



**Ethiopian Institute of Architecture, Building Construction and City Development
(EiABC)**

**THE STATUS OF MODULAR BUILDING SYSTEM IN BUILDING
CONSTRUCTION INDUSTRY: THE CASE IN ADDIS ABABA**

By

Wendmagegn Geleta

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University in Partial Fulfillment of the Requirements for the Degree of Master of
Science in Architectural Engineering

Advisor

Fisseha Wegayehu (PhD)

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Addis Ababa, Ethiopia

DECLARATION

I declare that this research work titled “The Status of Modular Building System in Building Construction Industry: The Case in Addis Ababa” is my own work and has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged / referred.

Wendmagegn Geleta

Signature: _____

CONFIRMATION

This thesis has been submitted to examination with my approval

Advisor: Fisseha Wegayehu (PhD)

Signature: _____

APPROVAL

The undersigned have examined the thesis entitled “The Status of Modular Building System in Building Construction Industry: The Case in Addis Ababa” presented by Wendmagegn Geleta, a candidate for the degree of Master of Science in Architectural Engineering and hereby certify that it is worthy of acceptance.

Approved By

Dr. Fisseha Wegayehu
Advisor

Signature

Date

Dr. Tibebe Asefa
Internal Examiner

Signature

Date

Dr. Daghachew Adugna
External Examiner

Signature

Date

Dr. Abunu Arega
Chairperson

Signature

Date

June, 2019
Addis Ababa, Ethiopia

ABSTRACT

The leading type of housing construction system in Ethiopia, which is conventional system, couldn't be compatible with increasing rate of housing demand. This has created a negative impact on housing and building construction industry, such as long-time that takes for construction, material wastage and rising cost. Previous studies conducted on housing and related problems indicates that, modular building systems could enhance problems within building construction industry.

The study dealt with an investigation on the current status of utilization and challenges of adapting modular building systems in building constructions industries of Addis Ababa. For that, investigations in 96 sampled construction project sites located in Addis Ababa have been looked in to. However, to conduct the study, interviews, questionnaires, observations and secondary data sources from literature and online publications were used.

The research result shows that, 61% surveyed building construction projects running at the current time utilizes at least one modular component for construction. Although the application of those components was in a very few amounts relatively, about 83% of them utilizes less than 10% of construction materials with modular components in each individual building project. Also, the research discovered unavailability of trained workforce, lack of design and engineering, limited number of providers, lack of designer's commitment, limited information and understanding, lack of local technological advancement and un-trust on quality and safety of components were the challenges for and utilization of modular building systems. Finally, based on findings conclusions were made and recommendations were drawn. In addition design proposal was made for implementation of modular construction.

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LIST OF ACRONYMS

AA	Addis Ababa
AARH	Agency for the Administration of Rental Houses
ACT	alternative construction technologies
APHMI	Addis prefab houses manufacturing Industries
CAD	computer aided manufacture
CAM	computer aided manufacture
CCT	conventional construction technologies
CSA	Central Statistical Agency
EMFA	Ethiopian Ministry of Federal Affairs
GDP	Growth Development Program
GTZ	German Technical Cooperation Agency
IHDP	Iterated Housing Development Program
MBI	Modular Building Institute
MEP	Mechanical Electrical and Plumbing
OSB	oriented strand board
PMC	permanent modular construction
QA	Quality Assurances
QC	Quality Control
RHS	Rectangular Hollow Steel
SECU	sustainable emerging city unit
UK	United Kingdom
UNECA	United Nations Economic Commission for Africa
US	United States

CHAPTER ONE

INTRODUCTION

1.1. Background

Modular buildings and modular homes are sectional prefabricated buildings, or houses, that consist of multiple sections called modules. "Modular" is a method of construction differing from other methods of building. The module sections are constructed at an offsite (sometimes remote) facility, then delivered to the intended site of use. Complete construction of the prefabricated sections is completed on site. The prefabricated sections are sometimes lifted and placed on basement walls using a crane, the module prefabricated sections are set onto the building's foundation and joined together to make a single building. The modules can be placed side-by-side, end-to-end, or stacked, allowing a wide variety of configurations and styles in the building layout (HUD, 2016).

Modular technology has already been used on many low-rise structures around the world and is gaining popularity in being used for multi-story medium to high rise buildings as well. Many countries around the world experienced its benefits for different types of purpose during the early nineties and after that especially in United States (US), Europe and Japan (RM Lawson, 1999).

Addis Ababa, which is the largest city in Ethiopia, and the nation's economic and political capital, it is also the "diplomatic capital" of Africa, housing the United Nations Economic Commission for Africa (UNECA) and African Union headquarters. Yet, despite its economic and political importance in the country and the region, Addis is faced with more than its fair share of problems. The rapid pace of urbanization approximately 3 percent has brought with its poverty and unemployment, and the city's infrastructure is grossly inadequate to cater to the increasing demand of its burgeoning population. The lack of adequate shelter and infrastructure for the poor majority has manifested itself in congested and unhygienic living conditions in most low-income settlements across Addis (Mathema, 2005).

Housing inadequacy is largely felt at the level of low and middle income and more so with a continuous rise in the cost of construction at all levels. This necessitates the use of appropriate and cost-effective technologies in house construction. Because the leading type of housing construction system in Ethiopia which is a conventional system couldn't be compatible with an increasing rate of housing providers and this created a negative impact on housing construction such as long-time construction, material wastage, rising cost, high embedded energy and so on. Therefore, by applying the appropriate construction technologies proposal, the ever-increasing cost of conventional building materials and construction techniques could be in time and people shall have alternative construction technology and access to affordable houses (Shimeles, 2013).

Modularization of building systems as alternative building construction technology taking in Addis Ababa is very advantageous to solve a wide range of problems in case of affordability, time to projects completions and quality of construction that couldn't has been solved by conventional construction technologies. Therefore, this research focuses on finding out of current status of modular building system utilization, challenges for adaptation of modular construction and its potential advantage in building construction industries of Addis Ababa, and also to propose modular design for possible implementation to enhance housing demand as alternative solution.

1.2. Statement of The Problem

Housing is one of the basic necessities for human beings. However, it is a critical problem for millions of poor people in developing countries including Ethiopia. Like most urban centers of developing countries, Addis Ababa faces a plethora of problems, including an acute and ever-worsening housing shortage, one of the major problems that call for immediate action. However, the number of people living in Substandard housing conditions is increasing every year. Studies have shown that without major improvements in housing markets and in the expansion and improved provision of infrastructure and service, it is inevitable that the population living in such environmental expand very rapidly (Robert, 1997).

While the Integrated Housing Development Program (IHDP) has the laudable aim of targeting the low-income sector of the population, unfortunately experience has shown that the low-incomes are not benefiting from the IHDP due to inability to afford the initial down payment and monthly service payments and because of the affordability problems women's and their children are excluded from development plans. In general, the current IHDP housing construction systems do not match the housing demand and supply due to cost, speed, and quality for the targeted group. Although construction technologies used for the program are based on a concrete pillar and slab system and also Agrostone board is applied in terms of minimizing the carpenter work concrete, reinforcement bar and others but still now huge amount of cement and gravel are used on the construction site and hollow concrete blocks are applied to fill the structures. But, the cost of housing units, time management and quality of those houses is not far from problem (Shimeles, 2013).

Experiences from advanced countries in case of modular building systems and constructions technologies indicate that there is a potential advantage to improve building construction performance in the aspect of cost, speed, and quality of building construction. Through the advantages of modularized building systems utilization to address a wide range of problems in housing and building construction industry, there are very little applications to solve those problems with modular construction except for some few components in this sector in case of Ethiopia including Addis Ababa. Government and private sector stake holders in construction industry are not well worked with modularized building systems.

1.3. Research Objective

General Objective:

To study the current status of modular building systems in building construction sector of Addis Ababa city.

Specific Objectives:

1. To investigate the current utilization status of modular building system and practices.
2. To examine current available challenges and possible important uses of modularization.
3. To study building construction stakeholders role in modularization of building systems.
4. To propose and illustrate a design with modular construction for apartment housing.

1.4. Research Questions

General Research Question:

How is the current status of modular building systems in building construction sector of Addis Ababa city?

Specific Research Question:

1. How is the current utilization status of modularized building system?
2. What are the current available challenges for modularized building system utilization?
3. What are the main stakeholders for modularization of building system?
4. What are the relevant design aspects for modular construction?

1.5. Significance

The findings of this research would help as an impute for local administration policy makers by giving information on the current status of the modular building system, as well as stakeholders in local building construction sector to look forward advantages in modularization of building systems. Also, the design proposal output of this research could help both as illustration of modular construction for builders and as an alternative solution for immediate response of affordable time efficient housing for local increasing demand through implementation by private and government house developers. In other ways, the finding of this study would help for scholars and researchers as an empirical background to conduct further research on related topics.

1.6. Scope of the Study

The thematic scope of the research is to study status of modular building construction and identification current available challenges for modular building system utilization in Addis Ababa city, mainly focus on current experience in modular building system utilization, challenges and role-playing by building construction industry stockholders in local building construction. Also, design proposal was made for implementation of a modular building construction for apartment housing based on results. The spatial scope of this study was within administrative boundaries of Addis Ababa city, on sample construction sites and some design offices to collect relevant data from professional respondents.

1.7. Limitations of the Study

Apart from the time and financial constraints, results of this study were subject to some limitations. Such as: limitations to make case studies on production of modular components that made with agrostone, due to manufacturing stop both at Yebel Industrial plc and Addis Agrostone production center located around Oromia water resource bureau. However, the reason behind is shortage of magnesium oxide supply that comes from mining sites out of Addis Ababa, which is one of ingredients for manufacturing of agrostone panels. Another limitation was unwillingness of project managers on some construction sites for direct observation to investigate application of modular components, due to site workloads and safety issues.

1.8. Organization of The Document

The document is organized into five chapters. The first chapter deals with the and background of the study, statement of the problem, the objective of the study, research questions, significance, scope, and limitations of the study. The second chapter states review of related literature, various aspects of written documents and articles by different writers. The third chapter Covers the research methodology including data collection and analysis methods. The fourth chapter comprises results and discussion of the findings and analysis based on data found from the study area, that focuses on presentations of data analysis with discussions of data results. Finally, the fifth chapter presents conclusions based on research result and recommendations and design proposal for illustration and implementation of an off-site and industrially fabricated modular building system that will be applicable for mass construction of apartment house dwelling. However, the design proposal is based on results of currently adapted modular construction technologies and some of from conventional method of construction for the possibility of application and with an available trained workforce and material technology.

CHAPTER TWO

LITERATURE REVIEW

2.1. Modular construction

The term “**modular**” describes a construction method or process where individual modules stand alone or are assembled together to make up larger structures as illustrated in Figure 2.1 (MBI, 2011).

‘**Modular construction**’ is a term that is used for the factory production of pre-engineered building units that are delivered to site and assembled as large volumetric components or as substantial elements of a building. The modular units may form complete rooms, parts of rooms, or separate highly serviced units such as toilets or lifts. The collection of discrete modular units usually forms a self-supporting structure in its own right or, for tall buildings, may rely on an independent structural framework. Modular units may be used for a wide range of building types, from residential buildings to complete fitted-out buildings such as fast-food restaurants. Modular construction should be differentiated from temporary or relocatable buildings, which, although similar in volumetric concept, differ greatly in terms of their quality, structural design, use of cladding materials, and general performance criteria. (RM Lawson, 1999)

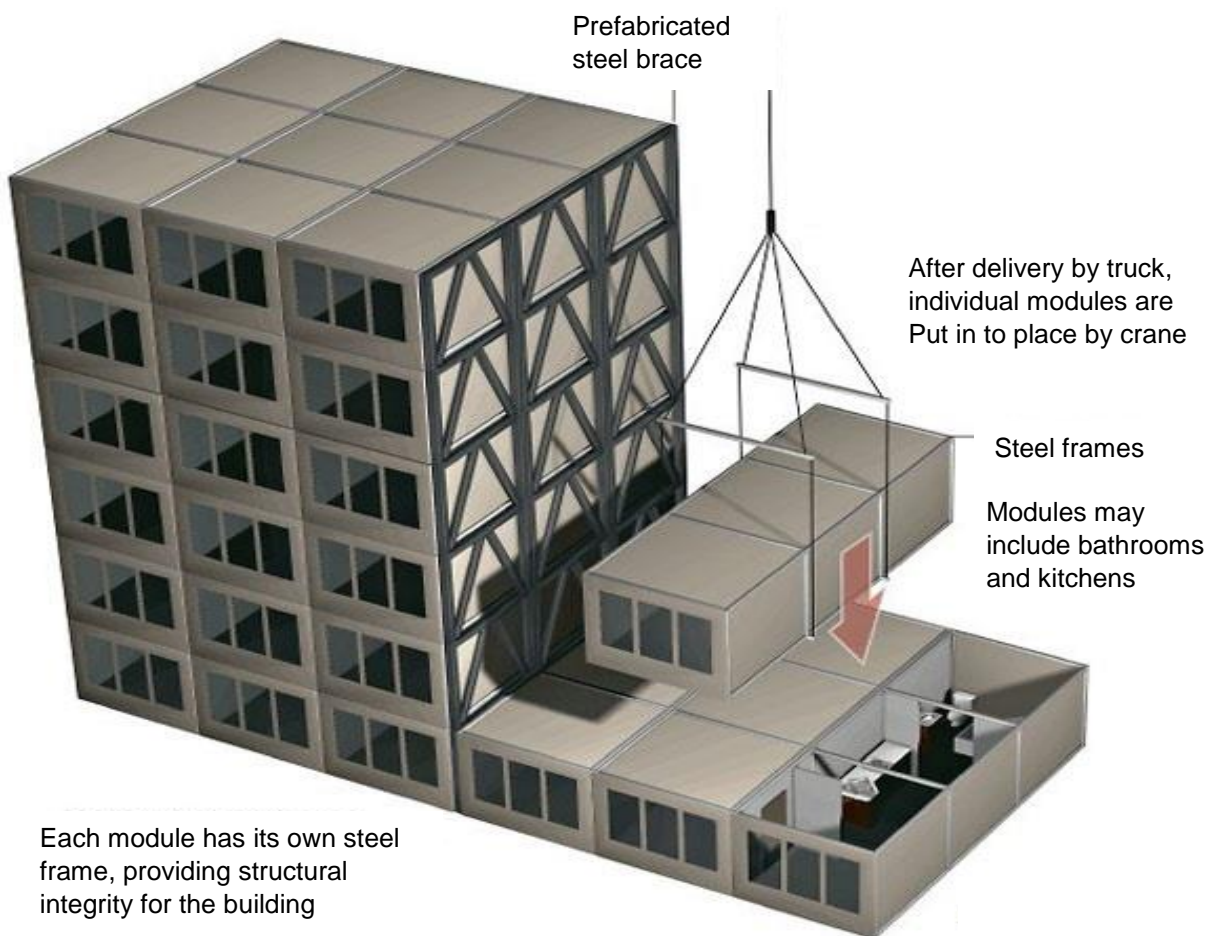


Figure 2.1: Example of modular construction (O’Connell, 2016)

2.2. Why use Modular Construction?

The use of modular construction is directly influenced by the client's requirements for speed of construction, high quality, an added economy of scale, and opportunity for single point procurement. These benefits may be quantified in a holistic assessment of the cost and value of modular construction in relation to more traditional alternatives. Light steel framing is an integral part of modular construction, as it is strong, light in weight, durable, accurate, free from long-term movement, and is well proven in a wide range of applications. It is part of an established infrastructure of supply and manufacture and is supported by British Standards and various design guides. Modular construction is also widely used in Japan and the US, where light Steel framing is the primary structural medium and leads to flexibility in Internal planning, robust structural behavior (even in seismic zones), and the possibility of exciting architectural solutions. There are also important opportunities for modular construction in extensions to existing buildings either by attaching units to the sides of buildings or by roof-top modules (RM Lawson, 1999).

Unique to modular construction, while modules are being assembled in a factory, site work is occurring at the same time or in some cases prior to construction. This allows for much earlier building occupancy and contributes to a much shorter overall construction period, reducing labor, financing and supervision costs. Saving even more time and money, nearly all design and engineering disciplines are part of the manufacturing process. Also unique to modular construction is the ability to simultaneously construct a building's floors, walls, ceilings, rafters, and roofs. During site-built construction, walls cannot be set floors are in position, and ceilings and rafters cannot be added until walls are erected. On the other hand, with modern modular methods of construction, walls, floors, ceilings, and rafters are all built at the same time, and then brought together in the same factory to form a building. This process often allows modular construction times of half that of conventional, site-built construction (MBI, 2011).

It is often thought that modular construction is by definition more expensive than traditional construction. While this may be true for 'one-off' buildings, there are considerable economies of scale that can be obtained from a greater refinement of the design (often by testing) and by investment in mechanized and possibly automated production. The Japanese house building market is dominated by modular construction, and over 150,000 houses are produced annually in modular form (see Figure 2.2). The high degree of sophistication at the design stage permits considerable input by the purchaser into the choice of finishes and even into the internal layout. The extremely high cost of land in Japan creates an economic imperative to build quickly and to achieve rapid pay-back, which could not be achieved by a conventional construction program. In the United Kingdom (UK), many major companies choose to go the 'modular route' because of the greater control they can exert over quality, speed and reliability, which are all business-related benefits. Good examples of the move from conventional to modular construction have been in hotels and fast-food restaurants as shown in Figure 2.3, where on-site construction times can be reduced by over 60% (RM Lawson, 1999).



Figure 2.2: Modular construction of large family houses in Japan (RM Lawson, 1999)



Figure 2.3: Fast-food restaurant in UK, which is fitted out before delivery to site (RM Lawson, 1999)

2.3. History of Modular Construction

In the early-1800s, a man named Henry Manning created the first known advertisement for a prefabricated home. The fabrication process was, of course, not as efficient as it is today; Manning's crew constructed the components in London and shipped them to be constructed in various other countries. It wasn't just small modular homes that were being made back then- a biggest modular project of the century was a 1,000-patient hospital, early use of modular buildings for medical application (Aries Building Systems, 2018).

1908 Brings Kit Homes: In 1908, the Sears Roebuck & Co. catalog began selling 'kit homes.' The idea was so simple and genius! They would sell the materials as a whole and provide the directions to construct the home so families could get everything in one place. It was a key precursor to modular and manufactured homes (Clayton, 2017).

Introduction of the Assembly Line: With the help of Richard Sears's ingenious advertising techniques and the introduction of the assembly line by Henry Ford in 1913, manufactured homes began to surface as a housing possibility for the general public. Assembly line innovations allowed for home builders like Gunnison Housing Corporation and Lustron Corporation to take off creating prefabricated homes in building facilities for the masses (Clayton, 2017).

Post-World War II Prefab Growth: It wasn't until after World War II in the 1950s that these prefabricated homes grew in popularity. To home building companies, constructing parts or sections of homes in a facility was a profitable and efficient way to meet the housing demands that rose during this time (Clayton, 2017).

In the US, the modular industry originated with the travel trailer industry increased in the Second World War as trailers became homes for thousands of defense workers. After the War, severe housing shortages created a demand for trailers as permanent housing. The industry responded by developing what is now called mobile homes, with designs that tried to strike a balance between the functions of house and vehicle (RM Lawson, 1999).

1958 Brings Modular Housing's Birth: These growing needs are what caused the modular homes industry to boom in 1958, the first double-wide home was constructed to a local building code, and thus the modular housing industry was born. For the following years, manufactured homes and modular homes continued to compete to become the best in efficient home building. With the help of technological advances and specifically, Computer Assisted Design (CAD) Programs, modular homes have only improved (Clayton, 2017).

The relatively low cost of starting a factory in the early 1950s, when demand was strong, encouraged the formation of many new companies in the USA. In 1959, there were 268 with 327 plants. By 1963, the companies producing manufactured housing had split into two distinct groups – mobile home producers and modular home producers. In 1955, plants could be started for as little as \$15,000. By 1966, the average start-up costs had risen to \$150,000. However, they were very low compared to the start-up costs of other manufacturing industries and remain so to this day. Many companies have folded as a result of economic recession, and there are now 34 companies in the USA producing modular units from 173 plants (RM Lawson, 1999).

2.4. Modular construction Experience

Modular construction is well established in North America, in Japan, and in parts of Europe particularly Scandinavia (RM Lawson, 1999). Large markets for modular construction use include the UK, Japan, and Australia, while China and India are poised to reshape the entire construction industry. While smaller in terms of total revenue, regions such as Scandinavia, where an estimated 90% of homes are prefab and modular, are leaders in advancing modular construction techniques (MBI, 2011). Here the topic discusses both international and local experiences in the following sub titles.

I. International Experience

North American Experience

Modular Building Institute (MBI) estimates the permanent modular construction (PMC) market in north America is about \$2 billion, making this region the largest in terms of revenue. Modular building techniques are now widely used in the USA, especially in the affordable housing and budget hotel sectors. Nearly eight million single-story manufactured units provide homes for almost thirteen million Americans. Until recently, there was no incentive for the modular manufacturers to develop designs for this market. As a consequence, although the USA the world's largest modular housing industry, it is much less advanced technically than its Japanese or European counterparts. For the foreseeable future, modular homes in the US are likely to be confined to lower end of the housing market. However, this situation will change as the American public becomes familiar with more up-market modular building types, and the advantages they offer (RM Lawson, 1999).

Japanese Experience

Based on architect guide SCI Publication P272 placement, the most important difference between Japanese and American modular housing is that the market for the modular homes in Japan is among the upper and higher-middle income groups, whereas in the USA it is among the lower income groups. In Japan, there is almost no 'second hand' housing market and most sites are re-built every 20-30 years. Consequently, the Japanese housing market is now 1.5 million dwellings per year. The background to the development of the modern Japanese modular home industry is very different to that of its American counterpart and is much more recent. In 1955, as a result of acute housing shortages, the Japanese government set up the Japan Housing Corporation (JHC). Initially JHC focused on the development of medium-rise concrete apartments, made from a limited range of heavy concrete panels. Industrialized building techniques of all types account for about 20% of housing production in Japan, or over 300,000 dwellings a year. The major builders in the industrialized production sector are Sekisui Chemicals, Daiwa, Misawa, and National. Their construction techniques are based largely on traditionally framed construction using a combination of steel sections, which are designed in accordance with the strict Building Standard Law. The facade panels often use lightweight concrete (RM Lawson, 1999).

Sekisui Heim was established in 1972 as the modular building part of Sekisui Chemicals Ltd. Since then, Sekisui Heim has produced almost half a million modular homes (each house typically consisting of 12 to 15 modules) and is Japan's biggest modular home producer. In 1976, Toyota (the car company) followed suit by setting up a modular homes' division. Although Toyota Homes' output of houses is only about a tenth that of Sekisui Heim's, its importance lies in its production methods, which owe much to sophisticated car manufacturing methods developed by the parent company. Though the two companies' Production levels are very different, they produce modules that are technically similar. Sekisui Heim produces approximately 35,000 modular houses a year, and their largest factory produces approximately 7,000 houses a year. Sekisui Heim and Toyota Homes use open framed steel modules that are customized to individual consumer specification to a significant extent. Customization is possible because of the extensive use of computer-aided design (CAD) and computer aided manufacture (CAM). The sophisticated software allows the architectural design and pricing processes to take place in the presence of the prospective homeowner (RM Lawson, 1999).

European experience

The motivation to use modular construction is less obvious in the continent of Europe than in the USA or Japan. However, in Scandinavia, the industrialized methods of the shipbuilding industry have led to extensions of this production technology into the building industry. One well known architectural example of social housing in Tampere, Finland, uses tubular construction as the supporting framework for modular wall elements inserted between the horizontal members. The internal elements were designed to be adaptable (RM Lawson, 1999).

In Denmark, modular units have been used in roof-top extensions in the renovation of apartment buildings. In this project, the key to the use of modular construction was the speed of construction and light weight of the modular light steel frames, which could be lifted into place onto the roof. Modular construction is well developed in Germany, where there are a number of manufacturers of modular units that are used primarily in housing. The largest manufacturer of modular houses is the company Alho, which has two manufacturing plants in Germany (RM Lawson, 1999).

China & India

While it is virtually impossible to get accurate construction data from these regions, no one will dispute the insatiable appetite these giant countries seem to have for construction services and materials. By some accounts, nonresidential construction spending in India is expected to exceed US \$300 billion by 2013, while China's market is expected to be double that figure. China builds the equivalent of one "Chicago-sized" city each year. A one percent market share for modular construction would equate to nearly US \$10 billion in these regions, five times the size of the current US market (MBI, 2011).

United Kingdom

In the UK, the market for modular construction is approximately \$2.44 billion, of which 33% is associated with leasing activity while 67% (\$1.63 billion) is for sales of modular buildings. Key markets in the UK. are similar to the U.S. – education, healthcare, and offices. The modular construction industry is driven by different markets in different parts of the world. For example, the energy/extraction industry utilizes modular facilities heavily in parts of South America and Australia, as well as in Northern Alberta, Canada. Oil, natural gas, and coal extraction often occur in underdeveloped parts of these regions, creating a demand for building infrastructure to accommodate workforce housing and administrative office space. This adoption of modular construction in the energy sector has often led to wider spread acceptance in other markets such as education, as is the case in both Alberta and Australia (MBI, 2011).

II. Modular Construction Related Works in Ethiopia

Addis prefab houses manufacturing Industries S.C (APHMI):

APHMI is established as a public company comprising 861 shareholders with a registered capital of 39.7 million Br in February 2004 E.C. The company has four core business units' namely Real estate, Manufacturing, Construction and Trading. These units are expected to become independent subsidiary companies in the long run. The real estate business unit constructs houses using the nine prefab building materials that the manufacturing business unit will produce. The construction business unit will be taking projects for the construction of different types of buildings through bidding using prefab technology (ethioconstruction.net, 2017).

The vision of the company is “To become the leading technology provider of green construction solutions to the development of affordable and industries buildings in the Africa continent”. The company will be building using Light Gauge Steel and Calcium Silicate Boards. In addition, the roofing system can serve as a competitive product for roofing solutions of any kind (Shimeles, 2013).

YBEL Industrial Private Limited Company (PLC)

YBEL Industrial Private Limited Company (PLC) is an Ethiopian Grade One construction company and manufacturer of building materials. The Industrial PLC was initially engaged in manufacturing Magnesium Board – factory-made, non-insulating sheathing board product – until recently. The mission of the Company is to provide affordable, efficient and safe House and building projects by changing the conventional ways of construction to modern method of construction. YBEL is manufacturing three types of building products: Magnesium Boards, Light Gauge Steel Structure Frames and FGC (Agrostone) panels. Starting from 2012, YBEL started to produce the following products: GA Sheet, and PVC Doors and Windows to suit any building from country cottages to city apartment buildings and from schools to commercial offices and industrial blocks, the doors and windows range includes contemporary styles offering exceptional energy, efficiency, security, and durability (Alemu, 2016).

Addis Ababa and Regionals Agrostone production centers

Type of products mostly produced by agrostone production center are agrostone panels, reliefs, and doors: - The length of the panels can vary to a maximum of 3.5m and there are 10cm and 20cm thick boards. The 10cm thick hollow partition board is the common product. Hundreds of different types of relief items are available. The reliefs include roman colons, roofing materials, wallboards, corner lists etc., and Doors which are lightweight doors and have a strength and weather resistant requirement for doors (Taffese, 2012).

Experimental prototypes for emerging housing constructions in Addis Ababa

Prototype SECU (sustainable emerging city unit) is implemented in April and May 2012. SECU is a testing and experimental research project for fast-emerging settlements and rural areas that examines alternatives to the standard housing concepts. All construction elements are made of prefabricated standard strawboard elements. The standard dimensions are 120 cm wide and 6 cm thickness, while the length is flexible. For the accomplishment of this work the following methodology was used: Suitable design pattern and construction details were identified and selected by an on-site survey to assess typical houses and living forms in Ethiopia, Intensive research studies by consultation and exchange dialogue were carried out to get the level of skills, affordability and identification with new materials and techniques for reasonable housing and comfort, the material behavior and parameters under the climate of Ethiopia were gained through experiments and laboratory tests and the construction of loadbearing walls out of strawboards took place after various structural long term and crash tests, waterproofing testbeds and a field analysis with a full-scale model (Donath, 2012).

2.5. Modular Building

Modular buildings are generally stronger than site-built construction because each module is engineered to independently withstand the rigors of transportation and craning onto foundations. Once together and sealed, the modules become one integrated wall, floor, and roof assembly. Building offsite ensures better construction quality management, manufacturing plants have QA/QC programs with independent inspection and testing protocols that promote a superior quality of construction every step of the way (MBA, 2016).

I. Components of Modular Building

Major components of modular components are as explained below (Civildigital, 2018):

Columns: A column is a vertical member carrying the beam and floor loadings to the foundation. It is a compression member and therefore the column connection is required to be proper. The main principle involved in making column connections is to ensure continuity and this can be achieved by a variety of methods.

Beams: Beams can vary in their complexity of design and reinforcement from the very simple beam formed over an isolated opening to the more commonly encountered in frames where the beams transfer their loadings to the column. Methods of connecting beams and columns are: a pre-casting concrete haunch is cast on to the column with a locating dowel or stud bolt to fix the beam, and a projecting metal corbel is fixed to the column and the beam is bolted to the corbel.

Waffle unit for flooring/roofing: These are suitable for roofs/floors spanning in two directions. They are laid in a grid pattern. These units are cast in modules. The saving achieved is not much. Also, Shuttering are complicated and costly and time consuming for construction is less.

Enclosure: Regardless of the building type or the method of construction, the functional requirements of building enclosures remain the same: the building enclosure needs to provide environmental separation between interior and exterior spaces, including providing security, privacy, views, and the primary architectural aesthetic (Tammy J. Harrell, 2016).

II. Types of Modules

There are three basic types of modules using light steel framing or sheeting, namely (RM Lawson, 1999):

- 1. Structural Modules:** which function as a load-bearing steel frame, a stressed skin box or combinations of the two functions. The modules can be stacked to produce multi-story buildings or may be combined with primary structural frames, particularly in heavily loaded applications.
- 2. Non-structural modules:** which are supported by a structural frame or on a concrete floor. These modules can be located between the primary structural members.

3. **Shutter modules:** in which the steel modules act as permanent formwork for in-situ concrete. The applied loads are carried by the concrete cross-walls and floor slabs in the same way that they would be in a conventionally constructed concrete building. The light steel structure supports the loads during construction.
4. **Other modular components:** Various forms of other modular components have been used in major building projects. These modular units exploit the benefits of speed of construction by taking more complex parts of the construction program off the 'critical path'.
5. **Lifts:** The time it takes to install conventional lifts will usually determine when a building is handed over to the client. Modular lift shafts can be fully integrated with the structure and can be designed to provide wind bracing, or they can be free standing elements.
6. **Stairs:** Prefabricated stairs are quick and easy to install and are immediately available for use by the erection team and other building workers. Prefabricated steel stairs are usually erected as story-high units and have been used for over 15 years in traditional steel framed construction. They are installed with protection to finished surfaces, or in a partially finished state that can be finished later.
7. **Plant rooms:** The advantages and the limitations of M & E plant modules are well known and appreciated by service engineers, particularly those specializing in the design of large commercial buildings. In these applications, air handling and cooling plant can be installed by lifting onto the roof of buildings in modular units.
8. **Toilet modules:** Toilet modules can be constructed as self-supporting units and Lifted and slid into place on the floor of buildings. Clearly, the floor of the toilet modules will be higher than that of the adjacent floor unless a raised access floor or other covering is provided.

III. Categories of modular systems as classified by (Sonja Oliveira, 2017)

Open panel systems: the construction of a structural frame for building using panels assembled in the factory. Open panel systems are typically delivered to site purely as a structural element with services, insulation, cladding and internal finishes installed in situ.

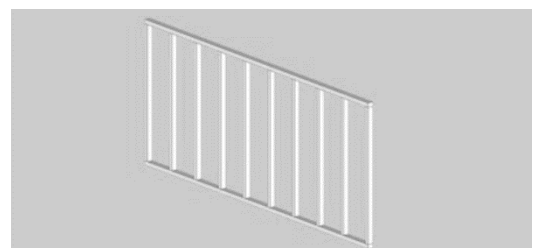


Figure 2.4: Open panel system

Closed panel system: these are similar to open panel system in that the structural elements of the building are delivered to site in flat panels. However, the closed panel systems typically include more factory-based fabrication such as lining materials and insulation and may even include cladding, internal finishes, service doors, and windows.

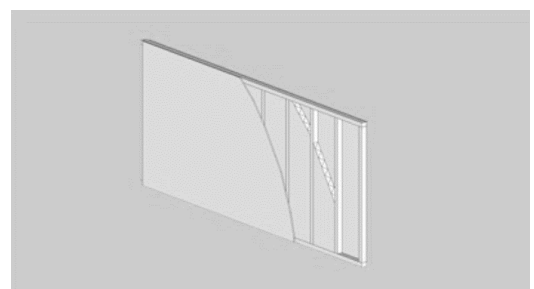


Figure 2.5: Closed panel system

Volumetric system: is the most factory-based form of production, volumetric systems involve three-dimensional modules that can be in isolation or in multiples to form the structure of the building. These modules can be prefinished in the factory to include all fixtures and fittings, requiring a very limited amount of installation work on site.

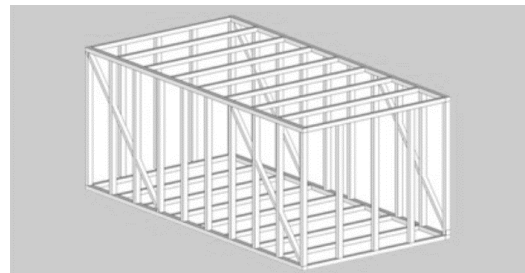


Figure 2.6: Volumetric system

Hybrid system: a combination of volumetric and panelized systems where the high-value areas (kitchens and bathrooms) are typically formed from volumetric units (sometimes referred to as pods) and the rest of the structure formed from some form of framing system.

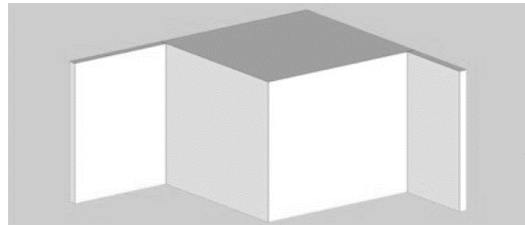


Figure 2.7: Hybrid system

Sub-assemblies: major building elements that are manufactured off-site but do not form the primary structure of the building. Foundation systems and cassette panels are typical examples.

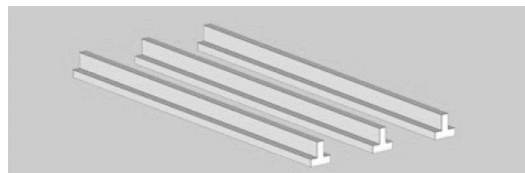


Figure 2.8: Sub-assemblies

Components: are non-structural elements that are assembled on-site. Although currently less common than structural elements, components such as mechanical and electrical services infrastructures are being developed with significant assembly work being carried out off-site.

