A Study on the Potential Implementation of Modular Construction in Housing Units to Accommodate Displaced People in Libya

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ABSTRACT

In the light of technological advancement, the construction industry have changed drastically. The adoption of various emerging technologies have positively disrupted the construction sector and changed in a good way. Construction practices became more reliable, save, cost and time efficient and sustainable; due to the rising exploitation of new construction-tech trends. Recently, the demand and adoption of construction innovations for resolving development issues and humanitarian crisis have escalated significantly. The most prominent innovation in this scope is design and constructing with off-site modular techniques. In recent years, it has been observed that most construction companies in developed countries have shifted their attention to Modular construction instead of traditional construction. This technique has made modular construction an evolving approach, as it is a fast and cost-effective construction technique and can produce high quality sustainable end products. Moreover, modular construction is such a versatile technique that is used in various construction sectors, for instance, medical and healthcare, industrial and commercial sectors, but it's most distinguished use manifests in residential or accommodation sector. This thesis explores the use of modular construction in the housing industry and examines its potential to reflect this to the current Libyan situation. In this context, it is one of the aims of this thesis to provide a rapid and innovative solution to the aggravating crisis of the resettlement of internally displaced people in Libya.

Throughout the literature review from books, papers and journals, a better comprehension of the different aspects of off-site modular construction technology was studied. In this context, three case study housing projects that incorporate modular construction were selected. These are analyzed on the basis of their structural system, construction process, quality of design and sustainability. Later on, these case study projects are evaluated and assessed according to cost efficiency, time efficiency and design flexibility. In the last part; By using the modular building technique that can be used to solve the problem of resettlement of internally displaced people in Libya, a modular housing model was proposed which suitable for Libyan culture and the vital uses of Libyans.

Keywords: modular construction, internally displaced people, off-site construction, modular housing

ÖZ

Teknolojik gelişmelerin ışığında, inşaat sektörü büyük ölçüde değişti . Gelişmekte olan çeşitli teknolojilerin benimsenmesi inşaat sektörünü olumlu bir şekilde bozdu ve iyi bir şekilde değiştirdi. Yeni inşaat teknolojisi trendlerinin artan kullanımı nedeniyle; nşaat uygulamaları daha güvenilir, tasarruflu, maliyet ve zaman açısından verimli ve sürdürülebilir hale geldi. Son zamanlarda, kalkınma sorunlarını ve insani krizleri çözmek için inşaat yeniliklerinin talep edilmesi ve benimsenmesi önemli ölçüde artmıştır. Bu kapsamdaki en öne çıkan yenilik, saha dışı modüler tekniklerle tasarım ve inşa etmektir. son yıllarda gelişmiş ülkelerdeki inşaat şirketlerinin çoğunun dikkatlerini geleneksel inşaat yerine Modüler inşaata kaydırdıkları görülmektedir. Hızlı ve uygun maliyetli bir inşaat tekniği olduğundan ve yüksek kalitede sürdürülebilir nihai ürün üretilebilen , bu teknik modüler inşaatı gelişen bir yaklaşım haline getirmiştir. Üstelik modüler yapı, tıp ve sağlık hizmetleri, endüstriyel ve ticari sektörler gibi çeşitli inşaat sektörlerinde kullanılan çok yönlü bir tekniktir, ancak en seçkin kullanımı konut veya konaklama sektöründe kendini gösterir. Bu tez, konaklama sektöründe modüler yapı kullanımını araştırmakta ve bunu mevcut Libya durumuna yansıtma potansiyelini incelemektedir. Bu bağlamda, Libya'da ülke içinde yerinden edilmiş insanların yeniden yerleşmesinin ağırlaşan krizine hızlı ve yenilikçi bir çözüm sağlamak bu tezin amaçlarındandır. Kitaplar, makaleler ve dergilerden yapılan literatür taraması boyunca, saha dışı modüler yapı teknolojisinin farklı yönlerinin daha iyi anlaşılması çalışıldı. Bu bağlamda, modüler yapım tekniği kullanılan üç konut projesi seçildi. Bunlar strüktürel sistem, yapım süreci, tasarım kalitesi ve sürdürülebilirlik temelinde analiz edildi. Daha sonra bu örnek konut projeleri, maliyet verimliliği, zaman verimliliği ve tasarım esnekliğine göre değerlendirilir. Son bölümde ise; Libya'da ülke içinde yerinden edilmiş insanların yeniden yerleştirilmesi sorununun çözümünde kullanılabilecek modüler yapı tekniği kullanılarak, Libya kültürüne ve Libyalıların yaşamsal kullanımlarına uygun bir model önerisinde bulunulmuştur.

Anahtar Kelimeler: modüler yapı, ülke içinde yerinden olmuş kişiler, saha dışı inşaat, modüler konut

DEDICATION

This work is dedicated to my family and many friends. A special feeling of appreciation and gratitude to my loving parents, Salah and Jalila, whose words of encouragement and push for tenacity ring in my ears, they have always been our biggest support to me and my siblings in anything we do. To my talented sister arwa who have never left my side, she is very special. And to my amazing brother Ahmed who was the number one supporter for me in this journey. also I dedicate this work to many amazing friends in LIbya and Cyprus who have supported me throughout the process, I will always appreciate all what they have done. And finally to all beloved family members, i would say Thank you so much.

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Chapter 1

INTRODUCTION

This chapter is to introduce and speechify the context of the thesis, and also to clarify the aims and objectives of this study, moreover, the chapter raised the research questions. Furthermore, an explanation of the used methodology is raised. Finally the chapter is concludes with a summary.

This thesis is based on a group of books, articles and recent studies that discuss the concept of prefabrication and off-site modular construction and the usage of modern methods of construction in several construction sectors, the most important of which is the housing sector. The most prominent studies includes: Design In Modular Construction, by Mark Lawson n Ray Ogden n Chris Goodier, published in 2014; Prefab Architecture: a guide to modular design and construction, by Ryan E. Smith, published in 2010; Offsite Architecture: constructing the future, by Ryan E.Smith and John D.Quale, published in 2017.

1.1 Introduction

As human beings, home has been always one of the most if not the foremost basic necessities for living. Resembled in a physical shelter, home is the sanctuary where people develop a sense of security and seek for settlement, it is also the base form which people practice their daily life routines. Although having a home is a very fundamental right that most of the people take for granted, still millions of refugees and displaced people around the world lack such right. According to Better Shelter organization and UNHCR, by the end of 2019 more than 79 million people are considered as forcibly displaced from their own homes and more than 26 million of them considered as refugees (UNHCR,2019). Moreover, there are more than 45 million people are internally displaced within the borders of their own country. most of these people flee to the refugee camps established by human organizations, and usually such camps are prepared to be a temporary refuge to these people, but these refuges may last for decades (D. Albadra, D. Coley & J. Hart , 2018). In these cases, social housing projects need to be implemented to provide better accommodation for the refugees and displaced people. However, using modular construction system considered to be a very effective strategy to construct these social housing units since it is a time and cost efficient (Woźniak-Szpakiewicz, 2016). This study will discuss the implementation of the social housing units using modular construction system to accommodate internally displaced people affected by the political conflicts in Libya in the past few years, whereas more than 350,000 people are displaced in different cities inside the country according to (OIM, 2020) (UNHCR,2019) (IDMC,2019) most of them were placed in public schools.

Modular construction system is a very effective method to construct such social housing projects due to its schedule-reduction, cost-reduction, number of units and multiplication. However, this method is using three-dimensional units that are prefabricated and completed in a factory-controlled environment, and then to be transported and assembled on the building site to create a single or a multi-story whole building. Moreover , simple materials such steel, wood or concreate can be used to construct these prefabricated units, and as an off-site method, modular construction has been marked as better solution since it is high in quality, fast to market and greener than the traditional site built construction (Woźniak-Szpakiewicz, 2016) . However, in many cases neither the design nor the structure are changing while using the modular construction method, the primary difference is the construction method itself (Piper, 2015). Furthermore, unlike the traditional housing procurement techniques that involve lengthy lead times, using modular construction, also known as off-site construction (OSC) to construct these residential buildings can provide an opportunity to better meet the needs by dramatically reducing construction times and ultimately providing strong economic value (Boyd, Khalfan, 2013). Certain benefits of OSC can include superior efficiency, low weight ratios, economies of scale obtained by reuse of prefabricated modules, usage on infill sites, sustainable building regulations and enhanced health and safety of workers. There are also important consequences for jobs and employment that can help mitigate a lack of expertise across the sector by the use of semi-skilled labor.

1.2 Statement of the Problem

Due to the aftermath of the political conflicts that Libya has gone through on the past nine years, the number of internally displaced people (IDPs) increase dramatically, according to the Displacement Tracking Matrix (DTM) provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) until December 2019 , there are more than 350,000 IDPs in Libya, more than 97% of them were displaced due to the degradation of the security situation, were 60% of these IDPs live in self-paid rented accommodation (OIM, 2020), hence, their tendency to seek shelter was inevitable, so the majority of these IDPs were accommodated by the government at public schools around the cities affected with the crisis, while other IDPs fled to refugees camps established by humanitarian organizations. However, these housing solutions are meant to accommodate the displaced on a temporary basis, but due to the uncertain conditions of the IDPs; their settlement within the refugees camps or public for prolonged periods of time is highly potential, thus, the demand for a better accommodation solution increased, to provide such vulnerable people with a better shelter that meets the basic needs for the activities of basic living, for privacy, security and familiarity.

1.3 Aim of the Study

Improving the people's life have been always the main purpose of architecture, and obtaining a home is one of the fundamental needs in people's life, however Current developments in migration to urban areas as a consequence of war, natural disasters and other factors suggest that half of world's internally displaced people (IDPs) already reside in these environments. At the same time, sustained displacement is progressively the rule. Many IDPs find themselves trapped in exile for years or even decades, incapable to attain permanent alternatives and with continuing challenges relevant to their plight (IDMC, 2015). Post-conflict reconstruction and recovery includes providing protection and assistance to internally displaced persons (IDPs) who have been uprooted from their homes and communities and subsequently made vulnerable to abuse, oppression, discrimination, and other human rights violations and With millions of internally displaced persons (IDPs) around the world, there is need to implement durable housing solutions post-conflict, that involves sustainable integration and sustainable reintegration using long term shelter programmes in the rural and urban areas.

The present study aims to investigate the potential of providing better accommodation solution for the internally displaced Libyan families due to political conflicts, by proposing a social housing project that utilizes modular construction method. Modular construction was praised for its potential to help address the issue of housing shortage in many countries around the world, developing and constructing pre-built homes of high quality at a quicker pace. Building industry is also facing disruptions due to various factors, like lack of manpower, or environmental conditions that impede or hinder on-site development. Modular accommodation offers a solution to such issues. Construction offsite in a managed factory atmosphere decreases risk, thus accelerating pace of development, product quality guaranteed and performance standards boosted. Along with the aim of this study, two research questions will be addressed:

1. Will the proposed modular housing aproach succeed in providing a better and prolonged settlement environment for the IDPs?
2. How feasible it is to implement the social housing units with modular construction strategy under the current circumstances in Libya?

1.4 Limitations and Scope

To get a detailed understanding on this thesis, it will be limited to a specific group of people which are internally displaced people (IDPs) in a specific north African country which is Libya.

Although there are many types and solutions for sheltering the IDPs, this study will be focusing on the usage of one of the modern methods of construction which is modular construction, a part of the off-site construction process, to provide the proper accommodation unites to those groups of people who are suffering from the lack of basic daily life means and proper accommodation. Due to the widespread use of steel and concrete in most of the construction projects in Libya, this study will be limited and focusing only on the use of steel and concreate together in the construction of modular homes.

1.5 Research Methodology

Mainly this thesis is based on a qualitative methodology (analytic method) in order to meet the study objectives, therefore a number of literature reviews through articles and books will be done to collect the necessary theoretical data. And it is divided into two parts:

The first part (Chapter 2) is covering the theoretical framework of the internally displaced people and sheltering the IDPs during the disaster time, also the IDPs in Libya and resettlement of the displaced.

The second part (Chapter 3) covering the theoretical background and studies on the usage of off-site constrcution and modular construction to provide sheltering solutions for IDPs, the use of the method in manufacturing, and it will also provide information regarding to the technologies and techniques used in this type of construction and also the materials that can be used in this construction method.

(Chapter 4) is covering some case studies and examples about some housing projects that utilizing prefabricated modular construction. And also will include the evaluation of providing housing units using modular construction in terms of time saving, cost reduction, flexibility in design and high quality of construction and finally a design suggestion for the apartment units is proposed by the author to accommodate libyan IDPs

Finally, (Chapter 5) will include the summery and the conclusion of this thesis and define the findings.

Chapter 2

REFUGEES AND DISPLACED PEOPLE

Recently, the world has experienced many wars and conflicts due to numerous causes, including those arising from political, cultural, economic and ethnic ends. As a consequence, the number of refugees fleeing to various places around the world have dramatically increased in search of new, more secure and stable homes and lands. More than 79 million people around the world forced to flee their homes and home countries due to the ongoing conflicts and disasters on their territories, according to the figures reported by "High Commissioner for Refugees" (UNHCR), and settle in places which are intentionally safer. Approximately, 26 million of those fleeing people are considered as refuges who are accommodated in refugee camps established by the hosting country they fled to. Many of these settlements mimic small towns with a population of approximately 250000 inhabitants. Nevertheless, a lot these camps and refuges endure extreme and unsafe living status that results in a significant and dramatic decline in their resident's quality of life (UNHCR, 2019).

Moreover, the word "refugee" typically defines someone who was compelled to flee their own country and home for various causes including political, war, or religious problems to seek a safe shelter. However, for these causes like armed combat, ethnic vehemence, international invasion or circumstances that dead earnest disrupt public demand, refugees may also leave the country, due to such circumstances (Sipus,2010).

It is estimated that approximately twenty six million of those uprooted people are considered as refugees, and over half of them are children. This figure is unmatched in recent world history. In addition, approximately 10 million of these displaced people are still stateless, meaning that they are immigrants who do not have full reach to basic freedom of movement, choice, health care and education.(IDMC, 2015) During a protracted crisis, humanitarian agencies provide emergency shelters such as tents for refugees; which are later substituted by much more stable, firm and resistant buildings. Furthermore, these shelters may be substituted many times in one year depending on the duration of the catastrophe and the lifespan of the available shelters. Some of these camps may become permanent, more stable and secure because of the prolonged camping duration, such as Shahrawi refugee camps in Algeria (Figure 1), founded in the year 1975, or refugee camps in the Levant established in Palestine, which can accommodate a very large population with multi story buildings, equipped with different facilities.

Figure 1: Sahrawi refugee camps in Tindouf , Algeria (URL1)

The design and performance assessment of accommodating shelter are understudied, overlooked and seldom evaluated, although it is well known that morbidity and spread of disease and potential mortality is facilitated; if exposure to extreme temperatures and thermal conditions are prolonged. The living and shelter areas accessible and supplied by philanthropic agencies are typically light in weight and tremendously inefficient in the face of severe summer heat or winter cold (Lee,etal., 2016). However, the strive to overcome these extreme conditions raises the psychic pressure of people experiencing the loss of their loved ones, their families, their societies and eventually their identities. It is therefore important to but in mind and be aware of all of the ongoing conditions in these camps as well as the thermal comfort extent and the covets of the population of concern, so as to plan proper future shelters for these people. There are minimal research on the thermal outputs of refuges' shelters and their internal space quality.Moreover, the practical provision of a refuge as a humanitarian response is one of the main issues. This is actually an extremely challenging issue, since it comprise a difficult task that must rapidly deliver a sustainable housing solution in the face of an unprecedented crisis of unpredictable duration (Cornaro,etal.,2015). Although the number of people involved and the associated potential risks, particularly for vulnerable population which children, one of the world's largest refugee groups, is constantly increasing especially during recent years, this area of research is yet underdeveloped (Crawford,2005).

2.1 The Concept of Internal Displacement

According to the international displacement monitoring center (IDMC), "Internally displaced persons (IDPs) are "Persons or groups of people who have been forced or obliged to flee or to leave their homes or places of habitual residence, in due to or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognize state border. As a result of these incidents, 14o nation of its former habitual home is either unable or unwilling to return to it, because of such terror".

One prerequisite for a refugee status is crossing an international border. Therefore, people who are forcefully displaced from their homes who cannot chose not to wither leave the country or not are not considered among refugees even if they face many of the same threats and risks as those who considered as refugees. Due to the fact that, ultimately, it's the national government responsibility to protect, accommodate, serve and assist IDPs; they are usually in an even much greater problematic situation compared refugees according to Guiding Principles on Internal Displacement, 1998.

In contrast to refugees, internally displaced people are not the concern of any international treaty, they neither have a specific UN agency operating for them, nor any special status under international law is dedicated to them. The terminology "internally displaced person" is a designation that may be given – and thus revoked – rather than a legal classification. Alternatively, the concept of IDPs found within guiding principles and expressed in regional and national structures is used to help define and describe a group of vulnerable people with particular issues relevant to the fact that they are internally displaced.

According to a recent report from the Norwegian Refugee Council's Internal Displacement Monitoring Center (IDMC), the number of internally displaced peole (IDPs) across the globe has reached an all-time peak value. Also, the Global report on Internal Displacement (GRID,2020) indicated that by the end of 2019, the number of IDP's across the world reached 50.8 million people, were 45.7 million people from 61 different countries undergoing political conflicts, civil wars and domestic violence, most of them from Afghanistan, Yemen, Syria, Democratic Republic of Congo (DRC) and Colombia and 5.1 million are displaced as a result of natural disasters in 95 countries. This number includes 1.2 million people in Afghanistan displaced as a consequence of flooding and drought. Additionally, another 500,000 individual in India forced to leave their houses due to monsoon rains. Also, an estimated number of 33,000 individuals from Haiti whose lives are still heavily impacted even after ten years from the destructive earthquake that raved the country (Figure 2) .

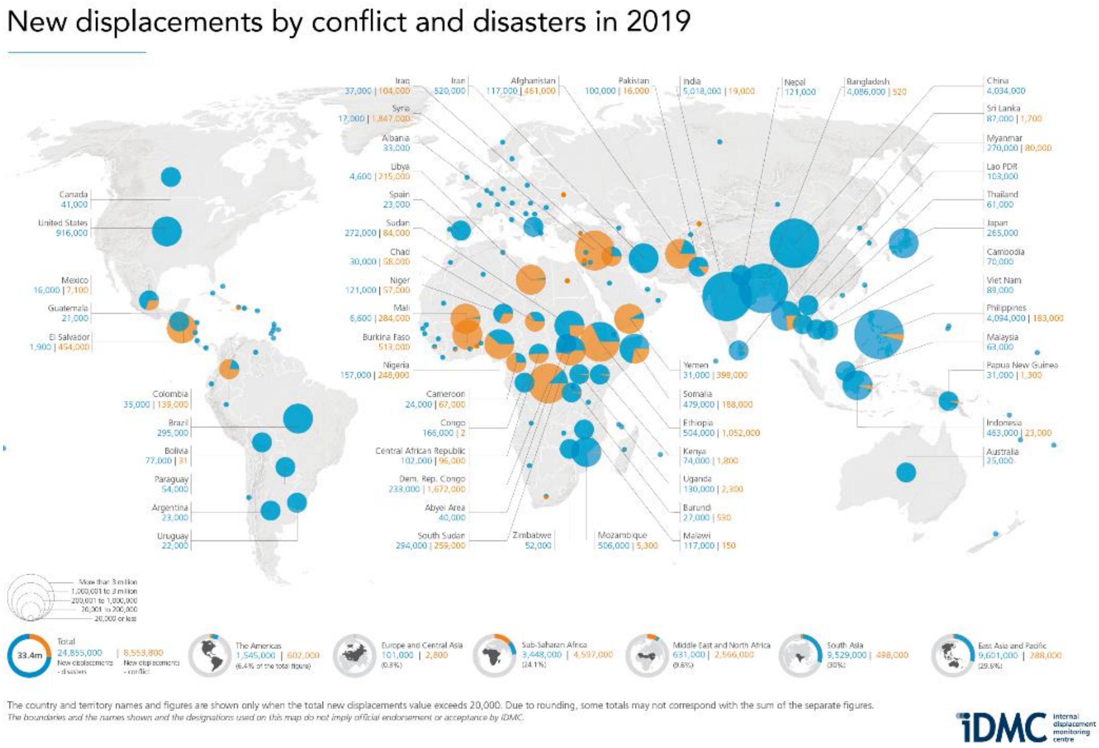


Figure 2: Countries and territories with most new displacements in 2019 (URL2)

In 2019, 33.4 million new displaced individuals were recorded, the highest annual number since 2012, adding to those recorded figures. Around 8.5 million IDPs have taken place in countries such as Syria, Libya, Ethiopia, South Sudan, Burkina Faso and the DRC in the sense of conflict and violence. Disasters have caused approximately 24.9 million new displaced people, including 4.5 million in India and Bangladesh as a result of cyclone Fani and cyclones Idai respectively, also cyclone Kenneth in Mozambique and hurricane Dorian in the Bahamas. Strong, heavy and sustained rains in Africa resulted in massive floods leading to two million new displaced individual (Figure 3).

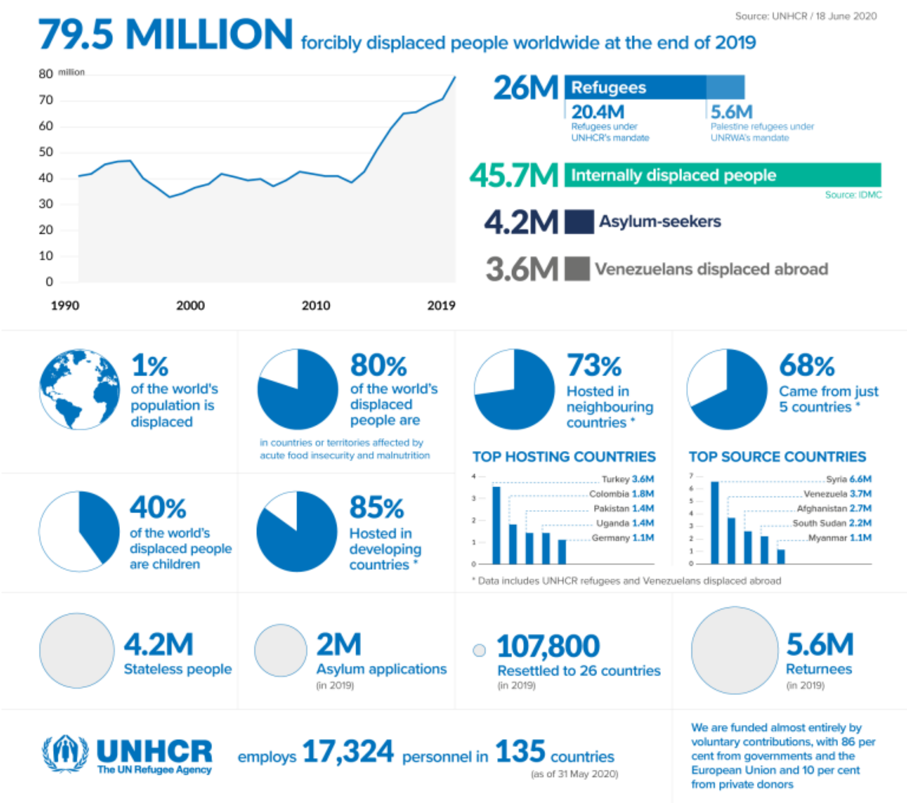


Figure 3: Forcibly Displaced People Worldwide at the End of 2019, UNHCR (URL3)

2.2 Internally Displaced People in Libya

Libya is currently stranded in a growing political crisis, which has led to the collapse of its state institutions, widespread violence, corruption and breach of law by malicious group is common nowadays in Libya since the Arabic spring in 2011. The initial peaceful protests against the deposed regime, quickly developed into a prolonged and dynamic armed conflict. The UN reports that the direct impact of the conflict on more than 1.6 million people, results to hundreds of thousands of displaced individuals, who were unwillingly displaced out of their houses either within Libya itself or across the Tunisian border. Population of displaced people are seriously susceptible to targeted or systemic violent attacks, and face challenging difficulties in accessing sufficient shelter and public services (Taraboulsi-McCarthy et al., 2019).

