APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

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Master of Science in Project Management

Department of Building Economics

University of Moratuwa
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Dissertation submitted in partial fulfillment of the requirements for the degree
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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Further, I am acknowledging the intellectual contribution of my research supervisor Dr.Thanuja Ramachandra for the successful completion of this research dissertation. I affirm that I will not make any publication from this research without the name(s) of my research supervisor(s) as contributing author(s) unless otherwise I have obtained written consent from my research supervisor(s).

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ABSTRACT

APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

The end of World War II brought an increment in the necessity of building construction along with insufficient provision of conventional constructions. The innovative techniques of Offsite Constructions (OSC) was brought into action to cope up with the risen demand as it delivers the products in desired quality and reduced time of construction. In the present global context, the credit goes to OSC for its process of planning, designing, factory fabrication, transporting and making an assemblage of the fabricated components in a rapid and time-saving on-site fixation, with its appreciable benefits of budget feasibility in cost without hampering the quality or strength of the end product against the conventional construction methods. The implementations of these techniques are rarely bought into practice in the Sri Lanka construction sector.

With the aim of increasing the adoption of offsite constructions in Sri Lanka this research examines the nature and level of adoption of different off-site construction systems in Sri Lanka, benefits and barriers in implementing off-site construction methods, and identify the challenges faced in the application of off-site construction methods. Through the snowball method of sampling 60 offsite construction professionals were picked as research samples. The research embraced the survey method; data was gathered through a well structured close ended questionnaire. The data was then statistically analyzed implementing percentage, weighted mean rating and standard deviations to obtain the objectives of the study.

The research concluded that all the OSC methods (i.e.; volumetric systems, panelized systems, hybrid construction, and sub-assemblies) are equal in offering high satisfaction, and would boost benefit/income through superior quality, less duration, financial benefits generation from early completion, and onsite less safety risks. The implementation of these methods also minimizes the waste leading to a reduction in the project budget. Contractors' profit is high in OSC due to low competitors in industry and due to "design and build" type quotation.

The study also brought to light that some critical and dominant challenges out of many are still existent in Sri Lankan construction industry, requiring proper attention for minimizing, or alleviating their impact on the OSC application, such as lack of experienced collaboration groups, complicated project planning and coordination, uncertainty of market demand, unpredictable planning decisions, unable to freeze design early on, fragmented nature of the construction industry, lack of awareness of prefabrication by the market and public, owners' negative perception, highly respective construction tolerance, transportation restraints and special requirements to unload OSC components, high initial and capital cost, longer capital payback period, resistance to change, lake of guidance and information, lack of technologies and testing institute, and limited suppliers for OSC components. However, the research also brought to a highlight the benefits such as increasing product quality and reducing construction duration, ensuring time certainty and cost certainty, compensating for shortage of skilled workers, increasing sustainability and value are usually offered or ripped through the implementation of the OSC techniques.

Many empirical suggestions were offered in this research to alleviate the obstacles and challenges to the implementation of OSC techniques; including removing logistical constraints, incapability for on-site alterations and expanding the design alternatives.

Keywords: Offsite production, Offsite construction Challenges, Sri Lanka.

This research is dedicated to my parents
for their everlasting love, endless support and
encouragement.

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LIST OF ABBREVIATIONS

CII	Construction Industry Institute
CIRIA	Construction Industry Research & Information Association
HDB	Housing Development Board
MMC	Modern Methods of Construction
NAHB	National Association of Home Builders Research Centre
OSC	Off-Site Construction
OSF	Off-Site Fabrication
OSM	Off-Site Manufacturing
OSMC	Off-Site Methods of Construction
OSP	Off-Site Production
POST	Parliamentary Office of Science and Technology
R&D	Research and Development
RICS	Royal Institute of Chartered Surveyors
UK	United Kingdom
USA	United State of America

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Research Background

The Construction Industry, with its rapid growth all over the world, is preferably, widely and incrementally adopting the Off-Site Construction (OSC) techniques. Offsite construction is an innovative construction methodology of utilizing OSC components, offering a variety of commercial and environmental advantages (Arashpour, Wakefield, Blismas, & Maqsood, 2015). This inclination will certainly enhance the prevailing popularity in the future too, because the OSC techniques facilitate the construction companies to comply with the project schedule, to efficiently handle cost control, and to minimize shortage of the skilled workforce presently experienced by the conventional construction industry. Moreover, it is stated in a study by Smith (2016), that offsite construction has a process through planning, designing, fabrication, transportation and assemblage of units for quick on-site assembling and fixation to a higher level of flawless finish than the conventional fragmentary on-site construction.

Conversely, the Sri Lankan construction industry has yet to magnify the implementation of OSC techniques. This constraint in Sri Lanka has hindered all the stakeholders from well understanding and experiencing advantages, profits and challenges connected to the application of the OSC methods in Sri Lankan construction industry. The currently prevailing scenario motivated this research undertaken for characterizing as well as recognizing the challenges facing the OSC's application in Sri Lankan Construction Industry.

The OSC, also considered as a segment of Modern Methods of Construction (MMC), is related to the production of building components in factories with a high level of consideration to product quality (Goodier & Gibb, 2007). Currently, several kinds of constructing components readily available for delivery to the job site for fixation at the ready-to-receive location (Kolo, Rahimian, & Goulding, 2014; Eastman & Sacks, 2008). The factories are the workshops to apply the innovative methods for fabrication and production of specialty building components such as doors, windows, stairs, wall panels, frame structure, and fully fledged volumetric Pods. Such manufactured products are subsequently delivered to the job site for their assembly and fixation at their respective locations (Kyjakova, Mandicak, & Mesaros, 2014).

Several studies including Vaghei, Hejazi, Taheri, Jaafar, and Alic (2014); Hansford (2015); Pan and Gibb (2009) conclude that maneuverings and offsite construction methods can be utilized in nearly all the kinds of construction. Offsite construction, traversing through the process of planning, design, fabrication, and transporting of building elements in bulk, facilitates rapid construction through quick on-site assembly and fixation of the fabricated elements and brings in a greater degree of finish than the conventional method which adopts on-site construction. As opined by Sparksman, Groak, Gibb, and Neale (1999); and Li, Shen, and Xue (2014), forming or connecting different types of materials to each other in a specialized work location is done to have the ultimate product element of the OSC.

OSC, known as an effectual and competent substitute to the conventional construction (Shakya & Kodur, 2015) with a variety of profits and values (Court, Pasquire, Gibb,& Bower, 2009) has been evaluated and perceived for betterment in adeptness and throughput in construction (Blismas, Pendlebury, Gibb, & Pasquire, 2005). As the OSC causes rapidity in construction process, a reduction in costs and project timeframe can be resultantly achieved. OSC with its several distinctive attributes which encourages for implementation of this methodology will have respectable sustainability recommendations (Krug & Miles, 2013).

Inevitably, owing to shortage in labour and shrinkage in professionals and craftsmen which cause poor performance and low productivity, the conventional construction industry in many countries incessantly suffered in various ways for the past several decades. Offsite construction methods (such as prefabrication and modularization) have been introduced as progression in order to resolve the above shortages, standardize the management of quality and also with an aim to boost efficiency of the resulted project (Neale and Sher, 1993; Gibb, 1999).

Reduction in construction cost due to no requirement of the number of professionals at the job site (because production is done in a factory), increment in the quality, decrement in construction timeframe, on-site less safety hazard, minimization of the environmental negative impact through reuse or recycle of waste materials in the factory premises (unlike in the conventional construction sites), and restraint of hazardous byproducts are some advantages interlinked with the OSC methods (Venables, Barlow, & Gann, 2004).

Nonetheless, as mentioned in studies by Eastman & Sacks, (2008); Chen, Okudan and Riley (2010); and Dawood (1995) precise designing and unflawed planning is required for ripping actual advantages, and also safety related vulnerabilities and clashes in the construction have stood as obstacles to navigate and negotiate towards the construction excellence and proficiency (Hu & Zhang, 2011). As stated in the research by Pasquire and Gibb (2002), most of the clients and contractors cited expensive logistic cost as a major reason behind their low preference toward the implementation of the OSC methods, but they did not try to experience the advantages caused by the offsite production to the project.

This research makes a contribution by identifying the current practice of off-site production practices within the Sri Lankan construction industry. This research does not only examine the driving factors and challenges interlinked with the application of various OSC methods employed in Sri Lanka, but also help for further uptake of OSC by explore and recommend new and valuable research topics for further study.

1.2 Problem Statement

Hence long offsite construction techniques are greatly contributing to the construction industry and establishing themselves as a major alternative to the traditional construction. Compared to the conventional on-site construction, the construction industry and the economy have become generally effective and efficient owing to a remarkable value generated by the OSC methods. By incorporating the OSC techniques to a project and by utilizing less on-site labour, good quality buildings can be constructed at moderate budget even in a shorter timeframe. However, the application of the OSC methods comparatively still remains with low profile in Sri Lankan construction industry.

Several government reports have mentioned offsite construction methods as part of solutions that assist improving the quality of houses by utilizing the quality materials (Venables et al., 2004), however, the OSC techniques have yet to be widely incorporated into the building technology (Ball and Barlow, 1999). The Minister of Housing of the United kingdom at the time was quoted saying OSC methods is a key component in stepping up the housing sector, but the construction industry was in a large extent very slow to make full use of the technology (Roskrow, 2004).

It looks reasonable to outline herein some problems as to the application of the OSC techniques, as referenced from some researchers:

i) Several studies have ignored many raised issues and overlooked the supply chain and its relevant applications while promoting the techniques (Roy, Brown, & Gaze, 2003).

ii) There is an understanding gap with respect to the overall characteristics about the setting up of the OSC techniques to assist the industry (Pan, Dainty & Gibb, 2004)

iii) According to Gibb (2001), several studies have been performed as to how offsite manufacture is assimilated with the purpose of fostering superior quality, curtailing material wastage generated on-site and minimizing on-site construction duration. But the practice of OSC methods is relatively very low in Sri Lankan construction industry (Silva, Rajakaruna, & Bandara, 2008).

Very limited numbers of studies in relation to the OSC methods have been done in Sri Lanka; one of them is by Uthpala and Ramachandra (2015) carried out to establish project owners' satisfaction levels with different off-site construction methods.

However, no research carried out in Sri Lanka has sufficiently raised the issue related to the challenges in implementing OSC methods in the Sri Lankan construction industry. This issue was found to have been researched in other countries, but due to variance in the conditions, the applications of these researches are not relevant and appropriate in Sri Lanka.

Therefore, the off-site construction challenges in Sri Lankan construction industry is used as the research problem. These outcomes and recommendations of the research would guide to the efforts targeting at solving the problems in connection to building shortage in Sri Lanka.

1.3 Aim

The aim of this research is to investigate the application of off-site construction in the building sector of Sri Lankan construction industry.

1.4 Objectives

The followings are the set objectives to achieve the above aim:

i) To identify the nature of off-site construction application in the Sri Lankan building construction sector.

ii) To identify the extent of application of different types of off-site construction methods adopted in the building sector of Sri Lankan construction industry;

iii) To identify the benefits of and barriers in implementing off-site construction methods; and

iv) To determine the challenges faced in the application of off-site construction methods with special emphasis to project managers.

1.5 Outline of Research

The research was approached as follows:

i) In depth review of relevant literature on off-site production was carried out referring reports, journals, conference papers, and books with the aim of summarizing past research and drawing conclusions from various studies that address the related problems.

ii) The major research method used in this research was survey. This included Questionnaires survey, field observations and pilot studies to identify benefits and challenges of offsite construction techniques and discussions with industry experts to gather detailed information on the study area.

iii) Questionnaires sought the views of professionals in the construction industry such as Project Managers, Architects, Civil Engineers, Quantity Surveyors, Contractors and Off-site Manufacturers among others.

iv) Mathematical review was used to examine the measured methods and operational definitions that were applied to the problem areas of the study.

v) Identifying the challenges faced by the project managers and recommending mitigation strategies for the challenges that prevents the offsite method of construction usage in Sri Lanka.

1.6 Scope and Limitations

The scope of the study was limited to key stakeholders in building sector of Sri Lankan construction industry. Conclusions are based on case studies and analysis of opinions of industry experts who are playing a managerial role in the building sector of Sri Lankan construction industry which comprises of Designers, Consultants, Contractors, Senior Quantity Surveyors, Project Mangers, Architects, Civil Engineers and Manufacturers of off-site produced building components.

1.7 Chapter Divisions

Chapter 1 : Introduction

This chapter presents a general idea about the study research and the outline of the research is given concisely with the research backdrop, problem statement, aim and objectives, research questions, research outline, scope, and limitation.

Chapter 2 : Literature Review

This chapter offers a brief history and examines the theoretical background of the current off-site production practices within the Sri Lankan construction industry. Further, it describes the past studies carried out on the benefit of and barriers to the various off-site construction methods employed in Sri Lanka, through which an essential specification will be determined for conducting a questionnaire survey.

Chapter 3 : Research Methodology

This chapter firstly places an emphasis on the importance of the study. Further, this chapter describes the methodology adopted in this research. Eventually, data collection and analysis methods all of which are elaborated broadly.

Chapter 4 : Data Collection, Analysis, and Finding

This chapter describes the data collection, analysis and research findings. The discoveries on implementations of various OSC techniques in Sri Lanka are described in this chapter.

Chapter 5 : Conclusions and Recommendations

This chapter provides the summary and conclusion of the research with its findings; along with propositions and recommendations offered for its enhancement and fostering, based on the survey consequences. Ultimately, the chapter deliberates about the prospects existing for additional studies.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The overall view of the research is explained in the previous chapter. The historical background of Offsite Construction (OSC) methods and offsite development techniques in various types are reviewed in this chapter through a detailed literature review of the application of OSC methods in the UK, Europe, Asia and Sri Lanka. Additionally, a background investigation related to the conclusions by researchers or various construction professionals is provided in this section. The research problem is developed using this literature review findings and arguments. Moreover, the first objective of this research is accomplished by examine the recent research literature from reliable sources in this chapter. This chapter provides a brief history and examines the recent research literature on the current off-site production practices within the Sri Lankan construction industry followed by a detailed discussion on the benefit of and barriers to the various off-site construction methods employed in Sri Lanka

2.2 Historical Background of Offsite Construction

It is obvious that there are numerous evidences to prove that the usage of prefabricated buildings is not a new phenomenon belongs to the recent times. Several researches have noted its prevalence from 19th century onwards. Taylor (2010) mentions about John Manning's creation of a movable colonial cottage and various other offsite productions used throughout the 19^{th} century. As per Gibb (1999), high requisition for 'accommodation of European design' and a lesser preference for utilizing of local workmanship and materials boosted the production and use of prefab houses during the European colonial expansion. Other historical instances Gibb (1999) has cited are:

1) The use of prefab hospitals during the Crimean War, and
2) Popularity of the 'industrialized building method' giving way to the application of prefab cast-iron buildings owing to the industrial renovation.

The post second world war scenario witnessed the enhanced scale utilization of the OSC due to the escalation in populace with a huge requisite for new accommodations and settlements, resulting consolidation of the prefabrication process in meeting the demand. The researcher Finnimore (1989) refers that high requisition for public housing arose particularly owing to the emergence of the Western World welfare. Prefabricated construction components suited perfectly for the said purpose because of their standardized approach and had popularity for budgetary scale derived from standardized voluminous production (Venables et al., 2004).

The 20thcentury end experienced the implementation of the OSC in large scale in varied areas such as buildings for prisons, schools, and hospitals, and many others. This increased utilization of the OSC method was seen in societies which like to maintain a wealthy status and were reluctant to benefits from public welfare projects. These societies tried to show their prosperity increased the usage of OSC method in commercial project like airports, hotels, gasoline outlets, retail hubs and in many others with typical design and specifications. Nevertheless, as highlighted in Gibb (2001), the OSC has yet again to become a suited method for fulfilling some rapidly enriching countries' desire for housings with similar design and quality or exceeding the housings of the post second world war western world. For this need of provision of economic standardized accommodations for larger population, priority of the OSC in the residential buildings is seen retained in developed countries like Germany and Japan.

Perceiving through Gibb (2001), the OSC going through increment and decline is not only a developing trend characterizing a kind of teleological tendency, but also stands for providing more advantages while perceived it as a cyclical phenomenon. The OSC's trend increment is like a periodic fashion, its application is on increment when usefulness of its inherent benefits perceived. As pointed out in Gibb (2001) and Venables et al. (2004), socially, culturally and economically influenced perception remains a key factor (throughout history) relating to OSC's application and implementation. Conclusively, societal perception overlay guides OSC's value and its wide application to some extent.

2.3 What is Offsite Method of Construction?

According to Gibb and Pendlebury (2005), off-site fabrication, semi building frameworks (PODS), assembling of the panelized frameworks and isolated structures are included in the OSC which involves a process of (prepare, design, manufacture, move and assemble)rapid assemblage of building components at the job site. Off-site construction, is an application of modern technique and also a combination in the middle of building and assembling, encompasses typical terms like off-site manufacturing, off-site pre-fabrication, and off-site production. It also includes offsite construction and modularization procedures which are currently innovative for all the stakeholders craving for primal budget feasibility.

2.4 Definition of Terms

2.4.1 Offsite pre-fabrication

Tatum, Vanegas, and Williams (1986) contended offsite pre-fabrication or pre-assembly, is a procedure applied for combing together various construction materials, pre-assembled segments at a distance area in order for on-site fixation; for example: rooftop trusses, and pre-fabricated vessels with protection, stages, the channel and stepping stools.

2.4.2 Volumetric systems

As per Lawson, Ogden, and Bergin (2012), the manufacturing of three dimensional modular elements in controlled factory environment and subsequently its transportation for on-site fixation is the process involved in volumetric construction.

2.4.3 Panelized systems

According to Ross, Cartwright, and Novakovic (2006), panelized construction system involves factory’s manufacture of panelized units and its subsequent on-site assemblage for formation of three dimensional structures. For instance; open panels consisting of skeletal structure only, but lining material, insulation, doors and windows, internal finishing and exterior cladding may be included in more advanced panels.

2.4.4 Hybrid systems

Combination of both panelized and volumetric construction systems come to be known as hybrid systems (also referred as POD). Volumetric units are in use in the construction of highly serviced and frequent foot paced areas such as washrooms, bathrooms, and kitchens and the remaining areas of the building get the usage of panels. (Tatum et al., 1986)

2.4.5 Sub-assembly and accessory system

Accodring to Ross et al. (2006) larger components (factory manufacturer, and not fully housing) facilitating self-incorporation into traditional build is the construction process familiar as sub-assembly and accessory system.

2.4.6 Prefabricated buildings

As per O'Brien, Wakefied, and Beliveau (2000), manufacturing of dwellings of one or more units (at a distance from the job site) in a fully-fledged industrial facility, followed by its transportation and fixation at the job site is a prefabricated building. It typically consists of 3 dimensional varied rooms and fully pre-installed internal utility services (electrical, mechanical, and piping). Strong, desired quality, rapid construction, multi-purpose use, and profitable utilization are some characteristics appreciably linked to prefab buildings (Tatum et al., 1986).

2.5 Overview of Offsite Construction Methods

According to O'Brien et al. (2000)and Bourn (2004); offsite development or off-site construction, rendering critical benefits for construction experts and designers, is a segment of contemporary techniques of construction and is considered as any of the elements of the building fabricated in factories (which give due consideration to quality control) where innovative techniques are used for manufacturing highly specialized products like bathroom pods, wall panels, frame structure of the buildings, and complete volumetric products, and finally delivering fabricated units to the job location and for on-site assembling.

According to the research done by the Royal Institute of Chartered Surveyors Construction Faculty, which evidenced that 63% of the conventional construction projects were completed on time, while only 49% could be delivered in compliance with the project budget. The research caused several construction companies to reconsider over their construction methods, and resultantly they started adopting offsite construction in order to minimize the resource inadequacy and increment of construction productivity. It was also noted that when the design team carefully considered the OSC techniques (which involves design standardization and prefabrication process) at the initial design phase, then only the OSC concept would get efficiency and effectiveness and would prove advantageous to the clients as well as the design team (CIRIA, 2003).

According to Tatum et al. (1986); many advantages are associated with off-site construction, and its adoption and application by companies and contractors have been wide in order to early or timely delivery/handing over of the project. They abide to the governments' strong insistence upon OSC method application for expediting the project completion and delivery, and also consider the following general benefits of offsite development:

- Better quality and less workmanship
- Sustainability, and cost predictability
- Reduction in health and safety risks, and maintaining the environment
- Short construction span
- Feasibility and economical for the typical building (Gibbs, 2001).

Off-site constructions progressively have impact in taking care of today's issue of moving towards an economical construction industry (Venables et al., 2004).

2.6 The Use of Offsite Construction Techniques

The application of offsite construction techniques in some international countries such as United Kingdom, European countries, and Asian countries are examined in this section. The international construction market's application of OSC techniques (as developed) might bring in ramifications in the Sri Lankan context. Additionally, the application and implementation of OSC techniques in Sri Lankan construction industry is also elaborated in this section.

2.6.1 Applications of offsite construction techniques in United Kingdom

England commenced making use of OSC techniques from 1624 firstly with a timber used panelized house for the fishing fleet in Cape Ann. Furthermore, Peterson (1948) highlighted that the said timber house was subsequently disassembled, moved to a different location, and reassembled several times to be utilized for multipurpose.

Early 20thcentury in the UK experienced mass prefab systems implemented for key activities for buildings and resulted motivational and a massive demand towards the system implementation. Great demands for new accommodations in the post first world war period, incapability of the conventional building approaches to produce sufficient number of houses in a short construction period, and a dearth of trade/skilled workforce were some main reasons caused the motivation and demand for the offsite construction. Waskett (2001) has emphasized about the conducive environment created for implementation of new and innovative construction methods, approaches, and processes owing to the slow and low productivity associated with the conventional construction method, and due to the war resulted massive destruction which prompted the situation for new housings to be built in very short time. Nevertheless, according to Waskett (2001) the OSC's constant evolution in the UK not occurred in the post first world war because of the initially primal focal laid over developing and applying of alternative construction elements rather than masonry and concrete. Hence, no substantial change resulted in the then housing construction approach towards the technology to proceed forth.

Waskett (2001) opines in his research that the OSC technique's development and promotion takes its relationship with the instant pressure fallen over the UK government's obligation for the post second world war reconstruction, and as well as for providing the war returned soldiers with proper housing and employment. The resultant scenario led the government for the formation of 'the UK Inter-departmental Committee on House Construction' in September 1924 for the committee to provide an instant proactive professional contribution for developing alternative methods and materials for construction with due consideration for the construction aspects related to construction finance, efficiency and rapidity. Resultantly, the OSC technique emerged and got implemented in the UK construction industry.