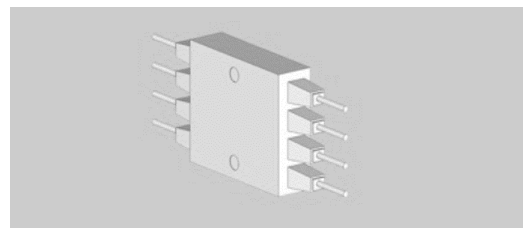


Figure 2.9: Components

IV. Production and logistics of Modules

Production efficiency and logistics, such as transport and crane costs, play an important role in determining the economic viability of modular building projects. The following points are relevant to these issues (RM Lawson, 1999):

Ease of manufacture: Modules may not be as efficient structurally as they could be because of the need for integrated assembly-line production and the requirements of the transportation and erection process. The way in which modules are assembled and fitted out in the factory, and lifted and assembled on site, frequently requires special components. However, there is also a need to minimize the number of components for production efficiency and to avoid unnecessary stocking.

Value per unit volume: The higher the value of the modular units per unit volume, the greater the distances over which modules can be transported and used competitively. It follows that the design of modules should be such that their value/size ratio is optimized to keep transport and installation costs at acceptable levels. Often the most highly serviced elements of the building are constructed from modular units and the remainder of the structure is constructed conventionally.

Finishing: Modules can be finished internally using 'dry-lining' techniques. Other methods may be more economical if they reduce assembly line costs.

Transportation: Delivery costs depend on travel distance from the factory to the site. To avoid problems arising from road transport width restrictions, modules should not exceed 4.2 m in width or 18 m in length. Whenever possible, modules, or parts of modules, should be sized so that they fit onto standard 20 ft (6.1 m) or 40 ft (12.2 m) long lorry trailers.

Erection: The larger and heavier the modules, the larger the crane needed to Handle them. Also, the crane will require more space in which to operate. However, large rooms can be constructed from small modular units although additional bracing is required on the open faces of the modules to provide stability during lifting.

Site logistics: The modular units are generally lifted straight from the lorry into their final position. It is self-evident that they should arrive on site at the right time and in the right sequence. In inner cities, road restrictions are often such that delivery and erection have to be done outside normal working hours. However, the operation is relatively quiet and does not involve significant waste onsite (i.e. lower waste removal costs and less disruption).

Today, computer-aided design (CAD) and computer-aided manufacturing (CAM) create better opportunities to link the role of architects with the production and fabrication processes. CAD/CAM function as technological tools; they can be used to explore new forms and complex shapes or for developing innovative designs and ideas derived from industrialized production. Therefore, there is a need for a system of data management and information exchange among different disciplines, one, which will reduce costs and time, while increasing quality and profits. Achieving this requires better communication skills and an understanding of digital fabrication techniques (Alkahlan, 2016).

2.6. Design of Modular Construction

The detailed design of modular units should take into account their special requirements for lifting and transportation, installation on site, and attachments of roof and wall cladding and service connections. The aspects of design that are particularly relevant to modular construction, rather than to conventional site construction, are described below (RM Lawson, 1999).

I. Requirements for Transportation and Weather-tightness

The principal requirements for transportation concern the maximum width and height for loads carried on the highways. The maximum width normally allowed for example in the UK is 3.5 m for general applications but this can be increased to 4.3 m if access routes permit. The maximum height of the load is 4.5 m for service roads but there may be local restrictions for clearance under older bridges, especially railway bridges. A maximum height of 3.9 m should be used in these cases, which may require the use of a low lorry trailer. modular units should be made weather-tight, particularly during the transportation phase, when damage due to wind buffeting can be a problem.

II. Lifting and installation forces

Lifting and maneuvering forces cause different internal stresses from those that exist during normal conditions. In particular, locally high forces exist at lifting positions, and the adjacent members and their connections generally need to be strengthened to resist these forces. Often hot rolled sections are used at these positions, whereas light steel members are used elsewhere. The optimum lifting points are at 20% of the length of the unit in from both ends so that the structure is most stable. However, units are often lifted from their corners, which generally necessitates the use of a separate lifting frame or pairs of cross-beams. A heavy lifting frame equal to the plan dimensions of the units is preferred as it does not cause horizontal or shear forces in the units. It is also possible to lift small units from their base. However, in this case, the change of angle of the lifting cables over the top of the module may cause local damage to the upper corner of the units. For design purposes, lifting forces should also include a dynamic component as a multiple of the self-weight of the unit. Forces are normally distributed equally among the four lifting points but should also include the horizontal forces (due to the component of force acting in the sloping cables).

III. Requirements for overall stability and integrity

The requirements for overall integrity and stability are characterized by the term 'robustness'. In principle, in the event of failure of one element of the construction, the remaining structure should be sufficiently robust to support the loads acting on it without disproportionate damage. Modular units differ from normal construction in that the units, although robust in themselves, are placed together so that the load path is through the walls of the units below. The possibility of the removal of this load path means that the walls should be designed either to span horizontally over the damaged area by acting as a deep beam or diaphragm or be supported in tension by the adjacent units.

IV. Cladding materials

Cladding is used for the facades and roof and their associated interfaces.

Facades

Placing of brickwork is a site activity that can be slow and requires its own foundation. Self-supporting brickwork walls can be designed up to 12 m high, although with use of high strength bricks, taller walls can be constructed. Lateral support is achieved by ties cast into the brickwork and attached to the light steel structure. The ties are placed at a minimum density of 2.5 ties/m² of the facade area. In light steel framing, this can be achieved by 'Chevron' shaped ties similar to those used in timber frame construction, or by attaching vertical tracks through the insulation to the steel studs. These vertical tracks are placed at 1.2 m spacing so ties should be attached every 5 or 6 brickwork courses. For tall buildings more than 4 stories' high, separate vertical supports at each or alternate floor levels may be required, and the modular units should be designed to resist these additional loads. Typical support details for brickwork differential vertical movement is accommodated by the ties.

Roofing materials

Generally, roofs are constructed conventionally on site. Although not often done except for mansard roofs, it is also possible to prefabricate whole roofs including their outer skin. The tile-hanging detail is also typical of pitched roofs and mansards. However, in most cases, the roof space is 'cold' and insulation is placed directly on the top of the modular units. Roof sheeting attached to purlins is typical of normal steel construction and is often used in shallow pitch roofs, where hidden by the facade.

Acoustic insulation of separating floors and walls

Modular construction provides a high level of acoustic separation because each module has a separate floor, ceiling and wall elements, which prevents direct transfer of sound along the members. Modular units are often used in hotel buildings because hotels generally require a high standard of acoustic insulation between rooms. The construction gap between the wall of one module and the adjacent module reduces the risk of sound penetrating across the construction. Similarly, there is a gap between a unit and the one below because the floor construction of one is independent of the ceiling construction of the other. The units are only connected at the corners or other discrete points, for structural purposes.

Thermal performance

Light steel construction can provide a high level of thermal insulation and airtightness economically and without leading to excessively thick walls. This has both environmental benefits and cost benefits (from reduced fuel bills). Furthermore, occupant comfort can be improved. Fabric insulation levels in buildings are slowly improving and there is an increased concern to reduce heat losses through air infiltration. Consequently, some traditional construction details may become inappropriate. Modular construction allows a greater degree of control of the construction process, which enables higher standards of thermal performance to be delivered without being compromised by site practices. When using light steel framing for modular units, it is important to ensure that the framing elements do not form a 'thermal bridge' through the external wall insulation layer. The 'warm frame' principle is used to prevent steel elements penetrating from the inside to the outside of the thermal insulation and to minimize the effect of cold bridging.

Foundations

Modular units are by their nature light in weight so foundations are not as large as in conventional construction. Strip footings are located under load-bearing walls and shear attachments are made by resin anchors into the concrete. The leveling of the foundations or ground beams is crucial to the subsequent installation and alignment of the modular units. Often it is necessary to provide for some adjustment in the foundation or in the legs of the modular units, and each manufacturer has its own system. Generally, a variation in level of about 20mm in the top of the foundations can be accommodated. Brickwork cladding also requires suitable strip foundations, which can be the same as used for the modules.

Services and drainage

Installation of services, particularly bathrooms, is labor and time-consuming in traditional construction. Therefore, the removal of these activities from the site has significant benefits in quality and speed. In modular construction, the key plumbing and electrical services are installed in the factory. Generally, a vertical service duct is incorporated into each unit, which provides for vertical drainage and pipework, and all service connections are made within this duct. Regular openings can be provided in the floor joists and wall studs for cables and small diameter pipes. Rubber grommets around the openings prevent damage to these cables. Larger pipes are usually located in the space between or below the joists. Drainage from the roof is handled conventionally from outside the building. Clearly, routing of services within or below the structure requires careful planning.

Fire safety

Fire resistance of the steel components is achieved by suitable fire protection. Two layers of fire-resistant plasterboard achieve 60 minutes fire resistance, which is normally sufficient for buildings up to 6 stories' high. A further requirement is to prevent passage of smoke or flame, particularly between the units, along corridors, and through service ducts. Special fire dampers and intumescent seals can be introduced at strategic locations to reduce the risk of fire spread.

2.7. Applications of Modular Construction in Buildings

Modular construction comprising light steel framing has various applications in general building construction, and particularly in residential buildings such as hotels and apartments. The following building types are most appropriate for modular construction (RM Lawson, 1999):

- hotels and hotel extensions
- 'cellular' apartment units
- student residences
- educational buildings
- sheltered accommodation, such as old people's homes
- toilet units for commercial buildings
- plant rooms for commercial buildings, hospitals etc.
- highly serviced units, such as lift shafts and industrial 'clean' rooms
- rooftop extensions to existing buildings
- external modular units in a renovation of 'panel type' buildings
- pre-manufactured buildings, such as 'fast food' restaurants and petrol stations

2.8. Advantages of Modular Construction

Modular construction techniques have been shown to be inherently advantageous in 7 major areas (Kobet, 2009):

Less Materials Waste – Pre-fabrication makes it possible to optimize construction materials purchases and usage while minimizing on-site waste and offering a higher quality product to the buyer.

Less Material Exposure to Inclement Weather – Many of the indoor air quality issues identified in new construction result from high moisture levels in the framing materials. Because the modular structure is substantially completed in a factory-controlled setting using dry materials, the potential for high levels of moisture being trapped in the new construction is eliminated.

Less Site Disturbance – The modular structure is constructed off-site simultaneous to the foundation and other site work, thereby reducing the time and impact on the surrounding site environment, as well as reducing the number of vehicles and equipment needed at the site.

Safer Construction – Modular construction is a safer alternative. Conventional construction workers regularly work in less than ideal conditions dealing with temperature extremes, rain, wind, or any combination of natural conditions. This, by its very nature, is a much more challenging environment to work safely in. Additionally, the potential for injury including falls, the most common work site risk, is much higher. In a factory-controlled setting, each worker is typically assigned to a work station supplied with all the appropriate equipment needed to provide the safest work environment possible.

Flexibility – When the needs change, modular buildings can be disassembled and the modules relocated or refurbished for their next use reducing the demand for raw materials and minimizing the amount of energy expended to create a building to meet the new need. In essence, the entire building can be recycled in some cases.

Adaptability – Modular buildings are frequently designed to quickly add or remove one or more “modules” minimizing disruptions to adjacent buildings and surroundings.

Built to Code with Shorter Build Times – The bottom line is that with modular construction you can get a facility built to the same local codes with construction quality as good as or better than a comparable site-built building in much less time. Additionally, the abbreviated construction schedule allows you to get a return on your investment sooner while minimizing the exposure to the risks commonly associated with protracted construction schedules.

2.9. Advantages of Modular Construction Using Light Steel

The following general advantages may be attributed to modular construction using light steel framing (RM Lawson, 1999):

Short build times: Typically, 50-60% less than for the equivalent conventionally constructed buildings. However, longer procurement times may be required before construction starts on site.

Superior quality: Achieved by factory-based quality control methods and standards. Steel is a reliable quality assured material.

Economy: Efficient manufacturing processes, fixed prices and earlier completions (leading to an early return on capital).

Low weight: Modular construction is about 30% of the weight of conventional masonry construction, leading to reduced foundation costs. Modular construction is ideally suited to roof-top extensions to avoid overloading the existing building.

Dimensional accuracy: Small tolerances can be achieved and maintained within the module interior and in the sizing and positioning of openings. This leads to ease and accuracy of fit-out in a production environment.

Environmentally less sensitive: Efficient factory production techniques are much less wasteful and disruptive on site than traditional construction operations.

Seismic properties: Steel modules have excellent robustness, which usually means that they can meet international seismic standards (with relatively minor modifications).

Reloadability: Buildings made from steel modules can easily be disassembled and modules can be relocated to create new buildings quickly and economically.

Innovative funding potential: The ability to recover and recycle modules quickly and easily provides scope for modules to be made available to users on terms that are not possible for conventional buildings (e.g. product lease or hire purchase).

Use on infill sites: Modules are useful in small urban infill sites, particularly where it is uneconomical to build because of problems of disturbance and site location.

Reduced site labor requirement: The erector and finishing teams who install and complete modular buildings involve fewer workers on site than traditional buildings.

Improved manufacturing skills: The way modules are made means that work in the factory and on site is reduced and greatly simplified, by advanced manufacturing techniques.

Safer construction: Modular construction sites have proved to be significantly safer than traditional sites because of the more controlled operations.

Component interchangeability: Standardized components, jointing details and the use of assembly jigs mean that module components using light steel framing are readily interchangeable.

Adaptability or extendibility: Adding modules to, or removing modules from, modular buildings is typically a very rapid and straightforward process that involves the minimum of disruption to the operations of adjacent buildings.

Mobility: Modules are designed to be transported easily and can be exported (subject to sensible transportation costs).

Reduced professional fees: Standardized design details for modular buildings simplify and reduce the need for specialist design input. Accurate costs can be obtained from the manufacturer.

Design flexibility: Steel modules can be grouped vertically and horizontally with good load resistance.

2.10. Value Engineering Assessment of Modular Construction

The motivation to use modular construction arises from various well-defined client benefits (as noted in the Introduction). The value attached to many of these benefits is dependent on the particular client and on the building use and location (RM Lawson, 1999).

I. Speed of Construction on Site

The cost savings due to the speed of construction on site may be quantified as:

- Reduced site preliminaries for hire of site huts and other facilities, etc. Typically, site preliminaries are estimated at 8 to 15% of the total construction cost. Therefore, a 50% reduction in time on site can lead to a commensurate saving in preliminaries cost to the contractor. Although site preliminaries are identified in the Bill of Quantities, the benefit of these savings to the client is not necessarily apparent.
- Earlier return on investment to the client. This benefit depends on the business operation, but the minimum level of this benefit is the savings in interest charges on the cost of the land and the average construction cost over the reduced construction period. The maximum level of this benefit is the earning potential of the building when in early operation.
- Loss of the earning potential of the existing facility. This is a real cost to the client that occurs particularly where existing buildings, such as hotels, are extended or modified. A reduced construction period will lead to commensurate savings to the client.
- Predictability of construction program (i.e. less risk of over-runs).

The total benefit of speed of the construction operation can be in the range of 5% to 10% of the total building cost when calculated from the time saving on site in comparison to more traditional site-intensive construction systems.

II. Benefits in The Construction Operation

Normal construction operations are often constrained by the features or locality of the site. Modular construction can lead to considerable benefits in the construction operation and can reduce or alleviate many common problems that may be encountered, such as:

- Limitations on delivery of materials to site in terms of time of day and impact on traffic in the locality working time and other restrictions in sensitive sites (often inner-city locations)
- Noise limitations due to the construction operations, particularly adjacent to existing buildings
- A short 'weather window' for construction, for example in an exposed or inhospitable location
- Lack of suitable site trades or the cost of transporting workers to a remote location
- lack of working space around the building for site storage, site huts, etc.

III. Economy of Scale

The economy of scale in production, therefore, leads to the following benefits:

- Greater investment in the production-line operation, leading to greater speed of assembly
- More emphasis on improvement in design by testing, and by rationalization of details based on ease of manufacture
- establishment of strict QA procedures and avoidance of re-working
- better design, including the possibility of variants at modest additional cost or difficulty
- more involvement of specialist suppliers, e.g. services
- Reduction of waste by efficient ordering and use of materials.

IV. Quality issues

Quality is often the crucial issue to the client who is concerned about the subsequent operation of the building. The following aspects of modular construction have a strong influence on quality:

- Some clients demand a high degree of quality assurance for their business operations, and in their view, a single point procurement route concentrates the responsibility of the manufacturer.
- In modular construction, off-site trials can be carried out to 'prove' the system before installation. This is particularly true of highly serviced units, such as plant rooms, lifts, and kitchens.

- In conventional buildings, many contractors also allow 1 to 2% cost for 'snagging' and 'callbacks'. These costs are considerably reduced when using modular construction, in comparison with site construction.
- Light steel framing is robust and does not suffer from deterioration in performance. Movements are minimal, which avoids cracking of finishes.

V. Application to renovation

The renovation sector represents over 40% of the construction market and has its own features in terms of construction operation. The particular benefits of modular construction in the renovation are:

- Reduced disruption in difficult sites. Units can be lifted easily into place.
- It may not be necessary to move the occupants during the renovation work (true of roof-top extensions).
- Modular units are light in weight and do not require extensive strengthening of the existing structure.

2.11. Environmental Benefit of Modular Construction

The main environmental benefits during the construction operation are derived from the shorter construction period, which lessens the impacts on the local environment. However, there are other, less obvious local environmental benefits of the construction operation, which are identified as follows (RM Lawson, 1999):

- Site installation of the modular units is a rapid and quiet operation that can be done 'just in time', with no requirement for site storage or additional noisy equipment.
- The delivery and installation of the modular units can be timed to observe any site working or road traffic constraints.
- The delivery of a large number of relatively small amounts of site materials is much reduced.
- Less waste is created so dumping of material waste from the site is much reduced. Foundation excavation is minimized and there are fewer potentially wasteful site activities.
- Materials are used more efficiently, with a considerable economy of use in production than is achievable on site.
- The main construction operations are less disruptive to adjacent or connected properties in terms of pollution and associated nuisance, etc.
- Modular units are very stiff and strong, due largely to requirements for lifting and transportation, and therefore have a solid 'feel'.
- All light steel framed structures require minimal maintenance and no callbacks for shrinkage, etc.

2.12. Limitation of Modular Construction

Modular construction can have disadvantages as well as advantages. This section discusses the main limitations that were identified (Torre, 1994).

Need for Additional Material: The need for additional material is a disadvantage of modular construction that develops from the structural requirements of the modules. The additional material can include more or larger structural members, more bracing for transportation loads, and redesigned (or increased capacity) structural connections. Additional bracing is often placed on the modules. The bracing, which provides the modules with strength, stiffness, and stability during transport and erection also provides support for equipment and can become permanent.

Need for Additional Construction Effort: More planning and scheduling is required for a modular project than a conventional project because of the greater interdependence of planning, design, fabrication, and transportation, handling, and erection. In modular construction, the effort involved in the fabrication activity increases compared with that of conventional construction due to the transfer of onsite work into fabrication shops. The need for inspection and supervision in fabrication shops can increase because a larger number of workers are involved in assembling the modules in parallel in various fabrication shops. Transportation, handling, and erection, which are more complex in modular construction, set limitations on the module dimensions and weight and must be addressed early in the planning of the project.

Reduced Adaptability to Design Changes: reduced adaptability to design changes is another disadvantage of modular construction. Modular construction increases the interdependency of construction activities, thus, changes in a design can disrupt a wide variety of inter-related activities. Once the design has been approved and the other interdependent activities are undertaken, the design must not change; modular construction is not adaptable to design changes.

Need for Additional Coordination of Activities: As the interdependence of construction activities increases, the need for communication and control mechanisms between activities increases. For example, in conventional construction, the work performed on the facility at the construction site can be inspected in place by representatives of the owner and the responsible engineer. However, in a modular construction project, modules are often fabricated and assembled at various locations (perhaps in different countries) and the ease of physically inspecting the facility and communicating among the individuals involved in inspection is not a simple process.

2.13. Modular vs Traditional Construction

Commonly known as prefabricated buildings, modular constructions are pre-built units created directly in a factory keeping in mind the precise requirements of the property and the type of construction these units are being designed for. These modules are then delivered to the site of construction and assembled with the help architectural experts. However, traditional construction defines the ordinary method of construction which utilizes

a standard block and brick method to build a structure. This method of construction builds the internal load-bearing sheet of the walling using brick and mortar which is then linked to bracing of steel bars and beams. Though traditional construction continues to be a prevalent method, the use of modular units for residential and commercial construction is progressively growing. Here’s a closer look at the difference between these two methods of construction based on specific parameters (Northgate Industries Ltd, 2017):

Table 2.1: Modular vs Traditional Construction

Parameter	Modular	Traditional
Time	Irrespective of the scope of the project, most modular constructions require only a few months for completion as they are designed and manufactured simultaneously in a factory with precise planning and measurement.	Traditional constructions are conducted linearly. This implies that the next step of construction cannot be executed until the previous one is finished. This increases their time of completion greatly.
Structural integrity	Modular units are constructed in the controlled milieu of a factory with constant supervision from various experts. These modules are usually built in compliance with the provincial construction codes with suitable licenses and permits.	Sustainability of traditional construction is largely dependent on the experts employed and the materials used, making them less reliable than modular unit.
Cost	Since the time required for these projects is much less modular constructions are more cost effective than traditional. Furthermore, utilizing used modular buildings help individuals to save up to 50% on overall construction expenses as their cost of assembly and installation is much lower.	The time of completion is much longer in traditional constructions as their progress is dependent on external factors such as weather conditions and labor dexterity. Hence, the cost is relatively higher.
Sustainability	Modular constructions are built with superior quality materials keeping in mind environmental sustainability of the construction.	Sustainability of these projects deepens on the skills of the contractors involved.

Source: (Northgate Industries Ltd, 2017)

2.14. Best Practice in Modular Construction

I. Habitat 67, Montreal, Canada

Habitat 67, designed by the Israeli-Canadian architect Moshe Safdie as the Canadian Pavilion for the World Exposition of 1967, was originally intended as an experimental solution for high-quality housing in dense urban environments (see Figure 2.10). Safdie explored the possibilities of prefabricated modular units to reduce housing costs and allow for a new housing typology that could integrate the qualities of a suburban home into an urban high-rise (Archdaily, 2008).



Figure 2.10: Habitat 67 (Archdaily, 2008)

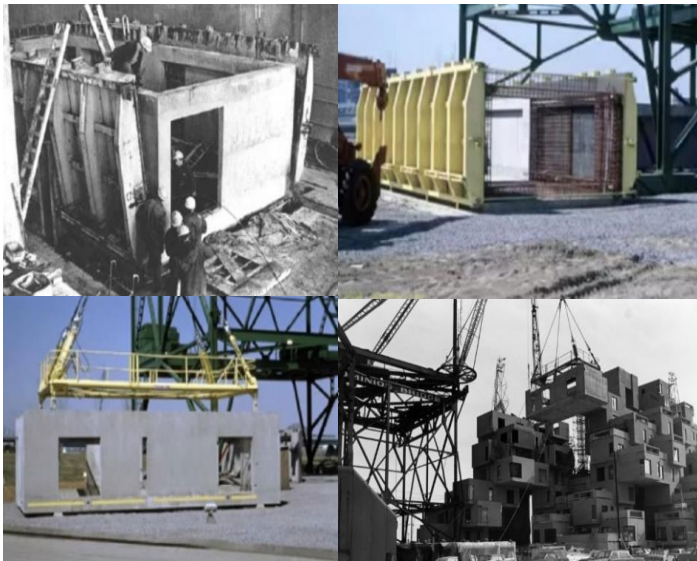


Figure 2.11: Habitat 67 construction (Decker, 2015)

A factory was built beside the Habitat site. It contained four large molds in which the standardized units were made. To make each of them, a reinforcing steel cage was placed inside the mold, then concrete was poured around the cage as illustrated in Figure 2.11. After the concrete cured, the unit was moved to an assembly line where a wooden sub-floor was installed with electrical and mechanical services below it. Windows and insulation were then inserted; afterward prefabricated bathrooms and kitchen modules. Finally, the unit was moved to its position in the building (Psoma, 2017).

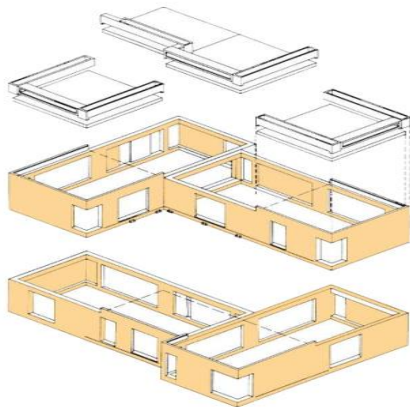


Figure 2.12: Habitat 67 module unit (Decker, 2015)

Figure 2.12 illustrates the prefabricated construction method but also allowed freedom to arrange modules in the variety of ways Safdie proposed 18 variations of apartment layouts. The complex is comprised of 354 units and 150 residences, and broken-down modularly 6% use one boxes, 60% use two boxes, 29% use 3 boxes, 4% use 4 boxes, 1% use 5 boxes, one unit has eight boxes (Decker, 2015).

II. Nakagin Capsule Towers, Tokyo, Japan

Built in the Ginza area of Tokyo, a total of 140 capsules are stacked and rotated at varying angles around a central core, standing 14-stories high (see Figure 2.13). Architect Kisho Kurokawa was very innovative in his creation of the Nakagin Capsule Tower in 1972, which was the first capsule architecture design. The module was created with the intention of housing traveling businessmen that worked in central Tokyo during the week. It is a prototype for the architecture of sustainability and recyclability, as each module can be plugged into the central core and replaced or exchanged when necessary (ArchDaily, 2008).

The capsules were designed as prefabricated modules designed so that all contain the same parts, factory assembled, in order to transfer the finished capsules to work for placement in the building.

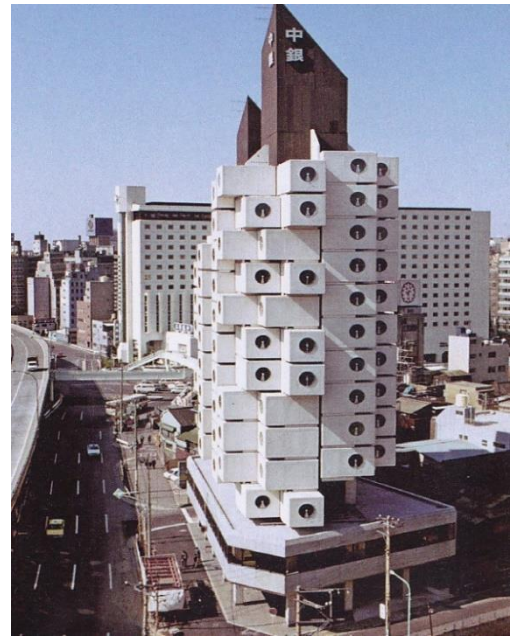


Figure 2.13: Nakagin Capsule Tower (ArchDaily, 2008)

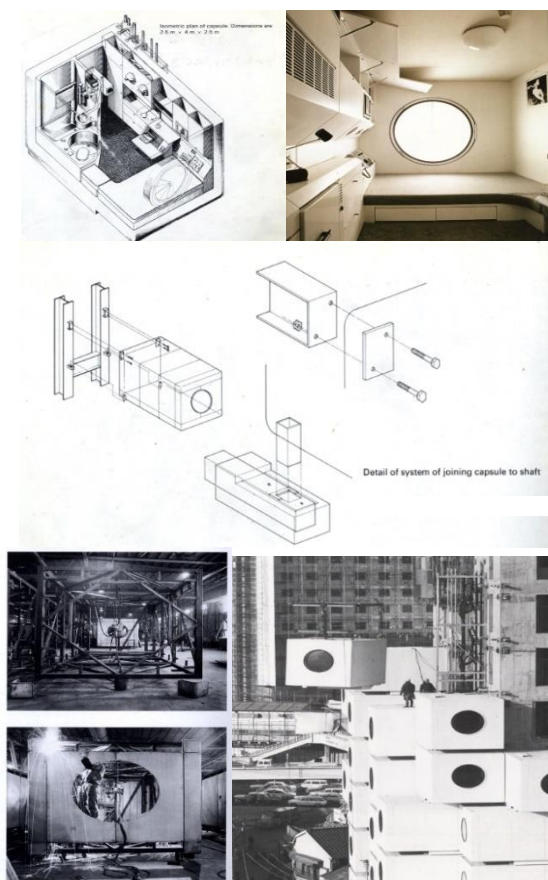


Figure 2.14: Nakagin Capsule Tower (photo from Kisho Kurokawa architecte: Le Metabolism 1960-1975)

The capsules adhere to the cores by four bolts high strength. The process of building these works similar to shipping containers, where a box-shaped structure of steel, as light as possible, to which all other parts are welded (see Figure 2.14). The capsules were designed as prefabricated modules designed so that all contain the same parts, factory assembled, in order to transfer the finished capsules to work for placement in the building. The capsules adhere to the cores by four bolts high strength. The process of building these works similar to shipping containers, where a box-shaped structure of steel, as light as possible, to which all other parts are welded. The exterior of the capsules is composed of panels of galvanized steel of 1 x 2 m 2 x 3 m. These measures are due to the number required for the manufacture of all capsules and the small size of the factories where they have produced panels. Structural cores are constructed of rigid steel frames and concrete. From the ground floor to the second floor it was used reinforced concrete while the upper floors lightweight concrete was used (wikiarquitectura.com, 2018).

2.15. An Overview of The Construction Industry and Housing Trends in A.A

I. Characteristics

In Ethiopia, the sector has registered a remarkable growth, over the last 11 years there has been increased investment in the development and expansion of various infrastructure projects. Among the major development's construction of road infrastructure, real estate developments, and condominium housing projects are some of the examples. More specifically public infrastructure development projects by Ministry of Education and Health and road infrastructure projects account the significant portion of the investment outlay on construction activities. Its contribution to the Growth Development Program (GDP) at the constant price has increased from Birr 2, 853,336,000 to Birr 8,185,747,000 at an average annual growth rate of 12.43%. Similarly, the percentage share of the construction sector to GDP at the constant price has increased from 4.5% in 2000/01 to 5.8% by 2009/10 (Ministry of Urban Development and Construction, 2012).

II. Performance Constraints

The inefficient and deteriorated state of the construction industry with poor performance has detrimental effects on the development of the industry. Weaknesses, problems and constraints hampering the performance and development of the industry include (Ministry of Urban Development and Construction, 2012):

- Low capacity and capability of the local contractors and consultants due to weak resource base and inadequate experience.
- Inadequate and erratic work opportunities, inappropriate contract packaging of works which favors foreign firms in donor-funded projects, low public investment in infrastructure projects and over-dependence on donor funding.
- Inefficient and non - transparent procurement Systems Corruption and financial mismanagement in public/private sectors.
- Lack of supportive institutional mechanisms in terms of financial credit facilities, equipment for hire and professional development.
- Poor working environment, including low standards of safety and occupational hazards on construction sites.
- Weak and non-facilitative policies and regulatory framework and low productivity and quality Low technological base.

III. Housing Stock (UN-HABITAT, 2017)

a) Formal Sector Housing

Formal housing refers to housing owned by individuals, private investors and by government and that complies with all legal standards - the land lease law as well as building codes and standards. Housing delivery systems under this group include housing cooperatives, privately owned individual houses, private real estate development, government housing for civil servants and the “newly” initiated “low-cost” condominium housing. In 2004, for example, formal sector housing delivery systems constituted the larger share of the housing stock 47% in the city of Addis Ababa.

b) Private Housing Cooperatives

The private housing cooperative is one of the major formal housing delivery mechanisms. It is a continuation of a housing delivery system introduced during the Dergue regime. Post-1991 private housing cooperatives made 75 to 250m² plots of land available for individual households. Under the private housing cooperative system groups of individuals establish cooperatives which then request leased land from the government. Land allocation is based on a lottery system. Between 1995 and 2002 this system helped deliver 2,049 plots to housing cooperatives in Addis Ababa. Between 2004 and 2005, that number increased significantly to 60,000 plots awarded to about 2000 cooperatives. Private cooperatives contributed significantly to formal housing supply (about 25% of the total housing supply) during the past decades.

c) Real estate Housing

Although the housing stock delivered by the private real estate sector is minimal, the sector has significantly grown in the post-1991 period, focusing primarily on high-income households in Addis Ababa in particular. Consequently, the real estate sector contributes little to reducing the housing demand by low-income households. The low contribution of the private real estate sector in low-cost housing persists in spite of attempts by the Addis Ababa city administration to attract private real estate development to the low-cost housing market by offering affordable land lease arrangements and other incentives. The absence of affordable mortgage finance has been identified as a key impediment for these providers to enter into the low-cost housing sector.

d) Government Rental Housing

Government rental housing concerns delivery of housing owned and managed by public institutions. Accordingly, the Agency for the Administration of Rental Houses (AARH) and Kebele Administrations are the two public institutions that manage and administer government-owned housing units. More than 90% of the government-owned housing units are administered through Kebele schemes. They are usually of low-standard, constructed with mud and sticks. Kebele housing constitutes more than 30% of the housing stock in Addis Ababa.

IV. The Integrated Housing Development Program (IHDP)

The Integrated Housing Development Program (IHDP) is a government-led and financed housing provision program for low-and-middle-income households in Ethiopia. The program was launched in 2004 (1996 in the Ethiopian calendar) by Arkebe Oqubay the Mayor of Addis Ababa. Within the IHDP, specific projects are undertaken on either brown-field sites or slum areas that are cleared and residents re-housed. The common attribute of each project is the type of housing developed, condominium housing: multi-storied housing units for several households where communal areas are jointly owned and managed. The mandate of the IHDP is to reduce slum areas in the city by 50 percent and address and improve the unemployment percentage in the capital within five years, through the building of nearly 400,000 new units nationally. As of mid-2010, the government had built a total of 80,257 housing units in Addis Ababa (UN-HABITAT, 2011).

Data from the city's Housing Development and Administration Agency shows a significant increase in condominium unit prices between the years 2006 and 2013. This partially explains the new unaffordability. For instance, during these years, the monthly mortgage unit price that was set for a studio, one bedroom, two- bedroom, and three-bedroom steadily increased by 183, 274, 260, and 214 percent respectively. An additional factor for housing cost escalation is persistent inflation over the past couple of years. According to the (World Bank, 2015), the construction cost for condominium housing in Addis Ababa has more than tripled from ETB 1,000 per square meter in 2005 to over ETB 3,000 in 2014. Increasing construction costs, in turn, translate into higher monthly mortgage payments for condominium owners. Out of 1,181 condominium unit owners, 648 (52%) reported that they had defaulted paying their mortgage. On the other hand, nearly 36% condominium owners reported that they have paid off their condominium mortgage debts way before the scheduled grace period (UN-HABITAT, 2017).