Libya has been an arena of displacement after four years from the 2011's revolution. It is estimated that about 59,400 Libyans by the end of 2013, had been displaced in their own country; by autumn 2014, the number of IDPs was estimated to be over 100,000 Although the ongoing civil war tangled the gathering of reliable displacement data, moreover, according to the "International Displacement Monitoring Center" (IDMC) by March 2015, the number of IDP's within Libya had skyrocketed and reached a number of 200,000. UNHCR reported that about 56,000 of these IDPs are displaced individuals who still suffer from the ramifications of 2011's revolution. With regard to IDP distribution at regional level, IDMC has reported that starting in middle of May 2014, a minimum number of 269,000 people fled the abuse in Western Libya, since mid-June 2014, an approximate 90,000 people have been displaced in the East side, yet another 18,500 people have been forced out of their homes and displaced within the Southern region of the country since 15 January 2015. Most of these IDPs spread across 35 towns and cities, accommodated improperly in schools and other public facilities.

There was hope of a decline in fighting and displacement and settlement of the situation in Libya in 2017, but armed clashes in different areas of the country intensified in 2018. In Tripoli, Derna and Sebha in particular there have brutal fights that lead to 70,000 new displacements. As of the end of the year, approximately

221,000 people had been displaced nationally and undergoing terrible life conditions and could not return back to their homes due to the devastating destruction the war caused the continued threats and lack of security (IDMC,2019).

The south of the capital, Tripoli, was hit by new armed clashes in April 2019. In June and July 2019, the Displacement Tracking Matrix (OIM, 2019) stated that, as of the number of IDPs in Libya has escalated from 268,629 to 301,407, and by the end of October 2019, according to the mobility monitoring study released by (OIM, 2020) the number of IDP's increased to 355,762. However, ever since, these numbers have been dramatically increasing until they reached peak of 401,836 IDPs by April 2020 (OIM, 2020). Moreover, it is anticipated that these numbers will continue gradually increasing in the future as long as the current armed clashes between the malicious groups continue (Figure 4).

Figure 4: IDPs from the town of Tawargha in refugee camp near the Libyan capital Tripoli (URL4)

According to the mobility tracking round 29 specified for libya, which is done by the Displacement Tracking Matrix (DTM), 59% of all IDPs identified in Libya were reported to be residing in privately rented accommodation, while 24% were staying with host families without paying rent, and 6% are taking shelter in schools and other public buildings. Other places for shelter include informal camps (3%), other shelter arrangements (7%) such as abandoned buildings (2%) (Tracking, 2019). Data on accommodation from last three rounds indicates that IDPs are increasingly staying with host families (without paying rent) rather than in accommodation rented by themselves.

This trend also points towards an erosion of coping strategies as several IDPs have been unable to return to their places of origin due to the increasingly protracted nature of ongoing armed conflict and are unable to continue paying for rented accommodation. Furthermore, reports on increases in rental prices of accommodation in areas considered safe from conflict were also received. 83% of returnees were reported to be back in their own homes at their area origin. The remaining returnees are in rented accommodation (8%), with host families (7%) and other accommodation arrangements (1%) (OIM, 2020) (Figure 5& 6).

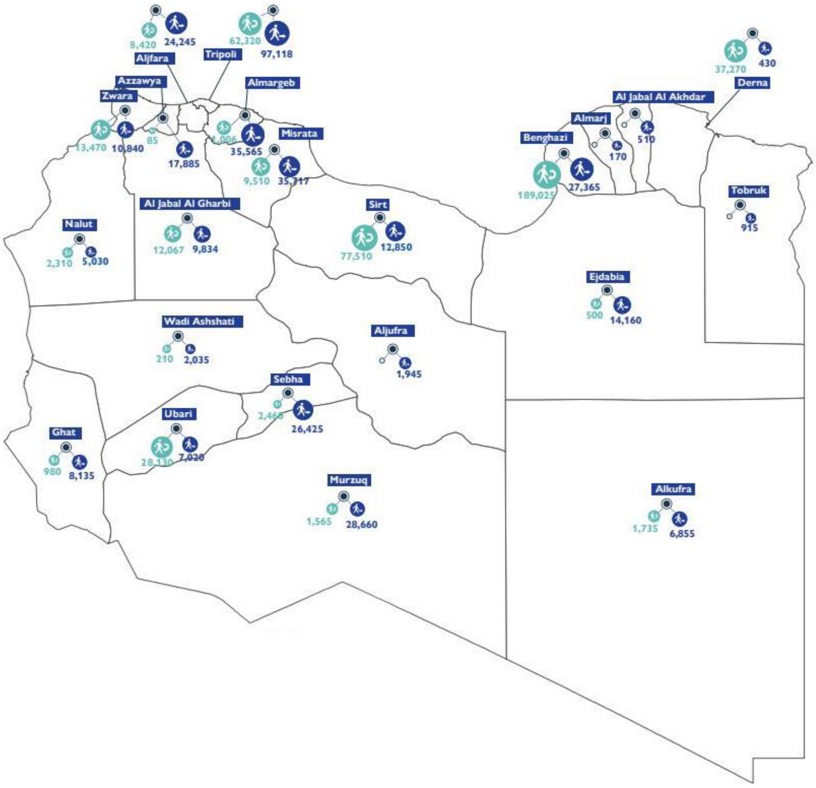


Figure 5: Map of IDPs and Returnees by Region (URL5)

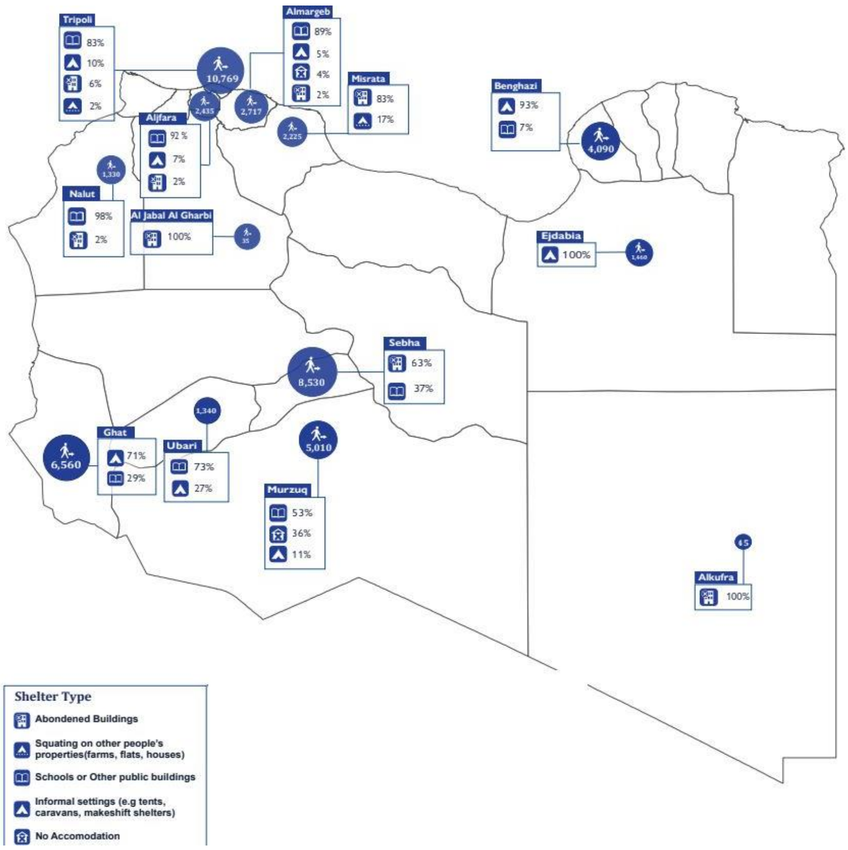


Figure 6: Map of public shelter or communal accommodation types used by IDPs by location (URL5)

2.3 Resettlement of the Displaced

The effects of climate change, violent conflict, and access to energy and resources culminate in rising international tensions in a global context marked by uncertainty regarding our common future. In addition to triggering the problem of people displacement, due to such disruption sustaining political conditions, it concurrently inhibits collaborative actions to reduce carbon emissions. Thus, leading to more natural disasters, extreme weather events, and hence, more amount of displaced people. The issue of the resettlement of the displaced population is in fact a self-maintaining one. the world now faces a high rate of forced displacement. In 2015, more than 65 million people were displaced as a result of conflicts of oppression, violence or violations of human rights (UNHCR, 2015). Parallel to this, is the rising severity and frequency of worldwide disaster events (UNISDR ,2015). Humanitarian aid networks are expanding beyond their capacity to respond. A paradigm shift has been observed by the High Commissioner for Refugees and, "an unregulated plunge into an age in which the size of global forced displacement as well as the response needed now clearly overshadow anything seen before" (UNHCR 2015). The first phase in wider human settlement and development trends for displaced people, first-line humanitarian assistance and shelter provision is facilitated by recovery and reconstruction processes. These phenomena are both measurable and immaterial, concerned with physically constructed environment, but also by the social effects observed. The shelter's ability to sustain ordinary daily lives, to facilitate encourage livelihoods and cultural traditions, and to reinforce community networks, has unseen results are all evidence for a tangible effects. The long-term consequences of first response assistance and early decision taking may have a huge impact on resettlement projects' progress or failure. Complexities associated with the allocation of aid funds and interagency coordination and the severity of high risk situations can lead to scenarios that simultaneously incorporate various first response strategies. The repatriation of displaced people by means of rehabilitation, rebuilding or resettlement invariably requires built environment expertise, which means such strategies inherently contribute to a cohesive and sustainable vision for a relief and recovery project. Although, architects are ideally qualified to design structures considering social impact, but the architectural professional presence in housing and residential projects is minimal (Harris,2011). In particular after disasters, architects are rarely prepared because shelter projects require different design strategies than those required under "natural" conditions (Aquilino 2011; Charlesworth, 2014). The complexity of a post-disaster design underlines a gap between architectural experience and the traditionally qualified architects, who can take the lead over a project. Humanitarian and development mass projects call more and more for community-led solutions that essentially reflect a "new facilitator" as the architect. Furthermore, Charlesworth (2014) claims that lack of disaster response design and planning architects arise from the lack of conventional architectural education and preparation the proper practice on post-disaster architecture and problem-solving. In addition, such construction and design training requires from architects to follow a design methodology or approach identified by the development of personal marks that are rarely reliable in response to an emergency.

2.3.1 Camps And Settlement

The refugee dilemma has been a critical problem for universal societies in recent years. Armed clashes and wars worldwide are the major reasons for almost 79.5 million displaced people, of whom 26 million live in camps made for refugees. Many of such settlement camps are resembling towns and villages, such as Zaatari camp in Jordan (Figure 7) (Slater, 2014).

Figure 7: Zaatari Refugee Camp, Jordan (URL7)

Camps are settlement locations that offers central security, humanitarian assistance, and other services to refugees or IDPs, from host governments and humanitarian initiatives. These settlements may be planned and built on government-allocated land or impulsively established when displaced people settle on a land that is not specified to accommodate them.

Refugee camps are the most fundamental lifesaving and secure spaces provided to displaced people in need by humanitarian establishments and organizations such as MSF (Medical Humanitarian Organization), UNHCR, the IFRC, OXFAM, and so forth. The main goals of these organizations is to establish refugee camps that offer safe and protected environments, to enhance refugees' sense of home, to provide minimum socio-economic inconveniences in living areas, and to provide private and social living areas (Habib.et.al, 2006 - Giacaman, 1985 – Filfil, 1999 – Farah, 2000-Al-Khatib.et.al, 2003).

Appropriate, thoroughly selected and integrated refugee sites and well planned refugee settlements are essential from the early stages of an emergency for the refugee, since this will tremendously mitigate their difficulties and hardships. Adequate infrastructure is also essential. Moreover, host families /neighborhoods/ communities, mass accommodation in established shelters or joint centers or organized camps all resembles the form of hosting and settling refugees during emergencies. However, identifying the most suitable solution or set of solutions for accommodating displaced individuals according to the sense in which displacement takes place according to the UNHCR emergency manual, is of paramount importance.

A camp's infrastructure, facilities, and shelter would have a significant impact on its residents' health and wellbeing. Therefore, during the humanitarian response, other critical sectors such as water (good quality, quantity and ease of access), sanitation, administration and protection, food distribution, safety, community services, education and income-generating activities should be considered. The first question to be raised when there is a refugee emergency is whether or not a camp is the most suitable settlement choice for the displaced people. All other choices should be considered, as they may be more fitting to the conditions of displaced population. When, for instance, displaced people lodge with host families or have self-settled within local communities that share cultural links with them, consider these choices and decide if these alternatives are more suitable. Any of these alternatives to camps will encourage self-dependence in the uprooted community; but these initiatives need the commitment and consent of the host government and the host communities themselves.

2.3.2 Solutions And Categories Of Disaster Time Shelters

Disaster is an abrupt incident that can happen suddenly without prior warning; it can be caused by natural Earth phenomena such as hurricane, earthquake tornado, etc. or by human's violent actions such as conflicts or wars. The mutual issue is that every catastrophe affects the nation and the survivors very negatively. In general, a lot of people are uprooted and displaced for either short or prolonged period of time following any disaster, and they immediately require refuges to settle in. The amount of individuals affected and displaced may be as small as one or two families, or, as big as a whole city. And the number of refuges and IDPs required depends on the amount of people influenced (Payan, 2017).

The basic concept of shelter is an inhabitable enveloped living space which offers privacy and dignity for those residing in the sheltering units by providing safe, healthy and secure environment. Shelter is a method in addition to a commodity in the sense of shelter responding to natural disasters, as it involves a transition from emergency shelter to long-lasting solutions, which can take several years according to the UNHCR. The major stakeholders are the affected communities of displaced people, since they are aware of the help and assistance they need and the available tools. However, for a variety of internal and external purposes, governments, humanitarian organizations and donors frequently, split their shelter interferences into phases. Nonetheless, accommodating and sheltering practices of displaced people post a disaster, is a fluid process that commence directly after a disaster occurs (Bashawri.et.al, 2014; Alnsour & Meaton, 2014).

The exhaustion of housing stock has consequences far beyond simply losing a building (IRP, 2010). Access to adequate shelter after a disaster may be essential for survival, as well as for providing security, personal health and general protection and human dignity (Ferrer et al., 2009). Furthermore, post to a disaster, it's essential to provide a sheltering solution with good quality, since this will tremendously impact the occupants socially, economically and culturally in a positive manner, and further enhance family structures and support habitual life. Managing to achieve the highest degree of satisfaction and attaining a sense of home and belonging in short periods of time is linked to having suitable shelters alongside a convenient camp arrangements with suitable blueprint. In addition, shelter is the most important item for survivors in the early phase of a catastrophe and will deliver a safe living space and protect people from climatic and environmental risks. Moreover, this will also serve as a prompt setting for family psychological and physical sides for instance, education, personal security and health care (Sphere Project,2011;Yüksel&Hasirci, 2012; NRC 2014). On this context, it can be concluded that shelter in the time of a disaster is of great psychological and physical importance to maintain human dignity and to preserve family.

Nonetheless, the sheltering process is complicated since many concerns required to be addressed, including land availability, land ownership, material acquisition, rubble removal, participation of influenced communities and government, and collaboration. Indeed, finding sufficient accommodation following a catastrophe can be considered one of the major challenges the humanitarian international community faces (Burnell & Sanderson, 2011). Furthermore, as depicted in (Figure 8), the housing cycle after a catastrophe does not pursue a single unique route to a permanent or sustainable home, and various approaches are used in different circumstances (Sampo, 2013).

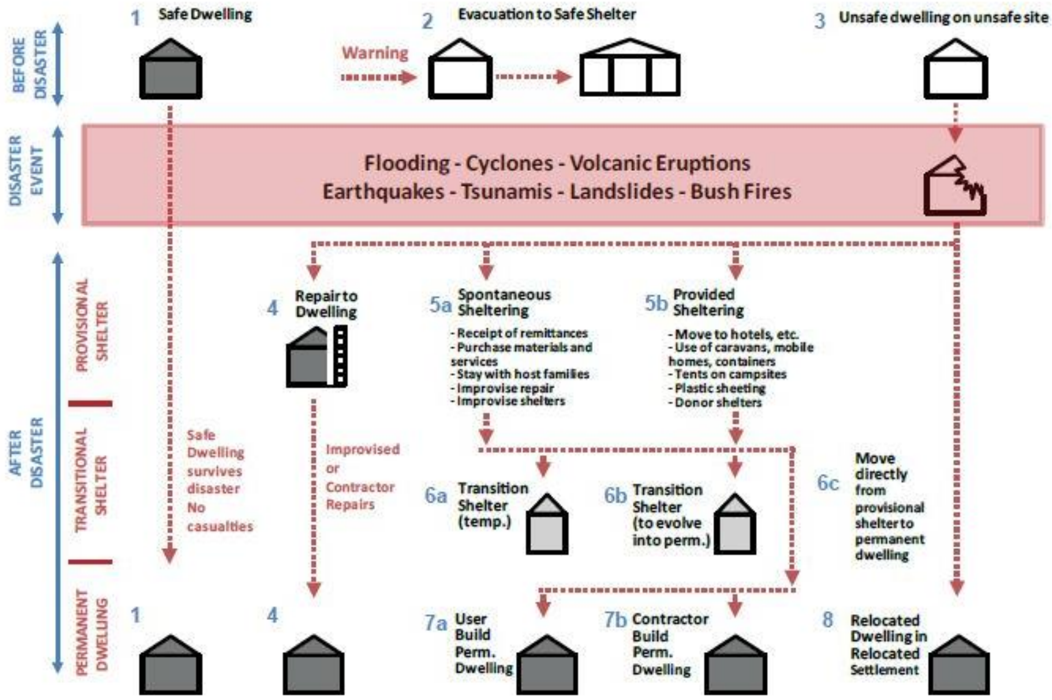


Figure 8: Sheltering process after disaster (URL8)

Depending on the initiatives involved in the restoration process affected communities and households can find accommodation and permanent housing in various ways. They do so by constructing themselves; being funded by polities; being sponsored by internal or foreign organizations; or by some integration of those options. The nature and size of the disaster, the local circumstances, the governmental environment and the capacity of the affected population to meet their shelter needs decide on the stakeholders which are involved and in which way shelters are developed (Sphere Project, 2011). Therefore, there is really no ideal solution which suits any tragedy or family damaged (Gray and Bayley, 2015). While the reactions to every other situation are varied and unique, the humanistic sector has developed standard tactics including the use of major structures such as communal shelters (public schools and governmental facilities), leased houses, temporary camps rented houses, repair of harmed homes, and transitional or temporary shelters and other methods (Shelter Centre, 2012). Transitional shelters or temporary shelters are used in the case when the displaced families cannot or reluctant to go back to their pre-tragedy homes or property (Sphere Project, 2011). To refer to building process and the approach, the terms temporary and transitional were used, and certain conceptual variations between them can be identified. Additionally, it is a common practice to interchangeably use the terms 'shelter,' 'housing' and 'accommodation'.

The sheltering process can be classified into: "emergency shelters, temporary shelter, translational shelters, temporary housing, core shelters and permanent housing". Urgent circumstances shelters are deployed for brief terms of time of one or two nights on the first days after the disaster; after a couple of days, T-Shelters are established and constructed and are mostly utilized for a prolonged period of about six months, depending on the system's demand and power. During this stage until permanent housing is ready, the temporary housing allocates survivors such as manufactured shelters with facilities supporting daily live needs that permits displaced (Duan&Faker, 2012). However, on the long run, permanent housing is utilized, such shelters incorporate a permanent infrastructure and various facilities and services such as plumbing and electrical systems. Further, the aforementioned concepts of sheltering are discussed in more depth as follows:

Emergency shelter: Quarantelli (1995) describes emergency shelter as a period in the instant consequence of tragedy where families seeks for a shelter for few days, while normal daily activities are stopped. Since the period is not long, this does not necessarily mean the demand for excessive food elaboration or extended medical care

(Johnson, 2007; Quarantelli, 1995). In several situations this process, despite its meaning, this period may continue form weeks to months. This may come in the form of a city shelter, large emergency facilities, such as gyms or hospitals, temporary support centers that include manufactured housing clusters, a friend's house, plastic cover, rental support or some other type of supplemental resources (McCarthty, 2009; Quarantelli, 1995; Duan&Faker, 2012). Since these shelter types vary considerably from each other, Oxfam has proposed that the shelter and accommodation requirements of Sphere should be utilized, assigning at least 3.5 m2 of enclosed area for each person (Oxfam GB, 2003; Sphere Project, 2011). The following (Figure 9) shows an emergency shelter tents in Sri Lanka.

Figure 9: Emergency shelter tents at the IDP camp at Menik Farm Sri Lanka. 2009 (URL9)

Temporary shelter: it is described as an area of accommodation where the damaged families live for an anticipated short stay following the disaster before more appropriate housing becomes available. This may take the shape of a tent, a self-constructed shelter, a cleanliness, an urban mass shelter, a hotel, a family home or a home for friends or a secondary home, and must be supported by water, food and medical support (Félix et al., 2013; Johnson, 2007; Johnson et al., 2006; Quarantelli, 1995). Though Quarantelli (1995) recommends that temporary shelters should be used in post disaster weeks, Barakat (2003) stated that these shelters are intended to be used in the initial months after a disaster, while IFRC (2013) notes that these shelters should be restricted with a fixed duration, prioritizing construction speed and restricting fees. While temporary shelters can have various shapes, they are typically produced, manufactured and utilized worldwide irrespective of the inhabitant's culture or environment, and they seem compact and made up of brisk materials for quick movement (Barakat, 2003; Félix et al., 2015). There are two main categories in terms of use, material and construction: "temporary shelters with transformable elements that use versatile and rigid elements that are simple to assemble, move and lightweight; and temporary shelters with non-transformable elements that use solid, easy to assemble but heavier and more difficult to transport materials" (Félix et al., 2015) (Figure 10) shows temporary shelters for Syrian refugees.

Figure 10: Illustration of temporary shelters for Syrian refugees (URL10)

Transitional shelter: This type of shelter is described as a gradual operation that offers shelter to the less fortunate displaced families, beginning with the first aid provided during the emergency phase and continuing through the duration of gaining land property rights and redevelopment that may last many years (Shelter Centre, 2012, p. 2). It is regarded a method instead of a step, and a mechanism instead of a commodity, that promotes the self-rearrangement and self-resuscitation of the populations doomed by the ramifications of a war or a natural disaster and foster the transmission to much more sustainable refuges (Collins et al., 2010; Sphere Project, 2011). The terminology "transitional" however underlines that housing or sheltering is a phase, a transition from an urgent situation to lasting solutions (Kennedy et al., 2008). Where such phase can have the shape of a simple shedding and structural members made of plastic, that later might be incorporated into transitional shelters, planned and generated locally (Shelter Centre, 2012).

The design phase of the translational shelters, should be compatible to the following criteria: it should be structurally sound; adequate environmental protection should be provided; overall security and safety should be offered ; water piping and sanitation services should be available; support basic living needs; thus, it finally should be according to the conventional agreed standards (Shelter Center 2012,). Moreover, translational shelters primarily utilization of domestic materials that contribute to national and provincial economies growth, but storage models can be utilized and developed when local markets cannot sufficiently supply enough material (Collinset al, 2010). Translational shelters should be designed in way that: allow them to be upgraded to be a segment that contributes to permanent sheltering in the future; reutilized for other purposes; moveable so they can be easily relocated from a temporary site to a permit one; tradable, so they produce revenue; and reprocessed, for the potential of redevelopment (Shelter Centre, 2012, p. 2).

The main aim of transitional shelters is to promote and sustain viable and eco-friendly processes, which are induced by displaced people, hence, they are considered to be appropriate this path can be considered for both of the displaced people and non-displaced. The shelter can be disassembled and re-used for the displaced communities, wherever possible, in new locations or in their original areas. It can also be used as a simple home that can be updated, extended or replaced over time for the displaced people (Sphere Project, 2011). Transitional shelters are planned to smoothen the switch to more sustainable accommodating solutions; thus, provide the potential to connect comfort with growth, when transitioning from urgent to recovery phase and finally, to redevelopment (Alegria Mira ,2014; Zea Escamilla and Habert, 2015). Translational shelters are considerably convenient when it comes to the span of life. They provide a more sustainable alternative, since they are mobile, easily reusable and recycled and easily reassembled, rather than being neglected structures after being used initially (Alegria Mira et al., 2014) (Figure 11) shows a transitional shelter.