The invention and implementation of timber framing systems from 1927 to 1941 brought a significant impulse and contribution to the OSC application. The inherent capability of timber to get easy formation into panels gave a boost to the factory fabricating accommodation unit and subsequently its transfer and on-site assembly, and furthermore, maturity of prefab and preassembly techniques occurred through the innovation and advancement of large panel systems in 1948.

As stated in BRE (2003) numerous factors, including rapid construction requirement and insufficient skilled trade workers greatly facilitated the OSC technique application in buildings, and also with the UK dominant construction companies' policy for incentive provision for prefab and standardized technique implementation for productivity enhancement and reduced construction duration. According to Gibb (2001) modularization or modular design is the chief factor in the UK OSC technique due to its offering of characteristic and distinct benefits (in contrast with traditional techniques) such as safe work environment, shorter construction duration, improved product quality and workmanship productivity to the clients. For instance, McDonald's restaurants. Not only in the commercial construction sector, but also the OSC's wide implementation was found in usage in the UK industrial construction sector (Blismas, Pasquire, & Gibb, 2006).

Despite the various advantages generated through this construction approach, the OSC has not yet got its dominant application in the UK due to some reasons (but not limited to) outlined below:

- Client’s reluctance for a new building technique due to no sure-shot benefits to a project (Pasquire & Gibb, 2002)
- Some trade rival's (construction companies) opposition to the new technique (Edge et al., 2002)
- General perception for construction cost increment (around 7-10%) (BRE, 2003)
- Requirement of highly skilled labour for appropriate assembly, and insufficient skills of on-site assembly workers
- The prefab factory’s lacking in capacity (Goodier & Gibb, 2005).

However, as comprehensively studied and researched by Edge et al. (2002), the OSC technique itself is not under opposition, indifference and dislike of the building project clients, but their partial reluctance toward the new construction materials. Further, he has expressed in his study about the increasing existence of a strong construction market for new-techniques-built housing with affordability, sustainability and flexibility.

2.6.2 Applications of offsite construction techniques in European Countries

The off-site construction technique, with its application in various ways by most European countries for several years, was implemented and enhanced as a system (in each country) adapting to their own tradition and construction methodology. The Netherlands used a hybrid method (concrete shells and timber frames) for home construction, wherein OSC techniques were applied mainly for roof and wall panels, which came to be known as 'techniques of rationalized fast-track housing'. Formworks of steel tunnel with cast-in situ concrete are used for completion of a building, considering feasibility and cost effectiveness (Pasquire & Gibb, 2002).

The Netherlands-used-OSC techniques involve prefabricated and insulated structural walls with windows and doors made of timber cavity leaves, and the prefabricated cavity walls containing timber panels, plasterboard, insulation, damp-roof courses, door frames. This technique used for building to achieve non-load bearing, flexibility in design layout, quality in acoustic and fire rating; such as gypsum blocks, prefabricated roofs with lights and ventilation, timer hinged roof elements fixing on wall plates (Waskett, 2001).

In additionally Waskett (2001) has stated that comparatively to the Netherland's conventional building technique; the OSC technique resulted in the following benefits, which always guide the dominant builders for its application in construction for reaping these associated advantages, and its successful implementation in the construction industry has been since a time more than 25 years :

- Reduction in construction period (approximately from 21 to 12 months)
- 33% More floor area for usage
- Reduction in construction cost approximately up to 17%

2.6.3 Applications of offsite construction techniques in other Asian countries

Unlike in Western countries, application and implementation of OSC techniques has not been so wide in Asia. The use of precast reinforced concrete (PRC) is one effective method for multi-story buildings, which is (an instance of the OSC) evolved in Singapore, along with other developed nations.

Housing Development Board of Singapore, with its intent for solving the problem of insufficient labour facing the construction sector due to its dependency on the overseas labour recruitment, innovated the following basic construction technologies:

1)Fully precast building system

2)Semi-precast building system

Referring to the research by Gibb(2001), this states that the HDB, gaining good lessons from European experience in relation to quality control and on-site workmanship, strongly required cautious pre-planning initiating with the design concepts for a project. The following are the major characteristics for HDB's semi-precast reinforced concrete building system:

- Cast -in-situ beams and columns (reinforced)
- Other reinforced concrete elements being pre-cast
- internal non-load bearing walls, parapets, and staircases being pre-cast

HDB of Singapore also innovated and implemented the following building systems associated with OSC techniques, targeting a reduction in quantities of modules, and expediting of the on-site installation process:

1) PCBS (Pre-cast column-beam-slab system) connecting the PC concrete and beams through incorporating bolts and anchors
2) Post-tensioned flat plate floor system requiring the three storey precast columns with on-site concrete flat slab with no supporting beams.
3) Volumetric bathroom unit comprising a concrete base or fiber glass with lightweight framing for the walls and ceiling enabling easy installation and on-site handling (Gann, 1993).

In contrast Pasquire and Gibb(2002)has emphasize, similar to most other Asian countries, Korea's clients / contractors preferred and widely adopted the OSC techniques for the construction of high-rise buildings even with 15 floors. For instance, Daewoo Corporation (Korea), a builder popular in OSC field, always prefer establishing a prefab facility in the project job site with an aim to alleviate the logistics and transportation headaches, and with its claim that their adopted system has the rapidity by three times more than the other conventional methods.

2.6.4 Applications of offsite construction methods in Sri Lanka

Even though the applications of offsite construction methods are relatively low, almost all offsite construction methods are used in Sri Lanka construction industry. The below photographs of Sri Lankan offsite construction projects containing modular, hybrid, and panelized construction projects are the clear evidence for it.

Figure 2.1:Some Sri Lankan Offsite Construction Projects

2.7 Types of Off-Site Construction

Innovative building products and new construction method increasingly being common, which characteristically involving extensive factory production of sub-assembly sections and components in sequence with the augmented methods of on-site assembly, are some features inherent in Off-site Construction. In OSC the component systems ranging from small sections to the substantially complete buildings. These features are highlighted hereunder.

Sevaral authors including AMA Research Ltd, Hartley, and Blagden (2007); BRE (2004); Boyd, Khalfan, and Maqsood (2013); Burwood and Jess (2005); CABE (2004); Miles and Whitehouse (2013); NAO (2005) have given different classifications to off-site construction. How ever by compairing all those classifications, OSC Method classification can be outlined under the following 4 main categories:

1) Volumetric systems (Modular and Pods)
2) Panel systems (open and closed)
3) Hybrid systems (semi-volumetric)
4) Sub-assemblies and components

The foregoing list/classification is by no means a comprehensive one due to continual evolution, development, progression, and innovation being in new materials and construction techniques.

2.7.1 Volumetric system

According to Doherty (2011) 'Off-site' production of three-dimensional units is a distinct characteristic involved in volumetric construction (also familiar as modular construction) having better sustainability value in contrast to the conventional techniques due to its requiring the minimum foundations, production activity under factory conditions, and resulting the better quality elements/products with least defects.

With the application of new advance finishing techniques, OSC (Modular Construction) can produce an easily customized, sophisticated elements/modules and panels (such as cladding and roofing) in line with the client's requirements as well as rendering the building with its natural interior /exterior surface suitable to the surrounding. Regardless modular construction's usage of the same industrial sector techniques, the resultant product is not similar to "mass production product".

As described above, the Volumetric construction (also referred as the modular construction) requires transporting (to the job site) as they are produced fully fitted 3-dimensional products, and their fixation on the on-site prepared foundations for forming the dwellings. This construction method, due to its extensive adaptability in usage of wide range components, including some hybrid building materials, usually facilitates the delivery (to the job site) of its products/modules in various forms from basic structural shell to finishes with services fully pre-fitted. Pods, which are on-structural within a load-bearing structure, are the best instance of volumetric construction (Tatum et al., 1986).

The advantages (but not limited to) inherent in the Volumetric Construction can be outlined as follows:

- Better quality control
- Minimizing the on-site workload
- Waste reduction of up to 90% at the job site
- Production within a controlled factory environment
- Optimal utilization of materials, and a reduction of waste generation

2.7.2 Panel systems

OSC is the most suitable method of panel construction, which requires a production under a controlled quality process within closed factory environment, with assembly on-site for forming a 3-dimensional structure (possibly consisting of pre-assembled wall, floor or roof units), thereby referred to Panel systems.

As per Pasquire and Gibb (2002), right selection of the supporting components (such as sealants), brings in benefits of OSC panels, results rapidity in the frames' fixation/erection. The simplified form of panel system is the pre-assembled sandwich panels consisting of the structural elements including the interior and exterior finishes.

According to Ross et al. (2006) the major types of Panel Systems are as follows (regardless being several different types):

Open panel: Components such as insulation, lining boards, and vapor control layers are not included in an Open Panel (either structural or non-structural).In open panel all structural components being visible, requiring the fixation of the above components to the frame system on site. On-site finishing application of an open panel requires careful control including protection until moves a weather proof stability.

Closed panel: Factory pre-installing insulation and lining materials, including finishing items, and with possibly usage of timber, steel frame or concrete panels and with pre-installed services are involved for the Closed Panel having the internal structural components visible around its perimeter (Ross et al., 2006).

Concrete panel: The structural wall panel, which can include cladding, insulation materials, windows and doors.

Composite panel: The panel consisting of a fusion of more than one kind of material is identified as composite panel wherein all the mixed materials have their own simultaneous performance for structural support; for instance, structural insulated panels (Ross et al., 2006).

Structural insulated panel: The structural insulated panel is fabricated through sandwich construction which applies two layers of sheet material attached to a foam insulation core. It doesn't depend on internal studs for its structural performance. Its primal use is usually for cladding the walls and roofs in a building.

Infill panel: The infill panel is a non load bearing panel implanted within a frame in a structural. Although the framed panel being common, any panel with the unfilled characteristics can serve the purpose.

Curtain wall: The curtain wall is the exterior wall system of a perpendicular building, which does not sustain any load other than its own mass and the environmental load performing upon it (Ross et al., 2006).

2.7.3 Hybrid system

Involvement of both the panelized and the volumetric approach is found in the Hybrid System. This system is familiarly known as semi-volumetric construction. As it typically produces volumetric components such as kitchens or bathrooms (highly serviced areas), while the rest of the dwelling is constructed with panels.

2.7.4 Sub-assemblies and component system

Sub-assemblies and component system is the most traditional and widely used system in OSC for many generations (Neale & Sher, 1993).Sub-assemblies involves factory-built components in conventionally constructed structural form. Typically it applies floor or roof cassettes, precast foundation, pre-fitted services and cladding systems; including elements with a different type of materials such as precast concrete, and voluminous elements that can be integrated either into the conventionally built or Off site fabricated accommodations. The precast or prefab elements are not the substantial housing 'system', but they are typically manufactured in an offsite factory, or on-site assembly is sporadically carried out.

Accodring to Ross et al. (2006) the following are some categories of Sub-assemblies and components:

Pre-fabricated foundation: The pre-fabricated foundation is a construction assembly method which involves the on-site assembling of pre-manufactured ground beams and other required structural elements for constructing a quick and precise foundation.

Floor cassette: The floor cassette is a pre-formed panel intended to create a floor. Reduction in man-hours, workmanship, and work at height is a beneficial factor rendered by this sub-assembly method.

Roof cassette: The roof cassette is a pre-manufactured panel particularly targeted for forming a pitched roof in a building. When the panel is fixed at the roof, it allows easiness for forming a room with no requirement of usage of construction supports and props, and also renders a better water leak proof to the building than a conventional (structural steel) roof truss system does (Ross et al., 2006).

Pre-assembled roof structure: Pre-assembled roof structure involves assembling of pre-manufactured elements at ground level, which is followed by lifting such assembled roof (by means of crane hoist) to be fixed in the designated location immediately after the completion of a building's superstructure. This kind of sub-assembly technique causes the better formation of a watertight roof than the in-situ roof does. Alleviation of occupational health and safety hazard is a primal benefit obtained from the above technique owing to reduction in the manual work at height.

Pre-fabricated dormer: The key intention behind the design of the pre-fabricated dormer and its fixation to the roof is to achieve rapidity in the roof construction process, and to consolidate water leak proof to the roof of a building.

Pre-fabricated chimney stack: The pre-manufactured chimney stack is a prefab unit which is manufactured through cladding by brick slips in an offsite factory, and is light in weight. The said chimney stack (due to its lightness) suitably fits on a roof structure, which takes in flue liners and performs simultaneously with other ignition appliances (Ross et al., 2006).

Wiring loom: The wiring loom is a cabling system manufactured in varied lengths for facilitating a quick assembly with comparatively unskilled labour. The beneficial factor associated with it is easy termination through simply plugging into sockets and other electrical accessories.

Pre-fabricated plumbing: The plumbing pipes and fittings are manufactured in an offsite factory through the pre-assembling process in volumetric units for the rapid throughput of units in the factory (Ross et al., 2006).

Timber I-beam: The Timber I-beam (the wood naturally being very rigid in weight) is fabricated in varied lengths and depths in an offsite workshop. The timber can be fabricated (either in solid or in composite form) to be used for multiple purpose in construction, such as (props, studs, beams, struts, supports, I-beams). The usage of Timber I-beam facilitates creating of a structure (which is supple in design plan) in required length with no support required.

Metal web joist: The metal web joist is lightweight unit fabricated by combining two timber flanges which is detached by a light gauge steel frame mesh. The usage of metal web joist facilitates creating of a structure in required length with no support required (Ross et al., 2006).

2.8 How Does the Off-Site Process Work?

The Off-site industry, whose growth history starts from the modular production (re-locatable) to the building construction sector, projects out some problems for off-site manufacturers(Smith, 2016). Off-site work manufacturers' accustom to delivery of the buildings on turn-key contract as per client's preference for the one-stop shop approach. Other difficulties facing the off-site industry can be outlined as follows:

- Insufficient experience of the off-site industry on complex projects
- Involvement of numerous project stakeholders through the project duration creating a new environment/ the territory for the manufacturers of off-site units.

The construction sector's ideological and structural transformation / inclination toward the design-build and integrated project delivery(involving performance and shared risk and benefit)from conventional design-bid-build contracts caused the OSC to be identically associated with integrated delivery. However, a research talks about an undesirable impact over project schedule and budget in a (post design phase off-site work implemented) project owning to the delayed application of modular in the building delivery process (Smith, 2016).

As outlined in Smith (2011); preferably, the following queries would be put as questions by the stakeholders of off-site projects throughout typical project stages:

- **Pre design:** Does the OSC's application assist in compliance with the budget, timeframe, resources, and schedule's aims targeted for the project?
- **Design:** Does the project's design incorporate the stakeholders connected to offsite production, delivery, on-site assembly and dismantling (if needed)?
- **Develop:** Is the design of the project provisioned therefore on-site activities and offsite manufacturing can be individually segregated or enlisted?
- **Detail:** Are the design details of the project prepared collaboratively with feedback from the designer, a general contractor, offsite manufacturers?
- **Order:** Is the reduction in design changes done and materials procurement order issued in a concise time frame for minimizing cost?
- **Fabricate:** Is a fabrication done with archetype and delivery period minimized after feedback taken from the project team?
- **Delivery:** Are site deliveries timely done to the site to lessen the handling process?
- **Assembling:** On-site assembling activities designed in collaboration and continuity maintained to confirm parameters as to budget, quality, timeframe and safety are complied with?

2.9 Why Off-Site Construction

Responsibility delineation is rigid and comprehensively elaborative on the failure consequences in Traditional Contracts and On-site Construction practices. Risk-abating practice including discouragement of the project teams' engagement in concerted processes gets reinforced by this context, which rises to an adversarial construction culture, posing substantial disadvantage to all stakeholders. Project Owners' monetary losses, indifference by project architects and engineers to quality increment in design, an imposition of unnecessary financial burden and risk on contractors in the process are the by-product factors of the above construction culture. This disintegration has been calculated in relevance to waste and productivity (AMA Research Ltd et al., 2007).

The designing and assembling of objects installed-in-place is a construction essentiality. Therefore, job site products, ever unique and the engagement of temporary teams are some construction features of traditional buildings. This triangle can be known as the "construction's idiosyncrasies", i.e.; a distinct from other production industries. The removal of site production, a disregard to uniqueness in a building, and the intact (project dedicated) workforce are considered as a support to the process which leads to more productivity (Smith, 2011).

The entire removal of the site being apparently not possible, nevertheless reduction or removal to a certain degree of site peculiarities, and adoption of factory production certainly assists to have a positive result in construction productivity.

The project dedicated (intact) work team is an idea, i.e.; resultant success to design-build entities and designers or builders in a constant engagement with the same engineers, contractors, and sub-contractors. Off-site production is an instance, having the capability in controlling the workflow and resultantly keeping the work teams intact (Smith, 2016).

Eventually, the typicality in the building design and manufacturing process is fickle, or alterable which can, in fact, be restrained through wastage eradication and value addition in the building process (Smith, 2011).

Construction performance examination is a requirement for increasing construction efficiency through offsite production. There are many functioning issues for each project to take into account; some of which are outlined hereunder:

- **Budget:** cash flow and functional financing
- **Workmanship :** The trained and untrained manual labour
- **Scope:** coverage or scale of project schedule
- **Quality:** complying with the targets and objectives of the design and construction
- **Risk:** susceptibility to likelihood commercial harm/, or loss

Despite all the aspects not be equally significant in a certain project; there is an existence of a reliant relationship for each. For a certain plan, establishing the relationships between quality, schedule and budget is usually (or even unintentionally) performed by the project design team. The connection existence between these remains so strong that a modification to one impacts all the others. For instance, the selection of a lower quality material by a project owner's team in view of value engineering (cost saving) or for allowing the project timely completion can be taken as a balancing factor with risk playing a critical component (AMA Research Ltd et al., 2007).

Nevertheless, offsite construction is not a sure-shot way out to each construction project. Intrinsically, a descending scale of chances and compromises (rather than absolute remedies) is embodied by the doctrines in relation to budget, workforce, limitation, quality, and risk. Off-site construction, while formulated with intent and early planning, may be a way out in balancing these contending functional targets of construction. Offsite production and primary preparation and scheduling are co-adjacent conceptions, requiring the early engagement of the offsite manufacturer in the design phase in order for establishing the balance which is a prime basis for the effective operation and exploitation of off-site construction (Smith, 2016).

2.10 When Should Off-Site Construction Be Used

Highlighting the advantages of offsite construction in general and presenting off-site methods as a way out to the problem faced in every construction is not herein the intent. Off-site better performance on some building types through the engagement of specific work teams has been achieved in some particular places. These procedural rules are not to be understood conclusive, but those rules are advisable to be taken into consideration while determining whether offsite system is apt (Smith, 2016).

- For projects with constrained schedule (such as schools and pupils' accommodations with a fixed timeframe opening, or embassies to be built as a fast track project in a foreign country, or retail units with nonnegotiable handing over date); designing and implementing a building type through fast track construction schedule is an appropriate method requiring Off-site construction.
- Off-site construction provides substantial benefits and advantages for typical projects such as the ones having similar features applied. For instance, they can be varied like classroom, dorm, office, laboratories, advanced facilities, communication structures, and lavatory pods, and also for other projects which embody exclusive forms, distinct sustainability requirements, or an enhanced level of control in the finish product (Smith, 2016).
- The implementation of OSC can be extensively determined by the project owner's selection of the delivery method. Any contract form can apply the OSC method. On the other hands, design and build contracts without the contractor's involvement for means and methods during the design process, or construction manager contracts without the project owners' inputs for the construction method can ignore off-site production and delivery. Mitigation for disregard to the off-site method can be achieved through selection of design-build or integrated contracts with the project owners opting an early fabrication, collaboration between designers and builders with dealers and/or direct involvement and assistance of producers of offsite goods through the design phase and during planning and sequential progression (Smith, 2016).

There are some features inherent with team members that contribute to the implementation of offsite system, including the following:

- The team members with previous experience in offsite construction are ready to give their preference for reusing the same construction method. Such experienced design team and contractors having off-site experience are always confident and proficient to redeliver. These proficiencies are dissimilar than on-site construction, as we have deliberated, where the performance of coordinating dispatching, installing and fitting requires and involves an incorporated course of action (Smith, 2016).
- Re-engagement of the team members on heterogeneous projects builds confidence between stakeholders, which is a required factor for project stakeholders dealing with a specified seller and manufacturer for a series of projects with a perpetual workflow and recurring process of decision-making, functions and accountability.
- Off-site (rather than traditional on-site construction) always remains preferable for a Project Owner being focal on maintaining project cost control, schedule and quality. Additionally, an owner with sufficient investment cash flow at the project commencement remains highly ensured to its successful completion and handover as project expenditures and payments being early as per contract agreement with the manufacturers (Smith, 2016).

The following are some off-site project location determinants:

- Off-site factory production is less beneficial for sites with easy access, affordable land, and a year-round construction seasons. In contrast, off-site is the most preferable as well as beneficial for sites located in a remote area, highly dense urban sites, sites within a short build season, or expensive land sites requiring a reduction of construction cost (Smith, 2016).
- Off-site construction is less preferable for locations with easy access to a range of construction materials, manufacturing of components using stick elements or planar elements, and easily available low waged labour.

- Finally, offsite construction methods cannot be followed in all the projects due to building code jurisdictions, which requiring extra care and precaution from the building team in preparing alternate means for permission and inspection. Comprehensive review and reporting cycles may fulfil these requirements that would customarily be observed in conventional on-site construction. Coordinating with the local building authority is an appropriate approach to confirm the process relating to the necessities of off-site departmental (regulatory) analysis (Smith, 2016).

2.11 Benefits of Offsite Construction Methods

Many researchers have been carried and ongoing pertaining to the benefits of offsite construction methods. These performances have made an immense contribution to the enhancement of the construction sector with respect to several factors (timeframe, budget, product performance, onsite occupational health and safety (OHS), throughput, maneuvering, and environmental matters) of a construction project (Pan, Gibb, & Dainty, 2012). The advantages obtained from offsite construction in a general view have been widely recognized (Connor, Brien, & Choi, 2014).The acknowledged benefits of offsite construction as against conventional on-site construction are summarized below.

