

THE EFFECT OF MODULAR SYSTEMS ON SPATIAL DESIGN AND DIVERSITY: ANALYSIS THROUGH CONSTRUCTED MODULAR BUILDINGS

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Beliz Sunsall

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THE EFFECT OF MODULAR SYSTEMS ON SPATIAL DESIGN AND DIVERSITY: ANALYSIS THROUGH CONSTRUCTED MODULAR BUILDINGS

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July 2022

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Aysu Berk Haznedaroğlu (Advisor)

Giorgio Gasco

Hilal Tuğba Örmecioğlu

Approved for the Graduate School of Engineering and Science:

Orhan Arıkan

Director of the Graduate School

ABSTRACT

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Beliz Sunsal
M.Sc. in Architecture
Advisor: Aysu Berk Haznedaroğlu
July 2022

Modular systems are prefabricated building elements as a product of modern architecture. Compared to conventional methods, modular construction systems can find a place in many different projects with their two- and three-dimensional types, however, they have never become quite popular as an architectural design method. Modular systems, which offer various alternatives in terms of materials and construction methods, are produced as prefabricated; therefore, the problems that may arise during the construction phase and the time for on-site operations are minimized. In this sense, it significantly differs from other techniques in terms of time and work control and provides an advantage. However, modular systems could not provide the necessary place for themselves in the market, and their examples were limited to specific functions and locations.

This thesis proposes an analysis method to investigate this problem, through examining the effect of modular systems on spatial design and diversity. In line with this target, this study examines the existing modular building examples worldwide through the number and the distribution of spaces generated, such as public-private zones, circulation areas, and bathrooms. When the relations of these areas with each other and the unit they are located in, are analyzed; it has been observed that the spatial design and diversity vary based on the number of utilized modules and the function of the project. When the shapes of the employed modules, indoor circulation, main entrance, private zones, and the relations of these areas with each other are compared with other examined projects, it is observed that the modular systems do not concentrate on a single type. Since a single type of unit does not have the vast majority, it has been concluded that modular systems have a high potential in terms of spatial diversity and design, they can be used in different projects and functions, but the spatial performance of curvilinear- or organic form-based modules and applicable examples in earthquake zones should also be examined in detail.

Keywords: Modularity, Modular Systems, Modular Buildings, Spatial Diversity, Layout Plan

ÖZET

MODÜLER SİSTEMLERİN MEKANSAL TASARIM VE ÇEŞİTLİLİĞE OLAN ETKİSİ: İNŞA EDİLEN MODÜLER BİNALAR ÜZERİNDEN ANALİZ

Beliz Sunsal
Mimarlık, Yüksek Lisans
Tez Danışmanı: Aysu Berk Haznedaroğlu
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Ön üretim özelliğine sahip olan modüler sistemler modern mimarinin bir ürünüdür. Geleneksel yöntemlerle kıyaslanıldığında modüler yapım sistemlerin mimarlıkta ve inşaat sektöründe çok fazla adı duyulmasa da iki ve üç boyutlu örnekleriyle bir çok farklı projede kendine yer bulabilmektedirler. Kullanılan materyal ve birleşim metotları açısından farklı alternatifler sunan modüler sistemler, prefabrik olarak üretildikleri için yapım aşamasında ortaya çıkabilecek sorunlar ve arazide projenin son halini alma süresi minimuma inmektedir. Bu anlamda zaman ve iş kontrolü açısından diğer yöntemlerden ayrılmakta ve avantaj sağlamaktadır. Ancak buna rağmen modüler sistemler pazarda kendileri için gereken yeri sağlayamamış, örnekleri belirli fonksiyonlar ve lokasyonlarla sınırlı kalmıştır.

Bu tez; bu durumun arkasında yer alabilecek nedenleri, modüler sistemlerin mekan tasarımı ve çeşitliliğine olan etkisini üzerinden araştırmak için bir analiz methodu önerir. Bu amaç doğrultusunda modüler yapım tekniğiyle inşa edilmiş farklı lokasyonlardaki mevcut örnekleri sahip oldukları genel-özel alanlar, sirkulasyon bölümleri, banyo ve sayıları üzerinden inceler. Bu alanların birbirleriyle ve bulundukları birim ile olan ilişkileri analiz edildiğinde; mekan tasarımı ve çeşitliliğinin, kullanılan modül sayısı ve projenin fonksiyonuna bağlı olarak değiştiği görülmüştür. Kullanılan modül şekilleri; mekan içi dolaşım, ana giriş, özel alanlar ve bu alanların birbirleriyle ilişkileri incelenen tüm projelerle kıyaslandığında modüler sistemlerin tek bir tipte yoğunlaşmadığı görülmüştür. Tek bir tip veya kombinasyon büyük çoğunluğa sahip olmadığı için modüler sistemlerin mekan çeşitliliği ve tasarımı açısından potansiyelinin yüksek olduğu, farklı proje ve fonksiyonlarda da kullanılabileceği ancak deprem bölgelerinde uygulanabilirliği olan örneklerinin ve organik hatlı modüllerin tasarım ve mekansallığının da detaylı incelenmesi gerektiği kanısına varılmıştır.

Anahtar kelimeler: Modülerlik, Modüler Sistemler, Modüler Binalar, Mekansal

Çeşitlilik, Yerleşim Planı

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CHAPTER 1

INTRODUCTION

Human beings lead their lives by meeting their basic needs and desires. All inventions, innovations, and technological developments that are provided by several sectors, help to meet these demands and needs. Architecture, which is defined as making buildings by combining art and science, is a part of this practice (Cambridge Dictionary, n.d.). Before the industrial revolution, buildings were coded as a space that was used for meeting shelter needs. With industrialization and mechanization, that perception has changed. Considering the increasing population and pace of life, the construction industry is also developing constantly to contribute to this process. New materials, construction methods, and structural systems have acted as a part of this alteration. Some of these innovations have been developed to quickly solve the problem of sheltering after events such as war, natural disasters, and epidemic diseases. One of the quick solutions generated and commonly used has been modular systems. The introduction of modular systems into architecture was due to the housing shortage that emerged after the 1st World War. Adopting standardization during the design and production phase put modular systems forward to be able to reply to the need of housing in a short span of time compared to the other systems in

that period. In conjunction with the ensuing developments and innovations; modular systems have progressed over time and started to be used not only in emergency architecture but also in the construction of different building functions in different locations. In particular, they are integrated into the design more in countries such as Japan, England, and America.

1.1. Research Problem

The building as a product of a critical process requires detailed work during both the design and construction phases. Over the years, new techniques are introduced to the industry to enhance this process. Modular building system is one of these techniques and early on it was utilized to respond to emergency situations. In time, this technique has enhanced and started to have the potential to be preferred for the construction of a building that is not a need of emergency architecture. The fact that modular systems are preferred or considered as a design option in the construction of different functions in many countries supports this situation. On the other hand, for some other countries, modular systems are still considered for emergency cases such as earthquakes, flood, etc. Therefore, the problem of the thesis is raised as whether or not accepting modular systems as emergency solutions or an option for regular architectural design since they may have spatial potential. Based on this problem, the main focus of this study is to investigate the spatial diversity of modular systems constructed around the world, and to examine the effects of using modular systems on the decision of interior plans by analyzing the plans of selected case studies. Therefore, this thesis examines the possibility of the extension of the utilization of the modular system in architectural design, by focusing its potential in terms of spatial design.

1.2. Aim of the Thesis

Modular systems are preferred for different needs in different periods in architecture and the type of adopted system varies based on multiple criteria such as building function and location. In the literature, cases that are constructed by using modular systems and their physical properties have been studied and examined (Çolak&İlerisoy, 2018; Javanifard et. al., 2013; Jiang et. al., 2019; Lacey et. al., 2018; Lawson et. al., 2018). In these studies; structural capacities of modular systems, material properties, and adopted construction methods have been discussed. However, there is no study that makes these comparisons by focusing on spatial design and the diversity of modular buildings. Moreover, this study will serve the literature to gather information on modular constructed systems together. Therefore; this thesis aims firstly to examine the relationship between the modular systems and their potential in spatial variety by analyzing interior layouts of modular case studies from an architectural point of view. Secondly, generating a database for the spatial characteristics of the modular case studies is achieved in this thesis.

In this context, 25 modular projects are selected as the case studies for this study. The selection of the case studies is based on the literature review conducted and the observation showing the popularity of the projects. Concordantly, the following research questions are investigated:

- Do modular systems have any effect on spatial design and diversity? If yes, is it in an advantageous or disadvantageous way?
- What is the proportion of temporary use of modular buildings vs permanent ones within the existing cases? Does modularity have more advantages over one of them?

- What is the distribution of modular buildings in and around the world? How does the country of the project affect the utilization of modular systems in design?

By answering the research questions throughout the thesis, it is aimed to prove the hypothesis that modular systems limit the layout design of the units or buildings in terms of spatial diversity.

1.3. Methodology of the Study

The methodology of this study is established based on two stages: data collection and spatial analysis on the case studies selected. In the first stage, a detailed data collection has been conducted on the modular systems and modular case studies selected. The basic characteristics and technical properties are investigated, collected and tabulated for each case, generating a detailed collection of information for the selected cases. A table is generated by the properties of each case, such as number of the stories, location and function and the physical features of employed modules. In the second stage, projects that fit to the scope of this study are collected and analyzed for their spatial layout and distribution. Plans of the selected group are diagrammatized and coded based on spatial properties. By investigating and comparing the diagrams and the tables, some meaningful findings have been observed and discussed.

1.4. Structure of the Thesis

The study consists of six chapters. Chapter 1 is the introduction where the main problem, scope, methodology, and structure of the thesis are introduced.

Chapter 2 is related with the theoretical information about modular systems, in terms of characteristics, material selection, and construction methods that are utilized for the modular-based buildings.

In Chapter 3, the methodology for the study is introduced. The two-staged strategy with a data collection and spatial analysis is explained in detail. The strategy of selection of the case studies is described. The method of spatial analyses of each case is explained.

In the following part, chapter 4; selected case studies are introduced and analyzed based on the methodology specified on the Chapter 3. Firstly, the selected case studies are introduced by giving specific information that is obtained by data collection; and secondly, these projects are examined through the diagrammatic floor/unit plans by defining module-unit borders; public-private spaces, bathroom(s), circulation and/or service zones, and entrances in the units to discuss the relation between modular construction systems and space distribution in the project layout.

Chapter 5 is placed for the discussion of the results of the analysis and detailed discussion of the generated diagrams in light of the results.

Chapter 6 is the conclusion. This chapter summarizes the thesis by establishing a correlation between modular building systems and their impact on layout design and space variation. Finally, the thesis is concluded with the list of references mentioned and used in this study.

