treated as commercial contractor, about 55 in total for commercial group. There were no A/Es firms concentrated on industrial work.

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 0ffsite 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 limits 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 limit their uses.	3.55	3.07	Yes

Table 4.52 Comparing A/Es' perceptions by market segments

As Table 4.52 shows, the architects/engineers in the residential market had different perceptions of using offsite construction techniques with those in the commercial market in the following aspects:

1) Only the residential A/Es disagreed that the use of offsite construction techniques limited design options.

2) Only the commercial A/Es disagreed that owner's negative perceptions of offsite construction techniques limit the use of offsite construction techniques.

3) Only the commercial A/Es disagreed that complicated computer software limit the use of offsite construction techniques.

Comparing the Residential vs. Commercial vs. Industrial Contractor's Perceptions

In this section, the respondents in GCs' group were divided into 3 subgroups by the company's market segments. The respondent's company with more than 50% of work in residential was treated as the residential sample, 14 of these in this study. The respondent's company with more than 50% of work in the commercial or institutional was considered as the commercial contractor, 43 samples in total. 7 industrial contractors whose work was in industrial segment more than 50%.

Perceptions	*Residential* *N=14*	*Commercial* *N=43*	*Ind.* *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 4.53 GCs' perception comparison by market segments
Note: the level of significant 0.05 was used in t-test:
two-sample assuming equal variance

As Table 4.53 shows, the residential, commercial and the industrial GCs had different perceptions of using offsite construction techniques as follows

1) Only the industrial GCs agreed that the use of offsite construction techniques increase the product quality.

2) Only the commercial GCs agreed that the use of offsite construction techniques limit the design options.

3) Both the residential and industrial GCs agreed that the use of offsite construction techniques increase jobsite management efficiency.

4) Both The commercial and industrial GCs disagreed that the use of offsite construction techniques increase overall project cost.

5) Only the commercial GCs agreed that owner's negative perceptions are one of the barriers.

6) Both the industrial and residential GCs disagreed that the local building regulations restrict the use of offsite construction techniques.

Comparing the Users' vs. Non-users' Perceptions

1) Comparing perceptions of using offsite construction technique by those who had used offsite construction techniques vs. who had never used offsite construction in A/Es' group.

In this section, the respondents in A/Es' group were divided into 2 subgroups by their past experience of using offsite construction techniques. Architects/engineers who had specified any forms of offsite construction techniques in their project before were treated as Users Group, 44 in total; while the rest of 23 Architects/engineers were treated as Non-users Group.

Perceptions	*Users* *N=44*	*Non-users* *N=23*	*Sig. diff.*
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 increases safety performance	4.45	4.17	Different
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 those 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 4.54 Comparing A/Es' perceptions by past experience with offsite construction
Note: the level of significant 0.05 was used in t-test:
two-sample assuming equal variance

As Table 4.54 shows, findings indicated that the architects/engineers who have specified offsite construction techniques (User's group) had different perceptions of using these techniques with those who had no experienced (Non-users) in the following aspects.

- Construction Cost

The users group agreed that the use of offsite construction techniques reduce the project construction cost.

- Onsite Safety Performance

The user's group agreed that the use of offsite construction techniques improve the onsite safety performance.

- Owner's Negative Perceptions

The user's group disagreed that owner's negative perceptions is the barrier of using offsite construction techniques.

Overall, compared to non-users, the user's group had a higher level of positive attitude towards the offsite construction techniques.

2) Comparing perceptions of using offsite construction technique by those who had used offsite construction techniques VS. who had never used offsite construction in GCs' group.

In this section, the respondents in GCs' group were divided into 2 subgroups by their past experience of using offsite construction techniques. General contractors who had used any forms of offsite construction techniques in their project were treated as Users Group, 41 in total; while the rest of 23 contractors who never had used offsite construction techniques were treated as Non-users Group.

Perceptions	*Users* *N=41*	*Non-User* *N=23*	*Significant* *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 4.55 Comparing GCs' perceptions by past experiences with offsite construction
Note: the level of significant 0.05 was used in t-test:
two-sample assuming equal variance

As Table 4.55 shows, the findings from statistical test (t-test for two-samples) indicated that there was sufficient evidence to support that the User's group had a different perception of using offsite construction technique with those in Non-user's group in the following aspects:

- Quality:

User's group believed that the use of offsite construction technique improved product quality.

- Design Options

The Non-users responded that the use of these techniques limits the design options.

- Management Efficiency

User's group agreed that the use of offsite construction technique improve onsite management efficiency.

- Overall Project Cost

User's group disagreed that offsite construction technique increase overall project cost.

In summary, compared to Non-user's group, the user's group had a higher level of positive attitude toward using offsite construction techniques.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

A large body of contemporary construction research has embraced offsite construction techniques as one of the most effective approaches to overcome industry-wide challenges, such as the shortage of skilled labor, owners' aggressive schedules and inclement weather conditions (Liska & Piper, 1999; Eickman, 1999; CII, 2000; Hass, 2000; Gibb, 2001; Venables, 2004; Sawyer, 2006). More recently, researchers examined the utilization of offsite construction techniques in the residential construction sector, investigated the impact on the construction workforce, and identified the benefits and barriers to the use of these techniques (O' Brien, 2000; Hass, 2000; Walter, 2001; Waskett, 2001; Venables, 2004; Blisams, 2006).