2.11.1 Time saving

Reduction in construction duration is the first and foremost benefit provided by off-site construction, which is construction time reduction on site through transfer to a significant portion of work to an off-site facility. An effective compliance with the construction deadlines (than in a traditional on-site environment) can be ensured through the certain conditions and economy scale generated by the factory. The contractors and designers are hugely encouraged through business advantages for adopting and incorporating off-site construction elements with their design and construction process. Rapid production and on-site assembling is a factor associated with business benefit (Blismas et al., 2006). It was found that modular construction is 40%-60% speedier than the conventional construction method. The business commercial calculation (cost and revenue) ensures the delivery predictability as accurate estimation for manufacturing process in a quality controlled factory. This processing performance confirms the occurrence of the product delivery and assembly operation as scheduled (Lu and Liska, 2008).

Bad weather condition is a hindrance for work progress in on-site construction and one of the main variables of the construction schedule. Off-site construction minimizes the likelihoods of delay, safety and precautionary requirements related to certain project. Nowadays, scheduling or detailing problems alone cannot assist many residential construction companies from huge productivity problems. Off-site construction technology can offer a way out of restraining the schedule and refining efficiency (Sawyer, 2006). Not only for housing, off-site construction method has gained application popularity for some major retail clients due to continual construction time reduction, schedule savings and no risk from inclement weather and as such no weather protection requirement. Procurement of factory-built units is no way impacted by weather conditions. The adverse weather conditions do not delimit or disturb the work program in the manufacturing line guided by the commencing and ending dates (Goodier & Gibb, 2007).

2.11.2 Quality improvement

Quality improvement is another significant benefit cited by all stakeholders. Tighter control over quality is an advantage of off-site construction. Significant improvement of quality and the efficiency of the building has occurred in off-site production of construction elements due to a high standard of quality control and test, even with buildings exceeding requirements on thermal and sound insulation levels, and resulted more sustainability (Goodier & Gibb, 2005). Precise design and close supervision results in achievement of higher product quality through application of prefabricated construction elements due to which scope change and the amount are minimized or avoided. Better quality control on the project is materialized through an accurate profiles and standardized dimensions of construction elements (Pan et al., 2012). Currently, variance of each product from each other is performed through computer-assisted manufacturing technology (Russell, 1981).

Steadiness of a procedures consistent with enhanced quality, hence more anticipatable product performance. A reduction in snag lists and imperfections enrich quality assurance. The quality assurance process implemented and capital spending in research and progression result in the elevated degree of thermal and acoustic performance(Gibb & Isack, 2003).

Three dimension modeling and module scheduling capacitates a substantially completed building to be envisaged preceding construction. Modifications and alterations in the layout can be prepared swiftly and economically. Factory production lines employ machines and manufacturing methods with reference to the fixation drawings. As-built drawings and lists of equipment are incorporated in the Operation and Maintenance guide facilitate the identifying and locating of parts for upkeep and repairing schedules (Venables et al., 2004).

2.11.3 Cost reduction

Cost saving is the perceived benefit of off-site construction, a major advantage in several surveys. OSC technique at a project results in savings at production stage due to a large volume fabrication which relates to savings in material and labour. According to an industrial project survey (CII, 2002; Tatum et al.,1986), a reduction in on-site labour cost reduction by 10% - 25%.

Quick delivery and fixation times are not billed in tenders, and the implementation of trades from conventional construction techniques abrogates, or rescinds several gains and improvements. For instance; pre-manufactured concrete piles and circular girders are pre-cast with concrete in offsite factory, which are transported to and installed at the job site (Blismas et al., 2006). On-site fixation of the aforesaid types of precast units can be performed in few days unlike in conventional construction techniques (i.e.; cast in-situ) which may take weeks for completion. Reduction in site stowage and job site wellbeing amenities are other benefits which result cost minimizing in a project's preliminaries (Gibb, 2001).

As stated in the research by Pan, Gibb, & Dainty (2008); the cost of maintaining off-site lavatory units can time and again be as little as 1/3 of those restroom units built on site. The OSC extends subsidiary budget minimizing and non-cost value-increased components. Resultantly, the tangible cost of off-site construction may be more inexpensive than the cost due to the implementation of conventional on-site methods. Earlier offsite construction used to be costlier than brick and block. Nowadays the cost reduction has been effectively to the neck and neck scale owing to the invention and application of several methods, and the offsite manufacturing of construction elements, and all these cause even bigger cost-cutting.

2.11.4 Cost predictability

Cost-effectiveness makes a significant difference while comparing the offsite construction method and the conventional construction technique. Roughly, the first 20% of the design process ascertains around 80% of the construction costs. Off-site construction cost certainty encouraged construction companies for its implementation on account of off-site construction being more anticipatable, because there is less likelihood for it to get hurt from cost overuses caused by unidentified circumstances such as the weather (Li et al., 2014).

2.11.5 Addressing shortages of skills

Skills shortage in the construction industry is a major factor behind stakeholders favoring OSC. OSC involves 'outsource' of the construction process to another environment, with engaging less labour, the application of the OSC method prevents dependability on the increasing labour shortage. This reduces the skilled labour requirement and the production work to be performed by the semi-skilled work force (Goodier & Gibb, 2005). Utilizing locally available human resource in order to increase value to a localized supply chain to bring up an upper quality product is inexpensively feasible when completed. Comparatively with the on-site construction approach, lower workmanship requirement on-site is targeted for OSC due to simplified work content (Blismas et al., 2006).

2.11.6 Productivity improvement

Conceptualizing the benefits of off-site productions is related to a productivity concept. According to some studies, productivity gain is outlined as a distinct category. Productivity has been taken as the key benefit of OSC methods. The respondents of conducted survey view productivity as their main reason behind incorporating off- site construction. Broadly perceived, the off-site construction's overriding benefit is a greater productivity through the less time, higher quality and lower cost, comparatively to on-site construction (Gibb & Isack, 2003).

2.11.7 Improve health and safety

OSC, also providing an advantage as regards health and safety issue, has proven to be a safer method of construction due to involvement of fewer components than traditional methods, and also no requirement of a high quantity of labour on-site for the assembly process. Increment of the on-site safety record through prefabrication by minimizing the exposure of workers towards inclement weather, height, hazardous operations, and on-site working time. No affect of inclement weather on workers in a fabrication shop is due to provision of more working space by prefabricated components to alleviate the potential possibility of accidents on-site (Ball, 1999).

2.11.8 Help society and environment

OSC can also offer assistance to society and environment. Offsite construction, on account of a satisfactory plan implemented from the initial phases of design and all the supply sequences integrated together, is affable and easy-going in terms of the environment. The requirement of a reduced amount of energy for developing off-site products, buildings being pre-engineered, adaptability for easy tiling and as such reduction of waste levels up to 70% and the cost are salient features inherent in off-site construction. Moreover, recycling raw materials is also made possible with improved control over their flow (Blismas et al., 2006). The OSC method provides benefits through reducing waste to landfill due to the reduction in consumption of materials in the factory to 90% through the accurate design and accordingly the procurement, which always avoids waste generation both on-site and off-site.

A reduction of on-site construction time, less waste and less noise on-site alleviates negative environmental impact. Additionally, large increment of material input and cost reduction are done through industrialized construction processes. As explained in the research by Blismas et al. (2006) that one exclusive scheme being advanced with European Community (EC) funding has been alluded to the following expected advantages:

- 50% reduction in the quantity of water consumed for the construction of a normal house.
- 50% reduction in the consumption of extracted materials in the construction.
- At least 50% reduction in the power utilization.

OSC, a prime potential method, promotes sustainability within the construction sector. Increment of sustainability is proportional to the improvement of acoustic and thermal insulation. Time minimization on site intends less disturbance to neighboring occupants or establishments.

2.11.9 Business integration and economy development

The supply chain also gets integrated in OSC. Through the effective performance, key manufacturers and suppliers involve early in the feasibility and design stages of the project in the OSC process. This involvement ensures the embedding of specialist skills and knowledge of key supplies within the project, and gives a positive impact upon the project and construction phases. Accordingly, the design ownership is to be provided to the key suppliers whose involvement continues in the execution of delivery, storage, and movements of components (Pan et al., 2012).

This concludes that that, off-site construction is inclusive of time, cost, scope, quality, health and safety process and people wise benefits.

2.12 Challenges / Barriers in Implementing Off-Site Construction

Arayici, Egbu, and Coates (2012) stated that uncertainty, complexity, unique, ambiguity, unsure are usual features of a construction project. The evaluated case studies by Sacks, Eastman, Lee, & Orndorff, (2005) done pertaining to off-site concrete construction (i.e.; precast concrete element) highlighted that minor mistakes, slipups, inaccuracies, inconsistencies, and variances found in the preliminary design and construction drawings are the sources for most of the problems facing the execution of the works (Nath, Attarzadeh, Tiong, Chidambaram, and Yu, 2015; Chan and Hu, 2002; Jaganathanan, Nesan, Ibrahimc, and Mohammad, et al., 2013).

Off-site Construction (OSC) within construction industries, with its application being limited mainly owing to cost, industry capability and public attitude and perception, is 7 to 10% costlier than the convention construction. Such costly nature of the OSC was indicated by the Parliamentary Office of Science and Technology (POST, 2003).

The following contributing factors are outlined hereunder for hindrance to the OSC wide application:

- Barrier of structural bulkiness (restriction on the floor to floor heights, wall thickness, spans and configurations of design)
- Existing factories' capability for manufacturing parts (POST, 2003)
- Increased Cost due to higher quality/rapid construction
- Increase in designer fees
- Logistic (Complex, costly and problematic transportation) (Boyd et al., 2013)
- Public preference for use of conventional construction materials
- Skilled labour shortage (Boyd et al., 2013)
- Shortage in technology and public awareness (Kumar, Alshawi, & Hamid, 2009)

The challenges in offsite construction have been investigated by a number of researchers and practitioners. The Table 2.1 summarizes the final list of 83 Challenges hindering the use of Off-Site Construction with their sources.

Table 2.1 : List of Off-Site Construction Challenges And Their Source

Cluster	Challenges	Sources
Industry Structure and Supply Chain	Defects during transportation	[1][3][5][6][9][16][17]
	Existing factories' capability for manufacturing parts	[2][6][8][9][12][17]
	Difficulty to the storage of prefabricated elements	[5][9][12][14][16]
	Lack of manufacturers and suppliers of prefabricated components	[1][6][8][12][17]
	Lack of experienced collaboration groups	[6][9][12][17]
	The fragmented nature of the construction industry	[6][8][9][17]
	Transportation of prefabricated elements and access to the building site	[3][5][6][14]
	Lack of experienced contractors on prefabrication	[8][7][9][17]
	Lack of practices and experiences from local projects	[6][8][10]
	Suppliers fail to deliver on time	[1][3][16]
	Suppliers fail to deliver correct components	[1][3][16]
	Losing factory production slot/production capacity	[2][6][16]
	Monopoly of techniques	[8][13]
	Poor integration for the supply chain	[3][17]
	Lack of experienced design consultancy and designers	[8][12]
	Longer lead-in time for OSC components	[10][17]
	Irregular features	[18]
	Organizational mechanism and culture	[6]
	Low infrastructure	[1]
	Low productivity	[1]

Constructability Implementation	High skill demands for labour	[3][6][8][9][16][17]
	Problem between joints	[6][16]
	Specific demands for the site logistics for pre-finished elements protection	[6][17]
	Corrosion and defect in reinforcement	[1][16]
	Foundations inaccurate/ unsuitable	[16]
	Damage to key pre-assemblies or critical components	[16]
	Cracks	[1]
	Tower crane position	[1]
	Design not suited to construction method	[16]
	Water penetrations	[1]
	Defects at handover/during liability period	[16]
	Highly restrictive construction tolerances	[17]
	Inability to make changes in the field	[6]
Architectural Performance	Unable to modify design scheme	[5][6][12][16]
	Monotonous design with poor aesthetic criteria	[1][5][17]
	Lack of enough flexibility	[6][17]
	Quality assurance	[1][16]
	Increase in complexity for maintenance	[1][17]
	Structural bulkiness	[2]
	Off-site construction techniques limits design options	[1]
Cost	High initial & capital cost	[2][5][6][7][17]
	Longer capital payback period	[2][6][17]
	Increased cost due to higher quality/rapid construction	[2][5][6]
	Difficulty of bidding price from contractors	[15]
	Error and mistakes in documentation and taking-off	[1]
	Price fluctuations during the construction phase	[16]
	Off-site construction techniques increases design cost.	[2]
	Additional cost and care required when manufacturing	[6]
	Increase in designer fees	[2]

Policies and Regulations	Lack of design codes and standards for prefabricated components	[7][8][10][14][16][17]
	Lack of governmental regulations and incentives	[7][8][9][14][17]
	The local zoning ordinance restricts the use of off-site construction techniques.	[9]
	The local building regulation restricts the use of off-site construction techniques.	[17]
	The financial institution restricts the use of off-site construction techniques.	[7]
	Legal issues	[6]
Technological Innovation	Lack of local R&D institutes and services	[4][8][12]
	Lack of technologies and testing institute to prefab. components	[4][8]
	Reluctance to innovation and driven	[6]
	Designing off-site construction components requires special computer software.	[4]
	Poor technology	[4]
	Monotony of structure type	[5]
Social Climate and Attitudes	The owner’s negative perception	[1][3][4][6][10][17]
	Lack of awareness of prefabrication by the market and public	[3][4][6][7][8][9]
	Dependence of traditional construction method	[1][4][6][11][16]
	Poor quality impression	[1][4][16][17]
	Lack of confidence of the industry in offsite production	[3][17]
	Public preference for use of conventional construction materials	[3][6]
	Durability of prefabricated unproven	[4][7]
	Lessons and attitudinal barriers due to historic failures	[6]
Other Challenges	The inability to freeze the design early on	[1][5][6][16][17]
	Project planning and coordination	[1][6][10][15]
	Unpredictable planning decisions	[1][6][16]
	Uncertainty of market demand	[1][7]
	Health and safety hazards	[1][16]
	Project scheduling issues	[1]
	Late appointment of contractor/manufacturer	[16]

Other Challenges	Manufacturer insolvency	[16]
	Potential unemployment issues to workers	[15]
	Inefficiency of labours	[1]
	Uncertainty of weather condition	[1]
	Wastages	[1]
	Service installation faults	[16]
	Longer lead-in time during design stage	[10]

[1] Jayasena, Yoosuff, and Jayasena (2016)
[2] POST (2003)
[3] Boyd et al. (2013)
[4] Kumar, Alshawi, and Hamid (2009)
[5] Jaillon (2009)
[6] Pan et al. (2007)
[7] Lovell and Smith (2010)
[8] Kamar et al. (2009)
[9] Park et al. (2011)
[10] Goodier and Gibb (2004),
[11] Pan (2008)
[12] Blismas et al. (2005)
[13] Chiang et al. (2006)
[14] Blismas and Wakefield (2009)
[15] Mao, Shen, Pan and Ye (2013)
[16] NAO (2005)
[17] Zhai, Reed, and Mills (2014)
[18] Added after pilot study

Some major challenges / barriers to the implementation of offsite construction (despite the offering of many benefits and advantages by the OSC) are paraphrased/summarized as follows as per the findings of some literature studies:

2.12.1 Project planning and coordination

The increased engineering effort incurred in the pre-project planning stage for OSC and the requirement of precise design and extensive planning before fabrication is a substantial disadvantage, and its successful implementation is also required to incorporate critical elements such as accurate design coordination, transportation logistics and on-site installation (CII, 2002).

2.12.2 Transportation restraints

Transportation restraint cannot be ignored for OSC; restriction in size, weight, width and height during materials transportation is a consideration factor in selecting method and route of transportation (CII, 2002). The following restrictions in roadway transport (i.e.; common method) are highlighted herein:

- Size restriction: 8-10 feet (W), and 40-45 feet (L) for modular building or pre-assembled component (CII, 2002).
- Weight restriction : Lifting equipment capacity usually between 10-30 tons
- Increment in design and construction cost due to overly design of the prefab building elements for alleviation of possible damage during transit (Gibb and Pendlebury, 2005)

2.12.3 Costly construction

Project success relates to construction cost, a prime concern of all project clients; optimal cost means a success (Ogunsemi & Jagboro, 2006). Application of the OSC method, usually considered costlier (so due to high quality and rapid construction) than the conventional one. OSC can be done in proper circumstances in the competitive construction market, for an instance open panel construction being not more expensive than the OSC, and cheaper than the conventional construction.

Overlapping in cost ranges exists despite a slightly higher cost in OSC. Simply, the lowest cost off-site constructed project is less than the highest cost traditional construction project (Fawcett &Allison, 2005).

Pasquire, Gibb, and Blismas (2004) highlights about financial advantages of hybrid and volumetric construction due to rapid construction and on-site work reduction. For instance, a panel construction involving the OSC method results in more cost-effective than traditional construction. The effectiveness of the volumetric construction associates with cost decrement of off-site elements whereas hybrid constructions get effective subject to the cost reduction in off-site components or on-site labour and material.

2.12.4 Resistance to change

As OSC, a change or a new approach to the construction culture, resultantly involves requirements of different skills on the set-knowledge including scheduling and planning. Change stands as lower preference due to implementation of new approach to training and skills at all levels. Substantial effort toward absorbing enhanced levels of update information is required for career progression (CII, 2002).

2.12.5 Flexibility to make changes on-site

Decrement in the application of OSC techniques is also related to inflexibility to on-site modification. A well-defined scope, precise design and specification are always required for OSC implementation even at the initial stage of the project planning, particularly for volumetric construction. Difficulty facing through future renovations as to flexibility and changeability of structure also gets connected with the OSC elements.

2.12.6 Capital investment

Commercial leadership with business operational management and professional technicalities; including sufficient capital investment decisions are some required factors to adopt the OSC, which defines high quality, timeframe, environmental impact and structure fabric performance. This leadership subsequently minimizes the misconceptions toward the OSC technique, among public or clients or insurers (CII, 2002).

2.12.7 Guidance and information

The OSC concept directly connects with the manufacturing process bringing in enhanced quality and efficiency and substantially reduced waste. OSC, in contrast to conventional construction, requires a set technical knowledge at all levels and always encompasses a flow of update information and guidance between design, production and assembly.

2.12.8 Cynical perceptions

Based on a literature studied, the general pessimistic, or cynical attitudes towards OSC methods were one of the most substantial challenges in both the U.S. and overseas excluding Germany and Japan (O'Brien et al., 2000).

2.12.9 Conventional construction industry models

Offsite construction adopts a distinct cash course model which transference towards extreme direct costs which possibly generate divergent investment provisions. However, the paces of construction counterbalance this generation, there are assured and warranted incomes. Nevertheless, the necessity for wide awareness of the conflicting commercial investment and cash flow sequences is the topical barrier so far as the usage of Offsite Solutions is concerned (Gibb and Pendlebury, 2005).

Based on the above studies by different authors on challenges/barriers of offsite construction methods; capital investment, transportation restraints, resistance to change, cynical perceptions, and conventional construction industry models are the major barriers. However, lake of understanding the real benefits of offsite construction usage is the major barrier for OSC take up.

2.13 Construction Clients' Fundamental Needs

Pertaining to Offsite construction (OSC) methods, the focal concern in any construction project is the Client's fundamental needs (Kamara, Anumba, & Evbuomwan, 2002). Kometa, Olomolaiye, and Harris (1995) summarize the following as the Client's fundamental needs:

2.13.1 Functionality of the building

As with any building, OSC is required for the fulfillment of the building functionality (i.e; desired performance). OSC strictly complies with the design and the accuracy in the design factors such as size, weight, dimensions, and load bearing. This compliance; respected and maintained by the OSC method ensures the building's desired performance.

2.13.2 Quality of a building

Piroozfar, Altan, and Larsen (2012), and Pan, Gibb, and Dainty (2007) highlighted that as the basis of construction being the design and specification, quality of construction deliverables/delivery is essential, meeting the client's expectation of quality standards. Owing to the OSC's strict compliance with the design and specification, and also it's implementing of improved technologies as well as the production being in a controlled factory environment, OSC products are always higher in quality in accordance with the set design and specification than the conventional construction method.

2.13.3 Completion in time

Comparatively, OSC method enjoys the resultant rapidity of approximately four times quickness than the conventional method of construction. Allowance for intensive use of limited workmanship, simultaneous engagement of different on-site workforces in the activities even in the factory production and not being prone to the adverse effects of the incremental weather are some main causes which result the timely completion of the targeted project through offsite construction faster than the conventional construction. The OSC method also incorporates volumetric construction requiring minimized construction duration in contrast to panelized, hybrid and conventional construction (Fawcett & Allison, 2005). Eventually, the project completion and hand over can be done within the designated/prescheduled timeframe, and meeting the client's expectation and satisfaction.

2.13.4 Cost of a building

Clients' focal concern always lays over a project's budget and a project with optimal cost usually leading to success (Ogunsemi & Jagboro, 2006). Despite off-site construction being considered costlier than conventional construction; the following factors always assist OSC to remain for the clients' preference:

- Rapid construction owing to on-site work reduction, and resultantly meeting the project schedule and facilitating the client's takeover of the project to be used for commercial benefits through the intended purpose.
- No impact or effect of inclement weather condition on the production work due to its production confirmed in controlled factory environment, and saving cost due to time loss
- Higher quality in products due to production following strict compliance with the design and specifications.
- Overlapping of the cost ranges (Fawcett & Allison, 2005)
- Implementing of volumetric construction, and cost minimize for off-site elements
- On-site work reduction resulting financial profits in hybrid and volumetric construction (Pasquire et al., 2004)
- Workmanship through limited workforce
- OSC Building's application flexibility and adaptability for multiple commercial purposes and at different times

2.13.5 Safety of a building

Occupational safety is an essential factor in the construction industry. Negligence or insufficient management in safety matters increases safety hazard, accidents and incidents, and also resulting in financial loss (Bourn, 2004). Kometa et al. (1995) highlighted that the client's high awareness concerns the safety factor of a building (particularly two aspects: safety during its construction phase as well as post construction operational phase). Supervising, managing and maintaining occupational safety is always high in OSC due to the most works being performed in a controlled factory environment.

2.13.6 Maintenance costs of the building

Clients do not concern only about the initial cost of the project, but also aims to minimize the running and maintaining cost of a building in arising off-site construction.

2.14 Findings of Literature Review

Offsite Construction (OSC), always standing as an appreciable way to get out from constraining project timetables and project costs, brings enhancement to construction quality, and reduction to environmental effect. The foregoing reality is usually in relation to the project stakeholders' sincere intent and adequate planning for the project. The professional team's active engagement and willingness for embracing the challenges and opportunities toward the project delivery provide a perceptible way to vibrant efficiency of the OSC in similar or typical projects.

