

EXPLORING THE CRITICAL SUCCESS FACTORS OF  
OFFSITE CONSTRUCTION IN TURKEY

by

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## **ABSTRACT**

### **EXPLORING THE CRITICAL SUCCESS FACTORS OF OFFSITE CONSTRUCTION METHOD IN TURKEY**

Offsite construction method consists of well-established techniques, which can enhance the construction industry by transferring some portion of onsite work to fabrication shops. However, its application in the Turkish industry limited. Offsite construction method has been faced with different challenges and a number of factors have different effects on the successful application of offsite construction. A limited number of studies focus on to determine critical success factors in order to enable wider use of offsite construction in Turkey. This paper aims to examine the CSFs for successfully implementing the offsite construction method. A total of 14 CSFs determined through literature review, in-depth interview and pilot studies with experts. A questionnaire survey was conducted in order to determine the level of significance of these factors in Turkey. CSFs were grouped for pairwise comparison using AHP. In the first stage of AHP, the factor groups were compared in pairs and their weights were calculated. Factor groups in descending order of significance were determined as (1) leadership, (2) technical, (3) resources, (4) regulatory, (5) process. The second stage of AHP involved the pairwise comparison of factors within the factor groups. Global weights of CSFs were obtained by multiplying the weights obtained through these two stages and 14 CSFs were compared accordingly. First five most significant CSFs were determined as: (1) project managers' problem solving ability, (2) contractors leadership & experience, (3) effective information sharing, (4) skilled labor availability, (5) the maturity of techniques & technologies used. This contribution provides an insight into the construction industry in Turkey for further deployment of offsite construction methods in the construction market.

## ÖZET

### SAHA DIŐI İNŐAAT METODU VE TÜRKiYE'DEKİ KRİTİK BAŐARI FAKTÖRLERİNİ ARAŐTIRILMASI

Saha dıŐı inŐaat yöntemi, sahadaki çalıŐmanın bir bölümünü imalat atölyelerine transfer ederek inŐaat endüstrisini geliŐtirebilecek köklü tekniklerden oluşur. Ancak, Türkiye'deki inŐaat sektöründe uygulaması sınırlıdır. Saha dıŐı inŐaat yöntemi Türkiye'de farklı zorluklarla karşı karşıya kalmıŐtır ve başarılı bir şekilde uygulanmasında bazı faktörler etkili olmaktadır. Sınırlı sayıda çalıŐma, Türkiye'de bina dıŐı inŐaatın daha geniş bir şekilde kullanılmasını sağlamak için kritik başarı faktörlerini belirlemeye odaklanmaktadır. Bu makale, Őirket dıŐı inŐaat yöntemini başarılı bir şekilde uygulamak için kritik başarı faktörlerini incelemeyi amaçlamaktadır. Literatür taraması, birebir görüşmeler ve uzmanlarla yapılan pilot çalıŐmalarla toplam 14 kritik başarı faktörü belirlenmiŐtir. Bu faktörlerin Türkiye'deki önem düzeyini belirlemek için bir anket çalıŐması yapılmıŐtır. Kritik başarı faktörleri, Analitik HiyerarŐi Süreci (AHP) kullanılarak ikili karşılaŐtırma için gruplandırılmıŐtır. AHP'nin ilk aşamasında belirlenen beŐ faktör grubu kendi arasında ikili olarak karşılaŐtırılmıŐ ve ağırlıkları hesaplanmıŐtır. Azalan önem sırasına göre faktör grupları: (1) liderlik, (2) teknik, (3) kaynaklar, (4) mevzuat, (5) süreç olarak verilebilir. AHP'nin ikinci aşaması ise, faktörlerin, kendi grupları içerisinde ikili olarak karşılaŐtırılmasını içermektedir. Bu iki aşamada elde edilen ağırlıklar çarpılarak, kritik başarı faktörlerini karşılaŐtırmak için kullanılan global ağırlıklarına ulaŐıldı ve buna göre 14 kritik başarı faktörü karşılaŐtırıldı. Sonuç olarak ilk beŐ kritik başarı faktörü önem sırasına göre: (1) proje yöneticilerinin problem çözüme becerisi, (2) müteahhitlerin liderliĐi ve tecrübesi, (3) etkili bilgi paylaşımı, (4) vasıflı işgücü mevcudiyeti, (5) kullanılan teknik ve teknolojilerin olgunluĐu olarak belirlenmiŐtir. Bu katkı, Türkiye'de saha dıŐı inŐaat metodunun pazarda daha geniş kullanıma nasıl sahip olabileceĐi konusunda bir fikir vermektedir.

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## LIST OF SYMBOLS

|                 |                              |
|-----------------|------------------------------|
| CI              | Consistency Index            |
| CR              | Consistency Ratio            |
| $m$             | Number of criteria           |
| S               | Pair-wise comparison matrix  |
| $w_f$           | Factor weights with in group |
| $w_g$           | Factor group weights         |
| $W(g,f)$        | Global factor weights        |
| $\lambda_{max}$ | Highest value in matrix      |
| $\Sigma$        | Summation                    |
| $v$             | Matrix eigenvector           |

**LIST OF ACRONYMS/ABBREVIATIONS**

|      |                                                |
|------|------------------------------------------------|
| AHP  | Analytic Hierarchy Process                     |
| ANP  | Analytic Network Process                       |
| CI   | Construction Industrialization                 |
| CIDF | Construction Industrialization Driving Factors |
| CSF  | Critical Success Factor                        |
| ENR  | Engineering News Record                        |
| GDP  | Gross Domestic Product                         |
| GTM  | Grounded Theory Method                         |
| IB   | Industrial Building                            |
| IBS  | Industrialized Building Systems                |
| ICF  | Insulating Concrete Framework                  |
| MMC  | Modern Methods of Construction                 |
| OSC  | Offsite Construction                           |
| OSM  | Offsite Manufacturing                          |
| OSP  | Offsite Production                             |
| PHP  | Prefabricated Housing Production               |
| RI   | Random Consistency Index                       |
| S&P  | Supply Procurement                             |
| UK   | United Kingdom                                 |
| US   | United States                                  |

# 1. INTRODUCTION

## 1.1. Background of the Research

Building activities are as old as humans themselves are. The construction activities had begun to meet the accommodation need of the humankind. The modern world evolved in such a way that construction became an indispensable requirement for all other sectors. Importance of the construction market can be derived from the GDP charts of countries. Only residential construction industry formed the 4,1% of the GDP of the US in 2017 and it has an increasing trend since the 2008 mortgage crisis (U.S. Bureau of Economic Analysis, 2019). Likewise, the construction of new houses is a significant contributor to the overall development of Australian economy by forming between 3%–4% percent of the Gross Domestic Product (Hsieh *et al.*, 2012). When all subdivisions of the construction market in China are included, the share of the construction sector in GDP increases to 7%. Turkish construction market consisted of 8,6% of Turkey’s total GDP in 2017 (TUIK, 2019). Construction industry becomes the most significant contributor to the Cambodian economy due to its links with other sectors (Durdyev and Mbachu, 2018). In the average contribution of the construction market is between 10-12% of the total GDP in the world. It is generally higher in developing countries while it decreases relatively on the developed countries.

There are many different and successful construction methods. The offsite construction method is one of the oldest construction methods. It refers to the planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure (Schoenborn, 2012). As far as discovered, the offsite construction techniques reach back to 3800 BC, “The Sweet Track”. This first engineered roadway was constructed using prefabricated timber members (Prasher and Mittal, 2002). The Great Pyramids of Giza is also constructed with the help of offsite construction techniques. The stones of the Giza was constructed offsite and carried to its final destination. The Mesopotamia architectures (2500-

600 BC), derived the block techniques used in the pyramids and applied that in much more smaller pieces. This way, lighter and more conveniently handled blocks are produced in offsite and used in palaces, temples, ziggurats, and bridges (Prasher and Mittal, 2002).

Although the offsite construction method is deep-rooted, it is not commonly used as the traditional method of construction. The market share of offsite construction is around 6-7% in the UK (Taylor, 2010). In the USA, the share of offsite construction method is 7% (HAC, 2011). Several studies are conducted in order to determine the reason behind the low preference of offsite construction methods. Architects' lack of experience about offsite construction is found to be one of the important factors which prevent offsite construction to become widespread (Hashemi, 2015). In another research conducted in the UK, flexibilities of the traditional method of construction and offsite construction method are compared. In this regard, the traditional construction method becomes more applicable since changes in the design do not require high investments of both money and time and enable to adapt to rapidly changing needs of the market (Lang *et al.*, 2016). Higher initial capital expenses and higher design and transport costs (Pan and Goodier, 2011) are determined to forge barriers to select offsite construction as methodology. In addition, there is society bias against offsite construction which can be used in low-cost buildings (Lu, 2007) decreases its popularity among the customers.

On the other hand, studies also show that offsite construction has many advantages over the traditional method of construction. Improved quality, lower costs and lower labor requirements on-site (Goulding *et al.*, 2017) are some advantages of the offsite construction method. Preproduction in a controlled environment minimizes the risk of delays due to weather conditions (Lu and Liska, 2008). Modular construction, which can be defined as a subcategory of offsite construction, can save around 40% of construction time compared with traditional construction. Offsite construction is offering possible cost reductions with factors of on-site overhead reduction, standardization of design, high level of energy efficiency and higher efficiency in installation. Automated machinery usage in offsite construction facilities can result in a higher level of product quality. (Kamali and Hewage, 2016).

## 1.2. Statement of Research Problem

Offsite construction offers much expediency to the construction sector (Tam *et al.*, 2007) with an improvement in productivity and performance. Regarding the benefits of offsite construction method and considering the technology level of it with techniques such as automation and modular construction, it can be indicated that it is not achieved its potential yet. Even for a well-developed country, United States, offsite construction method has not been utilized completely (Hass *et al.*, 2000). Factory-built housing represents approximately 14 percent of the U.S. house market (Manufactured Housing Institute, 2019), 6-7% in the UK (Southern, 2016) and 9% in Germany (RICS, 2018).

Turkey is a well-known country with its capabilities in the construction sector. In ENR's 2017 top 250 International Contractors list, 46 contractors from Turkey were listed (ENR, 2019). Despite having between 15-20% of the top 250 contractors in numbers were among Turkish Contractors, they had a market share changing from 3.5% to 5.5% in between 2013 and 2016 years (KMPG, 2018). It can be pointed out that the technology and added value of Turkish contractors are too low compared to other international opponents. A research conducted by Polat and Damcı points out that while the market share of precast concrete is only 6% in Turkey, it rises to 40% in northern Europe (Polat & Damcı, 2007). As well as the low market share of offsite construction, there is not much research conducted on determining critical success factors for offsite construction in Turkey.

## 1.3. Related Studies

Determining critical success factors for offsite construction has a crucial role in the development of the construction industry. Critical success factors vary up on related countries market conditions, capabilities, and economic adequateness. A research was conducted in the US for determining critical success factors of Industrial Modularization, which is a sub-technique of offsite construction, listed 21 CSFs (O'Connor *et al.*, 2014). Five most important CSF were listed as; module envelope limitations, alignment on drivers,

owner's planning resources & processes, timely design freeze, and early completion recognition. Another research from China, top CSF were designers' experience, manufacturer's experience, project manager's ability to solve problems, the maturity of techniques used and persistent policies and incentives (Li *et al.*, 2018).

In Malaysia, a study was conducted on industrial building systems determined the most important CSFs as; good working collaboration, coordination of design, manufacture, and construction, experienced workforce and technically capable, extensive planning and scheduling, design standardization and repetition (Kamar *et al.*, 2010). A study from the US concluded that the most significant factors were module envelope limitations, alignment on drivers, owner's planning resources & processes (James *et al.*, 2014). Another study from the UK determined that; time reduction, improving the quality of the final product and decreasing accidents on site was the most significant CSFs of offsite construction (Elnass *et al.*, 2014).

These varying results show that CSFs are changing according to the dynamics of the construction market of which the research takes place. In order to fill the gap in the literature and determined CSFs of offsite construction in Turkey this study conducted. In order to have a broader point of view, this study will cover all techniques that form offsite construction as a whole.

#### **1.4. Research Objectives**

Literature focusing on the subject of offsite construction in Turkey partly includes prefabrication and modular construction techniques, however, they do not comprise offsite construction as a whole, therefore leaving a gap in the literature. In addition, studies were conducted in other countries had varying results according to their market conditions. This study aims to contribute to the literature by determining critical success factors from the perspective of the Turkish construction market. The specific objectives of the study in order to achieve this aim are provided as:

- (i) To prioritize identified critical success factors in terms according to their significance level relative to each other,
- (ii) To determine the guideline for improving offsite construction utilization.

### **1.5. Scope and Limitations**

This thesis plays a great role in identifying and prioritizing critical success factors for offsite construction method in the Turkish construction market. The research scope included all submarkets of construction. In this research, data obtained from professionals with different background and experience, in order to cover the construction market as a whole. Responders were selected from engineers, architects, sales & marketing, company owners, purchase & procurement, field operations, and other construction-related departments. Responders did have experience in residential, commercial, industrial buildings and infrastructure. In Turkish literature, there are some studies, which investigated the factors affecting the techniques of offsite construction such as precast building elements (Polat and Damcı, 2007). However, existing studies in Turkish literature did not consider offsite construction methodology as a whole. Therefore, this study aims to fill this gap in the literature by determining and ranking CSFs of offsite construction, regarding Turkish construction market.

The population in this study was limited to Turkish professionals; therefore, the result of this study reflects the construction market of Turkey. Selected CSFs and ranking of them consider Turkish construction market conditions and may not apply for other countries.

### **1.6. Organization of the Thesis**

Chapter 2 provides a comprehensive literature review on the history of offsite construction. Explanation of similar terms used which are related to offsite construction also been included in this chapter. This chapter also provides categories of offsite construction and examples for these categories. Chapter 3 presents the methodology and procedures of

the research. It begins with the literature review. This is followed by a focus group interview and critical success factors determination process. This chapter also includes the preparation of questionnaire and methods used in order to evaluate the results of questionnaire quantitatively.

Chapter 4 presents the findings from the literature review and focus group studies. It also includes findings from questionnaire respondents and their quantitative analysis. Chapter 5 includes conclusions drawn from the data analyses and comparison of these data with previous research. Also, recommendations for further research are included. Chapter 6 consists of references.

## **2. BACKGROUND**

### **2.1. Offsite Construction and Relative Terms**

Offsite construction refers to the planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure (Schoenborn, 2012). Another research defines offsite construction productions as spectrums or parts of which are manufactured or assembled remotely from building site prior to installation in their final position (Goodier and Gibb, 2006). Offsite Construction (OSC) is interchangeably used with Offsite Production (OSP) and Offsite Manufacturing (OSM) according to what specialty of this method wanted to be outlined. All of these terms referring to carry out the construction process away from the building site, either in a factory or specially created temporary production facilities (Goodier and Gibb, 2006). In literature, there are many definitions closely related to having different meanings from offsite construction.

Industrialized building system (IBS) term is generally referred to as a synonym of offsite construction. IBS was defined by Abdullah and Egbu as a method of construction, developed due to human investment in innovation and on rethinking the best ways of construction work deliveries based on the level of industrialization. According to the level of industrialization, IBS is divided into three subgroups; pre-building system, modern construction, advanced automation and volumetric construction (Abdullah and Egbu, 2009). The IBS term is used often on behalf of other terms such as prefabrication, offsite manufacturing, however, they are distinct with their history and development processes. In general, the ideology behind the development of all these terms are same; manufacturing structural components for the construction in a controlled environment rather than doing on site.

Modern Method of Construction (MMC) was originated in the United Kingdom with referring to both offsite based construction technologies and innovative onsite technologies (Goodier and Gibb, 2006). As its definitions suggest, MMC is an innovation-based term, rather than consisting only industrialized or offsite techniques (BURA, 2005). Prefabrication is a manufacturing process which is conducted in a closed or controlled facility in order to form parts of the final assembly (Tatum, 1986). Preassembly term which relates with offsite construction is literally meant to “assemble before” and includes manufacture and assembly processes (usually off-site but not necessarily) of buildings or parts of buildings prior to they would traditionally be constructed on-site (Gibb and Isack, 2003). Pan, categorized these terms as suggested in Table 2.1 (Pan, 2006). In this paper, the Offsite Construction term will be considered for further research.

Table 2.1. Categorization of terminologies (Pan, 2006).

| <b>Terminology</b> | <b>Category Term</b>                 |
|--------------------|--------------------------------------|
| OS                 | Offsite Production (OSP)             |
|                    | Offsite Manufacturing (OSM)          |
|                    | Offsite Fabrication (OSF)            |
|                    | Offsite Construction                 |
| PRE                | Pre-assembly                         |
|                    | Prefabrication                       |
|                    | Prefab                               |
| MM                 | Modern Methods of Construction (MMC) |
|                    | Modern Methods of House Construction |
|                    | Modern Methods of House Building     |
| Building           | System Building                      |
|                    | Non-traditional Building             |
|                    | Industrialized Building              |

## 2.2. Offsite Construction Categories

Offsite construction has many synonyms, which can be used interchangeably. In addition, there are many construction techniques, which falls under the offsite construction methodology. The products of each technique differ from each other, regarding the complexities of their products and sizes. Products of offsite construction can vary from a

construction element to a modular building. According to the size and complexity of manufactured components, offsite construction types grouped into four categories; processed material, prefabricated components, panelized, modular (Schoenborn, 2012).