Figure 11: Illustration of transitional shelter (URL11)

Temporary housing: This type of sheltering or accommodation is a facility where affected people tentatively settles and takes up household and everyday activities (Quarantelli 1991). It is an individual physical structure, a part of a post-disaster re-housing cycle and a refuge from disaster events to permanent locations in which people can stay (Johnson, 2007, Johnt et al., 2006). The shelters may be a prefabricated housing unit, a self-built house, a mobile home, an apartment or a member of a family (Quarantelli, 1991). Several scholars argue, however, that this type of shelters takes an irrelevant form, as it reflects the mechanism by whom families will start to brisk and rejuvenate. Thus, presence of an significant physical tangible is essential, as well as position, reaches to works and services, vicinity to the prior residential buildings, where possible, community links and guidance for permanent living options and procedures (Fayazi & Lizarralde, 2013; Johnson, 2006; Lizarralde, 2009). Post to the phases portrayed by Quarantellit, tentative accommodation fills the void between tentative housing and the completion of the rehabilitation and reconstruction, where it facilitate the return to normal life conditions (Johnson, 2007; Johnson et al., 2006).

Temporal shelters are built to perpetuate from 6 months to 3 years where it tends to be very similar to permanent housing which a more durable and robust than form of shelters, it also provide basic services, such as water supply, electricity and drainage, and are mostly constructed or fixed on temporary territory (Bashawri et al . 2014; Félix ,2015, 2013). In context of the prosperity systems, there are two major classes of temporary housing: a) ready-manufactured units, created by manufacturers, transported on-site and then easily installed, and b) on-site kits which are construction elements supplied to be installed on the site (Félix et al., 2013) (Figure 12) shows a temporary house in Japan.

Figure 12: Paper Log temporary House Kobe, Japan (URL12)

Core shelter/ one room shelter: This type of shelter is planned, designed and constructed for the purpose of functioning as a permanent accommodation, providing a foundation and all or some of its main facilities such as plumbing and various utilities (International Organization for Migrations 2012). The purpose of this type of shelter is to build at least one or two rooms to meet permanent housing requirements and enhance them. Their cottages are not supposed to be a complete permanent house but are not planned (IFRC, 2013) (Figure 13) shows a one room shelter.

Figure 13: IOM's One Room Shelter Program, Pakistan (URL13)

Permanent housing: Permanent housing or accommodation is a form of sheltering that is used when for prolonged housing periods. Generally, permanent housing are upgraded from the aforementioned types of shelters (i.e. progressive, translational or core shelters) or it can be constructed independently (Quarantelli, 1991, Wu and Lindell, 2004, Johnson et al., 2006, Johnson, 2007, Félix et al., 2013). Permanent shelters should be designed in a way that makes them durable and resistant to future potential catastrophes (Figure 14) shows a permanent house in Chile.

Figure 14: Permanent homes for the people who are affected in Bío-Bío region in Chile (URL14)

The following (Table 1) summarize the sheltering process and the types of shelters that are used post to a disaster:

Table1: Process of sheltering Developed by author; based on (Bashawri, 2014; Ashmore.et.al, 2003)

Sheltering Process	Description
Emergency shelter	• Given for directly after a tragedy. • mostly used as a night or a couple days for brief periods • It is usually utilized in local circumstances and conditions • Installed in a neighbourhood or city plaza for a short amount of time • Tents are predominantly used.
Temporary shelter	• Usually utilized for prolonged time periods. • Utilization relays on the need and the capability of the system • Must offer minimal level of relief and welfare, and it should support the occupants mentally. • Must meet the criteria for various spatial functions.

	• May include the multipurpose and national and environmental conditions. • May be moved, and components can be reused.
Transitional shelter	• an approach instead of a stage, components and a procedure instead of an output • can take the form of plastic sheeting with basic structural elements • Utilize local resources to benefit the local and national economies • Suitable for the shift to more sustainable residential solutions • They provide a viable substitute, and instead of becoming outdated structures they could be relocated, recycled and reconfigured
Temporary housing	• Used often for at least 6 months over a prolonged period. • Is built on tentative soil
Core shelter	• Design with public infrastructure such as pipework and multiple utilities. • effectiveness in the provision of basic refuge relies on shelter costs, area safety and other socio-economic aspects
Permanent housing	• It is as upgrade and development model of transitional, progressive or core shelter, • Should be stable and resistant to future hazards

Chapter 3

OFF-SITE CONSTRUCTION AND MODULAR CONSTRUCTION

The term construction which also referred to as building construction can be defined as the process that describe the erection of structures, and the techniques, methods and industry related to this process. Since the beginning of time, humans have been engaged in construction with the essential practical necessity of combating the adverse effects of climate and surrounding environment, in order to afford a fully controlled habitation that can be termed as shelter to practice daily life activities with convenience. This influence of the natural environment has allowed mankind to further spread and adapt to a wide range of environments and has become a global species that have been prevailing since the dawn of time. Ordinarily, the human kind did not completely acquire the skill of shelter construction overnight, instead, shelter erection initially started with a very fundamental interim and vulnerable structures, that have lasted for few months or maybe few days (Swenson, Chang, 2020). But gradually, with the passage of time, humans evolved and their construction skills evolved concurrently, where they became able to construct more stiff and reined structures that actually arose from those modest and temporal ones, such as the Igloo structure. However, with the evolution of agricultural techniques; rapid increase of the population concentration induced by proliferation occurred, and thus the need for more permanent and durable structures became a necessity. The shelters were mainly residential at first, afterwards other shelters was needed for various purposes, such as supply storage and to held special occasions. Some structure changed from having a practical value to having a emblematic value, and by then the distinction between construction and architecture commenced.

Throughout the history, various and many construction process techniques and trends emerged, and one of them is the progression of the materials associated with building and construction practices, staring from using basic weak materials found in nature such as, branches, leaves and animal hides, to discovering and taking advantage of more strong natural materials like stones, clay, and timbers to lastly manufacturing and utilizing synthetic materials such as metals, plastics and concrete which considered to be the most durable. Furthermore, this evolution of building materials; opened the horizons for mankind to achieve huge structures with great heights and spans leading to the emergence of another trend. An additional modern trend that can be clearly seen in nowadays construction practices, is the ultimate control over the building's interior environment. Manifested in the further control over the prime factors that impacts the comfort of the inhabitants from the first degree, such as humidity, airflow, sounds, lights and temperature (Swenson, Chang, 2020). Another phenomenon is the strength that humans can leverage and use in the construction process, from using mere muscle power to utilizing sophisticated, very efficient tools and machinery. Nowadays, construction is in a very sophisticated and complex shape. Today, various markets and styles of buildings with a wide range of resources to reach them are available. Moreover, construction starts with a very structured and thorough design process, based on research institutions exploring and studying different materials and their distinct properties and performances, controlled safety standards set by code officials, studying the needs of potential future residents and finally achieving an optimum design that addresses and serves such needs (Sancheti , 2018).

Construction is a delicate job and its process is highly systematic and organized. It is in fact a multiphase process that involves the building materials and suppliers of machinery, the craftsmen responsible for installing them on the site of construction, contractors recruiting and coordinating the work of craftsmen and contractors skilled in the fields of construction management, quality control and security. Moreover, nowadays construction became a prominent contributor of industrial culture, a sign of its complexity and sophistication and a measure of its superiority, which can generate a wide range of built environments to meet the needs of the diverse society. In recent years, construction methodologies have gone through a drastic change, with the continuous adoption of advanced technologies that enhances the efficiency index of structures. This by its turn brings about enormous advantages, financially on the end user for instance, who will manage to save lots of money by getting rid of unnecessary redundant costs spent on works relevant to development and maintenance. Also, the executive responsible will be able to accurately justify construction costs and safe valuable time by diminishing project lead times. (Swenson, Chang, 2020). Nowadays there are many new building methods that can be utilized in construction processes such as: 3D Volumetric construction (modular design), Precast Flat Panel Process, Tunnel Formwork system, Flat Slabbing Technology, Pre-cast Base Technology, Hybrid Concrete Building Technique, Thin Joint Masonry Technique, Insulating Concrete Formwork Technique. (Sancheti,2018).

Three main terms will be used in this study, which are:

Prefabrication: general term for the construction of entire buildings or parts of buildings off site before being assembled on site. Prefabricated structures include mobile buildings as well as various types of permanent construction systems. Offsite construction is now the most widely used term for permanent buildings manufactured in this way (Smith & Quale, 2017).

Off-site construction: Completion of construction elements or materials at a specific location than where they would be permanently built. Typically, this can involve planning, design , manufacturing and assembly in purpose-built off-site factories. The finished item is then delivered to the site and assembled on site(Smith & Quale, 2017).

Modular construction: Volumetric construction modules in which the assemblies form the building structure and enclose useable space. Often the terms are also used to define room modules which do not include the macro-building structural system. These are especially common for hotels and student accommodations because of the scale economies available from other comparably sized modules and the specific benefit of shortened construction time for sites. Modular also consists of non-structural service pods and a modular standard of coordination (Smith & Quale, 2017).

3.1 The Concept of Off-site Construction (OSC)

Since the beginning of industrial revolution, off-site construction (OSC) in its essence has been utilized in modern society. OSC made its debut when the power saw was first introduced to the industrial word, where large chunks of timber were cut into predetermined sizes and supplied to the site of construction to be installed into stud-walls by using machine-cut nails. OSC practices can also be seen in the manufacturing of bricks, although this process started by manufacturing brick pieces from clay on site. But with the gradual advancement of industrial approaches, the process has been transported to the controlled environment in the factory, where large number of bricks are manufactured in less time and to precise dimensions (Bruce & Sandbank, 1944). However, OSC is usually linked to modernization, nevertheless, it is believed that OSC process dates back to the ancient Roman civilization, where several evidence of an ancient Roman shipwrecks that suggested some of the structural members of the ship were produced off site, then transported to the intended site of construction for assembly, thus, indicating that OSC might took place back in that days (Urban, 2012). Additionally, OSC practices manifested clearly in the actions of invasive colonies, were they tend to deploy rapidly assembled structures, mostly used for medical intents, there are sketches from the late 1800s that illustrate field hospitals and portable barrack as rapid methods to set up infrastructure and military facilities (Dietz, 1971).

However, the phase of industrial construction commenced following the World War II, as a consequence of the growing demand for residential housing, and this in fact was a tremendous boost for OSC. On the other hand, the American landscape suffered a massive shortage of conventional feasible housing during The Great Depression period (Bruce & Sandbank, 1944). But this did not prevent a lot of entrepreneurs, designers and technologists from working tirelessly to resolve the problem is such difficult time. Many of them were eager to reach to an optimum housing solution, and as a result, many innovative housing solution emerged from that time, like the working drawings influenced from the studies accomplished by Frederick Winslow and Henry Ford. Moreover, as an example, Lustron CO. and other construction companies attempted practicing OSC by developing a steel fashioned housing solution inspired from the automobile manufacturing process (Smith & Quale, 2017). Some other companies such as the Levitt, attempted what is called on-site fabrication by bringing the plant to the site. They had a genuine manufacturing and production line with lots of operating crews performing different tasks to boost productivity (Smith, 2010). Such building projects have not been universally accepted, however, and ambitious dreams of mass-produced building for the masses have waned. OSC has various connotations for various citizens in recent decades. Prefabricated that connote manufactured housing to the general public, which is symbolic of the ubiquitous trailer park. However, OSC can denote a radically different significance in the prospective of building professionals, whether OSC was inferred to a bathroom pods or a full commercial structures in the shape of a roof or floor truss. Yet, most of the newly emerging construction companies adopt OSC techniques to some extent. For instance, pre-hung doors which is a basic and universal prefabricated component widespread in the construction industry's practices, has tremendously enhanced the customization of the trade and standardized it (Smith & Quale, 2017).

Prefabricated structures and its primary composition have three general forms. Smith contends "in which the general categories manifested in components, modules and panels are produced offsite then transported to the site for assembling" (smith,2010). According to Gibb (1999) this breakdown by element is termed as volumetric and non-volumetric. European cutlers often use the terminology "volumetric" which previously was the main indicator for modular construction in the US. Volumetric construction have been referred to as "monolithic box construction" by Dietz (1971), but this terminology is a bit outdated nowadays. However, in this study, whenever the term "modular" is used, it will be for describing any construction technique that incorporates volume encompassing components produced offsite in a factory and assembled on site. (Figure 15) illustrates the potential implementations as proposed by both (Smith,2010 and Gibb,1999). Furthermore, Modular proponents argue that as the degree of OSC increases, greater benefits are harvested. A volumetric snipped-out assembly is thus more convenient to use than of incomplete floor and wall panels (Smith,2010).

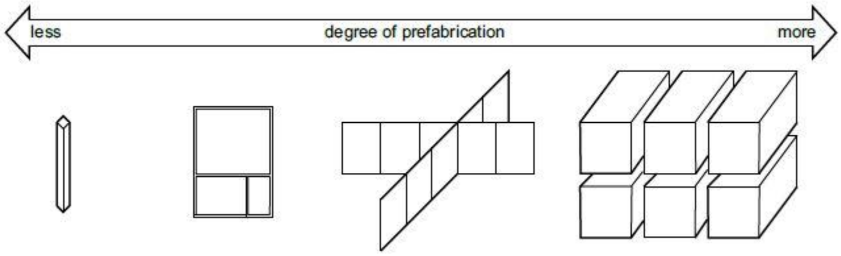


Figure 15: From materials to modules, different OSC degree (URL15)

These days, OSC is incorporated in all types of building projects, from expensive and costly industrial and commercial structures to single-family homes (Gibb, 1999). The degree of OSC varies from one project to another depending on the criteria determined by the particular work. In addition, the degree of OSC varies considerably depending on the geographic location. Where the majority of countries that considered to be developed have taken advantage of prefabrication more than other less developed countries, this can be observed from their extensive production of panelized systems, truss components or any other modules with other configurations. However, this disparity between such nations in terms of utilization of OSC might be due to the fact that developed countries have more stimulating building atmosphere that promotes the use of OSC.

For instance, the efficient use of OSC by Japanese construction establishment and their advanced construction practices, have raised the bar of manufacturing and industrial standards concerning housing production. In contrast, the drive for OSC is far less proclaimed in developing nations; since planners and government authorities get further value from the ample workers around the work site. It is advantageous for development companies, as the work is inexpensive and they able to benefit from leveraging the assets available. Meanwhile, with increasing capital projects, the local population and the government profits, since unemployment will be greatly diminished (Gibb,1999). For instance , during the 2008 Olympic games held In Beijing (P.R.C) build-up, Water Cube project designers proposed constructing components with (CNC)-cutting device (i.e. Computer Numeric Controlled) elements to Fitting the robust steel frame. The developer however chose to employ a large number workforce of approximately 3,000 local workers, including one hundred welders, to produce the structure (Smith, 2010).

While the majority of traditional construction materials are used for prefabricated building, advances are still coming into view from using pre-existing materials in modern ways. For example, timber that is cross laminated (CLT) which is a highly designed wood product, has been extensively used in the countries of northern European for several decades, but its gradually experiencing more and more use in Northern America (Figure 16). The manufacturing of CLT panels is achieved by placing the directional timber in a perpendicular framework where each sheet is positioned 90 ° to the neighboring board, a strong rigid panel is produced that utilizes the wood's material characteristics in any direction. With three to nine layers, these panels can be manufactured and can be used for walls, roofs and floors. While in North America they are still relatively uncommon, CLT panels are just another variant of the engineered wood products that are commonly used worldwide (Gagnon &Pirvu, 2011).

Figure 16: Cross Laminated Timber panel (URL16)

One of the OSC limitations, specifically in association with modular construction, is the limited size of the buildings. Lumber construction, for example, is usually bound to no more than 3 floors in height due to the material's ability (Gibb, 1999; Smith, 2010). Higher modular structures are typically constructed with materials possessing high strength in terms of shear, compression and tension such as steel and concrete that often have the additional advantage of improved fire-resistance. Nevertheless, CLT's physical and mechanical specifications are suitable for constructing far bigger wooden structures. There is a project built with CLT consisting of nine floors in London, however, testing shows that CLT buildings have the ability to go higher, although building code does not yet permit them to do so (Gagnon &Pirvu, 2011).

3.2 Applications of Off-site Prefabrication in Construction

As already stated, OSC is used in all building aspects and has a variety of specific applications, according to the scenario. This could range between a cut to size and numbered parts package to a set of completed modules which make up the entire building in commercial buildings. According to Constructor, a 2011 survey conducted by the Associated General Contractors of America (AGC) found that some distinct form of modular construction (i.e. OSC) is being utilized by a gross percent of 98% of respondents, but usage is inclusive to an insignificant part of the project (Jackson, 2013). Most generally such contractors that use prefab-methods prefer to concentrate their potentials to the fullest on repetitive elements. Things such as prefabricated bathroom boxes, cable trays, architectural metal frames and hospital headwalls are the pre - fabricated components most commonly used by major commercial project manager companies such as Balfour Beatty and Skanska (Jackson, 2013). OSC is used by Commercial general contractors in one single location to take advantage of several trades. Usually, there is a complex process that requires electrical, mechanical, piping (MEP) and other skills to interfere while they perform their respective job. (Jackson, 2013). This indicates that perhaps the sub - contractors are bound by the project timeline and also the project, in turn, is bound by the independent schedules of the different trades (Kaysen, 2011). For extremely complex projects, this produces a chaos of pipes and wires, and the possibility for redundant repair; even on the easiest of duties, this procession-of-trades is a two sided responsibility. By transferring these sophisticated processes into the plant, the contractors of MEP are able to move flexibly between tasks on pods installed in one row. This leads to placing most of different enterprises in the demanded places and facilitate and relieve the stress of various schedules by offering a good range of flexibility to trades people to function on several pouches, and several floors, in a unified single factory and a secure plane (Kaysen, 2011).

Additionally, mass-construction projects such as highways, dams, bridges, waterworks...ect exploit large-scale OSC. Usually, such civil projects lack bells and blare, but are typically incorporating heavy repeated elements, although in the project, few of them were present. For instance, a bridge construction can utilize up to 4 or 6 identical components to span a wide range, each of which can be a huge prefabricated element (Sundt, 2013). It would require a copious amount of formwork to construct each component on site, which is a time-consuming and non-cost-efficient. Nonetheless, in a dedicated casting-form, these components may be casted off site. The essence is to determine whether the cost of offsite casting deferred is significant enough to recompense the transporting cost of the precast item to the work site.

Off-site construction was also employed in a remarkable historic structure of La Maison Tropicale, were the story starts in the late 1940s, when French architect and designer Jean Prouvé designed the tropical house as a solution to the shortage of housing and civic buildings in the French colonies of West Africa. A large number of Maison Tropicales were planned to be built and transported from France to Africa. Therefore the houses had to be light and easy to assemble. This inspired Jean Prouvé to design a house that was made of prefabricated aluminum structures that could be easily constructed and dismantled. The framed structures of the house were also made to suit the tropical climate of West Africa, which led to Prouvé creating an inventive natural cooling system in the design. Due to its prefabricated components and innovative qualities, the Maison Tropicale became an exemplar of a modern standard type house. The functionality, rationality and standardization that characterized the project of the Maison Tropicale, make it an icon for industrial modernism. In the case of the Maison Tropicale, only three prototypes were produced: one commissioned by the Ministère de la France d'Outre mer (Ministry of Overseas France) and installed at Niamey (Niger) and another two for the office of the Regional Bureau of Aluminum Information and his director's residence at Brazzaville (Congo)(Figure 17) (Failed Architecture,2013) (Rausch, 2018).

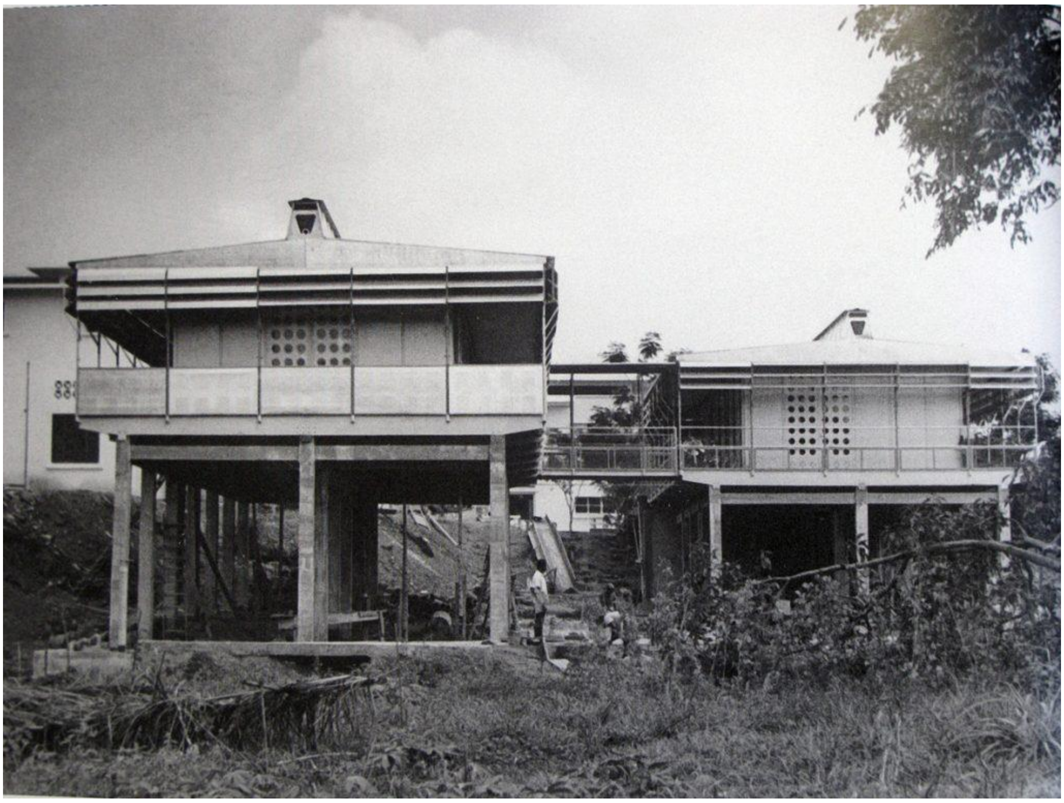


Figure 17: Tropical Maison Brazzaville, Republic of Congo. (URL17)

Utilization of OSC in the residential sector has many similar features seen in industrial implementations. Nevertheless, in residentiary construction, the size of the independent project is typically very small that OSC can smoothly be converted to a panellised and modular structure that completed the entire house. Moreover, Housing has long been a subject of research on OSC, in the terms of offering a standardized option for feasible accommodation and as a means of revolutionizing the manner houses are constructed (Arieff& Burkhart, 2002). Prefabricated housing and relocatable homes have consistently been constructed to a reasonable, albeit widely derided, norm for decades. Relocatable homes that are distinct from movable homes in that they existed before the HUD code referee to the U.S. Housing and Urban Development or U.S. HUD construction codes, not usually national or local construction codes. The Housing and Urban Development code stipulates that the prefabricated housing must be built on a permanent framework instead of on an enduring foundation, thereby obviously designating the distinction between a manufactured house and a modular house in the law certification (U.S. HUD, 2013). Nevertheless, several OSC of modular houses still build HUD-housing code, causing uncertainty as to whether modular houses and prefabricated houses are similar. It suffices to note that prefabricated houses and modular houses are two separate items, both of which are completely manufactured and prefabricated.

Manufactured housing has operated under bad influence for a long time, largely due to decades of low construction quality before the crossing of the United States. In 1976 HUD code (U.S. HUD, 2013). Ever since, manufactured homes has not changed significantly because of the obvious reality which is the most inexpensive housing per square foot, and is therefore the slightest effective in terms of service and efficiency in the event of disasters caused by mother nature (Smith, 2010). In addition, the transportability of what already to be considered movable housing has deteriorated significantly since the 1970s. Previously, mobile homes used to be 2.43m or less in terms of width and can be easily transportable by road using normal means of transport. By the year 1970s, they escalated to 4.26m and 3.65m, substantially decreasing the versatility of every and each produced unit. The double-wide housing unit was launched in 1976, which created a 8.53m wide houses by connecting two fourteen-foot parts together along the building's longitudinal axis. This type of home is certainly not movable. Composing these elements, the worth of the prefabricated housing does not increase at a similar rate to the at-site constructed housing and sometimes decreases, rendering the purchasing of the prefab-home less desirable from the retail prospective (Smith, 2010;Smith & Quale, 2017). The Roebuck, Aladdin and the Sears mail-requested houses as of the early 20th Century have been popular for decades (Smith, 2010). There are still many business models today including Aladdin and Sears, but funding is not generally given by the house manufacturing company, as it was with the case of Sears. Companies such as Rocio Romero and Deltec Homes Prefab produce houses, some of which are built as a kit and sent for assembly to the purchaser. Furthermore there are a variety of costs, most analogous to on-sitet constructed houses. A lot of these kit houses are sold as a DIY; however, because of the simplicity of design and construction that comes alongside with the package many suppositional builders find them attractive (Romero 2014). Houses are mostly made of kits which are sealed on the plant and ready for use on the worksite (Figure ...). The end walls and prefabricated roofs are often finished with clamping, but there are just too many possibilities to mention (Law,1985).