CHAPTER 2

MODULARITY&MODULAR SYSTEMS

modularity *noun* [U] mɒd.jə'ləɪ.ə.ti/

the quality of consisting of separate parts that, when combined, form a complete whole

The terms of the module, modularity, and modularization are handled by various disciplines. Based on literature (Çolak&İlerisoy, 2018; Erdem, 2017; Ismail&Rahim, n.d.; Khan&Jain, 2017; Laovisutthichai et. al., 2021; Miller& Elgård, 1998; Wuni&Shen, 2020), architecture is one of the fields in which these terms are mostly used. From the architectural point of view; a module means a smaller standardized part of a building and is lexicalized as modular, modularity, and modularization (Cambridge Dictionary, n.d).

The concept of modularity in architecture was firstly mentioned as “modulus” in ancient times by Marcus Vitruvius Pollio (Miller & Elgård, 1998). It is mentioned that modularity and the word “modulus” were related with the standardization of proportion in architectural elements (Miller & Elgård, 1998). Then the concept was carried to the Bauhaus period and it was developed by Walter Gropius by merging modularity with functionality and mass production for architecture (Miller & Elgård,

1998). Similarly; these approaches are in parallel with the current acceptance of modularity. Today; modular-based units are used for both the construction of buildings and the production of building elements with the help of the advancement of mass production and mechanization.

The first foundations of today's use are based on the post-World War 1 period. The housing shortage that emerged after the war necessitated meeting the need for shelter quickly (Staib et al., 2008). The first examples of the modular system in the modern sense were created in this period.

Modularity as an aptitude of creating a complete from smaller individual units is predicated on prefabrication construction. The prefabricated construction method is defined as the combination of factory-based production and on-site installation (Thai et al., 2020). Basically, prefabricated systems are examined under three categories which are panel systems, framed systems, and volumetric modular systems (Baghchesaraei et al., 2015). Panel systems are two-dimensional prefabricated horizontal or vertical building elements. Prefabricated wall, floor, or other functional planar elements might be shown as panel systems (Yaman, 2020). The second group, frame systems are generally defined as prefabricated structural elements which are composed of linear columns and beams (Yaman, 2020). The last type of prefabricated building system which is the main focus of the research is modular/cell systems. Modular systems are 3D spatial units that are composed of various sub-elements and are shown as the most industrialized (Yaman, 2020) and advanced version of prefabricated systems in terms of completion (Sezer, 2015). Due to these features, it plays a critical role in the construction of projects where there are restrictions such as space, time, and labor. In addition, these types of systems are preferred in the establishment of shelter and treatment spaces that are needed after

disasters such as earthquakes, floods, or pandemics. Post-earthquake containers are examples of the utilization of modular systems in emergency architecture. Otherwise, these systems are adopted to construct a modern architecture product. In the following sections, the modular systems and their role in architecture will be explained in more detail.



Figure 2.1: Precast Concrete Wall Panel¹ Figure 2.2: Prefab. Glued Laminated Timber Frame²



Figure 2.3: Volumetric Modular System³

2.1: Characteristics of the Modular Systems

Modular building systems become prominent with their features in the construction industry. The completion period, qualified production phase, and reusability of modules receive attention in a positive way. In contrast; huge initial investment cost,

¹ Image is taken from <https://www.archiexpo.com/prod/concast/product-105233-1025511.html>.

² Image is taken from <https://www.youtube.com/watch?v=60zDFKJd1ZU> - 3:20.

³ Image is taken from <https://builtoffline.com.au/news/dimensions-of-design-for-prefabrication/>.

size limitations that are derived from traffic regulations, and being incapable to undo action during the unmanned prefabrication phase because of the mechanization differentiate modular building systems from the conventional methods in a negative way. Both positive and negative characteristics of the modular systems are discussed under the following subheadings as advantages and disadvantages.

2.1.1: Advantages of Modular Building Systems

Modular-based construction techniques are mostly adopted for projects that have repetitive places such as hotels, dormitories, residential blocks, and offices (Thai et. al, 2020) (Laovisutthichai et al., 2021). However, these systems are not widely preferred compared to traditional methods although there are numerous advantages that are brought by adopting modular systems for the construction of a building (Khan & Jain, 2017). These advantages are mainly sorted as:

- **Shortening the construction period**

Also, the property of being prefabricated components provides quick off-site production and on-site establishment for the projects so it turns into a preferable option compared to other construction techniques in the countries that have high labor costs (Xu et al., 2020; Haas & Fagerlund, 2002). Specifically, in high-rise buildings, it creates cost and time advantages by decreasing on-site work with prefabricating and repeating modules (Lawson et al., 2012).

- **Quality enhancement in the prefabrication phase**

Being produced in a factory environment enhance the quality of products as a crucial step of the construction phase by virtue of minimizing human-induced errors by reducing manpower and increasing mechanization, and the opportunity of quality

control before being transported to the construction site (Haas & Fagerlund, 2002; Rogan et. al, 2000) .

- **Labor safety in the production line**

Compared to conventional on-site construction techniques, modular-based methods provide a safer working environment in the factories. Construction sites are risky areas in terms of being open to work-related accidents (Nawi et al., 2016). There are multiple factors from technical operations to weather conditions that cause accidents (González et al., 2016). The modular construction method minimizes these risks by shortening the on-site process (Laovisutthichai et al., 2021).

- **Sustainable construction process**

Material waste may be generated during the construction period of a building. The construction materials containing chemicals, such as sand, cement, and concrete, which are especially affected by environmental factors, require extra sensitivity during the construction period. Therefore, they can turn into waste in a very short time (Lu & Yuan, 2013). However, modular construction systems reduce on-site construction waste (Laovisutthichai et al., 2021) by adopting a machine-oriented production line in a closed space (Lu & Yuan, 2013).

- **Reusability**

Related to sustainability specialty; modular-based construction technique promises to be disassembled and reused thanks to their prefabrication and on-site assembly features (Lawson & Richards, 2010). However, there are not many cases that support this feature. Existing examples, which support the property of reusability, are limited

to projects such as post-emergency container cities established or temporary shelters at construction sites.

2.1.2: Disadvantages of Modular Systems

Modular systems as a type of construction technique have not only advantages but also disadvantages that differentiate them from conventional methods. These disadvantages are mentioned in various sources based on field surveys, reviews, and analyses (Laovisutthichai et al., 2021; Jiang et al., 2019; Wuni & Shen, 2020).

Possible challenges are determined as:

- **Huge initial investment cost**

Since the buildings built with modular systems are completed in a shorter time than those built with traditional methods, they provide a shorter financial return to the project owners (Laovisutthichai et al., 2021). However, in the fabrication part, it requires a huge initial investment in order to produce the desired number of modules in the desired time. Briefly, although the economic return is provided in a shorter time than conventional methods, it requires a high cost (Jaillon & Poon, 2008) for the production and construction steps and the follow-up of these phases because of being a newer technique (Laovisutthichai et al., 2021).

- **Transportation limitations**

One of the main concerns about modular construction systems is traffic regulations that affect the size of the modules. It is needed to know the capacity of the roads between the factory where modules are prefabricated, and the construction site to specify the dimensions of the modules (Laovisutthichai et al., 2021).

- **Technical drawbacks**

Since modular systems are pre-manufactured, they require strict control in production and quality workmanship during assembly (Jiang et al., 2019). If an error in the production part is not noticed, it causes bigger problems in the next steps. In addition, the lack of qualification of the assigned workers in the installation of modules leads to the disruption of the project and the emergence of a defective building (Wuni & Shen, 2020).

2.2: Materials in Modular Systems

Modular units are prefabricated based on project function and material selection is determined accordingly. This choice is affected by the function of the project, coefficient, land characteristics, and many other factors. There are multiple options in terms of material. However, steel, wood, and reinforced concrete are generally preferred for the manufacture of modular units.

2.2.1: Steel

Steel is one of the most preferred materials for modular construction systems. Steel-based modular units can be employed for both temporary and permanent building functions (Staib et al., 2008). The structure of a steel-based module (Figure 2.4), basically, consists of a steel frame and sections. Additionally, C-profile pillars are placed on lateral surfaces at different intervals depending on the module type and building characteristics (Sezer, 2015). Then the frame is covered according to whether the module is closed or not.

In the closed volumes, the module is insulated to turn into a fire-resistant system and covered by cladding panels. Staib et al. mentioned that for the exterior cladding and

floor construction, steel panels and insulation elements are preferred; however, additional floor covering is placed on the steel sheet and insulation layers. For the interior wall cladding, plasterboard or wooden panels are used before finishings (2008).

In open modules that can provide a variety of spaces, pillars are used in corners or on less than four surfaces. Thus, it helps to obtain a larger space by leaving at least one open surface (Lawson et al., 2014). To enhance the stability of the system, the low number of pillars compared to closed modules is eliminated by using bracings in other walls (Sezer, 2015).

After the assembly of 3D modules is completed off-site, the units are transferred to the construction site and craned for the inter-module connections (Staib et al., 2008).



Figure 2.4: Prefabricated Module with Steel Framing (Lawson et al., 2014)

2.2.2: Timber

Compared to other materials, timber-based modules are preferred for small-scale projects in terms of building height (Lawson et al., 2014). It is a lightweight system and is transported easier than steel- or concrete-based modules. However, Staib et al. explain that “if the wooden modules are required to employ for building that has more than three stories, they should be used non-structural elements and combine

with steel or reinforced concrete” (2008). Not only structural concerns but also fire can be a serious problem for this system (Hong, 2020). Therefore, necessary steps should be taken to ensure protection from such risks (Staib et al., 2008).

Basically, there are wooden wall and roof panels in the structure of a timber-based module (Sezer, 2015). There are two options for the wall detail. In the first one, the timber frame structure might be covered with wall panels and loads are transferred via linear elements on the corner points. As a second option, the wall can be left as a single wood panel that helps to transfer the load to the foundation (Sezer, 2015) (Staib et al., 2008). If it is used as timber frame, it follows similar construction steps in terms of insulation layers and interior cladding with steel-framed modules (Sezer, 2015).



Figure 2.5: 3D Timber Modules in Production Line⁴

2.2.3: Concrete

Concrete-based modules can be classified as 2D planar elements and 3D volumetric units (Lawson et al., 2014). In the scope of the thesis, 3D concrete-based modules will be mentioned.

⁴ Image is taken from <https://www.bizjournals.com/twincities/news/2020/09/20/rise-modular-begins-first-project-in-minneapolis.html>.