2.16. Summary of the Literature

Literature review obtained a lot of information background for this study especially on historical development of modular construction, experiences of modularization in different countries of the world as well as related construction practice in Ethiopia. Also, the literature review had given information about types and components of modular building systems including major aspects on design of modular buildings such as requirements for transportation, lifting and installation, requirements for overall stability and integrity, Cladding materials, acoustic insulation of separating floors and services and drainage. Major advantages and limitation of modular building systems, best practice of modular construction on building projects and overview of the construction industry and housing in Addis Ababa were another covers of topics in literature review that gives additional information for the study in order to clarify advantages of modular building system in building construction industry of Addis Ababa.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Study Area Description

Addis Abeba lies an altitude of 2,300 meters (7,500 ft), located at 90 1'48"N, 38044'24"E which is surrounded by Oromia regional state (World Population Review, 2018). This city's name is spelled "Addis Abeba," which means "new flower" in the Amharic language. Empress Taitu named the city, which is also known by the Oromo language name "Finfinnee." Other parts of the city were called hora Finfinnee, meaning "hot springs." The city is located at the southern foot of Mount Entoto, in the Entoto Mountains, on a plateau that is crossed by numerous streams and surrounded by hills and mountains, in the geographic center of the country. Addis Ababa had a population of 3,147,000, according to the 2007 census, consisting of 1,511,000 men and 1,636,000 women, and an eight percent annual growth rate. The city is home to 23.8 percent of all urban dwellers in Ethiopia, and has an estimated density of 5936.2 per square kilometer (The New World Encyclopedia, 2018).

To conduct the research 96 under construction building sites were surveyed through questionnaire all located within Addis Ababa city in order to find out the status of modular building system utilization, available challenges for adaptation of modular construction and building construction stakeholders role in modularization of building systems. Figure 3.1 illustrates the location map of Addis Ababa and site location of sampled construction projects, and also description of site location was tabulated in Table 3.1. In other ways, numbers with bubble marks pointed on map in Figure 3.1 indicates the site location of construction projects listed in Table 3.1. However, the selected sites were in condition of under construction; most of them on stage of super-structure construction, some were on substructure construction and others on finishing progress.

The selection criteria for those sample construction sites were all sample projects should be under construction and also must be located in Addis Ababa. This because the under-construction project to allow the researcher to get site managers and professionals on underway construction project for input of relevant information needed to conduct the research, and therefore buildings on service were not selected. Also, building function type, story heights, types of building systems and construction materials were not the criteria for selection of sites for sampling.

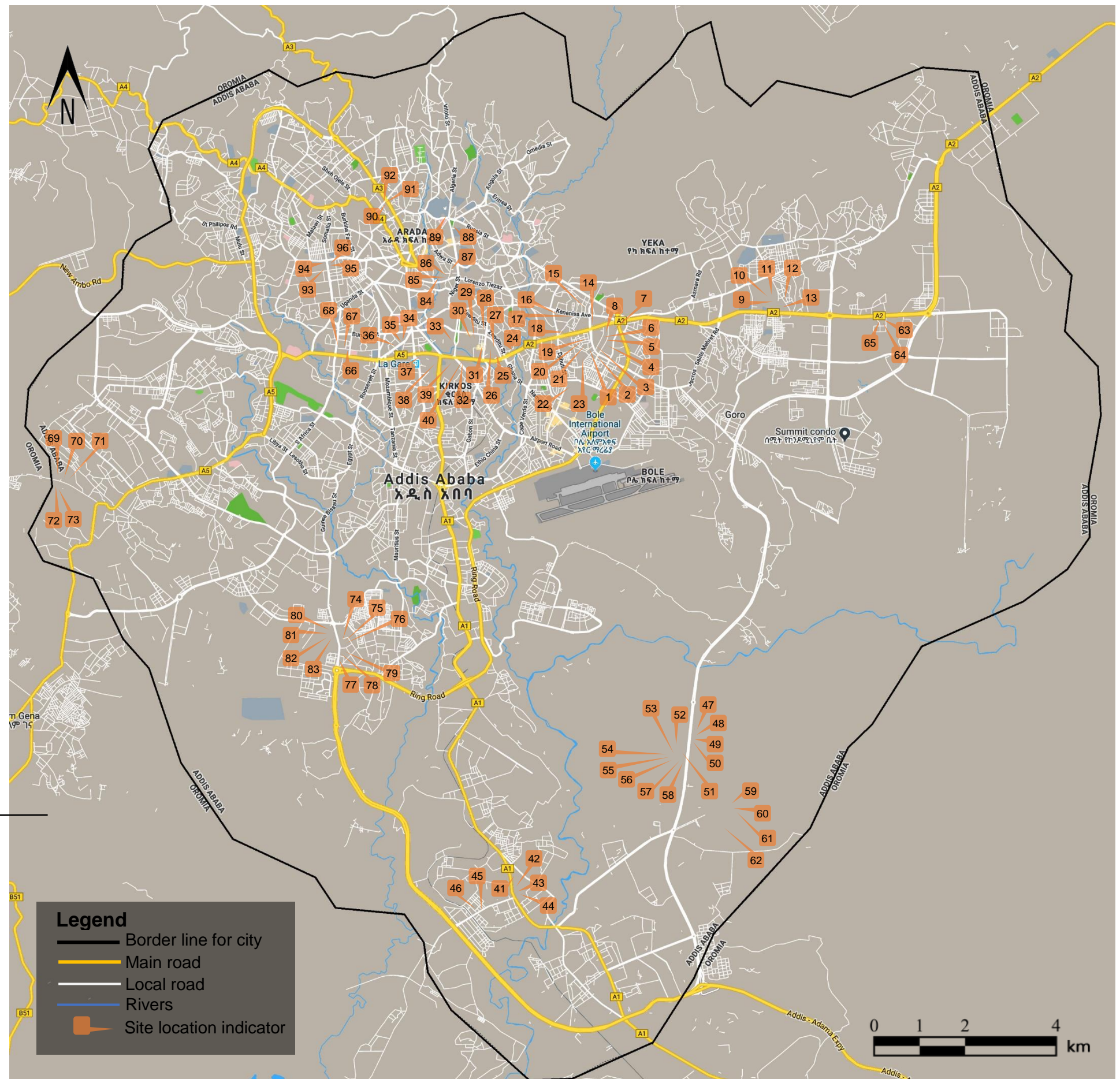


Figure 3.1: Location of Study area and sample construction sites (Google map)

Table 3.1: Selected projects site location

No	Location	No	Location	No	Location	No	Location
1	Apartment building project located at 50m inside from Lem Hotel to Gergi street	25	Commercial mixed-use building project located at Zewditu street	49	20/80 Apartment building project located at Kuyi Fiche condominium site	73	40/60 Apartment building project located at Kara condominium site
2	Hotel building project located at street from Lem Hotel to Gergi	26	Ministry of Foreign Affairs office building project located at Zewditu street	50	20/80 Apartment building project located at Kuyi Fiche condominium site	74	Warehouse building project located at 80m inside street from St. Arsema to Haile Garment
3	Apartment building project located at street from Lem Hotel to Gergi	27	Commercial mixed-use building project located at Zewditu street	51	Industrial building project located near Kuyi Fiche condominium site	75	Industrial building project located at 100m inside street from St. Arsema to Haile Garment
4	40/60 Apartment building project located at 20m inside street from Megenagna to 24	28	Commercial mixed-use building project located at D.A.R. Sahara street	52	Warehouse building project located near Kuyi Fiche condominium site	76	Industrial building project located at 120m inside street from St. Arsema to Haile Garment
5	40/60 Apartment building project located at 100m inside street from Lem Hotel to Gergi	29	Hotel building project located at Tito street	53	Warehouse building project located near Kuyi Fiche condominium site	77	Warehouse building project located at street from St. Arsema to Haile Garment
6	40/60 Apartment building project located at 150m inside street from 22 to Megenagna	30	Hotel building project located at 50m inside from Tito street	54	Warehouse building project located near Kuyi Fiche condominium site	78	Warehouse building project located at 50m inside street from St. Arsema to Haile Garment
7	Private organizations employee's social security HQ office building project	31	Hotel building project located at Guinea Conakry street	55	Warehouse building project located near Kuyi Fiche condominium site	79	Industrial building project located at 50m inside street from St. Arsema to Haile Garment
8	40/60 Apartment building project located at 50m inside street from 22 to Megenagna	32	Hayat hotel building project located at Africa Avenue	56	Industrial building project located near Kuyi Fiche condominium site	80	Residential villa building project located at 70m inside street from St. Arsema to Haile Garment
9	Residential villa building project located at inside 120m street from Gurdshola to CMC	33	Office building project located at Menelik II Avenue	57	Industrial building project located near Kuyi Fiche condominium site	81	Residential villa building project located at 70m inside street from St. Arsema to Haile Garment
10	Residential villa building project located at inside 180m street from Gurdshola to CMC	34	Nib bank HQ building project located at Ras Abebe Aregay street	58	Warehouse building project located near Kuyi Fiche condominium site	82	Residential villa building project located at 50m inside street from St. Arsema to Haile Garment
11	Residential villa building project located at inside 200m street from Gurdshola to CMC	35	Zemen bank HQ building project located at Ras Abebe Aregay street	59	20/80 Apartment building project located at Kuyi Fiche condominium site	83	Residential villa building project located at 50m inside street from St. Arsema to Haile Garment
12	Residential villa building project located at inside 100m street from Gurdshola to CMC	36	Hibret bank HQ building project located at Ras Abebe Aregay street	60	20/80 Apartment building project located at Kuyi Fiche condominium site	84	Residential villa building project located at 80m inside from General Wingate street
13	St. Michael Church building project located at street from Gurdshola to CMC	37	Office building project located at street from Leghar to Mexico	61	20/80 Apartment building project located at Kuyi Fiche condominium site	85	Commercial mixed-use building project located at General Wingate street
14	Commercial mixed-use building project located in front of Lem Hotel bridge	38	Commercial mixed-use building project located at Ras Biru street	62	Clinic building project near Kuyi Fiche condominium site	86	Commercial mixed-use building project located at 200m inside from General Wingate street
15	Building project for clinic rental located at 80m inside from Kenenisa Avenue	39	Office building project located at 50m inside from Africa Avenue	63	40/60 Apartment building project located at street from Gurdshola to CMC	87	Commercial mixed-use building project located at 250m inside from General Wingate street
16	Commercial mixed-use building project located at Kenenisa Avenue	40	Kirkos sub city HQ building project located at Jomo Kenyatta street	64	40/60 Apartment building project located at street from Gurdshola to CMC	88	Commercial mixed-use building project located at 50m inside from King George IV street
17	Hotel building project located at street from 22 to Shola market place	41	Akaki stadium building project located at Akaki street	65	40/60 Apartment building project located at street from Gurdshola to CMC	89	Educational building project located at Weatherall street inside 6Killo campus
18	Commercial mixed-use building project located in front of 22 bridge	42	Residential villa building project located at 150m from Akaki stadium	66	Commercial mixed-use building project located at 50m from Chad street	90	Ethiopia News Agency building project located at street from Semen Hotel to Adisu Gebeya
19	Apartment building project located at 120m inside street from 22 to Lem Hotel	43	Residential villa building project located at 150m from Akaki stadium	67	Commercial mixed-use building project located at Liberia street	91	Commercial mixed-use building project located at street from Semen Hotel to Adisu Gebeya
20	Residential villa building project located at 150m inside street from Lem Hotel to Gergi	44	Residential villa building project located at 200m from Akaki stadium	68	Commercial mixed-use building project located at Liberia street	92	Hotel building project located at street from Semen Hotel to Adisu Gebeya
21	Residential villa building project located at 50m inside street from Lem Hotel to Gergi	45	Residential villa building project located at Gelan condominium site	69	40/60 Apartment building project located at Kara condominium site	93	Commercial mixed-use building project located at Somalia street around Atobis Tera
22	Adey Abeba stadium building project located at street from 22 to Bole square	46	Residential villa building project located at Gelan condominium site	70	40/60 Apartment building project located at Kara condominium site	94	Commercial mixed-use building project located at Somalia street around Atobis Tera
23	Residential villa building project located at 50m inside street from Megenagna to 24	47	20/80 Apartment building project located at Kuyi Fiche condominium site	71	40/60 Apartment building project located at Kara condominium site	95	Commercial mixed-use building project located at Somalia street around Atobis Tera
24	Hotel building project located in front of Uriel church street from Uriel to 22	48	20/80 Apartment building project located at Kuyi Fiche condominium site	72	40/60 Apartment building project located at Kara condominium site	96	Commercial mixed-use building project located at Somalia street around Atobis Tera

3.2. Sample Design and Technique

I. Population

For this research, the target population was building construction projects, respondent professionals on project sites and project construction companies within the city of Addis Ababa located in all sub-cities. The responses taken from professionals for the study represent their host company's status and reflection because of their work relation with employer company and works on site where they located.

II. Sampling Unit

The sample unit of the study was each individual on going building construction project, each professional and project owner construction company in each of project sites that is located in the city of Addis Ababa within all sub-cities.

III. Sample Size

From projects under construction, 96 projects were selected for the sample to represent the whole population. The number of populations for total construction projects were unknown for the time of data collection because of unpredictable projects duration of each construction site. However, samples were classified based on utilization and non-utilizations of modular components with different methods of further categorizations to study the problem with different angles of observation. Also, to study challenges for those adaptations and utilization of modular building system samples were classified based on reactions towards the given questionnaires.

Cochran's Formula has been used to determine the sample size for unknown population size (Statistics How To, 2018). Where: n_o is sample size, z is confidence interval corresponding to a level of confidence; p is population proportion and e is precision or error limit. Hence, by considering the value of $Z=1.96$ (95% Confidence Interval), $p=0.5$ (for unknown population size) and level precession $e=10\%$.

IV. Sampling Techniques

$$n_o = \frac{Z^2 p (1-p)}{e^2} \qquad n_o = \frac{(1.96)^2 (0.5) (1-0.5)}{(0.1)^2} \qquad n_o = 96$$

The method of sample selection used for the study were both random and stratified selections. The number of samples for population (project sites) were stratified reasonably based on the amount of building projects that were permitted for construction in 2009(E.C) and 2010(E.C) by Addis Ababa city administration. This help distribution of samples based on propositions of projects in each sub city relative to each other, and finally samples were selected randomly in each sub-city's based on distributed number of samples that summarized in Table 3.2.

Table 3.2: Number of projects selected for sample

No	Sub-City	Number of projects permitted for construction in 2009 & 2010 (E.C)	Number of projects selected for a sample	% of Data sample
1	Addis Ketema sub-city	59	4	4%
2	Akaki-Kalitiy sub-city	95	6	6%
3	Arada sub-city	107	6	6%
4	Bole sub-city	554	32	33%
5	Gullele sub-city	43	3	3%
6	Kirkos sub-city	287	17	18%
7	Kolfe-Keranio sub-city	76	5	5%
8	Lideta sub-city	57	3	3%
9	Nifas-Silk-Lafto sub-city	163	10	10%
10	Yeka sub-city	168	10	10%

3.3. Data Source

For the purpose of this research study both primary and secondary sources of data were used.

I. Primary Data Source

Construction site managers, professional graduates (from architecture, civil engineering and construction management), design office workers, government officials and personal observation were the main sources of the primary data.

II. Secondary Data Source

Secondary data source for this research was collected from textbooks, reference editions, journals, magazines, reports, documents of standards and also official publications of different organizations and government agencies. However, those materials were accessed from libraries, online resources and data that has been published by government agencies and private companies that readily available and free of charge.

3.4. Data Collection Techniques

For collection of data from primary and secondary sources, various data collection techniques were employed. Here the techniques explained as follows:

I. Primary Data Collection Technique

The following data collection techniques were used to collect these primary data:

Questionnaire

Structured questionnaires were distributed to representative respondents located at ongoing projects sites in all sub-cities of Addis Ababa and also collected by data collection assistants. The size and the layout of the questionnaire were designed to make completion of filling as easy as possible by consideration of the targeted population, whereas possible answers were given in a multiple-choice and ranking format. In addition, open-ended questions were used with little space left for answers to encourage brief answering. Also, in order to deepen the study for major challenges for modularization of building systems, secondary questionnaires were used for the study of facts in a design office, practicing professional graduates and some regarded bodies.

Interview

Interviews were used to collect information from government officials such as Addis Ababa city building permission and regulation authority bureau, and also in some way free interview after the respondents filled the questionnaires on the concepts of modular construction.

Direct observation

The researcher conducted observations on the spatial and activity on the site to check the practice of construction, this helped the researcher a direct assessment on site on the utilization of modular components and to get reactions from respondent's opinion. Also, the researcher visited some industries that produce modular building elements.

II. Secondary Data Collection Technique

The secondary data were collected through reading, note taking and extracting of trusted websites from sources such as textbooks, reference editions, journals, magazines, reports and documents of standards; those accessed from libraries and online resources.

3.5. Research Design

Mixed method research design was employed because both quantitative and types of data qualitative were used to conduct the research. The Mixed types of quantitative and qualitative approaches were used under the two structures of inquiry modes. The first inquiry mode was the structured approach in which everything that forms the research process, objectives, sample and the questions planned to ask the respondents was predetermined. The second inquiry mode was unstructured approach It order to explore the nature of a problem, issue or phenomenon without quantifying it, such as responses of professionals towards challenges of modular building system utilization during triangulation of facts. However, Figure 3.2 illustrates diagram of research design that used to conduct the research.

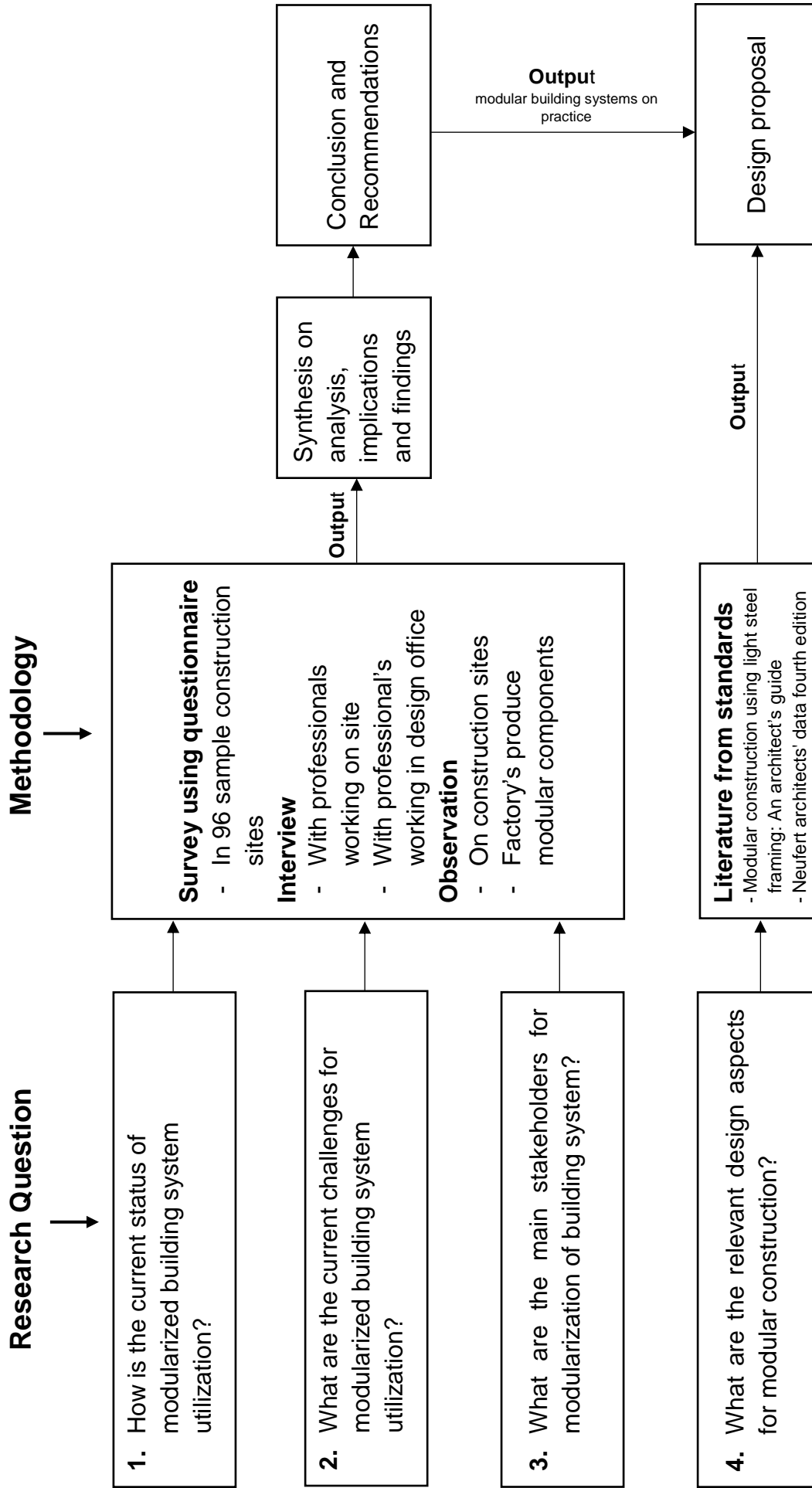


Figure 3.2: Diagram illustrating Research Design

3.6. Data Analysis

To meet the specific objectives of the research the data collected from both primary and secondary sources require rigorous analysis and interpretation, which provide comprehensive and meaningful results. To achieve this end the data that was collected from the survey using questionnaires was analyzed using descriptive statistics such as percent, frequency and percentile ranks. Microsoft Excel has been used to analyze the data with respective formulation and techniques and ArchiCAD has been used for design of modular buildings for proposal. In addition, discussions of respondents and observations as well as some open-ended opinions are analyzed qualitatively.

3.7. Data Presentation

Data presentation techniques were used depending on the nature of the data. The analyzed quantitative data was presented by using tables, graphs, percentages, and narrative descriptions. The qualitative data both from open questions and interviews was simply discussed and analyzed qualitatively in a way it presents the data properly.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. The Current Utilization Status of Modular Building System

I. General Utilization of Modularization

From survey data results out of 96 ongoing building projects 59 (61%) of projects utilize at least one type of modular component. However, 37 (39%) of projects doesn't utilize modular components.

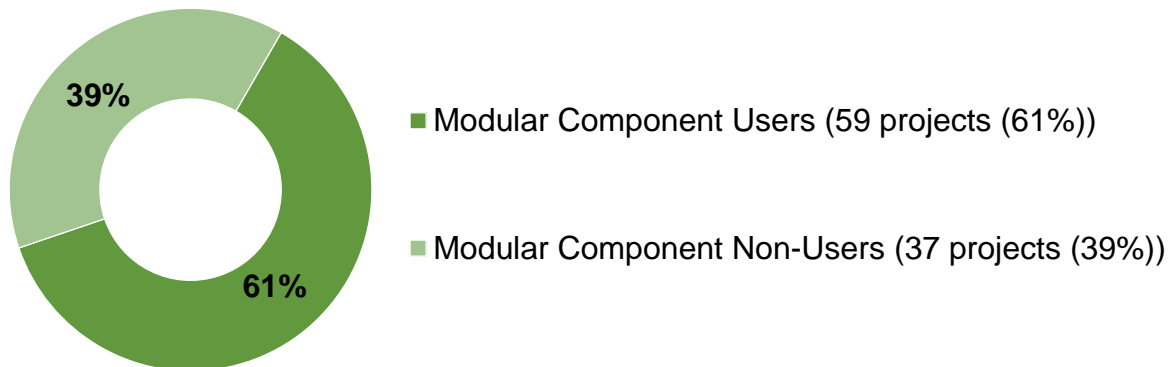


Figure 4.1: General Utilization of Modular Components

II. Utilization by Construction Company Types

Based on a survey at least one modular component were utilized above average of building construction projects both project work owned by general and building contractors in their building projects as shown in Table 4.1, although building contractors lead the utilization of components by firm type by closest to 64% from their respective type of contractors.

Table 4.1: Utilization of Modular Components by Construction Company Type

Project work Contractors Type	User of Modular Components	Non-user of Modular Components	Total Number of Contractors
General Contractor (GC)	31 projects (60%)	21 projects (40%)	52
Building Contractor (GC)	28 projects (64%)	16 projects (36%)	44
Total	56 projects (61%)	37 projects (39%)	96

As project work owned by contractor's grade type tabulated on Table 4.2, in all grades of contractor the utilization is more than an average. Grade-2 type contractors have the best utilization with an approximation to 75%, in case Grade1 and 2 have utilization of modular components above 70%. But contractor grade below five have a low record of utilization relative to other grades of firms. Also, Table 4.2 analysis shows that there is a relative increase in utilization through increasing of firm's grade category, but in the case of grades institutional capacities are increasingly coming from Grade-5 to Grade-1.

Table 4.2: Utilization of Modular Components by Contractors Grade Type

Project work Contractors Grade	User of Modular Components	Non-user of Modular Components	Total Number of Contractors
Grade - 01	12 projects (71%)	5 projects (29%)	17
Grade - 02	14 projects (74%)	5 projects (26%)	19
Grade - 03	8 projects (57%)	6 projects (43%)	14
Grade - 04	5 projects (63%)	3 projects (37%)	8
Grade - 05	9 projects (53%)	8 projects (47%)	17
Less than Grade - 05	11 projects (52%)	10 projects (48%)	21
Total	59 projects (61%)	37 projects (39%)	96

III. Utilization by Building Project/Function Type

Utilization-based on building project type is important to study the current utilization of modular components in Addis Ababa building construction industry, to identify which building project type is consuming components relative to other categories.

Figure 4.2 illustrates the stake of building projects/function in the utilization of modular components from 59 user projects. Based on the data apartment building projects consumes the largest stake of components more than a quarter (34%) from the list followed by commercial buildings (22%), in which together make half of the total utilization.

Although recreational, religious, educational and healthcare facility building functions have the least utilization stake which is below 2% each and the rest building project types consume relatively with a closer average greater than 7%.

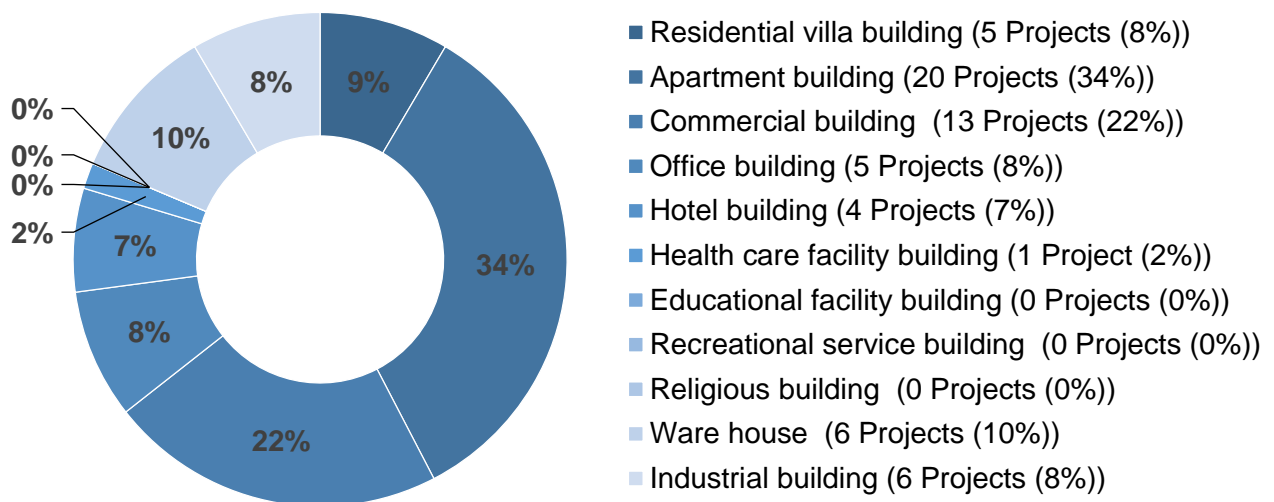


Figure 4.2: Stake of Utilization of Modular Components by Building Function Type Out of 59 Users Projects

In another way Table 4.3 analyze utilization of modular components by respective building project category. Based on results, apartment, warehouse and industrial building projects utilize components by more than 75% of projects in their category, but apartment building projects are the top consumers, about 87% utilize modular components. Also, commercial, office and hotel building utilize components by above half of project numbers in each category.

Table 4.3: Utilization of Modular Components Per Building Project Type

Building Function Type	Number of surveyed projects	Number of Modular Component Users	Percentage of Utilization in Respective Building Function
Residential villa building	17	5	29%
Apartment building	23	20	87%
Commercial building	19	13	68%
Office building	9	5	56%
Hotel building	8	4	50%
Health care facility building	2	1	50%
Educational facility building	1	0	0%
Recreational service building	2	0	0%
Religious building	1	0	0%
Ware house	8	6	75%
Industrial building	6	5	83%
Total	96	59	61%

However recreational service, residential villa, and religious building projects have the least consumption on their project category. But recreational service, health care, educational and religious building projects were with few project numbers which is less than five from all respondent’s project that affect the variation of data with greater amount of percentage.

IV. Modular Components Utilization

This subtopic demonstrates utilization of modular component types, which helps to analyze and investigate which type of component is utilized much or less and what building project type utilize what type modular components based on respondent’s selection frequency’s, that helps more to find challenges on adaptation of those types of building systems in Addis Ababa with broad results understanding. That also important to identify which project type needs more assistance and which modular component has a challenge in utilization.

a) Utilization by Type of Modular Components

Table 4.4: Utilization by Type of Modular Components

Modular Component Type	Number of User projects	Percentage of Utilization out of 96 sites
Prefab walling Modules	34	36%
concrete frames	36	39%
Steel frame	9	9%
Wood frame	1	1%
Roofing members	43	47%
Prefab foundation	0	0%
Roof Module	10	10%
Furnished Room Modules	1	1%
Elevator Modules	0	0%
Stair Modules	1	1%
Plant Room Modules	5	5%
Slab Modules	1	1%
Industrial Modules	4	4%
MEP System Modules	12	13%

Roofing frames/members are those produced both with on-site and off-site manufacturing made from wood and steel framing that is in the form of a module which is a common type of construction in a conventional way, but it had better utilization than others by 47%. On other hand concrete members/frames, such as precast concrete beams and prefab wall modules such as agrostone panels, both have utilization by about 39% and 36% respectively. And this followed by roof modules those assembled and lifted to the roofing place on site, especially in industrial constructions.

However, elevator modules, volumetric furnished room modules, prefab foundation, slab and staircase modules have the least number of practices in the surveyed building construction projects as shown on Table 4.4.

b) Utilization by Building Element Type

Based on survey result analysis on Figure 4.3 most of modular components are used for interior partitions by about 61% out of all 59 user projects, followed by its utilization with floor and slab construction (47%) and roof construction (44%).

In other way MEP parts with minimum complexity are utilized below 10% of the application, also plant room modules and stair modular construction are utilized relatively with the minimum amount. Also, foundation and elevator module construction has a record of closest to 0% of utilization.

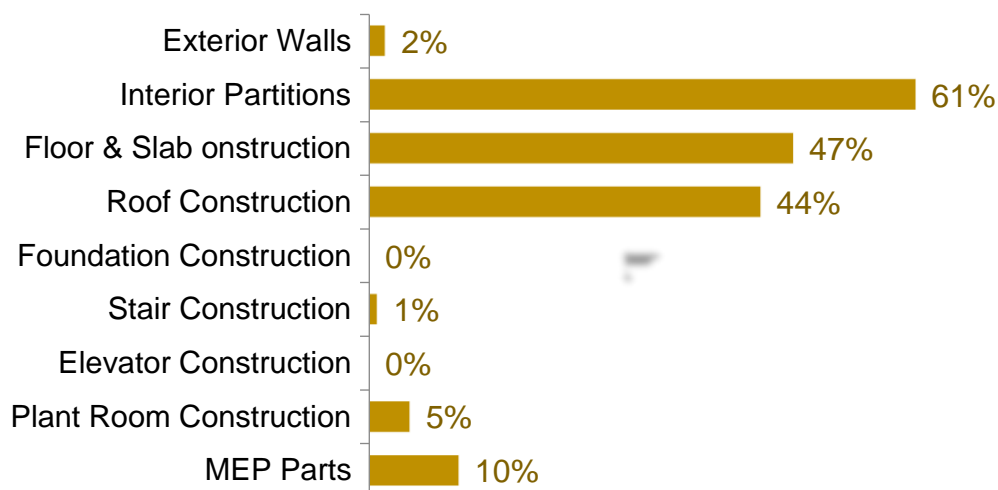


Figure 4.3: Modular Components utilization by Building Elements Type

c) Utilization by Project Completion

Among 59 utilizers of modular components, 47% & 37% of projects were completed with modular components 0% - 5% and 5% - 10% each, in another way 84% of projects were completed their buildings by about less than 10% with modular components. Also, 5% of projects in the utilization of components category are completed their construction of building with 10% – 25% with modular components, although 2% (1 project) constructed its building with above average (50% - 75%) amounts of modular materials. However, there were no projects that could complete their project above 75% or full completion of projects with modular building construction components based on survey analysis on Table 4.5.

Table 4.5: Modular Components Utilization by Project Completion

Percentage of A Single Project Completion with Modular Components	Number of Projects	Percentage of Out of 59 User Sites
0%-5%	28	47%
5%-10%	22	37%
10%-25%	5	8%
25%-50%	3	5%
50%-75%	1	2%
75%-100%	0	0%
Total	59	100%

In order to study which contractor grade firm is more aware and which is not about modular construction in Addis Ababa, it's better to classify utilization of components in building projects by contractors' grade. Based on Table 4.6 Grade-1 and Grade-2 contractors have the advantage of utilization above 10% of building construction project completion. However, the above analysis shows there is a relative reduction in percentage proportion of projects from Grade-1 to Grade-5 in an amount of modular component utilization in projects.

Table 4.6: Modular Components Utilization by Project Completion Based on Contractors Grade

Percentage of A Single Project Completion with Modular Components	Number of Project work Contractors with Modular Components Utilization					
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Less than Grade 5
0%-5%	7 (58%)	6 (43%)	5 (63%)	2 (40%)	3 (33%)	5 (45%)
5%-10%	3 (25%)	5 (36%)	2 (25%)	3 (60%)	5 (56%)	4 (36%)
10%-25%	1 (8%)	1 (7%)	1 (15%)	0 (0%)	1 (11%)	1 (9%)
25%-50%	1 (8%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	1 (9%)
50%-75%	0 (0%)	1 (7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
75%-100%	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Total	12 (100%)	14 (100%)	8 (100%)	5 (100%)	9 (100%)	11(100%)

d) Utilization by Method of Fabrication

Figure 4.4 shows industrial fabrication is the greatest method of modular components, but this amount mostly indicates fabrication of components like precast concrete members/ frames by small and medium enterprises for supply to condominium apartment projects construction. Also, about 15% use site fabrication and another 24% use both site and industrial fabrication.