The outcomes of enhancing the construction industry through the application of the OSC techniques are apparent and tangible in the project budget. According to Gray, (1983) the early incorporation of off-site production into the design stage of a project could accomplish 1% to 14% reduction in cost, and also rendering a way to obtain cost benefits of the overall project budget. A large effectual human resource yields the project completion ahead of the schedule including remarkable project outputs (Griffith & Sidwell, 1997). It brings reduction in wastage of materials (Koskela, 1992), and alleviates several conventional building work undertaking with severe risk circumstances (Pan, Dainty, & Gibb 2004). Conversely, while and when enquiring some concerned clients and contractors pertaining OSC technique implementation, the shipment cost (expensive as they perceive) was found to have been alluded to as a prime cause behind their low preference (Boyd et al., 2013).All of them had ignorance of the resultant advantages of the off-site fabrication as no effort has been exerted by them to identify the ultimate benefits rendered by it to the project (Pasquire & Gibb, 2002).

Appending to this, the Sri Lankan construction industry has certain problems which have given way to the construction shortfall being observed, which include (but not limited to):

- Use of costly construction materials,
- Shortage of sufficient systematization in the building construction sector,
- Insufficiency in ample professional and trade workforce,
- Land lease and budget,
- Deficit in housing investment including low economic status of potential purchasers.

As pointed out in a research by Formoso, Koskela, and Viana (1994), a key problem facing the building sectors in both developed and developing countries is material wastage control and manipulation, which generates through excess production, alteration, awaiting time, needless transfer of goods and manpower, and substandard or faulty fabrication.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

The preceding chapter contains a theoretic milieu of OSC applied worldwide and various perspectives of writers in that research area, which was done for comprehending the research field and benefits of off-site construction and barriers/challenges in its implementation.

Likewise, this chapter elaborates actual significance of research methodology in the beginning and afterward explains about the research sequence that was applied in this study and the study approach. Furthermore, it gives a description about the research methods, research design, how the sample frame was achieved, the statistical method applied, the sampling techniques implemented in reaching the population, the population definition and the sample handled in the research.

3.2 Research Methodology

According to Flick (2011), research approach can be termed as a methodology to sequentially resolve the research question, and it is a sequence of systematically viewing of the course of a research performance. Under the approach, precise actions can be kept on reasonably so to comprehend and successfully complete research purposes. While performing a research, empirical acquaintance about calculating standard deviation, percentage, mean, median, mode and procedure of applying various research techniques are not adequate. It is necessary to identify the proper and improper research techniques, rationales to accurate and inaccurateness. Additionally, suppositions, and choice benchmarks for methods are also necessitated to be comprehended. Consequently, several standards for methodology are there (Kothari , 2004).

3.3 Research Process

Research techniques normally comprised section components such as delineating the research problem, literature review, developing the research methodology, data collection, data analysis, research findings, conclusion, and recommendation. As per Anderson and Arsenault (2005) in spite of the research procedure looks to be sensible, it contained dynamic, which are in correlation.

Research sequence of this research commenced from backdrop study on OSC methods practised in Sri Lanka and recognition of the research question, What is the level of adoption of offsite construction techniques in Sri Lanka, and what are the challenges faced in the application of off-site construction methods? After recognizing the research question, aim and objectives were determined and scope and limits were specified. As the succeeding step, sufficient literature study has been performed on OSC and its benefits and challenges. With the particulars of all above, technique and procedure was planned. In accordance with the organized procedure, questionnaire survey was carried out. Statistical analysis was carried out to evaluate gathered data through the above methodology. Percentages, standard deviations and mean values were put in numerical evaluation. Moreover with scrutinized data, understandings and explanations were performed and outcomes were accounted. And, the closing pace of the research process established research findings and recommendations.

3.3.1 Research approach

The research approaches can be classified as quantitative approach, and qualitative approach (Kothari, 2004). Quantitative form of data is gathered in quantitative approach and its application is made for performing critical quantitative analysis in a standard procedure. Additionally, quantitative method is classified into survey method and empirical method. Qualitative method in a research will be a subjective evaluation of views, perceptions, and conducts. This kind of method generates non-quantitative structure, which is not dynamically quantitative. Ethnography research, grounded theory approach, action research, and case study approach are some qualitative research methods.

A multiple approach consists more than one approaches in a research (Esteves & Pastor, 2004). According to integrating approach it can be further classified as mix model research, multi method, and mixed method. Qualitative and quantitative approaches may be integrated into various modes. According to the integration method, there are minor alterations in each method which are termed as multiple approach. A study by Teddlie and Tashakkori (2009) defines the third method as “a type of research design in which qualitative and quantitative approaches are used in types of question,research methods, data collection and analysis procedures, and / or inferences”(p.7).

As cited from a study by Niglas (2000), research can have single or multiple research procedures and those procedures can make use of varied ways and diverse data to successfully achieve the research targets and purpose. Moreover, there can be quantitative data gathering tactic for researches which applied both qualitative and quantitative approach.

This research data gathered the perspectives of professionals from OSC industry only through close ended questionnaire survey. Hence, survey method is contained in the research, having quantitative method.

3.4 Research Methods

According to Tan (2002) data collection methods and data analysis methods are consisted in research methods. As per Kothari (2004) many studies become unsuccessful due to lake of sufficent data.As stated in their studies by Fellows and Liu (2008) data collection methods are influenced by the data analysis method.

3.4.1 Data collection methods

As stated in their studies by Adams, Khan, Raeside, and White (2007), various techniques for gathering data are existent which are surveillance, experimentations, questionnaire surveys, interviewing professionals, documentations, records, and corporal objects.

In this research, the data accumulation has been fulfilled by a questionnaire survey which contained only close ended questions. The data collection involved direct approach as well as electronic data collection. With the aim of increasing the response rate, the researcher personally approached the professionals involved in off-site construction wherever possible and gets the survey filled out, apart from the electronic data collection via Survey Monkey.

Questionnaire survey

Through the questionnaire survey, data was gathered on the off-site construction methods currently practiced in Sri Lankan construction industry, in which sector and building types each off-site construction techniques are mostly used in Sri Lanka, and finally the data was collected on the benefits and challenges in the implementation of each off-site construction methods in Sri Lanka.

Questionnaire survey was done as a close ended questionnaire, which included close ended questions and 1 to 5 ranking scale was applied for measuring diverse replies of participants.

Sampling technique

When the sampling population cannot be selected by adopting the theory of probability, it is paramount to implement the non-probability convenience sampling technique. This procedure of sampling is applied when the population cannot be personally recognized (Kumar, 2009).

Selection of sample

The research was able to add the varying perspectives of the major trend forerunners in the Sri Lankan construction industry. These encompassed chief executive officers, project managers, designers, consultants, architects, engineers, and quantity surveyors signifying the leading offsite contractors, consultants and off-site manufacturers in Sri Lanka.

Due to the difficulty in locate, or identify the required population and since it was not all enterprises that had coped with the offsite methods of construction, the study sample was stemmed from non-probabilistic convenience sampling method using the snowball sampling technique. With this sample method the researcher recognizes the authorities or the major contributors in the industry who then introduce their acquaintances as samples. Moreover, a team of project managers was also got in touch for the questionnaire survey. Owing to the snowball method a total of 60 professionals are targeted for the survey study.

Definition of Population

Participants were constrained to residential, commercial and industrial building developers and off-site manufacturers in Sri Lanka. This team was elected considering that they are prime establishments and they had performed numerous significant works with OSC methods.

3.4.2 Data analysis methods

The data obtained from the questionnaire survey was scrutinized with statistical data analytic techniques, which was performed through computer software Microsoft Excel. Percentages, weighted mean rating, and standard deviation were implemented for exploring the quantitative data.

Mean weighted rating

The survey participants were asked in the questionnaire survey to evaluate the satisfaction level of OSC methods, reasons restraining the usage of OSC techniques, reasons for usage of OSC techniques and the project management challenges in the implementation of OSC techniques individually through the tabulated scale from 1 to 5. Weighted mean score computed through applying of the following equation interpreted the credit values included with responses:

$$Mean\,Weighted\ Rating \quad = \quad \frac{\sum (V_i x F_i)}{n}$$

Where,

Vi - Rating given by the respondent

Fi - Frequency of responses

n - Total number of responses

Percentages

Percentage calculation was used to analyse several research questions and outputs in this research. Some of them are considered to determine the following: the categories in which offsite method of construction is mostly used; components that lend themselves easily to off-site fabrication; the more expensive and preferred construction method; the motivators for the usage of offsite construction methods; the cost reduction due to use of offsite construction methods and the materials used in OSC in place of the traditional materials.

$$Percentage \quad (\%) = \frac{Fi}{n} x100$$

Where,

Fi - Frequency of responses

n - Total number of responses

Standard deviation (SD)

The mean score technique was applied in the foregoing studies pertaining to project management for categorizing comparative significance of exclusive factors (Chan &

Kumaraswamy, 1995). In the current research, mean rating is implemented for ascertaining the comparative rating, as responded by the participants, in a descending order of importance. If two or more factors occurred presenting the same mean value, the value with a lower standard deviation (SD) was accorded a superior rank.

3.5 Difficulties and Problems Encountered

Availing the proper respondents to be questioned as well as the whereabouts of their offices are the key problems encountered by the researcher, and also the difficulty exists relating to the participants' pertinent knowledge. The questionnaire survey, also with a target of obtaining other perspectives, involved a close ended questionnaire but the following regrettable problems from the responding participants were also came across by the researcher:

- Partially completed questioner.
- Some firms (targeted for participation) no longer existing, or already shifted to new locations with no information about new address of the offices.

Further, in section "4.3.13 Off-Site Construction Challenges", the researcher intended to use the Factor Analysis technique to group the challenges. The suggested sample extent for Factor Analysis is 300 respondents at minimum, and every variable, which is subject to factor scrutiny, is required to have minimum 5 to 10 perceptions (Comrey & Lee, 1992). A usual circumstance is necessitated to reflect 10:1 (lowest) proportion between participants and variables, in which the factors are taken to be unchanging, and having cross validation with a proportion of 30:1.

In this research, the targeted survey participants (60) are lower than the number of variables (83). And the recommended minimum sample size (300) is very much higher than the targeted survey participants (60). This limits the application of factor analysis to the survey outcomes.

3.6 Summary

This chapter has a discussion regarding the process of performing the study. The study progression encompassed the consecutive process of studying the backdrop, recognizing research problems, determining aims and objectives, defining the research scope and its limitation, distinguishing research methodology, literature review, data collection, analyzing the gathered data, and formulating recommendations. Survey approach is applied in this research. As the data accumulation method, a close ended questionnaire was used to gather statistical data. For that reason the quantitative approach was implemented for gathering the data. After the questionnaire survey objective 1, 2, 3, and 4 were fulfilled, questionnaire survey data was scrutinized by statistical analysis with usage of weighted mean rating, percentages, and standard deviation. The chapter is a graphical elucidation of how research is to be performed.

CHAPTER FOUR

4.0 DATA COLLECTION, DATA ANALYSIS AND FINDINGS

4.1 Introduction

Research approach applied for this research study has been deliberated in Chapter 3 with an intention to illustrate the research discoveries and outcomes, and scrutinizing them in a proper way to conclude the research. The findings and scrutiny of the data gathered from the questionnaire survey, site visits and conversations with the concerned professionals related to the offsite construction are elaborated in this Chapter; including discussion as to the outcomes of the reports.

This chapter presents statistical analysis of the level of adoption of different off-site construction methods in Sri Lanka, drivers and barriers of offsite construction and the challenges faced by the project managers which limit the use of off-site construction methods and its purpose as discussed in the previous chapters.

4.2 Questionnaire Survey

The questionnaire survey facilitated the data collection and offered the following for the analysis:

- The nature and level of adoption of different off-site construction systems in Sri Lanka;
- The benefits of and barriers in implementing off-site construction methods;
- The challenges faced in the application of off-site construction methods with special emphasis to project managers.

4.2.1 Rate of response

The summary of the survey responses are presented in Table 4.1.

Table 4.1: Rate of Response

Response Category	**Rate of Response**	
	Nr.	**(%)**
Responded	33	55
Not Responded	26	43
Rejected	1	2
Total	**60**	**100**

According to the above Table 4.1, among 60 professionals contacted for the questionnaire survey, only 33 responded. That gives a response rate of 55%. This high rate of response is achieved through contacting professionals involved in off-site construction personally and by gets the survey filled out, apart from the electronic data collection. The subsequent analysis of the feedback found partial completion of one questionnaire. Such partial response indicated no proper attention of the responder while responding for the questionnaire, which raised a doubt toward response accuracy. Such doubt guided the researcher to exclude the partially responded questionnaire from the analysis process.

4.2.2 Profile of participants

Although the construction industry employs many professionals, it was a little challenge to identify professionals with knowledge and experience in offsite construction. Therefore data was collected by non-probability convenience sampling method from the professionals having different expert backdrops and involvement in at least one project where offsite construction was applied. Insufficient recordings of construction companies which have handled off-site construction (OSC), and their inadequate practice posed hitches in ascertaining the sample populace. The above circumstance led to experimenting approximately 60 professionals consisting of project managers, architects, engineers, and quantity surveyors signifying leading offsite contractors and consultants in Sri Lanka. Further a group of project managers also contacted for the questionnaire survey. The data collection involved direct approach as well as electronic data collection via Survey Monkey.

The survey respondents were professionals experienced in construction works in Sri Lanka. The type of organization, their expertise backdrop including their knowledge and experience on OSC projects were made as the basis for classifying the participants.

a) Type of organization

Respondents were asked to indicate the type of organization that they are working for and the findings are shown below:

Table 4.2: Type of Organization

Type of Organization	**Rate of Response**	
	Nr.	**(%)**
Consultant	5	15
Contractor	28	85
Total	**33**	**100**

As shown in the Table 4.2, majority of the participants (85%) were from the contractors group while remaining 15% represented consultants. This is due to the fact that most of the offsite contractors designers by themselves.

b) Professional background

Participants were asked to describe their professional background. The participants' responses are illustrated in the following Figure 4.1.

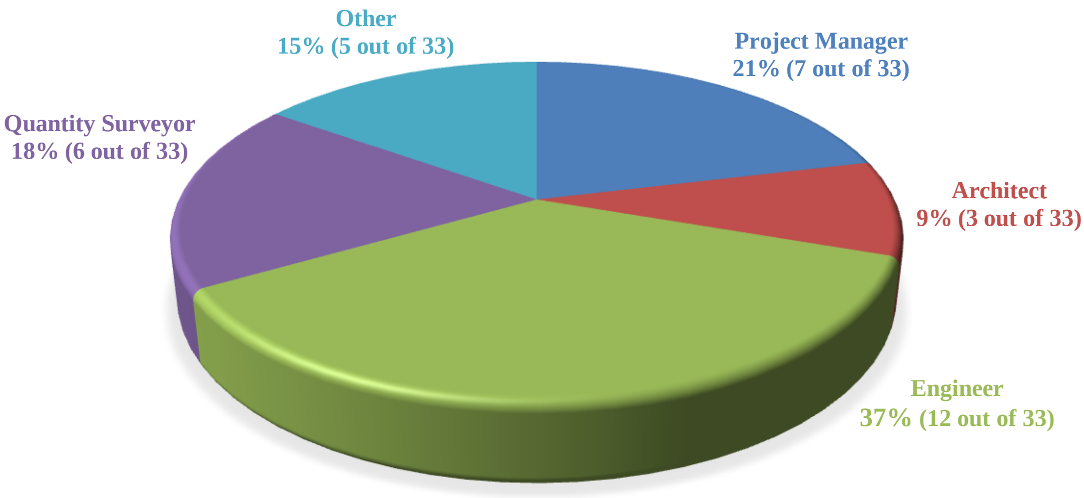


Figure 4.1: Professional Background of Participants

As observed in Figure 4.1, maximum participation was from engineers (37%), project managers (21%), and quantity surveyors (18%) whereas the feedback count from other professionals was nominal such as only 9% architects, and 15% other professionals.

c) Experience on off-site construction projects

To reach to the accurate findings, all the participants were asked to indicate years of experience with regard to involvement in off-site constructions projects and the survey outcomes are presented in Table 4.3.

Table 4.3: Participant's Experience in Off-Site Constructions Projects

Years of Experience in Off-Site Constructions Projects	**Rate of Response**	
	Nr.	**(%)**
Less than 5 years	9	27
5 to 10 years	15	46
11 to 15 years	7	21
More than 15 years	2	6
Total	**33**	**100**

Table 4.3 depicts maximum (46%) of the respondents are having 5-10 years involvement whereas 27% with experience less than 5 years, 21% with experience 11-15 years, and 6% respondents had experience exceeding 15 years.

d) Knowledge in the use of offsite construction methods

Participants were also asked to report their knowledge level in off-site construction methods and participants' responses are depicted in the Table 4.4.

Table 4.4: Participant's Knowledge in Offsite Construction Methods

Participant's Knowledge in Off-Site Construction Methods	**Rate of Response**	
	Nr.	**(%)**
Very High	5	15
High	15	46
Average	11	33
Below Average	2	6
Total	**33**	**100**

According to the Table 4.4, over 60% of the respondents were measured as above average (high + very high) while 33% of participants indicated their knowledge in offsite construction as average. The above survey results highlight the necessity for accelerating the learning need of offsite construction professionals on latest offsite construction technologies.

4.3 Findings of Questionnaire Survey

In order to address the research objectives, the questionnaire addressed the following aspects:

- Participant's overall satisfaction level of using OSC techniques
- Project/building sectors appropriate for each OSC techniques
- Cost of construction methods
- Preferred construction method
- Motivations for the usage of offsite construction methods

- Reasons restraining the usage of offsite construction methods
- Drivers for the usage of OSC methods
- Off-site construction challenges

The subsequent sections present the survey findings on the above.

4.3.1 Satisfaction level of offsite construction techniques

Perspectives of professionals were sought pertaining to overall satisfaction of their past experience of using off-site construction techniques through questionnaire survey. The overall satisfaction was measured using a scale of 1 - 5 where “1” indicated “Highly Unsatisfied” and “5” indicated “Highly Satisfied”. The respondents were given an option to skip any type if they were not experienced by selecting "0" which indicated "Not Experienced". In this way, the weighted mean rating values of these were calculated and findings are shown in Table 4.5.

Table 4.5: Participant's Overall Satisfaction Level of Using OSC Techniques

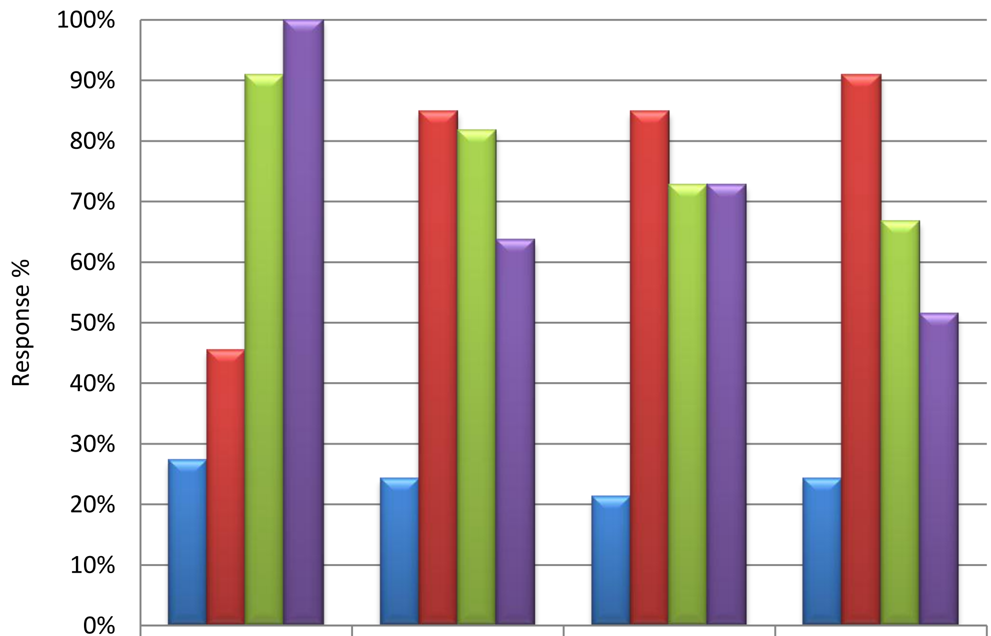
Construction Method	**Response Percentages %**						**Weighted Mean Rating**	**Std Dev**
	5	**4**	**3**	**2**	**1**	**0**		
Volumetric Constructions	46	27	9	6	0	12	4.276	0.922
Hybrid Constructions	40	33	12	6	0	9	4.167	0.913
Sub-Assemblies Constructions	36	43	9	3	3	6	4.129	0.957
Panelized Constructions	24	40	15	3	3	15	3.929	0.881

As presented in Table 4.5above, volumetric constructions, hybrid constructions, and sub-assemblies constructions hold their weighted mean rating exceeding the 4.000 with more than 46% of responses for ‘5’ in volumetric constructions and exceeding 36% of ‘5’ for sub-assemblies constructions. Similarly, hybrid construction is rated above 40% of ‘5’ and exceeding 33% of ‘5’. Weighted mean rating is less than 4.000 for Panelized constructions, and 24% and 40% feedbacks are rendered as rating ‘5’ and ‘4’ respectively.

While going through the obtained(33) responses and their through the weighted mean rating presented in the Table 4.5 above (overall satisfaction), it comes to be highlighted that the volumetric systems have the highest satisfaction level (4.276) and the panelized systems have the lowest satisfaction level(3.929). Hybrid and sub-assemblies systems are having almost equal satisfaction level with mean value 4.167, and 4.129 correspondingly. If the overall satisfaction of the respondents' past experience in the OSC methods is put through a scrutiny, the order of satisfaction ranks from volumetric constructions, hybrid constructions, sub-assemblies constructions, and panelized constructions.

4.3.2 Sectors Appropriate For Each OSC Techniques

Survey participants were ask to indicate in project/building sectors each offsite construction method is mainly used in Sri Lanka and the survey outcomes are presented below:



	Volumetric Constructions	Panelized constructions	Hybrid constructions	Sub-assemblies
Others	27%	24%	21%	24%
Industrial	45%	85%	85%	91%
Commercial	91%	82%	73%	67%
Residential	100%	64%	73%	52%

Figure 4.2: Building Sectors Appropriate For Each OSC Techniques

The Figure 4.2 portrays each of the OSC methods is predominantly implemented as per the feedbacks obtained from the participants. While viewing through the above figure, it comes to be known that the participants have confirmed that volumetric constructions are implemented cent percent in residential buildings, and 91%, 45% and 27% in commercial, industrial and other building sectors respectively. The feedbacks obtained from the survey participants push to a conclusion that volumetric constructions are commonly applied in residential and commercial buildings sector.