However, until this present investigation, no studies have examined the current level of utilization of offsite construction techniques in all of the building sectors in the United States construction industry. None of the previous studies have investigated the perceptions of architects/engineers (A/Es) and general contractors (GCs) regarding the benefits and barriers of the use of these techniques, which this study did. This study also identified the top three (3) motivations and challenges of using these techniques in the building sector of U.S construction industry. In addition, this study examined whether there was a linear relationship between A/Es' and GCs' levels of satisfaction with the use of offsite construction techniques and the degree to which these techniques were being used by them.

5.2 Conclusions

5.2.1 Current degree of use of offsite construction techniques

In 2005, architects/engineers had specified offsite preassembly techniques in 20% of their design work; hybrid systems in 1.58%, panelized systems in 4.88% and modular buildings in 1.58% of their design work respectively. A total of 26.8% of the A/Es' respondents design work had specified one or more forms of offsite construction techniques.

In 2005, GCs' respondents utilized offsite preassembly techniques in 12.32%, hybrid systems in 0.09%, panelized systems in 6.17% and modular buildings 1.04% of their total work. Therefore, a total of 19.62% of GCs' respondents work had incorporated one or more forms of offsite construction techniques. There was a difference between A/Es' and GCs' responses regarding the overall percentage of using these techniques, because in this study, the GCs' respondents do not necessarily work for the A/Es' respondents.

5.2.2 Perceived Benefits and Barriers

The findings in this study indicated that both the architects/engineers and general contractors perceived that the use of offsite construction techniques provided the following benefits: 1) reducing the overall project schedule, 2) increasing product quality, 3) increasing overall labor productivity, 4) increasing onsite safety performance, 5) reducing onsite disruption of other adjacent operations, and 6) reducing negative environmental impact of construction operations.

The findings also indicated both the architects/engineers and general contractors perceived two barriers to the use of offsite construction techniques: 1) transportation restraints and 2) the ability to make changes onsite. Both groups disagreed that by using offsite construction techniques, the overall project cost would be increased.

The findings indicated that GCs' and A/Es' perceptions of using offsite construction techniques were statistically different in the following:

1) General contractors agreed that the utilization of offsite construction techniques:

- would reduce the need for skilled craft workers onsite,
- would limit design options,
- would increase jobsite management efficiency and,
- would reduce project construction cost.

2) Architects/engineers disagreed that

- owners' negative perceptions of offsite construction techniques limit specifying these techniques in their projects
- using offsite construction techniques would increase design cost

In order to get a better understanding of A/Es' and GCs' perceptions of using offsite construction techniques, the research compared the residential A/Es' and commercial A/Es' perceptions of using these techniques and found that 1) the residential A/Es disagreed that the use of offsite construction techniques limited design options. 2) the commercial A/Es disagreed that owner's negative perceptions of offsite construction techniques limits the use of offsite construction techniques. 3) the commercial A/Es disagreed that complicated computer software limits the use of offsite construction techniques.

In addition, there were several differences between the residential, commercial and industrial GCs' responses to the benefits and barriers to the use of offsite construction techniques as follow:

1) Only the industrial GCs agreed that the use of offsite construction techniques increases the product quality.

2) Only the commercial GCs agreed that the use of offsite construction techniques limits the design options.

3) Only the industrial and residential GCs agreed that the use of offsite construction techniques increases jobsite management efficiency.

4) The commercial and industrial GCs disagreed that the use of offsite construction techniques increase overall project cost.

5) Only the commercial GCs agreed that the use of owner's negative perceptions is one of the barriers.

6) Only the residential GCs and the industrial GCs disagreed that local building regulations restrict the use of offsite construction techniques.

Findings from this study imply that there may be more challenges to using offsite construction techniques in the commercial construction sector than the residential and industrial sectors. The industrial GCs perceived more benefits and fewer barriers compared to the residential and commercial GCs, therefore, there might be more opportunities to increase the use of offsite construction techniques in the industrial sectors.

The finding also indicated that those A/Es and GCs had utilized offsite construction techniques (Users) before perceived differently of using these technique with those A/Es and GCs never used these techniques (Non-users) in the terms of the impact of quality, design options, jobsite management efficiency, overall project cost and owner's negative perception on the use of offsite construction techniques. Compared to the Non-users, the Users' group had a positive attitude towards these techniques.

5.2.3 The Motivation and Barriers to the Utilization of Offsite Construction Techniques

The study found that the top three (3) reasons that motivate architects/engineers to use offsite construction techniques in rank order were to 1) reduce the construction duration, 2) reduce overall project cost and 3) reduce the overall project schedule.

The top three (3) reasons that motivate general contractors to use offsite construction techniques in rank order were to 1) reduce the overall project schedule, 2) reduce construction duration, 3) reduce overall project cost and compensate for the local weather conditions.