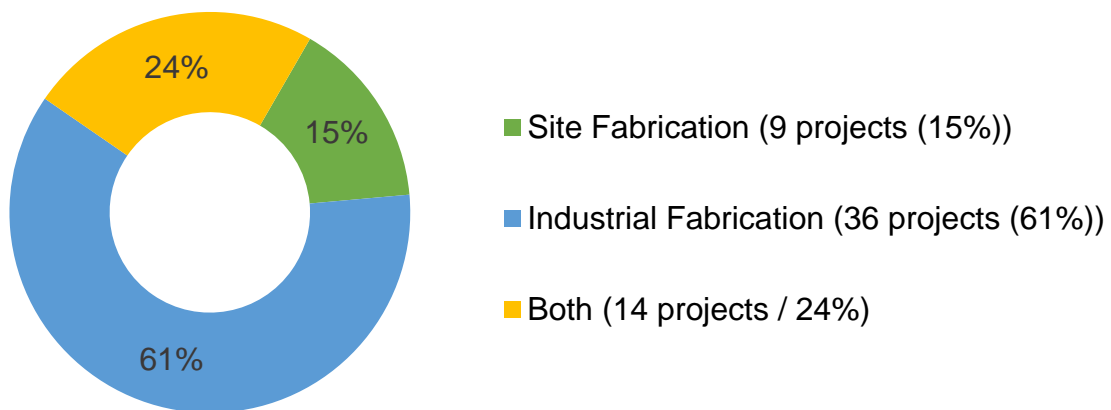


Figure 4.4: Modular Components Utilization by Method of Fabrication

4.2. Challenges and Important Uses of Modularization

Even though any type of large and small modular building components were quite rare in both production and utilization including most of the modules are reinforced concrete precast beams and industrially manufactured agrostone walling panels. The results obtained from respondents presented in Figure 4.5 and 4.6 found a number of potential importance's and challenges of modular building system utilization in building projects from users of components by construction industry drivers in Addis Ababa based on their relative satisfaction and understanding.

I. Challenges of Modularization According to Users

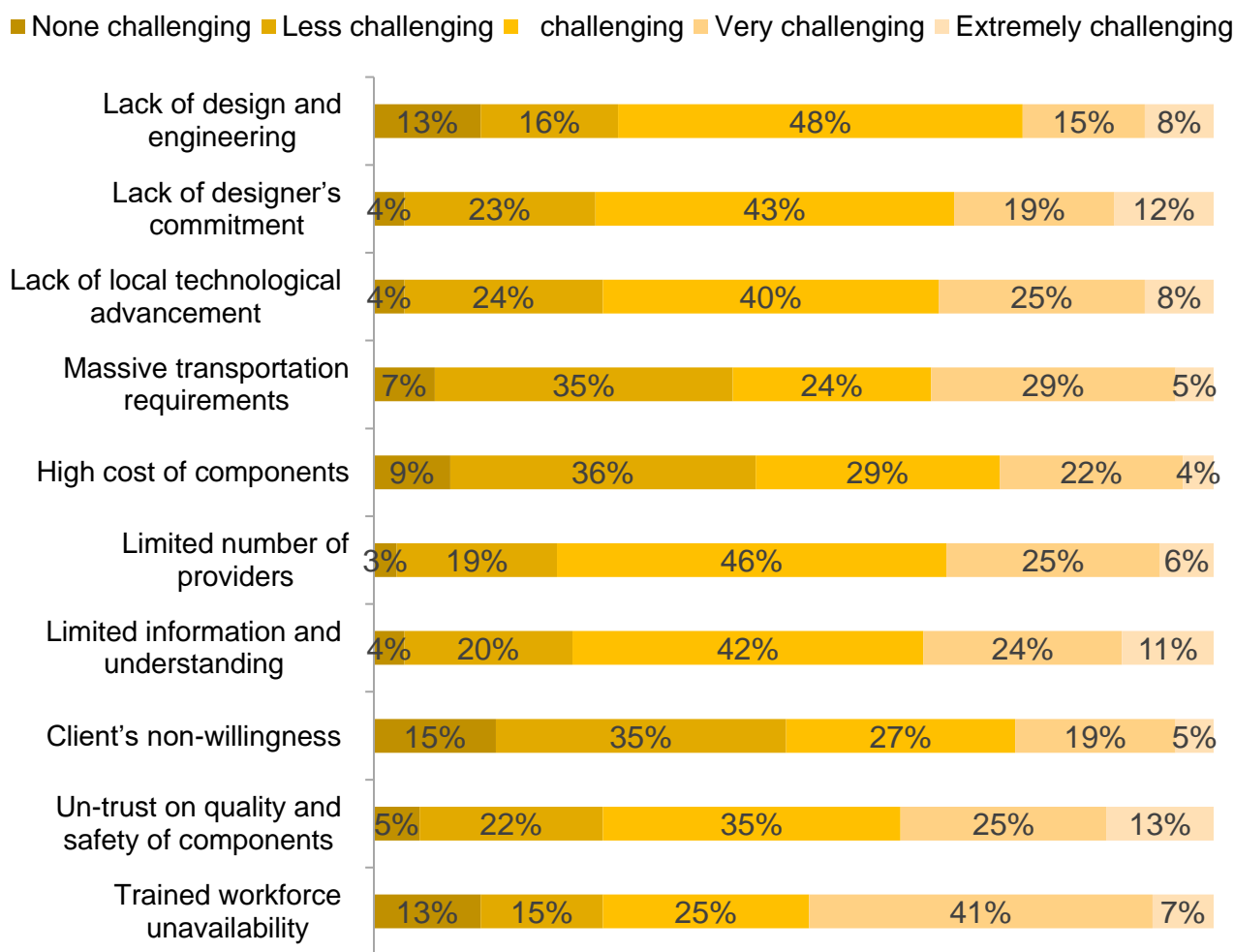


Figure 4.5: Challenging Factors of Modularization by Users

By majority of user respondents' unavailability of trained workforce were very challenging for utilization of modular components. And also lack of design and engineering, limited number of providers, lack of designer's commitment, limited information and understanding, lack of technological advancement and un-trust on quality & safety of components were moderately challenging. However, it seems that massive transportation requirement, a high cost of components, and client's non-willingness are less challenging in the utilization of modular components. And challenges were further explained on the following pages.

1) Unavailability of Trained workforce for Modular Design and Construction

By a majority of professional on construction sites indicates the loss of a trained workforce is the major problem for modularization of building systems. However, in order to prove the main problems on the unavailability of the trained workforce for modular construction, a secondary questionnaire is prepared to find out the gaps of professions for an understanding of modularization and about five graduated professionals from each of architecture, civil engineering and construction management disciplines were interviewed (see Appendix II).

General understandings

All interviewed architects, engineers and construction management graduates have experienced from 0 - 6 years through secondary questioner (see Appendix II), a majority of them reacted they had the concepts and knowhow about major advantages of modular building systems in the way that modular construction components can reduce cost, time and improve quality of construction, but they don't have experiences working with implementation.

Course training at higher education

From an assessment of the interview, architecture graduates had taken study about prefabrication and modular building components in Appropriate Building Technology course as one, of course content, and also some civil engineering and construction management students get knowledge about modular and prefabrication concepts from Building Construction courses. 3 architects 4 construction management and 2 civil engineering graduates believe it's very important the application of modular systems to building construction, and also the rest out of five interviewees from each discipline decide its moderately important application of modular systems. However, from total response architecture graduates have a better understanding of training relatively from civil engineering and construction management students.

Lack of practice capabilities of professionals in design of modular buildings

Except two civil engineering and one construction management graduates the rest of them reacted they moderately capable in design and engineering of modular building systems, in case all of the interviewees from three of professions reacted they didn't practice in design and engineering of modular building systems. From open response of graduates, the main reason behind their little capabilities, and none practice were, they had no enough training and except introductions of those modular building systems. Also, they don't think that they couldn't say about them enough capable and familiar for design and engineering of modular building systems.

Based on the above findings the conclusion of the challenge of modular building system adaptation with the reasoning of unavailability of the trained workforce had a moderate role in the development of modular building systems because of the limitation on broad coverage of modular concepts rather than single course titles in subjective courses. From the results, architects had better coverage of the modular concept relative to other graduate professionals, but also there is a limitation in the design and practice of buildings with modular system and materials for modular construction.

2) Limited Number of Providers

The limited number of providers for modular building system is one of challenging factors for adaptation of modular building system utilization for majority of building sites. In case during visits of factories that produce agrostone partition wall and boards in both Yebel industrial park and Addis agrostone production center, during visits of factories there is a production stop because of magnesium oxide supply shortage that resulted from mining production site conflict for more than seven months starting in June 2018, but the researcher couldn't able to analyze the current process of agrostone panel production. However, the Addis agrostone production center produce both partition walls and door panels from agrostone composition, that mainly produced from mixtures of (200 liters mixed magnesium chloride, 160kg of magnesium oxide, 19kg of straw from sugar cane bi-product, 42kg of pumice and 1kg of fiberglass) and molded to the desired shape, but the reflection from the factory is, although there was no production shortage before seven months ago in case they produce much more for condominium housing projects.

Therefore, the researcher couldn't able to find a possible case study in volumetric and paneled industrial production of modular building systems other than agrostone panels, however, the reason of limitation on the promotion and production of modular systems very sound in which factories that ready for design and production of the module system are challenging.

3) Lack of Design and Engineering

Based on design office reaction two of them reacted they are not capable in design and engineering of for modular building system, saying modular systems still not mandatory for utilization and it wasn't thought in educational institutes satisfactorily to the design and engineering of systems. Also, the rest four offices reacted they moderately capable, but there are limitations in experiencing and working with modular systems, for that there is no mandatory case for utilization that came from clients and government.

4) Lack of Designer's Commitment

From site professional's indication lack of designer's commitment is a challenge for modular building system utilizing that placed in fourth place, and then through interview of six offices, each of the consulting architects and engineer's office, four of them reacted very important and two of them reacted moderately important utilizing modular building systems because its simpler, cost efficient and advantageous in less time for working and also, better in housing and commercial construction projects.

Although three of them reacted they are very interested and another three reacted moderately interested in application of modularization in case of the wider traditional construction system couldn't satisfy the ever-growing construction demands in the case of time and cost effectiveness and also some indicated those systems will take time for greater technological advancement on the sector.

Therefore, from the result the design offices were aware of the advantage and benefits of utilizing modular building systems, but the major problem that affecting designers commitment is the little promotions and introduction of modular systems, both from manufacturers and government, and also the lack of local construction industry in awareness of modular building systems, in addition, lack of manufacturing in a complex volumetric and paneled industrialized manufacturing of modular components.

5) Lack of Local Technological Advancement

The local technological advancement of modular systems could be analyzed interims of practice in modular design, industrialization of building systems and components utilization, therefore the limited industrialization of modular construction and the lack of design and engineering capabilities are indications of in less technological advancement of the sector.

6) Limited Information and Understanding

Little promotion and introduction about modular systems in building construction industry both in project sites and design office create a limitation on application. Educational trainings were not enough for practice in modular design and engineering as indicated by professional's response that affect the application of components to be recommend for building design projects. Also, the current dominant modular components were promoted by the government and some private companies for job creation of micro enterprises and to promote environmentally friendly building materials, however the industrialized scale volumetric and paneled module production is tried in very little practice but it doesn't spread as it needed for construction industry input.

7) Un-trust on Quality and Safety of Components

Quality and safety of modular components are the last challenging factor listed by the majority of professionals. From the indication of site workers currently used prefab module materials were in a little amount less resistance to weather and produced with some workmanship errors and lacks of quality control. On the other hand, majority design office professionals trust the quality of modular building components because components produced with quality controlled off-site manufacturing with the help of research and manufacturing control.

Besides professional decisions on challenges for adaptation of modular construction, there is no legal control and codes for modular building design, construction and industrial manufacturing legalized by law told Mr. Dawit Hundesa on interview, who is head of Addis Ababa construction permission and regulation biro and most of the building designs came to his office had been with conventional building structural designs, that he never got any new way of design's related with modular building system.

II. Important Uses of Modularization by Users for Application

The respondents view related to important uses of modularization from modular component users' category are presented in Figure 4.6, and it's very important modularization for building project in cases of saving construction cost, saving time of project completion, material waste reduction, greener construction, increasing productivity and profit, competitive advantage and easing construction work by majority of professional respondents. In other case its moderately important in save construction and reduction of skilled labor.

Although modular components utilization was advantageous in most of the parameters listed on Figure 4.6, but better quality of building is un-reliable in majority of respondents and its less important in case of quality of construction. Some of respondents gave their opinions that materials quality and components durability are the main less important issue in modular building construction.

To generalize analysis on Figure 4.6, by more than an average respondent it has been believed modular building systems are very important in saving time to project completion, material waste reduction and easing of construction work respectively by rank from user's response.

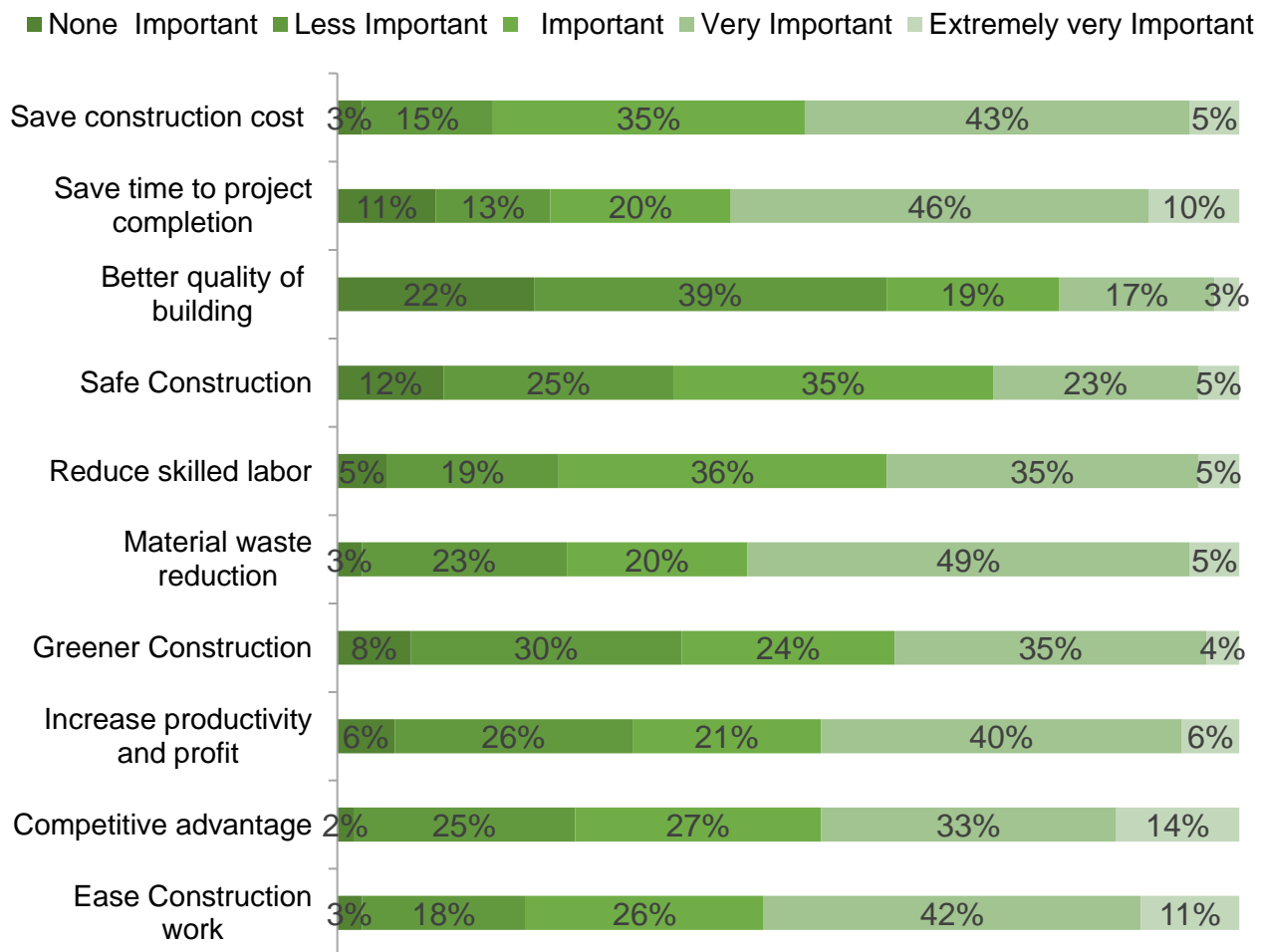


Figure 4.6: Important Uses of Modularization by Users

4.3. Stakeholders Role in Modularization

The building construction industry has stakeholders both professionally and organizationally, that have role by affecting the industry in one way or another through many cases. However, it's very important to study who has a responsibility in a variety of positions and who has a better influence to promote and advance the utilization of modular building systems in case of Addis Ababa city.

I. Promoters of Modular Components at The Current Time

From utilizers of modularization components (out of 59 modular building system user projects site managers response), a majority of respondents with 29% place designer firm in the first place which is promoting and planning for utilization. Its followed by client firm in second place with 22% and also contractor and government by 17% & 15% respectively. In other way, consultants and fabricators have promotion role less than 10% and 7% respectively in the utilization of modular components as illustrated in Figure 4.7.

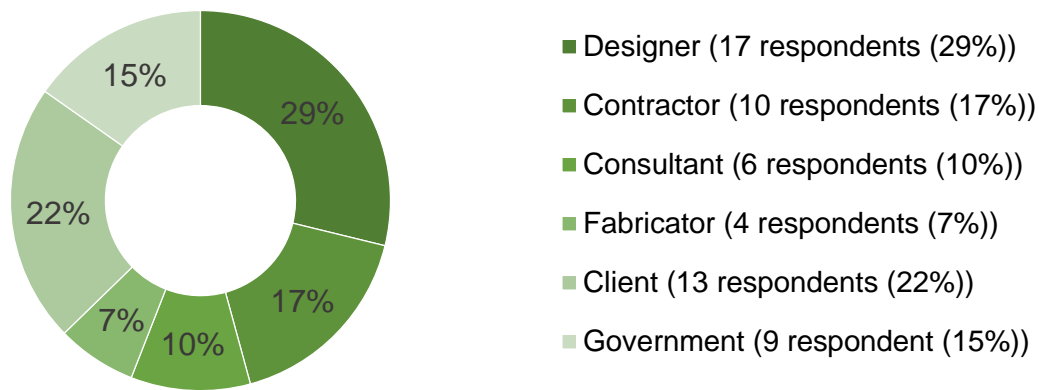


Figure 4.7: Promoters of Modularization

II. Organizational Responsibility in Promotion of Modularization

Professional recommendations survey is important in order to find the solutions by itself from respondent professionals in different fields of the sector. Based on Figure 4.8 analysis result a majority of respondents closest to thirty percent reacted designer firm is the most responsible firm for promotion and utilization of modular components followed by fabricator with 20% of respondent's professional recommendation, even though both designer firm and fabricator could and should play a role as voted by about average stake relatively to other bodies. Also, government and contractor role in promotion came respectively in third and fourth place. The consultant is the least role player which is recommended by few numbers of respondents relative to other bodies, but it has its role with little effort presided by client's role which has 7% of the vote by professionals from all disciplines.

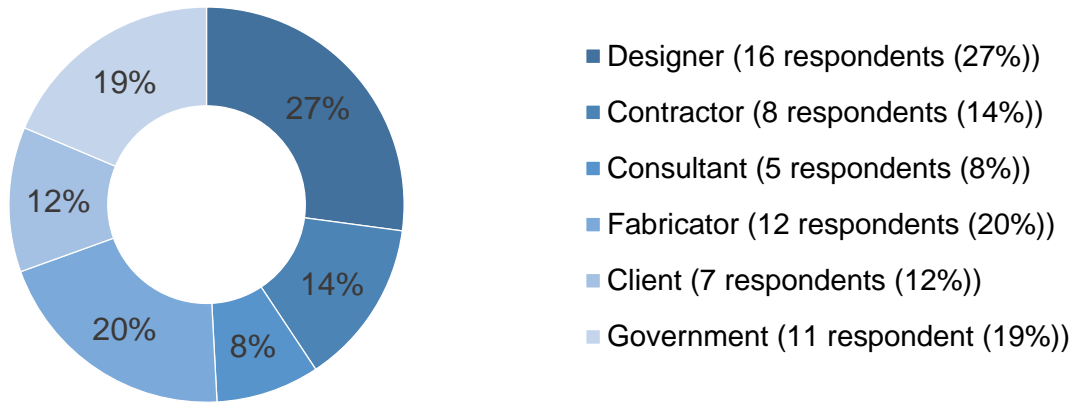


Figure 4.8: Organizational Responsibility in promotion of Modularization

III. Professional Responsibility in Promotion of Modularization

Professionals play a greater role in both creation and implementation of modularization of building systems, in which all professional disciplines who has a job in building construction sector has its own role in a broad or narrow manner to propel this sector with modular building system. Out of 59 user respondents, by 24% of majority it has been believed that structural engineers have a greater role in the promotion and development of modular building system and components. In second place by vote architects have a role in promotions of the sector followed by company managers, site engineers and construction managers.

- Company Manager (7 respondents (12%))
- Construction Manager (6 respondents (10%))
- Site Engineer (7 respondents (12%))
- Architect (9 respondents (14%))
- Structural Engineer (14 respondents (24%))
- Quantity surveyor (6 respondents (10%))
- Sanitary Engineer (4 respondents (7%))
- Safety Engineer (0 respondents (0%))
- Surveyor (2 respondents (2%))
- Electrical Engineer (0 respondents (0%))
- General Forman (3 respondents (5%))
- Technical assistant (1 respondent (2%))
- Drafting Aid (0 respondents (0%))
- Mechanical Engineer (1 respondent (2%))

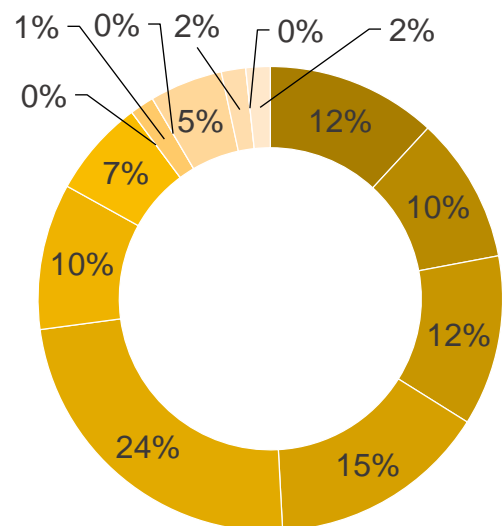


Figure 4.9: Professional Responsibility in promotion of Modularization by User Site Managers Recommendation

Analysis in Figure 4.9 shows both professionals in design firms and on-site work has a majority of a role in promotion and utilization of modular building systems, in case by a majority number of respondent's recommendation structural engineers and architects' professions that engaged works most probably in design offices has a role on the case.

IV. Understanding of Modular Construction

Professionals engaging on building construction industry sector their understanding towards the concept of modular building systems and technologies could and would affect utilization of the system, in another way without the knowledge of workers on the sector it's challenging in an adaptation of modular building systems. In this case, it's useful to study understandings of the concept with worker professionals participated in the industry.

Analysis in Figure 4.10 indicates a majority of respondents about 38% are familiar with the concept but they don't have experience with it and another second majority of respondents about 29% they are familiar with the concept of modular building systems and they had experiences with it. This also indicates above averages of professional respondents are familiar with modularization. However, 4% of survey respondents indicated they don't have any concept with modular building systems but 9% from total reacted they would like to know and work with it in future utilization.

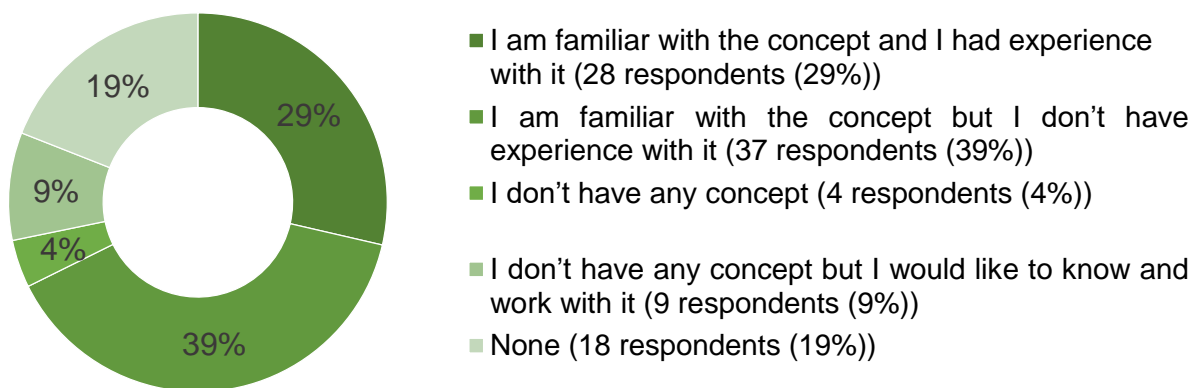


Figure 4.10: Understanding of Modularization by Total Respondents

V. Professionals Levels of Commitment in Future Utilization of Modularization

By Current Users:

Users include respondents with the utilization of modular components now in the building construction industries of Addis Ababa. From those respondents, 28% majorities decided with a good level of commitment and also 20% with a very good level of commitment in future utilization of modular building systems. However, about 14% of respondents are not yet to decide in the future application and 12% with poor interest working with modular building systems (see Figure 4.11).

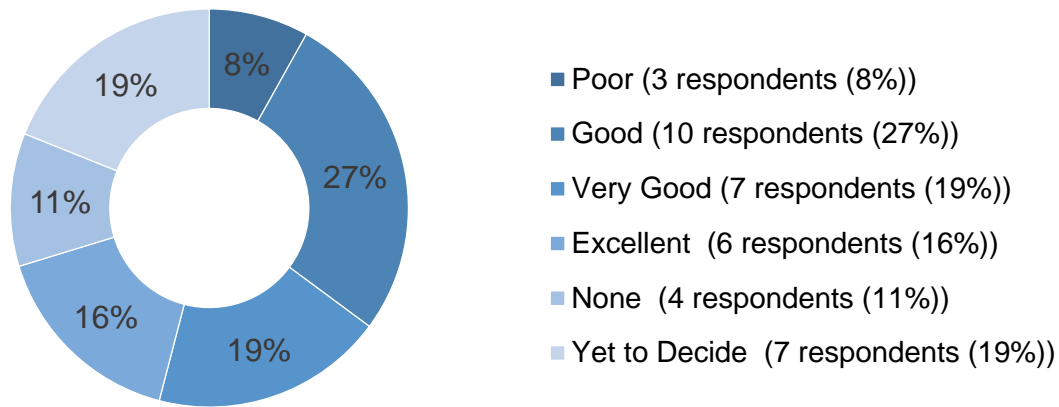


Figure 4.11: Commitments of Future Utilization by Users of Modular components

By Non-Users:

Non-users include both responded without modular components utilization and not sure of utilizing it. About 27% majority from non-user's category has a good level of commitment in future application of this building system and 19% with a very good level of response to the future application. In another case, 19% yet to decide on the future utilization and about 8% with less interest for its utilization. However, there are similarities in both users and non-users about future commitments.

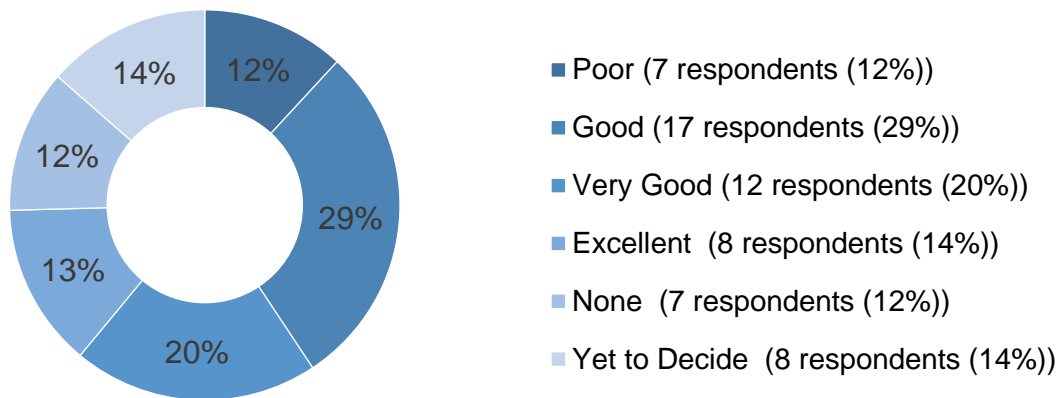


Figure 4.12: Commitments of Future Utilization by Non-Users of Modular components

VI. Modularization for Building Project Types

Depending on the advantage of the respondent professional's closeness to the sector of building construction industry, it's better to study which building project is more helpful with modularization in case of Addis Ababa city. This will help future and current investors on the sector to participate in more advantageous project based on the result analysis as one input of information for development.

Based on research survey questioner that given to professionals to rank the best building construction project in order to find out which project type is very successful for modularization opportunity according to their recommendation. For analysis in Figure 4.13 it's taken the first choose ranks from all responses. The majority of respondents reacted (14%) that modular building systems are suitable for industrial building projects followed by residential and apartment buildings with 12% and 10% of respondent's recommendation respectively, including warehouse building projects which has the same number of votes with apartments. The rest projects have a vote less than 10% of reactions in case religious buildings has the least number of a vote to apply modular building systems in Addis Ababa.

- Residential villa building (2 respondents (12%))
- Apartment building (6 respondents (10%))
- Commercial building (5 respondents (8%))
- Office building (6 respondents (10%))
- Hotel building (5 respondents (8%))
- Health care facility building (4 respondents (7%))
- Educational facility building (6 respondents (10%))
- Recreational service building (4 respondents (7%))
- Religious building (2 respondents (3%))
- Ware house (6 respondents (10%))
- Industrial building (8 respondents (14%))

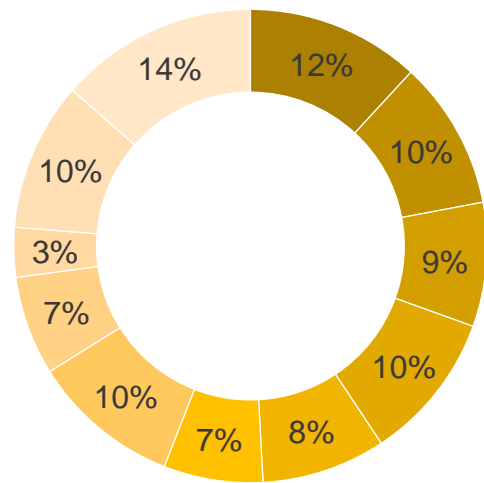


Figure 4.13: Recommendations of Projects for Modularization by User Site Managers

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND PROPOSAL

5.1. Conclusion

At the current time there is a utilization of currently adapted modular components, in which most of building construction projects running at the current time in Addis Ababa utilize at least one component of modular construction in their projects, however the application of those components was in a very few amounts relative to an individual consumption of building projects. Although, the most dominant modular technology utilized at the current time are precast concrete beams and agrostone wall panels in a greater amount relative to other components those made with small, medium and large industrial fabrication, that uses for floor/slab and internal partition wall construction.

The majority of available modular components produced at the current time was consumed by industrial, warehouse, apartment and mixed-use building projects but also other building functions have their own share with relatively less amount. Although panelized modular components in the form of agrostone panels and structural members like precast beams were utilized with a larger amount relative to other components except roof frames. However, modular components in the form of volumetric and panelized fabrication and assembly for the purpose of building construction were very rare. From data results, by the majority above 80% of sampled construction project sites, the utilization of modular components was less than 10% of total consumption in each of building construction projects that were used for specific building element construction especially for partition and slab/floor construction.

There is no greater gap in the utilization of modular components between construction firms in the form of contractors, but there is a slight difference in utilization regarding contractors' grade that increases with firms grades of contractors and although the little difference in numbers doesn't indicate there is differences in capabilities and challenges regarding utilization of modular components.

Towards adaptation of modular building system by most of professionals from modular component users decided that unavailability of trained workforce, lack of design and engineering, limited number of providers, lack of designer's commitment, limited information and understanding, lack of local technological advancement and un-trust on quality and safety of components were challenges for adaptation of modular building systems in descending order. However, massive transportation requirement, a high cost of components, and client's non-willingness are less challenging in the utilization of modular components.

The important uses of utilizing modular technologies at the current and in future application recommended by most of the professionals were; saving time for project completion, easing construction work, saving construction cost, increase productivity and profit, reduction of material waste and competitive advantage, however, by some experienced professionals with modular components has a drought of advantage of modular building systems in terms of better quality of building.

At the current time the main planners and promoters of modular building components are design firms that put in the first place and also, clients and contractors come in second and third respectively; on other hand fabricators of modular materials had relatively the least role in those promotions and plan of modular components utilization. However, from indication of professionals recommending vote towards which organ is the most responsible stakeholder to further promotion for utilization of modular building systems, first designer firms, secondly fabricators then government has a greater role in promotion of modular building systems; also its recommended that structural engineers, architects, and construction firm company managers could help in the promotion and utilization of modular building systems for betterment of construction through its advantage.

It has been believed that by majority of professionals, industrial, residential villa and apartment buildings are best to be applicable in the city of Addis Ababa for modularization because of its advantage in the case of simplicity of construction, creating affordability for housing and less time for building project delivery compared to conventional construction.

The majority of above average professionals in the construction industry at the current time were familiar with the concept of modular building systems and had the commitment to future promotion and utilization of modular components. This also could help for improvement and implementation of modular buildings trough recommendation of modular construction in the construction project, and also an investment in the sector doesn't have barriers of professional interest for utilization but limitations of design and engineering capabilities for modular building system design.

From an assessment of modular building system advantage in building construction industry, in case of Addis Ababa, it could help in the creation of housing affordability by minimization of costs through the advantage of modular buildings in their lightweight design that reduces foundation costs and less consumption of formwork for molding supports that reduce the cost of formwork construction. On the other hands modular construction could reduce site disturbances, creates construction flexibility and safer construction work environment; also, through utilization of modular construction, projects could gain benefit from shorter time for project completion that will help early return of investments from building service and in case of faster delivery of housing for dwellers. Although the quality of modular components was slightly interested, in some cases, if components are well designed and follow quality assurances and control process, it has an advantage of better-quality construction of buildings that minimize any site materials testing conflicts in trends of conventional construction.

5.2. Recommendations

Based on the major findings and conclusions, the following recommendations are drawn.