In accordance with the above summary table, the participants' responses evidence that the industrial, commercial and other building segments greatly use panelized constructions. The overall participants have confirmed that the application of panelized constructions is prevalent in all (residential, commercial, industrial and other) buildings sector, even though 64% for residential building and 24% for other buildings. The feedback givers (exceeding 80%) have confirmed their point of view for maximum application of panelized constructions in industrial and commercial buildings sector simply because of the industrial/commercial structures like workshops (factories) and warehouses construction by usage of steel panels and sections due to easygoing handling and fixation.

Referring to the above figure, 85% of the respondents have responded that industrial buildings make usage of hybrid constructions, and 73% of the participants view that hybrid constructions is equally applied in commercial and residential buildings sectors. The foregoing percentage gives an apparent indication for wide application of hybrid constructions in both industrial/commercial as well as residential buildings sectors.

As per the above tabulated Figure 4.2, the feedbacks from 91% of the participants depict for usage of sub-assemblies constructions in industrial building sector, which is followed by commercial building section for which the response percentage stands for 67%. Conversely, 52% of the feedbacks have stood for usage of sub-assemblies in residential building construction, followed by 24% responses for other building sector.

4.3.3 Components that lend themselves easily to off-site fabrication

The participants were asked to select the building components that lend themselves easily to off-site fabrication and the findings are shown in Figure 4.3.

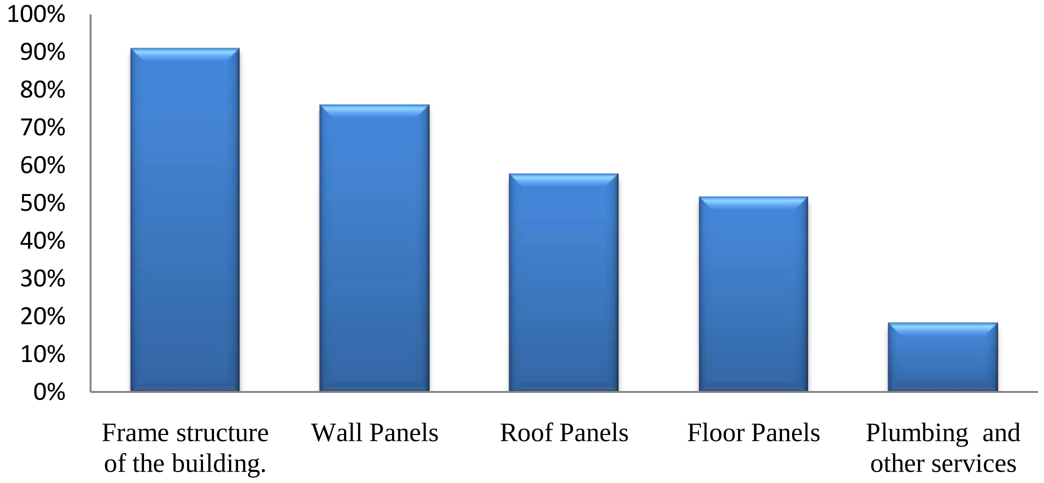


Figure 4.3: Components That Lend Themselves Easily to Off-Site Fabrication

As per the survey results, 91% of the respondents have selected 'frame structure of the building' as building component for easy pre-fabrication, where as 76% of the feedbacks have stood for wall panels as easy building component, and exceeding 52% of the responses have contained their view inclined towards the use of roof panels and floor panels as easy building components.

4.3.4 Cost of construction methods

The participants were asked to choose the more expensive construction method among off-site construction and in-situ/conventional means of construction. The findings are presented in the below Figure 4.4

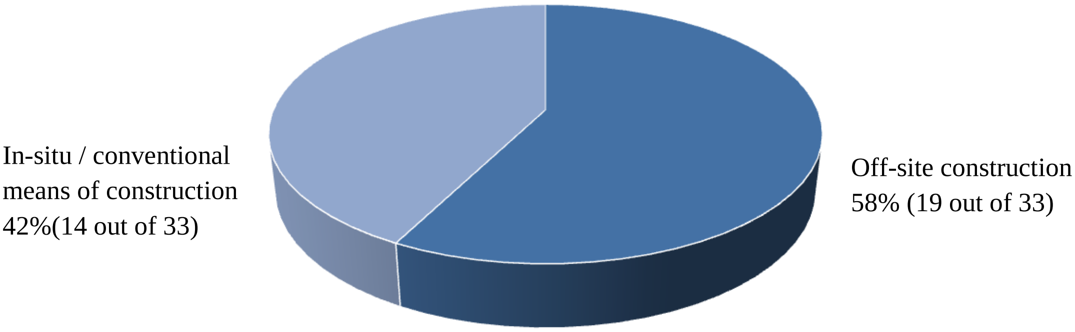


Figure 4.4: More Expensive Construction Method

As per the survey results 58% of the respondents opine that the off-site construction being costlier than the application of in-situ/conventional construction method, and 42% responses have represented the in-situ/conventional construction method being further expensive than the OSC.

4.3.5 Preferred construction method

The points of view received as responses from the surveyed participants pertaining to the preference between the off-site construction and the conventional (in-situ) construction method. The findings are depicted in the Figure 4.5.

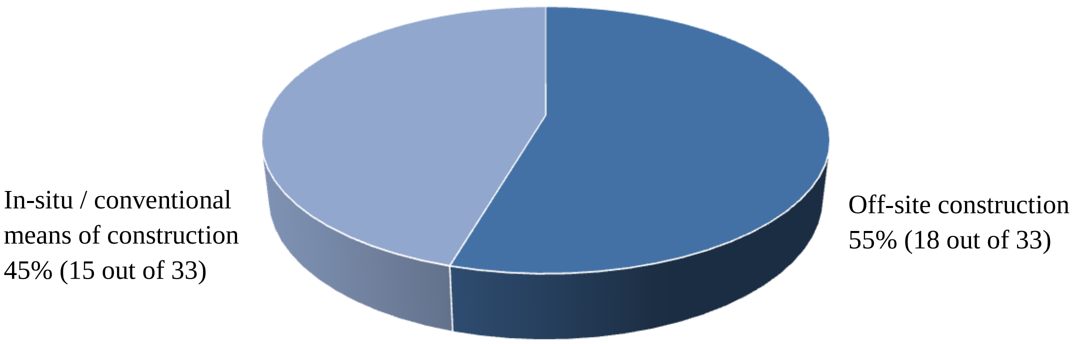


Figure 4.5: Method of Preference

The study of the respondents' perceptions as shown in the above Figure 4.5 have confirmed that 55% of the respondents have favoured the off-site constructions (OSC) method to 45% of the respondents stand for the traditional construction (in-situ) method.

4.3.6 Motivations for the usage of offsite construction methods

The major motivating factors for the implementation of off-site construction methods in a project were identified in the literature review and put in the questionnaire survey. And then the participants were requested to select the major motivators for the usage of OSC methods and the survey outcome is presented in the table below.

Table 4.6: Motivators For The Usage of Offsite Construction Methods

Motivators For The Usage Off-Site Constructions Methods	Rate of Response	
	Nr.	**(%)**
Work time and other restrictions in sensitive sites	31	94
Short weather window	28	85
Waste reduction	17	52
Lack of space around the building for site storage	12	36
Noise limitation	6	18
Total	**33**	**100**

As per the above survey summary Table 4.6, 94% of the received responses have confirmed "work time and other restrictions in sensitive sites" as a motivating factor for adoption of the OSC in a project, whereas 85% of the participants marked 'short weather window' behind the implementation of the OSC methods. Likewise 52% replies opined for 'waste reduction', followed by 36% for lack of work space at the job site as motivating factors for the OSC to be applied. Conversely, the factor (noise limitation) got the least mark (i.e.; 18% of the feedbacks) for the OSC. Accordingly, the hierarchy for the motivating factors to use Off-site construction technique in a project forms as being "work time and other restrictions in sensitive sites, short weather window, waste reduction, lack of work space for site storage, and noise reduction".

4.3.7 How does the waste reduction occur by the use of OSC affect total cost

Participants were requested to express their opinion on how does the waste reduction occur by the use of OSC affect total cost and the findings are presented in the Table 4.7.

Table 4.7: Did Waste Reduction Reduce The Total Cost of The Project?

Did waste reduction help reducing the project cost	Rate of Response	
	Nr.	**(%)**
Yes.	31	94
No.	2	6
Total	**33**	**100**

According to the Table 4.6, 94% of the professionals who had participated in the survey confirmed that the implementation of the OSC technique will cause reduction of waste generation at the job site, which will definitely bring in cost reduction in the overall project budget. Implementation of the OSC technique will eventually cut down extensive waste generated on job site as in OSC the pre-fabricated elements are fabricated in controlled environment and then delivered ready for on-site assembly and direct fixation.

The preference of the professionals for the OSC application due to the waste reduction is depicted in the above survey summary Table 4.6 presenting 52% of the received responses have confirmed “waste reduction” as one motivating element for adoption of the OSC in a building project.

4.3.8 Cost reduction due to the use of OSC methods

The respondents' view on cost reduction due to the use of offsite construction methods is illustrated in the Figure 4.6.

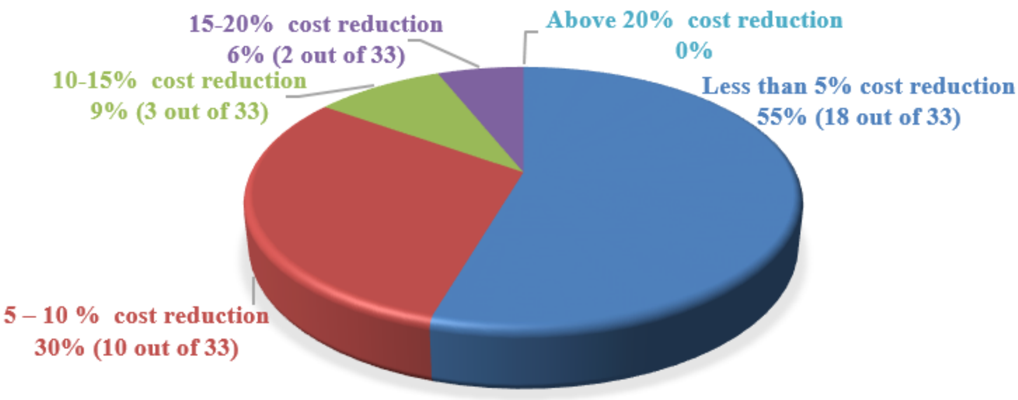


Figure 4.6: Cost Reduction Due To The Use Of Offsite Construction Methods

94% responses of the professionals as figuratively summarized in the previous Table 4.6 have confirmed that the implementation of the OSC technique ascertains the cost reduction in a building project. As per the above Figure 4.6, 55% confirmed their points of view that 0-5% cost reduction occurred due to the OSC technique applied in the projects, while 30% opined for 5-10% cost reduction, followed by 9% responses for 10-15% cost reduction, 6% replied for 15-20% cost reduction due to use of offsite construction methods

4.3.9 Contractor's profit margin

The views of participants regarding the contractor's profit margin in off-site construction methods is depicted in Figure 4.7.

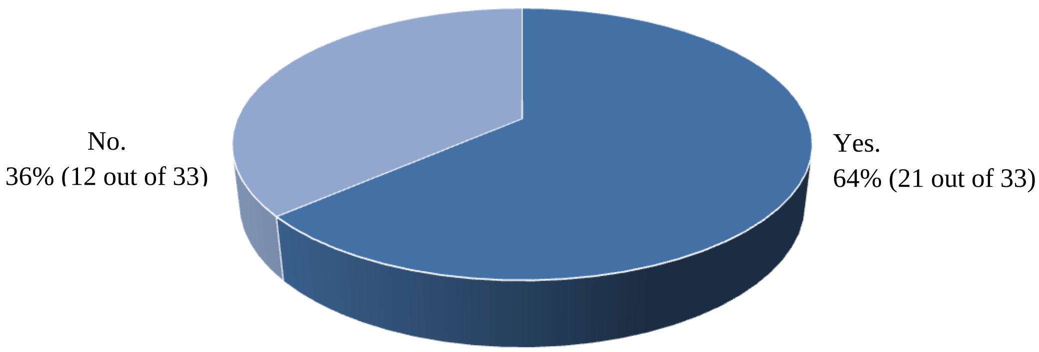


Figure 4.7: Could OSC Methods Increase Contractor's Profit Margin?

Pertaining to the profit margin, majority of the surveyed experts confirmed increment of contractor's profit margin due to the implementation of off-site construction (OSC) methods. While figuring the obtained feedbacks in the above Figure 4.7, 64% of the professionals' responses marked 'YES' for profit margin increment in the case of the OSC applied, but conversely 36% of the feedbacks stood for 'NO' for the same.

The increment in profit margin possibly occurs because of the contractors' quotations covering 'design and build' turnkey project, submitted as per the clients' requirement, and also incorporating the cumulative expenses for logistics or transportation, crane expense, and other associated costs in such quotations.

4.3.10 Materials used in off-site construction

Pertaining to the materials used in place of the traditional ones used in off-site construction (OSC), the options “fragile, sustainable, robust, and adequate” were given for the participants to choose for their response.

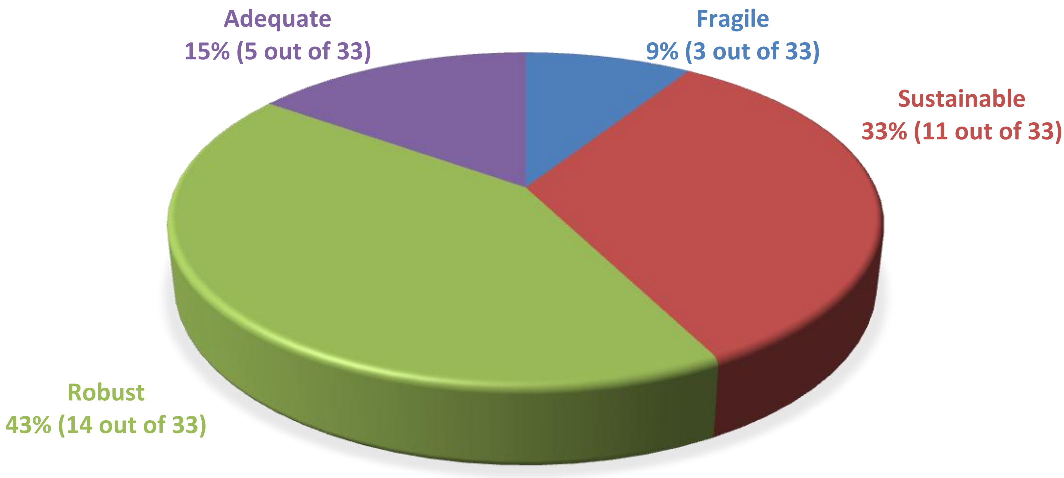


Figure 4.8: Materials Used in OSC in Place of Traditional Materials

The participants’ responses as obtained through the questionnaire were shown in the above Figure 4.8, as per which 43% of the surveyed professionals selected “Robust” for materials used in off-site construction, and 33% feedbacks marked “Sustainable” whereas 15% of the feedbacks stood for “Adequate” and the remaining 9% chose “Fragile” for the same.

4.3.11 Reasons restraining the usage of offsite construction methods

The survey view of professionals obtained through the questionnaire in relation to the reasons (15 nos. as recognized through a review of the literature) restraining the usage of off-site construction methods are summarily tabulated in the Table 4.8.

The question required the participated professional to position in hierarchy the identified reasons restraining the usage of offsite construction methods in Sri Lanka keeping in view their significance in a 5 point scale containing “1” indicated “Not at all important", "2" indicated "Slightly important", "3" indicated "Moderately important", "4" indicated "Very important" and "5" indicated "Extremely important".

Table 4.8: Reasons Restraining The Usage of OSC Methods

Reasons	**Responses**					**Weighted Mean Rating**	**Standard Deviation**
	5	**4**	**3**	**2**	**1**		
Using OSC techniques will increase the construction cost	20	9	4	0	0	4.485	0.712
Longer lead-in time	19	8	3	2	1	4.273	1.069
Company owner restricts using OSC techniques	18	7	4	2	2	4.121	1.219
Architect do not specify the use of OSC techniques	14	9	6	3	1	3.970	1.132
Complex interfacing between systems	13	9	6	3	2	3.848	1.228
Unable to freeze design early on	12	10	5	4	2	3.788	1.244
Transportation restraints	9	10	7	5	2	3.576	1.226
Lack of skilled assembly craft workers onsite	7	9	10	3	4	3.364	1.270
Negative image	5	8	9	5	6	3.030	1.334
Lake of guidance and information	3	7	11	7	5	2.879	1.193
Limited design options in using OSC techniques	3	3	12	7	8	2.576	1.226
Inability to make changes in the field by using OSC techniques	2	4	8	10	9	2.394	1.197
Collective bargaining agreement prohibited the use of OSC techniques	2	3	7	11	10	2.273	1.180
Local building regulations restrict the use of OSC techniques	1	1	5	15	11	1.970	0.951
Financial institutions restrict the use of OSC techniques	0	2	3	10	18	1.667	0.890

The above Table 4.8 has presented many reasons having weighted mean rating over 4.000. The major causes are "Increment of construction cost, Longer lead-in time, Company owner's restriction, Architect not specifying OSC techniques, Complex interfacing between systems, Unable to freeze design early on, Transportation restraints, Lack of trade skilled workers, and many others".

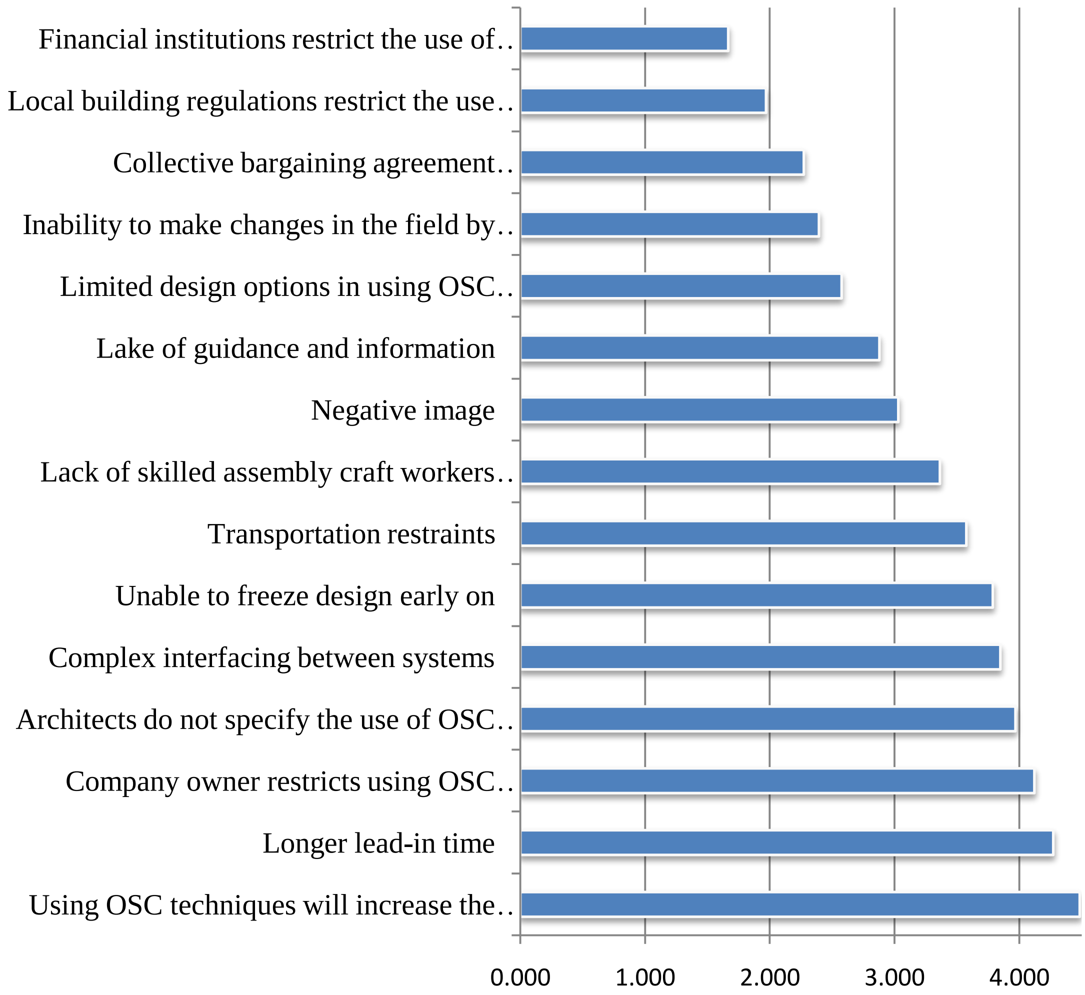


Figure 4.9: Reasons Restraining The Usage of OSC Methods

Furthermore, "Increment of construction cost" as the reason restraining the implementation of the OSC methods has the maximum weighted mean value (i.e.; 4.485) as responded by all 33 participants in which 20 responses rated as "5" in the scale indicating extremely important, whereas no participant rated as "2", and "1" for the said reason.

The reason "Longer lead time" was also marked as second priority reason having the weighted mean value (4.273) rated as "5" in the scale by 19 respondents valuing extremely important, scaled as "4" by 8 responses assessing very important.

Another prime reason restraining the application of the OSC methods is “Company owner’s restriction” which is weighted with mean value 4.121, as evaluated by the feedbacks obtained from all the participants in which the said reason is rated as “5” in the scale through 18 answers evaluating (extremely important), positioned as “4” in the scale by 7 responses assessing (very important), placed as “2” and “1” in the scale through 2 replies in equal weighing up slightly important, and not at all important respectively.

The survey through the questionnaire for evaluating the reasons behind restraining the implementation of the OSC methods and the responses obtained from the respondents also brought to the fore and other reasons with almost equal importance, which have the weighted mean value more than 3.500.

Among them, the reason “Architect not specifying the use of OSC techniques” was responded by all participants, which is rated as “5” (emphasizing extremely important), “4” (indicating very important) “3” (moderately important), “ 2” (slightly important) and “1” (not at all important) in the scale through the number of responses (14, 9, 6, 3, 1) correspondingly.