Figure 18: Panelized kit house during assembling process . (URL18)

3.3 Off-site Construction (OSC) and It's Typologies

For a certain project, when the construction practice and its main interim phases including design, planning, fabrication and assembly of a structures main components at location other than the main location of project development; in order to facilitate a quick and efficient construction of the final permanent structure, the construction however is termed as off-site construction. Moreover, such building elements may either be prefabricated at another location and taken to the site, or prefabricated and then installed directly on the final intended site of development. An integrated planning and supply chain optimization strategy characterizes offsite construction. Further, when it is substantial to refer to in-factory work and production of structural components; the terms Offsite manufacturing (OSM), offsite production (OSP), and offsite fabrication (OSF) are used (Smith & Quale, 2017;Gib,2001)(Gibb & Isack,2003).

Owing to industrialization and the growing transfer of previous on-site construction activities to off-site factory prefabrication, the existing state of OSC will be significantly affected in the future (Ginigaddara, et al., 2019). This results in limited on-site operations, which are based solely on building assemblies and construction components carried out by specialized self-directed work packages (Goulding, et al . 2014). Here the ratio of the on-site to the offsite varies, depending on the type of OSC conducted in the specific project. Likewise, depending on the form of OSC, on site and off-site improvements are required for qualified staff and practitioners (Southern, 2016). Furthermore, the major types of off-site manufacturing are discussed in more detail in (Table2):

Table 2: main types of off-site construction developed by other, (based on Gibb (2001); Gibb and Isack (2003);Kempton (2010);Boyd et al.(2013);Goh and Loosemore (2016);Abanda et al. (2017)

Type	Explanation	examples
Panelized	• 3D structures are produced by manufacturing and assembling flat panels onsite • All electrical and mechanical services, such as water feed pipes or light switch fittings, can be pre-fitted. • Two primary types: 'accessible panels,' containing a service frame, external covering etc. onsite, as well as 'closed panels,' requiring a higher degree of plant-based equipment.	Ready-made walls, roofs and floors Doors, windows, cladding, timber frames
Volumetric	• Factory 3D units which contain accessible rooms but do not constitute the structure of the building. • Also called non-structural volumetric spaces. • Prefabricated and pre-engineered, transportable to the site, installed or integrated into a pre-existing structure.	Plant-room, Bathrooms,toilet pods, lift shafts, kitchens

	The most prominent volumetric system includes bathroom pods.	
Hybrid	• Both of the panelized and volumetric systems/units are merged together. • Commonly utilized within the scope of highly serviced and repeatable areas. • Furnishings alongside together with finishes are moved to the construction site after being prepared and transported from the factory	Bathrooms, Trusses, staircases, precast elements
Modular systems	• Volumetric units pre-assembled that shape the whole building together. • Fully constructed houses or apartment blocks may be totally completed, including electrical works, plumbing, and trimming. • 90-95 per cent of the building is completed within a factory environment, including service facilities. • The modules are then transported to a permanent installation site to be permanently fixed on a pre-established foundation.	Complete houses, apartment blocks, Complete structures, Retail outlets, offices, prisons, multi-storey residential units
Components & sub-assembly systems	• Produced products which are not considered to be complete systems but replace parts of the structure usually manufactured on site. • Subassemblies can be as small as door locks and handles, or large components such as roof trunks that are pre-assembled.	Door furniture, windows, Floor cassettes, roof cassettes, light fittings, pre-assembled mechanical services.

Panellised: Panellised systems are manufactured by flat panels, assembled onsite to create a 3D design (Abanda, et al., 2017) the term panelized systems is generally use for floor, wall or ceiling components that are generated in a factory and installed in a building onsite (Figure 19). Both electric and mechanical facilities, for example water feed pipes or light switch fittings, can be pre-fitted for those tables. In order to form the final complete structure; a professional construction team assembles the building components quickly on site (Boyd, Khalfan, &Maqsood, 2013). Moreover, in the construction market, there are two major types of prefabricated panel units, the first type being “open panels” which constitute a skeletal structure incorporating other services such as external cladding etc.. on-site installed, the other type is “closed panels” , this type deals with a higher degree of factory based components (Kempton, 2010).

Figure 19: Panellised system. (URL19)

Volumetric: The volumetric systems are factory-produced 3D units which contain usable space but do not shape the framework of the building, such as bathroom pods, plant rooms, lift shafts etc. Volumetric structures are also known as non-structural volumetric spaces (Abanda, et al., 2017), which are pre-designed and pre-installed, which can be delivered to the site and placed into or integrated into an existing structure (Kempton, 2010). The Bathroom pod (Figure 20) is the most common volumetric device. All the sanitary equipment, electricity, plumbing and even the finished tiles are included in the bathroom pod.

Figure 20: Volumetric bathroom pod . (URL20)

Hybrid: The hybrid system is an integration between both panelized and volumetric systems/units (Abanda, et al., 2017) (Figure 21). Volumetric modular units are usually utilized for propping and reproducible spaces, such as toilets and other components that use technology of panels (Kempton, 2010). All furnishings and finishing works are accomplished in hybrid systems and are shipped from the plant to be installed in the site.

Figure 21: Hybrid system . (URL21)

Modular systems: Modular buildings are pre-assembled volumetric structures connecting the whole building together (e.g. hotel modules)(Figure 22) There may be additional on-site construction on modular houses, such as external brick skin and tiled roof, in some conditions (Abanda, et al., 2017). Modular housing may be entirely completed factory-built houses or apartment buildings, includes all electrical, plumbing and trim works. Lastly, these modules are then transferred to a pre-established base for permanent installation at the site (Lu,2007). Modules give the building structural strength and offsite occurs up to 60-70% of the construction project value (Lawson, et al., 2014). In comparison, a recent study by Prefab Logic (2019) on U.S. module construction demonstrates how 90-95 percent of the building is completed inside a factory including service facilities. Similarly, modules transfer to factories 90 per cent of project activities (Johansson and Meiling, 2009).

Figure 22: Modular system. (URL22)

Components & sub-assembly systems: Such systems are imported products that are not considered to be complete systems but substitute parts of the structure that are usually developed on site (Abanda, et al., 2017). This covers building methods which are not known as off-site production, but which contain components of them. For instance, slab or ceiling panels or pre-fitted mechanical assemblies etc, but otherwise are more conventional in genuine (Kempton, 2010)..Sub-assemblies can be as small as door locks and handles, or they can be larger components such as pre-assembled roof trusses (Figure 23).

Figure 23: Components & sub-assembly systems. (URL23)

3.4 Modular Construction

As already noted, modular construction is a high degree of OSC in the simplest sense. Nevertheless, the distinction between modular and prefabricated construction is necessary to distinguish, since the two are not so interchangeable. The notion of module is what distinguishes modular construction from other types of OSC. A module is a compact, nearly limitless construction unit which is constructed with easy assembly and transportation. However, there are limitations on the type of modules that need to be transported on the road. Modular units can be pre-fabricated up to 95 percent and installed on the foundation constructed on site (Smith, 2010).

In many different aspects of the building industry, modular construction has developed and elevated and hence became more popular. Although the prefabricated building system with volumetric special units is now being used in many different types of buildings, from hospitals and schools through to high-rise residential and commercial buildings, it mainly emerged from portable and temporary style buildings in the past. The external design of building, which leads to a genuine economic and sustainability advantage, has driven this demand. Moreover, for the creation of a a robust and complete building, modular construction uses a prefabricated 3D component which is basically finished and assembled on site (Ogden, Lawson, et al., 2014). Furthermore, to construct family residential houses, there are two main construction methods that comprise both off-site and on-site approaches, for instance, the "on-site" approach to building is often referred to as conventional, site-built and stick-built erection. On the other side, the building "off-site" applies to the production and pre-assembly process before transportation and installation on the final site of the project (Charles, Jacques, 2007). Gibb and Pendlebury divided site construction into various levels including subassembly sections, non-volumetric preassembly, pre-assembly volumetrics and complete construction. However, this approach to construction is primarily known as the "later level" and is called modular construction. A modular building comprises a range of components which are manufactured, transported to the site, permanently assembled and manufactured on an off-site manufacturing facility. Any modular building usually consists of three-dimensional multi-room units. Until they are built, the parts are assembled and all, electrical, cutting, hydraulic and piping works in the factory is then finished. (O'Brien, Wakefield, 2000). Once these units have been assembled by the manufacturer, they are sent to the location to be placed on similar stick-built foundations. (C Binnenmarkt, Di Carlo 2007). Thereafter, it is estimated that nearly 85% to 90% of construction and building works are accomplished off-site, meanwhile the rest 10% to 15% of the works including link services and base job are achieved at the very end of the project on site (Kawecki, 2010). Throughout recent years, off-site building techniques have been used as substitutes for on-site (i.e traditional or conventional) building (Pan and Sidwell, 2011). Different and various studies have came to conclusion that off-site construction can lead to sustainable growth, which in fact a valuable benefit (2007, Pan et al.). This construction method offers other various advantages as compared to their traditional equivalent, including project completion time reduction and increased product fineness and quality. (Rogan et al., 2000; Smith, 2011). Nonetheless, modular buildings have been minimally used to some extent; for instance, modular systems have built less than 3 per cent of the total US housing. (Quale, 2012). The cause is likely due to the fact that various building professionals, construction engineers and even the general public have little to no knowledge and realization of the great benefits of off-site construction relative to on-site construction. This new precast modular unit construction approach offers other long-term positive and economical benefits. Nevertheless, investing in the manufacturing process and fixed facilities at a particular location requires a broad economy to sustain the produced financial benefits. To this end, modular construction involves collaboration between all design and construction team members to maximize benefit from the repeated use of manufactured parts and to facilitate the integrated design , manufacturing, delivery, and commissioning processes (Ogden, Lawson, Goodier , 2014).

3.5 Traditional vs. Modular Buildings' Life Cycle

The life cycle of a traditional building usually comprises of four main phases, that include material production procedure, design and construction process, occupancy and end of life . Similarly, in the situation of a modular structure, four phases are also involved; moreover, structural design, parts production, transport onto the site and installation are the main functions of the building phases. Further, Such building practices differs from those used in traditional approach to construction (Figure 24). The life cycle of a conventional building usually consists of four main stages, including material production procedure, design and construction process, occupancy and end of life . In the case of a modular structure, four phases are also involved; furthermore, structural design, parts production, transport onto the site and installation are the main functions of the building phases. These are different from those used in conventional buildings. Resources and energy are used in all facets of the building life cycle, including processing and storage of raw materials. The production of goods and components, distribution of products and components, and the heating, ventilation, and lighting resources used for the buildings have similar roles, but there are also several distinctions that may create some chances for reducing energy and material usage, although the lifecycle for traditional and modular buildings has some similar functions.

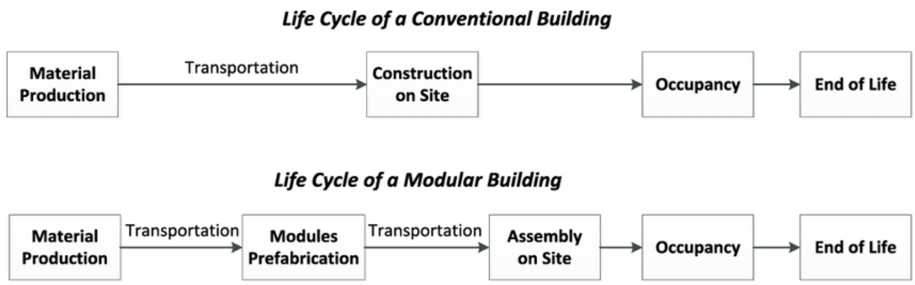


Figure 24: Traditional vs modular building life cycle (URL24)

The usage process has obviously been significantly influenced by the overall environmental impacts between life cycle stages in a building (Quale, Eckelman, Williams, 2012; SartoriHestnes, 2007). the energy consumption during the usage phase is estimated between 70% and 98% On the basis of certain factors such as the design and category of the buildings, compared with the phase of production of material and building which is about 2 to 26% (Ortiz, Castells, Sonnemann, 2009; Monahan, Powell, 2011). However, due to more successful and more efficient technologies, such as design methods and materials, and environmentally sustainable resources (e.g., solar and wind), buildings are becoming more energy-efficient over their time of use. As a result, other life-cycle processes, such as the phase of constructions are becoming more valuable. The very first 2 phases of an optimally energy-efficient structural system are construction and production according to (Gustavsson, Joelsson, 2010) which account for around 60 % of total energy consumed over the life cycle of the building. The combined power and the corresponding incarnate carbon therefore become highly important for this building, since the construction of high-level insulation systems requires more resources, new techniques using heavy bulk materials are being introduced. The share of the embodied energy in low energy buildings ranges from 9% to 46% (Thormark, 2002).

3.6 Types Of Modular Structures

Recently, modular construction has grown tremendously beyond what were once mere portable structures. Modular construction as completed projects provides consumers better, faster, and more sustainable solutions. This inexpensive approach easily takes over from the conventional construction market. The best modular design for individual needs differs, but inexpensive designs provide buildings that are both permanent and relocatable.

Permanent modular construction (PMC): Innovative, efficient and sustainable construction method, that take advantage of offsite, smart manufacturing technologies for the OSC of single- or multi-story whole-structure solutions in parts of deliverable modules. PMC buildings are generated in a secure, regulated environment and can be made of wood, concrete, or steel (Zdon, 2010). PMC modules can be incorporated into site-built or stand-alone projects as a turn-key solution, and can be implemented in less time with MEPs, fixtures and interior finishes, while generating less waste and better quality control compared to projects using conventional site-building only. For instance, the Hawaii Film Studio used PMC for strict timelines and budgets. Additional examples are healthcare centers, hotels, colleges and restaurants.(Figure 25). In the Great Britain, PMC is usually referred to as volumetric (Smith & Quale, 2017).

Figure 25: David H Koch Childcare Center, Cambridge, MA (URL25)

Relocatable buildings (RBs): Is A partially or fully assembled structure that complies with state regulations and relevant standards, and is built using a modular design process at a structure manufacturing facility. Reloadable modular buildings are designed in a fashion making them able to be reused or repurposed several times, and transported to different sites. They are semi-permanent and have a fairly short 20–30 year life cycle. They can be used, among others, for medical clinics, hospitals, retail centers and construction site offices (Figure 26). Most are leased to users (i.e. trailers on the building site and the school's classroom pods) (Economic et al., 2012) (Smith & Quale, 2017).

Figure 26: Energy Positive Relocatable Classroom, USA (URL26)

Even though the aforementioned modular construction types are abundant with beneficial features, they are quite different. The following (Table 3) however lists and illustrates those differences by distinguishing between the two types of modular construction on the basis of multiple criteria:

Table 3: Main Differences between the Two Types of Modular Construction

Category	PMC	RBs
Duration Of Use	• Its fabrication and installation is intended for long term usage. • Designed to be durable and resilient similar conventional buildings • Compared to traditionally constructed buildings, it can last just as long or even longer period of time.	• They are installed for the purpose of functioning for shorter durations, usually for few months or sometimes a year • They are also designed to be sufficiently durable to withstand several relocations and installations.
Types of Materials Used	• Normally, wood, steel, and/or concrete are used to construct them	To make them lightweight and easier to transport and reinstall, they are typically made up of wood.
Building Purpose	• Designed for the purpose of remaining in a single location for prolonged periods of time.	• For situations that demand rapid construction and future potential relocation and repurposing, these type of structures are ideal.

		• They are often built to provide temporary accommodation, such as construction site offices or mobile showrooms, as well as for other commercial purposes.
Architecture	• It can offer nearly endless interior options. From the addition of lobbies to elevators and stairwells, • They offer construction engineers countless design possibilities	• Offer less flexibility of style and layout. • They also offer less customization options.
Construction Duration	• The process of construction and on-site assemble usually take periods of months or more, depending on the size of the building and the complexity of design.	• Building duration depends on the work period, • Have the potential to be accessible on site and ready for use within weeks.

3.7 The Applicability of Modular Construction

With respect to such modular constructions, the factory is the most preferred place to manufacture the used building elements rather than being manufactured on site. Modular construction has many advantages that directly impact various facets of business sectors, serving as part of enhancing construction speed and creating better manufacturing economic conditions. It also has advantages in minimizing those difficulties arising from the projects in their construction phase or those demands arising from the planning process. The modular construction can be used in those buildings that act as: student-built dormitories, medium-level residential buildings, or commercial buildings. The publicly and privately managed housing estates. Multi-level hotels consisting of 4 to 12 floors, buildings used as health centers or hospitals on one side and buildings used for educational functions like schools on the other. Such buildings used for the purpose of housing either by the armed forces or by prisons or other places which requires a high level of security. And in the case of modifications to buildings already constructed, such as adding balconies and elevators, or extensions to the rooftop of the building. Or install bathroom pods for offices and hotels. Additionally, to build gardening and planting rooms or spaces or other facilities. (Ogden, Lawson, Goodier, 2014) In this regard, it can be seen that those industries that benefit completely from the modular construction methodology often benefit from OSM simultaneously in terms of their economic situation. Moreover, social pressures are also rising to increase population abundance in urban areas in order to meet the for single-or two person and main worker accommodation. Much recently, particularly in central cities where the OSM is more adoptable due to the strategies of the site and the constraints in construction method, the application of the modular construction technique was used in housing development projects at medium- to high levels. It also has to be said that the modular housing units can be provided with a concrete or a steel structural framework in those buildings which are intended for mixed used. In other words, those street areas that lie under the residential buildings will act as parking spaces, offices or retail outlets. (Gibb, 2006). For different industries around the world, modular construction is becoming the go to option. Some prefab-modular structures are available across the globe, if you look at the Los Angeles based Star Apartments building (Figure 27). Because of many advantages of this method of construction, it became the preferable option for various buildings and premises, form much smaller size facilities to massively built structures. Prefabricated structures are flexible, robust, multifaceted, quick and eco -friendly.

Figure 27: Star Apartments, Los Angeles (URL27)

However, modular construction is seen widely used in the following industries or sectors:

Commercial Spaces and Industries: Development with modular techniques is ideal for constructing industrial and commercial intended structures since the whole operation has no effect on the business functions. When you have an already existing building and you want to enlarge it or want to construct a warehouse or a stocking space for some reason, it possible to be achieved by avoiding abolishing the existing building. It does not even require a land nor a building for the project accomplishment because all the parts or modules are produced by factory. You just have to vacate the room when the modules have to be mounted together. Furthermore, the solution is always modular building, if a mobile office is demanded truck. Modular structures will also give the workers the space they need for a particular project, as an example a development site or a fossil fuel plant. Modular structures can be customized to suit the particular requirements of space and budget. Modular construction technology is ideal for constructing office buildings (figure 28), industrial structures, manufacturing, depots, stocking areas and similar facilities such as car wash or garage (VAMC,2019).

Figure 28: Modern office building in Klaipėda, Lithuania (URL28)

Medical Facilities: Modular construction is ideal for the construction of medical facilities for instance, medical clinics, health care facilities, hospitals (figure 29), chemical stores, labs, etc. While constructing a healthcare facility, safety is an essential concern. Hazards and accidents maybe costly, since they result in time delays and damage equipment's, repair costs, administrative costs, compensation or even fines are involved. They can be costly. It is simple to diminish the risks of hazards and incidents by opting for modular construction. Moreover, the property is barely impacted if components of health care facilities are prefabricated in manufacturing environments outside of the actual building site. When a clinic or hospital needs frequent upgrade of medical facilities to new equipment's and tools such as, wings, wards, floors as well as advancements in medical technology, modular construction turns to be the best solution. Elements of new extension, such as a floor or a wing may also be assembled in factories and added without any significant disruption to medical operations and functions (VAMC,2019).

Figure 29: Modern office building in Klaipėda, Lithuania (URL29)

Educational Institutions: It is hectic and time-consuming to create compound educational facilities on large campuses. But the project can be done easily and safely with modular construction. In fact, designing schools is a difficult and sensitive task, as healthy and environmentally friendly materials must be chosen that do not affect children by any means. Modular construction uses typically environmentally friendly materials for slabbing, toileting, paints, fixations and other components, such as lumber and structural steel. In short, modular construction reflects perfect approach for the constructing of colleges, universities, libraries, research laboratories, ect… (Figure 30), (VAMC,2019).

Figure 30: Harvard University Pagliuca Life Lab, Allston, MA (URL30)

Hospitality Attractions: Modular construction and development of the hospitality facilities are perfect match. For example, the "Canyon Lodge, Yellowstone National Park" and "Hawthorne Dual-Brand Marriott", in California. Modular construction provides unparalleled versatility, reliable quality and rapid installation and assembly – just what is needed to create a hospitality attraction (Figure 31). When dealing with hotels and resorts construction, modular construction two alternative solutions, either full modular solution (pre-fabrication and construction of the whole structure), or fractional modular solution (several portions of the hotel are manufactured in manufactories and installed into the conventionally erected structure), and system equipment's (where electrical and piping systems are factory-fabricated and then supplied in kits). Modularly constructed hotels and resorts are designed with accuracy, resulting in fine-quality performance. There will be no risk of rainfalls or melting snow penetrating through the roofs and walls of hotel rooms and giving an uncomfortable and unpleasant stay to the guests. To put it another way, modular hotels are suitable to sustain quality services and attract more visitors (VAMC,2019).

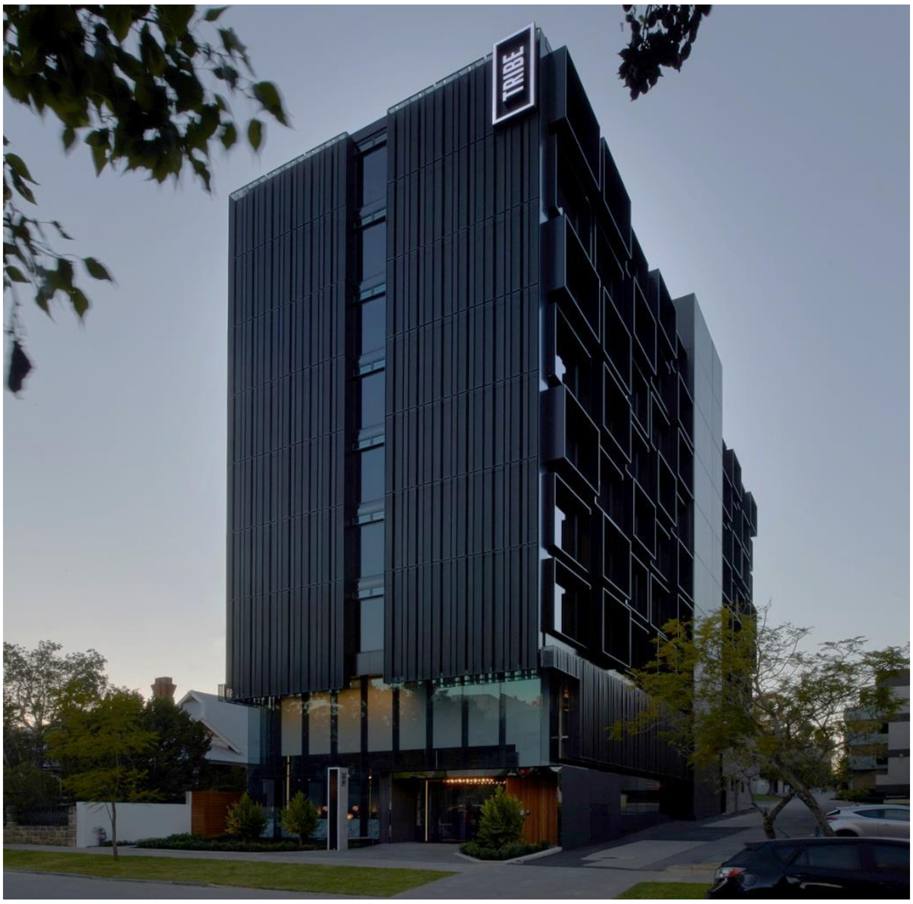


Figure 31: The Tribe Perth Kings Park hotel (URL31)

Residential Properties: Considered as one of the hugely popular prefab-modular development applications. Observing the 32-story (figure 32) lavishness Brooklyn apartment structure that has become the highest modular residential structure in the world. The tower, which consists of 363 single prefab apartment units, reveals that prefab-modular architecture can also be suitable for accommodation solutions. Mobile and modular houses are becoming inexpensive as this strategy is an economical option for housing. The whole operation of producing and assembling components of a home in regulated settings away from natural calamities and external influences on the spot is cheaper than the conventional construction approach. Furthermore, the utilization of eco-friendly and recycled materials makes modular construction and inexpensive and affordable approach. Additionally, it is easy to achieve customizable rooms and partitions in those housing units with such construction approach.