In the prefabrication process, a form -in the shape of needed module- is prepared and then concrete is molded which provides a quality surface and reduces the fill-up work (Staib et al., 2008). It is crucial to standardize the module type as much as possible to maximize the performance of the fabrication line. If the multiple module designs are adopted for a single project, each design requires a distinct production process and it is needed to prepare different formworks, and be trained to set up and dismantle for each. Basically, it requires a longer process. Therefore, standardization is crucial if the project comprises concrete-based modules (Sezer, 2015).

As a material high-strength concrete is utilized for this system, compared to the concrete that is used for the buildings that are constructed on-site with conventional methods because of minimizing damages on the demolding, transportation, and assembly steps (Lawson et al., 2014).

Concrete-based modular units are manufactured as closed or open systems. Closed modules can be defined as 6-sided reinforced concrete boxes with functional openings for windows and doors. However, in some cases to reduce the dead load of the unit, the floor is can be left as open and the unit uses the ceiling of the module below as a base (Lawson et al., 2014). Therefore, double-sided surfaces are prevented and the total structural load is reduced. Open precast concrete modules comprise posts and beams as a framing system but one or two surfaces such as floor and wall might be covered with reinforced concrete (Sezer, 2015).

Both closed and open concrete-based modules are pieced together in a way that the column, beams, and slabs follow each other. Thus, loads are transferred to the foundation via structural elements such as reinforced concrete walls and/or post and beam systems (Sezer, 2015). Additionally, the modules that have reinforced concrete

walls in their structure are appropriate for multi-story buildings because of the high load-bearing performance of reinforced concrete (Staib et al., 2008).

Although, these modular units are advantageous in terms of reducing craftsmanship after demolding, and being resistant to damages during transfer or load-bearing capacity; they are disadvantageous because of being heavier than steel-based modules (Gur, 2014) which causes high crane cost (Thai et al., 2020).



Figure 2.6: Positioning of a Concrete Module with Crane⁵

2.3: Construction Methods of Modular Systems

The stability of the building is one of the most critical concerns during both the design and construction phases. This becomes more critical for modular-based projects because of being comprised of the elements produced off-site and assembled on-site. Therefore, it highlights the importance of the intra- and inter-connection of modules (Lacey et al., 2018) that increase the structural stability of the project against the lateral loads (Hong, 2020) by employing X-bracings, structural cores, frames, or walls (Sezer&Koman, 2021) based on the number of floors (Lawson & Richards, 2010).

⁵ Image is taken from <https://www.greenprecastsystems.com/>.

Modular units are connected to each other via their corner points as seen in Figure 2.7 with exceptions (In some cases, module connections can be from off-corner points e.g. Figure 2.8) (Lawson & Richards, 2010). However, the modular cases with corner connections might adopt dissimilar paths to transfer loads that are generated by them. These are mentioned by Lawson et. al as; sidewalls of load-bearing modules and beam to column load path which is followed in the column-supported modules (2012).



Figure 2.7: Assembly of Modules from Corner Points (Chen et al., 2019)

For high-rise buildings that are built by utilizing modular construction systems, corner connections are crucial for being able to act together against lateral loads such as wind (Lawson & Richards, 2010).

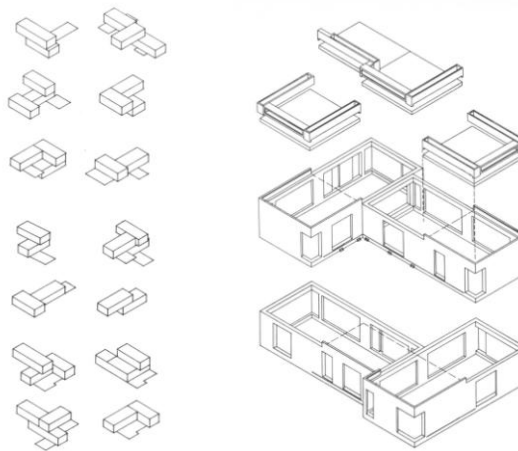


Figure 2.8: Off-Corner Module Connections of Habitat 67⁶

⁶ Image is taken from <https://www.safdiearchitects.com/posts/inherently-buildable>.

- **In buildings with 4 to 6 floors;**

X-bracings are inserted into the wall panels of the modules. These elements create a diaphragm movement against lateral loads to stabilize the building (Sezer&Koman, 2021; Lawson & Richards, 2010).

- **In buildings with 6 to 10 floors;**

Advanced structural bracings are assigned for service areas such as elevators and stairs (Sezer&Koman, 2021; Lawson & Richards, 2010).

- **In buildings with more than 10 floors;**

The modules are stacked on structural reinforced concrete or steel cores (Sezer&Koman, 2021; Lawson & Richards, 2010).

The techniques that are adopted for constructing a high-rise building by using modular units are categorized as “Core-Based”, “Podium-Based” and “Infilled Frame” in the article “*A review on modular construction for high-rise buildings*” (Thai et al., 2020). It is inspired by this article for this sub-chapter. However, these construction methods will be explained under three main categories without classifying them based on floor numbers in the chapter “Construction Methods of Modular Systems”. The following part highlights the main techniques that are utilized for the construction of modular units.

2.3.1. Adoption of Stacking Method

The construction of modular units by assembling them one on top of the other is called the stacking (yığma) technique (Erturan & Eren, 2012). This method might be divided into two categories (Sezer & Koman, 2021) as podium-free and podium-

based. The podium-free method is mostly preferred in low-rise buildings and modular part is placed without a supporting structure underneath. In a word, the prefabricated modules are brought to the site and placed on the slab which is placed to create a base for the building on the ground (Sezer & Koman, 2021). However, in high-rise buildings, the modules are built on the basement structure that acts as a podium (e.g. Figure 2.10). In this construction technique, which is called podium-based (Thai et. al, 2020), one or two-story structure is built on the ground level to support the upper floors that comprise modules.

In addition to its structural behavior; in masonry modular systems, walls and floors are double-layered in the junction areas. These areas can be used for technical elements such as water or electrical installations (Sezer & Koman, 2021).



Figure 2.9: Stacking Method (Erturan&Eren, 2012)

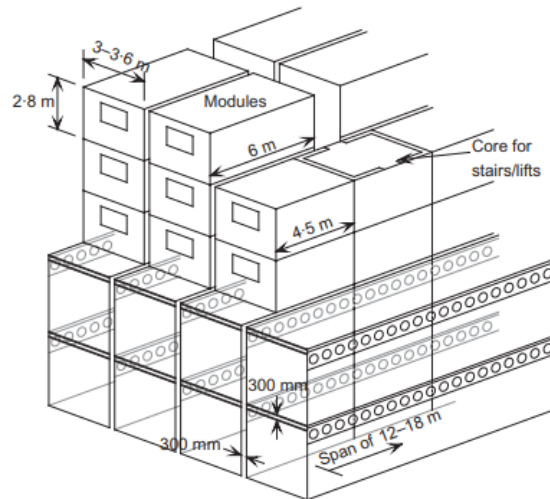


Figure 2.10: Stacking Modules on Podium Structure (Lawson&Richards, 2010)

2.3.2. Adoption of Core-Based Method

The core-based construction method is adopted for high-rise modular projects. To build up the system, single or multiple core towers, where the modular cells are connected, are structured (Park & Ock, 2015). These longitudinal structural towers help to carry the modules by transferring lateral loads that are received from the modules to the foundation (Thai et al., 2020). In the projects that are built by using this method, service and circulation cells can be connected to the main core along with unit modules (Park & Ock, 2015) or the circulation elements can be placed inside the main core (Sezer & Koman, 2021).

Steel or reinforced concrete are chosen for the material selection of cores. On the whole, the core-based method is employed for the smaller and lighter modules because of working as cantilever systems (Sezer & Koman, 2021). If it is required to choose larger modules for the projects, an additional construction method might be combined with the core-oriented method (e.g. adapting core and podium-based construction) depending on parameters such as size and material (Park & Ock, 2015).



Figure 2.11: Construction of Concrete Cores for a Modular Building (Lawson&Richards, 2010)

2.3.3. Adoption of Infilled Frame System

Infilled frame system comprises a framing structure that can be made of steel, reinforced concrete or precast concrete; and prefabricated modules (Park & Ock, 2015). On-site construction of non-modular frames that consist of posts and beams, and the off-site prefabrication of modular units are conducted synchronously (Ramaji & Memari, 2013). Then, modules are carried to the site and placed between horizontal and vertical linear structural elements (Thai et al., 2020).

Being structured by a frame that is constructed on-site helps to stabilize the building (Thai et al., 2020). Ramaji and Memari explain this by the fact that modular units need to resist only to their own gravity loads and construction loads while the main loads that are created by the system are carried by the framing structure (2013). Therefore, this method becomes distinct from other systems in terms of working principle, organism and properties of modular units that are not affected by external factors such as wind or earthquake loads, the number of the building story (Ramaji & Memari, 2013).



Figure 2.12: Placing a Module into a Framing System (Ramaji&Memari, 2013)

CHAPTER 3

METHODOLOGY

In this thesis, the selected modular projects are analyzed in order to observe and find the effect of the modularity in the diversity of spatial design of these modular systems. In this chapter, the stages that are utilized to process case studies, case study selection, and determination of terminology to evaluate the analysis will be explained.

3.1. The Analysis Method

The selected case studies are analyzed in two stages: Data Collection and Spatial Analysis. The first stage is the data collection. For data collection to access the case studies that are built by adopting modular building systems, a deep literature review is conducted by investigating through books, journals and the website of the projects and their construction companies. In this stage, theoretical and technical details of the case studies are researched, investigated, and gathered. The specific information of each project such as construction site, number of the employed modules, or sizes of adopted modules is collected and tabulated. Data collection stage consists of two parts: The first part deals with the details of the projects such as construction year,

function, location, construction duration, architect/manufacturer, and floor number of the projects (Table 3.1). Basically, the seven columns of Table 3.1 act as an ID card that represents the personal record of each project. In the second part of Table 3.1, technical information for each case is presented. This part comprises three sub-headings which are “module size”, “module type”, and “module material”. The width, length, and height of the modular units that are given under the “module size” heading. In the “module type” part, the openness and closeness status of the modules are questioned. Cells with uncoated surface areas, behaving as a modular frame system or covered with panels on at most two surfaces are defined as “open” modules, modular units with at least one fully open surface and more than two closed surfaces are defined as “semi-open” modules, those that have all their surfaces covered and only have openings for user and air circulation are called as “closed” modules in the table. In the last sub-heading "module material", material selection in the production of the prefabricated modular systems is presented. This table (Table 3.1) is aimed to provide a summary info about the selected modular cases and form a database for the data collection part.

building name	year	function	location	construction duration	module manufacturer & architect	storey	module size	module type (open-semiopen-closed)	module material	references

Table 3.1: Outline of the Project Info Chart

In the second stage, layout of the cases are assayed based on space distribution and relation. It is expected to analyze the effects of adopting modular systems on the plan layout depending on the function and duration of utilization. Each visual that is generated for the second stage comprises a diagram of the plan, an icon that shows the unit-module(s) relation and the legend. To show the colors and the signs of each data, a legend is prepared and placed underneath the layout diagram. As can be seen

in Figure 3.1, there are 8 data that are given on the diagram. 4 of them, borders and entrances, are shown with signs while 4 of them, areas in the plan, are represented with colors.