“Complex interfacing between systems” was also cited by the survey participants as a reason to restrain the use of the OSC techniques. While tabulating the obtained responses; the above table presents the weighted mean value (3.848) scaling this reason as “5”, “ 4”, “3”, “2”, and “1” value supported by the number of the received responses (13, 9, 6, 3, and 2) respectively.

Likewise, other factors “Unable to freeze design early on, Transportation restraints, Lack of skilled assembly craft workers, and Negative Image” were also indicated by the participants as the reasons to retrain the implementation of the OSC methods, which is substantiated through the weighted mean values (3.788, 3.576, 3.364, and 3.030) correspondingly.

Apart from the above evaluated reasons, the other reasons such as “Collective bargaining agreement, Limited design options, Inability to make changes in the field, Lack of guidance” as selected by the professional participants are also significant to some extent for restraining the application of the OSC techniques. While tabulating the gathered responses, the weighted mean rating for these reasons is in between the mean values 2.273 to 2.79.

Likewise the respondents cited “Financial institutions' restriction” and “Local building regulation restriction” as the least preferred reasons for restraining the implementation of the OSC methods, which having the weighted mean values 1.667, and 1.970 respectively.

While scrutinizing all the responses from the surveyed professionals and as per the evaluation for the weighted mean ratings for each reason; the top 10 reasons that restrain the usage of off-site construction (OSC) methods for a building project in Sri Lanka are:

1. Using OSC techniques will increase the construction cost
2. Longer lead-in time
3. Company owner restricts using OSC techniques
4. Architect do not specify the use of OSC techniques
5. Complex interfacing between systems
6. Unable to freeze design early on
7. Transportation restraints
8. Lack of skilled assembly craft workers onsite
9. Negative image
10. Lake of guidance and information

4.3.12 Drivers for the usage of OSC methods

The survey views of professionals obtained through the questionnaire in relation to the reasons (17 nos. as recognized through a review of the literature) encouraging the usage of Off-site Construction methods are summarily tabulated in the Table 4.9.

The question required the professional practitioners to rank the identified drivers for the usage of offsite construction methods in Sri Lanka in purview of their significance in a 5 point scale containing “1” indicated “Not at all important”, “2” indicated “Slightly important”, “3” indicated “Moderately important”, “4” indicated “Very important” and “5” indicated “Extremely important”.

Table 4.9: Reasons For Usage of Offsite Construction Methods

Reasons	**Responses**					**Weighted Mean Rating**	**Standard Deviation**
	5	**4**	**3**	**2**	**1**		
Increase product quality	24	8	1	0	0	4.697	0.529
Reduce construction duration	19	12	1	1	0	4.485	0.712
Ensure time certainty	15	14	3	1	0	4.303	0.770
Ensure cost certainty	17	10	4	2	0	4.273	0.911
Compensate for shortage of skilled workers	12	13	6	2	0	4.061	0.899
Improve project safety performance	13	8	9	2	1	3.909	1.100
Compensate for weather condition	7	9	15	1	1	3.606	0.966
To reduce snagging and defects	9	10	7	4	3	3.545	1.277
Increase sustainability	6	11	10	4	2	3.455	1.121
Increase value	8	6	11	5	3	3.333	1.267
Compensate for the restricted working space onsite	5	6	16	4	2	3.242	1.062
Increase overall labour productivity	3	10	13	5	2	3.212	1.023
Reduce material waste generated on site	2	4	8	11	8	2.424	1.173
Reduce overall project cost	0	4	8	10	11	2.152	1.034
Increase company’s profit margin	1	2	6	15	9	2.121	0.992
Enhance company’s reputation	1	3	4	13	12	2.030	1.075
Reduce design duration	0	1	5	12	15	1.758	0.830

The above Table 4.9 has presented many reasons having weighted mean rating over 4.000. Some major reasons are "Increase product quality, Reduce construction duration, Ensure time certainty, Ensure cost certainty, Compensate for shortage of skilled workers, Improve project safety performance, Compensate for weather condition, Reduce snagging and defects, Increase sustainability, Increase value, and Compensate for the restricted working space and many others".

Figure 4.10: Drivers For The Usage of OSC Methods

Among all the reasons incorporated in the survey questionnaire and while tabulating the responses ticked by the professional participants, "Product quality increment" stood as the prime driver behind the implementation of the OSC method which is substantiated by the maximum weighted mean value (4.697), and “Design Duration Reduction” was highlighted as the least motivating reason with the minimum weighted mean value (1.758).

The weighted mean value 4.697 is calculated in the above table in accordance with the responses from all 33 participants for the driving factor “Increase product quality” in which 24 responses rated as “5” in the scale indicating extremely important, 8 responses for “4” in the scale indicating very important, and one reply rated “3” in the scale for moderately important, whereas no participant responded to the scale “1” and “2” for the aforesaid reason.

The motivating factor “Reduce construction duration” has the weighted mean value of 4.485 as per the received responses in which 19 responses rated as “5” in the scale evaluating extremely important, 12 responses for “4” in the scale assessing very important, and one reply each rated “3” and “2” in the scale, whereas no participant pointed to the scale “1” for the aforesaid reason.

The reason “Ensure time certainty” was also evaluated as a priority reason with the weighted mean value 4.303 rated as “5” in the scale by 15 respondents valuing extremely important, and no participant indicated to the scale “1” for not at all important.

“To ensure cost certainty” also remains a considerable factor to encourage the use of the OSC methods which is substantiated by the weighted mean rating (4.273) evaluated by the received survey feedbacks for the scale (“5, 4, 3, and 2”) by the number of replies (17, 10, 4, and 2 sequentially), and the scale “1” achieved “ 0” feedback.

Similarly, another notable reason to drive the application of the OSC methods is “Compensate for shortage of skilled workers” which was selected by the respondents making the weighted mean value 4.061.

Likewise, the received feedbacks from the surveyed professionals also highlighted other reasons as the factors driving the use of the OSC methods, rating the weighted mean values “3.909”, “3.606”, “3.545”, “3.455”, “3.333”, “3.242”, “3.212” by all 33 responses for the causes “Improve project safety performance”, “Compensate for weather condition”, “Reduce snagging and defects”, “Increase sustainability”, “Increase value”, “Compensate for the restricted working space onsite”, and “Increase workmanship productivity” sequentially.

Similarly, the other causes for encouraging the use of the OSC methods such as; “Reduce material waste generated on site”, “Reduce overall project cost”, “Increase company’s profit margin”, and “Enhance company’s reputation” were responded by all 33 participants but stood lesser significant while comparing with the weighted mean ratings for other reasons described above. While positioning the afore-mentioned reasons in sequence, the tabulated calculation (Table 4.9) presents the weighted mean rating “2.424”, “2.152”, “2.121”, and “2.030” correspondingly. The reason “Reduce design duration” was evaluated the least significant to motivate the implementation of the OSC methods, with the weighted mean value “1.758”.

While scrutinizing all the responses from the surveyed professionals and as per the evaluation for the weighted mean ratings for each reason; the top 10 drivers for the use of the Off-site Construction (OSC) methods for a building project in Sri Lanka are:

1. Increase product quality
2. Reduce construction duration
3. Ensure time certainty
4. Ensure cost certainty
5. Compensate for shortage of skilled workers
6. Improve project safety performance
7. Compensate for weather condition
8. To reduced snagging and defects
9. Increase sustainability
10. Increase value

4.3.13 Off-site construction challenges

In order to accomplish Objective 4, identified possible OSC challenges (83nos) were listed out in the questionnaire survey, and then the respondents were asked to select the most significant off-site construction challenges (overall) from the list. Further the respondents were given an option to state the level of impact of those challenges in each type of offsite construction methods (Volumetric, Hybrid, Panelized, and Sub Assemblies).

In previous project management studies the mean score method was used to rank the relative importance of specific factors (Chan et al. 2003; Chan and Kumaraswamy 1995).Then mean value of the challenges were derived from the frequency of responses received for most significant (overall) challenges, where the total number of respondents is 33, and each respond is weighted as 1 (critical challenges) or 0 (non-critical challenges)

Challenges with mean scores higher than the average total value (0.468) were identified as critical challenges hindering the adoption of OSC in Sri Lanka. The results of ranking analysis presented in the Table 4.10 and according to that 39 out of the 83 identified possible challenges in the questionnaire survey have mean scores greater than 0.468, and are therefore deemed critical OSC challenges.

Further, the level of impact of those challenges in each off-site construction method was derived by comparing the frequency of response received for each OSC type.

Grouping of critical challenges

Grouping of the critical challenges is mandatory to simplify the research outcomes. Factor analysis is one of the most common methods used to group variables.

As cited from the study by Bartholomew, Knott, and Moustaki (2011), the concept followed by factor analysis is that computable and perceivable variables have possibility to get minimized to lesser subdued variables which allocate a usual discrepancy (i.e. variance) and remain subdued. The aforesaid assumption is recognized as downgrading dimensionality. A research by Cattell (1973) highlights that the measurement of these subjugated factors which are taken to be basically theoretical concepts for signifying variables, is not straightly carried out.

According to Child (2006), univariate and multivariate ordinariness is required to be within the data for doing a factor evaluation. The suggested sample extent is 300 respondents at minimum, and every variable, which is subject to factor scrutiny, is required to have minimum 5 to 10 perceptions (Comrey & Lee, 1992). A usual circumstance is necessitated to reflect 10:1 (lowest) proportion between participants and variables, in which the factors are taken to be unchanging, and having cross validation with a proportion of 30.1.

In this research, the targeted survey participants (60) are lower than the number of variables (83). And the recommended minimum sample size (300) is very much higher than the targeted survey participants (60). This limits the application of factor analysis to the survey outcomes.

The critical challenges were then sorted into the 8 clusters identified in the Chapter 2 – Literature Review and for the purpose of assisting interpretation the eight constructs were assigned names as follows:

- Cluster 1: Industry Structure and Supply Chain;
- Cluster 2: Constructability Implementation;
- Cluster 3: Architectural Performance;
- Cluster 4: Cost;
- Cluster 5: Policies and Regulations;
- Cluster 6: Technological Innovation;
- Cluster 7: Social Climate and Attitudes; and
- Cluster 8: Other Challenges

Cluster matrix of critical challenges after rotation is presented in Table 4.11.

Table 4.10: Ranking of Critical Challenges For The Uptake Of Off-Site Construction In Sri Lanka

Off-site Construction Challenges	Mean	Magnitude Of Challenge			
		Volumetric	Hybrid	Panel	Sub-Assembly
C01. Lack of awareness of prefabrication by the market and public	1.000	High	High	Medium	Low
C02. Lack of experienced collaboration groups	0.970	High	High	Medium	Low
C03. The owner's negative perception	0.970	High	High	Medium	Low
C04. The fragmented nature of the construction industry	0.939	Medium	Medium	Low	Low
C05. Lack of enough flexibility	0.939	High	Medium	Medium	Low
C06. Project planning and coordination	0.939	High	High	Medium	Low
C07. Lack of practices and experiences from local projects	0.909	High	High	Low	Low
C08. High initial & capital cost	0.909	High	Medium	Medium	Low
C09. Lack of technologies and testing institute to prefab. components	0.909	High	High	Medium	Low
C10. Transportation of prefabricated elements and access to the building site	0.879	High	Medium	Low	Low
C11. Lack of governmental regulations and incentives	0.879	High	High	Medium	Low
C12. Monotonous design with poor aesthetic criteria	0.848	Medium	Low	Low	Low
C13. Lack of local Research and Development institutes and services	0.848	High	High	Medium	Low
C14. Uncertainty of market demand	0.848	Low	Low	Low	Low
C15. Lack of manufacturers & suppliers of prefabricated components	0.818	High	High	Medium	Low
C16. Unpredictable planning decisions	0.818	High	High	High	Medium
C17. Highly restrictive construction tolerances	0.788	High	Medium	Low	Low
C18. Longer capital payback period	0.788	High	Medium	Medium	Low
C19. Poor integration for the supply chain	0.758	Medium	Medium	Medium	Low
C20. Reluctance to innovation and driven	0.758	Medium	Medium	Low	Low
C21. Lack of confidence of the industry in offsite production	0.727	High	Medium	Low	Low
C22. Lack of experienced contractors on prefabrication	0.697	High	High	Low	Low
C23. Specific demands for the site logistics for pre-finished elements protection	0.697	High	Medium	Low	Low
C24. Lack of experienced design consultancy and designers	0.667	Medium	Medium	Low	Low
C25. Additional cost and care required when manufacturing	0.667	Medium	Medium	Medium	Low
C26. Lack of design codes and standards for prefabricated components	0.667	Low	Low	Low	Low
C27. High skill demands for labour	0.636	Medium	Medium	Medium	Low
C28. Unable to modify design scheme	0.636	High	Medium	Low	Low
C29. Designing off-site construction components requires special computer software.	0.636	High	Medium	Low	Low
C30. Dependence of traditional construction method	0.606	High	Medium	Medium	Low
C31. Project scheduling issues	0.606	Medium	Medium	Low	Low
C32. Inability to make changes in the field	0.576	High	Medium	Medium	Low
C33. Legal issues	0.576	Low	Low	Low	Low
C34. Monotony of structure type	0.545	Medium	Medium	Low	Low
C35. Late appointment of contractor/manufacturer	0.545	High	High	Medium	Low
C36. Longer lead-in time	0.515	High	Medium	Low	Low
C37. Poor quality impression	0.515	High	High	Low	Low
C38. Off-site construction techniques limits design options	0.485	Medium	Low	Low	Low
C39. Increase in designer fees	0.485	Medium	Low	Low	Low

Table 4.11: Cluster Matrix of Critical Challenges After Rotation

Challenge	Industry Structure & Supply Chain	Constructability Implementation	Architectural Performance	Cost	Policies & Regulations	Technological Innovation	Social Climate & Attitudes	Other Challenges
C02	0.970	-	-	-	-	-	-	-
C04	0.939	-	-	-	-	-	-	-
C07	0.909	-	-	-	-	-	-	-
C10	0.879	-	-	-	-	-	-	-
C15	0.818	-	-	-	-	-	-	-
C19	0.758	-	-	-	-	-	-	-
C22	0.697	-	-	-	-	-	-	-
C24	0.667	-	-	-	-	-	-	-
C36	0.515	-	-	-	-	-	-	-
C17	-	0.788	-	-	-	-	-	-
C23	-	0.697	-	-	-	-	-	-
C27	-	0.636	-	-	-	-	-	-
C32	-	0.576	-	-	-	-	-	-
C05	-	-	0.939	-	-	-	-	-
C12	-	-	0.848	-	-	-	-	-
C28	-	-	0.636	-	-	-	-	-
C38	-	-	0.485	-	-	-	-	-
C08	-	-	-	0.909	-	-	-	-
C18	-	-	-	0.788	-	-	-	-
C25	-	-	-	0.667	-	-	-	-
C39	-	-	-	0.485	-	-	-	-
C11	-	-	-	-	0.879	-	-	-
C26	-	-	-	-	0.667	-	-	-
C33	-	-	-	-	0.576	-	-	-
C09	-	-	-	-	-	0.909	-	-
C13	-	-	-	-	-	0.848	-	-
C20	-	-	-	-	-	0.758	-	-
C29	-	-	-	-	-	0.636	-	-
C34	-	-	-	-	-	0.545	-	-
C01	-	-	-	-	-	-	1.000	-
C03	-	-	-	-	-	-	0.970	-
C21	-	-	-	-	-	-	0.727	-
C30	-	-	-	-	-	-	0.606	-
C37	-	-	-	-	-	-	0.515	-
C06	-	-	-	-	-	-	-	0.939
C14	-	-	-	-	-	-	-	0.848
C16	-	-	-	-	-	-	-	0.818
C31	-	-	-	-	-	-	-	0.606
C35	-	-	-	-	-	-	-	0.545

Cluster 1: Industry structure and supply chain

Table 4.12: OSC Challenges - Industry Structure And Supply Chain

Cluster 1 Industry Structure & Supply Chain	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C02. Lack of experienced collaboration groups	0.970	H	H	M	L
C04. The fragmented nature of the construction industry	0.939	M	M	L	L
C07. Lack of practices and experiences from local projects	0.909	H	H	L	L
C10. Transportation of prefabricated elements and access to the building site	0.879	H	M	L	L
C15. Lack of manufacturers and suppliers of prefabricated components	0.818	H	H	M	L
C19. Poor integration for the supply chain	0.758	M	M	M	L
C22. Lack of experienced contractors on prefabrication	0.697	H	H	L	L
C24. Lack of experienced design consultancy and designers	0.667	M	M	L	L
C36. Longer lead-in time	0.515	H	M	L	L

Nine critical challenges are contained in the cluster “Industry structure and supply chain”. The focus of all these concepts is on the insufficiency of OSC experience of varied respondents such as architects, designers, consultants, contractors, and offsite manufactures.

Cluster 2: Constructability implementation

Table 4.13: OSC Challenges - Constructability Implementation

Cluster 2 Constructability Implementation	Mean	Magnitude of Challenge H - High, M - Medium, L – Low			
		Volumetric	**Hybrid**	**Panel**	**Sub-Assembly**
C17. Highly restrictive construction tolerances	0.788	H	M	L	L
C23. Specific demands for the site logistics for pre-finished elements protection	0.697	H	M	L	L
C27. High skill demands for labour	0.636	M	M	M	L
C32. Inability to make changes in the field	0.576	H	M	M	L

The second cluster, as it is linked with deterring construction forbearances, particular requirement for the site logistics for pre-fabricated components safety, calls for the skillful labour and low interface with the supply chain, was designated 'Constructability implementation'. The notion of 'constructability' is usually known as course of obtaining maximum interface of construction information and experience in planning, engineering, procurement and site maneuvers in the building progression to equalize the different projects and environmental restraints for achieving the objectives of the overall project (Construction Industry Institute, 1986). Involving all prime stakeholders is a requirement as a portion of comprehensive planning for offsite production to embark on most functions in advance comparatively to the conventional construction procedures.

Cluster 3: Architectural performance

Table 4.14: OSC Challenges - Architectural Performance

Cluster 3 Architectural Performance	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C05. Lack of enough flexibility	0.939	H	M	M	L
C12. Monotonous design with poor aesthetic criteria	0.848	M	L	L	L
C28. Unable to modify design scheme	0.636	H	M	L	L
C38. Off-site construction techniques limits design options	0.485	M	L	L	L

The challenges pertaining to 'Architectural performance' of the OSC has been tabulated under the Cluster 3 table which constitutes traits of monotonous design, restrictive flexibility, design scheme, design options. The building's structural attributes with artistic feature, suppleness and utility for likely offsite fabrication is highlighted on by this cluster.

Cluster 4: Costing

Table 4.15: OSC Challenges - Cost

Cluster 4 Cost	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C08. High initial & capital cost	0.909	H	M	M	L
C18. Longer capital payback period	0.788	H	M	M	L
C25. Additional cost and care required when manufacturing	0.667	M	M	M	L
C39. Increase in designer fees	0.485	M	L	L	L

Cluster 4 was related to 'Cost' of offsite production with reference to higher initial and capital, and a longer capital payback period. The commercial boundary regularly gets much significance as an element influencing the determining process while opting for the ideal construction method.

Cluster 5: Policies and regulations

Table 4.16: OSC Challenges - Policies and Regulations

Cluster 5 Policies and Regulations	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C11. Lack of governmental regulations and incentives	0.879	H	H	M	L
C26. Lack of design codes and standards for prefabricated components	0.667	L	L	L	L
C33. Legal issues	0.576	L	L	L	L

The cluster 5 contains 3 challenges concerning weak regulatory policies and inducements in Sri Lanka: (1) lack of governmental regulations and incentives, (2) lack of design codes and standards for prefabricated components, and (3) legal framework issues.

Cluster 6: Technological innovation

Table 4.17: OSC Challenges - Technological Innovation

Cluster 6 Technological Innovation	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C09. Lack of technologies and testing institute to prefabricated components	0.909	H	H	M	L
C13. Lack of local Research and Development institutes and services	0.848	H	H	M	L
C20. Reluctance to innovation and driven	0.758	M	M	L	L
C29. Designing OSC components require special computer software	0.636	H	M	L	L
C34. Monotony of structure type	0.545	M	M	L	L

This cluster consists of five critical challenges: (1) lack of technology and testing institutes for prefabricated components, (2) lack of local research and development institutes and services (3) reluctance to innovation and driven, (4) designing OSC components require special computer software and (5) monotony of structure type. These five challenges pertain to the influence of technology on OSC.

Cluster 7: Social climate and attitudes

Table 4.18: OSC Challenges - Social Climate and Attitudes

Cluster 7 Social Climate & Attitudes	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C01. Lack of awareness of prefabrication by the market and public	1.000	H	H	M	L
C03. The owner's negative perception	0.970	H	H	M	L
C21. Lack of confidence of the industry in offsite production	0.727	H	M	L	L
C30. Dependence of traditional construction method	0.606	H	M	M	L
C37. Poor quality impression	0.515	H	H	L	L

Cluster 7 was assigned the name ‘Social climate and attitudes’, which included lack of awareness of prefabrication, the owner's negative perception, lack of confidence of the industry about offsite production. A detected variance from Cluster 1 refers to the domestic conflicts in the construction sector, where the cluster 7 bears a reference to the public and social environment with direct linkage to the peripheral milieu.

Cluster 8: Other challenges

Table 4.19: OSC Challenges - Other Challenges

Cluster 8 Other Challenges	Mean	Magnitude of Challenge H - High, M - Medium, L - Low			
		Volumetric	Hybrid	Panel	Sub-Assembly
C06. Project planning and coordination	0.939	H	H	M	L
C14. Uncertainty of market demand	0.848	L	L	L	L
C16. Unpredictable planning decisions	0.818	H	H	H	M
C31. Project scheduling issues	0.606	M	M	L	L
C35. Late appointment of contractor/manufacturer	0.545	H	H	M	L

The last cluster contains 5other off-site construction challenges: (1) Project planning and coordination, (2) Uncertainty of market demand, and (3) Unpredictable planning decisions, (4) Project scheduling issues, and (5) Late appointment of contractor/manufacturer.

4.4 Discussion

Industry structure and supply chain

Insufficient training and involvement in local projects is a chief hindrance to OSC at the present phase of construction advancement in Sri Lanka. Most developers invest as "rational economic men" with a target to achieve financial benefit. That is why project developers like to see prosperous situations or instances of OSC prior to taking larger risks. However, some developers implemented pre-fabricated elements in the housing projects in the nation. Enough self-assurance toward urging Sri Lankan property developers for embracing OSC cannot be generated due to the shortage of up-to-date practical measuring profile.