This study identified the top three (3) challenges that restrain architects/engineers from using offsite construction techniques in rank order were: 1) inability to make changes in the field; 2) transportation restraints, 3) limited design options

The top three (3) challenges that restrain general contractors from using offsite construction techniques in rank order were 1) transportation restraints; 2) limited design options of using off-site construction techniques and 3) inability to make changes in the filed.

5.2.4 A/Es and GCs' Response of Using Offsite Construction Techniques in the next 5-10 years

The majority of respondents believed the use of offsite construction techniques would increase in the next 5-10 years. 82% of A/Es' responses and 81% of GCs' responses positively forecasted the use of these techniques. Respondents discussed that labor cost savings, faster construction, shortage of skilled craft workers, and better product quality were the contributing factors to increase the use of these techniques in the future.

On the other hand, 7% of A/Es' and 16% of GCs' respondents argued that the use of offsite construction techniques would decrease in the next 5-10 years due to increased transportation costs, shrinking union workforce resulting in overall lower labor costs, lack of skilled assembly workers, the poor image of offsite construction techniques, and people's unwillingness to change.

5.2.5 Linear Relationships between A/Es' and GCs' Satisfaction Levels with Offsite Construction Techniques with the Percentage of Their Use Offsite Preassembly Techniques

A linear relationship was found between the A/Es' satisfaction levels with using preassembly techniques with the percentage of their use. It implied that to increase A/Es' acknowledgment of offsite preassembly is one of the most efficient approaches to increase their use. However, results of this study indicated that there was no linear relationship between the GCs' satisfaction levels of using preassembly techniques with the percentage of their use.

Panelized Building Systems

No linear relationship between both the A/Es' and GCs' level of satisfaction panelized building systems with the percentage of their use. Because too few respondents provided feedback on their percentage of hybrid systems and modular buildings no attempt was made to draw any conclusions since it would be inappropriate.

In summary, this study found that offsite construction techniques have not been widely utilized in the building sector of U.S. construction industry, especially for the hybrid and modular building systems. The percentage of work incorporating one or more forms of offsite construction techniques were 26.8% for A/Es' and 19.6% for GCs' in 2005.

Several benefits of using offsite construction were identified by both A/Es and GCs, including reducing construction duration, improving product quality, improving overall labor productivity, improving onsite safety performance, improving jobsite management efficiency, and reducing onsite disruption and the negative environmental impact.

The significant challenges of using offsite construction techniques were found to be transportation restraints, inability to make changes onsite and limited design options. Owners' negative perceptions of the use of offsite construction techniques were not as significant as expected. However, it appears to be a big challenge in the commercial construction sector. Surprisingly, local building regulations were not identified as a significant barrier for using offsite construction techniques.

Furthermore, the results of the study suggest that there was a linear relationship between the architects'/engineers' positive attitude about the use of offsite preassembly techniques and the percentage that specified these techniques for their projects. Therefore, to increase A/Es' awareness of the use of offsite preassembly techniques along with their benefits may be one of the most efficient approaches to help increase their use.

In addition, the findings also imply that there might be more challenges related to the use of offsite construction techniques in the commercial building sector, and that may be building more opportunities to increase the use of these techniques in the industrial sector.

Both the A/Es and GCs who have utilized offsite construction techniques (Users) had a more positive attitude towards these techniques than those who never used any of them (Non-users). The users group agreed that the use of these techniques improved product quality, improves safety performance, increased jobsite management efficiency, did not limit design options and did not increase overall project cost. The users group disagreed that owners' negative perceptions was a big challenge, while the non-users either had no opinion or a contrary point of view mentioned above. This suggests that lack of knowledge of these techniques might be one of the most significant challenges to overcome.

5.3 Recommendations

5.3.1 General Recommendations to Overcome the Challenges of Using Offsite Construction Techniques

This section presents four major recommendations that, if adopted, may not only increase the awareness of the use of offsite construction techniques, but eventually will help improve the construction industry.

1) Construction companies and professional organizations should invest more in research and development in area of customized design and alternative materials.

Findings from this study indicated that limited design options were one of the most significant barriers to increase the use of offsite construction techniques. Therefore, it would be very helpful to provide customized design options to engage customers' preferences by using 3D and 4D CAD and Building Information Modeling (BIM) systems. Same examples of design software packages include Autodesk's Revit, AG's Allplan and Bentley Architecture from Bentley Systems. Each customized design should include a variety of choices of materials, fittings and furnishings. In addition, manufactures, material suppliers and general contractors should work together to improve the efficiency of material delivery systems to satisfy all design options.

Furthermore, material manufacturers and suppliers, professional organizations and research institutions should also invest in developing alternative construction materials to overcome the transportation restraints on the use of offsite construction techniques.

2) Develop and provide awareness training to manufacturers, general contractors and designers in the use of offsite construction techniques.

The findings from this study indicate that lack of knowledge of offsite construction techniques is a significant barrier. Therefore, the construction and design discipline should work with mature manufacture and suppliers to develop continuing education course to increase the awareness of A/Es' and GCs' percentage of the use of offsite construction techniques.