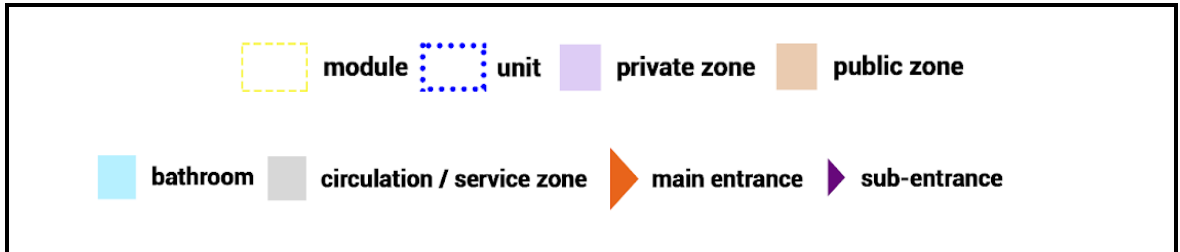


Figure 3.1: Codes for Spatial Analysis

For the second stage of the study, the aim is to understand the relationship of spaces within each other and whether the modular systems have the potential of generating variety in design. The plans are diagrammatized by coding each space in the units/buildings, demarcating modules and units, and showing main and sub-entrances. Firstly, the functions in each unit are labelled / grouped in order to understand the spatial configuration. The spaces are categorized based on their privacy level and functions on each plan, except the bathrooms and circulation/service areas. A space that is covered with walls is defined as a private area while uncovered ones are named as public spaces. Secondly, unit and module borders are drawn with blue dotted and yellow dashed lines respectively. Since all details such as function colors and space entrances create a complicated diagram, the module border and the floor area of the units are also symbolized on the right-bottom corner to avoid confusion (Figure 3.2). This method plays an important role in the separation of units, especially in projects that are examined through the floor plan. Lastly, entrances in the units/buildings are shown with arrows. However, sizes of the arrows differ depending on whether they are used in the main or sub-entrance.

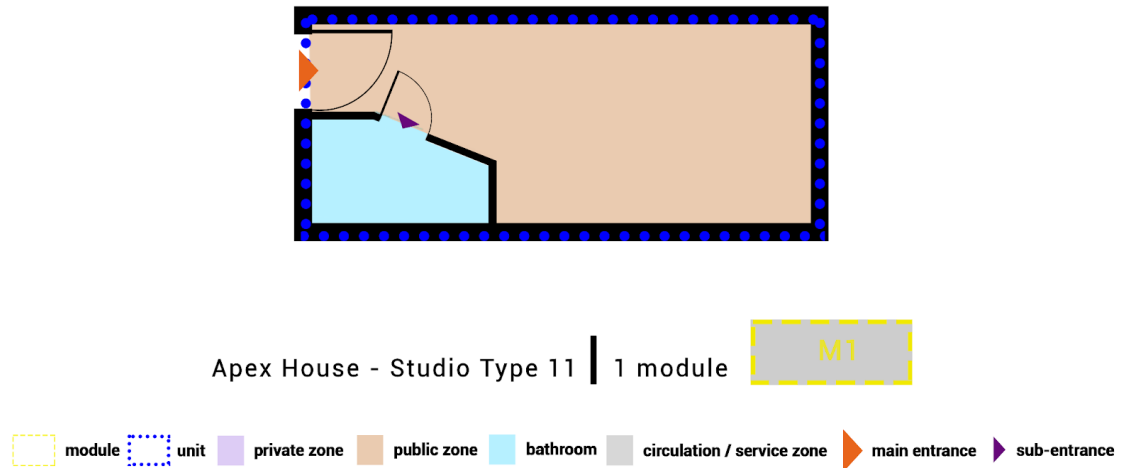


Figure 3.2: Example Unit Plan

To illustrate the final product of the diagramming process, Figure 3.2 that comprises living area and bathroom is shown as an example. Based on the analysis methodology; living area is coded as a public zone because it is not covered with walls, while the bathroom represents itself. Footprints of public spaces and bathrooms are painted with their selected representative colors. Blue dotted line is drawn to show the border of the unit generated by a single module. This is also represented on the right-bottom corner of the plan as footprints of units and borders of the modules. The combination highlights the relation between unit and module. On the other hand, there are cases that employ multiple module based units. For these cases, representation of the module-unit relation becomes more helpful to avoid confusion (Figure 3.3).

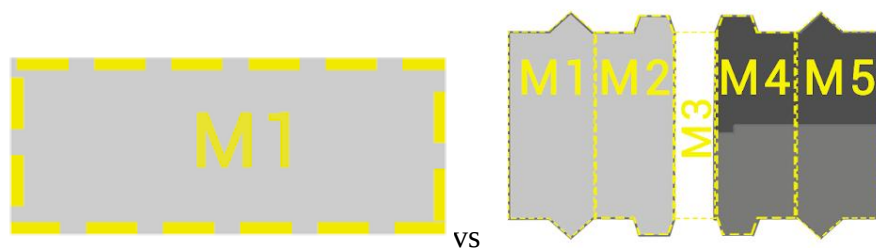


Figure 3.3: Module-Unit Relation of Single Module Based Unit vs Multiple Module Based Units

At the end of the second stage, a table is generated to summarize the main observations of the analysis. As can be seen in Table 3.3, the information about the

program in terms of combination of public, private and circulation/service zones is given for each unit type. Function data is supported with inputs that mention the number of the utilized module(s) for each unit and where main entrances of units open to.

	Unit Type	number of private zone(s)					public zone		circulation/ service zone		main entrance opens to		number of the modules utilized for each unit				
		0	1	2	3	3+	yes	no	yes	no	public zone	circulation zone	<1	1	2	3	*
Project 1	1																
	2																
	3																
Project 2	1																

Table 3.2: Outline of the Spatial Analysis Chart

3.2. Case Study Selection

While there are modular examples with different functions known globally in the literature, these functions are limited in Turkey. To focus on the problem, modular buildings are researched and it is observed that there are container city examples in Turkey although there are different alternatives abroad. The construction of a new modular container city after the Izmir earthquake (30 October 2020) that occurred in the same period showed that modularity came to the fore in Turkey after the emergency. Therefore, the projects were determined by two different methods for this thesis which aims to test the spatiality of modular systems through case studies. First of all, the globally discussed examples that have been reached as a result of the literature review have been selected. Secondly, modular buildings from Turkey have been added to the case study analysis for spatial analysis by comparing the utilization of modular systems in Turkey to the uses in the other countries.

SELECTED CASE STUDIES STAGE 1: LITERATURE REVIEW	NUMBER OF THE ANALYZED CASE STUDIES IN STAGE 1	SELECTED CASE STUDIES STAGE 2: LAYOUT ANALYSIS	NUMBER OF THE ANALYZED CASE STUDIES IN STAGE 2	ANALYZED UNIT TYPE(S) FOR EACH CASE STUDY	NUMBER OF THE UNIT TYPE(S)
Van Container City	1	Van Container City	1	1 - 2 - 3	3
Elazığ Container City	2	Elazığ Container City	2		
İzmir Container City	3	İzmir Container City	3		
The Museum Hotel Ant.	4	The Museum Hotel Ant.	4	1	1
Collins House	5	Collins House			
Little Hero	6	Little Hero	5	1	1
Wuhan Hospital	7	Wuhan Hospital			
Holon Apartments	8	Holon Apartments	6	1 - 2 - 3	3
Ten Degrees Tower	9	Ten Degrees Tower	7	a2 - a4 - a8 - b2	4
Apex House	10	Apex House	8	1	1
Raines Court	11	Raines Court	9	1 - 2 - 3	3
Murray Grove Housing	12	Murray Grove Housing	10	1	1
hoUSe	13	hoUSe			
B2 Tower	14	B2 Tower			
Carmel Place	15	Carmel Place	11	1 - 3 - 4 - 7	4
The Union Flats	16	The Union Flats	12	C.S. - C - F - F.S.	4
David H Koch C. C.	17	David H Koch C. C.	13	1	1
Vignes Street Interim H.P.	18	Vignes Street Interim H.P.			
The Stack (Broadway)	19	The Stack (Broadway)	14	1 - 2 - 3 - 4 - 5	5
Habitat 67	20	Habitat 67	15	1	1
Nakagin Capsule Tower	21	Nakagin Capsule Tower	16	1	1
Ogura Asahi K.	22	Ogura Asahi K.	17	1	1
Dortheavej Residence	23	Dortheavej Residence	18	1 - 2	2
Vale de Cambra	24	Vale de Cambra	19	1	1
Keetwonen Student H.	25	Keetwonen Student H.	20	A - B	2
Total:	25		20		39

Table 3.3: Number of Analyzed Case Studies

Based on the literature review, 21 most mentioned projects are selected because of being globally known. Then, in order to conduct a comparison between the cases in Turkey to the foreign ones, 4 different case studies are selected within Turkey. Thus, 25 modular projects are determined as the case studies of the thesis. Because of limitations (plans of 3 of them can not be accessed and the other 2 of them are dominated by the open 3D modules and 2D panels which are not in the scope of the thesis), 5 case studies are examined in the first stage of the analysis part but not included in the second stage. Thus, the analysis proceeds through 20 case studies in

the second stage. 12 of the 20 projects are examined through the multiple unit typologies while 6 of them are being analyzed through the single unit type. However, since the analysis of the Ogura Asahi and David H Koch kindergarten projects is made by focusing on the building plans, each project is counted as a single unit. As can be seen in Table 3.2, by adding these typologies, 39 unit types from 20 distinct case studies are chosen totally. They vary as 3 post-disaster accommodation units, 1 hotel room, 2 education facilities, 3 dormitory rooms and 30 housing units.

3.3. Definition of Terminologies

Throughout this thesis, some terminologies related to modular systems and spatial analysis are consistently used. Below are the most common ones that are defined clearly in order to be clear and precise with what has been achieved and meant in this study.