Patchy character of the construction industry is discernibly exhibited through inadequacy in number of fabricators and traders of pre-fabricated elements; including shortage of proficient association, pre-fabrication contractors, design consultants, and designers. A research study done by Kamar and Hamid (2011) highlights that in purview of any particular developer, the existing supply chain appears huge to be incorporated. Emergence of such circumstance occurs due to the overall advancement process engaging the industry in various individual and inter-reliant fields. The resources existing in the native construction market also facilitates, to a definite degree, the implementation of OSC. Obtaining professional OSC contractors, consultants, and suppliers in the same construction market is also a problem being faced by Sri Lankan property developers. The developers' inclination and propensity towards the implementation of a conventional method rather than an innovating one is also prompted by all of these factors interlinked with shortage, or inaccessibility of resources during the overall construction process.

The supply chain (which connects to logistics, different entities of the construction sector including production capability) is a terminology having linkage to the setup of the involved business establishments, various doings in process and particularities increasing values through products and services for advantage of the project clients or the end users, as mentioned in a study by Christopher(1998). Referring to a research by Vrijhoef and Koskela(2000), the supply chain intakes activities from the site and such process is deemed as urgency, and it is a sensible scheme for furthering the construction process. 3C (cooperation, coordination and collaboration) are efficient constituents that are straightly related and should function in a concurrent manner for the supply chain to increase individual effectiveness (Briscoe, Dainty, Millett, & Neale, 2004). All phases should implement the integration concept internally and between the enterprises engaged in the OSC process, conversely to being reliant on fractured collaboration for function relationships. The aforesaid 3C including the connections and linkages between the project stakeholders as well as the developers and end users is still meagre and lowly in Sri Lanka. A lot of parties engaged in constructing have mindset for functioning singly with their individual objective, and mutuality is in almost bottom degree in terms of transmitting information and knowledge, which resulted the intermission and break in OSC endorsement in residential development.

The Sri Lankan OSC supply chain also faces a logistical problem due to the difficulties linked with the overall budget expenditure needed to ascertain offsite finance scale, several contractors, OSC manufacturers and traders facing basic problems pertaining to site locations, complicated delivery procedures and logistic requirements. Along with growing complications of construction projects, the degree of supply chain interface is extensively required to be immediately improved by the Sri Lankan residential construction processes from a professional and administrative point of view.

Constructability implementation

Hence, that constructability application is a chief contest, or trial for Sri Lankan builders while striving for intensify the endorsement of offsite production is no more astonishment. The overall project team with a consorted objective is an influential requirement for a fruitful application of constructability. Excessive interaction, coordination and interface/interlink between the stakeholders (developers, designers, contractors, manufacturers and suppliers) is a requisite for proper planning and application of an offsite construction procedure. Nevertheless, Sri Lankan building construction sector has still retained a position with a variety of disintegrated businesses which causes an intense hurdle for proper coordination because of shortage of a distinctly outlined or specified project management plan before the commencement of a construction project.

Conventional building procurement is also a cause for the ineffectual construction issues. Despite of the necessity for a keen collaboration of the contractor and manufacturer at the start of a project for the design and planning stages (in the OSC methods) to obtain the adequate degree of feasibilities, Sri Lankan construction procedure generally avoids the contractor and other auxiliary stakeholders at the front-end phase of a project. Additionally, proficiency and empirical knowledge also associates with the implementation of the OSC methods, and the inadequacy of which is also a feeding factor to a practical obstacle to know-how about the constructability application on projects.

Architectural performance

While seeking for applying OSC methods at the preliminary stage of a project, a standard, modular and typical (repetitive) design normally seems to count importance, but that the extensive typicality (or repetitiveness) and standardization of procedures linked with OSC was a preventive factor for its enhanced implementation in the building sector has been discussed about earlier (Warszawski, 1999). According to Jaillon and Poon, (2010), the offsite procedures avoid recurring of modifications in architectural design. The high-rise building complexes in Sri Lankan town areas have already experienced a practical betterment in quality. Regardless to the difficulties linked with external factors, flexibility in building layouts and lofty degree of variety are considered as the chief benefits in the cutthroat construction market. Nevertheless, according to the obtained survey responses the application of OSC methods will really bring in a distress to the design adaptability and decoration/beauty aspects. As per the belief of several professionals, an elevated risk of economy and time ambiguities take a position at a time of amendments, or alterations required during construction in the projects commenced in offsite manufacture.

Referring to architectural contemplations associated to offsite manufacture, insufficient, or incomplete understanding of Sri Lanka-based-developers and designers towards the benefits inherent in OSC has been highlighted. The developers don't usually extend their sufficient support as regards to both time and commercial feedbacks to architects and engineers; otherwise they remain indisposed to innovation. Several respondents have opined that the stress of project timelines and finance made it strongly problematic to gain, or go through a comprehensive deliberation of implementing OSC methods at the design phase.

Costing

As identified in a researches by Polat (2008); Jaillon and Poon (2010), workforce and materials minimizing, quick fixation of structures, reduced expenses for maintenance and renovation are frequently the determinants in relation to the key financial advantages of offsite manufacture.

Previous studies by Goodier and Gibb (2007); and Polat (2008) have highlighted that a considerable increment has taken place over time in the degree of consciousness pertaining to the entire project budget savings owing to the application of OSC methods. Contrarily, the commercial functioning of OSC manufacture is still a contentious dispute. Researches done by Pan et al., 2007, 2008; Blismas and Wakefield (2009) states that according to the construction sector's point of view, the insight of higher initial investment cost and capital cost has formerly been debated as a significant hindrance to advancing OSC over the substantial period. As per Jaillon and Poon (2008), while evaluating a direct expense of tower building construction, the construction sum related through the OSC methods is approximately 20% superior than that of the traditional construction methods. As mentioned in a study by Taylor (2010), the constructing of one-off buildings repeals the OSC procedures. Until and unless the advantages associated with the OSC application are aligned in regularity and continuity, the commercial gains obtained through the OSC methods are hard to be evaluated. The targeted eventual result is a determinant channel for concluding the cost effective rendered from the fabrication frames, and other resources applied for offsite manufacturing of particular components.

High pricing is another issue related to the way comparison is done. Majority of stakeholders in the building industry usually do a comparison with the traditional construction methods over the short lasting period. While determining to implement the ideal construction approach, much thoughtfulness has not been given to the cost efficiency perception linked with offsite manufacture. Additionally there also exists a variance as well between Sri Lanka and Western nations regarding the commercial profits generated from minimized labour expenses, chiefly inexpensive labour availability in Sri Lanka. A criticism has been made for OSC method being an extreme industrialization building approach due to supplementary necessity of knowledge and training to the workers, particularly for some minor and moderate scale establishments.

Cost, deemed as a chief and critical impediment for the implementation of OSC in Sri Lanka, involves different types of expenditures in OSC; the initial cost is the one for the fixed property, hence a partial of the manufacture cost. Because of this reason repaying of the fixed cost is always in the ratio of the products. The transportation cost also takes its primacy in OSC. As the majority of the developers' major concern being toward the profit, the extra cost means a remarkable deficit of finance. The government assistance is highly required to obtain the desired commercial scale in OSC in the Sri Lankan existing market mechanism.

As concluded by Jaillon(2009), cost could be equalized through reduction in time, non-activities, labour, resources, and commercial scale. Nevertheless, in the event of no commercial benefits to the developers, they cannot afford the higher expenditure of OSC. Pan et al. (2008) in his study has strongly put his view that extensive transparency in costs evaluation methods is required to be implemented for ascertaining the controlled and better expenses. A study by Pan and Sidwell (2011), after scrutinizing the functioning of 4 kinds of construction techniques (i.e.; precast concrete cross wall panels, in-situ RC frames, steel frames, and timber frames), concluded that precast concrete cross wall was inexpensive than the other 3 frames. This finding is an encouragement for using OSC method. Effective management by the developers can lead to cost savings as well (Pan &Sidwell, 2011).

Policies and regulations

A major aspect for effective OSC project application is to have a competent and effectual legal structure and procedure with concerned codes, references, standards, regulations, policies, and qualifications to lead the attitude and manner of developers, designers, contractors, and authority's representatives taken part in OSC during the overall building progression. The governmental policy and regulation mediums in Sri Lanka as to the application of OSC techniques are also deemed insufficient and undeveloped. Rendering a high level of impact on requirement through the public authorities' policies and purchase system reserves a significant function in fostering innovation, or alteration through endorsement of innovative construction technique (Gann and Salter, 2000). In contrast, Sri Lanka has somewhat insufficient radical (progressive) laws, regulations, codes and standards concerning offsite manufacture techniques. This insufficiency in administering of laws and actions brings into light the stakeholders facing the hurdles while intending to take in effectual OSC procedures.

The survey participants' responses have accentuated insufficient public policies and inducements being the chief hurdle in the rating analysis of this research, and lack of assistance for progressing with the implementation of OSC methods. Despite of several authorities' policies issued with a focus on structural feature, low power consumption, and materials, meagre number of them pertains to OSC procedures. Meanwhile, the business firm's intentional involvement rather than as required by the public legal rule or regulations consequently contributed to a failure of several policies in their performance. A strong and effectively imposed implementation like the one applied in Singapore can make a remarkable influence on the advancement of OSC in Sri Lanka. Singapore's governmental residential system makes an obliged necessity for use of OSC products in the name of complying with legal provisions toward constructability.

Logical inducements can result an inspiration for pursuit of OSC procedures. Hong Kong's Building Affairs is an instance, which has practiced an inducement plan in the construction industry to foster the implementation of Green Building Technology, as well as pre-manufacture. The said scheme exempts GFA (gross floor area) for property developers to apply green façade through usage of pre-manufactured elements. But in Sri Lanka the government has yet to make such incentive provisions for encouraging the adoption and proliferation of OSC methods.

Thus, more incentives are required, not only to develop OSC, but to offset the additional costs involved in it as well.

Technological innovation

The progression of OSC is constrained by insufficient native Research and Development establishments and services. A vast difference is discernible between OSC methods in Sri Lanka and that in advanced nations like the United Kingdom. Currently, Sri Lanka lacks in methodical and wide-ranging technical procedure for maneuvering of OSC. Many off-site developers adopting OSC maintain their own standards at the establishment level, but the overall industry require to follow a common national standards. Non-existence of valid and trustworthy firms for testing the attributes and characteristics of pre-manufactured elements also gives a rise to ambiguity toward the manufactured items channeling through the market.

The disinclination for innovating due to lacking in research and development capital in the construction industry is another remarkable hindrance. Research and development capital investment in the construction sector in Sri Lanka is comparatively meagre than the investment made by advanced nations; for an instance, the United Kingdom Government's funding in investigation projects concerning OSC stands nearly at £5 million between the period of 1997 and 2001 (Blismas & Wakefield, 2009).

The repetitiveness in structure model due to the preliminary information or knowledge of the attributes of off-site construction also poses a barrier to OSC. Emergence of variety and further broadening of building models accompanies the advancement and proliferation of OSC methods; the vehicles sector is a likened instance. This is the reason (i.e.; insufficiency in such technologies) for the property developers to be inclined toward those projects adopting the already familiar structure models.

Social climate and attitudes

Likewise, referring to a scrutiny (analysis) the conduct of enterprises is defined and controlled by the industry framework which affects proficiency and output of the industry (McWilliams & Smart, 1993), inferring that the conventional building method is instigated by the stagnation (no newness) in the construction field to take an unchanging pattern. This is a circumstance guiding to an elaboration behind the reason of "reliance on the conventional construction approach" is an obstacle to the progression of OSC in Sri Lanka.

Unlike in Western nations, the Sri Lankan Government embarks on a crucial responsibility in commercial and communal advancement with significant control. Hence, extensive application of offsite manufacture which is resultant due to new methods to construction is not feasible without government interference. Currently, the financial investment from the construction industry has been regularly brought to light by the Sri Lankan government; nevertheless, integrating of technological advancements and revolution has not got sufficient consideration. The offsite manufacture in construction has not obtained support for fostering due to non-existence of defined policies. Additionally, a usual disinterest in ideal (novelty) construction method is seemed to exist with several industry professionals, especially individual residential developers. Offsite manufacturing method is normally deemed as a complicated construction procedure giving a challenge to the conventional construction approach.

The developer's intake of building method including OSC continue as self-justifying until and unless the same is sufficiently fostered and induced by the Sri Lankan governmental authorities. Constrained information and acquaintance toward the contemporary residential building is found in the urban based general populace who frequently likens the modern construction procedure to 'expensive cost and low preference' than the conventional onsite (i.e.; labour-demanding building method). The implementation of OSC techniques has yet to be identified as a prospect to deal with the subject of a building shortages and challenges of sustainability.

Other challenges

Production and price of OSC is promptly affected by the market's necessity. Shortage of necessity in the market is a hard circumstance for any businessman. The lack of market demand makes the property developers feel anxiety about potentiality of their construction business. On one side, the housing constructed through application of OSC can fulfill the consumers' necessities through offering choices more than those provided by the traditional constructions. On other side, as per the developers' point of view, insufficient consciousness and knowledge of the end users and the public creates the meagre demand for OSC. Actually, the end users themselves have no affair with the construction techniques and progression of buildings, rather being extensively focused on the attributes and characteristics of the buildings. So, it is appropriate to mention herein that so far as the quality matter is concerned, the determining of the ultimate requirement, or demand for OSC lays on the property developers and projects clients noticeably than the end users, or consumers.

It is apparent that the project preliminary phase involves appropriate grounding (basis) and comprehensive planning which are the constituents straightly related to accomplishment of OSC doings. An extensive homework (grounding) time is needed for the individual type of offsite fabrication processes in construction in order for the architectural design to be determined, availability of workforce and offsite elements to be settled, and deadlines to be coordinated between various involved parties, logistics availability, technological way out, and other concerned aspects.

4.5 Summary

The Chapter 4 exhibits the research findings that the Sri Lankan Construction Industry has implemented all 4 (Four) OSC methods, but the difference lies only in the degree of application for each OSC method, and kinds of industry, such as extensive usage of volumetric construction is found in the residential and commercial buildings while panelised construction method is used in industrial & commercial buildings; likewise hybrid construction method in industrial, commercial and residential buildings, and sub-assemblies method in industrial buildings.

The survey outcomes also highlights ‘work time & other restrictions in sensitive areas, short weather window, increment of product quality, reduction in construction duration, time certainty” being the major motivators for the use of OSC methods by Sri Lankan Construction Industry; as well as bringing to the fore the top reasons constraining the usage of offsite construction methods, such as increment in the construction cost, Longer lead-in time, Company owner’s restriction for using OSC techniques.

This chapter also presents several challenges being faced by OSC in Sri Lankan construction industry. The top challenges are outlined as bellows:

- Lack of awareness of prefabrication by the market and public
- Insufficiency of experienced collaboration groups
- The owner’s negative perception
- The fragmented nature of the construction industry
- Limitation in flexibility
- Project planning and coordination

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter provides the summary and conclusion of the research with its findings; along with propositions and recommendations offered for its enhancement and fostering, based on the survey consequences. The aim of this research is to investigate the application of off-site construction in the building sector of Sri Lankan construction industry. The recommendations are brought to the fore for tackling the dominant challenges perceived from the statistical analysis of the gathered data.

The principle objectives were to identify the nature of off-site construction application in the Sri Lankan building construction sector, identify the extent of application of different types of off-site construction methods adopted in the building sector of Sri Lankan construction industry, recognize the benefits and barriers in implementing off-site construction methods, and determine the challenges faced in the application of off-site construction methods with special emphasis to project managers. Furthermore, the chapter also delineates the restrictions of the study. Ultimately, the chapter deliberates about the prospects existing for additional studies.

5.2 Conclusions

The summary and conclusion of the research findings under each objective is presented below:

Objective 1 - To identify the nature of off-site construction application in the Sri Lankan building construction sector

The Chapter 2 - Literature Review and Chapter 4 - Data Analysis have been enabled to accomplish the Objective - 1 of this research. It has been found that the number of OSC Design/Consultant firms in Sri Lanka is relatively very low because most of the offsite contractors are designers by themselves which was substantiated through the most of responses received from the contractors' group. Only 61% respondents have above average knowledge in OSC which shows anecessity for accelerating the learning need of offsite construction professionals on latest offsite construction technologies. All the methods (i.e.: volumetric systems, panelized systems, hybrid construction, and sub-assemblies) are equal in offering high satisfaction and accordingly positioning their ranking. The data analysis also revealed that OSC is expensive when comparing to traditional construction but the difference is low. But the 'Table 4.15: OSC Challenges - Cost' clarifies that the high capital cost is not applicable to all OSC methods, and it is applicable to volumetric and hybrid only. Even though the cost is a high, the preference is given for OSC due to its advantages and the additional cost can be overcome by superior quality, less duration, financial benefit/income generated from early completion.

Likewise, the research outcomes also guide to an understanding that OSC minimizes the waste leading to a reduction in the project budget. Contractors' profit margin is high in OSC due to low competitors in industry, design and build type quotation, and no clear cost data for other expenses such as crane charges. Further, most of the respondents say that materials used in OSC are robust.

Objective 2 - To identify the extent of application of different types of off-site construction methods adopted in the building sector of Sri Lankan construction industry.

The Chapter - 4 Data Analysis Section -4.3.2 has conclusively emphasized that all four types of offsite construction methods are used in Sri Lanka.

Volumetric Construction is mostly used in residential and commercial because of its inherent attributes such as comparatively small in size, application of modular method, and easy transportation to site. The choice of volumetric technique stands the best at the time of urgency of the building, and of adverse weather conditions. It is identified that volumetric construction is not preferred for industrial buildings due to height, high span and transportation restrictions.

Panelized Construction is mostly used in industrial and commercial buildings as their structure is preferably constructed by steel and wall panels due to quick construction consuming less time. In contrast, Sri Lankan residential buildings in majority have concrete structure constructed through the traditional brick and block rather than wall panels. But, most of the industrial buildings such as warehouse and factories in Sri Lanka are made with insulated wall panels.

Hybrid Construction is mostly used in industrial, commercial and residential buildings. It encompasses volumetric construction (hence itself being known as semi-volumetric). Its application is included for all industrial, commercial and residential buildings due to its semi-volumetric nature facilitating the production of typical auxiliary components such as kitchens or bathrooms (highly serviced areas). However, hybrid construction method is preferably applied in industrial buildings which have been substantiated through 85% survey responses favouring this method, relatively to commercial and residential buildings.

Sub-assemblies Construction is mostly used in industrial and then commercial. Most of the elements are prefabricated in workshops and assembled in site. Preference of this method application in industrial is due to faster construction, not effected by adverse weather, and limited requirement of skilled labour, and also this method assists for some cost saving in the project budget.

Objective 3 -To identify the benefits of and barriers in implementing off-site construction methods

The Chapter 4 - Data Analysis Section - 4.3.11 and 4.3.12 accomplished Objective- 3 in identifying the barriers as well as benefits in implementing off-site construction methods.

Barriers:

The analysis of the surveyed professionals' responses to all (15) the identified reasons revealed that "Using OSC techniques will increase the construction cost" as a key barrier in implementing the OSC method. The reason “Longer lead-in time” was also found as a negation in the usage of OSC method. The data analysis based on the responses from the professionals also brought to light that the reasons such as “Company owner restricts using OSC techniques”, “Architects do not specify the use of OSC techniques”, “Complex interfacing between systems”, “Unable to freeze design early on”, “Transportation restraints”, “Lack of skilled assembly craft workers onsite” respectively and relatively have their own standing as barriers against the implementation of the OSC method, and accordingly obtaining their own weighted mean values. The analysis also presented that the selected reasons “Negative image” and “Lack of guidance and information” are considered as barriers having least impact or least value toward the OSC method, and concluding that “Increment in construction cost” and “Lead-in-time” are the key barriers restraining the implementation of the OSC Methods.

Benefits:

The analysis of the surveyed professionals’ responses to all the major 17 motivations or drivers for the use of the Off-site Construction (OSC) methods highlighted the reason “Increase product quality” asthe key driving factor toward the OSC methods in Sri Lankan context. The reason “Reduction in construction duration” was also found to have contributed for widening the use of OSC method. The data analysis based on the responses from the professionals and while computing their weighted mean ratings also emphasised that factors such as “Ensuring time certainty”, “Ensuring cost certainty”, “Compensating shortage of skilled workers”, “Improving project safety performance”, “Compensating wreathing condition” and “Reducing snagging and defects” respectively and relatively have their own motivations for the implementation of the OSC method, and accordingly obtaining their own weighted mean values. The analysis also brought to light that the selected driving factors “Increasing sustainability” and “Increasing value” are considered having least motivations or encouragements toward the proliferation of OSC method, and concluding that “Increasing product quality” and “Reducing the construction duration” are the key motivations driving the implementation of the OSC methods.

Objective 4: To determine the challenges faced in the application of off-site construction methods with special emphasis to project managers

Objective - 4 is accomplished through the Chapter - 4 Data Analysis Section - 4.3.13 where 39 critical OSC challenges are shortlisted by the ranking analysis and divided into 8 Clusters for easy explanation.

The Cluster - 1 “Industry structure and supply chain” have inherence of many challenges. However, the analyzing and computing of the obtained responses brought to highlight that “Lack of experienced collaboration groups”, “The fragmented nature of the construction industry”, “Lack of practices and experiences from local projects” and “Transportation of prefabricated elements and access to the building site” were critical challenges. The data analysis concluded that the transportation restriction highly impacts the volumetric construction while its affect is meagre on panel and sub-assemblies system.

So far as the Sri Lankan OSC supply chain is concerned, a logistical problem has stood due to the difficulties linked with the overall budget expenditure needed to ascertain offsite finance scale, several contractors, OSC manufacturers and traders facing basic problems pertaining to site locations, complicated delivery procedures and logistic requirements. Along with growing complications of construction projects, the degree of supply chain interface is extensively required to be immediately improved by the Sri Lankan residential construction processes from a professional and administrative point of view.

The Cluster - 2 “Constructability Implementation” has encompassed few challenges and the analysis process brought to the fore that “Highly respective construction tolerances” and “Specific demands for the site logistics for pre-finished elements protection” as the dominant challenges. A conclusion was reached to through the data analysis that the extreme restrictive construction tolerance has a high impact on the volumetric construction while its affect is low on panel and sub-assemblies system.