Figure 32: Atlantic Yards: B2 Bklyn, NY (URL32)

3.8 Materials Used In Modular Construction

Similar to the conventional on-site construction approach, a considerable range of materials are used to establish modular structures. However, the most commonly used materials for residential and commercial purposes includes the most basic construction materials which are steel, concrete and timber (J. Mooring, 2013).

3.8.1 Timber

Timber modular construction in the shape of the binding construction is quite similar, except in the factory. However, in a modular building there are a number of innovations which distinguish it from a stick building. For example the roof – as steep as it may be – is always a knockdown structure in a modular house with its sloped roof. It indicates a technique hinging the ceiling in a way that when the module has been mounted on the spot it can travel flat for transport and then re-charge. Furthermore, many wood modules are lifted by cranes without requiring a lifting framework. This process of lifting is achieved by lifting the whole building with long braces from the bottom of the platform and the crane is held in place by using a load spanner. This approach reserves the module intact was and still utilized for many decades effectively (J. Mooring,2013). Timber modules (figure 33) are restricted in height. Modular-timber structures are not allowed to exceed more a total of three floors in height without the addition of substantial structural components, making them economically inefficient. Therefore, steel is more frequently adapted when a need for robust and durable structure is inivatable (Smith, 2010).

Figure 33: Illustration of a concrete module (URL33)

3.8.2 Concrete

In numerous social housing projects concrete frames were used in the 1960s (Urban, 2012). In San Antonio, The Hilton building on the Riverwalk street was the highest modular building in the United States and was built by the Zachary Construction company in 1968 from the precast concrete modules (Hilton, 1968). Yet the most practical construction projects in the United States nowadays are exclusive to jails and manufacturing implementations (Smith, 2010). Nevertheless, several countries based in Asia routinely develop multi-family residential complexes with modular concrete construction. Such as the multiple-room module-based system, the Daewoo. Which is basically a precast concrete method, widely used in East Asian countries for instance, Korea, uses temporary factories erected on site in which a full floor is casted at once. The precast modules are installed one floor on a daily basis (figure 34). Additionally. Those concrete based modules are then fitted with prefabricated wall panel components with fundamental mechanical, electrical systems and plumbing equipment (MEPs). Daewoo indicates that such specific approach can be up to 3 times more rapid than traditional building method (Gibb, 1999).

Figure 34: Illustration of a concrete module (URL34)

3.8.3 Steel

For areas with abnormal seismic issues, modular steel structures are common. This is why steel modular components are commonly used on the bay area of the USA and in many countries in Asia (Smith, 2010). In order to exceed the height of three floors; developers tend to use steel plates. The B2 (Building 2), which is a part of Brooklyn-based Yards Atlantic project, uses steel modules for more than 30 floors (Atlantic Yards, 2013), as seen in (figure 35). Many commercial projects do actually use steel modules to benefit from their strength, but do not pay enough attention to the project's total height. Moreover, units of bathroom pods are regularly built by using steel members, because in commercial occupancy classes, non-flammable materials are highly required (Ching & Winkel, 2007). The decisive factors for selecting a certain material over another, as in conventional construction, depends upon the conditions of the project and the parameters affecting it; if such conditions involves steel, then it is chosen (Jacobson, Silverstein & Winslow 2002). Finally, both wood and steel have these principles which direct modular design: they could be exploited effectively and efficiently by implementing a modular- based strategy from the commencement of a construction project (Gibb, 1999).

Figure 35: Illustration of a steel module (URL35)

3.8.4 Steel Modules Classifications

Modular construction structures utilizing steel elements are basically constructed from floor, wall and roof panels sheets made up of cold-formed galvanized C sections made out of steel, often augmented by corner supports in the form of "hot-rolled steel" corners or square voided parts. The panels then creates a 3D modules which are internally wainscoted and typically externally covered, and are then prepared and transferred to the construction location. "Open-sided" modules can be generated utilizing edge beams and corner supports. The possibilities for architecture utilizing modules made out of steel were first described in (Lawson et al., 1999). It also provides guidelines on the construction of modular buildings in (Gorgolewski et al.,2001). In addition, Steel Construction Institute reviews different types of steel modules (Lawson, 2007) (Ogden, Lawson, Goodier, 2014) listed as follows:

1-FOUR-SIDED MODULES

This type of modules are also known as continuously supported modules, which are sustained from their linear sides, that rests on the walls of the below units. Wide openings at one end while the service riser and a door located at the other end usually highly perforate the end walls. The floor and ceilings usually consist of 400mm C section rafter centers that are either independently positioned or created as piece of a flooring cassette of the same depth with longitudinal edge members. instullation of the 2D panels into a modular 3D structure is depicted in (figure 36)(Ogden, Lawson, Goodier, 2014).

Figure36: Illustration of a four sided module being installed and assembled. (URL40)

Usually , in the form of "hot-rolled steel angles" or "square hollow sections" (SHSs), corner columns are utilized to supply other structural elements such as balconies with local lifting points, support and attachments In some structural systems, the edge beams in the floor and ceiling portion allows for an indirect factors of load transported by loading on one another, but usually, in many situations, the side walls produce an immediate load transportation. The indirect transportation process depends on the ultimate durability of the edge beams to stress forces across their width, and therefore this form of modular construction is restricted to structures of approximately a height of 4 floors. The direct process of load transportation mechanism that relies tremendously on the compression stress resistance of the C-sections through the side walls, which can be stacked in pairs or rolled to heavier steel for higher loads. Depending on the form in which construction takes place, relatively wide openings can be generated in the walls of the modules, as illustrated in (Figure 37) In this case, rely on the structure height, the edge beam in the floor cassette will extend up to around 2.5 m over the partly open sided frame. Corner posts are also used in continuously supported modules to supply it with supporting spots, and attaching points to the other units and structural components.

Figure 37: Illustration of open sided modular unit (URL41)

"Hot-rolled steel angles", or "cold-formed steel angles" in smaller modules, are utilized as a support for the corner in four-sided modules. Constancy is ensured either by inserting X shape bracing in the modular unit frames, or by sheathing boards' midriff action, or by an independent bracing method. (figure 38) Illustrates an application of this modular technique, where an integral corridor is composed of a 12 m long tube. This eliminates the need to create the panel-shaped hallway, and provides weather protection during construction .The modular unit demands 8 leveraging positions in this example, due to the open-sided corridors being fairly resilient. Caledonian Modular and Future form utilized this kind of design in high-rise buildings (Ogden, Lawson, Goodier, 2014).

Figure 38: Illustration of a modular unit that is edge-sustained with a middle corridor. (URL42)

2-CORNER-SUPPORTED MODULES

At the edges of these modules, and often at intermediary locations, corner-supported modular units have pillars, and side beams extend across posts. The modules can be constructed with open sides throughout this way, while infill walls could be used to shape the modular area. In general, the corner pillars have the shape of "hollow structural sections (SHSs)", and the border beams can be "parallel flange channels (PFCs)" or thicker cold-shaped sections. Usually, lengths of border joist or beams range from 6 to 12 m and thus generally are 200 to 350 mm thick. Consequently, the average width of the edge beams in the slab and roof is between 450 and 750 mm, accounting for a 50 mm distance amidst the beams. (Figure 39) depicts a schematic example of that type of module. The major benefit of corner-supported modules is that they can be planed and fabricated as open sided here amidst pillars. Medium posts might be added to decrease the span of the border beams or for the intent of transport. Nonetheless, since the beam-to-pillar links are fairly low concerning their bending strength, extra bracing is required for the integrity of the group of modules, which is mostly situated around the stairway and the lift center(Ogden, Lawson, Goodier, 2014).

Figure 39: Corner supported module . (URL43)

3-OPEN-ENDED MODULES

This type of modules can be generally produced by utilizing welded steel end frame. (figure 40) illustrates a exemplary illustration of a 250 * 150 mm fused end frame utilizing a "rectangular hollow sections (RHSs)". Full height cladding can be supplied in this sense, and modules can even be coupled together across their length. Based on the number of modules in a longitudinal array, this form of rigid end frame may be used for lateral resistance to dynamic loading that operate on the large side of the modules for structures up to 6-storey high(Ogden, Lawson, Goodier, 2014).

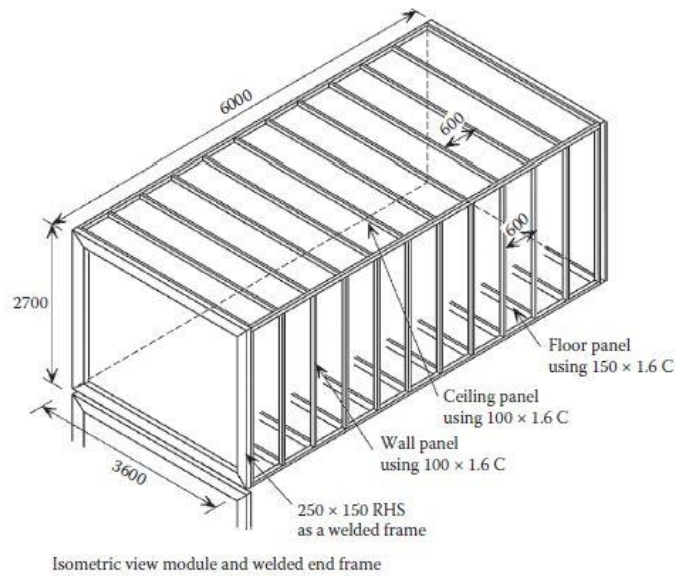


Figure 40: Open ended module illustration (URL44)

3.9 Advantages & Disadvantages of Modular Construction

The major factors of modular structures can be defined in terms of the well-understood decision-making cost, time and quality criteria that can be financially quantified. Current construction schemes have design standards and legislations that demonstrate the economic, financial and social implications of sustainability and that further broaden the range of policy criteria. According to (Kamali and Hewe, 2016) the major advantages and drawbacks of modular construction mentioned in (Table 4) (Table 5).

Table 4: Advantages of modular construction

Specification	Description
Time	• Site preparedness and synchronous construction • Avoiding sudden work interruptions due to bad weather conditions. • Shorter timetable that leads to less damage and theft of the construction site properties. • Reduce site management cost and early return on the investment as a result of less construction time.
Quality	• Well regulated and construction equipment and facilities • Highly crafted and engineered products. • Procedures and processes are repeatable. • Machinery are mostly computerized. • Specialized workers • Use of high quality products for transport survival. • Avoiding material exposure to extreme local weather on site • Superior and optimum quality are obtained due to factory based construction process and pre delivery inspections.
Economy	• Reducing the cost of workers transportation. • Reducing the cost of machinery transportation. • To purchase bulk products and to earn discounts on quantity. • Making more savings due to on site labor reduction. • Reduced pressure and noise on site of construction and its surroundings. • Reduced costs of interest because of rapid growth. • Avoid costly potential disruptions due to severe weather conditions.

	• Distribution of overhead costs particularly in large projects or multiple projects with the same modular design
On-site safety	• Manual labor and unsafe tasks are avoided to great extent. • Reduction or even removal of pressure at the workplace. • More flexible accessibility to nearly construction workers. • Less exposure to extreme weather conditions for the workforce. • Reduced on site work time. • Safer on site processes and plant building.
Productivity	• Less need of skilled labor. • Operations are highly organized. • Improve monitoring. • Less time intervals. • Staff are most stable. • Enhanced industrial efficiency and reduced demand for on site labor. • Professional staff assemble the devices.
Environmental performance	• Reducing generation of waste. • The waste management capacity. • Less on site disturbance like noise and dust. • Make effective use of land capital. • Emission of GHG is reduced. • If the components are used elsewhere there is a capacity to decommission the building to retain the asset value. • Community is susceptible to less damage during renovation which is crucial where the existing buildings will work without interference.

Insulation	• Thermal and acoustic insulation is superb as well as extreme fire safety thanks to the double skin design of the building ensuing that each module is essentially separated from its neighbors.

Table 5: Disadvantages of modular construction

Specification	**Description**
Project planning	• Does not allow for thorough pre-project preparation. • Less technical commitment. • Hard to make any alterations later.
Transportation restraints	• Dimensional limitations of the modules could cause some troubles during transportation. • Remote modules are hard to transport. • Late transit approvals for over dimensional parts could cause time delays. • Import customs waits as exported abroad.
Negative perception	• Poor and sometimes not appealing view of new build approaches.
Site restrictions	• Other inexpensive jobs might be available in the region. • Availability of professional designers and engineers in the area.
Organization and communication	• Improved and more comprehensive collaboration at all project levels.
Primary cost	• Big initial cost is required to operate modular services

For instance, (Figure 41) illustrates the difference between required construction procedures by using modular construction and on-site construction for a 6-storey building. Obviously in contrast to conventional on-site construction, depending on the building's shape and size, the construction period could be reduced to 50% most of the time by modular construction, on the other hand, this reduction of construction time can be decreased by about 30 % when structures are mounted on a podium stage and when extensive work is carried out on site (Ogden, Lawson, Goodier , 2014).

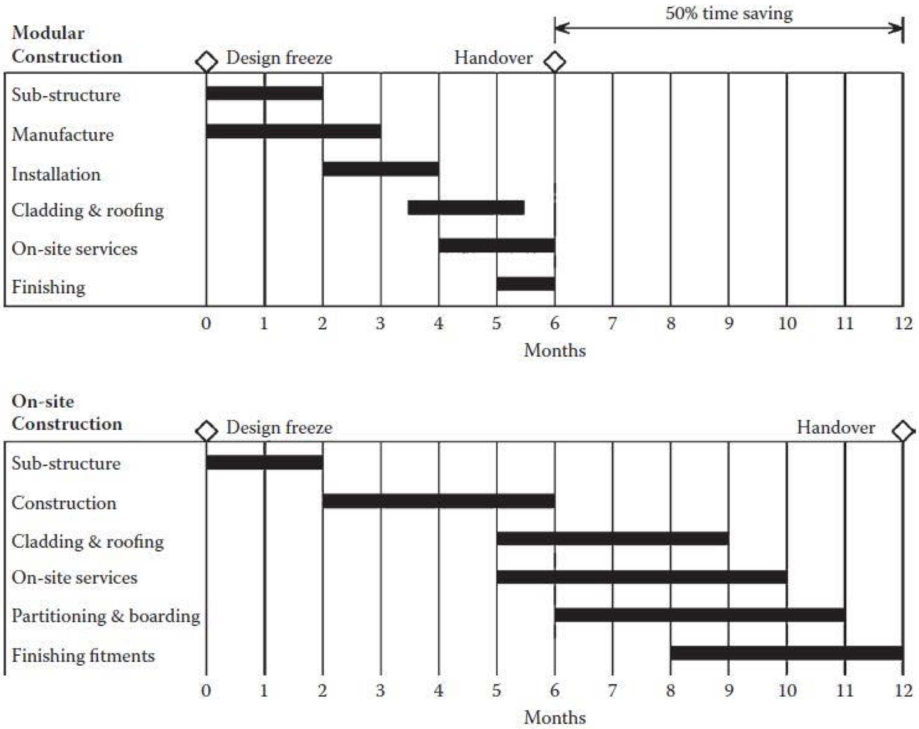


Figure 41: Construction period for 6-storey building , modular vs on-site construction (URL36)

3.10 Modular Building Construction Process

Modular construction is the method of fabricating various parts of a building in a remote building site assembly facility. Once installed on site, the building parts, called modules, fitted with plumbing, HVAC and electrical connections that run throughout. Some of the main benefits of the modular construction process is that many of the processes occur simultaneously which can reduce the construction time by half. Although the preparation to ensure that all links fit correctly entails some difficulty, it is not hard to grasp the overall modular construct strategy (Deluxe Modular, 2020). Which is splited in 3 stages:

1-Pre-Construction Stage

This stage comprises every activity before construction takes place, which includes:

Design: the phase of designing a modular construction building begins at the time of pre construction stage. This is about formulating the original idea and taking all design decisions and arrangements. It involves key decisions like dimensions and design layout to particular finishes, like cabinetry and appliances. It is critical at this point that the stakeholder or contractor has obliged themselves completely to building modularly. If it chooses to do so later in the procedure, costly design modifications would be needed.

Engineering: With utilization of engineering and architectural technological advancements such as BIM, structures are designed customarily in this phase.

Earning permits and assents: The modular process also involves acquiring any required construction permission.

2- Construction and Erection Phase:

The whole modular procedure is built with care to remove inconveniences at each stage. However, this is most noticeable during building phase, as there are literally two simultaneous operations going on. Those modular operations of building are:

Site-Based Construction: This is the most analogous process to conventional construction. Crews arrive at the structure's future site to start construction on the pre constructed foundation and any existing load-bearing structures for the modules which are expected to arrive. This will typically involve completion of conventional building methods before even the construction of the superstructure commence, this stage involves actual potential problems that halt the whole project. Nevertheless, this potential delay will not affect the process of manufacturing the modules. Since modules are already being manufactured while the construction site is being organized and prepared, (Figure 42).

Figure 42: Foundation work for a modular building project (URL37)

Off-Site Construction: Within the process, modular units undergo various development;

- Essential materials are bought when they are not accessible. Structural steel is weighed and laser cut according to exact design requirements, and prepared for assembly.
- The module's structural components are constructed and mounted to form a six-sided unit.
- Framing starts with the construction of floor, ceiling and wall joints.

- Wall and floor pieces, placed anywhere else within the room, are fixed to the posts. Door and window apertures are removed.
- Professionals incorporate all the necessary "MEP" fixations and services from the exterior of the module
- The outside of the module is completed, and every ventilation and piping openings are sealed off pending configuration time
- The interior of the unit is finished. Finishes are added, from significant apparatus to final decorative touches (Figure 43).

Figure 43: Modules being assembled in the factory DeLuxe Building Systems, Berwick, PA (URL38)

3- Building Installation Stage:

The modular units are shipped to the work site and assembled into a building after as soon as they are ready. Final installation is relatively straightforward and quick because most work has been done inside or on site, during the manufacture of the modules. The single units are hoisted and placed in place on the foundation by cranes. They are on-site assembled. With the new structure introduced, teams are linked or permanently "married" to the new structure,(figure 44). The owner is delivered a robust and durable structure in no time, to receives the tenants or visitors with no delays, no stress and no overages and no time as soon as the workers exit the site.

Figure 44: Fairfield Inn & Suites hotel modules being installed in the site, Folsom, California (URL39)

Chapter 4

INTERPRETATION OF MODULAR CONSTRUCTION APPROACH IN HOUSING PROJECTS

This chapter is focusing on the usage of modular construction in housing projects, the chapter is divided into three parts. Firstly, the selected cases will be introduced. The second part will include the study and analysis of the selected cases according to the construction and structural system and design quality. After that, the modular construction will be evaluated according to time, cost and design flexibility. The final part will be discussing the traditional living spaces in the Libyan culture and the Libyan house and the possible link to the modular construction and a design for some modular apartments proposed by author.

4.1 Modular Housing Projects Cases Selected

Nowadays, the applications of modular construction in various aspects have seen a tremendous and rapid growth, especially in housing and accommodation sector, where this versatile construction approach have been utilized in numerous housing projects around the world. Moreover, this construction methodology in general employs different materials such as steel, concrete, timber or a combination of them to manufacture the modules. However, in the following section, the covered case studies will mainly shed the light on housing projects that predominantly utilize steel with concrete to fabricate the modules. As mentioned before in the limitation part, the decision of selecting those case projects that uses steel with concrete for analysis, was mainly governed by the fact that such construction materials (i.e. steel and concrete) are the most widely available materials in the Libyan construction market. Furthermore, USA considered one of the leading nations utilizing modular construction, which made its way to the US in response to the housing needs of the California gold rush in 1840s, and this sector have seen signifecant evlution ever since. among the several available housing project cases that use modular construction, the selected case projects are by far the most unique and eye-catching ones since they had significant impact on the society they were built in, also they were completely successful in terms of construction methodology and approach that were utilized.

4.1.1 461 Dean Street Apartments (B2) by FullStack Modular (Case A)

An amusing and illustrative example of the use of modular structural systems in constructionis the architecture of a high-rise residential building 461 Dean Street apartments building in Brooklyn, New York. Constructed by FullStack Modular, the architectural solution and approach and design concept was generated by Shop Architects. Previously, it was the world's tallest modular building with a height of 109.4 m and 32 floors. This building is part of a great "Pacific Park" complex and constitute 363 apartments including studio apartments, one-bedroom and two-bedroom apartments. The B2 system consists of about 32 thousand square meters. The tower building is divided into three main "blocks" and has a recess "ruler" in order to dodge any monolithic extrusion appearance in the structure and give it a scale. A mixture of setbacks, cantilevers, and exterior variations accentuate the reglets (figure 45). In addition, 50 percent of all accommodation units are rented to low- and middle-income families as part of a system designed to provide affordable housing for these families. Further, a total of 930 modular blocks were used to construct the entire building, and the need for large variety in the shape, façade design and unit types of the building resulted in 225 specific module types, where these modules were produced and manufactured at the "FCModular" plant which was specially designed for this purpose. The world-renowned Arup company carried out the architectural and engineering work. Also the project's output pace was not very high but at the same time it allows maximum consistency, completeness of the equipment and interior finishing work to be done (Farnsworth, 2014).

Figure 45: Illustration of 461 Dean Street Apartments by FullStack Modular(URL45)

4.1.2 Carmel Place by nARCHITECTS (Case B)

Carmel Place is the winning design proposal funded by the NYC Department of Housing Preservation & Development (HPD) in the adAPT NYC competition. Many New Yorkers are left without adequate housing choices with 1.8 million small households and only 1 million appropriate apartments. In general, Carmel Place provides micro-unit living units smaller than the $37m^2$ currently approved for new construction, but with expanded and more streamlined shared amenities strategies. In those micro-units, a living by your self does not really mean living alone (Figure 46). The biggest challenge for the design team was to creat a potentially new and innovative housing model that could be duplicated systemically from one side, and from the other side, within a very tight set of regulatory and economic constraints, would deliver a significant social impact. Fully knowing that residents of small apartments actually live on different scales, the design of the exterior structure of the house, the distribution of facilities and the unit interiors, followed a nested scale philosophy(Place & Murphy, 2019).

Figure 46: Illustration of Carmel Place by nARCHITECTS (URL46)

The Design Team chose modular construction as a form of building, in line with the project's ambitious social and environmental goals and its existence as a prototype for the city's new housing approaches. Modular construction provided significant advantages to the design and development team, manifested in the concurrent erection of onsite foundations and in-factory manufactured elements, as well as a rapid construction (total 4 weeks of construction). Construction of Carmel Place consisted of 65 individual steel framed modules being produced, transported and stacked, of which 10 units are the building core and the remaining 55 are the residential micro units. After the base and ground floor were erected on-site, the remainder of the assembled modules were transported and placed on top. These modules were installed locally at the Capsys factory in the Brooklyn Navy Yard, simultaneously, foundation work was taking place on site. There, they were built ready to mount appliances and interior finishes. Splitting the construction process significantly decreased on-site building noise and damage to the surrounding community. As well as being New York City's first micro-unit apartment building, Carmel Place is one of Manhattan 's tallest modular buildings and one of Manhattan's first multi-unit buildings constructed completely using modular construction approach (Figure 47).

Figure 47: Carmel Place front façade (URL47)

4.1.3 The Stack Modular Housing by Gluck+ and Deluxe Modular (Case C)

The landmark Broadway Stack, located in New York City at 4857 Broadway, is the first prefabricated apartment building, made with a modular steel-and-concrete (Figure 48). The seven-story multifamily modular housing complex manufactured by Berwick, Pennsylvania's Deluxe Modular and designed by New York's architecture firm Gluck+. This is one of the first modular apartment buildings to be constructed in Manhattan and could be the solution to much-needed cost-saving housing in the area. For this project, modular architecture was chosen because it shortened the construction period by as much as half and lowered the building budget by almost 20 per cent. The manufacture of the 56 modules commenced at the Deluxe plant in Pennsylvania, while at the same time the foundation, basement, and first floor in Manhattan were being designed by a construction team on site. Installing the modules after site planning and manufacture took only 19 days, a crew of eight-person, and a crane. The developer of the Stack reports that he cut short 6 to 8 months from construction time and saved 15 to 20 per cent of the estimated $7 million in construction costs. The Stack is being advertised as "moderate income" housing for families. In addition, six of the 28 apartments were reserved for affordable housing for families who met certain conditions in terms of income and household size. Moreover, the Stack was designed to be a pilot project, according to Gluck+ Architect, in order to create a quality and economically feasible housing solution for dynamically upgrading and filling gaps in outdated housing infrastructure (Ated et al., 2015).