- **Temporary emergency:** It is used to define the housing cases which are built to fulfill the need after any emergency case for a short-term period. Post-earthquake container cities and pandemic hospitals are coded as temporary emergency functions because they are occupied for a specific period until the emergency situation has disappeared.
- **Permanent non-urgent:** It is utilized to define the building functions which are constructed for a long-term period and not a product of emergency architecture. Hotel, dormitory, housing and kindergarten projects are defined as permanent non-urgent buildings because of being utilized for a long-term period. Although dormitories, and hotel rooms are rented for a specific period, the buildings are protected. Therefore, these projects are defined as permanent functions as in the housing project example which is used by the

user for a long-time as a permanent living area. On the other hand, since container cities and pandemic hospitals are temporarily occupied by the users, they are designed to be demolished or disassembled after the emergency situation disappears. Briefly, they are designed for short-term use and not protected although post-emergency container tenanship is an open-ended period which depends on the completion of new housing for earthquake victims.

- **Spatial variety:** It represents the potential of having multiple numbers of the spaces in the unit program. Variation represents space combinations that can be generated by the association of bathroom(s), public, private and circulation space(s) in different ways. While evaluating the diversity, the parameters which are the occupation styles of the modules, the form of the analyzed unit plan which are generated by (combined) modules, and the relationship between the areas in the unit layout will be examined.
- **Occupation of modules:** It shows how the modules are utilized. In the thesis, there are varied case studies that use employed modules based on three distinct occupation ways. In the first group, the units use all floor areas that are provided by utilized modules. The units in the second group share the employed module(s) with another unit. In the last group, the utilized module(s) is shared by the unit and the circulation core of the building.
- **Single-module-based unit:** It defines the unit types that comprise a single module.
- **Multiple-module-based unit:** It defines the unit types which utilize multiple modules.



Figure 3.4: Occupation of Utilized Modules

To sum up, the methodology is generated in order to analyze case studies to discuss the influence of modular systems on spatial design. Firstly, 25 projects of modular systems are selected as case studies of the thesis. The cases that are composed of 2D modular elements or related information for their plans are not accessible, are excluded for the second step of the analysis. After the elimination, 20 case studies are analyzed through the layout diagrams on the second stage. In order to visualize utilized spaces in the building/unit, a coding system is progressed and applied to the plans. By using the layout plan of each analyzed unit, a scheme for plan of each case is generated. The borders of the adopted modules and units; public, private and circulation/service areas; main and sub-entrances are shown on the layout diagrams to examine the effects of modular systems on space creation. In the following chapter (Chapter 4), the detailed spatial analyses for each case, how the data is used and diagrammed are discussed with the help of figures and tables.

CHAPTER 4

CASE STUDY ANALYSIS

As mentioned in Chapter 3, case studies are selected as being the pioneer projects of the construction industry as mentioned in the literature. There are two stages in the methodology of the study. The number of case studies changes within these two stages, due to the lack of detailed information necessary for the second stage.

In the first stage, 25 case studies are selected. The list is as follows: post-disaster shelters located in Van, Elazığ, İzmir, The Museum Hotel Antakya, Collins House, Little Hero, Wuhan Huoshenshan Hospital, Holon Apartments, Ten Degrees (Croydon Tower), Apex House, Raines Court, Murray Grove, Urban Splash (hoUse), B2 Tower, Carmel Place (My MicroNY), Union Flats, David H. Koch Childcare Center, Vignes Street Interim Housing Project, The Stack Broadway, Nakagin Capsule Tower, Ogura Asahi Kindergarten, Habitat 67, Dorteavej Residence, Modular Concrete Housing (VDC- Vale de Cambra), Keetwonen Student Housing. Case studies are examined through the diagrammatized layouts in the second stage. 5 of the 25 case studies had to be excluded from the analysis. because plans of Urban Splash, B2 Tower and Vignes Street Interim Housing Project could not be accessed; and Collins House and Wuhan Hospital are dominated by the 2D

panels which are not in the scope of the thesis as modular elements. Therefore, spatial analysis is gone through the 20 case studies which provide 39 distinct unit types to diagramming process to discuss the spatial design and diversity.

4.1. Van (Anadolu) Container-City, 2011

After the 2011 Van Earthquake, the temporary housing complex was constructed by using 2000 prefabricated container modules (Konteynerler, n.d.). Some of the 3*7 m modules was used as a housing unit that consisted of a cooking area as a countertop; a bathroom with a sink, a toilet, and a shower; and two bedrooms while the rest of them were assigned as an office, classroom, and storage (Konteynerler, n.d.).

4.2. Elazığ Container-City, 2020

Elazığ is another city that was damaged by the earthquake in Turkey, in 2020 (TRT Haber, 2020). Doğukent, Kırklar ve Aşağı Demirtaş and Sivrice districts are affected mostly (T.C. İçişleri Bakanlığı Bilgi Teknolojileri Genel Müdürlüğü, 2020). For these regions, four different temporary housing complexes were created by utilizing 2584 containers (T.C. İçişleri Bakanlığı Bilgi Teknolojileri Genel Müdürlüğü, 2020) based on 6 varied module plans (Balcı Yaşar, 2021).

4.3. İzmir Container-City, 2020

As the latest post-earthquake shelter, İzmir container-city was founded within 18 days in İzmir (gazetem İZMİR, 2020). 493 container units were placed on Haydar Aliyev district of Bornova, İzmir (gazetem İZMİR, 2020). Similar to previous post-disaster shelters, 21 sqm modules were preferred (IHA, 2020). Each module comprises a lobby, a room, and a wet zone with a shower and a toilet (IHA, 2020; Güngör, 2020).

As a result of research, three temporary accommodation unit types that were utilized for the post-earthquake container cities, could be reached (Balcı Yaşar, 2021; Konteyner, 2021). On the website of one of the container manufacturer firms, it is mentioned that two different types of module types were employed; and it is highlighted that 21 sqm containers are prefabricated as fully-finished units while 42 sqm modules are brought to the site as demounted (Konteyner, 2021). Therefore, 21 sqm accommodation containers will be analyzed within the scope of the thesis.

The container cities are not categorized based on location on the firm of Karmod's website and it is stated that containers were provided by the company for Van, Elazığ, and İzmir earthquake regions (Konteyner, 2021). Also, Sertap Balcı Yaşar, the author of the "*Afet sonrası geçici yerleşim alanlarının seri üretim kavramı ile değerlendirilmesi*", has worked on Elazığ and Malatya container cities and unit types (2021). Thus, the plans of the containers on the manufacturer's website and on the Yaşar's thesis were compared and crosschecked; and utilized to prepare diagrams for the part of the case study analysis.



Figure 4.1: Van Container City⁷

⁷ Image is taken from <https://capoglu.com.tr/van-konteyner-kent/>.



Figure 4.2: Elazığ Container City⁸



Figure 4.3: İzmir Container City⁹

Three container types that were employed in the earthquake regions of Van, Elazığ, and İzmir, were analyzed based on their layouts. As can be seen in the diagrams (Figure 4.4 and Figure 4.5), Container Type 1 and Type 2 have similar functions; consist of a public zone, a private zone, and a bathroom. However, the placement of the bathroom and main entrance on different points affect the privacy level of the units. On the first plan (Figure 4.4), it is seen that the entrance is directly leading to the public zone and encountered by the bathroom. The position of the bathroom intercepts direct visual access to the main core of the public zone. On the contrary, the main entrance of the second container type directly opens into the center of the public zone. Therefore, there is a privacy contrariness between the first two units although they have similar functions.

⁸ Image is taken from <https://www.cnnturk.com/turkiye/elazigda-konteyner-kent-kurulumlari-son-asamaya-geldi>.

⁹ Image is taken from <https://www.tokihaber.com.tr/haberler/izmirde-kurulan-konteyner-kent-depremzedeleri-agirlamaya-basladi/>

Unlike Type 1 and Type 2, Type 3 has a divergent layout and functions (Figure 4.5). There are two private areas and one bathroom, which are clustered around the circulation zone on the main entrance. Instead of leaving a part of the container as non-covered, the second private room is obtained by placing a wall. Depending on the number of the users of containers, the utilization of two private zones can be more useful instead of having a single private zone and non-closed public area in the same square meter like plans of Type 1 and Type 2.

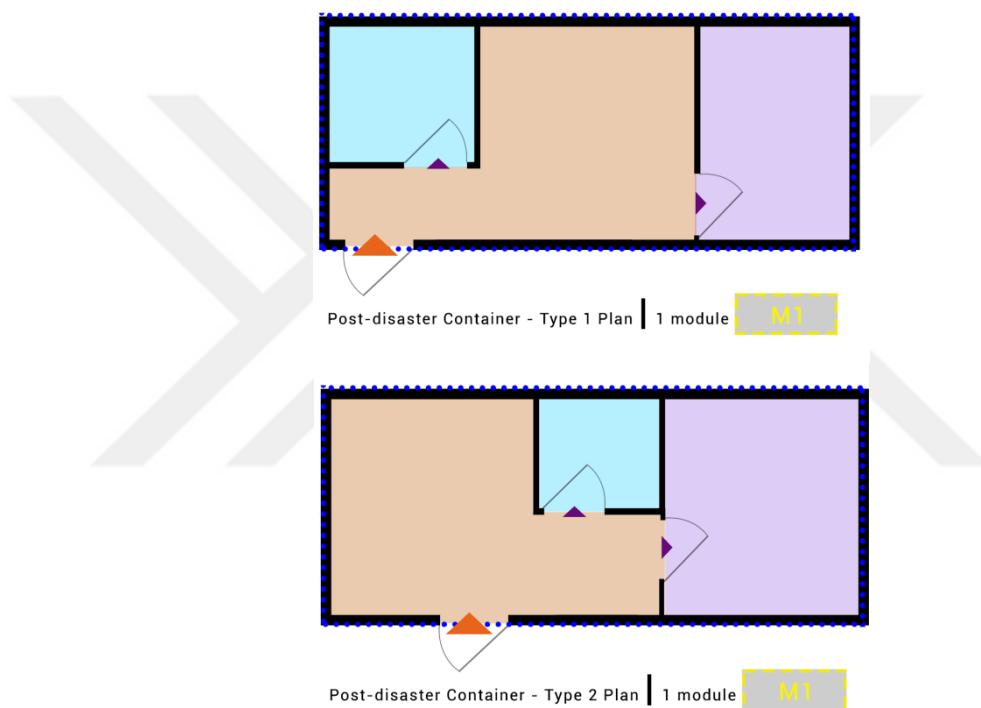


Figure 4.4: Diagram of Post-disaster Container Type 1 and Type 2

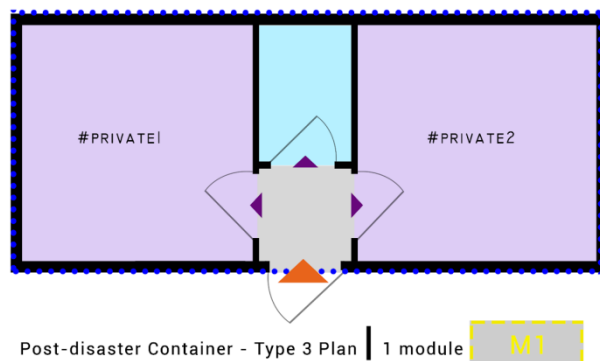


Figure 4.5: Diagram of Post-disaster Container Type 3



4.4. The Museum Hotel Antakya

Museum Hotel Antakya is a historically significant project (Luco, 2021). During the excavation process of the hotel's construction, archeological remains were found and the project was turned into a museum hotel project by assigning Emre Arolat Architecture (EAA Emre Arolat Architecture, n.d.). The hotel building was placed in the archeological zone by using 66 composite steel columns which were connected with steel beams to create the structural system of the project (EAA- Emre Arolat Architecture, 2020), (Arkitektuel, 2021).