### **2.2.1. Processed Materials**

Due to increasing technology and manufacturing capabilities, modern world construction has various material options to be used in the construction. In order to set standards, there are some certain dimensions or forms accepted globally. This enables the manufacturers and contractors easy understanding of what they are trading (Schoenborn, 2012). In some projects, however, project managers tend to have custom dimension orders. Custom dimension orders generally fasten the construction processes and decrease the onsite labor force need. Precut or shaped steel rebar or cladding units are examples of this kind of offsite construction sub-methods.

### **2.2.2. Prefabricated Components**

Prefabricated components are one of the most commonly preferred techniques in construction. The components are produced repeatedly in a production plant and the output is generally installed as a piece of bigger assembly (Schoenborn, 2012). The products on this category can be listed as precast cladding, pre-cast structural elements, insulating concrete formwork (ICF), tunnel form construction, facade systems, frames of steel, timber, precast.

### **2.2.3. Panelized**

Panelized structures are another method falls under the offsite construction. Prefabricated components are assembled in factories in order to lower the demand for additional labor onsite (Schoenborn, 2012). These assembled components do not enclose any volume and they can be stacked on the trailer for easier transport options.

#### **2.2.4. Modular**

Modular offsite components are volumetric units. Before the modular components moved to the site, some of their installations are completed at offsite (Schoenborn, 2012). Modular units also can be subcategorized regarding their sizes. Pods are designed for enclosing only one room, such as the bathroom. There are larger modules, which encloses more than one room. In addition, there are expandable modular units, which can be cover more than 60m<sup>2</sup> upon installation and used as mobile homes.

### **2.3. History of Offsite Construction**

Offsite construction method reaches back to 3.800 BC with a road called “The Sweet Track” which was formed of partial members produced offsite (Prasher and Mittal, 2002). In order to observe a higher level of application in offsite construction, it is necessary to look at about four hundred years ago. A wooden house was shipped from England to Cape Ann, Massachusetts in 1624 to provide housing for a fishing fleet (Arieff and Burkhart, 2002). In 1755, the great Lisbon Earthquake caused massive destruction in Portugal. The Baxia district where is effected of the destruction severely was rebuilt by the offsite construction techniques. The buildings produced outside of the city transferred to the Baxia district in pieces and assembled in there. The offsite construction methods used in the European countries following the successful implementation in Baxia (Hamblyn, 2008). In the early 1800s, kit houses were produced and transferred by rail for settlers during the California Gold Rush (Arieff and Burkhart, 2002). This is followed by John Manning’s portable colonial cottage creation in the 1830s (Taylor, 2010). The symbol of Paris, Eiffel Tower, is also one example of the offsite construction method. It was formed of 18.000 metallic parts, which were produced in a factory and transported to the site. It was one of the most significant buildings when completed in 1889 with 300 meters in height (Barthes, 2012).

The mass offsite production in a factory for complete modern home relates back to 1930s in Northern America (Arieff and Burkhart, 2002). Advancement of the automobile

technology created a new sector of mobile homes, which were named trailer or caravans. The trailers on wheels were preferred by fisherman, hunters, and campers. During World War II, the US Government requested a quick assembly of an atomic manufacturing facility from one of these trailer companies. The project was successful and the demand for this quickly established homes was increasing. In the 1950s the sector was divided into two, as recreational trailers and permanent housing (Hart *et al.*, 2002).

Not only in the US, but also in Europe, there was a high demand for new housing after World War II. Trials of applying offsite construction techniques in high-rise buildings led to the emergence of twenty and more story pre-constructed buildings. The safety of this type of buildings became questionable after a gas explosion in one of these buildings. Ronan Point, a 22 story high construction, made with offsite construction method. The gas explosion caused the collapse of one flat's outer walls and the consequent flats followed this (Delatte, 2009). Eventually, a part of the tower collapsed, killing four people in the incident. The Ronan Point accident caused fear and doubts about the offsite construction methods and its popularity decreased in Europe temporarily (Delatte, 2009).



Figure 2.1. Ronan Point accident.

Modern techniques increased the possible complexity level of usage offsite construction. In 2015, a skyscraper called J57 Mini Sky City was constructed in China by

using modular construction technique. This building has 57-floors and consists of 800 residential units. This building is famous for proving the capabilities of offsite construction. The building parts of this building were produced in factories within 4 months. More astonishingly, the installation of the building completed within just in 19 days (Generalova, 2016). The tallest modular building was constructed in New York in 2016. It is called the 461 Dean apartment. This building is 32-story high and there are 363 units in it. This is the only modular tower which is built for residential housing (Generalova, 2016).

#### **2.4. Factors, Enablers, and Barriers of Offsite Construction**

Critical success factors of offsite construction have been a research topic in order to understand the concept and determine ways to increase its application. Findings from numerous studies vary due to the market conditions of related countries in which study takes place. In literature, there are studies which investigate different subsections of offsite construction such as; modularization (James *et al.*, 2014), prefabrication (Li *et al.*, 2018), preassembly (Gibb *et al.*, 2003), industrial building systems (Kamar *et al.*, 2010 and Yunus *et al.*, 2012). In addition, there is much research on the offsite construction and its subsections, in order to determine benefits, weaknesses, and barriers for it. In this research, in order to start from a broader perspective, literature with different countries, different subsections of offsite construction are used as a source.

A study was conducted in the US investigated critical success factors and enablers for industrial modularization (James *et al.*, 2014). In this study, through brainstorming and researching within the literature, 82 critical success factors were determined. These initial 82 CSFs were reduced to 21 by weighting their importance with their frequency of seen in literature and validation by 15 external experts. Findings from this research showed that 57% of CSFs were related with the owner of the project, 33% were related with the contractor, 7% of critical success factors were related with vendors & technology licensors while 3% were related with other stakeholders (James *et al.*, 2014). In this study, CSFs were also examined according to the project phases to which they were related. It was found that 31% of CSFs were related to assessment phase while 23% of them were related to the basic design

and 20% of them were related to the selection. Three other phases of the project; execution, opportunity framing, and startup, were related with 27% of CSFs. According to this research, the first ten CSFs which had the most impact were module envelope limitations, alignment on drivers, owner's planning resources & processes, timely design freeze, early completion recognition, preliminary module definition, owner – furnished/long lead equipment specification, cost-saving recognition, contractor leadership and contractor experience (James *et al.*, 2014). Remaining determined CSFs were; module fabricator capability, investment in studies, heavy lift/site transport capabilities, vendor involvement, operations and maintenance (O&M) provisions, transport infrastructure, owner delay avoidance, data for optimization, continuity through project phases, management of execution risks, management of execution risks, transport delay avoidance (James *et al.*, 2014). All of these CSFs were included in this research for consideration.

A study which was conducted in the UK investigated the critical success factors of industrialized building systems (IBS) (Kamar *et al.*, 2009). In this research, a literature review was done in order to determine CSFs for contractors using IBS. Interview and discussion were conducted in order to validate CSFs. In this research CSFs were investigated in five subcategories; barriers, push factors, enabling, pull factors, the nature of the construction industry (Kamar *et al.*, 2009). Highlighted CSFs for contractors were listed as; adequate training and education in IBS, leadership and management level, information technology appliance, careful and detailed cost planning and management, supply & chain integration and site management & process. These were further validated through interviews (Kamar *et al.*, 2009).

The same researcher conducted another research on critical success factors for industrialized building systems considering the Malaysia market conditions (Kamar *et al.*, 2010). In this research, literature review and case study analysis were conducted in order to validate found CSFs. According to the case study, CSFs were determined as; need of good working collaboration, effective communication channel, coordination of design, manufacturing, and construction, the need of experienced workforce and technically capable, close relationship with suppliers, extensive planning and scheduling, standardization, supply

chain, top-down commitment on IBS and the need for skilled labor for installation (Kamar *et al.*, 2010). Results of these two studies show that for different market conditions, different CSFs are valid.

In order to obtain a broader perspective, papers with different focuses were also considered. A research conducted in China was investigating CSFs for project planning and control in prefabrication housing production (Li *et al.*, 2018). In their research, they identified CSFs through literature review. In order to validate these factors, an investigation through a questionnaire was applied. 23 CSFs were considered to be critical. Five most important CSFs were listed as; designers' experience of PHP, manufacturers' experience of PHP, project manager's ability to solve problems, the maturity of techniques used in the detailed design phase, persistent policies and incentives (Li *et al.*, 2018).

A study was conducted in Australia in order to determine drivers, constraints and the future of offsite manufacture (Blismas and Wakefield, 2008). Data were obtained by a broad qualitative survey, workshops, interview with case studies. Results of this study showed that on-site trade skill shortage is the most prominent driver of OSM in Australia (Blismas and Wakefield, 2008). The reason behind this driver to become the most important factor was indicated as the lack of qualified people to work onsite in some parts of Australia. Process and program were determined as both a driver and a constraint for OSM in this paper (Blismas and Wakefield, 2008). According to this paper, cost, value, and productivity were determined as a driver and an advantage of OSM rather than building a barrier in Australia (Blismas and Wakefield, 2008). In this paper it was also reported that; lack of experience in the level of industry & professional knowledge, negative bias against OSM, limited supply-chain related with OSM, logistics and site operations were posing a barrier and reduce the OSM usage in construction. OSM had benefits such as better work condition for people, reduced health and safety risks, increased environmental sustainability, increased quality aspects (Blismas and Wakefield, 2008).

Blimas *et al.* (2005), conducted another research on offsite production (OSP) in the UK. In this research, a questionnaire was shared with two hundred and eighty-nine (289) members of the IMMPREST (Interactive Method for Measuring PRE-assembly and standardization benefit in construction), lean construction network mailing list, and the delegates of the way forward conferences (Manufacturing the Future, 2002). Seventy-three professionals replied which were consisted of clients (12%), architects (11%), design engineers (15%), project managers (7%) specialist suppliers (15%), contractors (30%) and others (10%). Questionnaire responses were gathered on the Likert scale. As a result, determined constraints were listed according to their impact. Being unable to freeze design and specification early was determined as the most significant constraint affecting the implementation of OSP. Obligation to accept the lowest cost rather than best value, key decisions early in process preclude S&P, unwilling to commit to a single-point supplier and limited choice of the supply chain for the project were found to be forming most important five constraints of offsite production (Blimas *et al.*, 2005). Early advice unavailable, limited previous S&P experience within the team, limited capacity of suppliers, obliged to accept element-specific costing were determined as other important constraints according to the analysis of this research. Short project time scales factor was found to be a driver according to results (Blimas *et al.*, 2005). As a summary, the main challenges of OSP were determined, as knowledge related issues and these have to be removed in order to achieve wider use of OSP in construction (Blimas *et al.*, 2005).

Pan *et al.* (2007), conducted a survey including top 100 house builders in the UK. According to this study, the most important drivers for using offsite construction were determined as; addressing skills shortages, ensuring cost certainty, ensuring time certainty, achieving high quality, minimizing on-site duration. Less important drivers were listed as reducing health and safety risks, government promotion, restricted site specifics, maximizing environmental performance (Pan *et al.*, 2007). Higher capital cost, difficult to achieve economies of scale, complex interfacing between systems, unable to freeze the design early on, nature of the UK planning system, reluctance to innovation and lack of previous experience were some of the barriers listed in this paper. This research also determines that nearly two-thirds of UK housebuilders were actually believing that there

needs to be an increase in the take-up of offsite technologies in the housing sector, while barriers against offsite technologies prevent it (Pan *et al.*, 2007).

Gibb *et al.* (2003), conducted research on pre-assembly technique in which 59 representatives of major construction clients were interviewed. From the customer perspective, time was determined as the most important benefit of pre-assembly (Gibb *et al.*, 2003). Other most important benefits were determined as; increased quality, reduced cost, increased productivity and easy measurement of success (Gibb *et al.*, 2003). Clients also determined the disadvantages of pre-assembly as; poorly built products, lack of experience of contractors, late deliveries, volatile nature of supply chain and higher upfront cost (Gibb *et al.*, 2003). Also, some clients indicated that the limited number of suppliers in offsite construction market was making it hard to find an adequate company to work with. Another issue arose as in the small amount of order since the repetition was low, the unit prices of this technique was becoming relatively higher than the conventional construction method (Gibb *et al.*, 2003).

Another research considered future opportunities for offsite in the UK as a topic (Goodier and Gibb, 2007). In this paper, a literature review was followed by a preliminary survey of six organizations in order to construct the framework of the questionnaire. The data was obtained by a questionnaire through 75 UK construction organization. In addition, a workshop was conducted with 13 delegates of offsite foundation representatives. Regarding the client/designers and contractors; decreased construction time was the most significant advantage, while it was followed by increased quality, more consistent product, reduced snagging & defects (Goodier and Gibb, 2007). Most significant three barriers were determined as; offsite method being more expensive than conventional construction method, longer lead-in times and client resistance (Goodier and Gibb, 2007). According to the findings of this research, the negative image of offsite was the main factor that limited the uptake of the offsite construction. This issue was determined in other studies also (Venables *et al.*, 2004 and RGU, 2002).

Nadim and Goulding (2009), conducted research from the construction industry perspective. In order to obtain data, a questionnaire was prepared with a simple framework of Likert scale. Gathered data was investigated for its validity with SPSS. A total of 36 valid responses were obtained (Nadim and Goulding, 2009). This research included offsite construction and all of its techniques. In this research also Modern Methods of Construction MMC was defined and its relevance with offsite construction was determined. Field of operation of professionals joined to this study were diversified by including residential sector, office, commercial/retail, educational, industrial, health, mixed-use and other. This study revealed the level of offsite construction method appliance was 1-25% for almost half of the participants. In contrast, 73% of the responders were considering offsite construction methods as the future of the UK construction industry (Nadim and Goulding, 2009). In this research, time reduction, improving the quality of the final product and decreasing accidents on-site were considered as the top three reasons for using offsite construction (Nadim and Goulding, 2009). Cost reduction was less valued (31 percent) and even some participant thought it was actually increasing the cost. Most significant three added value of offsite construction were determined as; meeting the deadlines, waste reduction and improved eco-homes rating (Nadim and Goulding, 2009). Improved maintenance, improved aesthetics, improved life cycle costing and design flexibility were not considered as added values of the offsite construction method (29 to 4 percent, correspondingly). Factors, which prevent the wider use of offsite construction, were determined as; inflexible design, limited market demand, poor aesthetic, hard to maintain, limited supply (Nadim and Goulding, 2009).

Elnass *et al.* (2014), conducted another research on the factors and drivers affecting the decision of using off-site manufacturing systems in the house building industry. A literature review was done in this study in order to outline the questions that were not answered in the literature. Thirty interviews were conducted in order to understand the OSM from the perspectives of construction professionals. The participants of surveys were selected from clients, contractors, consultants, project managers, design managers, and contract/construction managers. Outcomes of the interviews were crosschecked with 15 case studies (Elnass *et al.*, 2014). According to the result of this research; time, quality and cost were selected as highly important factors, which were affecting the decision to implement offsite construction. Predictability, productivity, interface issues, environment issues,

performance, labor, lack of space were considered as moderate important factors. Safety, project complexity and logistics issues were determined to be usually important with very low importance impact with 10 to 14 out of 100 (Elnass *et al.*, 2014). Determination of safety to be relatively less important and this results contradicting with another research conducted in the UK where the reducing health and safety risks were selected as the most important factor for selecting offsite construction method (Nadim and Goulding, 2009). In this research, the availability of resources, planning issues, and market conditions marked as unimportant factors for selecting offsite construction techniques (Elnass *et al.*, 2014).

Xiahou *et al.* (2018) conducted research on driving factors of construction industrialization (CI) in China. The term of construction industrialization was used in order to represent techniques such as; industrial building (IB), prefabrication, pre-assembly, modern method of construction, off-site manufacturing, off-site production, and off-site construction (Xiahou *et al.*, 2018). In this research, a systematic literature review was conducted and 182 CI related journal articles were obtained. Construction industrialization driving factors (CIDF) were obtained from the related articles. Using the grounded theory method (GTM), 14 CIDFs were determined. A questionnaire conducted with 123 professionals involved and the identified factors were listed according to their relative importance. Findings of this research showed that; lack of labor, shortage of resources, productivity improvement, serious environmental problems, quality improvement were forming the most significant five driving factors of CI (Xiahou *et al.*, 2018). The minimum importance given factor among this research was health and safety improvement as other researchers point out (Elnass *et al.*, 2014),(Nadim and Goulding, 2009). Technology process, cost reduction, integration of advanced technologies, demands for more production were forming the least important driving factors (Xiahou *et al.*, 2018). Supporting policies, management improvement, integration of the supply chain were mentioned as other driving factors (Xiahou *et al.*, 2018).