An example of a typical outline for an awareness training course should include the following:

I. Introduction to course

II. Offsite construction techniques-an overview

A. Offsite preassembly techniques

B. Hybrid building systems

C. Panelized building systems

D. Modular buildings

E. Other techniques

III. Proven benefits

A. Reducing the overall project schedule

B. Increasing product quality

C. Increasing overall labor productivity

D. Increasing onsite safety performance

E. Reducing onsite disruption of other adjacent operations

F. Reducing the negative environmental Impact

G. Reducing the need for skilled craft workers onsite

IV. Current challenges

A. Transportation restraints

B. Limited design options

C. Inability to make changes onsite.

V. Case studies of actual uses by offsite construction techniques

A. Offsite preassembly techniques

B. Hybrid systems

C. Panelized building systems

D. Modular buildings

E. Other techniques

VI. Incorporating offsite construction techniques with the design process

This section would explain in detail how an engineer or architect could effectively and efficiently incorporate the use of offsite construction techniques with their design.

VII. Incorporating offsite construction techniques with the construction process

This section would explain in detail how a general contractor could effectively and efficiently incorporate the use of offsite construction techniques with their construction.

VIII Overview resources available to A/Es and GCs

IX. Review and Summary of course

As part of the course development, case studies would have to be undertaken to compare the use of offsite construction techniques with conventional ones in terms of project schedule, cost, quality and safety.

The actual course development should be done by a team of individuals experienced in the use of offsite construction techniques in the design and construction process along with one or more people experienced in curriculum development.

3) Develop new and improve existing offsite construction certification schemes.

Construction and design discipline should work together to develop new and improve existing certification schemes for both manufacturers of offsite construction techniques and the final product themselves. In terms of developing a process to certify manufacturers, the first step is to review existing schemes and identify the strength and weakness of each. The next step would be to develop a set of measurable outcome that should exist within the manufacturers' organization that would impact the quality of their product (s). For example, does the manufacturer have an internal quality control and assurance program and is it being effectively utilized? Does a manufacturer provide and/or support training for its employees.

It is essential when developing new certification program that experienced and qualified individuals be utilized within the process. There are many consultants that specialized in the development of certification program. A comprehensive website search would result in a list of them. It is important that certifying agency be one that is independents of their companies that may be certified.

As for the finished product (offsite construction building components), it is a must that it adhere to all prevailing buildings at other codes. Therefore the components would have to meet specified structural, compositional, size and other characteristics in area for to be certified. As for the new certification program, the same issues are described above would pertain to the development and improvement of a product certification program.

4) Owners, designers and general contractors should collaborate with each other on pre-project planning

Compared to conventional construction, one of the most significant disadvantages of the using offsite construction techniques is the inability to make changes onsite, which was also been identified as one of the top three restraints by both architects/engineers and general contractors in this study. To overcome this challenge, the researcher recommends that the manufacturers, architects/engineers and general contractors should collaborate on improving product quality, onsite workmanship, and engage with the owner in pre-project planning during the conceptual design phase to minimize the possibility of onsite changes. The Construction Industry Institute has many publications on how to conduct effective pre-project planning.

5.3.2 Recommendations for Future Research

The following recommendations are proposed for further research on the use of offsite construction techniques based on the finding from this study.

1) Conduct a study similar to this one but using a larger sample size. Improvements to this study could include increasing the number of respondents from northern of United States and increasing the number of general contractors in the industrial sector of the U.S. construction.

2) Conduct one or more cast studies to examine the cost impact of the use of offsite construction techniques as compared to conventional techniques, because both the A/Es and GCs in this study were not clear about the cost impacts of these techniques. It would be very valuable to monitor the actual cost of design, construction for one or several buildings using offsite construction techniques and to create a database to compare with the similar buildings completed by conventional construction techniques.

3) Conduct research on the impact of transportation restraints and costs on offsite construction techniques in order to find ways to alleviate and/or accommodate the restraints and decrease costs for the purpose of promoting the use of these techniques.

4) It would also be worthwhile to examine the impact of advanced design technologies on offsite construction techniques, such as 3D CAD, 4D CAD and Building Information Modeling (BIM), etc. It would be extremely valuable to identify how these technologies would increase design options, decrease lead-time for procurement, and decrease the need of onsite construction changes.

All of the above recommend research would serve to raise the visibility and credibility of the use of offsite construction techniques in the U.S. building industry. It will be only through this and similar research projects that the barriers identified in this project will be alleviated. The researcher believes that based on the findings from the study that the increased use of offsite construction techniques will constantly benefit the entire construction industry.

APPENDICES

Appendix A- Survey Questionnaire to A/Es

Investigation of Designer's Use and Perceptions of Off-Site Construction Techniques in the United States

Direction: The purpose of this survey is to identify the level of using off-site construction techniques in the building sector of the U.S. construction industry, and to investigate the benefits and challenges of using these techniques. I would appreciate if you would complete the attached questionnaire and return it in the enclosed self-addressed, stamped envelope by **February 8, 2007.**

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

- **Off-Site Pre-assembly**

Pre-assembly is a process by which various building materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system. For example: roof trusses; pre-assembled vessels complete with insulation, platforms, piping, and ladders.

- **Hybrid Systems (PODS)**

Prefabricated building facilities, fully factory finished internally complete with the building services. For example: bathrooms, shower rooms, office washrooms, and plant rooms.