Figure 48: Illustration of The Stack Broadway by Gluck+ (URL48)

4.1.4 The ecoMOD Project, a Design / Build / Evaluate Project at the University of Virginia (Case D)

ecoMOD is an ecological, modular and affordable residential building and design / design / assessment project. Since 2004, over the course of three ventures, the ecoMOD project has designed a total of five units for the Piedmont Housing Alliance (PHA) and Habitat for Humanity (HFH). The housing units are designed and constructed in close collaboration with faculty and external experts by interdisciplinary teams of students. Student assessment teams track and review them closely while occupied, with the outcomes influencing subsequent designs. The ecoMOD project is a collaboration between the School of Engineering and Applied Science and the UVA School of Architecture. The purpose of the project is to provide a compelling educational experience, illustrating the environmental and financial value of OSC and thus challenge the U.S. housing industry to examine this value in greater depth.

This ecoMOD project tackles the next generation of designers' two main challenges: the substantial environmental effect of houses, and the expanding economic gap between high-investment individuals and low-income individuals. In the national and international fields the ecoMOD program has been acknowledged as a model for sustainable architectural and technical training, with three US awards for architectural education in 2007. In the framework of the project, students and faculty of vocational education are involved in the architectural, engineering, architectural, landscape, forestry, planning, industry, environmental science, business and secondary and education teams.

EcoMOD's goal is to develop modular homes, affordable high-performance. To train future generation designers in the creation and production of sustainable, affordable accommodation, prefabricated and refurbished homes. By socially involving partners in the subordinate groups with organizations and individuals. The three suggestions made in connection with the ecoMOD project were presented in the following (figure 49) (figure 50) (figure 51).

Figure 49: ecoMOD1 the OUTin house (URL57)

Figure 50: ecoMOD2 the preHAB house (URL57)

Figure 51: ecoMOD2 the preHAB house (URL57)

The following (Table 6) summarizes the 4 case studies and their significant features:

Table 6: Cases details and information, developed by author

Project name	Location	Project area and floors	Number of modules	Structural Material of the modules	Project and assembly duration
461 Dean Street Apartments	Brooklyn, New York, USA	• $32500m^2$ • 32-stories	930 modular blocks	Steel frame	• 24 months • 9 months to assemble
Carmel Place Apartments	Manhattan, New York, USA	• $3250m^2$ • 10-stories tall	65 modular blocks	Steel and concrete	• 22 months • 4 weeks to assemble

The Stack Broadway	Broadway, New York	• $3530m^2$ • 7-stories tall	56 modular blocks	Steel and concrete	• 20 months • 19 days to assemble
The ecoMOD project		ecoMOD1	8 modules	Timber/ Thermasteel	–
		ecoMOD2	/	Thermasteel	
		ecoMOD3	2 modules	Thermasteel	

4.2 Cases Analysis

4.2.1 Construction Process and Structure

The fabrication or manufacturing approach for modular systems generally has two typologies, the first typology being the volumetric approach, where the modules are typically 80-90% completed off-site without any exterior or interior finishes, then transported, assembled and finished in the construction site. On the other hand, the other typology which is the complete module, incorporate less amount of on-site construction time, where about 90-95% of the entire work is achieved off-site within the factory, including plumbing, electrical and even design finishes, which means that the assembling process is the only lift on-site activity.

4.2.1.1 Case A

The building contains a total of 930 steel framed frames. Apartments are arranged around an articulated central hallway, which is loaded in two main directions (East – West and North – South) to generate a bar formed floor plates, with bolt-shaped brace frames supporting the moving lateral load via the adjacent building modules

(Farnsworth 2014). Considering that the supporting frame typically has beams and columns arranged in a grid, another type of frame-supporting modular construction will take advantage of each grid to sustain either one module or a group of modules. Figure 52). The building's foundation is conventionally designed and constructed, with concrete reinforced basement layers and perimeter walls, with steel frame cellar and a ground floor and a traditional stainless steel layer over the ground level, providing a platform on which to commence start stacking modules. 225 unique modules were created by the need for broad variety in building design, façade design and unit characteristics.

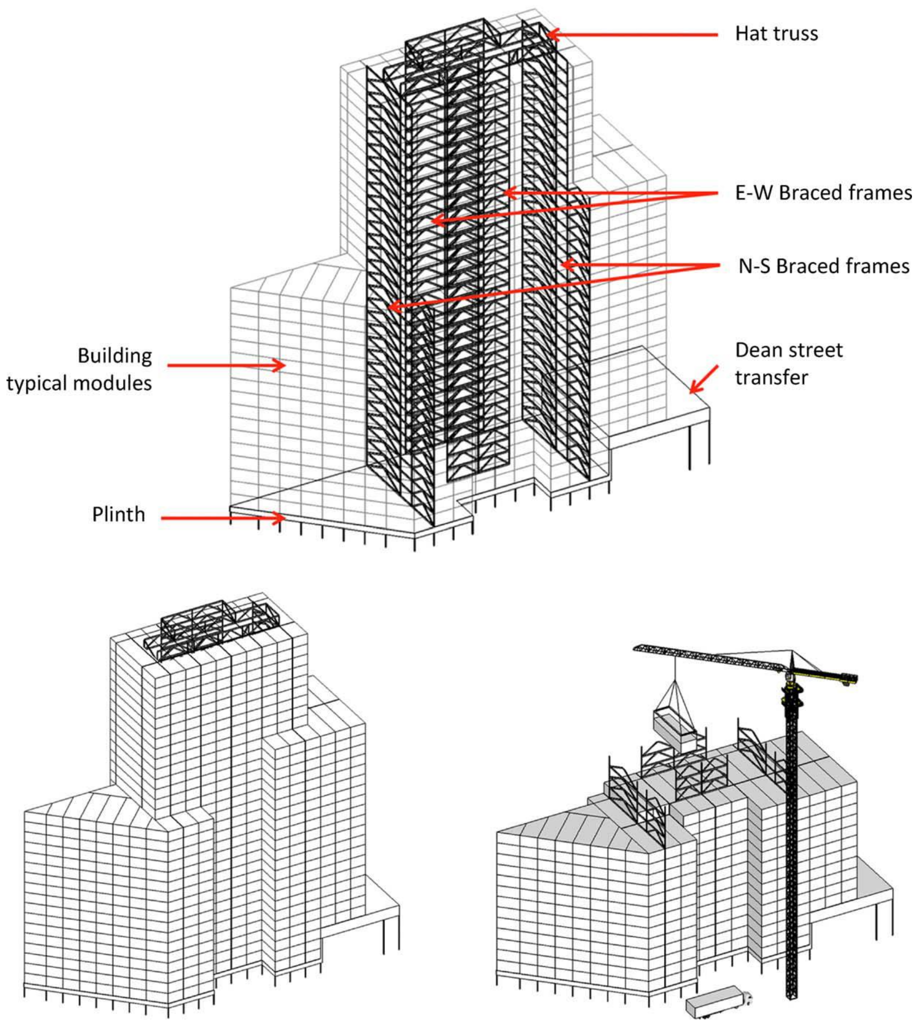


Figure 52: Illustration of structural system for the Atlantic Yards B2 modular residential building with supporting steel-braced frames (URL49)

Moreover, both the elevator core and the stairwells were fabricated as off-site modules. In order to optimize the efficiency of the production cycle, information and design methodologies were standardized. Every module's perimeter walls, floors, and ceilings were designed in a way to facilitate their combination with the walls, floors, and ceilings of adjacent modules when installed to provide both the sufficient fire isolation between units and membrane fire safety for the module frames' steel members. Each of the prefabricated curtain wall panels of the project consists of a compression joints around its perimeter creating a seal with the joints of the adjacent modules. Such façade panels have been installed off-site on the modules, which is not standard practice, since it does not allow as much flexibility in adjustment as a façade system built on site.

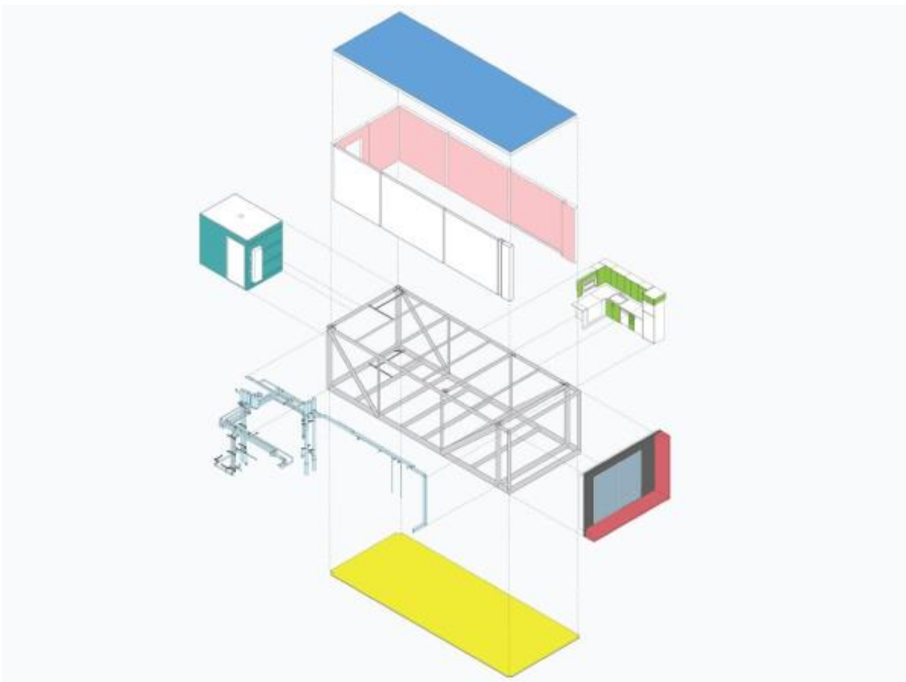


Figure 53: Illustration of assembling the module unit (URL49)

The modular system's basic building block consists of a fully welded steel framework (figure 53). The side of the modules serves as a welded vierendeel truss system extending between columns at corners, which bears the weight of all modules above the columns on the module below. The average floor-cover ceiling sandwich for the modular solution is just 1'5 "[430 mm]; and a clear ceiling heights of 8'6"[2.59 m] which are achieved with floor-to - floor gap of 9'11" [3.02 m]. In the modules there is no concrete, which makes the device relatively light in contrast to traditional platforms. The modular design approach on an average basis weighs around 65 % of traditional flat-slab RC buildings. The substantial reduction in the weight of the superstructure by its turn lead to significant savings in the amounts of the foundations and the transition steel, thus, saving a considerable amount of money. When the finished modules are delivered to the site, they are piled onto the plinth and attached to neighboring modules both vertically and laterally. The roof of the modules serves as the lateral diaphragm and holds a series of braced frames with wind and seismic charges across the floor plate. In each primary direction, two braced frames are placed and tied together at the roof level with a hat truss.

The modules transmit their own gravity loads to the ground, but traditional braced frames are used for transmitting lateral loads safely. The braced frames are governed mainly by rigidity. Before shipping modules to the intended site of construction, stacking and matting, mechanical systems and finishes must be applied (figure 54).

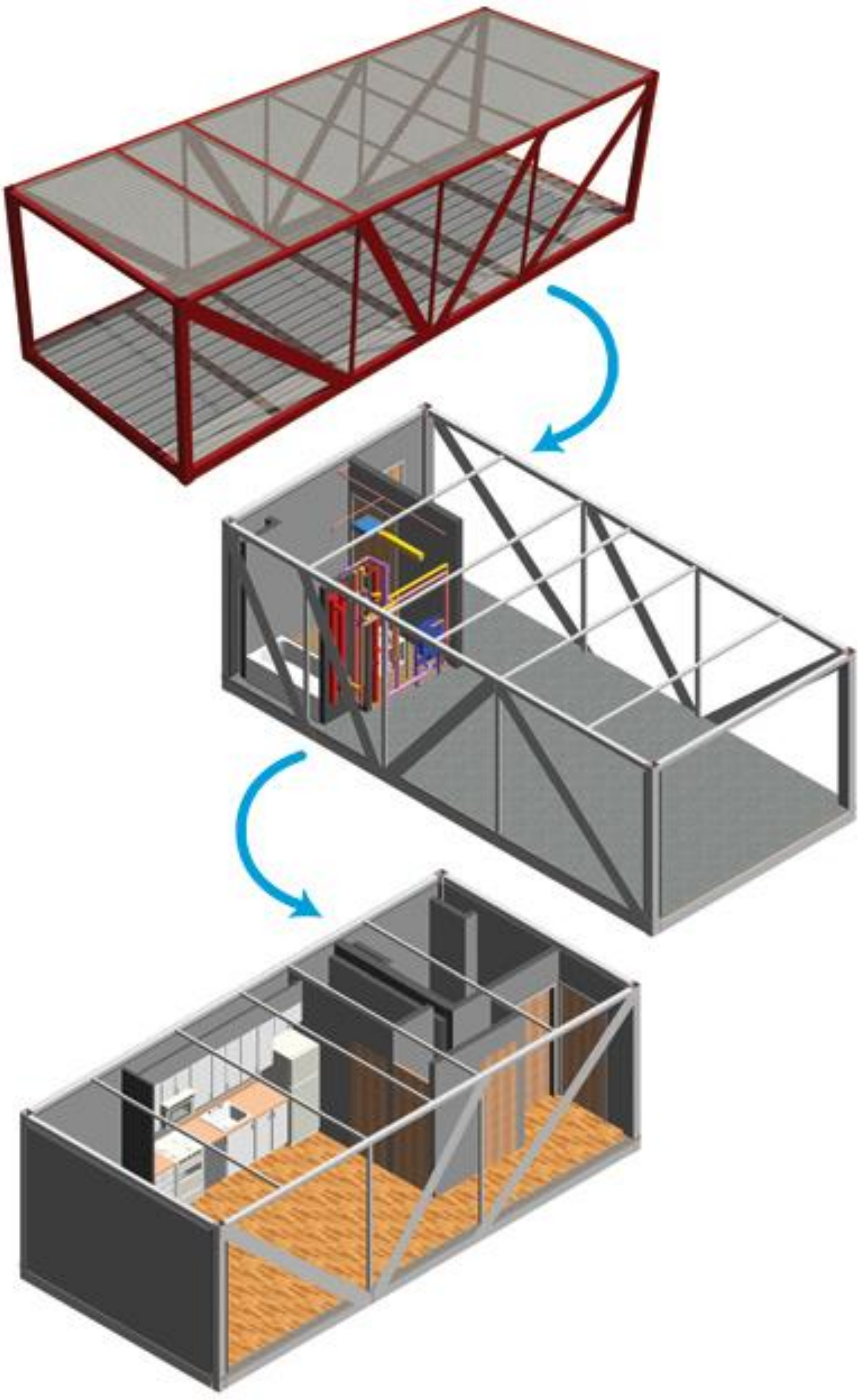


Figure 54: Illustration showing the mechanical system,bathroom and kitchen being added to the unit (URL51)

Throughout the handling process at the fit-out plant, the first contractor had troubles managing the geometry of the parts, and some façade panels had to be re-adjusted on site. The second contractor, who was able to install the upper 20 floors within the prescribed tolerances, however proved the overall viability of the veneer and the casketed framework (Figure55).

Figure 55: Placing the modules on top of each other (URL52)

In the 461 Dean Apartment building, the using of off-site modular construction to manufacture 70-90% of the apartment modules in the factory help to reduce the cost of the project by 20% and reduce the schedule from 30 months to 20 months. Moreover, the controlled factory process helped to reduce the carbon footprint of the building in terms of material waste and transport resource and also reducing the neighborhood inconvenience by reducing the on-site work and transport the modules at night to the site (Generalova, Generalov, & Kuznetsova, 2016).

4.2.1.2 Case B

This project is New York's first micro unit apartment building and consists of 66 modules, 55 of which are retail and affordable studio apartments, the remaining 10 modules constitute the staircase and elevator core of the building . Every apartment is a single unit module, with 24 to 33 m^2 of space. The modules are vertically interconnected in each column, and in the corridor at the floor level. Connections to building services were made inside the hallway. The building's "rawest" room allow system connections works to be completed easily on-site, including plumbing, hydraulic, electrical, and fire protection. Moreover, without the stairs, the stair core was produced and was hoisted into place as the building stacking continued. The standard floor is shaped by eight resident micro units of 5 different sizes and orientation (figure 56)(figure 57). This system makes it possible for the architect to achieve productivity by repeating the changes in the apartment layout and thereby broaden the option spectrum for smaller family households.

Figure 56: Typical floor plan of Carmel Place shows the 5 different size and orientation in the units per floor. (URL53)

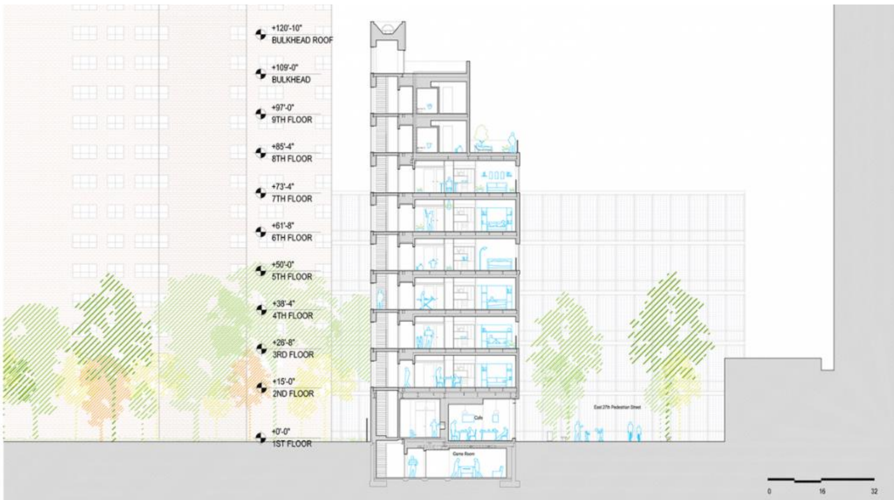


Figure 57: Section of Carmel Place (URL54)

In the Capsys plant, the modular units are constructed of self-supporting steel frames and concrete slabs and prefabricated off-site, whilst the base and ground floor is installed on site. As (figure 58) shows, once the modules left the plant, most materials , equipment, fixtures, and windows were in place, leaving only the finishing floors, appliances, and brick work to be done on site.

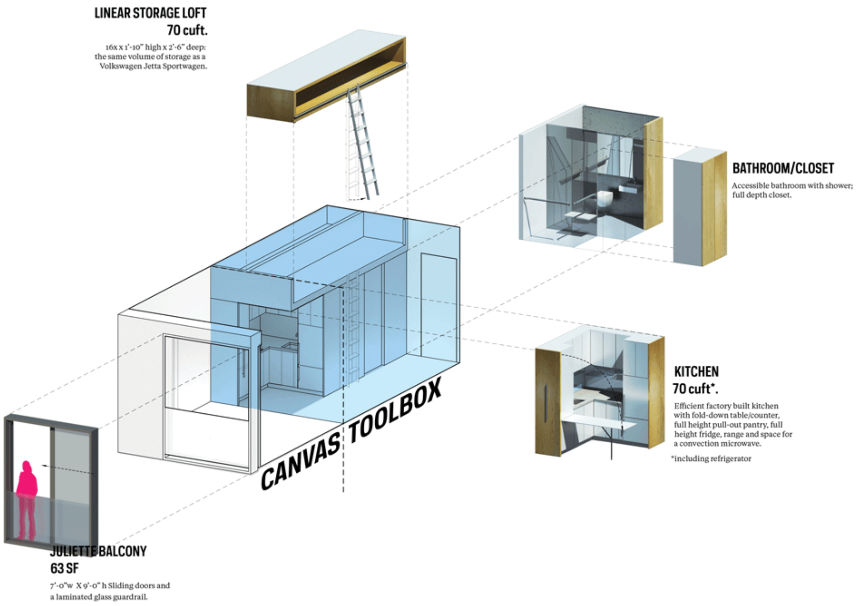


Figure 58: Module components(URL55)

The units stacking took three and a half weeks to be completed (Figure 59). Dividing the construction cycle minimized on-site construction noise and disturbance in the neighborhood, while the factory's monitored and regulated environment allowed the team to track quality and maintain essential interior measurements.

Figure 59: Assembling and installation of the modules on-site (URL56)

In the Carmel Place apartment building, utilizing modular construction approach led to a significant construction time reduction by reducing the overall timeline of the project by half. Also manufacturing the modules in Capsys factory led to a reduction of the construction cost by 5-8% and also a greatly reduced carbon footprint in terms of wasted material , transport resources, and the local suppliers usage. Stacking of the modules lasted three and a half weeks, adding the rewards of significantly decreased community noise and construction time to a dense residential location.

4.2.1.3 Case C

The Stack, is a modular apartment building consist of 38,000 square feet, seven-story, 28-unit, it is one of the first modular buildings in New York City. The subtle and beauty of the design stem from its simplicity. The project's creativity and challenge was to take simple building materials, use them to improve their quality and customize them for use in modular construction. 56 modules had to be designed, delivered, and assembled (Figure 60). The dimensions and weight of the modules were regulated by restrictions on shipping and cranes. Different geometries on each floor, with terraces, balconies, , stained polished concrete floors and cantilevered "boxes" were key architectural features that added to the construction defiances, creating a complex conundrum to be constructed quickly and correctly in field. In addition, the configuration of the modules with an appealing ceiling height was crucial to rental success.

Figure 60: Modules being assembled on the site using a single crane (URL56)

The ground floor is constructed of field-made ground-level steel framed structure, using the imported "tree columns" to sustain both sides of the frames. At the end of those columns, the "tree columns" were placed and attached to girders to create moment frames, with the boxes directly sitting on the steel. Entry through the boxes was necessary to handle large lateral loads that were translated into the base building (Figures 61).

Figure 61: Ground level steel "tree columns" (URL56)

The modules were about 12 foot in width. Also, 4½-inch thick slabs resting on metal decks were used to frame the floors, they span between “band rail” channels 10-inch in depth. The channels extended between rectangular post columns of Hollow Structural Section (HSS) different in size ranging from HSS 3×3 to HSS 6×3. The 3-inch dimension on the tubes was crucial in minimizing the double-wall dimensional effect. The entire structure was fire-protected, with pre-shipping inspection and certification taking place at the plant with stickers attached to the boxes (Figures 62).

Figure 62: Modules during manufacturing process in the factory (URL56)

For modular construction, the transport loads may often be critical loads. The interior finishes will crack if the boxes are not robust enough. The boxes incorporate stability in the floor framing and ceiling framing. Furthermore, with a shipping height limit of over 11 feet, shipping the boxes and hitting a ceiling height as near as possible to 9 feet is a real gauntlet, but the ceiling steel construction for the Stack was limited to 4 inches in depth to maximize the ceiling height. Moreover, The Developer is persistent to using modular methods to construct the building. The challenge was to translate common adjoining features into modular box joints. There were no rising corridors with The Stack, and vertical shafts easily accessed.

Link specifications were built between the modules in such a way that the boxes could be lowered to position on alignment pins and then bolted or welded in position. Throughout construction, the timing was critical to diminish the potential for water infiltration. Also temporary roofs were Included to mitigate this prospect (Figures 63). (Figures 64).