Yunus *et al.* (2012), conducted research in order to identify critical sustainability factors for improved implementation of Industrialized Building Systems (IBS). In this research, a literature review was used in order to identify factors. The level of significance

of each factor was determined through data obtained from 115 questionnaire answers. The significance level each factor were determined in the Likert scale. Responders were contractors (20%), designer/consultant (18%), user (15%), authority/government agency (14%), client (12%), manufacturer (11%), and academicians (10%) which shows a great variability in order to obtain results from wider perspective (Yunus *et al.*, 2012). Applying statistical models according to data obtained, critical factors were determined as 18 out of 62. Five most important sustainable factors are determined as; construction time, production, waste generation, constructability, knowledge, and skills. Other factors were also considered as important and significant according to the statistical test results which they conducted. Other factors were listed as; defects and damages, labor cost, waste disposal, procurement system, durability, working conditions, standardization, usage efficiency, labor availability, material consumption, legislation, project control guidelines, maintenance and operation costs (Yunus *et al.*, 2012).

Ismail *et al.* (2012) conducted another research in Malaysia in order to determine management factors for successful IBS Project implementation. In this research, a literature review was conducted to identify factors. A questionnaire survey with the Likert scale was prepared and answers were used as the data source. As a result, 12 factors were determined to be important with having a mean of greater than 3.00 out of 5.00. Most significant five factors were determined as; good working collaboration, industry marketing strategies, extensive planning and scheduling, effective communication channel and top-down commitment. Following these factors, in the order of descending agreement (mean); environmentally friendly methods, improvement in planning and scheduling of the project, strategy and business approach had a mean greater than 4.00. Remaining four critical management factors for IBS were determined as team members involved during the design stage, risk management, close relationship with suppliers, management of supply chain and logistics with less agreement upon the responders of the questionnaire (Ismail *et al.* 2012).

In order to cover the critical success factors of offsite construction, similar studies from different countries selected. This showed that different countries with different construction market dynamics had also variable critical success factors compared to each other. Studies

conducted by Kamar *et al.*, (2009,2010) demonstrated that even the same research team's studies on the determination of CSFs differ regarding the countries they consider. In addition, different techniques of offsite construction tend to have different CSFs (Elnass *et al.*, 2014 and Xiahou *et al.*, 2018). In Turkish literature, critical success factor determination for the offsite construction was partly done by some study which had a focus on some specific techniques of offsite construction (Polat and Damcı, 2007). This results showed the gap in the literature, since the CSFs of offsite construction changes regarding the country and the techniques of it. This study aims to fill this gap and contribute to the literature.

### **3. METHODOLOGY**

This study aims to find the critical success factors of offsite construction in Turkey and determine a consistent ranking among them. The steps of this study are formed of:

- (i) Literature review,
- (ii) Focus group interviews,
- (iii) Questionnaire,
- (iv) Analytic Hierarchy Process (AHP)

#### **3.1. Literature Review**

A literature review was conducted, in order to understand the concept of Offsite Construction Method and determining its benefits and usage areas. In total, over fifty papers were reviewed related to the off-site construction. Through this literature review, similar terms such as OSM, OSP, OSF, IBS, Pre-assembly, Prefabrication, Prefab were taken into account. The modern method of construction was not included because it focuses on new techniques and technologies which can be applied both offsite and onsite. In order to determine CSFs from the literature, a systematic selection of the papers was processed. In order to determine the critical success factors, the first step was to determine papers by using the following keywords; offsite construction, OSM, OSP, IBS, pre-assembly, and prefab. The second step was to determine papers which involves the same terms with a focus on determining driving factors, enablers and barriers of them. The last step was to eliminate papers which were published more than years ago and had a very specific focus. The papers which do not comply with any of these criteria were eliminated. As a result, thirteen of these papers were selected and initial factors were gathered through these papers. The articles which were referred to in order to determine the critical success factors are listed in Table 3.1.

A list of factors was gathered by a literature review, which was affecting the offsite construction. The factor list obtained from the literature review had to be inspected because some factors had similar meanings while others were a subcomponent of other factors. In order to avoid falling into repetition, factors with the same meanings were reduced to a factor that conveys the information of all its subfactors. Frequency of each factor was considered for validation. Factors with only one frequency in the literature review were eliminated.

Table 3.1. Paper research for critical success factor determining.

| No | Title                                                                                                               | Author                 | Year |
|----|---------------------------------------------------------------------------------------------------------------------|------------------------|------|
| 1  | Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization                             | O'Connor <i>et al.</i> | 2014 |
| 2  | Critical Success Factors for Project Planning and Control in Prefabrication Housing Production: A China Study       | Li <i>et al.</i>       | 2018 |
| 3  | Drivers, Constraints, and Future of Offsite Manufacture in Australia.                                               | Blismas <i>et al.</i>  | 2008 |
| 4  | Perspectives of UK Housebuilders on the Use of Offsite Modern Methods of Construction                               | Pan <i>et al.</i>      | 2007 |
| 5  | Re-engineering Through Preassembly: Client Expectations and Drivers                                                 | Gibb <i>et al.</i>     | 2003 |
| 6  | Future Opportunities for Offsite in the UK.                                                                         | Goodier <i>et al.</i>  | 2007 |
| 7  | Offsite Production in the UK: The Way Forward? A UK Construction Industry Perspective                               | Nadim <i>et al.</i>    | 2009 |
| 8  | Factors and Drivers Affecting the Decision of Using Off-Site Manufacturing (OSM) Systems in House Building Industry | Elnass <i>et al.</i>   | 2014 |
| 9  | The Critical Success Factors (CSFs) to the Implementation of Industrialized Building System (IBS) in Malaysia.      | Kamar <i>et al.</i>    | 2010 |
| 10 | Exploring the Driving Factors of Construction Industrialization Development in China                                | Xiahou <i>et al.</i>   | 2018 |
| 11 | Critical Sustainability Factors in Industrialized Building Systems                                                  | Yunus <i>et al.</i>    | 2012 |
| 12 | Management Factors for Successful IBS Projects Implementation                                                       | Ismail <i>et al.</i>   | 2012 |
| 13 | Constraints to the Use of Offsite Production on Construction Projects.                                              | Blismas <i>et al.</i>  | 2005 |

### 3.2. Focus Group Interviews

Focus group were formed in order to evaluate factors determined from the literature review. Collected factors from the literature were investigated the offsite construction from every different point of view so they were not necessarily mean to be critical success factors. Focus group consists of experts with different areas of the construction industry in order to have a broader perspective.

Interviews with focus group members were held separately. Each focus group member was interviewed face to face. All of the interviews lasted around one and a half hours. Due to the different backgrounds of the experts, these interviews were able to address all the aspects of the construction industry. Through brainstorming and interviews on the factors listed by the literature review, the final critical success factors are determined. These critical success factors were used in the questionnaire to collect data. The information about the focus group is provided in Table 3.2.

Table 3.2. Focus group information.

| <b>No</b> | <b>Profession</b>    | <b>Experience</b> |
|-----------|----------------------|-------------------|
| 1         | Academician          | 11 years          |
| 2         | Business Development | 18 years          |
| 3         | Project Management   | 10 years          |
| 4         | Manufacturer         | 13 years          |

### 3.3. Questionnaire

Focus group determined the critical success factors and a questionnaire survey was formed. The aim of this questionnaire survey was finding the ranking of the critical success factors by using the Analytic Hierarchy Process (AHP). AHP process is described in detail in the next chapter.

The questionnaire was distributed by e-mail to 138 professionals from the construction market. Mainly professionals found through INDER (İnşaatçılar Derneği) which is an association founded in 1967 and have over 60 developers under its roof. The questionnaire was responded by 42 experts. The response rate of answers was 30,4%. Experts with less than 5 years of experience formed only 22,5% of the total responders. The majority of experts had experienced between 15 – 20 years. Level of experience of responders is presented in Table 3.4. It was aimed to gather answers from experts with different professions in order to prevent any bias that may arise relative to the profession. Among the responders, experts from technical office, company owners and field operations are almost the same in number. The number of experts according to their profession is listed in Table 3.3. This indicates there is no majority of any profession so it will not affect the overall results obtained from the questionnaire. The consistency level of each answer was checked according to their consistency levels by the tools of AHP. Answers with inconsistency level greater than 10% are excluded.

Table 3.3. Professions of experts.

| <b>Experience</b>    | <b>Number of Experts</b> | <b>Percentage (%)</b> |
|----------------------|--------------------------|-----------------------|
| Technical Office     | 12                       | 30,0                  |
| Company Owner        | 10                       | 25,0                  |
| Field - Operation    | 9                        | 22,5                  |
| Business Development | 3                        | 7,5                   |
| Procurement          | 3                        | 7,5                   |
| Design               | 1                        | 2,5                   |
| Management           | 1                        | 2,5                   |
| Academic             | 1                        | 2,5                   |

Table 3.4. Experience of experts.

| <b>Experience</b> | <b>Number of Experts</b> | <b>Percentage</b> |
|-------------------|--------------------------|-------------------|
| Less than 5 years | 9                        | 22,5%             |
| 5 – 10 years      | 13                       | 32,5%             |
| 10 – 15 years     | 1                        | 2,5%              |
| 15 – 20 years     | 16                       | 40,0%             |
| +20 years         | 1                        | 2,5%              |

### **3.4. Analytical Hierarchy Process (AHP)**

AHP was introduced to literature by Thomas Saaty in 1980. It was designed to compare interchangeable elements efficiently and determine their importance by pairwise comparison. Following attributes of AHP makes it suitable for the purpose of this study (Saaty, 1988): measuring priorities and choosing among different alternatives, measuring the consistency of the acquired answers.

The power of AHP could be traced from the other relative literature studies. The review of 232 different papers published between 2005 and 2009 was examined (Sipahi and Timor, 2010). This review investigated the studies regarding their methodologies. The frequency of the methods used in the literature is listed in Table 3.5 (Sipahi and Timor, 2010). Among 232 papers, AHP was used in 169 papers where the nearest alternative is Fuzzy AHP which was used only in 42 papers. Shortly, Sipahi and Timor showed that AHP is used more frequently than Fuzzy AHP, ANP, Fuzzy ANP. Since the dependency between the determined CSFs is absent or negligible, AHP is also applied in this study.

Table 3.5. Literature review of usage frequencies for decision-making tools (Sipahi and Timor, 2010).

| Area                                     | AHP | ANP | AHP & ANP | Fuzzy AHP | Fuzzy ANP | Fuzzy AHP & ANP | Total |
|------------------------------------------|-----|-----|-----------|-----------|-----------|-----------------|-------|
| Manufacturing Industry                   | 45  | 2   | 4         | 23        | 1         | 1               | 76    |
| Environmental Management and Agriculture | 24  | -   | 1         | 1         | -         | -               | 26    |
| General Decision Problems                | 12  | 2   | 1         | 3         | 1         | -               | 19    |
| Power and Energy Industry                | 14  | -   | -         | 1         | -         | -               | 15    |
| Transportation Industry                  | 12  | 1   | -         | 2         | -         | -               | 15    |
| Construction Industry                    | 8   | 1   | 1         | 1         | -         | -               | 11    |
| Health                                   | 10  | -   | -         | -         | -         | -               | 10    |
| Others                                   | 44  | 3   | 2         | 11        | -         | -               | 60    |
| Total                                    | 169 | 9   | 9         | 42        | 2         | 1               | 232   |

(i) Pairwise comparison of elements

AHP is based on the pairwise comparison. Binary combinations of elements and their performance relative to each other are determined. Thomas Saaty used a linear scale for the AHP process which is provided in Table 3.6:

Table 3.6. Thomas Saaty's scale (Saaty, 1977).

| Intensity of Importance | Definition                              |
|-------------------------|-----------------------------------------|
| 1                       | Equal Importance                        |
| 3                       | Moderate importance of one over another |
| 5                       | Essential or strong importance          |
| 7                       | Demonstrated importance                 |
| 9                       | Absolute/Extreme importance             |
| 2,4,6,8                 | Intermediate values                     |

The intensity of importance used during the judgments varies from individual to individual. Some may consider ‘three times’ as extreme while some may consider ‘five times’ as extreme. AHP focuses on to collect answers on a standard scale by determining the magnitude itself. In fact, answers are collected qualitatively according to the definitions provided in Table 3.7. This property of AHP enables to use different scales for the intensity of importance while ranking the elements. (Hossain *et al.*, 2014).

Table 3.7. Aupetit & Genest’s scale (Aupetit and Genest, 1993).

| <b>Intensity of Importance</b> | <b>Definition</b>                       |
|--------------------------------|-----------------------------------------|
| 1                              | Equal Importance                        |
| 2                              | Moderate importance of one over another |
| 3                              | Essential or strong importance          |
| 4                              | Demonstrated importance                 |
| 5                              | Absolute/Extreme importance             |

Different scales of judgments were introduced to literature following studies of Saaty. Reducing the range of the linear scale to 1-5 was proposed by Aupetit and Genest (Aupetit and Genest, 1993). Likert scale AHP eliminates the intermediate values in order to obtain more consistent results. Using the Likert scale in order to conduct judgments does not affect the resulting ranks of elements. The Likert scale has an advantage with increased consistency by means of limiting the input of aberrant data (Hossain *et al.*, 2014). In this paper, the Likert scale used for determining the judgments.

#### (ii) Forming Judgment Matrix

Pairwise comparisons of elements are gathered in  $n \times n$  square matrix where  $n$  is the number of total elements evaluated. If an element “ $i$ ” has the intensity of importance “ $k$ ” compared to activity “ $j$ ”, then “ $j$ ” has the reciprocal value of importance “ $1/k$ ” compared to the element “ $i$ ”. The upper part of the judgment matrix becomes the reciprocal of the lower part of it. The diagonal of judgment matrix has the value of “1” since element “ $i$ ” compared

to itself has equal importance. Assuming there are four elements to be compared, then the judgment matrix will be as in Table 3.8.

Table 3.8. Judgment matrix assuming there are four elements to be compared.

|                               | <b>1<sup>st</sup><br/>Element</b> | <b>2<sup>nd</sup><br/>Element</b> | <b>3<sup>rd</sup><br/>Element</b> | <b>4<sup>th</sup><br/>Element</b> |
|-------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| <b>1<sup>st</sup> Element</b> | 1                                 | $k_{1,2}$                         | $k_{1,3}$                         | $k_{1,4}$                         |
| <b>2<sup>nd</sup> Element</b> | $k_{2,1}$                         | 1                                 | $k_{2,3}$                         | $k_{2,4}$                         |
| <b>3<sup>rd</sup> Element</b> | $k_{3,1}$                         | $k_{3,2}$                         | 1                                 | $k_{3,4}$                         |
| <b>4<sup>th</sup> Element</b> | $k_{4,1}$                         | $k_{4,2}$                         | $k_{4,3}$                         | 1                                 |

(iii) Summation of Every Column in Matrix

In this step, all columns of the matrix summed up individually like Table 3.9.

Table 3.9. Judgment matrix with the summation of columns.

|                               | <b>1<sup>st</sup><br/>Element</b> | <b>2<sup>nd</sup><br/>Element</b> | <b>3<sup>rd</sup><br/>Element</b> | <b>4<sup>th</sup><br/>Element</b> |
|-------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| <b>1<sup>st</sup> Element</b> | 1                                 | $k_{1,2}$                         | $k_{1,3}$                         | $k_{1,4}$                         |
| <b>2<sup>nd</sup> Element</b> | $k_{2,1}$                         | 1                                 | $k_{2,3}$                         | $k_{2,4}$                         |
| <b>3<sup>rd</sup> Element</b> | $k_{3,1}$                         | $k_{3,2}$                         | 1                                 | $k_{3,4}$                         |
| <b>4<sup>th</sup> Element</b> | $k_{4,1}$                         | $k_{4,2}$                         | $k_{4,3}$                         | 1                                 |
| <b>Summation</b>              | $\sum(\text{column 1})$           | $\sum(\text{column 2})$           | $\sum(\text{column 3})$           | $\sum(\text{column 4})$           |

(iv) Normalizing the Judgment Matrix

In this step, the judgment matrix is normalized by dividing the columns of the matrix by summation of columns. Example of it provided in Table 3.10.