The constructability Implementation is a chief contest/ trial for Sri Lankan builders while striving for intensifying the endorsement of offsite production is no more astonishment. The overall project team with a consorted objective is an influential requirement for a fruitful application of constructability. Excessive interaction, coordination and interface/interlink between the stakeholders (developers, designers, contractors, manufacturers and suppliers) is a requisite for proper planning and application of an offsite construction procedure. Nevertheless, Sri Lankan building construction sector has still retained a position with a variety of disintegrated businesses which causes an intense hurdle for proper coordination because of shortage of a distinctly outlined project management plan before the start of a construction project.

It came to be identified that “Lack of enough flexibility” and “Monotonous design with poor aesthetic criteria” as the critical challenges in the Cluster - 3 “Architectural Performance”. A conclusion was drawn through the data analysis that the “lack of enough flexibility” has a high impact on the volumetric construction while its impact is medium on panel system, and low on sub-assemblies system.

Considering the architectural performance with linkage to offsite manufacture, insufficient / incomplete understanding of Sri Lanka-based-developers and designers towards the benefits inherent in OSC; the developers does not usually extend their sufficient support as regards to both time and commercial feedbacks to architects and engineers; otherwise they remain indisposed to innovation. Therefore, the stress of project timelines and finance made it strongly problematic to gain, or go through a comprehensive deliberation of implementing OSC methods at the design phase.

The Cluster - 4 “Costing” has it’s linkage with few challenges as tabulated in Table 4.14 and it was recognized that“High initial and capital cost” and “Longer capital payback period” were the critical challenges. It was concluded that the “High initial and capital cost” has a high impact on the volumetric construction while its affect is medium on panel system, and low on sub-assemblies system.

The additional cost can be equalized through reduction in time, on-site activities, labour, resources, and through commercial scale production. Nevertheless, in the event of no commercial benefits to the developers, they cannot afford the higher expenditure of OSC. Extensive transparency in cost evaluation methods is required to be implemented for ascertaining the controlled and better expenses. And, effective management by the developers can lead them to cost savings as well.

The Cluster - 5 “Policies and regulations” has entailed some challenges and the statistical analysis revealed that “Lack of governmental regulations and incentives” and “Lack of design codes and standards for prefabricated components” were the vital challenges. A conclusion was established that “Lack of governmental regulations and incentives” has a high impact on the volumetric construction as well as hybrid construction whereas its affect is low on sub-assemblies system.

Logical inducements can result an inspiration for pursuit of OSC procedures. An inducement plan is a requisite for the construction industry to foster the implementation of Green Building Technology, as well as pre-manufacture. The Sri Lankan government is required to develop and circulate such incentive provisions to develop and offset the additional costs involved in OSC for encouraging the adoption and proliferation of OSC methods.

“Lack of technologies and testing institute to prefabricated components” and “Lack of local research and development institutes and services” were identified as the crucial challenges in the Cluster - 6 “Technological Innovation”. It was conclusively determined that the “Lack of technologies and testing institute to prefabricated components” has an extreme impact on the volumetric construction as well as hybrid construction and on the contrary, its impact is low on sub-assemblies system.

The Cluster - 7 “Social climate and attitudes” has reflected some challenges and it was found that“Lack of awareness of prefabrication by the market and public” and “The owner’s negative perception” were the dominant challenges among those challenges. A conclusion was established that both challenges highly impact on the volumetric construction as well as hybrid construction, and conversely, their impact is medium and low on panel system and sub-assemblies system respectively.

The developer's intake of building method including OSC continue as self-justifying until and unless the same is sufficiently fostered and induced by the Sri Lankan governmental authorities. Constrained information and acquaintance toward the contemporary residential building (built offsite) is found in the urban based general populace who are in the mindset that offsite construction procedure is expensive and least preferred. The implementation of OSC techniques has yet to be identified as a prospect to deal with the subject of a building shortages and challenges of sustainability.

Other challenges which were not fallen under the above clusters ware presented under the Cluster - 8 "Other Challenges". It was revealed that"Project Planning and coordination", "Uncertainty of market demand", and "Unpredictable planning decisions" are the critical challenges in that cluster. It was concluded that the "Project Planning and coordination" has an excessive impact on the volumetric construction as well as hybrid construction, and conversely, its impact is low on sub-assemblies system. "Project planning and coordination", a remarkable challenge in this cluster places higher concentration on the preliminary phase of OSC with extensive consideration toward timely containing the design and delivery lead time.

5.3 Recommendations

The research findings can have the conclusion that the application of Offsite Construction (OSC) techniques has entailed many challenges, including many gains and profits over the conventional construction techniques. Some problems as identified through the respondents are interlinked and the empirical way-outs applied on site are not always adequate. These interlinked problems and insufficient practical results on site are resulting in expending of remarkable time and cost.

Although the many contributing factors such as Cost increment due to high quality/rapid construction, Shortage of skilled labour, Lack of technology, Public awareness, Public preference for conventional construction materials and many other factors also have linkage with the shortfall of the application of OSC methods; the major critical challenges associated with the OSC techniques in Sri Lankan construction industry can be outlined as: Complicated project planning and coordination, Unable to freeze design early, Transportation restraints, Costly construction, Resistance to change, Higher capital investment, Lake of guidance and information, and Limited suppliers for OSC components.

The challenge under the project planning and coordination can be addressed through micro-managing the engineering efforts in pre-project planning phase, and also with strictly implementing of accurate and precise design coordination and onsite fixation. The experienced team members can advice the client and design team to freeze the design quickly by explicate the consequences to offsite construction thus alleviating design changes. Full consideration of weight and dimensions of the prefab elements and accordingly the logistic arrangement during the transit period will alleviate the transportation restriction challenge. Cost challenge can be handled through transparency in direct and indirect costs as well as setting the appropriate profit margins, and most importantly through implementing volumetric construction as well as hybrid construction systems. Lake of enough suppliers for OSC components can be mitigated by advance decisions and by discussions with potential OSC suppliers to start production early on.

Extensive and enhanced degree of familiarity with update and upgraded information related to various technologies and different skills implementable in offsite construction will offer acceptable capability, flexibility and adaptability to the change in the design and production process. Commercial leadership with business operational management and professional technicalities including firm decisions facilitates the funding of sufficient capital investment and also alleviates the misconceptions toward the OSC technique in the minds of public/clients. The challenge linked to 'Lake of guidance and information' can be minimized or alleviated through implementing of a set technical knowledge at all levels and always encompassing flow of update information and guidance between design, production and assembly.

Confirmation to majority of the discoveries from the literature review was made by the scrutiny of the participants' responses to the survey questionnaires. Nevertheless, to a specific limit, remarkable variances are existent between the international industry and the Sri Lankan Industry of Offsite construction. Furthermore, depending on the characteristics and influence of the business firms in the industry, a deviation has existed pertaining to the difficulties and challenges facing the construction enterprises in the Sri Lankan Construction Sector. Inadequate workforce, indifference in workmanship, prejudices and constrained mentality of the investors and patrons are still prevalent as challenges facing the industry.

5.4 Further Study

The following suggestions are offered for additional study on the application of OSC methods based on the findings of this research:

- Identical research can be done to formulate mitigation strategies for the challenges that prevent the offsite method of construction usage in Sri Lanka.
- Can carry out a research similar to this one but applying a sample with greater dimension and conduct factor analysis. Enhancements to this study could encompass enlarging of the number of the participants from island wide and adding to the number of offsite contractors in the Sri Lankan construction industry.
- Supplementary research is inspired and is required to include qualitative and mixed method studies into Offsite construction substantiated by interviews, case studies, and offsite stakeholders to authenticate the research discoveries. The illustration study of particular projects would be inspired as well to offer a detailed or extensive scrutiny facilitating to achieve a comprehensive, consistent and authenticated data.
- Undertake a research on the influence of transportation constraints and finance on OSC methods so that ways can be found to erase and/or adapt the constrains and minimize expenses for the intent of fostering the application of these techniques.

The above further studies are recommended by the researcher would serve to increase the visibility and reliability of OSC adoption in the buildings sector of Sri Lankan construction industry. The identified OSC challenges will be alleviated through such further researches. Considering the research findings, the researcher strongly believes that the adoption of OSC methods will definitely benefit Sri Lankan construction industry by addressing most of the problems faced in traditional construction methods.

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APPENDICES

APPENDIX A: QUESTIONNAIRE

……………………………………

……………………………………

……………………………………

Dear Sir / Madam,

Regarding Dissertation – MSc in Project Management

I am a post graduate candidate in Project Management at University of Moratuwa. Currently, I am conducting dissertation research entitled "Application of Off-Site Construction in Sri Lanka".

Your opinion on using off-site construction techniques is crucial to the success of my research. The survey is very straightforward and will take less than 10 minutes. I will deeply appreciate if you complete the survey at your earliest convenience. The participation is completely voluntary, but again I need your help to accomplish this effort.

Please be assured that your response will be held in strictest confidence. Under no circumstance, will your company's information be available to any individual or organization. If you have any questions about this survey, please feel free to contact me at sanjeevan.ravi@gmail.com or 0771125093.

Click the button below to start the survey. Thank you for your participation!

Respectfully requested,
R. Sanjeepan.
Post Graduate Student,
Department of Building Economics,
University of Moratuwa.

Begin Survey

QUESTIONNAIRE SURVEY FOR RESEARCH ON APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

Introduction

Although the use of offsite methods of construction provides several significant advantages and is a possible solution for addressing time, quality and cost concerns often associated with 'traditional' construction, the use of these methods is limited in the Sri Lankan building industry.

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

The primary aim of this study is to investigate the application of off-site construction, investigate the benefits and to determine the challenges that are encountered in using different types of OSC techniques adopted in the building sector of Sri Lankan construction industry, and find solutions to the challenges that limit the use of these construction techniques. The findings and recommendations of the study would lead to enhance the usage of offsite construction methods in Sri Lanka.

This study is conducted as part of my postgraduate study at Department of Building Economics, Faculty of Architecture, University of Moratuwa. I strongly belief that the participants will provide practical and convincing answers to the questions below and thereby enable me to complete my research successfully. Any confidential information related to your organization's project will be not disclosed in this report or any other document relating to this study. The information provided will be treated with strict confidence. Thank you in advance for your contribution to this research study.

Thank you.

R. Sanjeepan

Post Graduate Student,
Department of Building Economics,
University of Moratuwa.

QUESTIONNAIRE SURVEY FOR RESEARCH ON APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

Guidelines

Please go through the following guideline before attempting to fill-in the questionnaire in order to assist you and make yourself comfortable to understand.

- **It is not compulsory for you to disclose your name and /or the name of the organisation you are attached to. It is at your discretion to give such information.**
- **Please try to give a genuine opinion when selecting answer for the questions irrespective of personal biases.**
- **In order to clarify ambiguous/less familiar terms relating to this research, a glossary of key words and their meanings are listed below.**

Definition Of Terms

Off-site construction (OSC) are components which are manufactured in a factory and transported to the site to assembly.

Panelized units are produced in a factory and assembled on-site to produce a three dimensional structure. Open panels consist of a skeletal structure only, whereas more advanced panels may include lining material, insulation services, windows, doors, internal wall finishes and external claddings.

Volumetric construction involves the production of three-dimensional modular units in controlled factory conditions prior to transport to site.

Hybrid techniques combine both panelized and volumetric approaches. Typically, volumetric units (sometimes referred to as pods) are used for the highly serviced and more repeatable areas such as kitchens and bathrooms, with the remainder of the dwelling or building constructed using panels.

Sub-assemblies & accessory system include larger components that can be incorporated into either conventionally built or MMC dwellings. These items are not full housing systems and are generally factory made.

QUESTIONNAIRE SURVEY FOR RESEARCH ON APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

Details Of The Respondent

1. Name of respondent (optional)

2. Name of the organisation employed to (optional)

3. Type of organisation

- ○ Consultant
- ○ Contractor

4. Designation

- ○ Project Manager
- ○ Architect
- ○ Engineer
- ○ Quantity Surveyor
- ○ Other

5. Years of experience in off-site constructions

- ○ Less than 5 years
- ○ 5 to 10 years
- ○ 11 to 15 years
- ○ More than 15 years

6. How will you rate your knowledge in off-site construction techniques?

- ○ Very High
- ○ High
- ○ Average
- ○ Below Average

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

	Highly Unsatisfied	Unsatisfied	Neither Unsatisfied or Satisfied	Satisfied	Highly Satisfied	Not Experienced
Volumetric Systems	◯	◯	◯	◯	◯	◯
Hybrid Systems	◯	◯	◯	◯	◯	◯
Panelized Systems	◯	◯	◯	◯	◯	◯
Sub-assemblies Systems	◯	◯	◯	◯	◯	◯

QUESTIONNAIRE SURVEY FOR RESEARCH ON APPLICATION OF OFF-SITE CONSTRUCTION IN SRI LANKA

Questionnaire Fill-up

8. What kind of project or building sectors would be more appropriate for each of these offsite construction techniques by your understanding?

	Residential	Commercial	Industrial	Others
Volumetric Constructions	☐	☐	☐	☐
Panelized constructions	☐	☐	☐	☐
Hybrid constructions	☐	☐	☐	☐
Sub-assemblies	☐	☐	☐	☐

9. As a offsite construction practitioners, please tick the following building components that lend themselves easily to prefabrication?

☐ Wall Panels

☐ Roof Panels

☐ Floor Panels

☐ Plumbing and service walls

☐ Frame structure of the building.

10. On the basis of a cost analysis, which one is more expensive;

○ Off-site construction

○ In-situ / conventional means of construction

11. Which of these do you prefer?

○ Off-site construction

○ In-situ / conventional means of construction

12. What are the motivations to use off-site construction techniques in your project?

- [ ] Waste reduction
- [ ] Noise limitation
- [ ] Short ’weather window’
- [ ] Work time and other restrictions in sensitive sites
- [ ] Lack of work space around the building for site storage

13. Did the waste reduction by the off-site construction techniques (OCT) help reduce the total cost of the project?

- ○ Yes.
- ○ No.

14. Based on your experience, how significant was the cost reduction due to use of offsite construction?

- ○ Less than 5%
- ○ 5 – 10 %
- ○ 10-15%
- ○ 15-20%
- ○ Above 20%

15. Is there the possibility that using offsite construction methods could increase the general contractor’s profit margin?

- ○ Yes.
- ○ No.

16. How would you describe materials used in place of the traditional materials used in offsite construction?

- ○ Fragile
- ○ Sustainable
- ○ Robust
- ○ Adequate

17. How significant the following reasons are for your company to use off-site construction techniques. If your firm has not specified off-site construction techniques, please skip this question, and go to next question.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
To compensate for the shortage of skilled craft workers	○	○	○	○	○
To compensate for weather condition	○	○	○	○	○
To reduce design duration	○	○	○	○	○
To reduce construction duration	○	○	○	○	○
To increase product quality	○	○	○	○	○
To reduce overall project cost	○	○	○	○	○
To increase overall labour productivity	○	○	○	○	○
To compensate for the restricted working space onsite	○	○	○	○	○
To reduce material waste generated on site	○	○	○	○	○
To improve project safety performance	○	○	○	○	○
To increase your company's profit margin	○	○	○	○	○
To enhance your company's reputation	○	○	○	○	○
To ensure time certainty	○	○	○	○	○
To ensure cost certainty	○	○	○	○	○
To increase value	○	○	○	○	○
To increase sustainability	○	○	○	○	○
To reduce snagging and defects	○	○	○	○	○

18. How significant are the following reasons that restrain your company from using Off-Site construction techniques.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
Company owner restricts using off-site construction techniques					
Architect do not specify the use of off-site construction techniques					
Local building regulations restrict the use of OSC techniques					
Financial institutions restrict the use of OSC techniques					
Lack of skilled assembly craft workers onsite					
Using OSC techniques will increase the construction cost					
Collective bargaining agreement prohibited use of OSC techniques					
Limited design options in using off-site construction techniques					
Inability to make changes in the field by using OSC techniques					
Transportation restraints					
Longer lead-in time					
Negative image					
Lake of guidance and information					
Unable to freeze design early on					
Complex interfacing between systems					

19. Please select the most critical off-site construction challenges (overall) from the list. Then, tick the relevant OSC methods to indicate their level of impact is high in particular OSC method. *(Eg. If the Challenge 1 is a critical OSC challenge and its impact is high in volumetric system, then tick both Critical challenge & Volumetric boxes)*

	Challenges	Sub - Assembly	Volumetric	Hybrid	Panel	Sub - Assembly
Industry Structure and Supply Chain	Defects during transportation	☐	☐	☐	☐	☐
	Existing factories' capability for manufacturing parts	☐	☐	☐	☐	☐
	Difficulty to the storage of prefabricated elements	☐	☐	☐	☐	☐
	Lack of manufacturers and suppliers of prefabricated components	☐	☐	☐	☐	☐
	Lack of experienced collaboration groups	☐	☐	☐	☐	☐
	The fragmented nature of the construction industry	☐	☐	☐	☐	☐
	Transportation of prefabricated elements and access to the building site	☐	☐	☐	☐	☐
	Lack of experienced contractors on prefabrication	☐	☐	☐	☐	☐
	Lack of practices and experiences from local projects	☐	☐	☐	☐	☐
	Suppliers fail to deliver on time	☐	☐	☐	☐	☐
	Suppliers fail to deliver correct components	☐	☐	☐	☐	☐
	Losing factory production slot/production capacity	☐	☐	☐	☐	☐
	Monopoly of techniques	☐	☐	☐	☐	☐
	Poor integration for the supply chain	☐	☐	☐	☐	☐
	Lack of experienced design consultancy and designers	☐	☐	☐	☐	☐
	Longer lead-in time for OSC components	☐	☐	☐	☐	☐
	Irregular features	☐	☐	☐	☐	☐
	Organizational mechanism and culture	☐	☐	☐	☐	☐
	Low infrastructure	☐	☐	☐	☐	☐
	Low productivity	☐	☐	☐	☐	☐

Constructability Implementation	High skill demands for labour	☐	☐	☐	☐	☐
	Problem between joints	☐	☐	☐	☐	☐
	Specific demands for the site logistics for pre-finished elements protection	☐	☐	☐	☐	☐
	Corrosion and defect in reinforcement	☐	☐	☐	☐	☐
	Foundations inaccurate/ unsuitable	☐	☐	☐	☐	☐
	Damage to key pre-assemblies or critical components	☐	☐	☐	☐	☐
	Cracks	☐	☐	☐	☐	☐
	Tower crane position	☐	☐	☐	☐	☐
	Design not suited to construction method	☐	☐	☐	☐	☐
	Water penetrations	☐	☐	☐	☐	☐
	Defects at handover/during liability period	☐	☐	☐	☐	☐
	Highly restrictive construction tolerances	☐	☐	☐	☐	☐
	Inability to make changes in the field	☐	☐	☐	☐	☐
Architectural Performance	Unable to modify design scheme	☐	☐	☐	☐	☐
	Monotonous design with poor aesthetic criteria	☐	☐	☐	☐	☐
	Lack of enough flexibility	☐	☐	☐	☐	☐
	Quality assurance	☐	☐	☐	☐	☐
	Increase in complexity for maintenance	☐	☐	☐	☐	☐
	Structural bulkiness	☐	☐	☐	☐	☐
	Off-site construction techniques limits design options	☐	☐	☐	☐	☐

Cost	High initial & capital cost	☐	☐	☐	☐	☐
	Longer capital payback period	☐	☐	☐	☐	☐
	Increased cost due to higher quality/rapid construction	☐	☐	☐	☐	☐
	Difficulty of bidding price from contractors	☐	☐	☐	☐	☐
	Error and mistakes in documentation and taking-off	☐	☐	☐	☐	☐
	Price fluctuations during the construction phase	☐	☐	☐	☐	☐
	Off-site construction techniques increases design cost.	☐	☐	☐	☐	☐
	Additional cost and care required when manufacturing	☐	☐	☐	☐	☐
	Increase in designer fees	☐	☐	☐	☐	☐
Policies and Regulations	Lack of design codes and standards for prefabricated components	☐	☐	☐	☐	☐
	Lack of governmental regulations and incentives	☐	☐	☐	☐	☐
	The local zoning ordinance restricts the use of off-site construction techniques.	☐	☐	☐	☐	☐
	The local building regulation restricts the use of off-site construction techniques.	☐	☐	☐	☐	☐
	The financial institution restricts the use of off-site construction techniques.	☐	☐	☐	☐	☐
	Legal issues	☐	☐	☐	☐	☐
Technological Innovation	Lack of local R&D institutes and services	☐	☐	☐	☐	☐
	Lack of technologies and testing institute to prefab. components	☐	☐	☐	☐	☐
	Reluctance to innovation and driven	☐	☐	☐	☐	☐
	Designing off-site construction components requires special computer software.	☐	☐	☐	☐	☐
	Poor technology	☐	☐	☐	☐	☐
	Monotony of structure type	☐	☐	☐	☐	☐

Social Climate and Attitudes	The owner's negative perception	☐	☐	☐	☐	☐
	Lack of awareness of prefabrication by the market and public	☐	☐	☐	☐	☐
	Dependence of traditional construction method	☐	☐	☐	☐	☐
	Poor quality impression	☐	☐	☐	☐	☐
	Lack of confidence of the industry in offsite production	☐	☐	☐	☐	☐
	Public preference for use of conventional construction materials	☐	☐	☐	☐	☐
	Durability of prefabricated unproven	☐	☐	☐	☐	☐
	Lessons and attitudinal barriers due to historic failures	☐	☐	☐	☐	☐
Other Challenges	The inability to freeze the design early on	☐	☐	☐	☐	☐
	Project planning and coordination	☐	☐	☐	☐	☐
	Unpredictable planning decisions	☐	☐	☐	☐	☐
	Uncertainty of market demand	☐	☐	☐	☐	☐
	Health and safety hazards	☐	☐	☐	☐	☐
	Project scheduling issues	☐	☐	☐	☐	☐
	Late appointment of contractor/manufacturer	☐	☐	☐	☐	☐
	Manufacturer insolvency	☐	☐	☐	☐	☐
	Potential unemployment issues to workers	☐	☐	☐	☐	☐
	Inefficiency of labours	☐	☐	☐	☐	☐
	Uncertainty of weather condition	☐	☐	☐	☐	☐
	Wastages	☐	☐	☐	☐	☐
	Service installation faults	☐	☐	☐	☐	☐
	Longer lead-in time during design stage	☐	☐	☐	☐	☐