- **Panelized Systems**

Construction of the structural frame for the building using panels assembled in the factory. It consists of factory-built structure components instead of completed modules, transported to the site, assembled and secured to a permanent foundation. Typically including additional factory based fabrication, such as cladding, insulation, internal finishes, doors and windows, and structurally insulated panels (SIPs).

- **Modular Building**

Three-dimensional units, which are constructed and pre-assembled, complete with trim work, electrical, mechanical, and plumbing installed. Upon the completion by the manufacturing factory, these units are shipped to the site for installation on permanent foundations. Examples include modular homes, hotel units, prison units.

Manufactured houses or mobile homes are not included in the scope of this study.

Section I Company Information about Using Off-Site Construction Techniques

1. Job title ____________________________

2. Company's annual volume for 2005 is ____________

3. Please indicate the approximate percentage of your design work in each of the following segments of construction industry.

Residential	Commercial	Industrial	Institutional
________	_________	________	___________

4. The majority of your company's design work is performed on a____ basis. (Circle one)

A. International B. National C. Regional D. State-wide

5. For 2005, indicate what percentage of you company designed projects incorporated the use of the off-site construction techniques.

2005	Off-Site Preassembly	______	Hybrid System	_________
	Panelized System	______	Modular Building	_________

6. Please indicate your overall satisfaction of your past experience of using off-site construction techniques by circling the number that best represent your experience.

0=have not specified 1=highly unsatisfied 2=moderately unsatisfied 3=slightly unsatisfied 4= neither unsatisfied or satisfied 5=slightly satisfied 6= moderately satisfied 7=strongly satisfied

Off-Site Preassembly	0	1	2	3	4	5	6	7
Hybrid Systems	0	1	2	3	4	5	6	7
Panelized Systems	0	1	2	3	4	5	6	7
Modular Buildings	0	1	2	3	4	5	6	7

Section II Perceptions of Utilizing Off-Site Construction Techniques

Please ***circle one number*** that most closely represents your level of agreement/ disagreement with each statement. Please respond to all items even if you have not used any of off-site construction techniques.

1=strongly disagree 2=moderately disagree 3=slightly disagree 4= neither disagree or agree 5=slightly agree 6= moderately agree 7=strongly agree

	Strongly Disagree						Strongly Agee
1. Off-site construction techniques reduces the overall project schedule.	1	2	3	4	5	6	7
2. Off-site construction techniques reduces the need for skilled craft workers onsite.	1	2	3	4	5	6	7
3. Off-site construction techniques reduces the project construction cost.	1	2	3	4	5	6	7
4. Off-site construction techniques increases product quality.	1	2	3	4	5	6	7
5. Off-site construction techniques increases overall labor productivity.	1	2	3	4	5	6	7
6. Off-site construction techniques limits design options	1	2	3	4	5	6	7
7. Off-site construction techniques increases safety performance.	1	2	3	4	5	6	7
8. Off-site construction techniques reduces onsite disruption of other adjacent operations.	1	2	3	4	5	6	7
9. Off-site construction techniques reduces environmental impact of construction operations.	1	2	3	4	5	6	7
10. Off-site construction techniques increases project design efficiency.	1	2	3	4	5	6	7

.

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7
11. Off-site construction techniques increases design cost.	1	2	3	4	5	6	7
12. Off-site construction techniques increases the overall project cost.	1	2	3	4	5	6	7
13. Transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of off-site construction techniques.	1	2	3	4	5	6	7
14. The owner's negative perception of off-site construction techniques limits the use of those techniques.	1	2	3	4	5	6	7
15. Off-Site construction techniques limits the ability to make change onsite work.	1	2	3	4	5	6	7
16. Complicated computer software for designing off-site construction techniques limits their uses.	1	2	3	4	5	6	7

17. Please provide any other benefits or barriers of specifying off-site construction techniques that were not listed above.

18. Do you anticipate using off-site construction techniques will increase in the next 5-10 years?

A. Yes. State why (Please by as specific as possible)

B. No. State why (Please by as specific as possible)

Section III The Reasons of Using Off-site Construction Techniques

Please ***circle top 3 reasons*** why your firm specifies the off-site construction techniques.
If your firm has not specified off-site construction techniques, please skip this section, and go to Section IV.

A. Project owners require using off-site construction techniques
B. To compensate for the shortage of skilled craft workers
C. To compensate for the local weather conditions
D. To reduce design duration
E. To reduce construction duration
F. To reduce project overall schedule
G. To reduce overall project cost
H. To increase product quality
I. To increase overall labor productivity
J. To compensate for the restricted working space onsite
K. To reduce environmental impact
L. To improve project safety performance
M. To increase your company's profit margin
N. To enhance your company's reputation
O. Any other reasons ____

Section IV The Challenges of Using Off-Site Construction Techniques

Please ***circle top 3 reasons*** that restrain your firm from specifying off-site construction techniques.