Table 3.10. Normalized judgment matrix.

|                               | <b>1<sup>st</sup> Element</b>    | <b>2<sup>nd</sup> Element</b>    | <b>3<sup>rd</sup> Element</b>    | <b>4<sup>th</sup> Element</b>    |
|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| <b>1<sup>st</sup> Element</b> | $1/\sum(\text{column } 1)$       | $k_{1,2}/\sum(\text{column } 2)$ | $k_{1,3}/\sum(\text{column } 3)$ | $k_{1,4}/\sum(\text{column } 4)$ |
| <b>2<sup>nd</sup> Element</b> | $k_{2,1}/\sum(\text{column } 1)$ | $1/\sum(\text{column } 2)$       | $k_{2,3}/\sum(\text{column } 3)$ | $k_{2,4}/\sum(\text{column } 4)$ |
| <b>3<sup>rd</sup> Element</b> | $k_{3,1}/\sum(\text{column } 1)$ | $k_{3,2}/\sum(\text{column } 2)$ | $1/\sum(\text{column } 3)$       | $k_{3,4}/\sum(\text{column } 4)$ |
| <b>4<sup>th</sup> Element</b> | $k_{4,1}/\sum(\text{column } 1)$ | $k_{4,2}/\sum(\text{column } 2)$ | $k_{4,3}/\sum(\text{column } 3)$ | $1/\sum(\text{column } 4)$       |
| <b>Summation</b>              | 1                                | 1                                | 1                                | 1                                |

## (v) Finding the Weights of Elements

Weights of the elements are determined by calculating the means for rows of the normalized judgment matrix (Table 3.11).

Table 3.11. Normalized judgment matrix with weights calculated.

|                               | <b>1<sup>st</sup> Element</b>    | <b>2<sup>nd</sup> Element</b>    | <b>3<sup>rd</sup> Element</b>    | <b>4<sup>th</sup> Element</b>    | <b>Element Weights</b> |
|-------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------|
| <b>1<sup>st</sup> Element</b> | $1/\sum(\text{column } 1)$       | $k_{1,2}/\sum(\text{column } 2)$ | $k_{1,3}/\sum(\text{column } 3)$ | $k_{1,4}/\sum(\text{column } 4)$ | <b>Mean_1</b>          |
| <b>2<sup>nd</sup> Element</b> | $k_{2,1}/\sum(\text{column } 1)$ | $1/\sum(\text{column } 2)$       | $k_{2,3}/\sum(\text{column } 3)$ | $k_{2,4}/\sum(\text{column } 4)$ | <b>Mean_2</b>          |
| <b>3<sup>rd</sup> Element</b> | $k_{3,1}/\sum(\text{column } 1)$ | $k_{3,2}/\sum(\text{column } 2)$ | $1/\sum(\text{column } 3)$       | $k_{3,4}/\sum(\text{column } 4)$ | <b>Mean_3</b>          |
| <b>4<sup>th</sup> Element</b> | $k_{4,1}/\sum(\text{column } 1)$ | $k_{4,2}/\sum(\text{column } 2)$ | $k_{4,3}/\sum(\text{column } 3)$ | $1/\sum(\text{column } 4)$       | <b>Mean_4</b>          |
| <b>Summation</b>              | 1                                | 1                                | 1                                | 1                                |                        |

## (vi) Checking Consistency of the Ranking.

Rankings of elements found according to the weights of the judgment matrix should be checked in terms of consistency. In order to calculate the consistency of answers, as a first step the  $\lambda_{max}$  (the highest eigenvalue of the matrix) has to be calculated (Saaty, 1977):

$$\lambda_{max} = \sum_{j=1}^m \frac{(S.v)_j}{m.v_j}, \quad (3.1)$$

where;  $m$  is a number of independent rows of the matrix,  $S$  is pair-wise comparison matrix (judgment matrix), and  $v$  is matrix eigenvector.

Then the consistency index ( $CI$ ) can be calculated as:

$$CI = \frac{\lambda_{max} - m}{m - 1}, \quad (3.2)$$

$CI=0$  means the matrix is perfectly consistent. Saaty suggested readjustment for consistency check by introducing the consistency ratio ( $CR$ ) which can be calculated as (Saaty, 1980):

$$CR = CI / RI, \quad (3.3)$$

where random consistency index ( $RI$ ) values are calculated as average  $CI$  values that Saaty obtained from a random simulation of pair-wise comparison matrices. Saaty suggested the calculated values of  $CR$  should not be higher than 0,1 which corresponds to 10%. (Saaty, 1980). The  $RI$  values used for calculating  $CR$  are provided in Table 3.12.

Table 3.12. Random consistency index values (Saaty, 1980).

| Matrix size | Random consistency index (RI) |
|-------------|-------------------------------|
| 1           | 0,00                          |
| 2           | 0,00                          |
| 3           | 0,58                          |
| 4           | 0,90                          |
| 5           | 1,12                          |
| 6           | 1,24                          |
| 7           | 1,32                          |
| 8           | 1,41                          |
| 9           | 1,45                          |
| 10          | 1,49                          |

AHP is a powerful method yet it has some limitations. It is based on pairwise comparison techniques which require the user to ask experts for  $(n(n-1)/2)$  questions for comparing all elements of research where  $n$  is the number of elements compared. The increasing number of elements results in failure of experts to consistently assign weights to pairs and AHP turns into trial and error method. (Macharis *et al.*, 2004). In this study, the number of critical factors determined was 14. In order to apply AHP to these factors at once, experts needed to consistently conduct 91 pair-wise comparisons. It would be too much time-consuming and decrease the participation ratio to the research. Also, the vast amount of comparison would cause to experts to lose track of the weights they assigned previously and result in losing their consistency.

This limitation of AHP avoided by applying it in two phases. In the first phase, the factors are grouped according to their relevance. Five groups are determined for critical success factors. Weight of these groups are calculated by applying AHP on them ( $w_g$ ). In the second phase, factors located in the groups are considered for AHP. Local weights of factors determined by applying AHP within groups ( $w_f$ ). In order to obtain the global weight of the factors  $\{W(g,f)\}$ , local weights of factors are multiplied with corresponding group weights which can be stated as:

$$W(g,f) = w_g * w_f \quad (3.4)$$

Applying AHP in two-phase, increased the consistency of the pairwise comparison. At total, 24 pairwise comparisons were required to be conducted by experts in order to fully compare all of the critical factors are listed.

According to the methodology applied in this paper, factors were determined through literature review. Factors with similar meanings were combined to represent a single factor. These factors further eliminated through focus group study and they were grouped according to the focus group suggestions. As a result, initially determined 74 factors were reduced to 14 factors which were gathered in five groups. This process decreased the interrelations between factors to a minimum level. The negligible level of interrelations enabled for the use of AHP instead of ANP.

## 4. RESULTS AND FINDINGS

### 4.1. Literature Review

Through literature review, 74 factors were determined. The initial list of factors is shown in Table A.1 including their frequency of appearance through researched papers and their sources. This initial list had some factors with very similar meanings. Factors with very similar meanings were combined together in order to avoid repetitive factors. Combination of factors with similar meanings also decreased the dependency among factors. As a result of this process, the number of factors decreased from 74 to 48. Combined factors with their original factor names are provided in Table 4.1.

Table 4.1. Combined factors with original factor names.

| Combined No | Original Factor Name                                          | Combined Factor Name                 | Frequency |
|-------------|---------------------------------------------------------------|--------------------------------------|-----------|
| 1           | Cost Savings Recognition                                      | Cost Savings                         | 10        |
|             | Lower Preliminary Costs                                       |                                      |           |
|             | Reduced Whole Life Cost                                       |                                      |           |
|             | Minimizing non Construction Cost                              |                                      |           |
|             | Reduced Labor Cost                                            |                                      |           |
|             | Less Material Consumption                                     |                                      |           |
| 2           | Recognizing the Quality Increase                              | Quality Increase                     | 10        |
|             | Reduced Snagging & Defects                                    |                                      |           |
| 3           | OH&S Risks Reduction                                          | OH&S Risks Reduction                 | 9         |
| 4           | Skills and Knowledge of Labors                                | Skilled Labor Availability           | 9         |
|             | Labor Availability                                            |                                      |           |
| 5           | Owner's Planning Resources & Process                          | Owner's Planning Resources & Process | 8         |
| 6           | Reduced Environmental Damage During Construction              | Reduced Environmental Damage         | 8         |
|             | Maximizing Environmental Performance Throughout the Lifecycle |                                      |           |

Table 4.1. Combined factors with original factor names (cont.).

| Combined No | Original Factor Name                                         | Combined Factor Name                           | Frequency |
|-------------|--------------------------------------------------------------|------------------------------------------------|-----------|
|             | Easier Waste Disposal                                        |                                                |           |
| 7           | Early Completion Recognitions                                | Shorter Total Project Time                     | 7         |
|             | Less Time on Site                                            |                                                |           |
| 8           | Productivity                                                 | Productivity                                   | 5         |
| 9           | Good Working Collaboration                                   | Government Regulations and Initiatives         | 5         |
|             | Continuing Improvement and Learning                          |                                                |           |
|             | Improvement in Procurement Strategy and Contracting          |                                                |           |
|             | Persistent Policies and Incentives                           |                                                |           |
| 10          | Ensuring Time Certainty                                      | Ensuring Time Certainty                        | 4         |
| 11          | Timely Design Completion                                     | Timely Design Completion                       | 4         |
|             | Team Members Involved During the Design Stage                |                                                |           |
|             | Early Involvement of All Parties                             |                                                |           |
| 12          | Contractor Leadership                                        | Contractor Leadership & Experience             | 4         |
|             | Contractor Experience                                        |                                                |           |
|             | Project Manager's Ability to Solve Problems                  |                                                |           |
|             | Project Manager's Attitude Towards Planning and Control      |                                                |           |
| 13          | Ensuring Cost Certainty                                      | Ensuring Cost Certainty                        | 3         |
| 14          | Operations and Maintenance (O&M) Provisions                  | Operations and Maintenance (O&M) Provisions    | 3         |
| 15          | Effective Communication Among Participants                   | Effective Information Sharing                  | 3         |
|             | Information Sharing Among Participants                       |                                                |           |
| 16          | The Maturity of Techniques Used in the Detailed Design Phase | The Maturity of Techniques & Technologies Used | 3         |
|             | Use of the ICT, BIM, ERP, RFID Technologies                  |                                                |           |
| 17          | Assembly Planning Method                                     | Assembly Planning Method                       | 2         |
| 18          | Good Working Collaboration                                   | Good Working Collaboration                     | 2         |
| 19          | Management of Execution Risks                                | Management of Execution Risks                  | 2         |
| 20          | Preliminary Module Definition                                | Preliminary Module Definition                  | 2         |
|             | Module Envelope Limitations                                  |                                                |           |

Table 4.1. Combined factors with original factor names (cont.).

| <b>Combined No</b> | <b>Original Factor Name</b>                                                       | <b>Combined Factor Name</b>                                                       | <b>Frequency</b> |
|--------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------|
| 21                 | Industry Marketing Collaboration                                                  | Integration of the Supply Chain                                                   | 2                |
|                    | Integration of the Supply Chain                                                   |                                                                                   |                  |
| 22                 | Module Fabricator Capability                                                      | Sufficiency of Manufacturers and Suppliers of Prefabricated Components            | 2                |
|                    | Sufficiency of Manufacturers and Suppliers of Prefabricated Components            |                                                                                   |                  |
| 23                 | Top-Down Commitment and Corporate Motivation                                      | Top-Down Commitment and Corporate Motivation                                      | 2                |
| 24                 | Increased Component Life                                                          | Increased Component Life                                                          | 2                |
| 25                 | Process Standardization and More Effective Use on the Concept of Repetition       | Process Standardization and More Effective Use on the Concept of Repetition       | 2                |
| 26                 | Designers' Experience                                                             | Designers' Experience                                                             | 2                |
| 27                 | Strategy and Business Approach                                                    | Strategy and Business Approach                                                    | 1                |
| 28                 | Allows Systems to be Measured                                                     | Allows Systems to be Measured                                                     | 1                |
| 29                 | Data for Optimization                                                             | Data for Optimization                                                             | 1                |
| 30                 | Owner Delay Avoidance                                                             | Owner Delay Avoidance                                                             | 1                |
| 31                 | Continuity Through Project Phases                                                 | Continuity Through Project Phases                                                 | 1                |
| 32                 | Transport Delay Avoidance                                                         | Transport Delay Avoidance                                                         | 1                |
| 33                 | Program Driven Centrally                                                          | Program Driven Centrally                                                          | 1                |
| 34                 | Management Improvement                                                            | Management Improvement                                                            | 1                |
| 35                 | Greater Customization Options                                                     | Greater Customization Options                                                     | 1                |
| 36                 | Achieving Predictability of Quality                                               | Achieving Predictability of Quality                                               | 1                |
| 37                 | Achieving the Performance Predictability Throughout the Lifecycle of the Facility | Achieving the Performance Predictability Throughout the Lifecycle of the Facility | 1                |
| 38                 | Well Developed Specifications and Regulations                                     | Well Developed Specifications and Regulations                                     | 1                |
| 39                 | Sustainability Request by the Local Government                                    | Sustainability Request by the Local Government                                    | 1                |
| 40                 | Difficulty to Obtain Planning Permission by the Local Government                  | Difficulty to Obtain Planning Permission by the Local Government                  | 1                |

Table 4.1. Combined factors with original factor names (cont.).

| <b>Combined No</b> | <b>Original Factor Name</b>            | <b>Combined Factor Name</b>            | <b>Frequency</b> |
|--------------------|----------------------------------------|----------------------------------------|------------------|
| 41                 | Heavy Lift/Site Transport Capabilities | Heavy Lift/Site Transport Capabilities | 1                |
| 42                 | Transport Infrastructure               | Transport Infrastructure               | 1                |
| 43                 | Restricted Site Specifics              | Restricted Site Specifics              | 1                |
| 44                 | Simplifies Construction Process        | Simplifies Construction Process        | 1                |
| 45                 | Shortage of Resources                  | Shortage of Resources                  | 1                |
| 46                 | Investment in Studies                  | Investment in Studies                  | 1                |
| 47                 | People and Work Conditions             | People and Work Conditions             | 1                |
| 48                 | Continuing Improvement and Learning    | Continuing Improvement and Learning    | 1                |

Frequencies of each factor were considered for the validation of the literature review. If any factor does not appear on at least two different papers, then it was omitted from the list. Factors remaining after the elimination process according to their frequency are listed in Table 4.2.

Table 4.2. Factors remaining after elimination according to their frequency.

| <b>Combined Factor No</b> | <b>Original Factor No</b> | <b>Combined Factor Name</b>            |
|---------------------------|---------------------------|----------------------------------------|
| 1                         | 7,48,52,58,68,71          | Cost Savings                           |
| 2                         | 25,49                     | Quality Increase                       |
| 3                         | 38                        | OH&S Risks Reduction                   |
| 4                         | 27,70                     | Skilled Labor Availability             |
| 5                         | 3                         | Owner's Planning Resources & Process   |
| 6                         | 37,61,69                  | Reduced Environmental Damage           |
| 7                         | 5,44                      | Shorter Total Project Time             |
| 8                         | 36                        | Productivity                           |
| 9                         | 42,43,67,22               | Government Regulations and Initiatives |
| 10                        | 40                        | Ensuring Time Certainty                |
| 11                        | 4,75,2                    | Timely Design Completion               |
| 12                        | 8,9,28,30                 | Contractor Leadership & Experience     |
| 13                        | 39                        | Ensuring Cost Certainty                |

Table 4.2. Factors remaining after elimination according to their frequency (cont.).

| <b>Combined Factor No</b> | <b>Original Factor No</b> | <b>Combined Factor Name</b>                                                 |
|---------------------------|---------------------------|-----------------------------------------------------------------------------|
| 14                        | 13                        | Operations and Maintenance (O&M) Provisions                                 |
| 15                        | 29,31                     | Effective Information Sharing                                               |
| 16                        | 32,33                     | The Maturity of Techniques & Technologies Used                              |
| 17                        | 34                        | Assembly Planning Method                                                    |
| 18                        | 53                        | Good Working Collaboration                                                  |
| 19                        | 18                        | Management of Execution Risks                                               |
| 20                        | 1,6                       | Preliminary Module Definition                                               |
| 21                        | 73,66                     | Integration of the Supply Chain                                             |
| 22                        | 10,26                     | Sufficiency of Manufacturers and Suppliers of Prefabricated Components      |
| 23                        | 57                        | Top-Down Commitment and Corporate Motivation                                |
| 24                        | 50                        | Increased Component Life                                                    |
| 25                        | 56                        | Process Standardization and More Effective Use on the Concept of Repetition |
| 26                        | 20                        | Designers' Experience                                                       |

#### **4.2. Focus Group Study**

Combined factor list includes factors related with offsite construction method. However, they were not necessarily critical success factors. A focus group was formed in order to determine critical factors among the combined factor list. This focus group consists of an academician and three industry experts specializing in business development, site management and manufacturing. The variety of professions were considered in order to prevent any bias related to the profession.

Focus group study was conducted in individual meetings which lasted between 1,5 to 2 hours each. During these meetings, all factors were examined separately. Comments on the factors were noted down and each factor criticized. As a result of this focus group study, it was determined that some of the listed factors were actually regarding the benefits of the offsite construction method. After the elimination, a total of 14 factors left (Table 4.3).