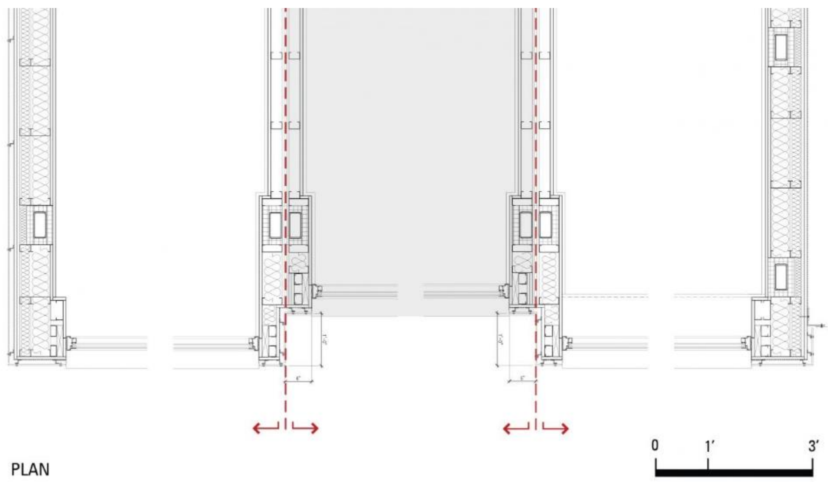


Figure 63: Plan detail shows modules connected to each other (URL56)

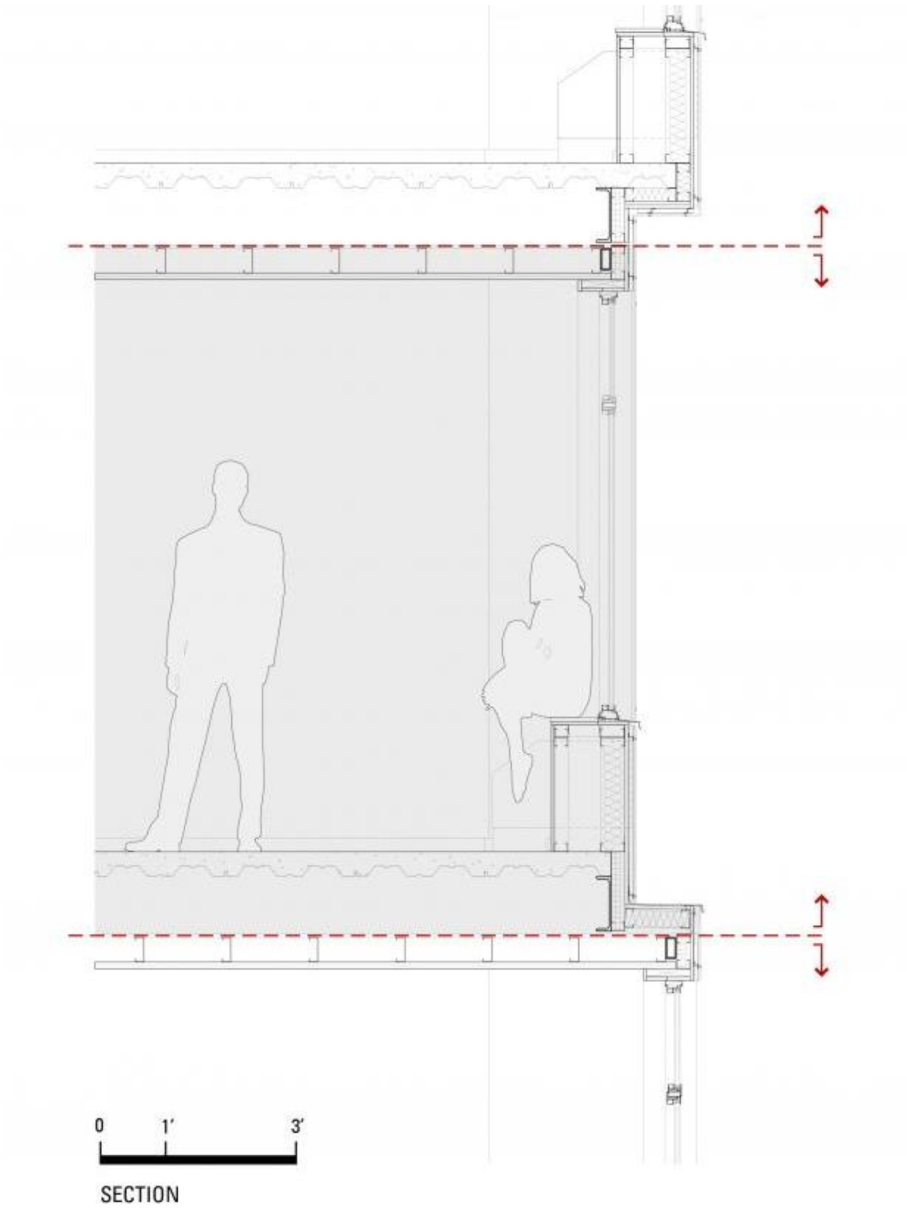


Figure 64: Section detail shows modules structure and connection (URL56)

In The Stack Apartments, the challenge was to construct a building in a highly dense urban environment, so the key is to do that as fast as possible to reduce the negative impact on the surrounding neighborhood. Utilizing modular construction was the ideal solution to achieve this goal. Building modular was more effective in terms of cost and construction time. Producing the units in controlled factory environment led to a reduction of 10% from the total cost. Moreover, the manufacturing and assembling process in the factory speeded up the construction process by 25%. The project only required 14 workers, one crane and 19 days to fully assemble the units on-site and this resulted in reducing the noise in the surrounding neighborhood.

4.2.1.4 Case D

EcoMOD works exclusively with affordable homes to ensure that sustainable housing does not become a privilege reserved for affluent people. EcoMOD1, 2 and 3 are all in culturally mixed, gentrifying neighbourhoods, providing low income residents an opportunity to combat and invest in their communities. The prototypes they build are available for each EcoMOD team. The prototypes are produced at an airfield recess operated by the University of Virginia to imitate the development and sent to their destination as modules or as panels (J. Quale, 2006).

The first prototype, ecoMOD1: In the Fifeville area, Virginia, the first prototype, ecoMOD1, OUTin Building, was completed. The building, a condominium of two units, was designed in summer of 2005 as eight little modules from isolated structural panels. In comparison to traditional modular houses, students have built their modules to match the percentage of urban infill sites and be transported easily along narrow streets. The modules were smaller than half the size of a standard module, which allowed a cheaper cranes to be used and the modules to be relocated to narrow streets with the tightest turning radiuses (figure 65). A drinking rainwater system (the first in town), a solar panel, low-impact ends and healthy forested woodlands are all features. The OUTin House's primary construction approach is to make the whole site accessible and habitable (J. D. Quale, 2008).

Figure 65: One of the eight modules being placed on the foundation (URL 58)

Students have been working together with professionals in each work field and they are interested in building (figure 66). Some have little to no experience in construction. The team worked through all logistics, including collaboration among different building companies, procurement of materials and transportation. The entire house was also constructed, with the exception of the cellar / foundation and the final plumbing infrastructure construction. The following (figure 67) shows the process inside the plant (J. D. Quale, 2008) (J. Quale, 2006).

Figure 66: Construction team preparing the modules (URL58)

Figure 67: Construction and assembly process (URL 57)

ecoMOD2: the preHAB house was built in Gautier Mississippi in 2006, in response to the destruction of Hurricane Katrina. The aim was to show how contemporary architecture and sustainable forestry are compatible with Habitat for mankind's construction methods. The house has a solar panel array of photovoltaics and a heat pump / heat recovery system to supply domestic hot water. The house consists of a highly energy-efficient, creative panel structure of steel and mould (Thermasteel of Radford in Virginia) surviving both hurricane and mould. The goal of preHAB is to take even further by designing a prefabricated home that could be produced in different ways – panels, room modules or smaller components (Figure 68). HFH's affiliates usually use traditional wood framing and "built-in" techniques for a large and often novice workforce(J. Quale, 2006).

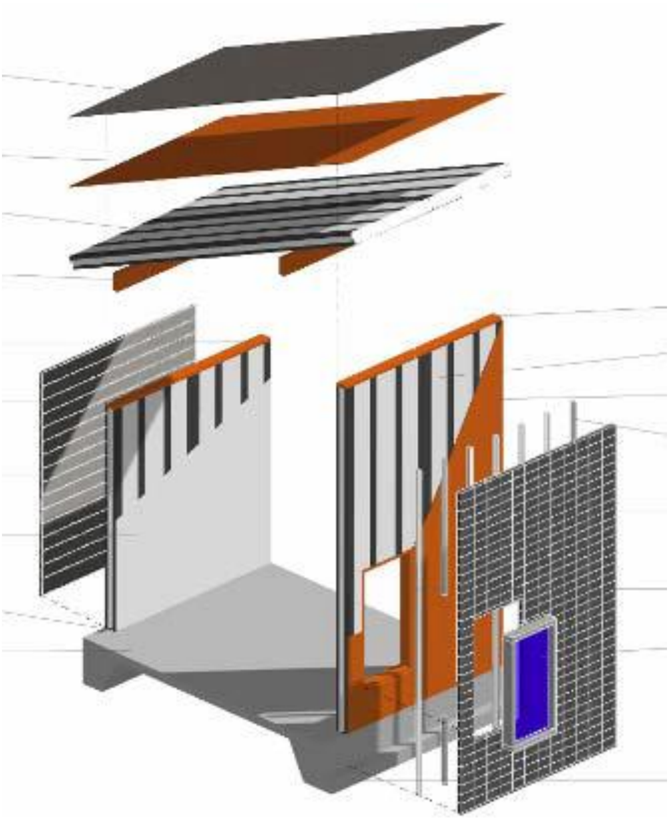


Figure 68: Post katrina replacement housing system (URL 58)

ecoMOD3: The SEAM house tackles the need of accommodation for the elderly and the refurbishment of the historic property of the mid-19th century. The project comprises two housing units: a historical house for modular use and an extension leasing unit consisting of two parts, a Thermasteel project and a modular building project (Figure 69,70). The historic house was possibly designed as a slave district. It was carefully restored and renovated after thorough historical study. The front unit contains a high-energy spum isolation; historic refurbished timbers; hot water solar tube evacuated with water heating on demand; and a modular green roof system with attachment to a modular bedroom. The back unit has a super insulated wall and roofing panels; low impact materials; a modular green roof system; a wide deck with a space for the rainy garden and courtyard. The healthy landscape and green roof relieve the storm water that damaged the historical house over the years (J. D. Quale, 2008;J. Quale, 2006).

Figure 69: OSC phase of the ecoMOD3 (URL 58)

Figure 70: Placing one of the modules of ecoMOD3 on site (URL 58)

4.2.2 Design Quality of Prefab Modular Construction

The fact that off- site modular construction approach is basically achieved within a fully controlled factory environment concerning the manufacturing of modules, gives this approach the upper hand compared to conventional construction when it comes to quality of design. Since the modules are produced within the factory, in a monitored and controlled environment; thus, an overall better design quality is guaranteed. The manufacturing process of modules guarantee a high quality of the materials used, achieved overall finishing, and the living space, such as interior and thermal comfort of future inhabitants. Therefore, the following section will be focusing on analyzing the design quality, in terms of quality of living space and quality of interior and exterior finishing for the previously covered case studies.

4.2.2.1 Case A

The 461 Dean Apartment building has been designed by shop architect and provides 363 apartment buildings, about half of them affordable and leased to low- and middle-income families. The apartment modules are manufactured and assembled in the FCModular factory, which was built for the sole purpose of manufacturing the modules and rapidly achieving a high quality final product, within a monitored and regulated environment. As stated before the building has 225 different types of module to achieve the building's shape and façad. The scale of a modular unit is: up to a width of 4.57 m, a length ranging from 6.10 m to of 15.24 m (on average 9.10 m) and 3 m in height. The production line which makes the modular units completely ready depends on their functionality and includes the fixation of all engineering connections and systems (electricity supply, drainage and water supply, conditioning and ventilation), gear (bathroom gear, kitchen gear, etc.) and finishing elements (lamps, switches, ceramic tiles and flooring, , etc.). The average output level is 4 modules per day, which makes roughly 1 floor per week (Figure 71).

Figure 71: 461Dean module being assembled and prepared in the factory (URL 45)

There are 23 distinct types of apartments, ranging from condos to three bedroom suites. However, until being transported to location of construction, ,stone backsplash, stainless steel appliances and the countertop for each apartment were mounted on the brooklyn navy yard. The usage of large floor-to-ceiling frameless windows which are fixed in the apartments provides the inhabitants an extraordinary outside view, and also gives the impression of a larger living area (Figure 72) and (Figure 73). A variety of fabrics, colors and production methods produce a dynamic light, pattern and texture play across the façades of the building. In a structure typical of the local urban landscape, covered entrances to the towers are combined with full storey glass storefronts at street level. MG McGrath produced and built over 1,100 unitized panels containing glass windows as well as metal paneling together to shape the building's façade.

Figure 72: Interior view of one of the apartments living area (URL 52)

The apartments have white walnut floors with large planks, brushed metal fixtures, superior ventilation, and indoor washing machines and dryers, and the building has a common outdoor space, lounge and a workout room. Apartments are also available.

Figure 73: Interior view showing some of the apartment's features (URL 52)

4.2.2.2 Case B

The architects envisioned Carmel Place as a manifestation of the city skyline, planned as a repeatable and scalable modern paradigm for housing in NYC. The exterior of the building resembles four slender "mini towers" which link the micro-living concept with the building's form and identity. The building has been designed to have an open social environment with egalitarian community spaces such as a community meeting room , a green roof, a relatively spacious terrace and a fitness centre. Furthermore, the aim was to make it more than just an inexpensive single unit housing apartment. The colors used for the exterior of the building contribute to the local background of the project (Figure 74). Additionally, traditional home spaces are scattered throughout the building , thereby allowing residents to communicate with their neighbors during their daily routine.

Figure 74: The colors used for the exterior look of the building (URL 47)

Amongst the 55 micro-units rented in Carmel Place-22, they are classified as affordable housing units, 8 of which are reserved for formerly needy US soldiers. The design goals for the unit interiors were to maintain a sense of spaciousness, comfort and productivity, even though their footprint was dwindling. To accomplish this goal, the architect-developer team enlarged the size of everything but the floor area: 3m high ceilings resulted in a volume that is similar to or exceeds that of a controlled 37m2 apartment, combined with the ample daylight made accessible by 2.4m high sliding windows and Juliet balconies, increasing the expected volume of space. Additional storage space above the toilets is situated at the added height. NARCHITECTS also collaborated with Resource Furniture to provide modular built-in furnishings that incorporate storage, sofa and bed into the layout of nearly half of the units (including veteran housing) (Figure 75).

Figure 75 : Interior view showing the built-in-furnishing (URL 46)

Stage 3 Properties offered additional furnishings through Ollie, an all-inclusive living plan that offers furniture and services to the tenants. The five basic types of micro-units in the building differ in size and configuration, thereby expanding the range of options for tiny family dwellings. The finishes, including polished white cabinets, back-painted glass back splashes, crafted stone countertops, and natural wood flooring, add to the modern , clean feel, as do the smart, slightly Danish Modern furnishings that come with several of the apartments.

4.2.2.3 Case C

THE STACK is a modular building that has been put together in Pennsylvania with 28 flats and then installed over 19 days in seven floors. The building provides imaginative design, and comfortable interiors make living simple and pleasant. Large windows funnel natural sunlight into each room, while many residences offer exterior and private cottages. Stainless steel Energy Star appliances provide all modern living conveniences, and some models have washers and dryers. The Stack includes a central washing facility complete with washers and dryers, and a beautiful landscaped courtyard with numerous seating areas for the everyday enjoyment of the residents. In addition, public workshop and car storage are available (Figure 76,77).

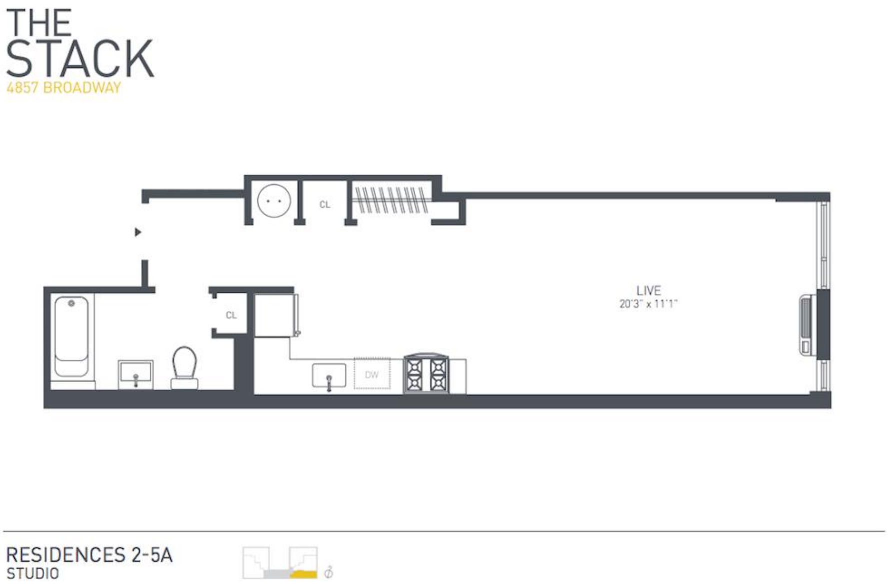


Figure 76: Studio apartment plan (URL48)

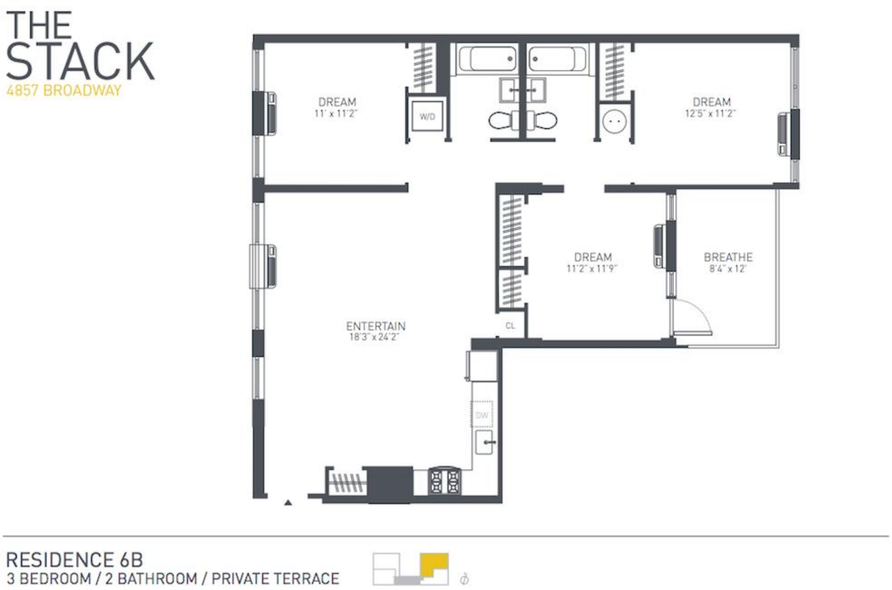


Figure 77: 3+1 apartment plan with a private terrace (URL48)

The interiors of The Stack radiate a feeling of lavish luxury. Residences feature colored tile walls for a raw elegance, offset by a luxurious palette of trendy high-end finishes. The generously proportioned rooms have highly stylised kitchens fitted with bamboo cabinetry and stainless steel equipment, as well as mosaic-tiled restrooms that feature built-in vanities with embedded storage and Water Sense fittings. All residences provide yearly heating and cooling individual climate control, while private enclosed patio is included in the selected units (Figure 78).

Figure 78: Interior view of the living area (URL48)

4.2.2.4 Case D

The ecoMOD1 OUTin house is positioned to combine outside and inside instead of a rectangular box with no usable outdoor area. Passive design techniques, moved modules describing outdoor and indoor areas, introduce sunshine, brisks, trees, the earth and the surrounding background into the building (Figure 79,80). OUTin 's architecture methods are based on an ecological task conceptual and formally, which makes ecology readable to the citizens. The system consisted of a potable rain harvesting system that offers approximately 35 percent of a family of four wanted water in a year, a solar thermal heater that lowers the cost of water heating about $300 to $350 a year for people living there, Daylighting that is produced by at least two windows for every room that reduces energy costs about 20-30 percent per year, a Daylighting that is provided by at least two windows in each room that reduces energy costs about 20-30 percent each year. In the roofs and walls, the structural insulated panels are used, thermal bridges reduce and air penetration decreases, the interior materials are low /no VOC: Due to the damage to occupancy health by VOC, this material did not be used by designers in the project and a sustainable wood floor created by poplars, a budget-accessible option. The residing population has decreased their maintenance costs by building the OUTin Home, with a total cost of $135 per square foot for both units (Alliance & Science, 2007).

Figure 79: Sections showing the spaces of the house (URL57)

Figure 80: Daylight and used materials around the house (URL57)

The team has built a house for the ecoMOD2 (preHAB) adaptable to the Southern Mississippi climate. Included, outdoor space is an integral design element which increases the house's overall size while assisting to cool it passively. These spaces have features that both shade the sun and adapt to the safety of hurricanes. The construction costs of recycled materials, including buildings damaged by Hurricane Katrina, were further reduced to a minimum. The team has a more expensive heat pump / heat recovery system with good site design, which emphasizes solar orientation and cross ventilation. This house is also equipped, as stated earlier, with a solar (photovoltaic) system installed with university funding. EcoMOD predicts that this device would generate sufficient electricity to satisfy the domestic consumption needs (except the air conditioning unit that only minimally requires a house)(Figure 81) (Alliance & Science, 2007).

Figure 81: ecoMOD2 team working on façade installation (URL57)

ecoMOD3 the SEAM: this project mixes historical and modular buildings renovation. The homes have universal architecture, on-demand (tankless) hot water solar system, green town roofs, high-energy-efficient steel and foam walls and recycled materials. This project is in line with the Homes Standards EarthCraft as well as LEED, the LEED platinum certification accessory device. The team reports 55 to 50% more efficiency in the historic home — and 60% more efficiency in the accessory unit — than comparable homes. The figure below shows the standard of the historical house and accessories (Figure 82)(Alliance & Science, 2007).

Figure 82: ecoMOD2 team working on façade installation (URL57)

4.3 Evaluation of the Cases

After the identification of the cases and analysing them, this part will be focusing on the evaluation of the cases in terms of time saving, cost efficiency and design flexibility of each building. After the evaluation part is covered a better comprehension on the suitability of using off-site modular construction in housing sector as a construction method.

The utilization of modular constrcution have proved it's cabability of diminitishing the overall construction cost, and that what was opserved in the previous analysis and literuture part. The cost efficiency of modular construction compared to conventional construction stem from achieving the first in a monitored and regulated factory environment, that is not vulnerable to weather conditions, it also eliminates the need for formwork, that is highly costly , and this by its turn results in a better construction quality ahieved in a considerably less time, Also, modular construction have better future value, since it generates more profit on the long run. This was clearly observed in the previous cases where in (Case A) the cost reduction was estimated as 20% and for (Case B) the cost reduction was 5-8% and for the last case which is (Case C) the cost reduction was 10%.

On the bases of time saving, the usage of modular construction contributes in reducing the construction time significantly since the majority of the construction process carried out within the factory hence, delays due to weather conditions, potential on-site accidents are avoided. Using modular construction method can accelerate the construction process by 30-50%, and that was observed from (Case B) where the construction time was cut down by 50% and for (Case C) where the construction time was reduced by 25%. But in the condition of (Case A) the construction process experienced some delays due to some legal disputes between the developer and the contractor.

In terms of the design flexibility, modular construction is advantageous. Designing living spaces with modular construction is flexible since by using the same module variety of housing typologies can obtained such as studio apartments, 1,2 or 3 bedrooms apartment depending on the number of used modules. Also modular construction offers design flexibility by allowing for the possibility of adding or subtracting modules later on. Finally, designing with modular construction allows for bespoke options, in other words modules can be supplied from the manufacturer as customized or tailored by the designer which was clear in (Case A) where 225 different module types where produced to form the building and it's façade.

The following (Table 7) explain the evaluation criteria:

Table 7: Cases Evaluation

Building	Location	Cost efficiency	Time efficiency	Design flexibility
461 DEAN Apt (Case A)	Brooklyn, New York, USA	✓	✕	✓
Carmel Place (Case B)	Manhattan, New York, USA	✓	✓	✓
THE STACK (Case C)	Broadway, New York	✓	✓	✓
The ecoMOD project	Virginia, USA	✓	✕	✓

4.4 The Link To Traditional Living Space Of The Libyan Culture

This part will mainly focus on the traditional living spaces in the Libyan house based on the Libyan cultural aspect, and how the design flexibility of modular construction can be exploited to create a permanent suitable solution to the problem of accommodating the IDPs families, and how it could be an adaptable solution to the traditional Libyan family's life style.