I. Recommendations for Enhancement of Modular Building Systems

- Government organizations such as housing agencies responsible for mass housing development planning should play a role in modular building construction adaptation and play as initiations agent to building construction industry through industrial development for modular building design and fabrication for housing construction. This will allow increasing of interests in the utilization of modular building systems by building design and construction firms as a possible practical role model.
- Promotions and initiations of modular building system design and construction in building construction industry especially for designers and contractors through pieces of training and community servicing, by government housing or construction related authorities and universities, should be done in order to maximize awareness and motivation of modular construction towards its advantages. And also, by invitation of international and local experts on advanced modular construction technologies by regarding government body should be facilitated to give training and exchanges of experience for local stakeholders of building construction industry.
- High grade and capable local contractors should be initiated to develop flexible off-site manufacturing plants for the possible manufacturing of modular buildings that allow design firms for implementation of designs with modularization through integrated works.
- Foreign investments on the sector of industrialized modular building system fabrication should be motivated and it should be placed as one of the investment opportunity options for foreign investment invitation, that could bring advanced technologies in modular building construction. This will allow technological transfers of advanced systems to local stakeholders in the development of building construction sector.
- Universities and science and technology research institutions should play a role in the development of researched materials and systems that are possible for modular building construction with affordability, light weightness, and quality advantages.
- Universities regarding in training of architecture and structural engineering professions should have maintained students in design and engineering of modular building systems by intensifying of courses related to building construction and technologies through more course content coverage of about modular building systems and also it could be by design of curriculum with independent course coverage modular building system.
- Government bodies regarding building design permission and approval works should establish a compressive design and construction regulations and approval standards with angles of other countries experiences and local context for the possible practice of modular construction.

II. Recommendations for Stakeholders of Construction Industry

1) Designers

Design firms should have to enhance the sector of modular building construction by application on their design projects and they are the top responsible organs for decision of designing of building, however design firms could benefit their clients and contractor firms through practicing of modular building systems in design projects with available possible materials and construction technology utilization for modularization of building systems towards its advantage in low cost, less time to project completion and quality control.

2) Contractors

Contractors could benefit themselves through investments and application of modular construction with an integration design firm, that could help them to minimize site waste and disturbance during construction. Also, modular construction could help contractors in case of creating safer construction, minimization of large working and storage spaces need like a conventional trend of construction, and it helps on the flexibility of construction that will allow design changes during construction with assembly and disassembly of module components.

3) Fabricators

Industrial fabricators of currently adopted modular building systems should have to maximize the quality of materials in order to create trusting of components by building construction industry and also promotions have to be made for awareness of industrially made building systems for possible utilization of modular components. Large industrial building component fabricators should work in the development and promotion of industrially manufactured building system together with design firms through engineering and design of systems.

4) Government

Government organs working in housing development could benefit from modular building systems by creating housing development with affordability and less time for construction in order for early habitation. Also, concerning government body should have to initiate the development of modular construction through entrepreneurial job creation by designing module systems and training of construction assembly of modular components both for housing development and to other building functions application.

5) Real estate developers

Property developers in the realestate industry could benefit from modular construction in their mass housing development in case of faster delivery of housing, creating housing affordability for inclusive of middle-income societies and to deliver quality housing for inhabitants.

5.3. Design Proposal

The design proposal is based on the findings on the potentials of modular building systems application in the housing industries in Addis Ababa and to illustrate the application of modular construction in the most dominant and current demand on apartment housing in the city. As recommended by professional's apartment buildings were in third place relative to other building functions for an advantage of application in modular construction and the most dominant project of mass construction in the city, also projects utilize greatest amounts of currently available modular components.

I. Design Concept

The recommended design concept for apartment housing construction with modular building system was based on the mass building project size character of apartment construction in current time to satisfy high demand of apartment housing with better quality, less cost and fastest delivery of shelters for those in need. Therefore, its better those modules for apartment buildings to be produced by mass production of industrial fabrication to deliver house modules with trucks and easily placing module components those assembled in a factory with a proper arrangement on the building site by using medium weight cranes.

Each module was designed with the proper size to deliver modules on the site that doesn't affect traffic flows and follow the proper regulations of trailer load size as illustrated in Figure 5.1. In case of international traffic regulations modules on trucks could take 3.5m horizontal dimension (for the road cross-section) and it may increase to 4.3 m if access routes permit, heights for loads should be less than 4.5m above the road ground together with truck trailer height but, the longitudinal dimension for truck within trailer loads could be up to 25.8m. However, for the proposed design the dimension of modules were designed to satisfy these regulations, therefore four modules containing different room numbers of apartments, each with a volumetric dimension of 3m x 3m x 9m and one stair module with 2.8m x 2.8m x 3m size, also roof modules with 3m x 9m x 1.2m size was designed.

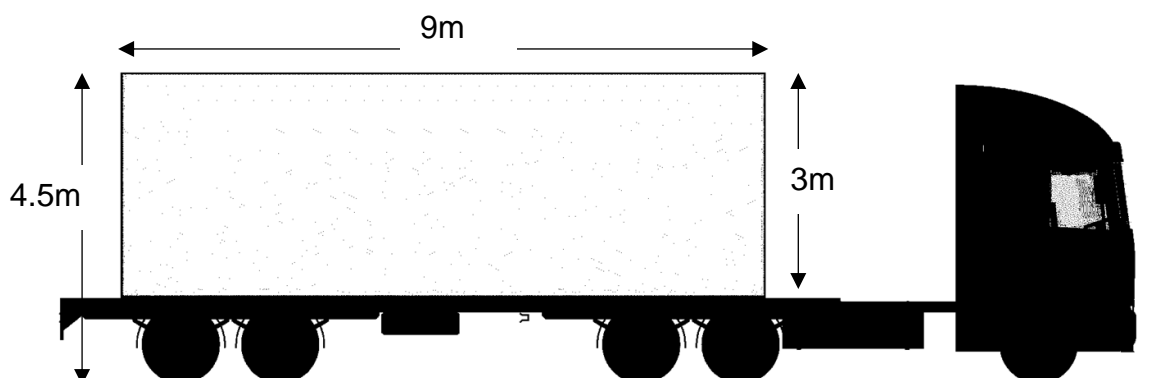


Figure 5.1: Dimension of Single Module

II. Plan Layout of Proposed Apartment

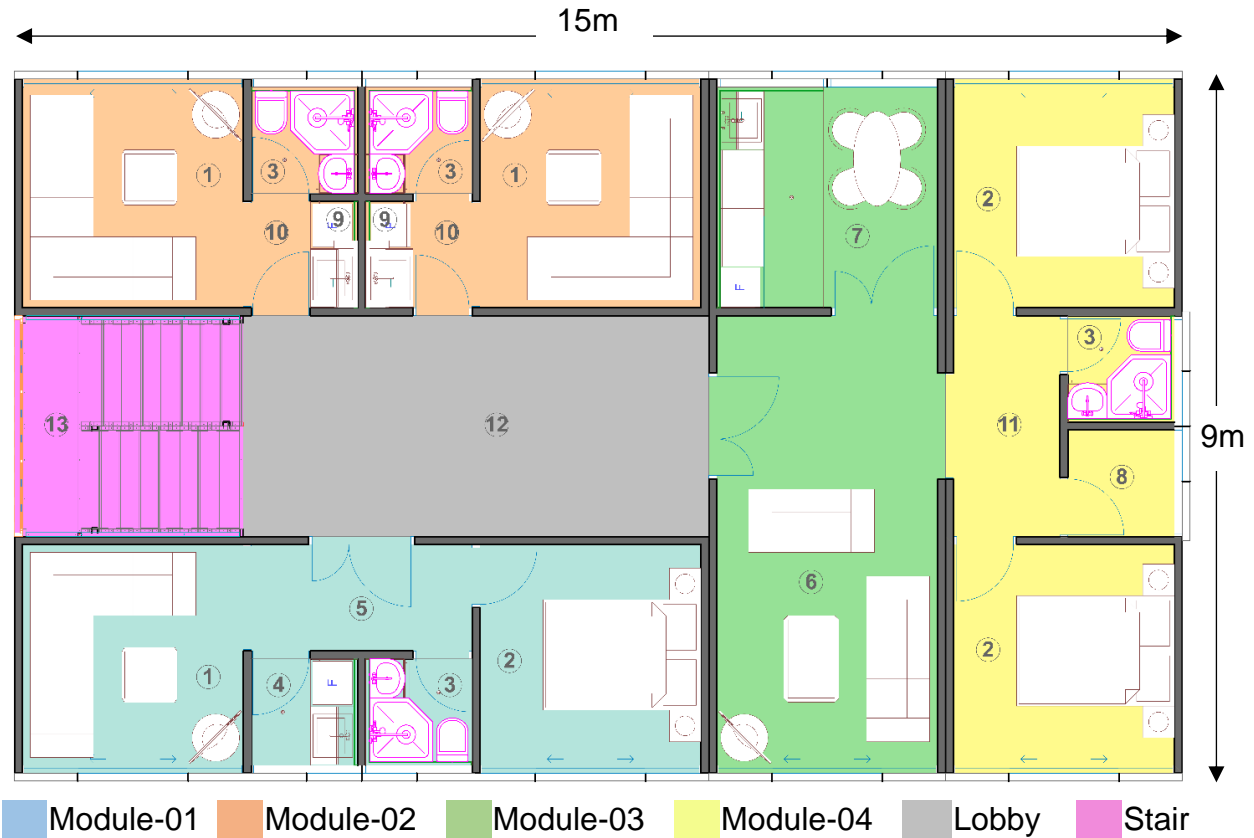


Figure 5.2: Typical Typology of Proposed Modular Apartment

Figure 5.2 illustrates typology of a modular compound, which has one single bedroom with bath and Kitchen (Module-1), two studios with bathroom (Module-2) and also one double bedroom apartments (Module-1 and Module-4). Each independent module has a dimension of a 9m x 3m area and 3m floor height. The lobby dimension is 6m x 3m that helps for community gathering and children playing for single story neighborhood and the following table summarizes room dimensions that illustrated in Figure 5.2.

Table 5.1: Summary of Apartment Rooms dimension and Area

Room No	Function	Interior Dimension	Area
1	Living Room-01	280cm x 280cm	7.84m ²
2	Bed Room	280cm x 280cm	7.84m ²
3	Bath Room	135cm x 135cm	1.82m ²
4	Kitchen-01	135cm x 135cm	1.82m ²
5	Entrance Hall-01	280cm x 135cm	3.78m ²
6	Living Room-02	570cm x 280cm	15.96m ²
7	Kitchen-02	280cm x 280cm	7.84m ²
8	Store	135cm x 135cm	1.82m ²
9	Kitchen-03	135cm x 60cm	0.81m ²
10	Entrance Hall-02	135cm x 75cm	1.01m ²
11	Corridor	280cm x 135cm	3.78m ²
12	Lobby	590cm x 280cm	16.52m ²
13	Staircase	290cm x 280cm	8.12m ²

III. Assembly of Apartment Dwelling and Staircase Module components

There are seven independent assembled modules that will be delivered to the site using truck, that includes four dwelling modules, staircase, lobby floor, and roof modules, and there are modules on figure carried on trucks independently.

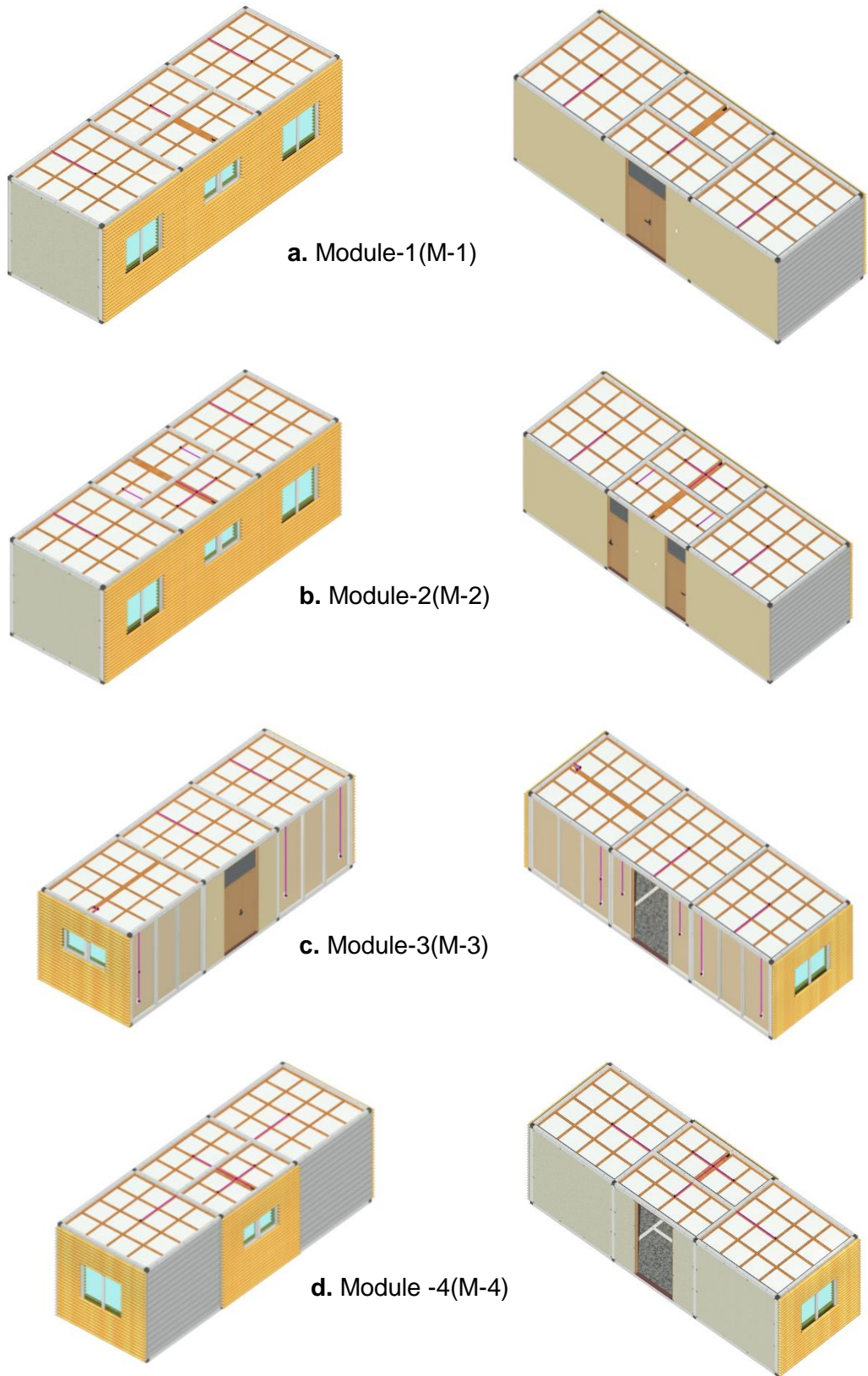


Figure 5.3: Assembly of Dwelling Modules



Figure 5.4: Stair Module

Figure 5.4 shows typical stair module made of lightweight steel framing and wood panels for stair trade and riser construction (more details discussed in Figure 5.16), handrails and balusters for stair made of lightweight steel that connects to trade holder steel in each step.

Lobby floor deck illustrated in Figure 5.5 is made of two hollow RC slab and hang on the module M-1 and M-2 on an inside face of an apartment with connector cables, in case c shaped beams on two ends of the deck and one I-section used to handle the slab that will connect to connector cables.

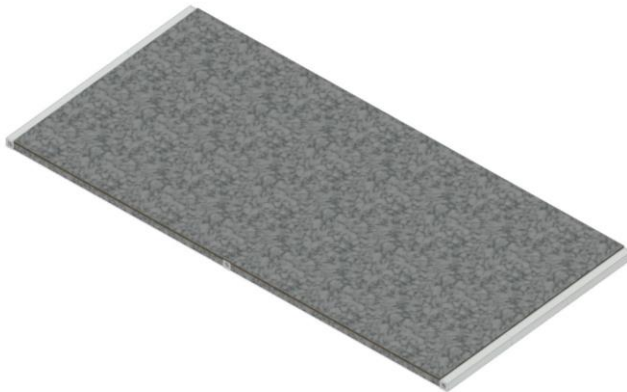


Figure 5.5: Lobby Deck Module

Roof modules (Figure 5.6 and 5.7) also made from lightweight steel, wood purlins and galvanized G-28 roof cover including a galvanized sheet for roof sides cladding. There are two types of roof modules used for roof construction, two on opposite end sides of the apartment and three on the middle.

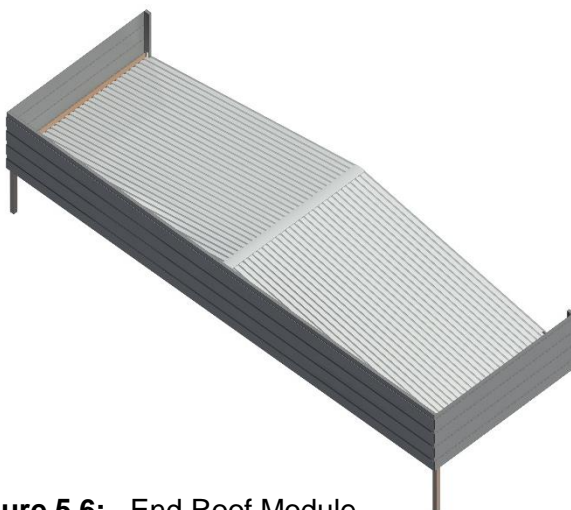


Figure 5.6: End Roof Module

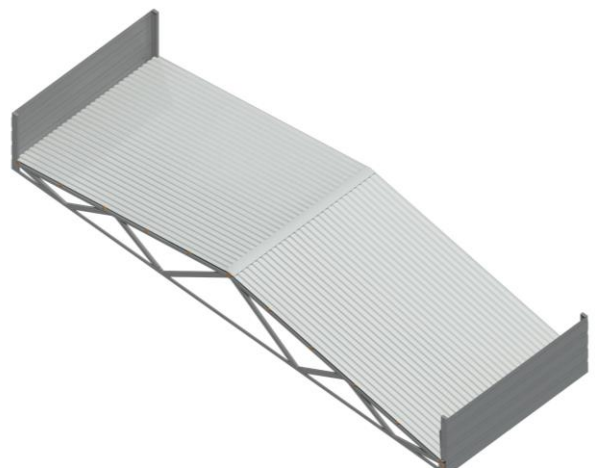


Figure 5.7: Middle Roof Module

a) Assembly of Dwelling Module-1

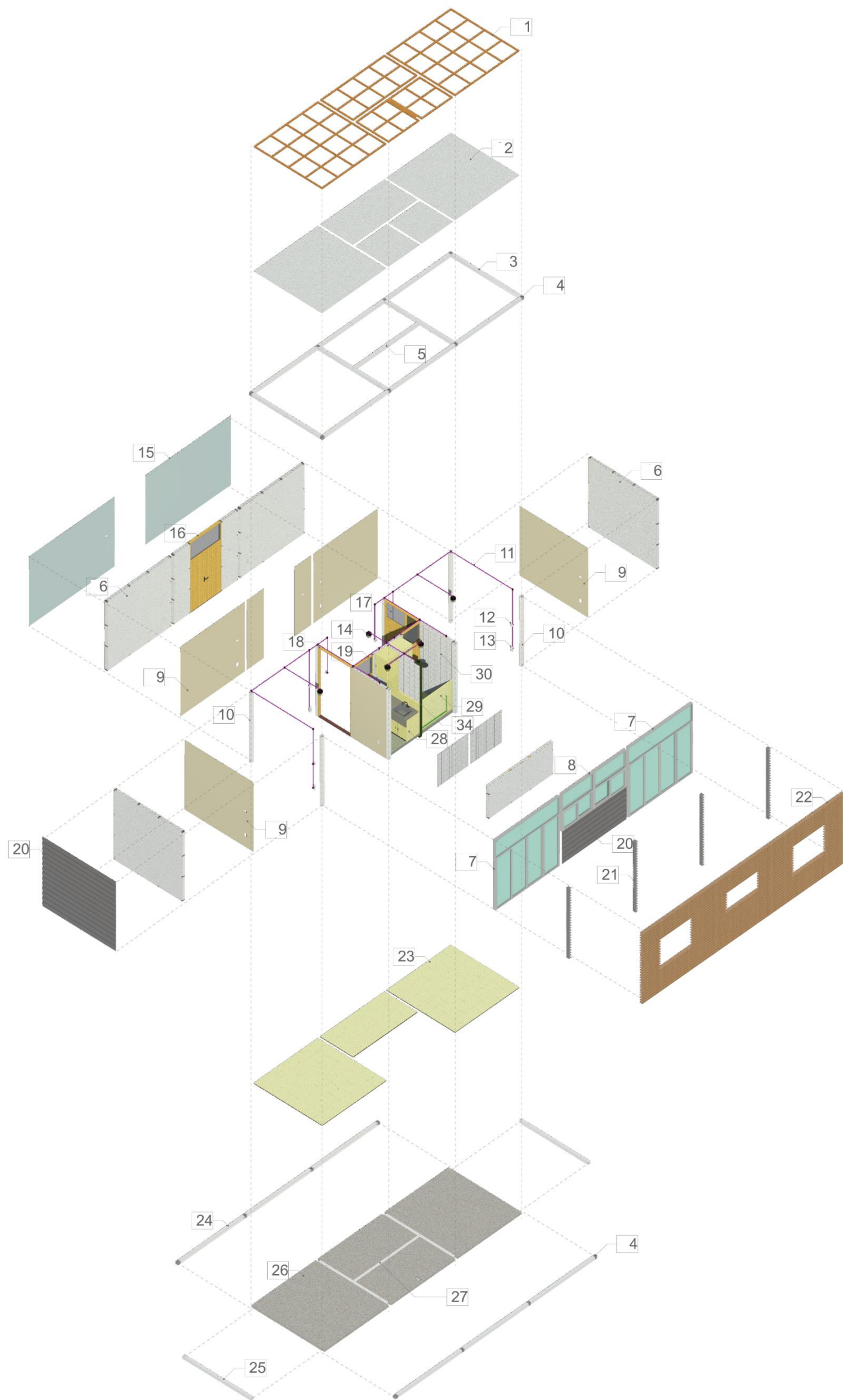


Figure 5.8: Assembly of Dwelling Modules-1

b) Assembly of Dwelling Module-2

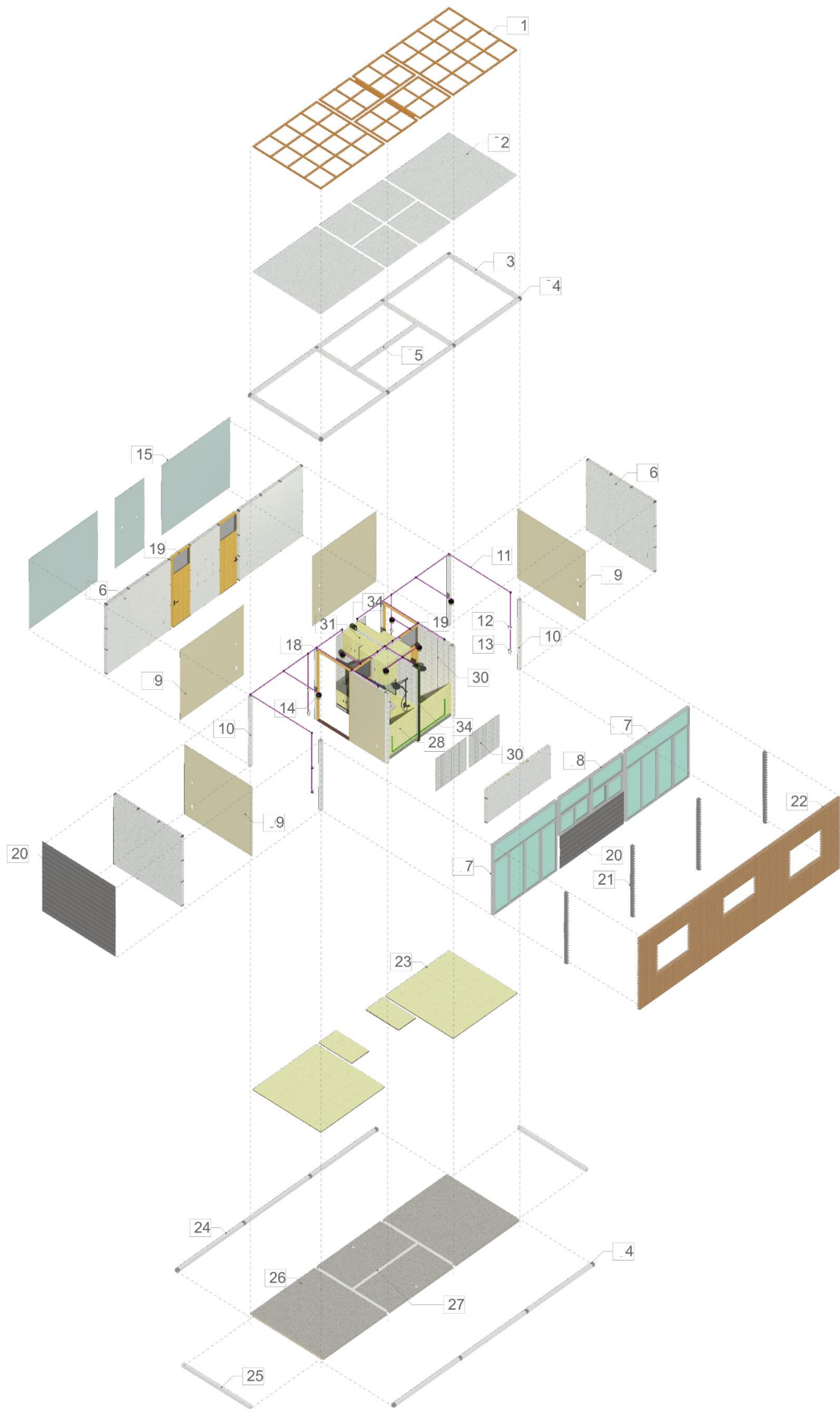


Figure 5.9: Assembly of Dwelling Modules-2

c) Assembly of Dwelling Module-3

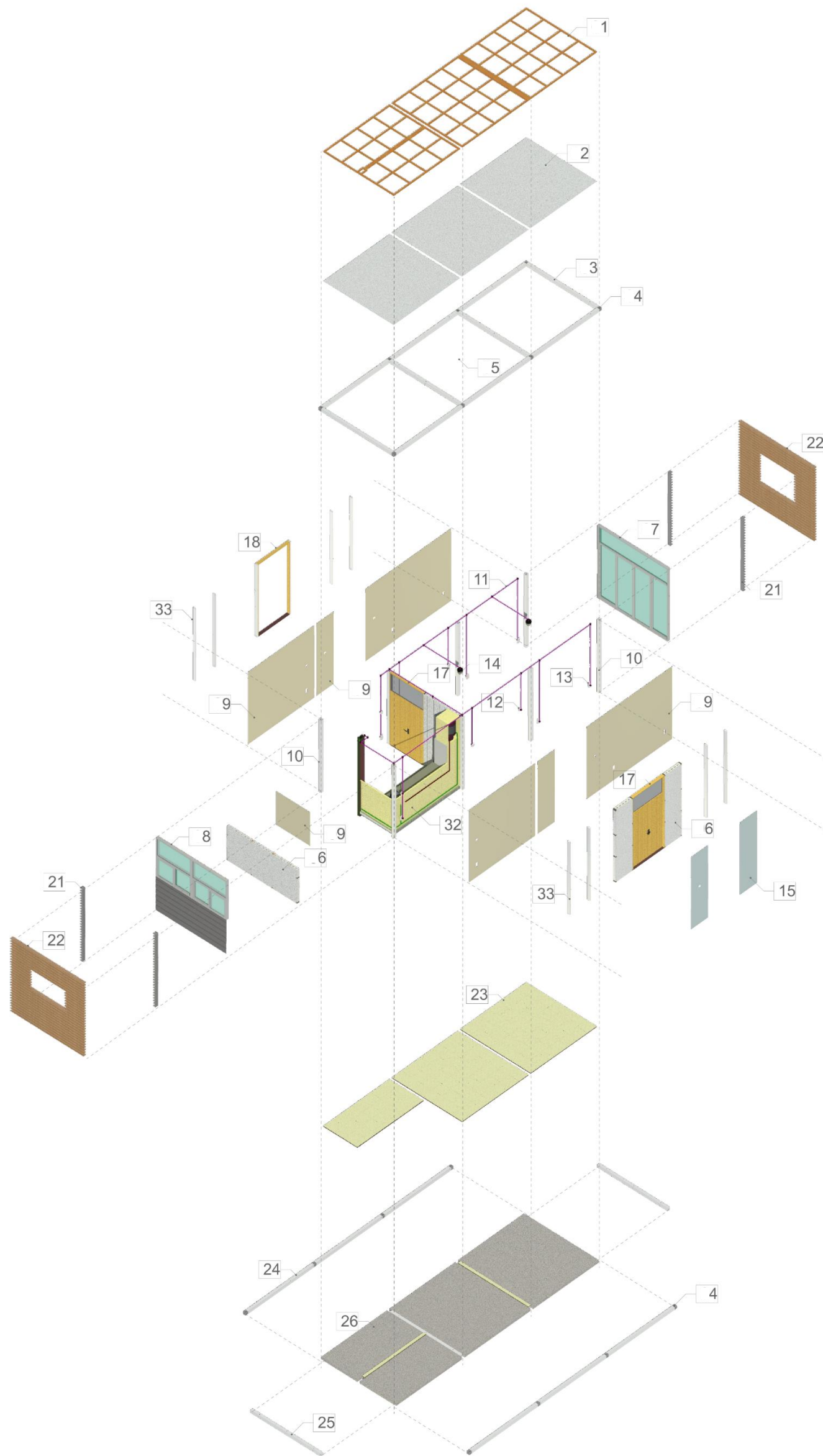


Figure 5.10: Assembly of Dwelling Modules-3

d) Assembly of Dwelling Module-4

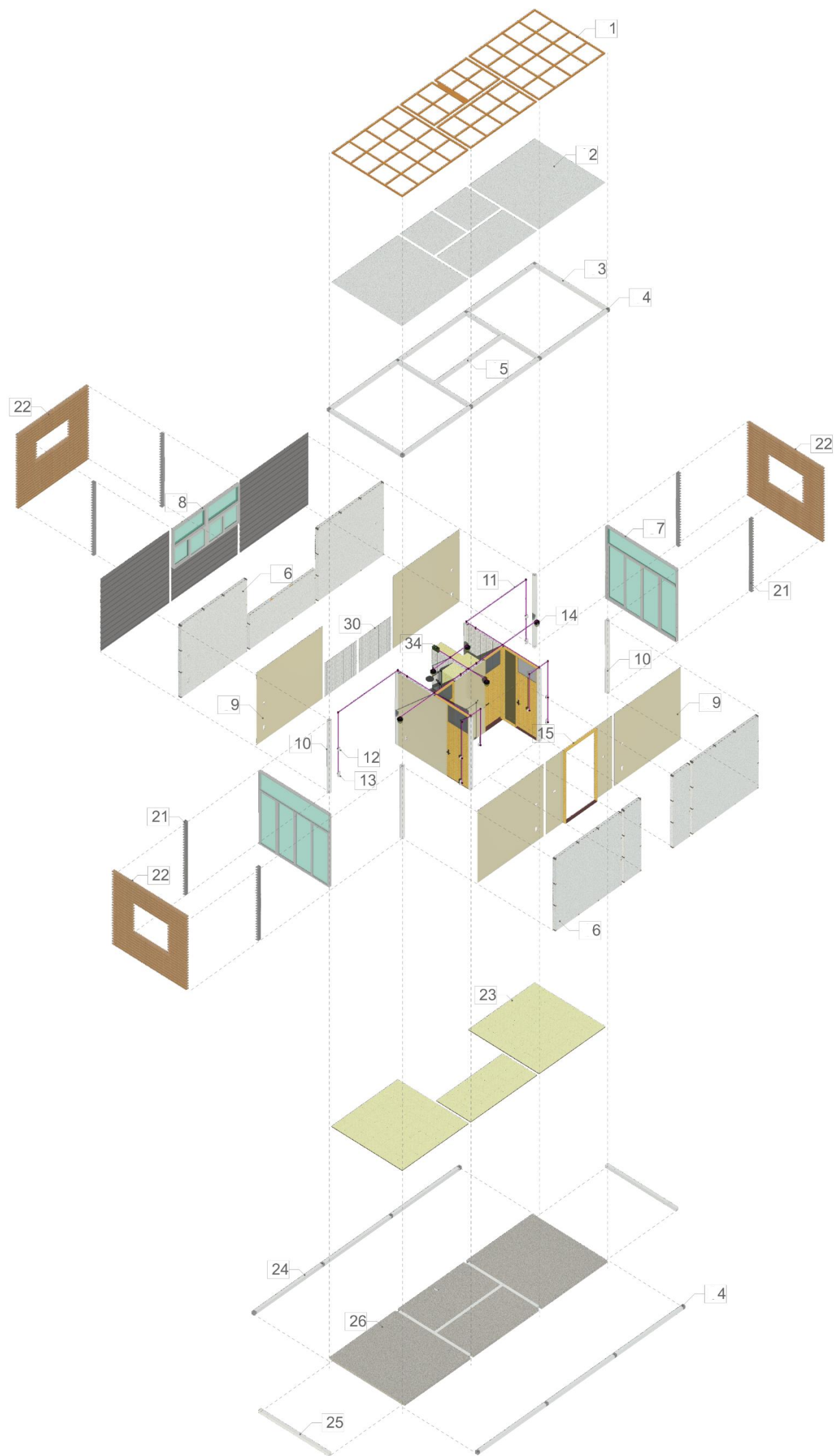
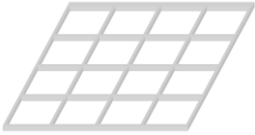


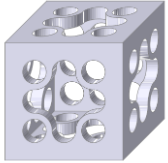


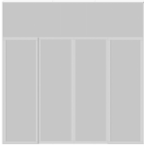

















Figure 5.11: Assembly of Dwelling Modules-4









e) Dwelling Modul Components Description

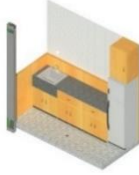


Table 5.2: List of Apartment Dwelling Modules Construction Components

No	Isometric 3D	Description	Width:	Length:	Height:	Total Quantity	Quantity(Pcs)
1		Ceiling Batten Battens construct with 4cm*4cm cross-sectional wood attached to steel beams to hold the ceiling board.	280cm	280cm	4cm	24	M-1: 3 M-2: 3 M-3: 3 M-4: 3
2		Celling Board Construct with MDF panels hold by ceiling battens by small nails.	70cm	70cm	0.3cm	144	M-1: 48 M-2: 48 M-3: 48 M-4: 48
3		Beam-01 Constructed with RHS steel which located both on top of each room module.	10cm	10cm	280cm	34	M-1: 8 M-2: 8 M-3: 10 M-4: 8
4		Connector Made with better quality ticker steel that has bolt holes to connect beams & columns, and openings for access on 6 faces.	10cm	10cm	10cm	64	M-1: 16 M-2: 16 M-3: 16 M-4: 16
5		Beam-03 Constructed with RHS steel that located the top middle of each module that welded with the I shape.	280cm	280cm	280cm	3	M-1: 1 M-2: 1 M-3: 0 M-4: 1
6		Agrostone Panel-01 Made of 10cm thick hollow inside agrostone panels used for filling purpose both for external and internal partition walls.	280cm	280cm	10cm	12	M-1: 4 M-2: 4 M-3: 0 M-4: 4
7		French Door Made with glass and uPVC framing fixed to steel beams and columns.	280cm	280cm	10cm	7	M-1: 2 M-2: 2 M-3: 1 M-4: 2