Table 4.3. Critical success factors with their groups.

| Group      | No | Factor Name                                                            |
|------------|----|------------------------------------------------------------------------|
| Regulatory | 1  | Government Promotion                                                   |
|            | 2  | Supporting Policies & Legislations                                     |
|            | 3  | Revisions to Building Regulations                                      |
| Technical  | 4  | Timely Design Completion                                               |
|            | 5  | Assembly Planning Method                                               |
|            | 6  | Preliminary Module Definition                                          |
|            | 7  | Designers' Experience                                                  |
| Process    | 8  | Effective Information Sharing                                          |
|            | 9  | The Maturity of Techniques & Technologies Used                         |
| Resources  | 10 | Integration of the Supply Chain                                        |
|            | 11 | Sufficiency of Manufacturers and Suppliers of Prefabricated Components |
|            | 12 | Skilled Labor Availability                                             |
| Leadership | 13 | Contractor Leadership & Experience                                     |
|            | 14 | Project Managers Ability to Solve Problems                             |

These 14 factors were grouped. In order to specify group names and their contents, the literature review was used. Among the already selected papers, two of them were identified as the most suitable to be used. As a result; technical, process, regulatory and resources groups were taken from one study (Elnass *et al.*, 2014) while the leadership group was obtained from another study (Kamar *et al.*, 2009). Critical success factors with their groups are listed in Table 4.3.

### 4.3. Questionnaire Survey

The questionnaire is comprised of four major parts:

- Part 1: demographic information of experts.
- Part 2: pairwise comparison of critical success factor groups.

- Part 3: pairwise comparison of critical success factors within their groups.
- Part 4: the additional comments or suggestion by the respondents.

The questionnaire survey was prepared as an online form and responded by 42 professionals. Answers were collected and saved separately in order to analyze them with AHP. The questionnaire was formed of 10 pair-wise comparisons for determining rankings of factor groups. Additional 14 pair-wise comparisons were prepared in order to determine the ranks of factors among groups. Two of the experts incorrectly filled out the questionnaire so their answers were eliminated.

#### 4.4. Analytic Hierarchy Process (AHP)

AHP template, which was developed by Klaus, D. G., was used for analyzing data (Klaus, 2013). Pairwise comparison judgments of experts were inserted in this template for obtaining weights and consistency ratios according to the AHP method.

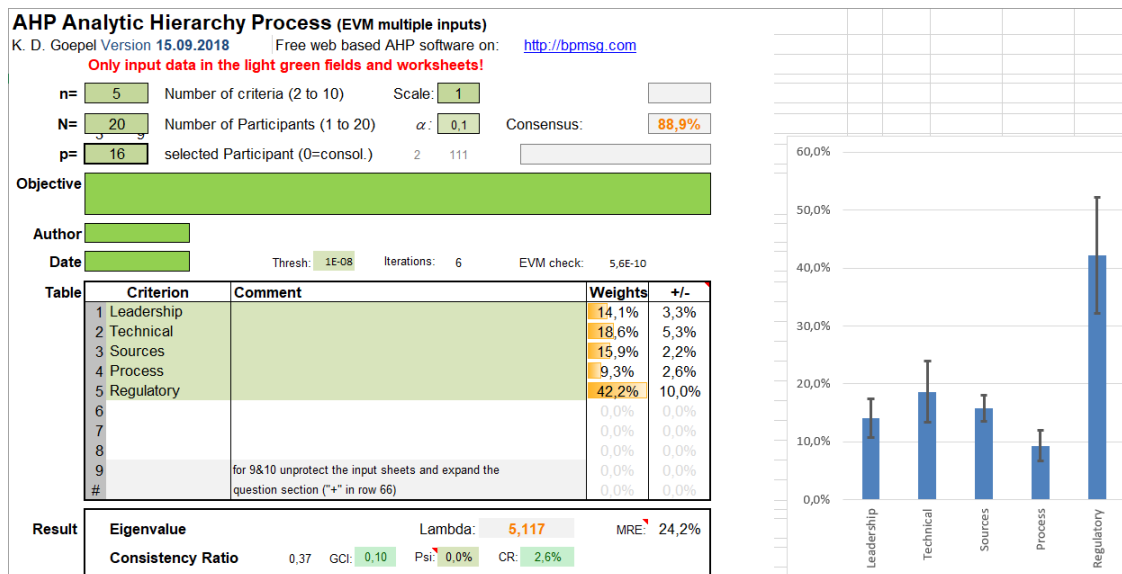


Figure 4.1. AHP Template Interface (Klaus, 2013).

Performing AHP in two-phase was resulted in forming a total of six different AHP comparisons which are listed in Table 4.4.

Table 4.4. AHP comparison groups.

| No | Comparison Group            | Number of Elements | Number of Comparisons | Consistency Check |
|----|-----------------------------|--------------------|-----------------------|-------------------|
| A  | Factor Groups               | 5                  | 10                    | Required          |
| B  | Factors of Technical Group  | 4                  | 6                     | Required          |
| C  | Factors of Resources Group  | 3                  | 3                     | Required          |
| D  | Factors of Regulatory Group | 3                  | 3                     | Required          |
| E  | Factors of Leadership Group | 2                  | 1                     | Not Applicable    |
| F  | Factors of Process Group    | 2                  | 1                     | Not Applicable    |

In order to use the weights which were obtained from the AHP method, consistency ratios of the answers were calculated. Acknowledged inconsistency level of answers for AHP was 10% at maximum (Saaty, 1980). Answers with greater inconsistency than 10% were omitted from the study.

In this study, pairwise comparison answers were obtained through mailing. The pairwise comparison matrices are provided in Table B.1 - Table B.6. An example draft of the questionnaire is provided in Appendix C. Rather than revising the inconsistent answers through the mail, the number of experts who participated to this questionnaire was increased in order to have enough consistent pairwise comparison data to be used.

Consistency ratios of answers were calculated for pairwise comparisons of A, B, C and D. Consistency check for pairwise comparisons of E and F were not applicable since those group had only two factors. If answers of an expert were failed to pass any of four consistency checks, answers those obtained from him/her were omitted completely. Consistency ratios of answers, which were gathered from experts, are provided in Table D.1. As a result of the consistency check, 12 answers were omitted and 28 valid answers left. Consistent answers were determined and they were used as data.

Factor groups' weights are presented in Table 4.5. According to valid responses of experts, leadership (0.232) was selected to be the most important CSF group with only two factors involved in it. Technical group (0.231) was selected to be the second most important factor group involving four factors. Since leadership and technical groups achieved the almost same amount of significance with one them involving two times more factors in it, a practical calculation shows that individual significance of average impact level of leadership factors would be double time more relative to the average of technical group factors. Resources group (0.199) was determined to be the third most significant factor group involving three factors in it. Regulatory group (0.171) and process group (0.167) were the last two important factor groups among these five with having three and two factors in them respectively.

After groups of factors were compared with the AHP method, factors within groups were considered for pairwise comparison. Results of the pairwise comparison of factors, which form the technical group, were provided in Table 4.6. This group was formed of four factors, therefore, the average importance level of these factors was calculated as (0.057) regarding its group importance level. In this group, the most significant factor was determined as the designers' experience (0.309). Timely design completion (0.269) was determined as the second most important factor within the group. Assembly planning method (0.230) was determined as the third most important factor while preliminary module definition (0.193) was considered to be the least important factor in the group.

Resources group's factors were almost equally weighted. This group consisted of three factors so the factors involving this group had a higher average (0.066) in the global perspective. Among the factor group, skilled labor availability's weight (0.355) was determined to be a little higher than weights of the sufficiency of manufacturers and suppliers (0.324) and integration of the supply and chain (0.321) factors. Process group pairwise comparison results are provided in Table 4.7.

Table 4.5. Calculated weights for groups.

| <b>Expert</b>                                     | <b>Leadership</b> | <b>Technical</b> | <b>Resources</b> | <b>Process</b> | <b>Regulatory</b> |
|---------------------------------------------------|-------------------|------------------|------------------|----------------|-------------------|
| 1                                                 | 0.322             | 0.245            | 0.185            | 0.107          | 0.141             |
| 2                                                 | 0.270             | 0.270            | 0.142            | 0.194          | 0.124             |
| 3                                                 | 0.213             | 0.213            | 0.123            | 0.123          | 0.328             |
| 4                                                 | 0.266             | 0.266            | 0.215            | 0.163          | 0.090             |
| 5                                                 | 0.355             | 0.114            | 0.195            | 0.085          | 0.251             |
| 6                                                 | 0.225             | 0.198            | 0.146            | 0.167          | 0.264             |
| 7                                                 | 0.227             | 0.227            | 0.197            | 0.197          | 0.152             |
| 8                                                 | 0.121             | 0.286            | 0.230            | 0.220          | 0.143             |
| 9                                                 | 0.245             | 0.322            | 0.141            | 0.185          | 0.107             |
| 10                                                | 0.130             | 0.320            | 0.180            | 0.106          | 0.264             |
| 11                                                | 0.150             | 0.275            | 0.275            | 0.150          | 0.150             |
| 12                                                | 0.319             | 0.275            | 0.181            | 0.128          | 0.097             |
| 13                                                | 0.318             | 0.194            | 0.144            | 0.191          | 0.153             |
| 14                                                | 0.155             | 0.267            | 0.188            | 0.145          | 0.245             |
| 15                                                | 0.313             | 0.133            | 0.166            | 0.166          | 0.222             |
| 16                                                | 0.190             | 0.293            | 0.109            | 0.190          | 0.218             |
| 17                                                | 0.223             | 0.191            | 0.332            | 0.180          | 0.074             |
| 18                                                | 0.264             | 0.228            | 0.192            | 0.145          | 0.171             |
| 19                                                | 0.185             | 0.221            | 0.121            | 0.231          | 0.242             |
| 20                                                | 0.345             | 0.173            | 0.179            | 0.157          | 0.146             |
| 21                                                | 0.167             | 0.274            | 0.244            | 0.218          | 0.097             |
| 22                                                | 0.170             | 0.182            | 0.375            | 0.113          | 0.160             |
| 23                                                | 0.178             | 0.165            | 0.350            | 0.182          | 0.125             |
| 24                                                | 0.264             | 0.201            | 0.168            | 0.174          | 0.193             |
| 25                                                | 0.274             | 0.249            | 0.128            | 0.274          | 0.075             |
| 26                                                | 0.264             | 0.197            | 0.197            | 0.171          | 0.171             |
| 27                                                | 0.200             | 0.200            | 0.200            | 0.200          | 0.200             |
| 28                                                | 0.143             | 0.280            | 0.280            | 0.108          | 0.189             |
| <b><i>Mean Overall<br/>Normalized Weights</i></b> | 0.232             | 0.231            | 0.199            | 0.167          | 0.171             |

Table 4.6. Calculated weights for technical group factors.

| <b>Expert</b>                                | <b>Timely Design<br/>Completion</b> | <b>Assembly<br/>Planning<br/>Method</b> | <b>Preliminary<br/>Module<br/>Definition</b> | <b>Designers'<br/>Experience</b> |
|----------------------------------------------|-------------------------------------|-----------------------------------------|----------------------------------------------|----------------------------------|
| 1                                            | 0.391                               | 0.195                                   | 0.138                                        | 0.276                            |
| 2                                            | 0.340                               | 0.239                                   | 0.140                                        | 0.281                            |
| 3                                            | 0.198                               | 0.239                                   | 0.168                                        | 0.395                            |
| 4                                            | 0.298                               | 0.246                                   | 0.210                                        | 0.246                            |
| 5                                            | 0.250                               | 0.250                                   | 0.250                                        | 0.250                            |
| 6                                            | 0.276                               | 0.195                                   | 0.138                                        | 0.391                            |
| 7                                            | 0.288                               | 0.330                                   | 0.175                                        | 0.207                            |
| 8                                            | 0.257                               | 0.257                                   | 0.229                                        | 0.257                            |
| 9                                            | 0.140                               | 0.200                                   | 0.165                                        | 0.495                            |
| 10                                           | 0.305                               | 0.158                                   | 0.146                                        | 0.391                            |
| 11                                           | 0.198                               | 0.239                                   | 0.168                                        | 0.395                            |
| 12                                           | 0.299                               | 0.124                                   | 0.188                                        | 0.389                            |
| 13                                           | 0.253                               | 0.209                                   | 0.239                                        | 0.299                            |
| 14                                           | 0.338                               | 0.288                                   | 0.169                                        | 0.205                            |
| 15                                           | 0.247                               | 0.175                                   | 0.289                                        | 0.289                            |
| 16                                           | 0.246                               | 0.246                                   | 0.210                                        | 0.298                            |
| 17                                           | 0.250                               | 0.250                                   | 0.250                                        | 0.250                            |
| 18                                           | 0.204                               | 0.204                                   | 0.246                                        | 0.346                            |
| 19                                           | 0.198                               | 0.248                                   | 0.209                                        | 0.345                            |
| 20                                           | 0.305                               | 0.113                                   | 0.277                                        | 0.305                            |
| 21                                           | 0.140                               | 0.330                                   | 0.200                                        | 0.330                            |
| 22                                           | 0.340                               | 0.239                                   | 0.140                                        | 0.281                            |
| 23                                           | 0.246                               | 0.189                                   | 0.135                                        | 0.430                            |
| 24                                           | 0.288                               | 0.205                                   | 0.169                                        | 0.338                            |
| 25                                           | 0.488                               | 0.276                                   | 0.118                                        | 0.118                            |
| 26                                           | 0.250                               | 0.250                                   | 0.250                                        | 0.250                            |
| 27                                           | 0.210                               | 0.246                                   | 0.246                                        | 0.298                            |
| 28                                           | 0.286                               | 0.286                                   | 0.142                                        | 0.286                            |
| <b><i>Mean Overall<br/>Norm. Weights</i></b> | 0.269                               | 0.230                                   | 0.193                                        | 0.309                            |

Table 4.72. Calculated weights for resources group factors.

| <b>Expert</b>                            | <b>Integration of the Supply Chain</b> | <b>Sufficiency of Manufacturers and Suppliers</b> | <b>Skilled Labor Availability</b> |
|------------------------------------------|----------------------------------------|---------------------------------------------------|-----------------------------------|
| 1                                        | 0.196                                  | 0.311                                             | 0.493                             |
| 2                                        | 0.311                                  | 0.196                                             | 0.493                             |
| 3                                        | 0.311                                  | 0.196                                             | 0.493                             |
| 4                                        | 0.493                                  | 0.311                                             | 0.196                             |
| 5                                        | 0.333                                  | 0.333                                             | 0.333                             |
| 6                                        | 0.493                                  | 0.196                                             | 0.311                             |
| 7                                        | 0.333                                  | 0.333                                             | 0.333                             |
| 8                                        | 0.250                                  | 0.250                                             | 0.500                             |
| 9                                        | 0.333                                  | 0.333                                             | 0.333                             |
| 10                                       | 0.400                                  | 0.400                                             | 0.200                             |
| 11                                       | 0.260                                  | 0.413                                             | 0.327                             |
| 12                                       | 0.169                                  | 0.444                                             | 0.387                             |
| 13                                       | 0.400                                  | 0.400                                             | 0.200                             |
| 14                                       | 0.260                                  | 0.413                                             | 0.327                             |
| 15                                       | 0.333                                  | 0.333                                             | 0.333                             |
| 16                                       | 0.413                                  | 0.260                                             | 0.327                             |
| 17                                       | 0.413                                  | 0.260                                             | 0.327                             |
| 18                                       | 0.196                                  | 0.311                                             | 0.493                             |
| 19                                       | 0.260                                  | 0.327                                             | 0.413                             |
| 20                                       | 0.400                                  | 0.400                                             | 0.200                             |
| 21                                       | 0.400                                  | 0.400                                             | 0.200                             |
| 22                                       | 0.311                                  | 0.196                                             | 0.493                             |
| 23                                       | 0.196                                  | 0.311                                             | 0.493                             |
| 24                                       | 0.333                                  | 0.333                                             | 0.333                             |
| 25                                       | 0.333                                  | 0.333                                             | 0.333                             |
| 26                                       | 0.200                                  | 0.400                                             | 0.400                             |
| 27                                       | 0.333                                  | 0.333                                             | 0.333                             |
| 28                                       | 0.333                                  | 0.333                                             | 0.333                             |
| <b><i>Mean Overall Norm. Weights</i></b> | 0.321                                  | 0.324                                             | 0.355                             |

Table 4.83. Calculated weights for regulatory group factors.