In general, types of Libyan housing styles varies depending on the number of inhabitants, their living needs and their financial capabilities, commonly, these type of houses manifests in medium to large size villas or residential apartments. However, those different type of housing spaces share a certain feature identifies the traditional Libyan house, which is high level of privacy. This is achieved by the partial or full separation or segregation of the interior living spaces. This is in fact significantly influenced by the cultural and religious background of Libyans. Libya is known to have a conservative society, which is reflected on the separation of the private living spaces including bedrooms, private bathrooms and kitchens from the living spaces intended for guests such as saloons and quests' toilets within the Libyan household. Also, the concept of open kitchens to living spaces in the traditional Libyan home is not very common, where kitchens are usually designed in a separated space from the living area to avoid any insolvencies that stem from cooking. However, in some villas in Libya, the open kitchen-living room design concept is used, but this kitchen is usually intended for light cooking duty where another separated kitchen is designed to handle heavier duties. Moreover, studio apartments style is not used in the traditional Libyan house, because this type of housing style does not offer sufficient privacy.

The design of living spaces within the traditional Libyan house also involves allocating some space intended for hosting guests. This space however depends on the size of the house. In villas or big apartments, two separated guest rooms equipped with their own toilets are designed for hosting men and women, while in smaller apartments, one quest room is allocated for hosting men and woman but not at the same time, or the living room might be designed to be spacious enough so it can be also used for hosting woman guests, since the Libyan culture allows woman to have more access to some private spaces of the households such as living rooms (Figure 83).

The main focus of this part will be on attempting to integrate the same modular space that were used in the previously analyzed cases with the traditional Libyan living space in order to create an optimum and inexpensive accommodation solution that provides IDP's in Libya the necessary living spaces that fulfill their desires while maintaining the Libyan identity in the design. However, the following (Table 8), (Table 9) and (Table 10) provides a summary of various potential accommodation solutions in the form of different types of apartments depending on their areas and the area and number of modules according to the analyzed case study projects, and after that the proposed design for each unit is shown in (Figure 84,85&86) :

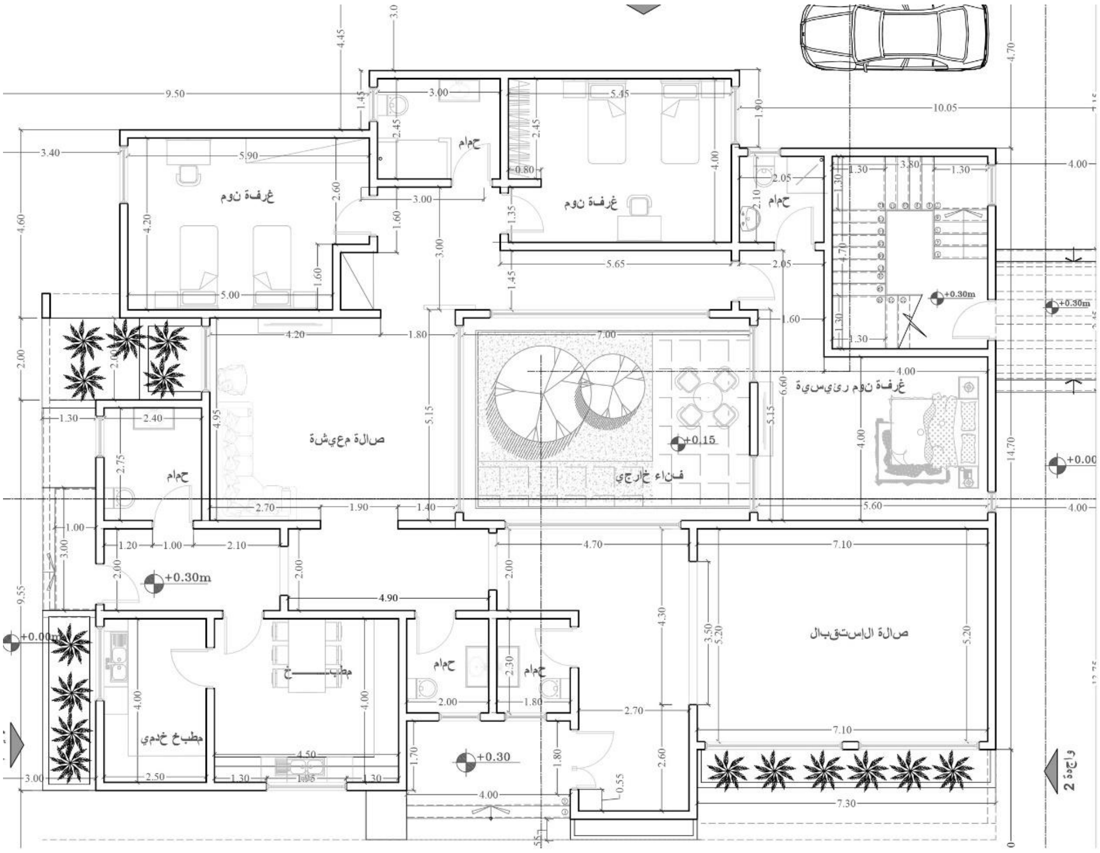


Figure 83: Main living spaces in the Libyan house

Table 8: 2 Bedroom Apartment

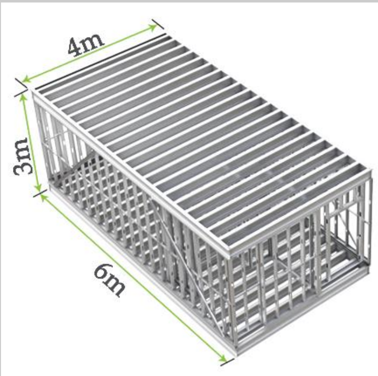
Type	**Needed Space**	**Number Of Spaces**	**M²**	**Total Area**	**Number Of Modules**	**Module Dimensions (Steel And Concrete)**
2 Bedroom apartment	Living room	1	$24m^2$	$120m^2$	5 modules	5 modules will be needed for 2 bedroom apartment with the dimensions of : 4m in width, 3m in height, 6m in length 
	Master Bedroom	1	20-$24m^2$			
	Bedroom	1	12-$16m^2$			
	Kitchen	1	$20m^2$			
	Bathroom	1	6-$7m^2$			
	Guest salon	1	16-$20m^2$			
	Toilet	1	3-$4m^2$			

Table 9: 3 Bedroom Apartment

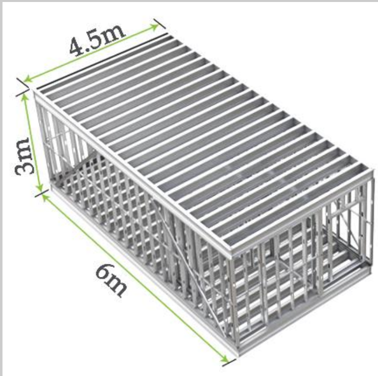
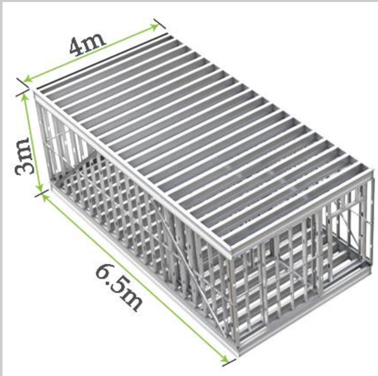
<table>
<tr><th>Type</th><th>Needed Space</th><th>Number Of Spaces</th><th>M^2</th><th>Total Area</th><th>Number Of Modules</th><th>Module Dimensions (Steel And Concrete)</th></tr>
<tr><td rowspan="7">3 Bedroom apartment</td><td>Living room</td><td>1</td><td>$30m^2$</td><td rowspan="7">150-160m^2</td><td rowspan="7">6 modules</td><td rowspan="7">6 modules will be needed for 3 bedroom apartment with the dimensions of : 4.5m in width, 3m in height, 6m in length
</td></tr>
<tr><td>Master Bedroom</td><td>1</td><td>$25m^2$</td></tr>
<tr><td>Bedroom</td><td>2</td><td>$16m^2$</td></tr>
<tr><td>Kitchen</td><td>1</td><td>$24m^2$</td></tr>
<tr><td>Bathroom</td><td>1</td><td>6-7m^2</td></tr>
<tr><td>Guest salon</td><td>1</td><td>16-20m^2</td></tr>
<tr><td>Toilet</td><td>1</td><td>3-4m^2</td></tr>
</table>

Table 10: 4 Bedroom Apartment

Type	**Needed Space**	**Number Of Spaces**	**M^2**	**Total Area**	**Number Of Modules**	**Module Dimensions (Steel And Concrete)**
4 Bedroom apartment	Living room	1	$35m^2$	170-180m^2	7 modules	6 modules will be needed for 3 bedroom apartment with the dimensions of : 4m in width, 3m in height, 6.5m in length 
	Master Bedroom	1	$25m^2$			
	Bedroom	3	$16m^2$			
	Kitchen	1	$28m^2$			
	Bathroom	1	6-7m^2			
	Guest salon	1	$24m^2$			
	Toilet	2	3-4m^2			

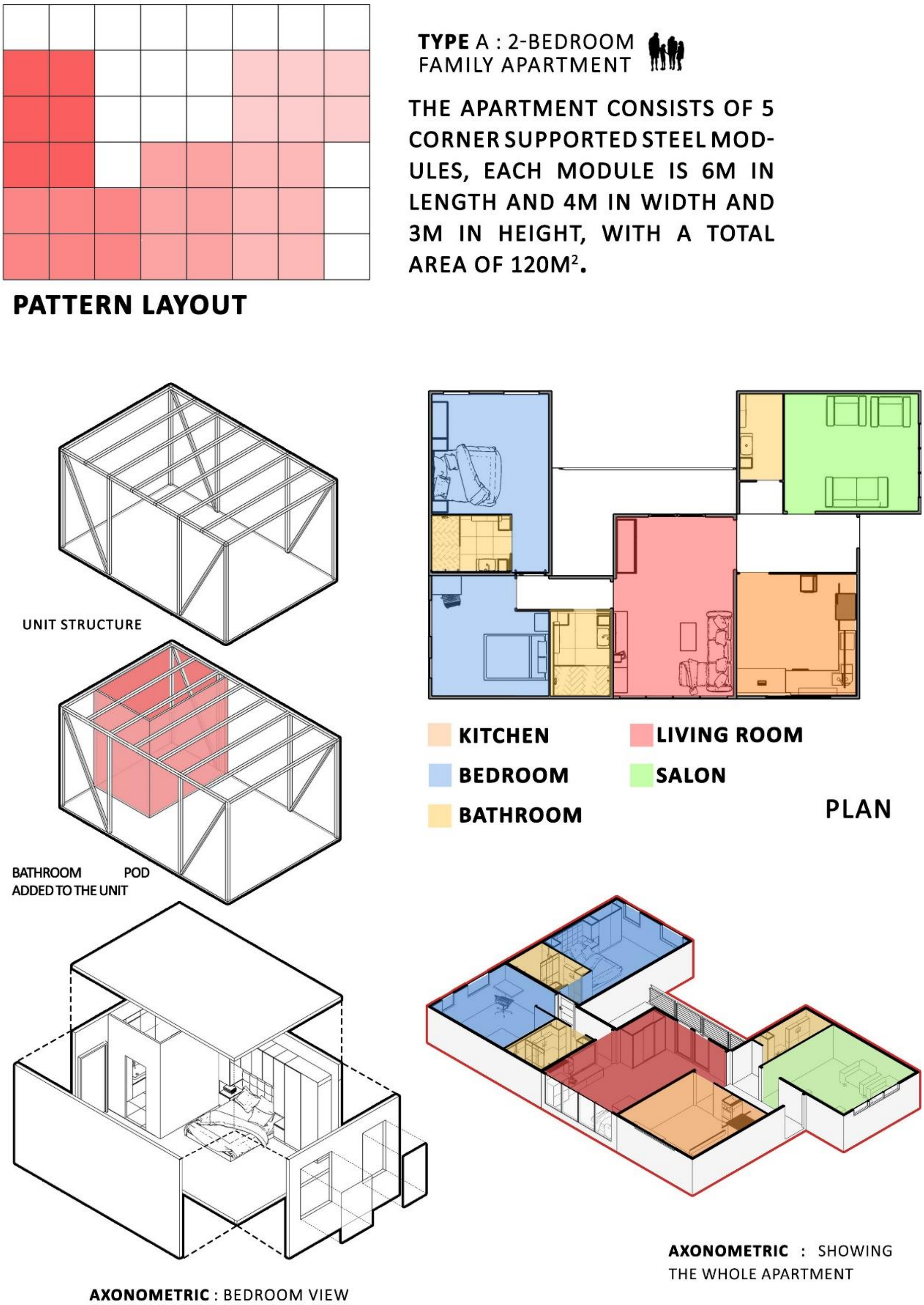


Figure 84: Type A , 2 bedroom apartment unit, proposed by author

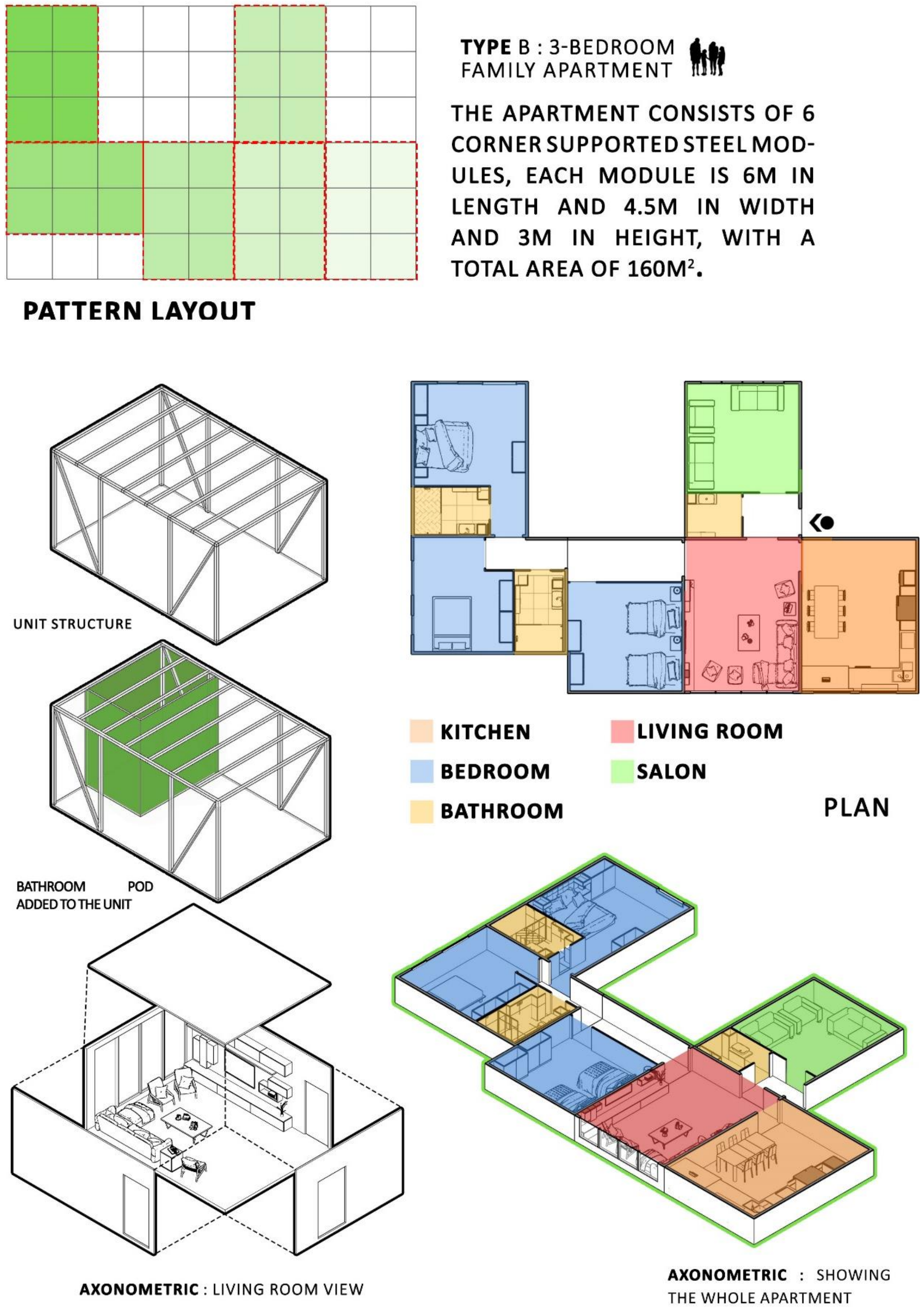


Figure 85: Type B , 3 bedroom apartment unit, proposed by author

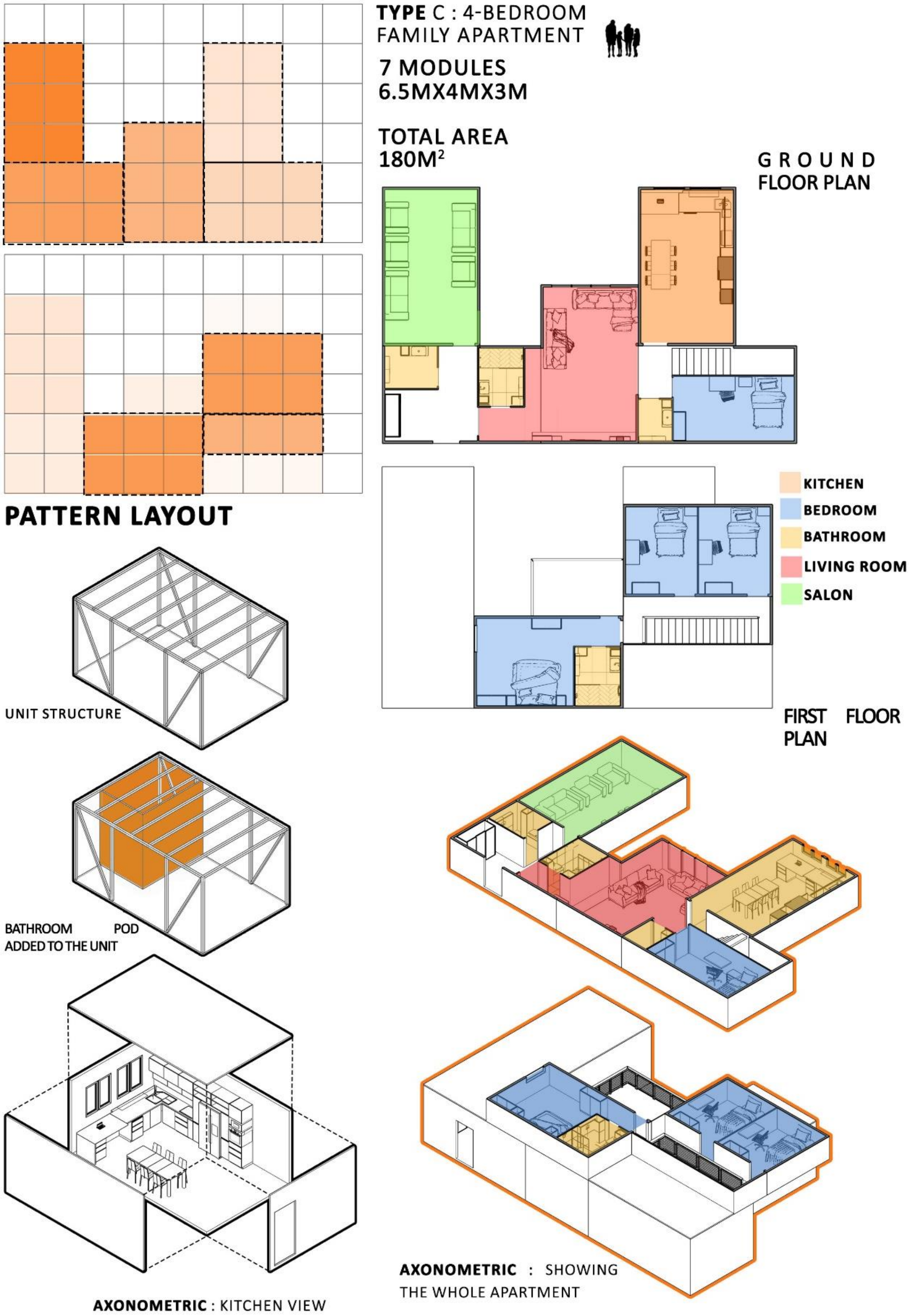


Figure 86: Type C , 4 bedroom apartment unit, proposed by author

Chapter 5

CONCLUSION

Throughout the last decade, political and armed conflicts and also natural disasters have seen a substantial increase, consequently the number of refugees, internally displaced people and the people who are affected have skyrocketed around the world. Due to such conflicts and natural disasters those people lost their homes, hence the demand for creating an optimum accommodation and housing solutions increased significantly.

As previously stated in the scope and objectives of the thesis study, one of the innovative methods of construction which is off-site modular construction is investigated. Throughout the literature review, the suitability and viability of using modular construction techniques in the housing sector to provide a housing or accommodation solution for the internally displaced Libyan families is studied.

In the beginning the general concept of the refugees and internally displaced people is discussed, and distinguished between them. Then, the focus is shifted to study the internally displaced people in Libya and their current living and wellbeing statues, and highlights their current difficult accommodation condition. Moreover, the potential of resettlement of those displaced and their camps and settlement is further investigated. Lastly, various types of sheltering solutions are discussed. Then, the methodology of off-site prefabrication and off-site modular construction are discussed in details.

Prefabricated Off-site modular construction method have become more popular and replaced the conventional (on-site) building methods. Modular construction is one of the key methods of off-site construction, providing a range of advantages that effectively promote sustainable design. Throughout the literature it was clear that modular construction method has many advantages, especially faster time of construction, lower construction cost, and higher quality finishing and flexible design approach which allows constructing a very sustainable modular buildings. It was proven that the modular off-site construction provides greater control of the consistency of the materials and the health of the construction process. After that, the approach of OSC and the types of OSC is discussed and specifically highlights the off-site modular construction type and the materials used in this type, also the different applications and the construction process. The last chapter was dedicated for discussing 3 different case study projects that utilized modular construction in the housing and accommodation aspect. The 3 projects manifests in: 461 DEAN Apartment, Carmel Place Apartment and THE STACK Apartment. The begging of the chapter provides a concise overview on each case project and discusses their distinct features. Subsequently, the chapter moves on to the analysis part, which is analyzing each case in terms of construction process and structural system, the quality of the design and the sustainability. The chapter concludes by evaluating the 3 projects on the bases of cost and time efficiency and design flexibility.

From the previously discussed literature review and based on the case study projects that were investigated and analyzed; a further study on the traditional living spaces of the Libyan houses was conducted. In the light of this study, the living areas within the conventional Libyan home was determined. And based on that, the feasibility and suitability of using modular units similar to the ones used in the analyzed case study projects, to construct traditional Libyan home is studied

After the literature review and the case study projects has been discussed, it could be Farley said that the research questions that have been previously raised, are answered, where the modular construction has proven to be very effective in housing projects. It is a speedy and sustainable construction approach that saves a lot of valuable time while guaranteeing a high quality of final products. And with the demand for new homes and the need of a fast and affordable construction process, also therefore, it can be said that modular construction can offer a convenient solution to the dilemma of re-accommodating the displaced Libyan families affected by the armed conflicts. Despite the potential feasibility of applying modular construction method in the Libyan scenario, a challenging problem may raise, which is the unavailability of factories or plants that produces modular units in Libya. However, this can be overcome by considering two solutions, either the modules are designed by cooperating with experienced Libyan architects who are familiar with the traditional living space of Libyan homes, then the modules are produced in another manufacturing country and then shipped to Libya. Moreover, the other solution is to establish factories in Libya that are intended for producing modular units, with assistance and monitoring of experienced construction foreign companies, similar to what was observed from the first case.

Answering the first research question and based on the previously discussed cases, (especially in case D) it was reached to a conclusion that modular construction methodology is successful to a certain extant in providing a convenient housing solution for the IDPs, since this construction aproach is highly flixeble when it comes to execution and also it is a significantly cost and time efficient aproach and also this aproach targets the affected IDPs and low-income families. moreover, as observed from the previously coverd cases, this construction aproach could be highly sustainable, hence, a further potential study focusing on measuring the sustainability of the modular apartments' design proposed by the author, could be conducted in the future.

If successfully carried out, modular construction is capable of disrupting and changing the construction process in a good manner, making it significantly more efficient than traditional methods with factory controlled efficiency, shortened construction schedules and a smarter use of materials. It is the future of construction.

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