A. The project owners do not allow using off-site construction techniques.
C. General contractors do not have expertise of assembling prefabricated building components onsite.
D. The local zoning ordinance restricts the use of off-site construction techniques.
E. The local building regulation restricts the use of off-site construction techniques.
F. The financial institution restricts the use of off-site construction techniques.
G. Designing off-site construction components requires special computer software.
H. Lack of skilled assembly craft works locally.
I. Using off-site construction techniques will increase the design cost.
J. Using off-site construction techniques will increase the construction cost.
K. Transportation restraints
L. Limited design options of using off-site construction techniques.
M. Inability to make changes in the field by using off-site construction techniques.
N. Any other reasons____

Appendix B- Survey Questionnaire to GCs

Investigation of General Contractor's Use and Perceptions of Off-Site Construction Techniques in the United States

Direction: The purpose of this survey is to identify the level of using off-site construction techniques in the building sector of the U.S. construction industry, and to investigate the benefits and challenges of using these techniques. I would appreciate if you would complete the attached questionnaire and return it in the enclosed self-addressed, stamped envelope by **February 8, 2007.**

In this study off-site construction techniques are defined as those construction techniques that accomplished off-site applications where building systems or assemblies are manufactured or fabricated away from the building site prior to installation. Those techniques include:

- **Off-Site Pre-assembly**

Pre-assembly is a process by which various building materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system. For example: roof trusses; pre-assembled vessels complete with insulation, platforms, piping, and ladders.

- **Hybrid Systems (PODS)**

Prefabricated building facilities, fully factory finished internally complete with the building services. For example: bathrooms, shower rooms, office washrooms, and plant rooms.

- **Panelized Systems**

Construction of the structural frame for the building using panels assembled in the factory. It consists of factory-built structure components instead of completed modules, transported to the site, assembled and secured to a permanent foundation. Typically including additional factory based fabrication, such as cladding, insulation, internal finishes, doors and windows, and structurally insulated panels (SIPs).

- **Modular Building**

Three-dimensional units, which are constructed and pre-assembled, complete with trim work, electrical, mechanical, and plumbing installed. Upon the completion by the manufacturing factory, these units are shipped to the site for installation on permanent foundations. Examples include modular homes, hotel units, prison units.

Manufactured houses or mobile homes are not included in the scope of this study.

Section I Company Information and Use of Off-Site Construction Techniques

1. Job title ______________________________

2. Company's annual volume for 2005 is ____________

3. Please indicate the approximate percentage of your total volume for 2005 in each of the following segments of construction industry.

Residential	Commercial	Industrial	Institutional
________	________	________	___________

4. The majority of your company's work is performed on a _______basis. (Circle the most appropriate one)

A. International B. National C. Regional D. State-wide

5. For 2005, indicate what percentage of you company's total volume incorporated the use of the off-site construction techniques.

2005	Off-Site Preassembly	______	Hybrid System	_________
	Panelized System	______	Modular Building	_________

6. Please indicate your overall satisfaction of your past experience of using off-site construction techniques by circling the number that best represent your experience.

0=have not used 1=highly unsatisfied 2=moderately unsatisfied 3=slightly unsatisfied 4= neither unsatisfied or satisfied 5=slightly satisfied 6= moderately satisfied 7=strongly satisfied (Circle one)

Off-Site Preassembly	0	1	2	3	4	5	6	7
Hybrid Systems	0	1	2	3	4	5	6	7
Panelized Systems	0	1	2	3	4	5	6	7
Modular Buildings	0	1	2	3	4	5	6	7

Section II Perceptions of Utilizing Off-Site Construction Techniques

Please ***circle one number*** that most closely represents your level of agreement or disagreement with each statement. Please respond to all items even if you have not used any of off-site construction techniques.

1=strongly disagree 2=moderately disagree 3=slightly disagree 4= neither disagree or agree 5=slightly agree 6= moderately agree 7=strongly agree

	Strongly Disagree						Strongly Agree
1. Off-site construction techniques reduces the overall project schedule.	1	2	3	4	5	6	7
2. Off-site construction techniques reduces the need for skilled craft workers onsite.	1	2	3	4	5	6	7
3. Off-site construction techniques reduces the project construction cost.	1	2	3	4	5	6	7
4. Off-site construction techniques increases product quality.	1	2	3	4	5	6	7
5. Off-site construction techniques increases overall labor productivity.	1	2	3	4	5	6	7
6. Off-site construction techniques limits design options.	1	2	3	4	5	6	7
7. Off-site construction techniques increases safety performance.	1	2	3	4	5	6	7
8. Off-site construction techniques reduces onsite disruption of other adjacent operations.	1	2	3	4	5	6	7
9. Off-site construction techniques reduces environmental impact of construction operations.	1	2	3	4	5	6	7
10. Off-site construction techniques increases jobsite management efficiency.	1	2	3	4	5	6	7

	Strongly Disagree						Strongly Agree
11. Off-site construction techniques increases the overall project cost.	1	2	3	4	5	6	7
12. Transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of off-site construction techniques.	1	2	3	4	5	6	7
13. The owners' negative perception of off-site construction techniques limits their uses.	1	2	3	4	5	6	7
14. The local building regulations restrict the use of off-site construction techniques.	1	2	3	4	5	6	7
15. Off-site construction techniques limits the ability to make change onsite work.	1	2	3	4	5	6	7
16. Lack of skilled assembly craftworkers limits the use of off-site construction techniques.	1	2	3	4	5	6	7

17. Please provide any other benefits or barriers of using off-site construction techniques that were not listed above.

18. Do you anticipate the use of off-site construction techniques will increase in the next
5-10 years?

A. Yes. State Why? (Please be as specific as possible)

B. No. State Why? (Please be as specific as possible)

Section III The Reasons for Using Off-site Construction Techniques

Please ***circle the top 3 reasons*** why your company uses off-site construction techniques. If your company has not used off-site construction techniques, please skip this section, and go to Section IV.