| <b>Expert</b>                                | <b>Government<br/>Promotion</b> | <b>Supporting Policies &amp;<br/>Legislations</b> | <b>Revisions to Building<br/>Regulations</b> |
|----------------------------------------------|---------------------------------|---------------------------------------------------|----------------------------------------------|
| 1                                            | 0.311                           | 0.493                                             | 0.196                                        |
| 2                                            | 0.260                           | 0.327                                             | 0.413                                        |
| 3                                            | 0.163                           | 0.540                                             | 0.297                                        |
| 4                                            | 0.196                           | 0.493                                             | 0.311                                        |
| 5                                            | 0.400                           | 0.400                                             | 0.200                                        |
| 6                                            | 0.311                           | 0.493                                             | 0.196                                        |
| 7                                            | 0.311                           | 0.493                                             | 0.196                                        |
| 8                                            | 0.250                           | 0.250                                             | 0.500                                        |
| 9                                            | 0.333                           | 0.333                                             | 0.333                                        |
| 10                                           | 0.540                           | 0.163                                             | 0.297                                        |
| 11                                           | 0.196                           | 0.311                                             | 0.493                                        |
| 12                                           | 0.400                           | 0.400                                             | 0.200                                        |
| 13                                           | 0.260                           | 0.413                                             | 0.327                                        |
| 14                                           | 0.400                           | 0.200                                             | 0.400                                        |
| 15                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 16                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 17                                           | 0.311                           | 0.493                                             | 0.196                                        |
| 18                                           | 0.400                           | 0.400                                             | 0.200                                        |
| 19                                           | 0.311                           | 0.493                                             | 0.196                                        |
| 20                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 21                                           | 0.250                           | 0.250                                             | 0.500                                        |
| 22                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 23                                           | 0.196                           | 0.311                                             | 0.493                                        |
| 24                                           | 0.493                           | 0.311                                             | 0.196                                        |
| 25                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 26                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 27                                           | 0.333                           | 0.333                                             | 0.333                                        |
| 28                                           | 0.400                           | 0.400                                             | 0.200                                        |
| <b><i>Mean Overall<br/>Norm. Weights</i></b> | 0.322                           | 0.368                                             | 0.310                                        |

Table 4.9. Calculated weights for leadership group factors.

| <b>Expert</b>                                 | <b>Contractors Leadership &amp; Experience</b> | <b>Project Managers Problem Solving Ability</b> |
|-----------------------------------------------|------------------------------------------------|-------------------------------------------------|
| 1                                             | 0.667                                          | 0.333                                           |
| 2                                             | 0.333                                          | 0.667                                           |
| 3                                             | 0.667                                          | 0.333                                           |
| 4                                             | 0.333                                          | 0.667                                           |
| 5                                             | 0.667                                          | 0.333                                           |
| 6                                             | 0.333                                          | 0.667                                           |
| 7                                             | 0.500                                          | 0.500                                           |
| 8                                             | 0.333                                          | 0.667                                           |
| 9                                             | 0.667                                          | 0.333                                           |
| 10                                            | 0.500                                          | 0.500                                           |
| 11                                            | 0.500                                          | 0.500                                           |
| 12                                            | 0.333                                          | 0.667                                           |
| 13                                            | 0.500                                          | 0.500                                           |
| 14                                            | 0.500                                          | 0.500                                           |
| 15                                            | 0.750                                          | 0.250                                           |
| 16                                            | 0.333                                          | 0.667                                           |
| 17                                            | 0.250                                          | 0.750                                           |
| 18                                            | 0.333                                          | 0.667                                           |
| 19                                            | 0.500                                          | 0.500                                           |
| 20                                            | 0.500                                          | 0.500                                           |
| 21                                            | 0.500                                          | 0.500                                           |
| 22                                            | 0.333                                          | 0.667                                           |
| 23                                            | 0.333                                          | 0.667                                           |
| 24                                            | 0.500                                          | 0.500                                           |
| 25                                            | 0.500                                          | 0.500                                           |
| 26                                            | 0.500                                          | 0.500                                           |
| 27                                            | 0.500                                          | 0.500                                           |
| 28                                            | 0.250                                          | 0.750                                           |
| <b><i>Mean Overall Normalized Weights</i></b> | 0.461                                          | 0.539                                           |

Table 4.40. Calculated weights for process group factors.

| <b>Expert</b>                                 | <b>Effective Information Sharing</b> | <b>The Maturity of Techniques &amp; Technologies</b> |
|-----------------------------------------------|--------------------------------------|------------------------------------------------------|
| 1                                             | 0.667                                | 0.333                                                |
| 2                                             | 0.667                                | 0.333                                                |
| 3                                             | 0.667                                | 0.333                                                |
| 4                                             | 0.667                                | 0.333                                                |
| 5                                             | 0.667                                | 0.333                                                |
| 6                                             | 0.333                                | 0.667                                                |
| 7                                             | 0.333                                | 0.667                                                |
| 8                                             | 0.667                                | 0.333                                                |
| 9                                             | 0.667                                | 0.333                                                |
| 10                                            | 0.333                                | 0.667                                                |
| 11                                            | 0.667                                | 0.333                                                |
| 12                                            | 0.667                                | 0.333                                                |
| 13                                            | 0.667                                | 0.333                                                |
| 14                                            | 0.667                                | 0.333                                                |
| 15                                            | 0.500                                | 0.500                                                |
| 16                                            | 0.667                                | 0.333                                                |
| 17                                            | 0.333                                | 0.667                                                |
| 18                                            | 0.500                                | 0.500                                                |
| 19                                            | 0.333                                | 0.667                                                |
| 20                                            | 0.750                                | 0.250                                                |
| 21                                            | 0.500                                | 0.500                                                |
| 22                                            | 0.667                                | 0.333                                                |
| 23                                            | 0.667                                | 0.333                                                |
| 24                                            | 0.500                                | 0.500                                                |
| 25                                            | 0.500                                | 0.500                                                |
| 26                                            | 0.500                                | 0.500                                                |
| 27                                            | 0.500                                | 0.500                                                |
| 28                                            | 0.500                                | 0.500                                                |
| <b><i>Mean Overall Normalized Weights</i></b> | 0.563                                | 0.437                                                |

The regulatory group also consisted of three factors which had the lowest global importance level globally (0.057). Supporting policies & legislation had the highest level of significance in the group (0.368) while government promotion (0.322) and revisions to building regulations (0.310) factors were following it. Pairwise comparisons of the regulatory group's results were provided in Table 4.8.

Leadership group consisted of two factors. The average global importance of factors forming this group was the highest (0.116). Factors forming this group was selected to be the most important two factors since this group achieved to be the first among groups with the least amount of factors involving in it. Project managers' problem solving ability (0.539) and contractors' leadership & experience (0.461) were compared in pairwise and results are provided in Table 4.9.

The process group was another group involving only two factors in it. However, it was determined to be the least important group (0.167); therefore, the factors forming this group had a less global level of significance on average (0.084). Effective information sharing was (0.563) determined to be more significant than the maturity of techniques & technologies (0.437) by pairwise comparison within the group. The results of the pairwise comparisons of factors forming this group are provided in Table 4.10.

Until now, the results of the pairwise comparison among the factor groups and factor within groups were completed. In order to compare factors in the same manner and determine them a comparable global importance level, factor's group weights were multiplied with their weights among the group. The calculation formula can be demonstrated as follows:

$$W(g,f) = w_g * w_f \quad (4.1)$$

where:

$W(g,f)$  = Global Factor Weight,

$w_g$  = Group Weight

$w_f$  = Factor's Weight among Group

Table 4.11. Global weights of critical success factors.

| <b>Group</b> | <b>Group Weight (<math>w_g</math>)</b> | <b>Critical Success Factor</b>             | <b>Factor Weight Among Group (<math>w_f</math>)</b> | <b>Factor Weight Global (W)</b> |
|--------------|----------------------------------------|--------------------------------------------|-----------------------------------------------------|---------------------------------|
| Leadership   | 0.232                                  | Contractor Leadership & Experience         | 0.461                                               | 0.107                           |
|              |                                        | Project Managers Problem Solving Ability   | 0.539                                               | 0.125                           |
| Process      | 0.167                                  | Effective Information Sharing              | 0.563                                               | 0.094                           |
|              |                                        | The Maturity of Techniques & Technologies  | 0.437                                               | 0.073                           |
| Regulatory   | 0.171                                  | Government Promotion                       | 0.322                                               | 0.055                           |
|              |                                        | Supporting Policies & Legislations         | 0.368                                               | 0.063                           |
|              |                                        | Revisions to Building Regulations          | 0.310                                               | 0.053                           |
| Resources    | 0.206                                  | Integration of the Supply Chain            | 0.321                                               | 0.066                           |
|              |                                        | Sufficiency of Manufacturers and Suppliers | 0.324                                               | 0.067                           |
|              |                                        | Skilled Labor Availability                 | 0.355                                               | 0.073                           |
| Technical    | 0.231                                  | Timely Design Completion                   | 0.269                                               | 0.062                           |
|              |                                        | Assembly Planning Method                   | 0.230                                               | 0.053                           |
|              |                                        | Preliminary Module Definition              | 0.193                                               | 0.045                           |
|              |                                        | Designers' Experience                      | 0.309                                               | 0.071                           |

Calculated global weights of factors are provided in Table 4.11. According to this calculation, the project manager's problem solving ability had the highest weight (0.125) among 14 CSFs. Contractor leadership & experience factor (0.107) followed it. These two

leading factors were forming a leadership process on their own. Effective information sharing (0.094) was the third factor with the highest weight. Skilled labor availability (0.073) was selected to be the fourth highest important factor. Maturity of techniques & technologies (0.073) held the fifth place. Next most important five factors were listed in descending order as follows; designers' experience from technical group (0.071), sufficiency of manufacturers and suppliers (0.067) and integration of supply chain (0.066) from resources group, supporting policies & legislation (0.063) from regulatory group and timely design completion (0.062) from technical group. Last four important CSFs are listed as; government promotion (0.055) and revisions to building regulations (0.053) from regulatory group and assembly planning method (0.053), preliminary module definition (0.045) from technical groups.

## 5. DISCUSSION AND CONCLUSION

### 5.1. Discussion

Offsite construction has many advantages over the traditional method of construction. However offsite construction method obtains a very low percentage of market share relative to the traditional method of construction.

In order to have an understanding of this issue, the literature review was conducted. Factors related to the offsite construction were gathered. Through literature review, factors were selected by having a frequency of mentioned in at least two papers with different authors. In order to determine whether gathered factors were critical or not, focus group formed. Interviews and brainstorming with focus group resulted in the determination of critical success factors. After critical success factors were determined, a questionnaire survey conducted. Forty experts from the construction industry involved in determining rankings of these critical success factors. The data collected mostly from managers and technical office professionals. The overall experience of these experts was over 12 years.

Results of this study showed project managers problem solving ability (0.127) and contractor leadership & experience (0.107) were yielding the most important critical success factors for offsite construction. These two factors showed that in order to offsite construction method can successfully use, experience and leadership were playing the most crucial roles. A study conducted in Australia resulted that industry knowledge was the most important barrier for offsite construction method (Blismas and Wakefield, 2008). Findings of Blismas and Wakefield (2008) matches with findings in this study looking from another point of view. Project manager's problem solving ability was rated as the second most important critical success factor in a study conducted in China (Li *et al.*, 2018) which some similarity with the results obtained in this study. Another study conducted in the UK also determined the

leadership and management level as the second most important CSF which also validates this study (Kamar *et al.*, 2009).

Effective information sharing (0.094) was the third most critical success factor according to the findings of this study. In another study which was conducted in Malaysia shows that good working collaboration and effective communication channel were considered as the most significant four critical factors (Ismail *et al.*, 2012). These factors were subcomponents of the factor of effective information sharing that took place in this study. In another study conducted in Malaysia, effective information sharing was found to be the second most important CSF for industrialized building systems (Kamar *et al.*, 2010).

Skilled labor availability (0.073) was determined as the fourth CSF having a strong impact according to this study. The possible margin of error in offsite construction is very limited compared to the traditional construction method. Therefore, the skilled labor factor gains importance. This factor was also observed in the research of Yunus *et al.* (2012) by the name of knowledge and skills and having the fifth most significant level. Lack of skilled labor availability was determined as drivers of off-site manufacturing systems by other researches conducted in the UK (Pan *et al.*, 2007 and Elnass *et al.*, 2014). found that labor was one of the driving factors for off-site manufacturing systems. This factor can be considered with project managers solving ability and contractors experience under the same roof as industry knowledge.

The maturities of the techniques & technologies used had the same weight with skilled labor availability (0.073). The off-site construction method can increase the complexity of design and application process proportional to its utilization in the project. Building Information Modelling (BIM) and 3D visualization systems are carrying forward the capabilities of the construction industry. These techniques offer to foresee any problems that can be faced during the construction process and enables to interfere and solve it in the design phase. This factor did have the same level of importance in the research done in China with being determined as the fifth most important factor (Li *et al.*, 2018). However, even though

another study conducted in Malaysia gave place to this factor, it was not determined to be significant as other factors (Kamar *et al.*, 2010). This factor does not show up in the studies of the UK, USA and other well-developed countries which have advanced technologies relative to Turkey.

Designers' experience was valued to be the most significant factor of the technical group. In the global ranking, it had (0.071) share and was valued as the most significant factor following the first five. This factor was listed as the most significant factor in the research done in China (Li *et al.*, 2018). As it appeared in the maturities of the techniques & technologies factor, this factor was listed in the study done in Malaysia but did not consider to be one of the important factors (Kamar *et al.*, 2010). Also, this factor does not appear on the other research conducted in UK, USA. This situation shows that especially in the field of offsite construction, Turkey needs designers that are more experienced.

Sufficiency of manufacturers and suppliers had a share of (0.067) barely outranking the integration of the supply chain factor which had a share of (0.066). Both of these factors were sub-factors of resources group. Sufficiency of manufacturers and suppliers is related to the construction markets readiness to the offsite construction. This factor does not show up in the UK, USA and Malaysia literature. A study conducted in China was determined that this factor as the second most significant factor (Li *et al.*, 2018). On the other hand, integration of the supply, chain factor is collaboration related. This factor was observed in the studies conducted in China (Xiahou *et al.*, 2018) and Malaysia (Ismail *et al.*, 2012). In both of these studies, it appeared as the factor with the lowest significance. It did not appear in the USA and UK literature. It can be concluded that the coordination of Turkish contractor & subcontractors is lower and it has to be strengthened in order to achieve wider use of offsite construction.

Supporting policies & legislation was rated as having a significant rate of (0.063). This factor does not appear in the UK and the USA because offsite construction has already a market share of 20% in the housing industry (Manufactured Housing Institute, 2000). Some

products of offsite construction have a market share of 40% in northern Europe (Polat & Damcı, 2007). Compared with these levels of utilization, the lower market share of offsite construction can be increased by the supporting policies & legislation. This was also mentioned as a driver in a study conducted in China (Xiahou *et al.*, 2018).

Timely design completion factor was the second most important factor of the technical group. It had (0.062) weight and determined to have a moderate significance according to the results. This CSF was determined to be the fourth most important in a study conducted in the US (O'Connor *et al.*, 2014). This factor was moderately valued in a study conducted in China (Li *et al.*, 2018) similar to this research paper. According to these results, it can be concluded that timely design completion becomes more important to achieve better for offsite construction.

Preliminary module definition was a CSF located in the technical group and it was determined to be least significant of its own group and in global regarding the results. Offsite construction has many different techniques involved in, according to the size and complexity of manufactured components it can be categorized into; processed material, prefabricated components, panelized and modular (Schoenborn, 2012). The reason behind this CSF to be valued at least may be caused by the experts less involvement or use of offsite construction techniques with bigger sizes, such as modular construction. In a research conducted for determining CSFs of modular construction, preliminary module definition was determined as 6<sup>th</sup> most important CSF out of 23 (James *et al.*, 2014). This confirms that increasing the size of the product of offsite construction increases the importance of the preliminary module definition as a CSF.

Remaining factors can be listed as government promotion (0.055), revisions to building regulations (0.053) and assembly planning method (0.053). These factors among the least significant factors with having weights less than 6%.

Rankings of these factors determined in this study and their comparison with the similar studies conducted in different countries showed that the Chinese construction market and Turkish construction market have very similar dynamics. Determined CSFs in this study are very similar to the studies conducted in China in terms of ranks and content. If the construction markets of China and Turkey investigated, it can be seen that both of these countries have very cheap labor, relative to other countries studied; Malaysia, the US, and the UK. This enables to solve problems confronted during the construction with more labor force in China and Turkey. An example can be given as; in order to shorten the project duration, Turkey and China have a chance to increase the labor employed in the field as a cheap alternative. However, in the developed countries where the salaries for labor is much higher, the decrease in the labor cost (O'Connor *et al.*, 2014 and Elnass *et al.*, 2014) and an increase in the productivity (Blismas *et al.*, 2008 and Goodier *et al.*, 2007) of labor were determined to be driving factors for offsite construction. The need for alternative construction methods diminishes in Turkey and China, considering the cheap labor force advantages in those countries. This reduces the use of the offsite construction method and leads to less investment in research and development for this method. On the contrary, in the developed countries, it was observed the adoption of offsite construction techniques were more prevalent and the CSFs were mostly related to increasing the efficiency of offsite construction techniques rather than implementing them.