No	Isometric 3D	Description		
8		Top Window	Width: 280cm	Quantity(Pcs)
		Made with glass and uPVC framing fixed to steel beams and columns.	Length: 150cm	M-1: 1
			Height: 10cm	M-2: 1
			Total Quantity	M-3: 1
9		Wall Paper - internal	Width: 280cm	Quantity(Pcs)
		It's made of wallpapers for internal finish and can be with an order of deferent types of appearance that steak on wall panels.	Length: 280cm	M-1: 7
			Height: -	M-2: 9
			Total Quantity	M-3: 7
10		Column	Width: 10cm	Quantity(Pcs)
		Constructed with RHS steel which connected with connector cube both on up and bottom of a column.	Length: 10cm	M-1: 8
			Height: 280cm	M-2: 8
			Total Quantity	M-3: 8
11		Electrical Conduit	Radius: 1cm	Quantity(m)
		PVC conduits for electrical wire insulation that inserted on beams and wall panels.	Length: -	M-1: 74
			Height: -	M-2: 74
			Total Quantity	M-3: 68
12		Lighting Switch	Width: 4cm	Quantity(Pcs)
		It's a switch for lighting control of indoor rooms in each module.	Length: 4cm	M-1: 7
			Height: 3.5cm	M-2: 9
			Total Quantity	M-3: 3
13		Socket	Width: 8cm	Quantity(Pcs)
		For use of socket jacks both for appliances and other purposes.	Length: 8cm	M-1: 10
			Height: 3.5cm	M-2: 12
			Total Quantity	M-3: 6
14		Light Bulbs	Width: 10cm	Quantity(Pcs)
		Include those lighting appliances used in all rooms of modular compartments of rooms.	Length: 10cm	M-1: 5
			Height: 10cm	M-2: 6
			Total Quantity	M-3: 3
15		Wall Paper - External	Width: 280cm	Quantity(Pcs)
		It's made of wallpapers for an external finish and can be with an order of deferent types.	Length: 280cm	M-1: 3
			Height: -	M-2: 3
			Total Quantity	M-3: 1
			7	M-4: 0

No	Isometric 3D	Description			
16		Door-01	Width: 280cm	Quantity(Pcs)	
		This type of door is for external gate inside corridors in M-01 & M-03 modules and for kitchen of M-03.	Length: 135cm	M-1:	1
			Height: 10cm	M-2:	0
			Total Quantity	M-3:	2
3	M-4:	0			
17		Door-02	Width: 280cm	Quantity(Pcs)	
		This type of door is for bed rooms inside dwellings in M-01 & M-04 modules with extended walling purpose.	Length: 135cm	M-1:	1
			Height: 10cm	M-2:	0
			Total Quantity	M-3:	0
3	M-4:	2			
18		Door-03	Width: 280cm	Quantity(Pcs)	
		This type of door is open frame countering beam and side walls used for gate of living rooms in all modules.	Length: 135cm	M-1:	1
			Height: 10cm	M-2:	2
			Total Quantity	M-3:	1
5	M-4:	1			
19		Door-04	Radius: 280cm	Quantity(m)	
		This type of door is for external gate inside corridors in M-02 and for kitchen and bath gate of M-01, M-02 and M-04.	Length: 75cm	M-1:	2
			Height: 10cm	M-2:	4
			Total Quantity	M-3:	0
8	M-4:	2			
20		External wall cladding	Width: 280cm	Quantity(Pcs)	
		Made with stainless steel corrugated sheet of metal for the purpose of weather insulation.	Length: 300cm	M-1:	1 1/2
			Height: 2cm	M-2:	1 1/2
			Total Quantity	M-3:	1/2
6	M-4:	2 1/2			
21		Sun breakers holder	Width: 10cm	Quantity(Pcs)	
		Made lightweight steel to hold wood panels and connecting itself with steel columns.	Length: 10cm	M-1:	4
			Height: 280cm	M-2:	4
			Total Quantity	M-3:	4
18	M-4:	6			
22		Sun breakers	Width: 280cm	Quantity(Pcs)	
		Made of 2cm x 10 cm x 290cm wood panels about 30 in number for one room facade.	Length: 300cm	M-1:	5
			Height: 10cm	M-2:	6
			Total Quantity	M-3:	2
16	M-4:	3			
23		Floor tiles	Width: 280cm	Quantity(Pcs)	
		It's made of 40cm x 40cm PVC floor tiles that sticks with floor with past materials.	Length: 280cm	M-1:	2 1/2
			Height: 0.3cm	M-2:	2 1/2
			Total Quantity	M-3:	2 1/2
10	M-4:	2 1/2			

No	Isometric 3D	Description			
24		Beam-05	Width: 10cm	Quantity(Pcs)	
		Constructed with RHS C-section steel that located and on single axis side of each module floors to hold hollow section slab	Length: 10cm	M-1: 6	
			Height: 280cm	M-2: 6	
			Total Quantity	M-3: 6	
24			24	M-4: 6	
25		Beam-02	Width: 10cm	Quantity(Pcs)	
		Constructed with RHS steel which located and on single axis side of each module floors.	Length: 10cm	M-1: 2	
			Height: 280cm	M-2: 2	
			Total Quantity	M-3: 4	
10			M-4: 2		
26		Hollow section slab	Width: 280cm	Quantity(Pcs)	
		Is constructed with light weight concrete, has hollow openings of rebid structure reinforced with steel straws.	Length: 280cm	M-1: 3	
			Height: 8cm	M-2: 3	
			Total Quantity	M-3: 3	
12			M-4: 3		
27		Beam-04	Width: 280cm	Quantity(Pcs)	
		Constructed with RHS steel that located bottom middle of each module that welded with the I shape.	Length: 280cm	M-1: 2	
			Height: 280cm	M-2: 4	
			Total Quantity	M-3: 0	
7			M-4: 1		
28		Kitchen module-01	Width: 135cm	Quantity(Pcs)	
		Its kitchen module that fitted to M-01 module (see the details on figure 7.13).	Length: 135cm	M-1: 1	
			Height: 280cm	M-2: 0	
			Total Quantity	M-3: 0	
1			M-4: 0		
29		Bath room module	Width: 135cm	Quantity(Pcs)	
		Its bath module that fitted to in all modules (see the details on figure 7.14).	Length: 135cm	M-1: 1	
			Height: 280cm	M-2: 2	
			Total Quantity	M-3: 0	
2			M-4: 1		
30		Water proof claddings	Width: 280cm	Quantity(Pcs)	
		Made PVC tiles that resist fire and water pouring and sticks with agrostone wall panels with past materials	Length: 135cm	M-1: 21/2	
			Height: 0.3cm	M-2: 5	
			Total Quantity	M-3: 4	
14			M-4: 21/2		
31		Kitchen module-02	Width: 135cm	Quantity(Pcs)	
		Its kitchen module that fitted to M-02 module	Length: 60cm	M-1: 0	
			Height: 280cm	M-2: 2	
			Total Quantity	M-3: 0	
2			M-4: 0		

No	Isometric 3D	Description			
32		Kitchen module-03	Width: 280cm	Quantity(Pcs)	
		Its kitchen module that fitted to M-03 module	Length: 135cm	M-1: 0	
			Height: 280cm	M-2: 0	
			Total Quantity	M-3: 1	M-4: 0
1					
33		Bracing columns	Width: 10cm	Quantity(Pcs)	
		Constructed with C-section lightweight steel to seport wall clading on to M-03 module.	Length: 5cm	M-1: 0	
			Height: 280cm	M-2: 0	
			Total Quantity	M-3: 10	M-4: 0
10					
34		Service duct	Width: 20cm	Quantity(Pcs)	
		Made with sheet of metal that uses for handling of water supply pipes, sewerage pipes and electrical conduits.	Length: 10cm	M-1: 1	
			Height: 300cm	M-2: 2	
			Total Quantity	M-3: 1	M-4: 1
5					

All the components described and summarized in the above table are those assemblies of apartment dwelling modules that utilized on each of Module-1, Module-2, Module-3 and Module-4. With those materials, manufacturing on independent sections or place of fabrication components can bring together and assembled in a single area for finalizing modular assembly, in case all components have its design and manufacturing tag that will be identified by assembly workers and modular component fabricators to fit the required assemblies in the desired pace. The design proposal objective for apartment dwelling module components is to ease the process of modular assembly by defragmentation of components that could be carried by human workforce and small industrial cranes, and also the materials used for modular components manufacturing are locally available and it could be adapted for mass fabrication with untrained workers.

Structural materials used for modular assembly such as steel beams and columns has a cross sectional dimensions of 10cm x 10cm, but the internal thickness of beams and columns change deplanned on the structural requirement, for columns the internal thickness of RHS steel increases with the story of apartment that carry above and it increases from roof top carrying column to the ground floor, also for beams the thickness of 10cm x 10cm RHS steel depend on the lateral load indexes (earthquake and wind load) of the site that the apartment buildup. But for this design proposal the structural design for framing of modules is deplanned on the required strength of module the place that will be assembled and the position of module in apartment building, however the limit in this proposal is the maximum thickness of the RHS steel is up to 18 mm both for RHS all columns and beams because of space for bolt connection with frames and connector cubes and 10mm thickness for C-section beam that carry hollow concrete slab, but the maximum story of apartment is based on the maximum capacity of both columns and beams within 18mm thickness.

f) Assembly of Service Modules

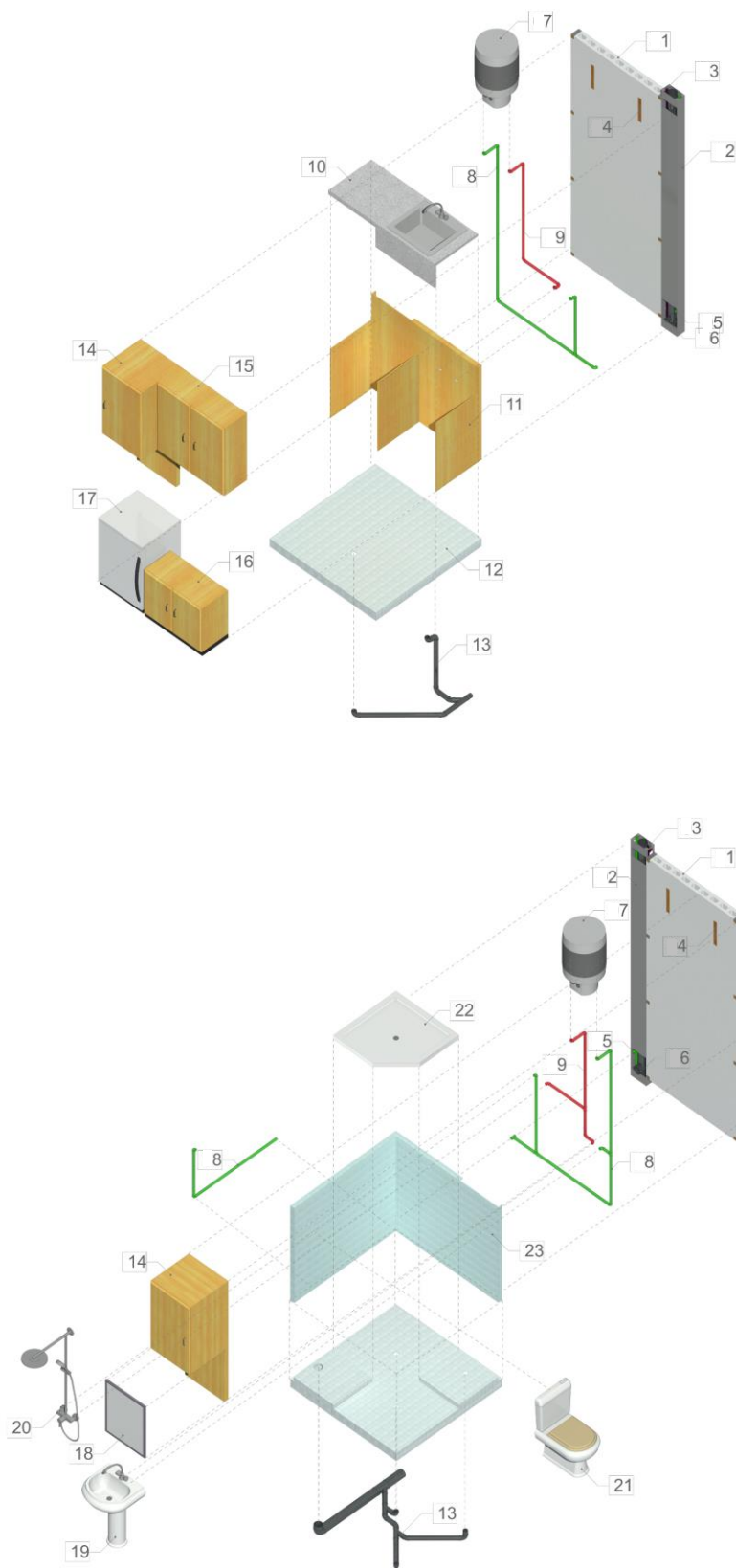


Figure 5.13: Assembly of Bath Module

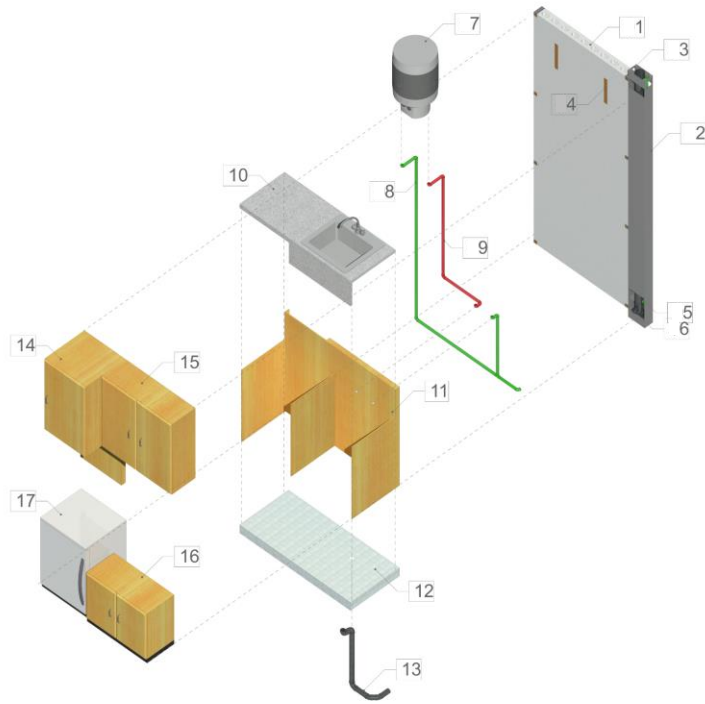


Figure 5.14: Assembly of Kitchen Module-2 (K-2)

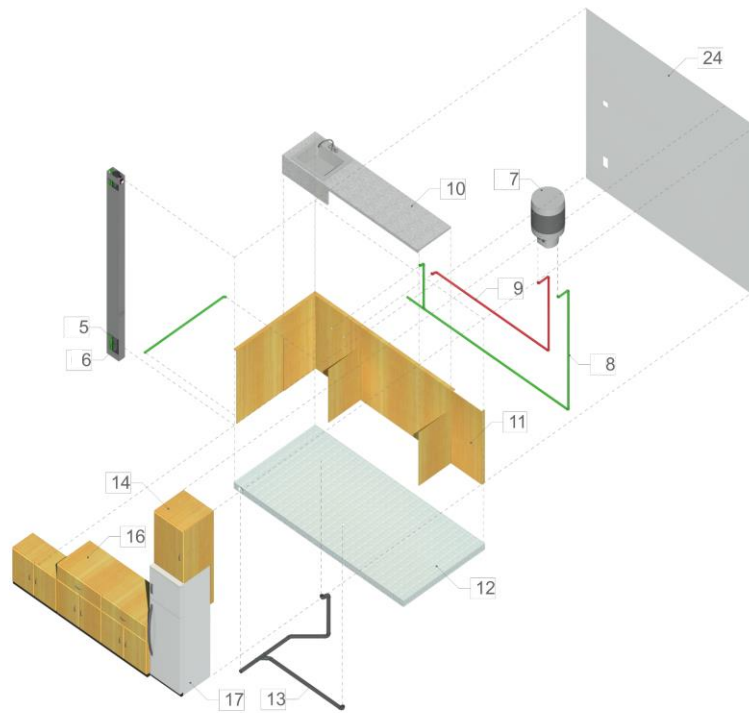


Figure 5.15: Assembly of Kitchen Module-3 (K-3)

g) Service Modul Components Description

Table 5.3: List of Apartment Dwelling Modules Construction Components

No	Description	K-1	K-2	K-3	Bath
1	Agrostone Panel	K-1	K-2	K-3	Bath
	Made of 10cm thick hollow inside agrostone panels used for partision purpose and to hold top kitchen cabinet.	Width: 10cm	10cm	-	10cm
		Length: 115cm	115cm	-	115cm
		Height: 280cm	280cm	-	280cm
2	Service duct	K-1	K-2	K-3	Bath
	Made with sheet of metal that uses for handling of water supply pipes, sewerage pipes and electrical conduits.	Width: 20cm	20cm	20cm	20cm
		Length: 10cm	10cm	10cm	10cm
		Height: 300cm	300cm	300cm	300cm
3	Electrical Conduit	K-1	K-2	K-3	Bath
	PVC conduits for electrical wire insulation that inserted on service duct for connection of all electrical systems.	Radius: 1cm	1cm	1cm	1cm
		Length: -	-	-	-
		Height: 300cm	300cm	300cm	300cm
4	Wall Support	K-1	K-2	K-3	Bath
	It's a wood pice molded together with agrostone panel inorder to support wall cabinates and water heater easily scriwing on the wood.	Width: 10cm	10cm	-	10cm
		Length: 4cm	4cm	-	4cm
		Height: 30cm	30cm	-	30cm
5	Water supply pipe	K-1	K-2	K-3	Bath
	Made with PVC pipes for suply of water that inserted on service duct for connection of all water supply systems.	Radius: 1.6cm	1.6cm	1.6cm	1.6cm
		Length: -	-	-	-
		Height: 300cm	300cm	300cm	300cm
6	Sewerage pipe	K-1	K-2	K-3	Bath
	Made with PVC pipes for sewerage outlet that inserted on service duct for connection of all sewerage pipe systems of modular stories.	Radius : 5cm	5cm	5cm	5cm
		Length: -	-	-	-
		Height: 300cm	300cm	300cm	300cm
7	Water Heater	K-1	K-2	K-3	Bath
	Uses for water heating for suply of hot water to kitechens and bath rooms.	Width: 50cm	50cm	50cm	50cm
		Length: 50cm	50cm	50cm	50cm
		Height: 70cm	70cm	70cm	70cm
	Quantity: 1	1	1	1	

No	Description		K-1	K-2	K-3	Bath
8	Cold water pipe		K-1	K-2	K-3	Bath
	Made with PVC pipes for supply of water that connected to main water supply service duct.	Radius:	1.6cm	1.6cm	1.6cm	1.6cm
		Length:	550cm	550cm	650cm	650cm
		Height:	-	-	-	-
	Quantity:	1	1	1	1	
9	Hot water pipe		K-1	K-2	K-3	Bath
	Made with PVC pipes for supply of hote water that connected to water hiter and sinks and shower valves.	Width:	1.6cm	1.6cm	1.6cm	1.6cm
		Length:	250cm	250cm	350cm	300cm
		Height:	-	-	-	-
	Quantity:	1	1	1	1	
10	Kitchen sink		K-1	K-2	K-3	Bath
	Made with plastic laminated MDF wood and stainless still dish washing snick.	Width :	50cm	50cm	50cm	-
		Length:	135cm	135cm	280cm	-
		Height:	3cm	3cm	3cm	-
	Quantity:	1	1	1	-	
11	Sink Holder		K-1	K-2	K-3	Bath
	Made with laminated MDF board fixed to floor and walls that uses to hold kitchen sink.	Width:	50cm	50cm	50cm	-
		Length:	135cm	135cm	280cm	-
		Height:	120cm	120cm	120cm	-
	Quantity:	1	1	1	-	
12	Floor deck		K-1	K-2	K-3	Bath
	Made with water proof laminated Wood frame and steel sheet coverd with tiles for flooring.	Radius:	135cm	135cm	135cm	135cm
		Length:	135cm	280cm	135cm	135cm
		Height:	10cm	10cm	10cm	10cm
	Quantity:	1	1	1	1	
13	Floor Sewerage Pipes Φ 5cm		K-1	K-2	K-3	Bath
	Made with PVC pipes for sewerage outlet from floor decks that connected to sanitary fixtures.	Radius :	2.5cm	2.5cm	2.5cm	5+2.5cm
		Length:	280cm	280cm	280cm	125+240cm
		Height:	-	-	-	-
	Quantity:	1	1	1	1	
14	Water heater cover		K-1	K-2	K-3	Bath
	Made with laminated MDF board fixed to walls that uses to contain water heater.	Width:	50cm	50cm	50cm	50cm
		Length:	50cm	50cm	50cm	50cm
		Height:	150cm	150cm	150cm	150cm
	Quantity:	1	1	1	1	
15	Top kitchen cabinet		K-1	K-2	K-3	Bath
	Made with laminated MDF board fixed to walls that uses for storage purpose.	Width:	75cm	75cm	-	-
		Length:	30cm	30cm	-	-
		Height:	90cm	90cm	-	-
	Quantity:	1	1	-	-	

No	Description					
16	Bottom kitchen cabinet	K-1	K-2	K-3	Bath	
	Made with laminated MDF board fixed to floor that uses for storage purpose.	Width:	50cm	50cm	50cm	-
		Length:	75cm	75cm	220cm	-
		Height:	90cm	90cm	90cm	-
Quantity:	1	1	1	-		
17	Fridge	K-1	K-2	K-3	Bath	
	It placed on space occupied for siting of fridge appliance.	Width:	50cm	50cm	60cm	-
		Length:	55cm	55cm	60cm	-
		Height:	85cm	85cm	180cm	-
Quantity:	1	1	1	-		
18	Mirror	K-1	K-2	K-3	Bath	
	Placed on the bottom of water heater cover by fixing on it with glues.	Width :	-	-	-	50cm
		Length:	-	-	-	50cm
		Height:	-	-	-	2cm
Quantity:	-	-	-	1		
19	Bath Basin	K-1	K-2	K-3	Bath	
	Uses for hand wash in the bath module fixed on floor deck and connected to Sewerage, cold and hot water pipes.	Radius:	-	-	-	50cm
		Length:	-	-	-	50cm
		Height:	-	-	-	90cm
Quantity:	-	-	-	1		
20	Bath Shower	K-1	K-2	K-3	Bath	
	Uses for showering in the bath module fixed on bath wall and connected to Sewerage, cold and hot water pipes.	Radius :	-	-	-	20cm
		Length:	-	-	-	20cm
		Height:	-	-	-	120cm
Quantity:	-	-	-	1		
21	Water closet	K-1	K-2	K-3	Bath	
	Fixed on bath floor and, connected to both Sewerage, cold and hot water pipes.	Radius :	-	-	-	60cm
		Length:	-	-	-	60cm
		Height:	-	-	-	45cm
Quantity:	-	-	-	1		
22	Shower tray	K-1	K-2	K-3	Bath	
	Fixed on bath floor and, connected to both Sewerage, cold and hot water pipes.	Width:	-	-	-	80cm
		Length:	-	-	-	80cm
		Height:	-	-	-	5cm
Quantity:	-	-	-	1		
23	Bath room wall	K-1	K-2	K-3	Bath	
	Made with water proof laminated Wood frame and steel sheet coverd with wall terazzo tiles.	Width:	-	-	-	135cm
		Length:	-	-	-	135cm
		Height:	-	-	-	15cm
Quantity:	-	-	-	1		

h) Assembly of Staircase

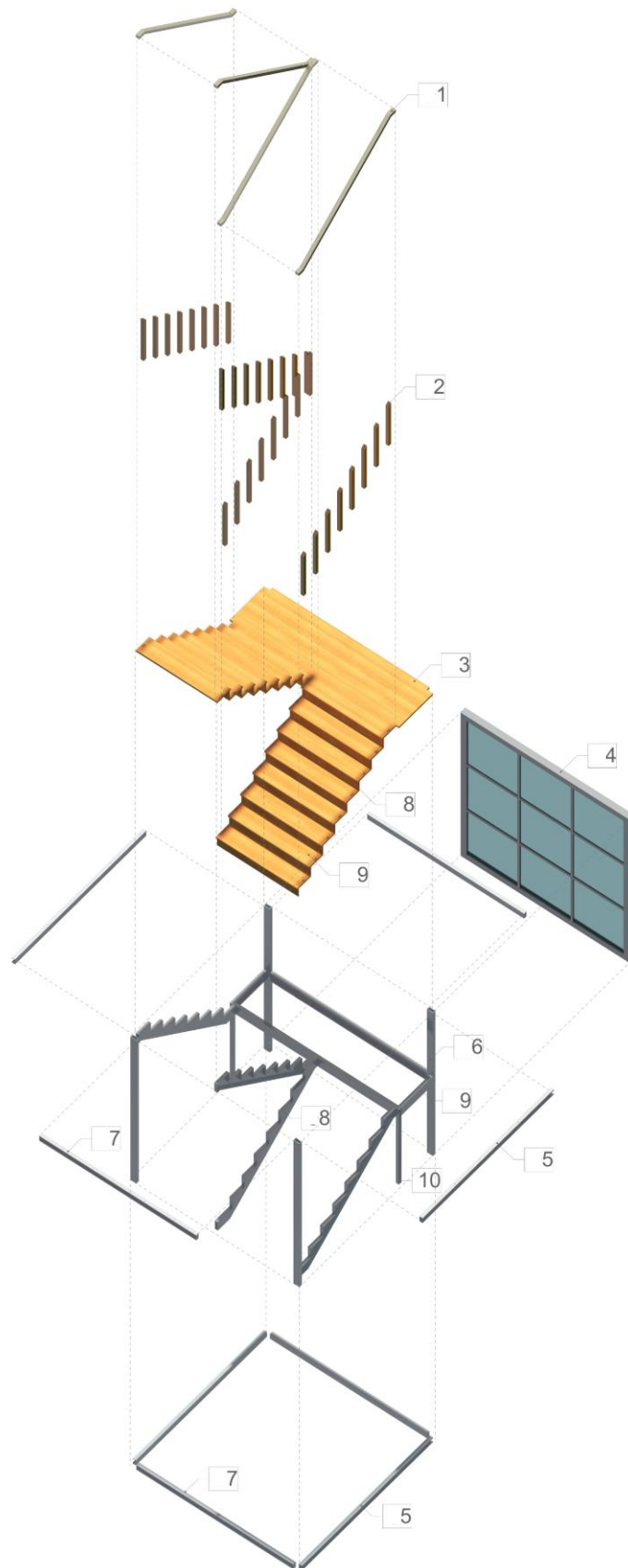
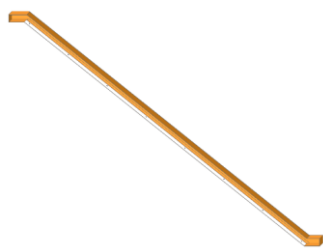


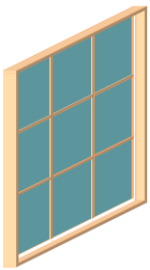



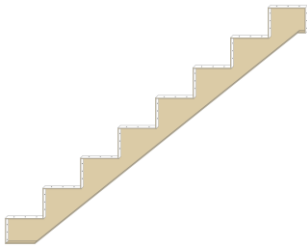


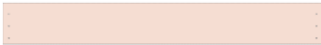
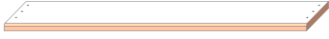


Figure 5.16: Assembly of Staircase

Table 5.4: List of Staircase Modules Construction Components

No	Isometric 3D	Description	Width:	Length:	Height:	Quantity(Pcs)
1		<p>Handrail</p> <p>It made of lightweight stainless steel with C-cross section 5cm x 5cm and has 2mm thickness with smooth filet at the ends of corner edges, and also connects with bolt with balusters at the bottom.</p>	5cm	5cm	340cm	4
2		<p>Baluster</p> <p>It made of lightweight stainless steel with C-cross section 5cm x 5cm and has 2mm thickness connected with handrail with bolt at the top and with trade and trade holder at the bottom.</p>	5cm	5cm	90cm	32
3		<p>Landing</p> <p>It made of wood panel with terrazzo finishes at the top and connects with landing frames at the bottom.</p>	110cm	280cm	3cm	1
4		<p>Window</p> <p>Window frame is made of PVC plastic farming and glass panels.</p>	280cm	300cm	10cm	1
5		<p>Beam-1</p> <p>It made of lightweight steel with C-cross section that connected on opposite sides bottom and top of holding column.</p>	10cm	5cm	270cm	4
6		<p>Column-1</p> <p>It made of 5cm x 10cm RHS steel cross section.</p>	10cm	5cm	300cm	4

No	Isometric 3D	Description	Width:	Length:	Height:	Quantity(Pcs)
7		<p>Beam-2</p> <p>It made of lightweight steel with C-cross section that connected on front and rear sides bottom and top of holding column.</p>	10cm	5cm	260cm	5
8		<p>Stair Trade Holder</p> <p>It made of lightweight steel with a round of 5cm width on the steel plate shape on no 8 that holds steps trade, riser and balusters.</p>	17cm	135cm	2cm	4
9		<p>Beam-3</p> <p>It made of lightweight steel that holds landing on opposite sides of stair module.</p>	5cm	10cm	85cm	2
10		<p>Column-2</p> <p>It made of lightweight steel that holds beam-3 and landing and supported with beam-1 at the bottom.</p>	5cm	5cm	137cm	2
11		<p>Riser</p> <p>It made with wood panels supported on trade and riser holder.</p>	17cm	135cm	2cm	16
12		<p>Trader</p> <p>It made with wood panels and terrazzo finish on the top that supported on trade and riser holder.</p>	27cm	135cm	3cm	18

i) Assembly of Roof Modul

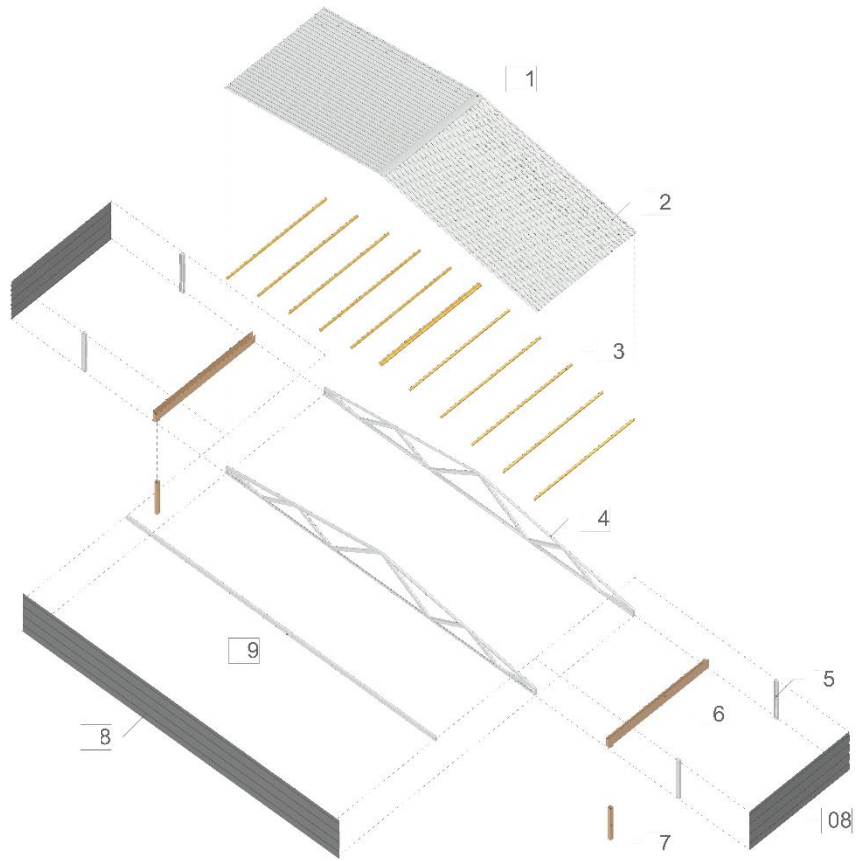


Figure 5.17: Assembly of End Roof Module

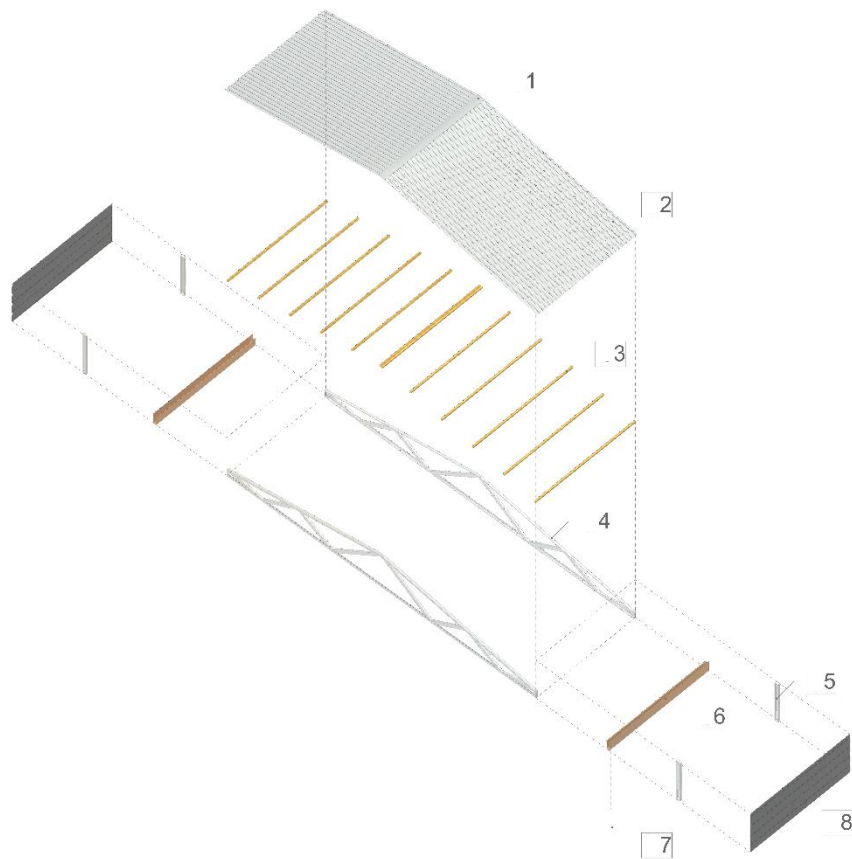
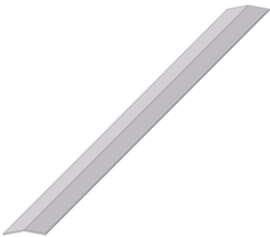
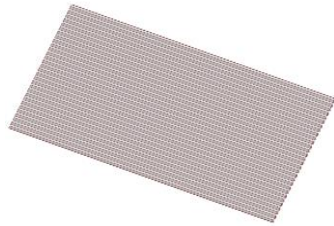


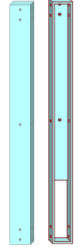
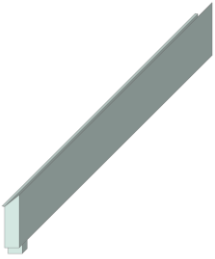





Figure 5.18: Assembly of Middle Roof Module

Table 5.5: List of Roof Modules Construction Components

No	Isometric 3D	Description	
1		Roof Top Cover The top cover is to protect the roof top bending opening from rain, that made of galvanized sheets.	Width: 60cm Length: 300cm Thickness: 0.1cm Quantity(Pcs) 5
2		Roof Cover It made of galvanized sheet for roof coverage.	Width: 446cm Length: 300cm Thickness: 0.1cm Quantity(Pcs) 5
3		Purlin It made of wood purlin that will bolt on roof truss and carry roof cover which connected by nail.	Width: 4cm Length: 4cm Height: 300cm Quantity(Pcs) 60
4		Roof truss It made of lightweight steel with C-cross section and rectangular steel that shown on exploded view on figure 7.18 and 7.19.	Width: 10cm Length: 880cm Height: 100cm Quantity(Pcs) 10
5		Cladding support-01 It made of lightweight steel with C-cross section that connected to roof truss to handle roof top cladding.	Width: 10cm Length: 5cm Height: 120cm Quantity(Pcs) 4
6		Roof Gutter It made of metal sheets for purpose of roof water drainage.	Width: 10cm Length: 300cm Height: 30cm Quantity(Pcs) 10

No	Isometric 3D	Description	
7		Down Pipe	Width: 8cm Length: 8cm Height: + <hr/> Quantity(Pcs) 4
8		Roof Side Cladding It made of galvanized steel sheets.	Width: 120cm Length: 300cm Thickness: 1cm <hr/> Quantity(Pcs) 16
9		Cladding support-02 It made of lightweight steel with C-cross section that connected to cladding support-01 to handle roof top cladding.	Width: 5cm Length: 880cm Height: 10cm <hr/> Quantity(Pcs) 2

IV. Detail Illustration of Module Components

a) Wall construction

All partition and exterior wall for modular assembly is made of agrostone hollow agrostone panel the technology available and locally adapted in industrial fabrication but the researcher made some modifications on design proposal for walling construction with agrostone. The panel will be manufactured on independent compartment for mass production, for the proposal there are four types of wall assembly dimensions and here the details for one of the types illustrated.