A. To compensate for the shortage of skilled craft workers
B. To compensate for weather condition
C. To reduce design duration
D. To reduce construction duration
E. To increase product quality
F. To reduce overall project cost
G. To increase overall labor productivity
H. To compensate for the restricted working space onsite
I. To reduce environmental impact
J. To improve project safety performance
K. To increase your company's profit margin
L. To enhance your company's reputation
M. Any other reasons ___________________________________

Section IV The Challenges of Using Off-Site Construction Techniques

Please ***circle the top 3 reasons*** that restrain your company from using Off-Site construction techniques.

A. Owner company restricts using off-site construction techniques.
B. Architect/Engineers did not specify the use of off-site construction techniques.
C. Local building regulations restrict the use of off-site construction techniques.
D. Financial institutions restrict the use of off-site construction techniques.
E. Lack of skilled assembly craft workers onsite.
F. Using off-site construction techniques will increase the construction cost.
G. Transportation restraints
H. Collective bargaining agreement prohibited the use of off-site construction techniques.
I. Limited design options in using off-site construction techniques.
J. Inability to make changes in the field by using off-site construction techniques.
K. Any other reasons______________________________________

Appendix C- In-depth Interview Questions

Objective:

The purpose of this interview is to identify the current utilization of Off-site construction techniques in the US construction industry, and to investigate the benefits and challenges of utilizing those techniques. I would appreciate if you could share you experience/knowledge in this field with me.

Definition:

In this study, the term of offsite construction refers to the applications where building systems or assemblies are manufactured or fabricated away from the building site prior to installation in their final positions.

Offsite Construction Techniques (OCT for short)

- **Pre-assembly**

Pre-assembly is a process by which various building materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system. (Tatum et al, 1986)

For example: pre-cast cladding panel

- **Hybrid Systems (Pod)**

Prefabricated building facilities, fully factory finished internally complete with the building services. For example: bathrooms, shower rooms, office washrooms, plant rooms.

- **Panelized Building**

It refers to the construction of the structural frame for the building using panel assembled in the factory. It consists of factory-built structure components instead of completed modules, transported to the site, assembled and secured to a permanent foundation, typically including additional factory based fabrication, such as cladding, insulation, internal finishes, doors and windows.(NAHB, 2004)

- **Modular Building**

Generally it refers to as the factory-built homes of one or more units completely assembled or fabricated in the manufacturing plant away from the jobsite, then assembled with the foundation and ground utilities on site.

It normally has multi-rooms with three-dimensional units, which are constructed and pre-assembled complete with trim work, electrical, mechanical, and plumbing installed. Upon the completion by the manufacturing factory, these units are shipped to the site for installation on permanent foundations.

Section I. Current Application on Off-site Construction Techniques (OCT)

1. Have you utilized the OCT in your previous project recently? In which of the following construction categories: residential, commercial, industrial or heavy construction?

2. What percent of OCT being utilized accounted for the overall production?

3. What the techniques you have utilized in your project?

4. How would you summaries your experience of OCT?

5, Do you believe utilizing OCT help you (or diminish your ability) to provide a higher level of customer satisfaction?

6. Is there any specific technique you would like to use more?

7. What kind of project or building sectors would be more appropriate for OCT by your understanding?

Section II Benefits of utilizing OCT

1. What are the motivations to use OCT in your project?

1. Is there possibility of using OCT could increase the general contractor's profit margin?

2. Did OCT help you solve the lack of skilled labor issue?

3. Did utilizing OCT increase the project quality? Or increase the predictability of project outcomes?

4. Did utilizing OCT greatly reduce the project schedule?

5. Did utilizing OCT greatly improve the project safety performance?

6. Did utilizing OCT reduce onsite disruption of adjacent operations?

7. Did utilizing OCT increase the labor productivity?

8. Is there any other benefits you (your company) have experienced?

Section III Barriers of utilizing OCT

1. Is the increased complexity of project planning system the one of the barriers?

2. Did the local planning department and code department support the OCT or not?
3. Is there any manufacturing company you preferred? Have you (your company) experienced any logistic problem?

4. Have you experienced any specific resistance from the owner, architects/Engineer or bankers that you want mention?

5. Have you experienced any resistance from union organization or other local construction organizations?

6. Do you think the design inflexibility is one of the challenges?

7. Does OCT have less construction error tolerance compared to conventional techniques? If yes, is that one of the primary challenges?