## 5.2. Conclusion

Offsite construction is well known for its higher quality, time-saving, and controllable working environment properties. This research aimed to fulfill following objectives: (1) to evaluate the factors affecting offsite construction, (2) to rank and determine critical factors of offsite construction, (3) make recommendations on how offsite construction method can achieve more against the traditional method of construction. In this research, the Analytic Hierarchy Process (AHP) technique was used in order to rank and assign weights to the critical factors and to their groups, which determined through literature review and focus group study. 14 critical success factors were determined and they were separated into 5-factor groups. In the first level, the five factor groups were compared in pairs. At the second

level, the critical success factors in the groups were compared. The weights found were multiplied correspondingly and factors were ranked according to the resultant global weights.

A literature review was conducted and it was followed by critical factor determination by focus group. The questionnaire was formed based on the determined critical factors. 42 experts participated in the questionnaire phase. The findings of the questionnaire were processed in an excel template (Klaus, 2013) and consistency ratios of answers were obtained. Consistent expert responses were utilized in the study. This elimination reduced the number of expert answers down to 28.

According to the results of this study; project manager ability to solve problems, contractor leadership & experience, and effective information sharing are determined as the top three most critical success factors for offsite construction. These factors are forming almost one-third weight of all factors (0.326). Results showed that experts considered managerial factors are more critical in order to reach success than other factors. Least important factors which have lower than (0.060) weight are determined as; government promotion, revisions to building regulations, assembly planning method, preliminary module definition. All these four factors form only (0.206) weight of all factors. Remaining seven factors are very close to each other in terms of their weights. Skilled labor availability shows the importance of experience with (0.073) weight following the first three of the most significant critical factors.

Comparison of these factors with the factors found in other countries shows that Turkish construction market is very similar to the Chinese construction market in terms of the dynamics affecting the offsite construction. Determined critical factors and their importance level show similarity with studies conducted in China. The reason behind this can be concluded as both China and Turkey depend on cheap labor. Due to this market condition, the use of offsite construction method is minimized which results in slower implementation of the offsite construction method. Investing in offsite construction techniques seems to have some burden on the contractors in comparison with the companies

using the traditional method of construction. CSFs determined in the UK and US are actually considering how to more efficiently use offsite construction techniques, rather than implementing it. Their construction market well developed in terms of the application of offsite construction techniques. The most significant factors of these developed countries are finding skilled labor and the expense of it.

The method used in this study had some limitations as well. The data used in the analysis are obtained from experts and the answers of the experts are subjective. Another limitation is related to the elimination of factors. Initially, 74 factors were obtained from the literature. Factors which have similar meaning were combined and further elimination was conducted according to their frequency in the literature. This elimination process was done in order to obtain healthy data from the experts that participated in this study. If any of this elimination had not been performed, the questionnaire would be too long which would lead to less involvement. Also as the number of pairwise comparisons increases, the expert may pay less attention, which may cause missing data or high inconsistency ratio. Considering the disadvantages of a long list of factors may cause, the list of factors has been simplified as much as possible.

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## APPENDIX A: FACTOR GATHERED THROUGH LITERATURE

Table A.1 Factors gathered through literature review.

| Factor No | Factor Name                                      | Source                                                                                                                                                                                                                                                                           | Factor Frequency |
|-----------|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 1         | Skills and Knowledge of Labors                   | (Li <i>et al.</i> , 2018), (Bliskas <i>et al.</i> , 2008), (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Elnass <i>et al.</i> , 2014), (Kamar <i>et al.</i> , 2010), (Xiahou <i>et al.</i> , 2018), (Yunus <i>et al.</i> , 2012)                                     | 9                |
| 2         | Recognizing the Quality Increase                 | (Li <i>et al.</i> , 2018), (Bliskas <i>et al.</i> , 2008), (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Goodier <i>et al.</i> , 2007), (Nadim <i>et al.</i> , 2009), (Elnass <i>et al.</i> , 2014), (Xiahou <i>et al.</i> , 2018), (Bliskas <i>et al.</i> , 2005)   | 9                |
| 3         | OH&S Risks Reduction                             | (Bliskas <i>et al.</i> , 2008), (Xiahou <i>et al.</i> , 2018), (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Nadim <i>et al.</i> , 2009), (Elnass <i>et al.</i> , 2014), (Kamar <i>et al.</i> , 2010), (Ismail <i>et al.</i> , 2012), (Bliskas <i>et al.</i> , 2005) | 9                |
| 4         | Reduced Environmental Damage During Construction | (Bliskas <i>et al.</i> , 2008), (Yunus <i>et al.</i> , 2012), (Xiahou <i>et al.</i> , 2018), (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Elnass <i>et al.</i> , 2014), (Kamar <i>et al.</i> , 2010)                                                                | 8                |
| 5         | Cost Savings Recognition                         | (O'Connor <i>et al.</i> , 2014), (Bliskas <i>et al.</i> , 2008), (Gibb <i>et al.</i> , 2003), (Elnass <i>et al.</i> , 2014), (Xiahou <i>et al.</i> , 2018), (Bliskas <i>et al.</i> , 2005)                                                                                       | 7                |
| 6         | Owner's Planning Resources & Process             | (O'Connor <i>et al.</i> , 2014), (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010), (Bliskas <i>et al.</i> , 2008), (Elnass <i>et al.</i> , 2014), (Yunus <i>et al.</i> , 2012), (Ismail <i>et al.</i> , 2012)                                                             | 7                |

Table A.1. Factors gathered through literature review (cont.).

| Factor No | Factor Name                                 | Source                                                                                                                                                    | Factor Frequency |
|-----------|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| 7         | Early Completion Recognitions               | (O'Connor <i>et al.</i> , 2014), (Gibb <i>et al.</i> , 2003), (Goodier <i>et al.</i> , 2007), (Nadim <i>et al.</i> , 2009)                                | 6                |
| 8         | Productivity                                | (Blismas <i>et al.</i> , 2008), (Yunus <i>et al.</i> , 2012), (Goodier <i>et al.</i> , 2007), (Kamar <i>et al.</i> , 2010), (Xiahou <i>et al.</i> , 2018) | 5                |
| 9         | Less Time on Site                           | (Gibb <i>et al.</i> , 2003), (Goodier <i>et al.</i> , 2007), (Yunus <i>et al.</i> , 2012), (Blismas <i>et al.</i> , 2005)                                 | 4                |
| 10        | Ensuring Time Certainty                     | (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Blismas <i>et al.</i> , 2005), (Nadim <i>et al.</i> , 2009)                                     | 4                |
| 11        | Use of the ICT, BIM, ERP, RFID Technologies | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010), (Xiahou <i>et al.</i> , 2018)                                                                    | 3                |
| 12        | Ensuring Cost Certainty                     | (Pan <i>et al.</i> , 2007), (Gibb <i>et al.</i> , 2003), (Blismas <i>et al.</i> , 2005)                                                                   | 3                |
| 13        | Effective Communication Among Participants  | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010), (Ismail <i>et al.</i> , 2012)                                                                    | 3                |
| 14        | Operations and Maintenance (O&M) Provisions | (O'Connor <i>et al.</i> , 2014), (Blismas <i>et al.</i> , 2008), (Yunus <i>et al.</i> , 2012)                                                             | 3                |
| 15        | Early Involvement of All Parties            | (O'Connor <i>et al.</i> , 2014), (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010)                                                                  | 3                |
| 16        | Reduced Snagging & Defects                  | (Gibb <i>et al.</i> , 2003), (Goodier <i>et al.</i> , 2007), (Yunus <i>et al.</i> , 2012)                                                                 | 3                |

Table A1. Factors gathered through literature review (cont.).

| Factor No | Factor Name                                                                 | Source                                                                                          | Factor Frequency |
|-----------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|------------------|
| 17        | Reduced Whole Life Cost                                                     | (Goodier <i>et al.</i> , 2007), (Nadim <i>et al.</i> , 2009),<br>(Blismas <i>et al.</i> , 2005) | 3                |
| 18        | Integration of the Supply Chain                                             | (Xiahou <i>et al.</i> , 2018), (Ismail <i>et al.</i> , 2012)                                    | 2                |
| 19        | Supporting Policies & Legislations                                          | (Xiahou <i>et al.</i> , 2018), (Yunus <i>et al.</i> , 2012)                                     | 2                |
| 20        | Management of Execution Risks                                               | (O'Connor <i>et al.</i> , 2014), (Ismail <i>et al.</i> , 2012)                                  | 2                |
| 21        | Designers' Experience                                                       | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010)                                         | 2                |
| 22        | Project Manager's Ability to Solve Problems                                 | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010)                                         | 2                |
| 23        | Information Sharing Among Participants                                      | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010)                                         | 2                |
| 24        | The Maturity of Techniques Used in the Detailed Design Phase                | (Li <i>et al.</i> , 2018), (Kamar <i>et al.</i> , 2010)                                         | 2                |
| 25        | People and Work Conditions                                                  | (Blismas <i>et al.</i> , 2008), (Yunus <i>et al.</i> , 2012)                                    | 2                |
| 26        | Revisions to Building Regulations                                           | (Pan <i>et al.</i> , 2007), (Elnass <i>et al.</i> , 2014)                                       | 2                |
| 27        | Lower Preliminary Costs                                                     | (Gibb <i>et al.</i> , 2003), (Goodier <i>et al.</i> , 2007)                                     | 2                |
| 28        | Increased Component Life                                                    | (Goodier <i>et al.</i> , 2007), (Yunus <i>et al.</i> , 2012)                                    | 2                |
| 29        | Good Working Collaboration                                                  | (Kamar <i>et al.</i> , 2010), (Ismail <i>et al.</i> , 2012)                                     | 2                |
| 30        | Improvement in Procurement Strategy and Contracting                         | (Kamar <i>et al.</i> , 2010), (Yunus <i>et al.</i> , 2012)                                      | 2                |
| 31        | Process Standardization and More Effective Use on the Concept of Repetition | (Kamar <i>et al.</i> , 2010), (Yunus <i>et al.</i> , 2012)                                      | 2                |
| 32        | Top-Down Commitment and Corporate Motivation                                | (Kamar <i>et al.</i> , 2010), (Yunus <i>et al.</i> , 2012)                                      | 2                |
| 33        | Module Envelope Limitations                                                 | (O'Connor <i>et al.</i> , 2014), (Li <i>et al.</i> , 2018)                                      | 2                |
| 34        | Contractor Leadership                                                       | (O'Connor <i>et al.</i> , 2014), (Kamar <i>et al.</i> , 2010)                                   | 2                |
| 35        | Timely Design Freeze                                                        | (O'Connor <i>et al.</i> , 2014), (Li <i>et al.</i> , 2018)                                      | 2                |
| 36        | Module Fabricator Capability                                                | (O'Connor <i>et al.</i> , 2014), (Li <i>et al.</i> , 2018)                                      | 2                |
| 37        | Continuing Improvement and Learning                                         | (Kamar <i>et al.</i> , 2010)                                                                    | 1                |

Table A.1. Factors gathered through literature review (cont.).

| Factor No | Factor Name                                                            | Source                          | Factor Frequency |
|-----------|------------------------------------------------------------------------|---------------------------------|------------------|
| 38        | Assembly Planning Method                                               | (Li <i>et al.</i> , 2018)       | 1                |
| 39        | Project Manager's Attitude Towards Planning and Control                | (Li <i>et al.</i> , 2018)       | 1                |
| 40        | Restricted Site Specifics                                              | (Pan <i>et al.</i> , 2007)      | 1                |
| 41        | Greater Customization Options                                          | (Goodier <i>et al.</i> , 2007)  | 1                |
| 42        | Government Promotion                                                   | (Pan <i>et al.</i> , 2007)      | 1                |
| 43        | Simplifies Construction Process                                        | (Gibb <i>et al.</i> , 2003)     | 1                |
| 44        | Allows Systems to be Measured                                          | (Gibb <i>et al.</i> , 2003)     | 1                |
| 45        | Program Driven Centrally                                               | (Gibb <i>et al.</i> , 2003)     | 1                |
| 46        | Minimizing non Construction Cost                                       | (Blismas <i>et al.</i> , 2005)  | 1                |
| 47        | Transport Infrastructure                                               | (O'Connor <i>et al.</i> , 2014) | 1                |
| 48        | Owner Delay Avoidance                                                  | (O'Connor <i>et al.</i> , 2014) | 1                |
| 49        | Data for Optimization                                                  | (O'Connor <i>et al.</i> , 2014) | 1                |
| 50        | Well Developed Specifications and Regulations                          | (Li <i>et al.</i> , 2018)       | 1                |
| 51        | Persistent Policies and Incentives                                     | (Li <i>et al.</i> , 2018)       | 1                |
| 52        | Sustainability Request by the Local Government                         | (Li <i>et al.</i> , 2018)       | 1                |
| 53        | Difficulty to Obtain Planning Permission by the Local Government       | (Li <i>et al.</i> , 2018)       | 1                |
| 54        | Continuity Through Project Phases                                      | (O'Connor <i>et al.</i> , 2014) | 1                |
| 55        | Sufficiency of Manufacturers and Suppliers of Prefabricated Components | (Li <i>et al.</i> , 2018)       | 1                |
| 56        | Transport Delay Avoidance                                              | (O'Connor <i>et al.</i> , 2014) | 1                |
| 57        | Achieving Predictability of Quality                                    | (Blismas <i>et al.</i> , 2005)  | 1                |
| 58        | Team Members Involved During the Design Stage                          | (Ismail, <i>et al.</i> , 2012)  | 1                |
| 59        | Strategy and Business Approach                                         | (Ismail, <i>et al.</i> , 2012)  | 1                |

Table A.1. Factors gathered through literature review (cont.).

| <b>Factor No</b> | <b>Factor Name</b>                                                                | <b>Source</b>                   | <b>Factor Frequency</b> |
|------------------|-----------------------------------------------------------------------------------|---------------------------------|-------------------------|
| 60               | Preliminary Module Definition                                                     | (O'Connor <i>et al.</i> , 2014) | 1                       |
| 61               | Investment in Studies                                                             | (O'Connor <i>et al.</i> , 2014) | 1                       |
| 62               | Heavy Lift/Site Transport Capabilities                                            | (O'Connor <i>et al.</i> , 2014) | 1                       |
| 63               | Contractor Experience                                                             | (O'Connor <i>et al.</i> , 2014) | 1                       |
| 64               | Achieving the Performance Predictability Throughout the Lifecycle of the Facility | (Blismas <i>et al.</i> , 2005)  | 1                       |
| 65               | Maximizing Environmental Performance Throughout the Lifecycle                     | (Blismas <i>et al.</i> , 2005)  | 1                       |
| 66               | Implementing Respect for People Principles                                        | (Blismas <i>et al.</i> , 2005)  | 1                       |
| 67               | Demand for More Production                                                        | (Xiahou <i>et al.</i> , 2018)   | 1                       |
| 68               | Shortage of Resources                                                             | (Xiahou <i>et al.</i> , 2018)   | 1                       |
| 69               | Management Improvement                                                            | (Xiahou <i>et al.</i> , 2018)   | 1                       |
| 70               | Reduced Labor Cost                                                                | (Yunus <i>et al.</i> , 2012)    | 1                       |
| 71               | Easier Waste Disposal                                                             | (Yunus <i>et al.</i> , 2012)    | 1                       |
| 72               | Labor Availability                                                                | (Yunus <i>et al.</i> , 2012)    | 1                       |
| 73               | Less Material Consumption                                                         | (Yunus <i>et al.</i> , 2012)    | 1                       |
| 74               | Industry Marketing Collaboration                                                  | (Ismail, <i>et al.</i> , 2012)  | 1                       |

## APPENDIX B: AHP COMPARISON MATRICES

In this study, each of the experts was asked to complete six different pairwise comparison matrices through the questionnaire. AHP matrices including one of the expert's answer are provided in Table B.1-B.6.