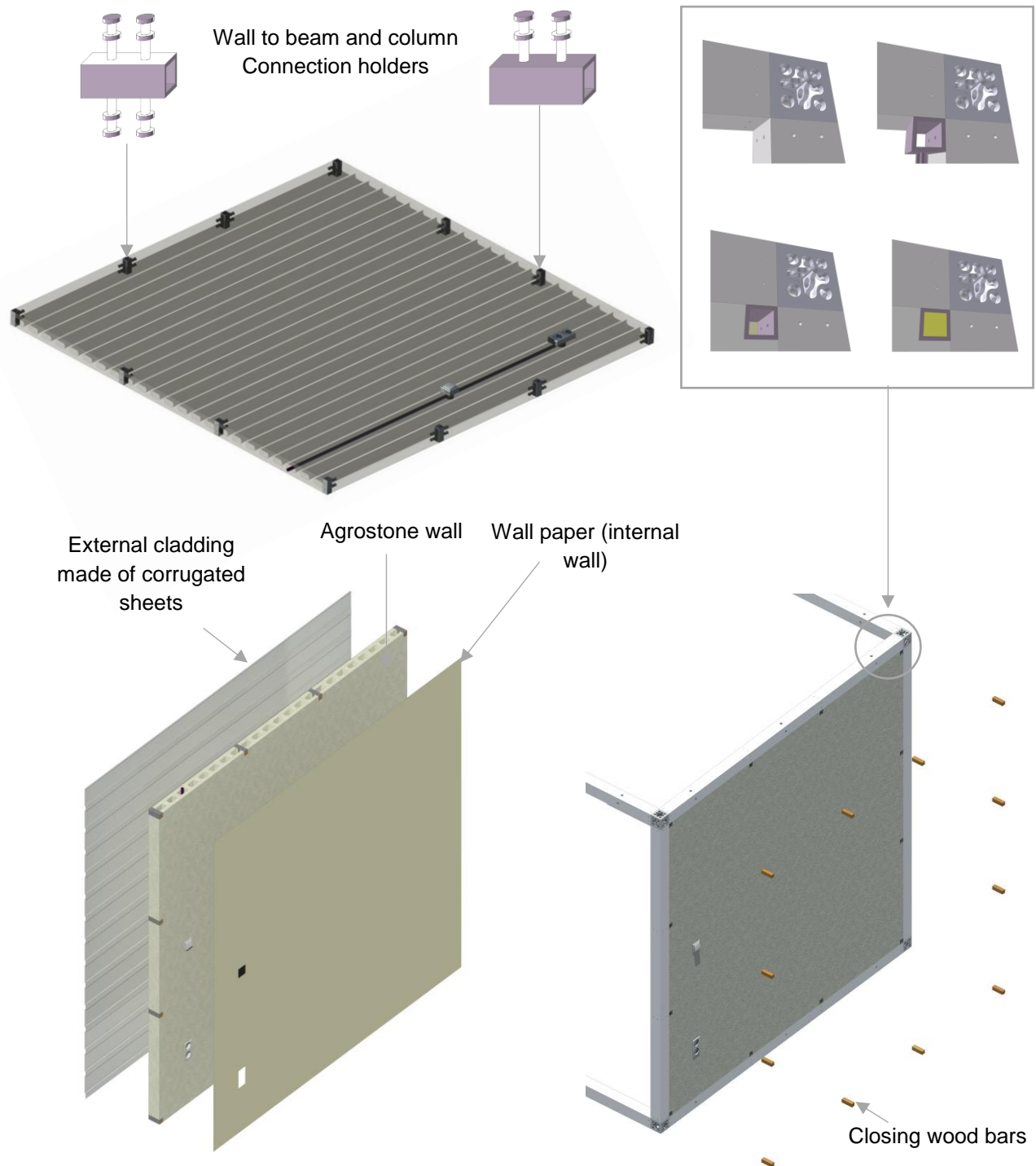


Figure 5.19: Wall module details

b) Connector Cube

Columns and beams are connected using connector cube as shown on the figure and all the faces of the cube is with similar face that will join with adjacent same face of col column and beams and also to connect different modules within the same story and on story of module to the next module.

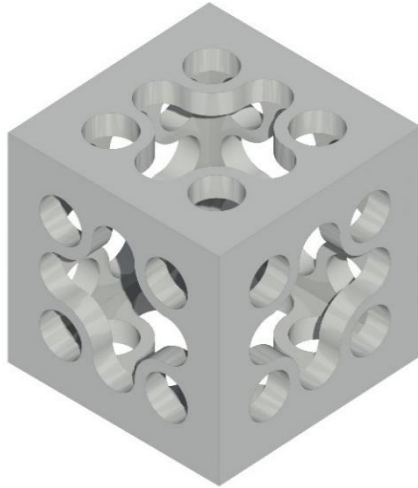


Figure 5.20: Connector cube

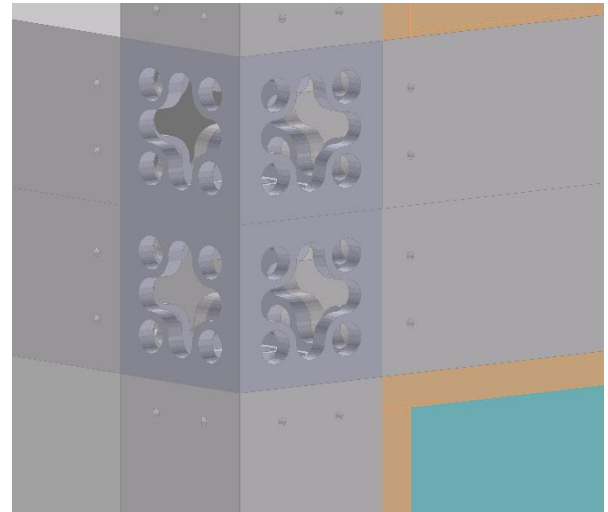


Figure 5.21: Connection of modules of one story to the other

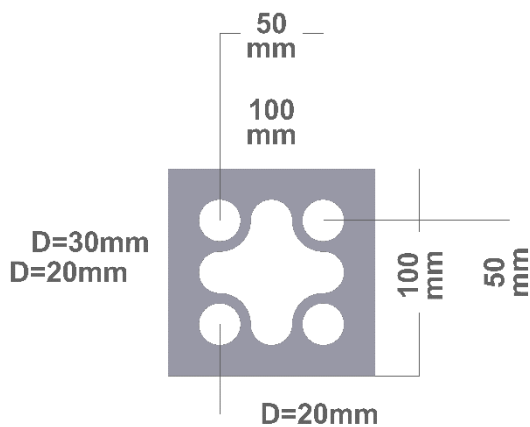


Figure 5.22: Connector cube detail

There is at least a face of the connector cube (Figure 5.20) with hand access opening for modules to module connection work that helps workers to connect beams, columns and independent modules by accessing bolts through the middle opening in each face of connector cubes. Figure 5.21 also shows the connection between two independent modules in different flowing story's that each cube connects with bolts which has the same face it connects.

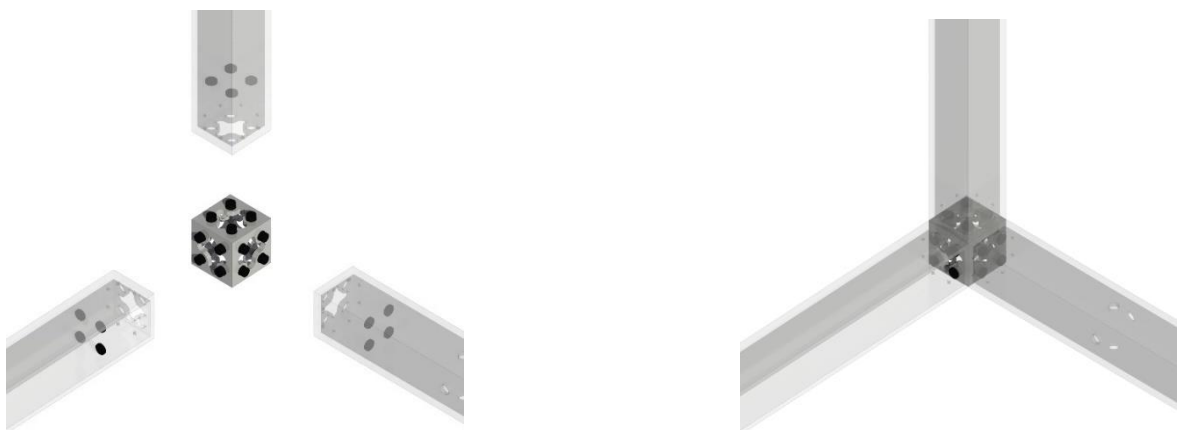


Figure 5.23: Connection of beams and columns

Figure 5.23 also illustrate how beams and columns connect to each other with the cube connector, the researcher concept of the design is for simple connection of beams and columns with a connector that helps to steel beams and columns independently carry by workers, easing modular construction, in case all beams and columns except the beams located in the middle room of M-1, M-2 and M-4 have 280cm with the cross sectional dimension of 10cm x 10cm. Each face of beams and columns at the end of the connection has identical face and dimension with the connector cable and easily bolt together.

c) Columns

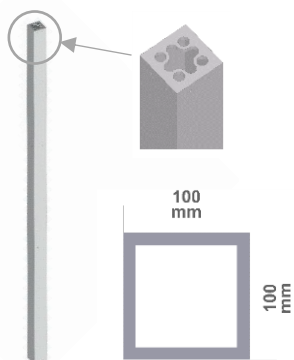


Figure 5.24: Columns detail

Columns in all module have the same dimension which with 10cm x 10cm cross sectional dimension and 280cm long. But the correctional interior thickness of the hollow rectangular section could vary depending on the module that could carry the load from adjacent above story's and the dimension of thickness will decrease from bottom story to the next above story of modular organization. However, the maximum changes of thickness are 18 mm to leave spaces for bolts inside the column and connector cube.

d) Beams

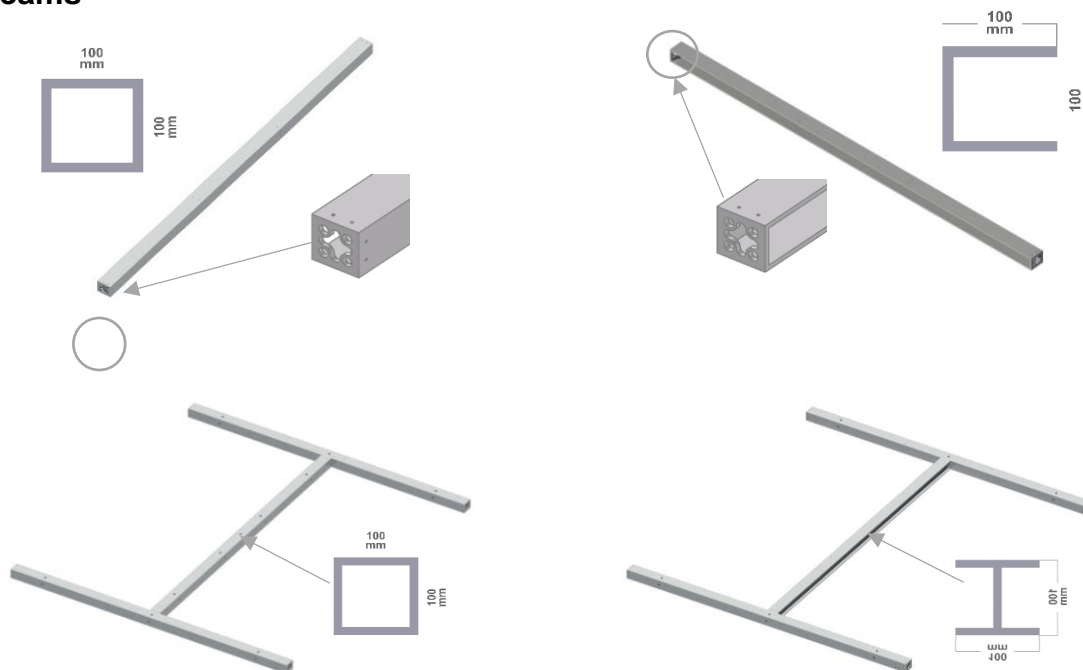


Figure 5.25: Beams detail

There are four types of beams used for modular assembly. A type of beam on figure a with rectangular cross section uses for top and one side bottom of module, and a beam on figure b with C-cross section to hold the floors in opposite sides of a slab. Beam type of figure c is used on top middle of module M-1, M-2 and M-4, also beam on figure d used on bottom middle of the same modules which has I section steel in the middle of slab deck hanging. But all beams have the cross-sectional boundary of 10cm x 10cm that could differ in their internal thickness depend on the structural requirement of the area that modules organized for dwelling.

e) Doors

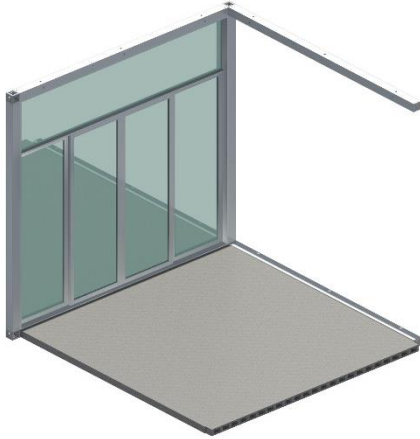


Figure 5.26: French door

There are seven French windows and four top windows proposed for four modules in one story an apartment dwelling organization. Doors and windows connect with frames with screwing through pre-drilled holes on beams and columns. Doors and windows also serve as additional strength for lateral loads applied to the whole module in addition to agrostone wall panels. All windows and doors are prepared in independent compartments and move to the modular assembly area.

f) Shades

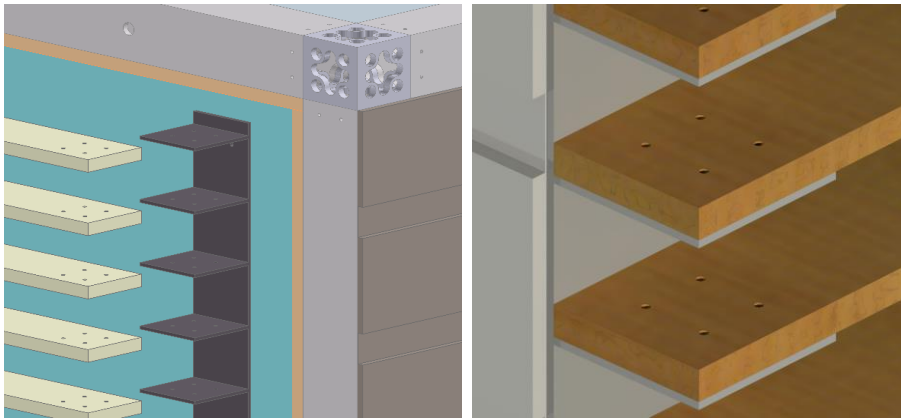


Figure 5.27: External shade assembly

Before shade wood panels screwed on hanger plates, hanger plates screwed on columns and then each shade panel screwed on hangers as shown in Figure 5.27.

g) Ceiling

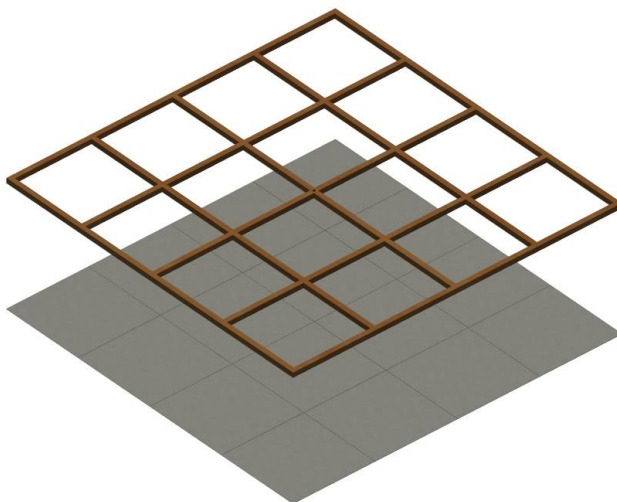


Figure 5.28: Ceiling assembly

Ceiling battens made with wood prepared independently and ceiling boards will then be screwed to battens to make single module of ceiling and then take to modular assembly area and the module will attached and screwed to top beams of main module by screwing on pre-drilled holes on each beam. There are two types of ceiling modules the larger one on opposite side of rooms and the smaller one on the middle of main module.

h) Slab Assembly

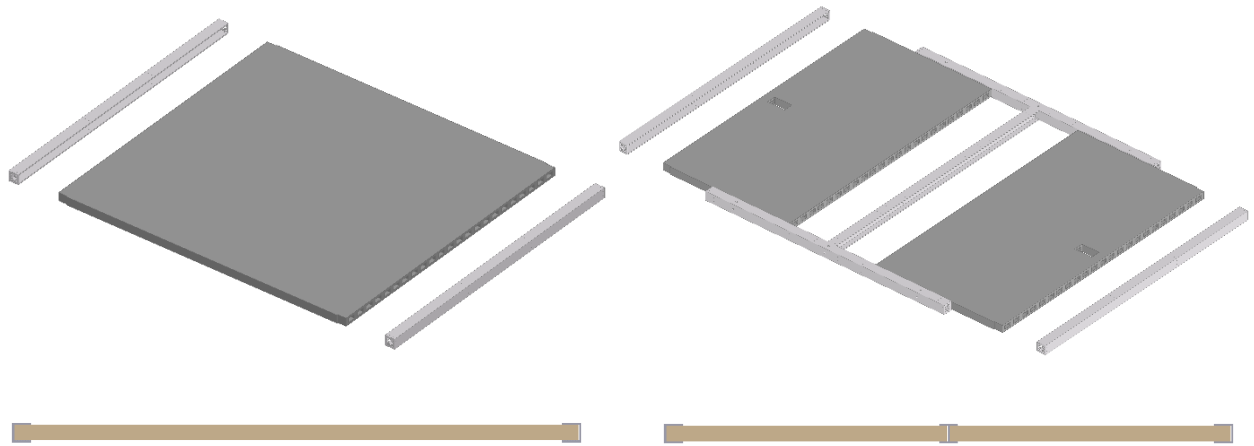


Figure 5.29: Flooring slab assembly

i) Staircase Assembly

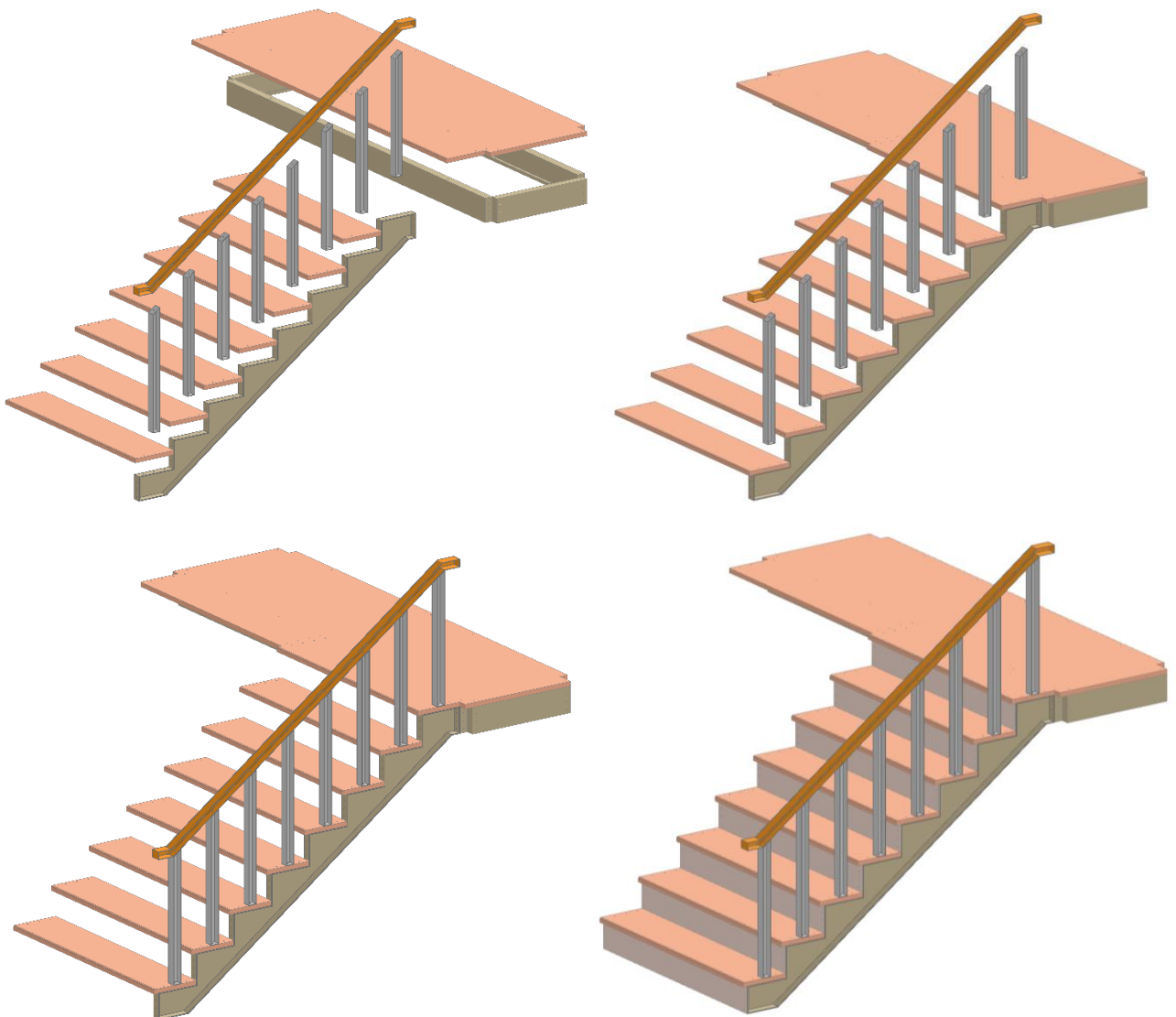


Figure 5.30: Staircase assembly

j) Roof Assembly Details

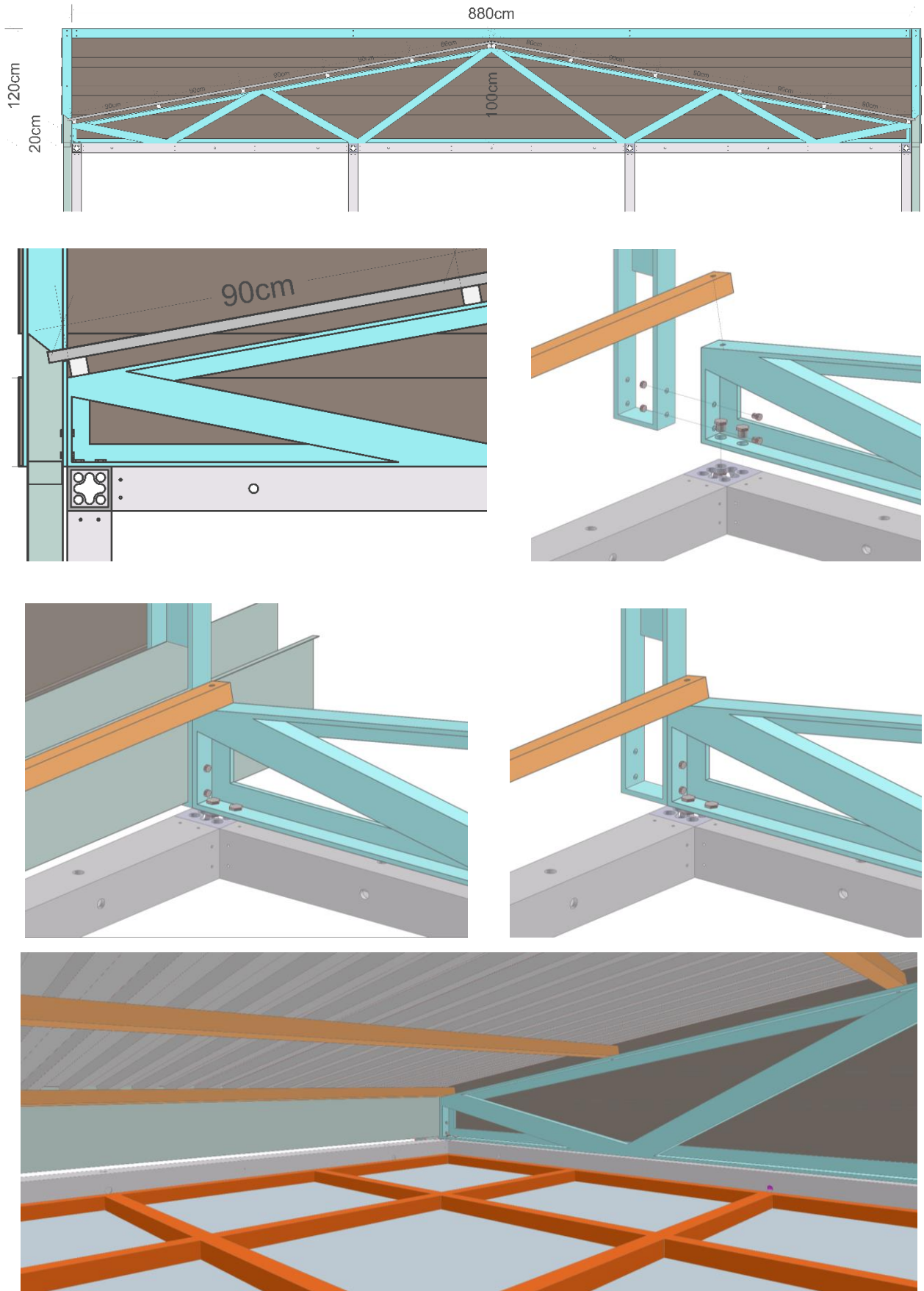


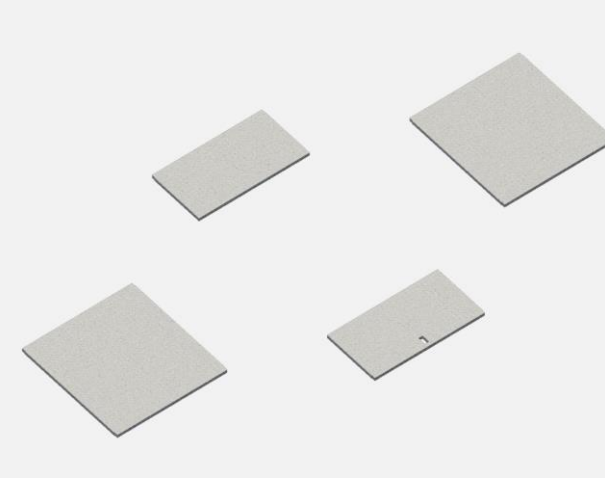
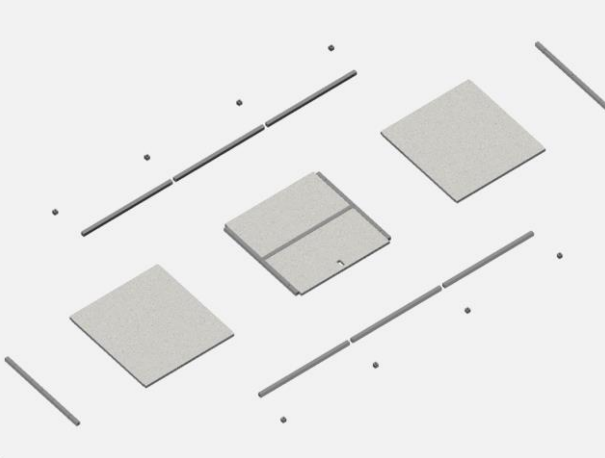
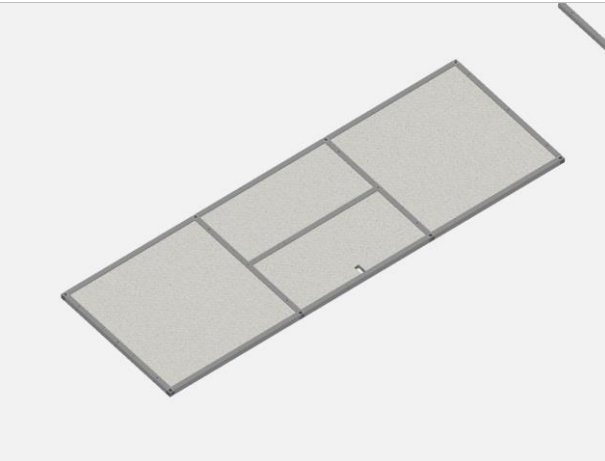
Figure 5.31: Roof module assembly

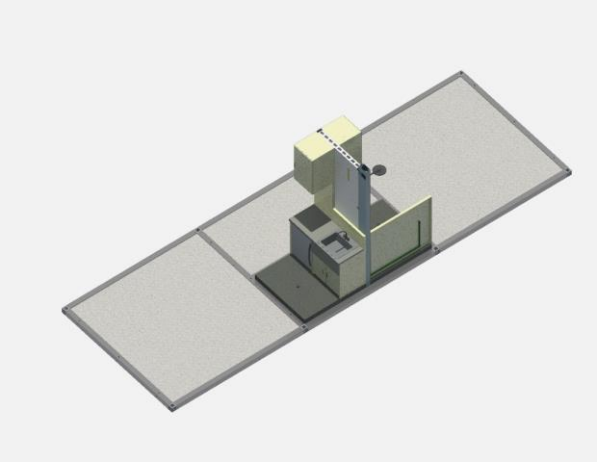
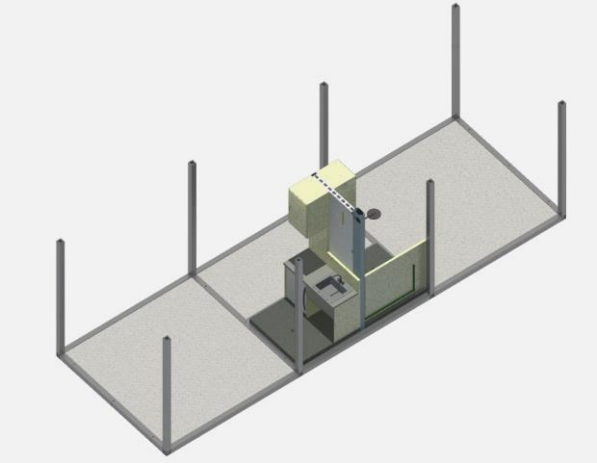
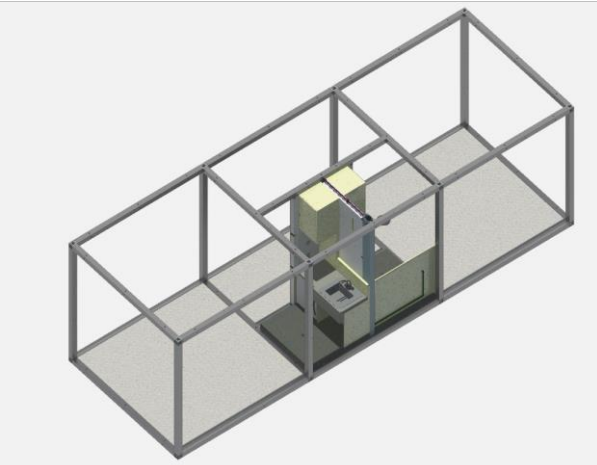
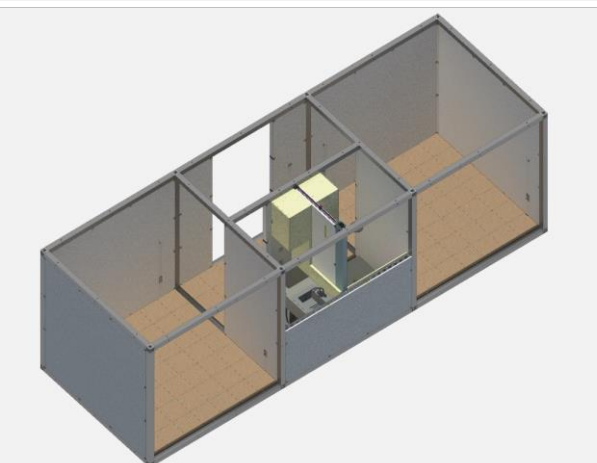
V. Steps for Assembly of Designed Modules