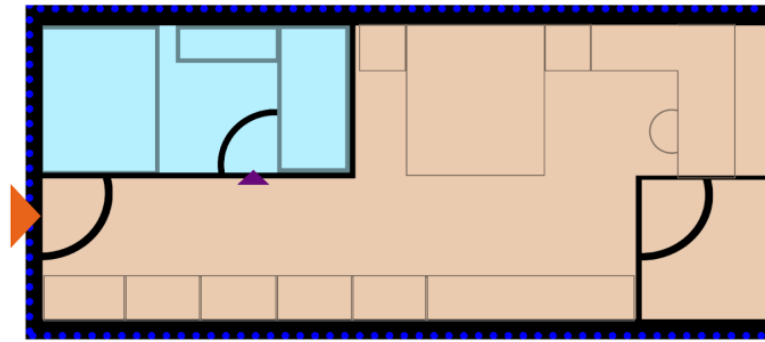
This project is a partially modular project; there are three floors comprising 200 prefabricated modular room units that were stacked on top of steel beams (EAA- Emre Arolat Architecture, 2020).



Figure 4.6: The Museum Hotel Antakya- Emre Arolat Architecture¹⁰

The accommodation floor of the hotel project is designed by using equal-sized modules. One typical module is used for each standard room. As it can be seen in the given image, each single module has a public zone and a bathroom area and there is not any closed private zone for various purposes. The user enters the public zone directly by passing near the bathroom.

¹⁰ Image is taken from <http://www.themuseumhotelantakya.com/tr/mobile/contact.php>.



The Museum Hotel Antakya - Standart Room Plan | 1 module

 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ▶ main entrance
 ▶ sub-entrance

Figure 4.7: Diagram of Standard Room Plan of The Museum Hotel Antakya¹¹

As a second type; a larger room consists of two modules and they are placed on the corner part of the building. The size of each module is the same with standard room modules. As it can be seen on the plan of a larger unit; the first module, where the entrance is located, has a similar space flow with standard rooms. It has a smaller bathroom and public zone which has an opening for the entrance of the private zone.

4.5. Collins House

Collins House is one of the world's tallest buildings that were constructed by using modular volumes and panels (Thai et al., 2020). It was completed in 2019 as a 60-story and slimmest high-rise building in Australia (Langston&Zhang, 2021). The site where the Collins House was built on it has required a rapid construction period because it was located between existing buildings (Hickory, 2021). To reduce the number of construction sounds and traffic, modular construction methods were preferred (Block, 2020).

¹¹ Diagram was generated by me. Unit Plan was taken from <https://emrearolat.com/project/the-museum-hotel-antakya/>



Figure 4.8: Construction of Collins House (Hickory, 2018)

For the project; both conventional and modular construction techniques were adopted. The first 14-story, which acts as a podium for the modules, was built by using conventional concrete while the modular system was utilized for the upper floors (Thai et al., 2020).

4.6. Little Hero (Fender Katsalidis)

Little Hero is another modular building that was constructed in Australia in 2010. It is a core-based building and for the ground level and core tower “conventional concrete slab techniques” were preferred (Fender Katsalidis Australia, n.d.). During the on-site construction process, apartment modules were prefabricated as fully-finished systems with steel structures, all technical equipment, covering materials, and furniture. Then all prefab modules were brought to the site and mounted on the core.

The building consists of 8 floors; 7 of them, modularized floors, are used as residential while the ground floor is preferred for commercial purposes. It has 58 single-story units and 5 double-story units (Gunawardena et al., 2012). Both single- and double-story apartment modules were prefabricated and tacked together within eight days. The building was located on an extra narrow street. Therefore rapid

construction is one of the main concerns of this site compared to usual construction areas (Javanifard et al., 2013). On the website of the Fender Katsalidis, the design office of the “Little Hero”, the building is declared as ‘the world’s first example of using Unitized™ Building System Technology’ (Fender Katsalidis Australia, n.d.). This system enables reducing the budget for the workforce and time for construction by having both on-site and off-site production stages (Jay, 2018).

On the website of OC Bristo, operator of modular houses, light steel prefabricated systems, etc., Little Hero Building was showed also as 9.0 magnitude earthquake resistant by virtue of the structure of modular units (Jay, 2018).



Figure 4.9: Little Hero Building (Fender Katsalidis Australia, n.d.)

The feature that distinguishes this project from other examples is that the building consists of identical modules. Each module has an equal size and the same space flow. Based on a rectangular plan, there is one bathroom, one private zone, and one public zone. After entering the unit, the user can access the bathroom and private area, respectively, on a long circulation line. The circulation line not only transfers

users to the spaces in the unit but also creates a neutral zone by providing direct entrances to the main spaces such as private-public zones.

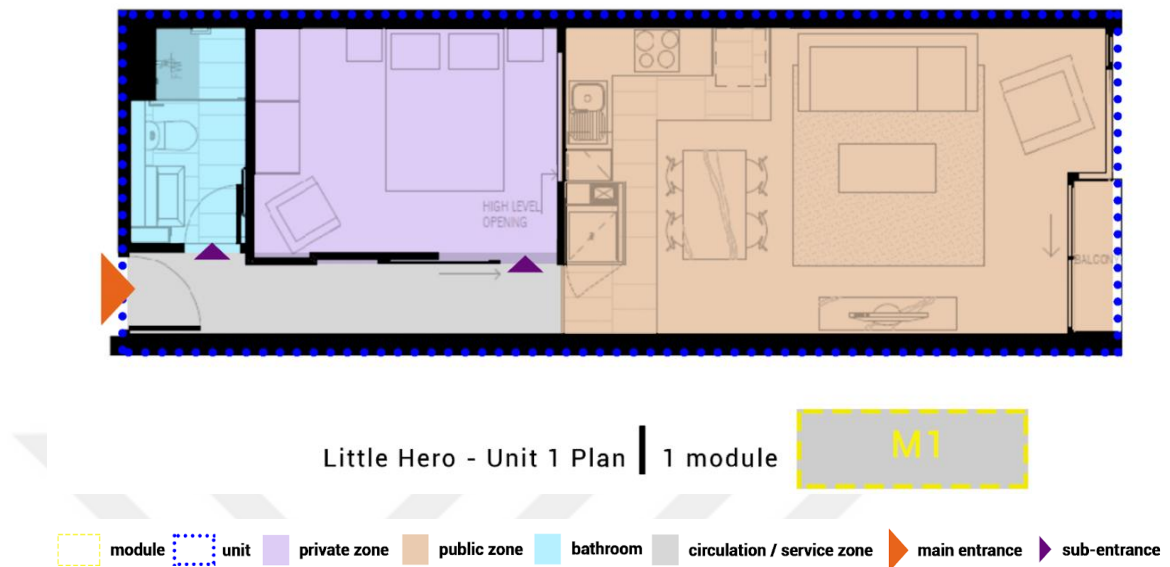


Figure 4.10: Diagram of Little Hero Unit Plan¹²

4.7. Wuhan Huoshenshan Hospital

Wuhan Huoshenshan Hospital is a two-story and 33,940 sqm building that diverges from other case studies with its aim and function (Tan et al.,2021). It is built as a hospital with a 1000 bed capacity for the COVID-19 pandemic so rapid construction turns into a requirement rather than being an advantage (Zhou et al.,2021). On the side, compared to the other modules that are used for repetitive spaces such as apartments or hotel rooms; the modules that are utilized for the construction of pandemic hospitals are needed to be varied in terms of openness or size because of the hospital program and layout (Zhou et al.,2021). Not only openness but also the inner organization and dimensions of the modular units might change based on three module typologies in the quarantine zone (Zhou et al.,2021).

¹² Diagram was generated by me. Unit Plan was taken from <https://www.livinspaces.net/projects/architecture/this-apartment-building-in-australia-designed-by-fender-katsalidis-was-completed-in-30-days-using-ppv/>



Figure 4.11: Wuhan Huoshenshan Hospital Construction (Stringer – Anadolu Agency, 2020)

4.8. Holon Apartments

Holon Building is one of the pioneer modular cases in China (Ravenscroft, 2021). The BROAD Group, the owner of the project; claims that the project has the “world’s shortest construction period in that scale” (Ravenscroft, 2021) because it was assembled from modules. All modular units were produced at the factory with all technical equipment and installed on-site in 29 hours (Modular Building Institute. n.d.). Also, all units were fabricated as equal-sized with a standard container unit to be able to be transported easily (Modular Building Institute. n.d.). Additionally, to have more flexible spaces, one wall of each unit was designed as foldable elements. It was aimed to use that wall as a floor of another module for column-free spaces (Ravenscroft, 2021). When it is compared to other cases, this project has provided a variety on apartment plans by using the same container-based modular units.



Figure 4.12: Holon Apartments (BROAD USA, n.d.)

Holon Apartment is a residential project that has three units based on two varied typologies on each floor. As it can be seen on the examined floor plan (figure..), the floor is composed of five modules. In the middle part, a narrow module (M3) is placed for the circulation core of the building. The two modules on the right and left of this area formed the accommodation units. The first two modules (M1 and M2) on the left side, create a single unit, while two modules (M4 and M5) form two separate units on the right side.

The M2 module has an open plan, except for two bathrooms, to provide a public zone for the larger unit. Oppositely, there are three separate private areas that have entrances from the circulation zone on the M1 module. The plan of the right side of the building has been solved in a similar way in terms of the placement of public and private zones. However, instead of generating one single unit, two separate units are obtained by using half of the M4 and M5 modules. These units have similar space flow with the larger unit, users directly enter the public zone without passing through

a transition area, and then they are transferred to the private zones from the inner circulation core.

This project shows that multiple modules might be in use to comprise a unit, instead of assigning a single module for each space or one module might stand for two separate units. These features provide an opportunity to obtain larger floor areas and adjunctly spatial varieties such as private zones for the units.