Table B.1. Factor group comparison matrix.

| <b>Group Name</b> | <b>Leadership</b> | <b>Technical</b> | <b>Resources</b> | <b>Process</b> | <b>Regulatory</b> |
|-------------------|-------------------|------------------|------------------|----------------|-------------------|
| <b>Leadership</b> | 1                 | 3                | 5                | 1/3            | 4                 |
| <b>Technical</b>  | 1/3               | 1                | 1                | 2              | 1/5               |
| <b>Resources</b>  | 1/5               | 1                | 1                | 1              | 3                 |
| <b>Process</b>    | 3                 | 1/2              | 1                | 1              | 1/2               |
| <b>Regulatory</b> | 1/4               | 5                | 1/3              | 2              | 1                 |

Table B.2. Technical group factors comparison matrix.

| <b>Factor Name</b> | <b>A: Timely Design Completion</b> | <b>B: Assembly Planning Method</b> | <b>C: Preliminary Module Definition</b> | <b>D: Designer' Experience</b> |
|--------------------|------------------------------------|------------------------------------|-----------------------------------------|--------------------------------|
| <b>A</b>           | 1                                  | 1/3                                | 1                                       | 1                              |
| <b>B</b>           | 3                                  | 1                                  | 2                                       | 3                              |
| <b>C</b>           | 1                                  | 1/2                                | 1                                       | 4                              |
| <b>D</b>           | 1                                  | 1/3                                | 1/4                                     | 1                              |

Table B.3. Resources group factors comparison matrix.

| <b>Factor Name</b> | <b>A: Integration of the Supply Chain</b> | <b>B: Sufficiency of Manufacturers and Suppliers</b> | <b>C: Skilled Labor Availability</b> |
|--------------------|-------------------------------------------|------------------------------------------------------|--------------------------------------|
| <b>A</b>           | 1                                         | 2                                                    | 3                                    |
| <b>B</b>           | 1/2                                       | 1                                                    | 4                                    |
| <b>C</b>           | 1/3                                       | 1/4                                                  | 1                                    |

Table B.4. Regulatory group factors comparison matrix.

| <b>Factor Name</b> | <b>A: Government Promotion</b> | <b>B: Supporting Policies &amp; Legislations</b> | <b>C: Revisions to Building Regulations</b> |
|--------------------|--------------------------------|--------------------------------------------------|---------------------------------------------|
| <b>A</b>           | 1                              | 3                                                | 2                                           |
| <b>B</b>           | 1/3                            | 1                                                | 2                                           |
| <b>C</b>           | 1/2                            | 1/2                                              | 1                                           |

Table B.5. Leadership group factors comparison matrix.

| <b>Factor Name</b> | <b>A: Contractors Leadership &amp; Experience</b> | <b>B: Project Managers Problem Solving Ability</b> |
|--------------------|---------------------------------------------------|----------------------------------------------------|
| <b>A</b>           | 1                                                 | 2                                                  |
| <b>B</b>           | 1/2                                               | 1                                                  |

Table B.6. Process group factors comparison matrix.

| <b>Factor Name</b> | <b>A: Effective Information Sharing</b> | <b>B: The Maturity of Techniques &amp; Technologies</b> |
|--------------------|-----------------------------------------|---------------------------------------------------------|
| <b>A</b>           | 1                                       | 1/4                                                     |
| <b>B</b>           | 4                                       | 1                                                       |

## APPENDIX C: QUESTIONNAIRE TEMPLATE

### Exploring the Critical Success Factors of Offsite Construction in Turkey

**Direction:** This study is carried out as Master Degree research at the Boğaziçi University, Faculty of Engineering by Alper Zafer under the guidance of Assist. Prof. Semra Çomu Yapıcı. The aim of this survey is to rank the critical success factors (CSFs) of offsite construction in Turkey. I would appreciate if you would complete the attached questionnaire and return it by **April 30, 2019**.

In this study, offsite construction techniques are defined as planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure. Those techniques include preassembly, prefabrication, panelized systems, industrial building systems, modular construction. According to the size of the final products through these techniques, offsite construction can be investigated in four subcategories, which can be illustrated as follow:

- (i) *Processed Materials*: Precut or shaped steel rebar or cladding units.
- (ii) *Prefabricated Components*: Pre-cast structural elements, insulating concrete formwork (ICF), tunnel form construction, frames of steel, timber, precast.
- (iii) *Panelized*: Precast concrete panels, timber panels, facade systems.
- (iv) *Modular*: Bathroom pods, rooms, temporary prefabricated buildings, modular building parts.

Modern methods of construction techniques are not included in the scope of this study.

Within the scope of the study, the literature was searched for domestic and foreign sources and 74 factors affecting the offsite construction were determined. These factors were studied in order to determine factors with the same meanings and reducing them into one resulting factor. These factors are further studied by focus group workshop which had the intention of determining the critical success factors and grouping them in a consensus after several rounds of revision. As a result; 14 critical success factors and five groups were determined. In this questionnaire, the pairwise comparison of these factors and groups will be conducted.

### **Section I Personal Information**

Name surname

---

A phone number to contact you if needed

---

Your experience in the construction industry

- (i) Less than 5 years
- (ii) Between 5 - 10 years
- (iii) Between 10 - 15 years
- (iv) Between 15 - 20 years
- (v) More than 20 years

Job title

- (i) Company Owner
- (ii) Business Development
- (iii) Field - Operation
- (iv) Design
- (v) Technical Office
- (vi) Procurement - Purchase
- (vii) Other (please specify) \_\_\_\_\_

## **Section II Factor Group Comparison**

In this section, the groups that are formed of the same scope of factors will be compared pairwise. The factors which are forming the groups are provided below. Please consider the number of factors that are forming the groups while doing the comparison of groups, which may affect the global weight of each individual factor.

### **Leadership**

- Contractor Leadership & Experience
- Project Managers Problem Solving Ability

### **Process**

- Effective Information Sharing
- The Maturity of Techniques & Technologies

### **Regulatory**

- Government Promotion
- Supporting Policies & Legislations
- Revisions to Building Regulations

### **Resources**

- Integration of the Supply Chain
- Sufficiency of Manufacturers and Suppliers
- Skilled Labor Availability

### Technical

- Timely Design Completion
- Assembly Planning Method
- Preliminary Module Definition
- Designers' Experience

Please do the pairwise comparison of all criteria. AHP Scale:

- 1- Equal importance,
- 2- Moderate importance,
- 3- Strong importance
- 4- Very strong importance
- 5- Extreme importance

|           | A - wrt Group Selection - or B?                                      | Equally important       | How much more important?                                                                        |
|-----------|----------------------------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------|
| <b>1</b>  | <input type="radio"/> Leadership or <input type="radio"/> Process    | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>2</b>  | <input type="radio"/> Leadership or <input type="radio"/> Regulatory | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>3</b>  | <input type="radio"/> Leadership or <input type="radio"/> Resources  | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>4</b>  | <input type="radio"/> Leadership or <input type="radio"/> Technical  | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>5</b>  | <input type="radio"/> Process or <input type="radio"/> Regulatory    | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>6</b>  | <input type="radio"/> Process or <input type="radio"/> Resources     | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>7</b>  | <input type="radio"/> Process or <input type="radio"/> Technical     | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>8</b>  | <input type="radio"/> Regulatory or <input type="radio"/> Resources  | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>9</b>  | <input type="radio"/> Regulatory or <input type="radio"/> Technical  | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>10</b> | <input type="radio"/> Resources or <input type="radio"/> Technical   | <input type="radio"/> 1 | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |

### Section III Factor Comparison within Groups

In this section, the factors which are forming the groups will be compared pairwise. This section has a total of 14 pairwise comparisons. This section involves five different AHP matrix in itself. All of the matrices have negligible interrelation therefore direct AHP will be considered. The scale of AHP will be again;

- 1- Equal importance,
- 2- Moderate importance,
- 3- Strong importance
- 4- Very strong importance
- 5- Extreme importance

|           | <b>A - wrt Factor Selection - or B?</b>                                                                                  | <b>Equally important</b> | <b>How much more important?</b>                                                                 |
|-----------|--------------------------------------------------------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------|
| <b>1</b>  | <input type="radio"/> Contractor Leadership Experience or <input type="radio"/> Project Managers Problem Solving Ability | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>2</b>  | <input type="radio"/> Effective Information Sharing or <input type="radio"/> The Maturity of Techniques & Technologies   | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>3</b>  | <input type="radio"/> Government Promotion or <input type="radio"/> Supporting Policies & Legislations                   | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>4</b>  | <input type="radio"/> Government Promotion or <input type="radio"/> Revisions to Building Regulations                    | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>5</b>  | <input type="radio"/> Supporting Policies & Legislations or <input type="radio"/> Revisions to Building Regulations      | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>6</b>  | <input type="radio"/> Integration of the Supply Chain or <input type="radio"/> Sufficiency of Manufacturers, Suppliers   | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>7</b>  | <input type="radio"/> Integration of the Supply Chain or <input type="radio"/> Skilled Labor Availability                | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>8</b>  | <input type="radio"/> Sufficiency of Manufacturers, Suppliers or <input type="radio"/> Skilled Labor Availability        | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>9</b>  | <input type="radio"/> Timely Design Completion or <input type="radio"/> Assembly Planning Method                         | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>10</b> | <input type="radio"/> Timely Design Completion or <input type="radio"/> Preliminary Module Definition                    | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>11</b> | <input type="radio"/> Timely Design Completion or <input type="radio"/> Designers' Experience                            | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>12</b> | <input type="radio"/> Assembly Planning Method or <input type="radio"/> Preliminary Module Definition                    | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>13</b> | <input type="radio"/> Assembly Planning Method or <input type="radio"/> Designers' Experience                            | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |
| <b>14</b> | <input type="radio"/> Preliminary Module Definition or <input type="radio"/> Designers' Experience                       | <input type="radio"/> 1  | <input type="radio"/> 2 <input type="radio"/> 3 <input type="radio"/> 4 <input type="radio"/> 5 |

## APPENDIX D: CONSISTENCY RATIO CALCULATIONS

Table D.1. Consistency Ratio check for expert answers.

| <b>Expert No</b> | <b>AHP - A (%)</b> | <b>AHP - B (%)</b> | <b>AHP - C (%)</b> | <b>AHP - D (%)</b> | <b>Status</b> |
|------------------|--------------------|--------------------|--------------------|--------------------|---------------|
| 1                | 4.3                | 4.4                | 5.6                | 5.6                | Valid         |
| 2                | 3.4                | 2.2                | 5.6                | 5.6                | Valid         |
| 3                | 6.2                | 9.1                | 14.1               | 14.1               | Omitted       |
| 4                | 9.5                | 2.2                | 5.6                | 5.6                | Omitted       |
| 5                | 1.7                | 2.2                | 5.6                | 1.0                | Valid         |
| 6                | 1.3                | 2.2                | 5.6                | 5.6                | Valid         |
| 7                | 4.2                | 0.0                | 0.0                | 0.0                | Valid         |
| 8                | 11.5               | 23.6               | 52.2               | 5.6                | Omitted       |
| 9                | 8.8                | 4.4                | 5.6                | 5.6                | Valid         |
| 10               | 1.7                | 6.8                | 0.0                | 5.6                | Valid         |
| 11               | 4.9                | 14.1               | 0.0                | 0.0                | Valid         |
| 12               | 5.3                | 6.8                | 5.6                | 52.2               | Omitted       |
| 13               | 4.3                | 2.2                | 0.0                | 0.0                | Valid         |
| 14               | 5.3                | 4.3                | 0.0                | 1.0                | Valid         |
| 15               | 6.9                | 2.2                | 5.6                | 5.6                | Valid         |
| 16               | 2.6                | 2.2                | 5.6                | 14.1               | Omitted       |
| 17               | 2.6                | 5.2                | 1.9                | 0.0                | Valid         |
| 18               | 3.0                | 1.7                | 0.0                | 14.1               | Omitted       |
| 19               | 3.6                | 6.8                | 0.0                | 5.6                | Valid         |
| 20               | 8.6                | 2.2                | 5.6                | 0.0                | Valid         |
| 21               | 2.2                | 2.2                | 0.0                | 0.0                | Valid         |
| 22               | 1.7                | 2.2                | 5.6                | 0.0                | Valid         |
| 23               | 10.4               | 4.4                | 14.1               | 0.0                | Omitted       |
| 24               | 6.9                | 11.8               | 1.9                | 1.9                | Omitted       |
| 25               | 5.4                | 2.2                | 5.6                | 22.7               | Omitted       |
| 26               | 3.2                | 0.0                | 5.6                | 5.6                | Valid         |
| 27               | 4.4                | 2.2                | 5.6                | 0.0                | Valid         |
| 28               | 8.9                | 6.8                | 5.6                | 5.6                | Valid         |
| 29               | 5.8                | 0.8                | 0.0                | 0.0                | Valid         |

Table D.1. Consistency Ratio check for expert answers (cont.).

| <b>Experts</b> | <b>AHP - A</b> | <b>AHP - B</b> | <b>AHP - C</b> | <b>AHP - D</b> | <b>Status</b> |
|----------------|----------------|----------------|----------------|----------------|---------------|
| 30             | 3.9            | 2.2            | 0.0            | 0.0            | Valid         |
| 31             | 1.8            | 2.2            | 5.6            | 0.0            | Valid         |
| 32             | 4.9            | 7.9            | 5.6            | 5.6            | Valid         |
| 33             | 37.6           | 16.5           | 5.6            | 0.0            | Omitted       |
| 34             | 3.9            | 2.2            | 0.0            | 5.6            | Valid         |
| 35             | 3.0            | 5.7            | 0.0            | 0.0            | Valid         |
| 36             | 1.7            | 0.0            | 0.0            | 0.0            | Valid         |
| 37             | 0.0            | 2.2            | 0.0            | 0.0            | Valid         |
| 38             | 0.0            | 24.0           | 0.0            | 58.5           | Omitted       |
| 39             | 3.0            | 0.0            | 0.0            | 0.0            | Valid         |
| 40             | 3.2            | 11.8           | 0.0            | 14.1           | Omitted       |

# APPENDIX E: AHP HIERARCHY DIAGRAM

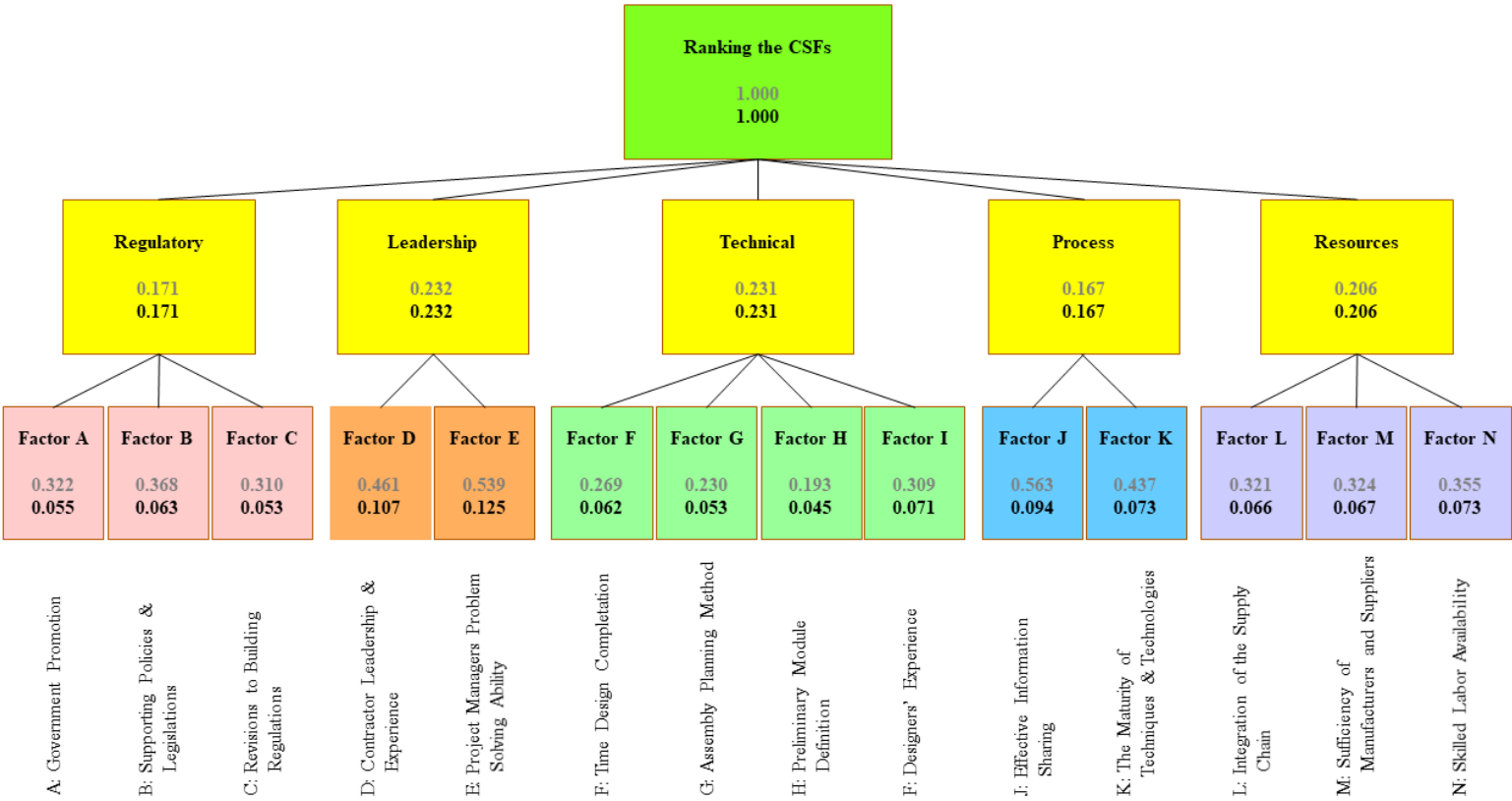


Figure E.1. AHP Hierarchy with Weights