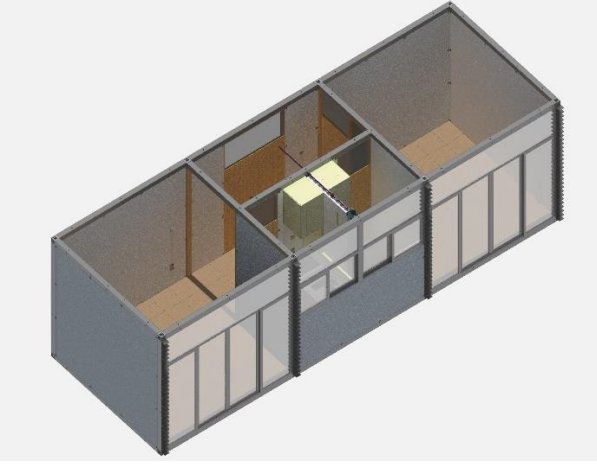

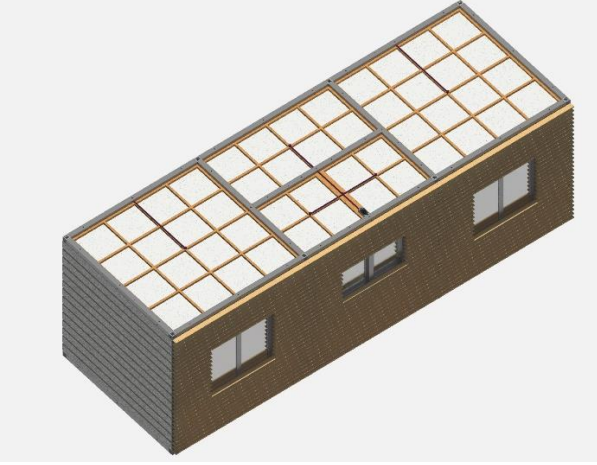

The following sections demonstrate the proper proposed steps for dwelling and service modules that will help the construction of modules in a simple and organized way that avoid miss alignment and fatigues of assembly works. But all the assembles for volumetric construction is pre-fabricated and ready for assembly that was made in independent sections of components manufacturing.

a) Dwelling Modules

Table 5.6: Steps for Dwelling Modules Assembly



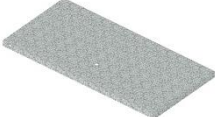
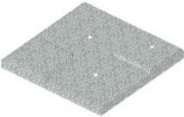
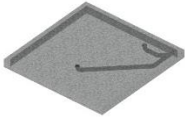
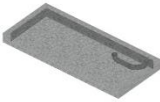
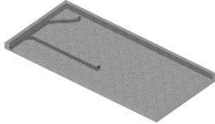
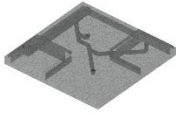


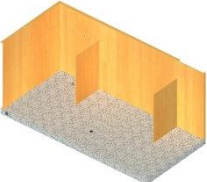
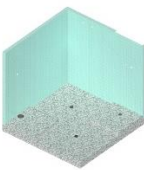
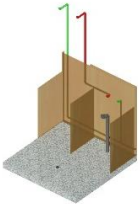
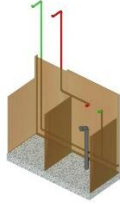
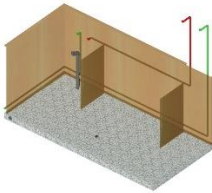
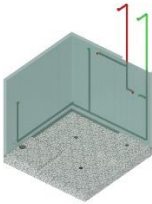

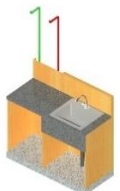
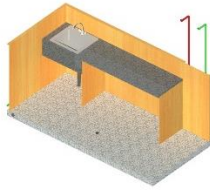

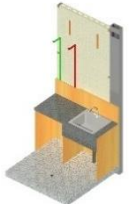
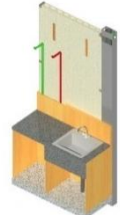
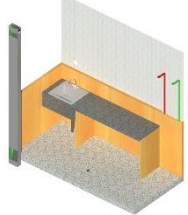


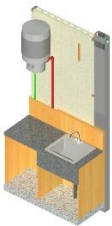
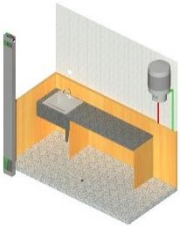



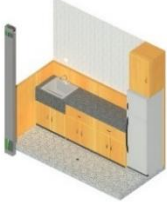

Description	Isometric 3D
<p>Step-1</p> <p>At this step floor decks constructed with light weight concrete put together in order for floor assembly. Each M-01, M-02 and M-04 dwelling modules use two 280cm x 133cm and 280cm x 298cm floor decks, and M-03 module uses three 298cm x 298cm. Floor decks produced with independent place in a factory compartment are bring to assembly area with factory loader truck for assembly.</p>	
<p>Step-2</p> <p>This step involves connection of floor decks with C-shape steel beam and jacking it inside the deck. 280cm x 133cm deck is jacked with I-shape welded beam in I-section beam located in the middle and 280cm x 298cm deck jack with two opposite sides of the deck with C-section steel beams.</p>	
<p>Step-3</p> <p>After connection of C-section beams with floor deck this step involves with closing of floor deck with RHS- steel on the opposite side of the longitudinal side the module together with connector beams and finally the floor part be ready for column and modular service parts construction.</p>	

Description	Isometric 3D
<p>Step-4</p> <p>This step involves placement of pre-assembled service duct, modular kitchen and bath rooms components before erection of columns in order to avoid narrowing of movement for placement of those sub-modules.</p>	
<p>Step-5</p> <p>After placing service module parts both kitchen and bath room accessories, steel columns will erect on each of the eight connector cubes with bolts by accessing trough working openings in each face of cube in the same adjacent face of column. Each column has the same shape and hole drills for other connections such as walls, doors and windows.</p>	
<p>Step-6</p> <p>For finalizing of structural framing all top beams connect to columns together with connector cubes, this step of assembly gives structural rigidity to the module that able to move by hanging on the crane with cable suspension and other systems. Electrical conduits also assembled and inserted in to the beams for electrical connections of rooms.</p>	
<p>Step-7</p> <p>In this step walling elements made of agrostone panels with different length will connect by screwing on small holes on beams and columns. Walls also give additional strength to modular compound trough bracing connections of beams and columns.</p>	

Description	Isometric 3D
<p>Step-8</p> <p>Following walls placement windows and door follow for assembly to take their place and also sun breaker holder will be screwed to column holes in order to handle sun breaker rectangular wooden plates.</p>	
<p>Step-9</p> <p>This step involves the assembly of ceiling battens module that made of wood with 4cm x 4cm cross section on beam holes in order to handle ceiling boards. And also, sun break wood panels also erected on sun breaker holder that protects rooms from direct sun radiation exposure in addition good architectural appearance, and external cladding using corrugated metal sheet.</p>	
<p>Step-10</p> <p>After ceiling battens erection in this step ceiling boards made with MDF boards will be screwed on ceiling battens. And also, wallpapers on interior rooms and on corridor side of the module apartment will be glued to agrostone panels for room finishing.</p>	
<p>Step-11</p> <p>After finishing of all module components assembly, the dwelling module will be placed on truck and finally goes to the required apartment construction site for site assembly of each finished module.</p>	


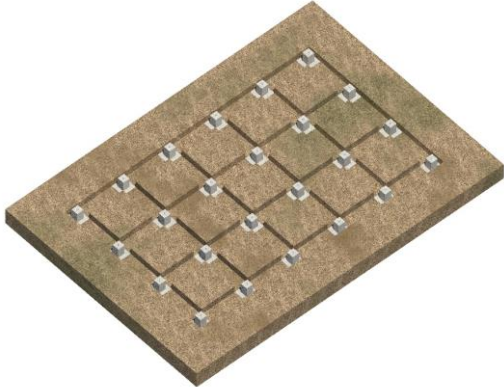
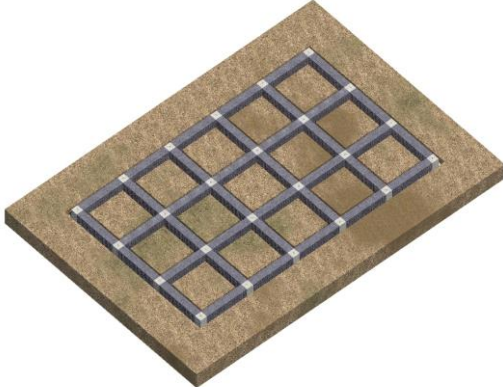
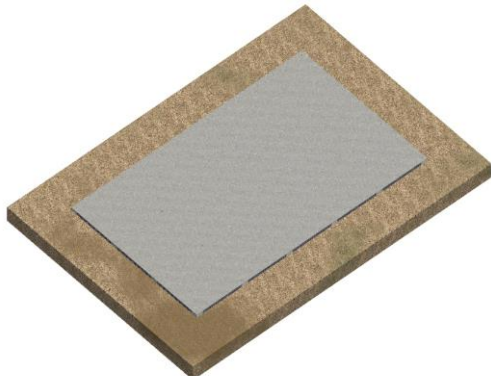
b) Kitchen and Bath Modules

Table 5.7: Steps for Kitchen and Bath Modules Assembly

Description	Isometric 3D			
	K-1	K-1	K-1	Bath
<u>Step-1</u> Preparation of decks.				
<u>Step-2</u> Installation of sewerage pipes.				
<u>Step-3</u> Placement of kitchen sink holder and bath wall.				
<u>Step-4</u> Installation of cold and hot water pipes.				
<u>Step-5</u> Installation of kitchen sink and bath room accessories.				
<u>Step-6</u> Placement of step-5 assembled module in to partition wall.				
<u>Step-07</u> Installation of water heater connecting with water pipes and hanging on wall.				
<u>Step-8</u> Installation wall cabinets and water heater cover.				

VI. Placement of Apartment Dwelling Modules

Table 5.8: Steps for site Placement Apartment Modules

Description	Isometric 3D
<p>Step-1</p> <p>After site clearance for construction site preparation the foundation hole and trench will be excavated depending on the foundation design, however center to center dimension between column foundation is 290cm in both areal dimensions of the apartment. And this step involves preparation of the site and excavation of foundation and tranches.</p>	
<p>Step-2</p> <p>Depending on the required story of apartment and site condition the foundation design could vary such as foundation depth and area. But each foundation has foundation bolts for the connection of columns and has 40cm depth and 40cm x 40cm area of reinforced concrete column on top of foundation.</p>	
<p>Step-3</p> <p>After foundation construction, masonry will be constructed depending on the size of the design. The masonry that extends from footing to footing should extend from ground level above 20cm in order to protect the module components from ground water and site drainage.</p>	
<p>Step-4</p> <p>This step involves covering of ground bed slab with concrete in order to avoid water and organic components that will react with modular steel and other materials. But the depth and the design of ground slab is depending on site condition of the site and it doesn't carry any load of modules.</p>	

Description

Isometric 3D

Step-5

After the site is well prepared for the construction and placement of pre-manufactured apartment modules, then each module part will begin transporting by trucks for desired site step by step depending the order of apartment module organization, for example keeping module orders in each floor by not repeating the same modules before ending of a single story.

**Step-6**

If the required module is brought by truck on the site, then a crane track will take the module from the truck to the specific location by hanging on cable strands holding the module on four corners using hoes in each side on connection cables. In case each organization of modules will follow the floor, layout and arranged face of apartment modules as shown in the figures.

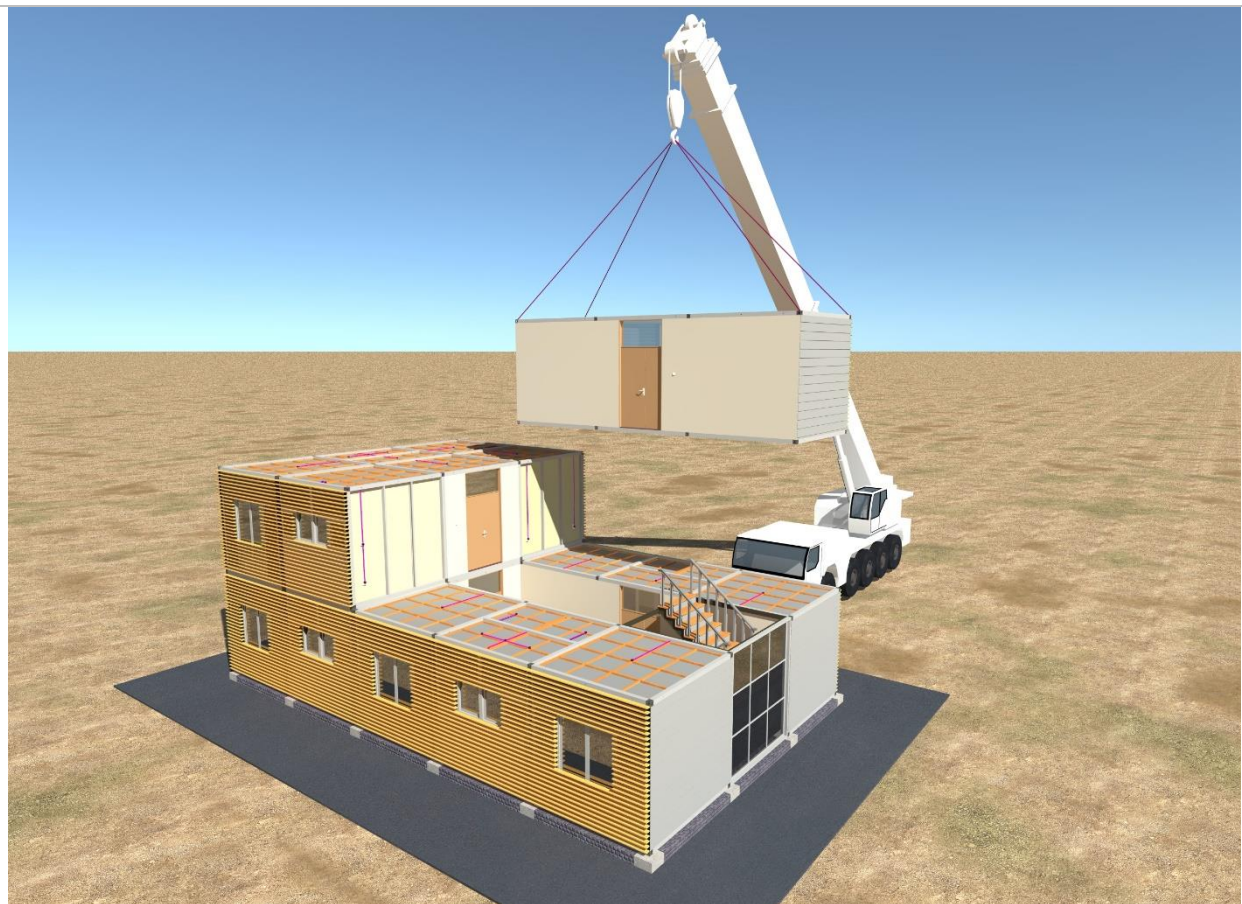
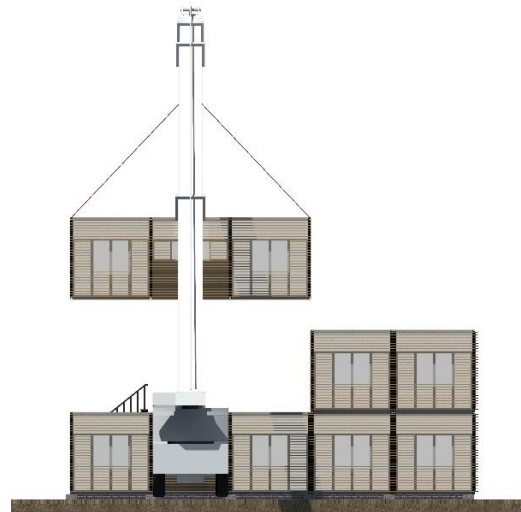




Figure 5.32: Illustration of final modular building habitation

VII. Comparison of the Modular Design with Conventional Design

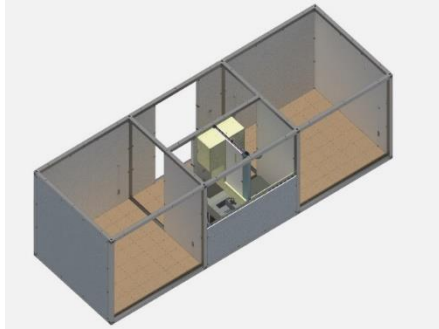


Figure 5.33: Analytical module parts

Because of the limitation of time for the researcher, comparison of one of the modules were analyzed with the respective model of conventional design. Although all the same materials used for both in modular design and conventional model such as window, doors, electrical and sanitary fittings, ceiling and figures were neglected to include workmanship costs. For minimizing structural analysis time for columns and other structural cases in both way of constructions, the section of construction is ground story without additional story.

Table 5.9: Cost and weight analysis of components with design modular construction

No	Modular materials	Quantity	Unit Pries (Birr)	Unit Weight	Total Price (Birr)	Total Weight (kg)
01	Agrostone module walls each 10cm thick	55.44m ²	80/m ²	33kg/m ²	4435.20	1823.52
02	Conection RHS 4cm*4cm*0.2cm	9.60m	57/m	7700kg/m ³	547.20	0.24
03	Closing rectangular timber 4cm*4cm*10cm	9.60m	27/m	580kg/m ³	264.00	8.91
04	Wall papers	87.92m ²	25/m ²	0.22kg/m ²	2198.00	19.34
05	Clading coregated sheet	12.32m ²	175/m ²	7700kg/m ³	547.20	94.86
06	8* RHS Column with 10cm*10cm*0.25cm*280cm	21.02kg/p cs	35/kg	7700kg/m ³	5885.60	168.16
07	6* chanel beam with 10cm*10cm*280cm, f=0.5, t=0.25	31.26kg/p cs	35/kg	7700kg/m ³	6564.60	187.56
08	15* RHS Beams with 10cm*10cm*0.25cm*280cm	21.02kg/p cs	35/kg	7700kg/m ³	11035.50	315.30
09	1* I-section beam with 10cm*10cm*0.5cm*280cm	31.26kg/p cs	35/kg	7700kg/m ³	1094.10	31.26
10	3*Hollow concrete slab 298cm*280cm*8cm	577.1kg/p cs	1645/m ³	1840kg/m ³	1105.44	1731.07
11	Total 45 Φ 8mm reinforcement bars 298cm	1.15kg/ pcs	21/kg	7700kg/m ³	1089.27	51.87
12	16*Conection Cubes	3.94kg/ pcs	35/kg	7700kg/m ³	2207.74	63.07
Total					36,973.85 Birr	4,495.16 kg

Table 5.10: Cost and weight analysis of components with conventional construction

No	Conventional materials	Quantity	Unit Pries (Birr)	Unit Weight	Total Price (Birr)	Total Weight (kg)
1	HCB wall 15cm thick	55.44m ²	175/m ²	1400kg/m ³	9702.00	11612.40
2	Wall plastering 3cm thick	110.88m ²	1530/m ³	2 162kg/m ³	5089.39	7191.68
3	Painting	221.76m ²	220/gall	0.018kg/m ²	258.74	3.99
4	4*concrete column with 30cm*30cm *300cm	640kg/ pcs	1645/m ³	2400kg/m ³	1776.60	2592.00
5	Total 32 Φ 16mm columnn reinforcement bars 300cm	4.64kg/ pcs	21/kg	7700kg/m ³	3119.54	148.54
6	Column stirups 12*4 Φ8mm 110cm	0.43kg/ pcs	21/kg	7700kg/m ³	428.94	20.42
7	2340cm concrete beam with 30cm*45cm	324kg/m	1645/m ³	2400kg/m ³	5196.56	7581.60
8	Total 8 Φ 16mm beam reinforcement bars 2360cm	36.52kg/ pcs	21/kg	7700kg/m ³	1094.10	292.15
9	Beam stirups 96 Φ8mm 110cm	0.43kg/ pcs	21/kg	7700kg/m ³	857.87	40.85
10	One way concrete slab 900cm*300cm *20cm	2400kg/ m ³	1645/m ³	2400kg/m ³	8883.00	12960.07
11	Oneway slab reinforcement bars otal 24 Φ 16mm 457.5cm	7.08kg/ pcs	21/kg	7700kg/m ³	3567.97	169.92
Total					39,974.71 Birr	42,613.62 kg

Conventional Construction Timeline



Modular Construction Timeline



Figure 5.34: Convention Vs Modular Construction Timeline Comparison

Based on the above analysis in Table 5.9 and 5.10 the singular designed modular construction had advantage over conventional construction by about a factor of 8% in cost excluding the cost of formwork construction, and building load reduced by more than 800% that also plays a role in the foundation cost reduction. In case construction time for completion of a module is faster than the conventional one; in which after approval of the designs in both cases, site preparation and foundation work starts together and on-site assemblies are faster than the conventional construction in the way of modular construction.

The design proposal was based on the current demand in the city of Addis Ababa to enhance the housing industry with off-site manufactured modular building system, that will help on creation of housing affordability and fastest delivery of construction for early habitation. The design proposal illustrates the details of each modular assemblies from design to manufacturing assembly and site installations of each module parts. Also, the design is feasible with free connections of each volumetric modular parts for construction of up to 4 stories including ground floor, but it could be applicable more than four stories with additional structural supports such as shear walls.

Although, the design is limited on some structural design parts of steel columns, beams and light-weight concrete slab deck because of the limitation of time for the researcher. However, any organ to apply the design proposal it needs structural engineer for the design of columns, beams, slab deck and foundation structures depend on the minimal dimensions given on the details in the proposal part by the researcher and the nature of site for application (for example the minimal dimension of columns for every module is 10cm x 10cm RHS steel with allowable thickness adjustment of 2mm up to 18mm. Depending on the structural location of the column in the module part and story of the building, structural engineers can vary the steel column thickness for load carrying).

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APPENDIX

APPENDIX I: Questionnaire to Site Managers

EiABC Ethiopian Institute of Architecture, Building Construction and City Development	MASTER OF ARCHITECTURAL ENGINEERING RESEARCH QUESTIONNAIRE	AAU Addis Ababa University								
This questionnaire is to conduct research on title of "The Status of Modular Building Systems in Building Construction Industry: The Case in Addis Ababa". particularly for this questioner to evaluate the current status of modular building system in Addis Ababa.										
Respondent Instruction Please use or <input checked="" type="checkbox"/> or / sign on radio buttons for your choice. Please If you had experience on Modular construction, materials & technologies, please respond part I and II. If not leave part II		Researcher Information Name: Wendmagegn Geleta Megersa ID: GSR/5748/09 Email: wendmagegneleta@gmail.com +251912308420 Mobile: /+251945545241								
TANK YOU FOR YOUR COLLABORATION !!!										
Part I Respondent information										
1 What is your host construction firm (company) type?										
	Grade <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 12.5%;">1</td> <td style="width: 12.5%;">2</td> <td style="width: 12.5%;">3</td> <td style="width: 12.5%;">4</td> <td style="width: 12.5%;">5</td> <td style="width: 12.5%;">6</td> <td style="width: 12.5%;">7</td> <td style="width: 12.5%;">8</td> </tr> </table>	1	2	3	4	5	6	7	8	
1	2	3	4	5	6	7	8			
Company		Other								
General contractor (GC)										
Building contractor (BC)										
Road contractor (RC)										
Consulting Architects & Engineers										
Sub-contractor	<input type="checkbox"/> Civil <input type="checkbox"/> Electrical <input type="checkbox"/> Mechanical <input type="checkbox"/> Sanitary									
Any Other										
2 Years of your host company work Experience? (estimate)										
0 – 2 years	10 – 10 years	15 – 20 years								
2 – 5 years	10 – 15 years	Above 20 years								
3 What is your professional position on Site / Design office?										
Company manager	Construction Manager	Safety Engineer								
Architect	Site Engineer	General Forman								
Structural Engineer	Sanitary Engineer	Surveyor								
Drafting aid	Electrical Engineer	Site technical assistant								
Quantity surveyor	Mechanical Engineer	Other								
4 Years of professional work Experience?										
0 – 2 years	4 – 6 years	Above 8 years								
2 – 4 years	6 – 8 years	Internship								
5 What is your Building Project / Design Work type?										
Residential villa building	Hotel building	Religious building								
Apartment building	Health care facility building	Industrial building								
Commercial building	Educational facility building	Ware house								
Office building	Recreational building	Other								

6	What is your understanding of Modular construction?					
	I am familiar with the concept and I had experience with it.					
	I am familiar with the concept but I don't have experience with it.					
	I don't have any concept.					
	I don't have any concept but I would like to know and work with it.			None.		
7	Is there any Modular construction materials, elements or technologies that were used in your building project?					
	Yes	No	I am not sure			
Part II	Please If you had utilization and experience on Modular construction, materials & technologies in your projects, please respond part II					
8	What type of modular building components you are using in your building project?					
	Prefab walling modules	Roof modules	Other components			
	Structural concrete frames	Elevator modules	1.			
	Structural steel frames	Stair modules	2.			
	Structural wood frames	Plant room modules	3.			
	Prefab foundation	Slab modules	4.			
	Roofing members	MEP system modules	5.			
	Furnished room modules	Industrial modules	6.			
9	For what building parts you are using modularization most frequently in your projects?					
	Exterior walls	Elevator Construction	Other components			
	Interior partitions	Stair Construction	1.			
	Floor Construction	Slab Construction	2.			
	Roof Construction	Plant room Construction	3.			
	Foundation Construction	MEP parts	4.			
10	At what phase of the project do you plan using modular assemblies?					
	Design phase	Pre-construction phase	None			
	Construction phase	I am not sure	Other			
11	Which one is your method of modularization use?					
	Site fabrication	Industrial fabrication	Other			
12	How much of your projects completed with modularization?					
	0 - 5%	10 - 15%	15 - 25%			
	25 - 50%	50 - 75%	75 -100%			
13	Who plans or promote utilization of modular assemblies most probably?					
	Designer	Consultant	Government body			
	Contractor	Client	Fabricator			
	I don't have idea	All	None	Other		
14	Rank the important uses of modularization according to your project satisfaction?					
No	uses	None Important	Less Important	Important	Very Important	Extremely Important
1	Save construction cost					

2	Save time to project completion									
3	Better quality of building									
4	Safe Construction									
5	Material waste reduction									
6	Reduce skilled labor									
7	Greener Construction									
8	Increase productivity and profit									
9	Competitive advantage									
10	Ease Construction work									
Other	1.									
	2.									
15 Rank the challenges for using modularization according to your experience?										
No	challenges	None	Challenging	Less	Challenging	Challenging	Very	Challenging	Extremely	Challenging
1	Lack of design and engineering									
2	Lack of designer's commitment									
3	Lack of local technological advancement									
4	Massive transportation requirements									
5	High cost of components									
6	Limited number of providers									
7	Limited information and understanding									
8	Client's non-willingness									
9	Un-trust on quality and safety of components									
10	Trained workforce unavailability									
Other	1.									
	2.									
16 Which profession do you think the right person to promote utilization of modularization, especially in Addis Ababa?										
Company manager			Construction Manager			Safety Engineer				
Architect			Site Engineer			General Forman				
Structural Engineer			Sanitary Engineer			Surveyor				
Drafting aid			Electrical Engineer			Site technical assistant				
Quantity surveyor			Mechanical Engineer			Other				
I don't have idea			All		None					
17 Which organ do you think the right person to promote utilization of modularization especially in Addis Ababa?										
Designer			Consultant			Government body				
Contractor			Client			Fabricator				
I don't have idea			All		None		Other			

18	For which building project type do you think modularization is the most important and appropriate for application, in order of preference? [E.g. 1,2...]			
	Residential villa building		Hotel building	
	Apartment building		Health care facility building	
	Commercial building		Educational facility building	
	Office building		Recreational building	
			Religious building	
			Industrial building	
			Ware house	
			Other	
19	How much is your level of commitment in future promotion and utilization of modularization in your construction firm?			
	Poor		Good	
	Excellent		None	
			Very Good	
			Yet to decided	
20	What is your recommendation in promotion and utilization of modularization?			

APPENDIX II: Questionnaire to Design Offices(consultants)

EiABC Ethiopian Institute of Architecture, Building Construction and City Development	MASTER OF ARCHITECTURAL ENGINEERING RESEARCH QUESTIONNAIRE	AAU Addis Ababa University
This questionnaire is to conduct research on title of “The Status of Modular Building Systems in Building Construction Industry: The Case in Addis Ababa”. particularly for this questioner to evaluate the current status of modular building system in Addis Ababa.		
Respondent Instruction Please use or <input type="checkbox"/> or <input type="checkbox"/> sign on radio buttons for your choice.		Researcher Information Name: Wendmagegn Geleta Megersa ID: GSR/5748/09 Email: wendmagegngelata@gmail.com Mobile: +251912308420 /+251945545241
TANK YOU FOR YOUR COLLABORATION !!!		
1 Which one is your host company type?		
Company	Grade	Other
	1 2 3 4 5 6 7 8	
Consulting Engineers	<input type="checkbox"/>	<input type="checkbox"/>
Consulting Architects	<input type="checkbox"/>	<input type="checkbox"/>
Consulting Architects & Engineers	<input type="checkbox"/>	<input type="checkbox"/>
Any Other	<input type="checkbox"/>	
2 What is your professional position in design office?		
Company manager	Construction Manager	Safety Engineer
Architect	Site Engineer	General Forman
Structural Engineer	Sanitary Engineer	Surveyor
Drafting aid	Electrical Engineer	Site technical assistant
Quantity surveyor	Mechanical Engineer	Other
3 Years of professional work Experience?		
0 – 2 years	4 – 6 years	Above 8 years
2 – 4 years	6 – 8 years	Internship
4 What is your understanding of modular construction?		
I am familiar with the concept and I had experience with it.		<input type="checkbox"/>
I am familiar with the concept but I don't have experience with it.		<input type="checkbox"/>
I don't have any concept.		<input type="checkbox"/>
I don't have any concept but I would like to know and work with it.		<input type="checkbox"/>
None.		<input type="checkbox"/>
5 Is there any modular construction materials, components or technologies that were utilized in your building design project?		
Yes	No	I am not sure
If your answer is yes, please specifying what type of components utilized in your design projects and for how many design projects did you use. If your answer is no, please specify the major reason of non-utilizing of modular building systems.		

<p>.....</p> <p>.....</p> <p>.....</p>			
6	How did you understand the importance of utilizing modular building systems in your design projects?		
Non-important	<input type="checkbox"/>	Moderately important	<input type="checkbox"/>
Very-important <input type="checkbox"/>			
Please explain why less, moderately or very important?			
<p>.....</p> <p>.....</p> <p>.....</p>			
7	How are your interest of utilizing modular building systems in your design projects?		
Un-interested	<input type="checkbox"/>	Moderately interested	<input type="checkbox"/>
Very-interested <input type="checkbox"/>			
Please explain why less, moderately or very interested?			
<p>.....</p> <p>.....</p> <p>.....</p>			
8	How are your design and engineering technical capabilities for modular building systems utilization in your design projects?		
Non-capable	<input type="checkbox"/>	Moderately capable	<input type="checkbox"/>
Very well capable <input type="checkbox"/>			
If you are non-capable please explain the reason?			
If you are very well capable please explain how far you go with it?			
<p>.....</p> <p>.....</p> <p>.....</p>			
9	How much trusting quality and safety of modular components affect your utilization?		
Non-trusted	<input type="checkbox"/>	Moderately trusted	<input type="checkbox"/>
Very trusted <input type="checkbox"/>			
Please explain why non, moderately or very trusted?			
<p>.....</p> <p>.....</p> <p>.....</p>			
10	How much cost of modular components affects your utilization?		
Non-costly	<input type="checkbox"/>	Moderately costly	<input type="checkbox"/>
Very costly <input type="checkbox"/>			
Please explain why non, moderately or very costly?			
<p>.....</p> <p>.....</p> <p>.....</p>			
11	How did you evaluate the local technological advancement and amounts of supply on modular building systems?		
<p>.....</p> <p>.....</p> <p>.....</p>			

APPENDIX III: Questionnaire to Selected Graduate Professionals

EiABC Ethiopian Institute of Architecture, Building Construction and City Development	MASTER OF ARCHITECTURAL ENGINEERING RESEARCH QUESTIONNAIRE	AAU Addis Ababa University		
This questionnaire is to conduct research on title of “The Status of Modular Building Systems in Building Construction Industry: The Case in Addis Ababa”. particularly for this questioner to evaluate the current status of modular building system in Addis Ababa.				
Respondent Instruction Please use or <input type="checkbox"/> or <input type="checkbox"/> sign on radio buttons for your choice.	Researcher Information Name: Wendmagegn Geleta Megersa ID: GSR/5748/09 Email: wendmagegngelata@gmail.com Mobile: +251912308420 /+251945545241			
TANK YOU FOR YOUR COLLABORATION !!!				
1 What is your professional position/discipline in your current work/career?				
2 In which profession did you graduate from college/university?				
Architecture	Construction Management	Surveyor		
Civil Engineering	Drafting	Other		
3 Which one is your educational level?				
Diploma	Bachelor	M.Sc.	Doctor	Other
4 Years of professional work Experience?				
0 – 2 years	4 – 6 years	Above 8 years		
2 – 4 years	6 – 8 years	Internship		
5 What is your understanding of modular construction?				
I am familiar with the concept and I had experience with it.				
I am familiar with the concept but I don't have experience with it.				
I don't have any concept.				
I don't have any concept but I would like to know and work with it.				
None.				
6 Have you learned about modular building systems during your professional study?				
Yes	No	I am not sure		
If your answer is yes, what did you learn? ----- ----- ----- -----				
7 If you learned about modularization in what way did you take?				
In separate course	As one of course title	Other		
If your answer you take as one of course title please specify the course name? If your answer you take in separate course please specify the course title? ----- ----- ----- -----				

8 How did you understand the importance of utilizing modular building systems in your design projects?

Non-important	<input type="checkbox"/>	Moderately important	<input type="checkbox"/>	Very-important	<input type="checkbox"/>
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Please explain why less, moderately or very important?
.....
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.....
.....

9 How are your design and engineering technical capabilities for modular building systems?

Non-capable	<input type="checkbox"/>	Moderately capable	<input type="checkbox"/>	Very well capable	<input type="checkbox"/>
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If you are non-capable please explain the reason?
If you are very well capable please explain how far you go with it?
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.....
.....
.....

10 Have you applied modular building systems in your career/work?

Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	I am not sure	<input type="checkbox"/>
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If your answer is yes, for how many projects did you applied them?
If your answer is no, what is your major reason?
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.....
.....

11 How did you evaluate the local technological advancement and amounts of supply on modular building systems?

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