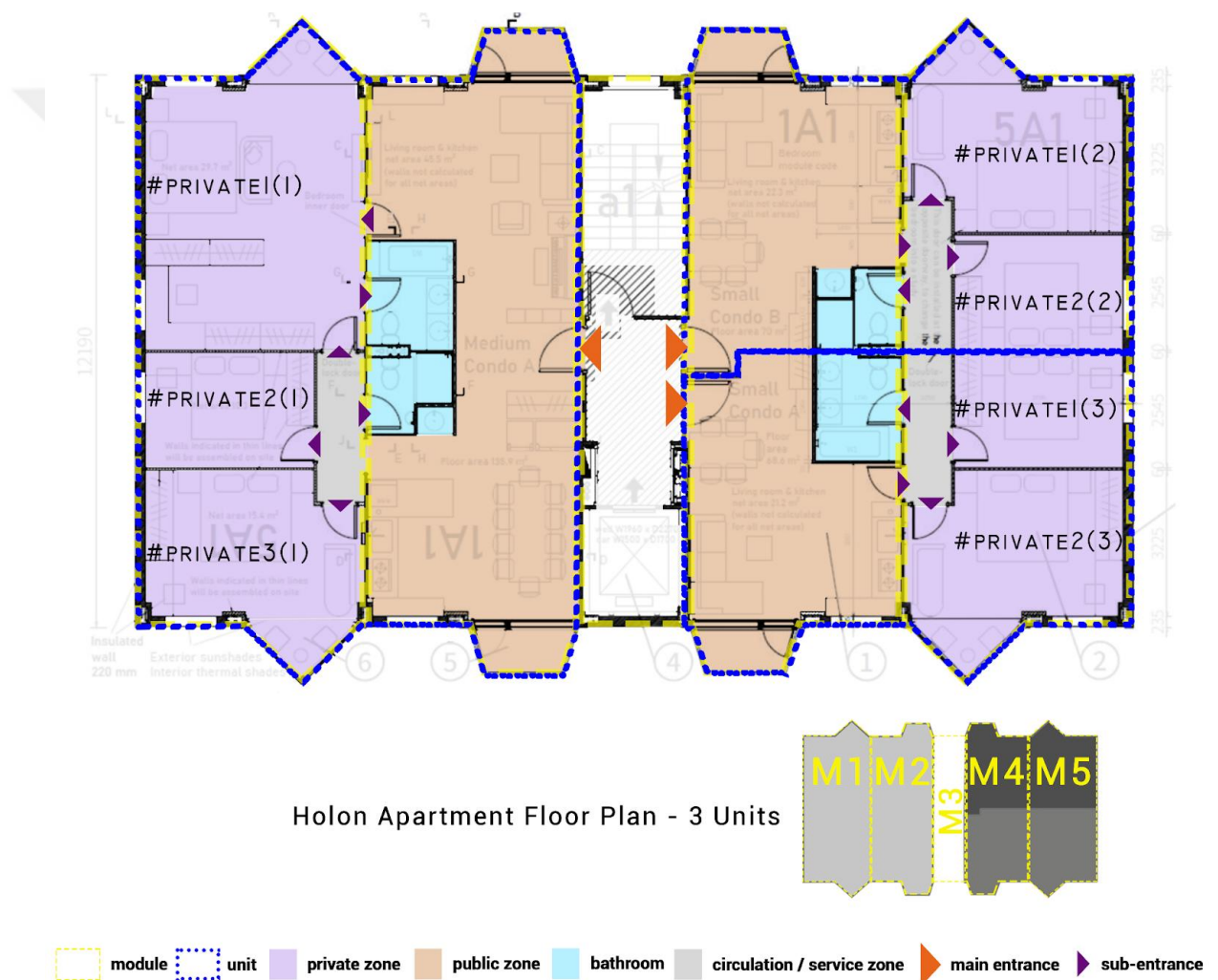


Figure 4.13: Diagram of Holon Building Floor Plan¹³

¹³ Diagram was generated by me. Floor plan was taken from <https://broadusa.com/broad/wp-content/uploads/2021/09/HOLON-Building-August-2021.pdf>

4.9. Ten Degrees (Croydon Tower)

Ten Degrees is another pioneer building because of being known as one of the tallest modular towers in the world (Parkes, 2022, Sketchley, 2020). It was constructed by using podium- and core-based structures. Both two types of structural elements, twin-core towers, and podium, were built with conventional concrete-based construction techniques (Thai et. al, 2020).

546 new homes, composed of over 1500 modules have been offered for the Croydon region by 38 and 44-story towers of Ten Degrees (HTA, n.d.). Each residential floor has seven different apartments. These units have varied based on their room numbers (Karakoç, 2021). This feature sets the project apart from other modular-based constructed cases. In addition, it has the potential to eliminate the possible prejudices against the monotonousness of modularity by representing several layout alternatives.



Figure 4.14: Ten Degrees- Croydon Tower (HTA, n.d.)

For the analysis of the modules of Ten Degrees Tower (Croydon Tower); 4 different housing types from 12 typologies were selected. Chosen units have similar spatial

functions and module combinations with the rest of them. but each has a different spatial flow.

In the first example (a2) which consists of 2 modules, it is seen that the circulation area is defined at the entrance, to prevent direct access to the public zone. However, in order to access the bathroom from the public zone, it is necessary to pass through the private area. Just as in the second example, this transition indirectly leads to a re-questioning of the privacy of the private space.

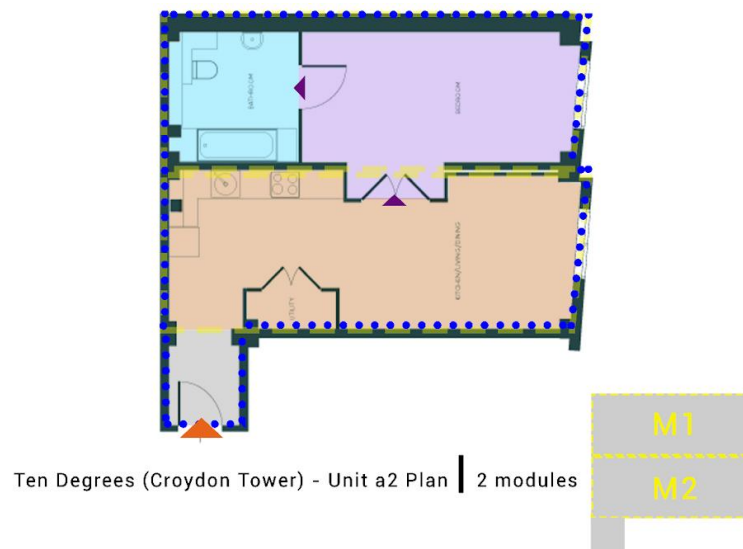


Figure 4.15: Diagram of Plan of Unit a2, Croydon Tower

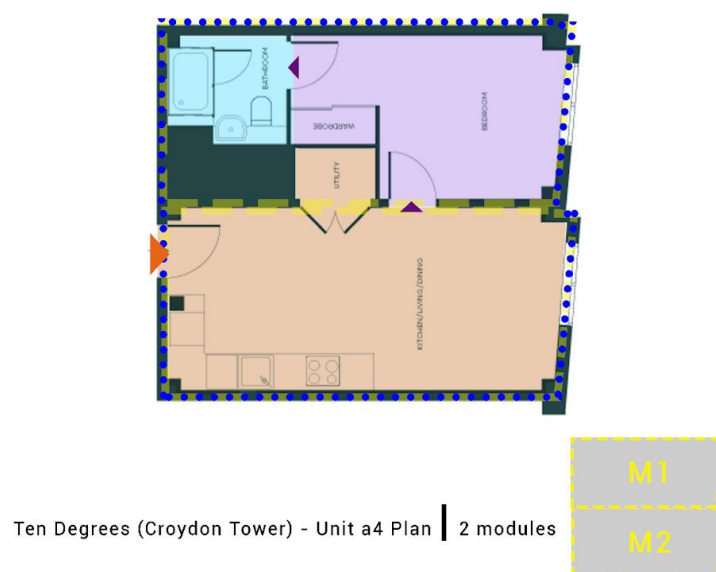


Figure 4.16: Diagram of Plan of Unit a4, Croydon Tower

 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ▶ main entrance
 ▶ sub-entrance

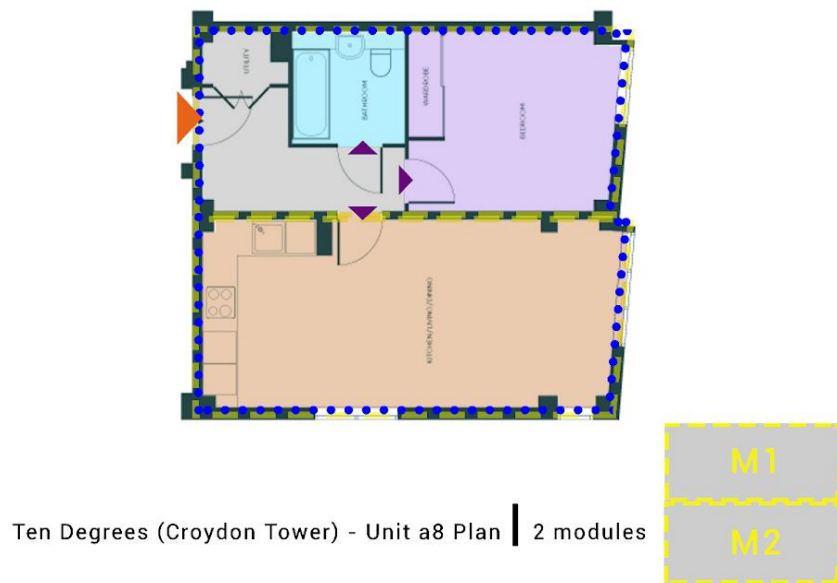


Figure 4.17: Diagram of Plan of Unit a8, Croydon Tower



Figure 4.18: Diagram of Plan of Unit b2, Croydon Tower¹⁴

 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ➤ main entrance
 ➤ sub-entrance

Unlike the a4; in the last two examples (a8 and b2), the main entrance opens to a wide circulation area and other spaces are placed around this part. The b2 becomes dissimilar from the a2, a4, and a8 by having the third module to create the extra bathroom and private zone. Moreover, although the a8 is similar to the a4 in terms of

¹⁴ Diagrams were generated by me. Unit plans were taken from https://entrata.tendegreescroydon.co.uk/Apartments/module/property_info/property%5Bid%5D/910090/occupancy_type/conventional/is_responsive_snippet/1/snippet_type/website/

the plan, access to the bathroom is provided via the corridor as being independent from the private zone.