8. Have you experience any failure because of the manufacturing delay or bad quality, or transportation issue?

9. Have you experienced any resistances from your employers/employees in your firm? Why?

10. Are there any specific barriers you have personally experienced?

Section V Opportunities that OCT provides

1. Would you like to use OCT more along with increased design flexibility?

2. What are the primary determining factors of using OCT or not in a project?

3. Would you adopt the OCT more widespread if your major competitor using it more?

4. Would you adopt the OCT more widely if the resources are available in your operational areas? (Qualified manufacturers, skilled assembling labors, etc)

5. Do you believe the utilizing the OCT will increase or decrease in next decades?

6. Are there any other factors would influence you adopting the OCT?

Appendix D- Cover Letter for Survey Questionnaire

(Prefix, First Name, Last Name)
(Company Name)
(City, States, Zip)

Dear (Prefix Last Name),

I am a doctorate candidate in Construction Education at Clemson University, South Carolina. Currently, I am conducting dissertation research entitled "Investigation of Designer and General Contractor's Perceptions of Off-Site Construction Techniques in the United States". The objectives of this study are:

- Investigate the current use of off-site construction techniques including off-site preassembly, hybrid systems, panelized systems and modular buildings.
- Identify the perceptions of using off-site construction techniques by architects/engineers and general contractors in the building sector of U.S. construction industry.
- Determine the reasons why or why not off-site construction techniques have been used by architects/engineers and general contractors.
- Provide insight from construction executives of using off-site construction techniques.

Your opinion on using off-site construction techniques is crucial to the success of my research. The survey is very straightforward and will take less than 15 minutes. I will deeply appreciate if you complete the survey and return it in the postage-paid, self-addressed envelope provided at your earliest convenience (prior to February 08, 2007). The participation is completely voluntary, but again *I need your help* to accomplish this effort. If you have any questions about your rights as a research participant, please contact the Clemson University Office of Research Compliance at 864.656.6460.

Please be assured that your response will be held in strictest confidence. Under no circumstance, will your company's information be available to any individual or organization. If you have any questions about this survey, please feel free to contact Lu, Na at Nal@clemson.edu (864.656.0181) or Dr. William Paige at 864.656.7647.

I thank you in advance for your support.

Respectfully requested,

Lu Na
Doctorate Candidate
Clemson University

Appendix E- IRB Compliance Approval Letter

April 12, 2007

Dr. William Paige
Career and Technology Education
207 Tillman Hall
Clemson University
Clemson, SC 29634

SUBJECT: Human Subjects Proposal **#IRB2006-339 entitled "Investigation of Designer and General Contractor's Use and Perception of Off-Site Construction Techniques in the United States".**

Dear Dr. Paige:

The Chair of the Clemson University Institutional Review Board (IRB) validated the proposal identified above using Exempt review procedures and a determination was made on **December 13, 2006** that the proposed activities involving human participants qualify as Exempt from continuing review under **Category 2** based on the Federal Regulations. You may begin this study.

Please remember that no change in this research proposal can be initiated without prior review by the IRB. Any unanticipated problems involving risks to subjects, complications, and/or any adverse events must be reported to the IRB immediately. The Principal Investigator is also responsible for maintaining all applicable protocol records (regardless of media type) for at least three (3) years after completion of the study (i.e., copy of validated protocol, raw data, amendments, correspondence, and other pertinent documents). You are requested to notify the Office of Research Compliance (ORC) if your study is completed or terminated.

Attached are documents developed by Clemson University regarding the responsibilities of Principal Investigators and Research Team Members. Please be sure these are distributed to all appropriate parties.

Good Luck with your study and please feel free to contact us if you have any questions. Please use the IRB number and title in all communications regarding this study.

Sincerely,

Laura A. Moll, M.A., CIP
IRB Administrator
Institutional Review Board

Appendix F- Information Letter to Interviewee

December 13, 2006

Dear (Prefix Last Name),

You are invited to participate in a doctorate dissertation research conducted by Dr. William Paige and Lu Na at education department at Clemson University, South Carolina. The objectives of this study are:

- Investigate the current use of off-site construction techniques including off-site preassembly, hybrid systems, panelized systems and modular buildings.
- Identify the perceptions of using off-site construction techniques by architects/engineers and general contractors in the building sector of U.S. construction industry
- Determine the reasons why or why not off-site construction techniques have been used by architects/engineers and general contractors.
- Provide insight from construction executives of the use off-site construction techniques.

You will be invited to an open-end interview with Lu Na on perception of using off-site construction techniques based on your immense knowledge of off-site construction techniques. The amount of time required for your participation will be 45-60 minutes.

There are no known risks associated with this research. However, your participation is crucial to the success of this research effort. As an expression of my gratitude for your participation you will be provided a summary of the study's findings.

Please be assured that your response will be held in strictest confidence. Under no circumstances will result specific to your company or yourself be made available to any individual or organization. Your participation in this research study is completely voluntary. You may withdraw your consent to participate at any time. However, your input is critical to this study.

If you have any questions or concerns about this study, please feel free to contact Dr. William Paige at Clemson University at 864.656.7674. If you have any questions or concerns about your right as a research participant, please contract the Clemson University Office of Research Compliance at 864.656.6460.

Thanks in advance,

Respectfully requested,

Lu Na
Clemson University

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