Briefly; in Ten Degrees Tower, varied module types were utilized in both horizontal and vertical directions to generate accommodation units. Therefore, it shows the potential of modular design in terms of creating different spaces by escaping monotonousness.

4.10. Apex House

Apex House was built as the tallest project in Europe in its construction year, 2017 (HTA- Apex House, n.d.). It was constructed by using 679 fully-finished modules (Wang, 2017). 242 of them, which were supported with steel bracings, were placed at two 8-story wings on both left and right sides of the main part. The rest of them, smaller units, were mounted around the main structural concrete core on the 29-story corner (Thai et. al, 2020, Construction Management, 2017). All modules were produced at the factory as fully finished volumes (Construction Management, 2017). The partner of the HTA, the designer of the Apex House, stated that 70% of the workload of the construction process belonged to off-site production (Construction Management, 2017). Therefore, the on-site construction period was shorter than the off-site production process (Thai et. al, 2020).

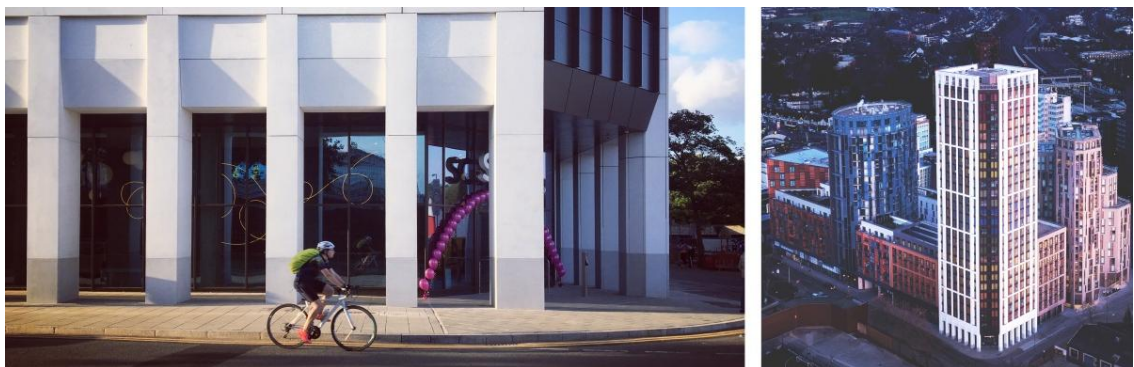


Figure 4.19: Apex House (HTA- Apex House, n.d.)

Divergent module typologies in terms of design are placed on each floor. Although having module variations, all units have limited widths because of transportation limitations (Construction Management, 2017). In some different modular cases, this limitation was solved by producing semi-open modules to design wider or column-free spaces.

Apex House is a dormitory project that can be called a temporary living space due to its function. From the nomenclature in the dormitory plan Figure 4.11, it was understood that there are 17 different unit types. However, when the plan is evaluated in terms of private-public area distribution, it is seen that most of the units are designed with the same strategy and similar rectangular-shaped plans except few of them. Apart from that, each unit opens to a public zone and has a bathroom. Also, there are no private areas in any of them. As can be seen in the analyzed plan, in addition to the student rooms which consist of separate modules, 4 more modules without any partition have been placed to create public zones as socializing spaces for each floor.



Figure 4.20: Floor Plan of Apex House¹⁵

¹⁵ Floor plan was taken from <https://constructionmanagement.co.uk/modular-h6its-heig5hts-nor4th-london/>

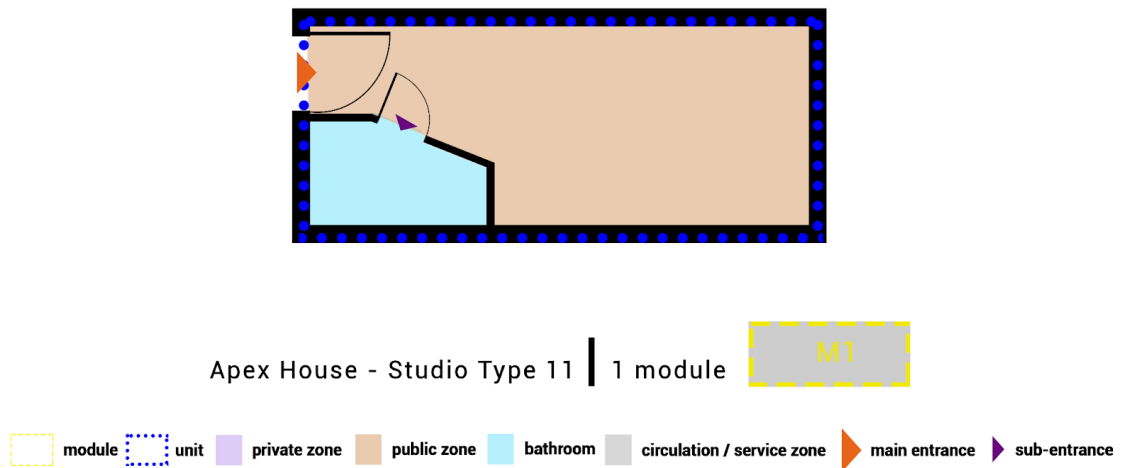


Figure 4.21: Diagram of Studio Type 11, Apex House¹⁶

4.11. Raines Court

Before the Raines Court, modular prefabricated construction techniques had been preferred for non-residential buildings (AHMM, n.d.). Based on the declaration of the developer company “The Peabody Trust”, it was aimed to answer the housing needs of the UK bringing new residential alternatives like other countries (AHMM, n.d.). 61 self-supporting container-like home units were distributed through 6 floors (AHMM, n.d., Ismail& Rahim, n.d.). Being self-supporting is the distinctive feature of the Raines Court because there were not any other structural elements to connect modules except supportive bracings and the structure of vertical and horizontal circulation shafts (Ismail& Rahim, n.d.).

The project was the first example of a multi-story modular residential building in the UK (Ismail& Rahim, n.d.). Although using this kind of system for the the housing building for the first time, three different-planned unit types were used rather than repeating a single unit (Melvin, 2005). To illustrate, three-roomed houses were obtained by adding two sub-modules to one of the main modules that consist of two bedrooms and one bathroom (Melvin, 2005). However, from a different viewpoint, a

¹⁶ Diagram was generated by me.

combination of three different unit types is not sufficient for the adaptability of the project because of fully factory-finished modules (Ismail& Rahim, n.d.).



Figure 4.22: Raines Court (AHMM, n.d.)

Raines Court is a residential project that is designed by using three different unit types. When these 3 unit types are analyzed it is seen that multiple private areas are provided for each unit. Additionally, these units do not directly open to the public zone. A transition space is utilized to create a secondary zone to prevent direct access. As it can be seen on the plan of Unit 1, the area with the name #PRIVATE2 was designed with larger square meters when it is compared to the private zones of Unit 2 and Unit 3.

When the plans are analyzed based on module-unit relation; it is achieved that

- Unit 1 is composed of 2 modules and uses all areas that are provided by these modules.
- Unit 2 is composed of 2 modules but does not use all areas; it gives some part of the second module for the building circulation.

- Unit 3 is composed of 3 modules but uses 2 and a half of the floor area of these modules. There is no partitioning in the middle module except for the entrance part, and it is planned as a public zone completely. One of the remaining modules houses two private zones and a bathroom. However, the third module gives its semi-space to the unit to provide a bathroom and another space.

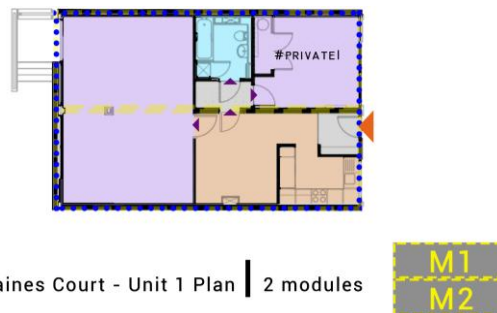


Figure 4.23: Diagram of Unit 1 Plan, Raines Court

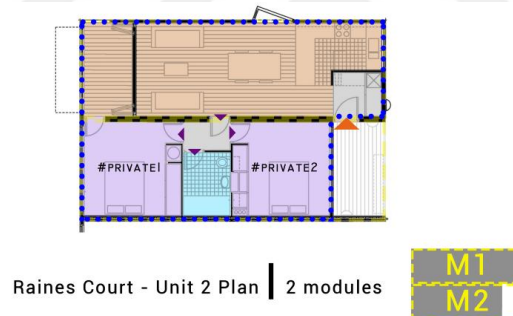


Figure 4.24: Diagram of Unit 2 Plan, Raines Court

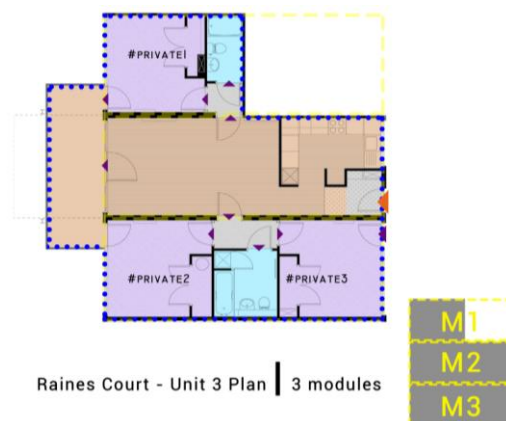


Figure 4.25: Diagram of Unit 3 Plan, Raines Court¹⁷

 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ▶ main entrance
 ▶ sub-entrance

¹⁷ Diagrams were generated by me. Unit plans were taken from https://www.ahmm.co.uk/assets/lib/2019/09/12/Raines%20Court%202010_LR-compressed.pdf

4.12. Murray Grove (Shepherdess Walk N1)

Murray Grove, also known as Shepherdess Walk N1 (Peabody, n.d.), is a five-story residential building, that was built from steel-framed modular units (Robinson, n.d.; McGrath & Horton, 2011). Compared to other modular projects, the Murray Grove has a unique module type. Each unit consists of two or three “room-sized” modules (Powell, 2002; McGrath & Horton, 2011). The room number of the modules changes based on the room numbers of the apartments (Powell, 2002). The entrance of each unit was stated on the public corridor where can be accessed from the corner circulation tower (Powell, 2002).



Figure 4.26: Murray Grove (Robinson, n.d.)

Murray Grove is constructed by utilizing a single-unit type. Each unit has the same floor plan and is composed of two modules. The user directly enters the public zone and can access two different private zones, bathrooms, and service areas from there. The main separation is done by dividing the module into two spaces; but in the second module, there are additional divisions to define the bathroom and service areas. The front part of the modules is assigned to the public zone and bathroom, while the back part is dominated by private zones. Therefore there is no excessive layout differentiation between the two modules of the unit.

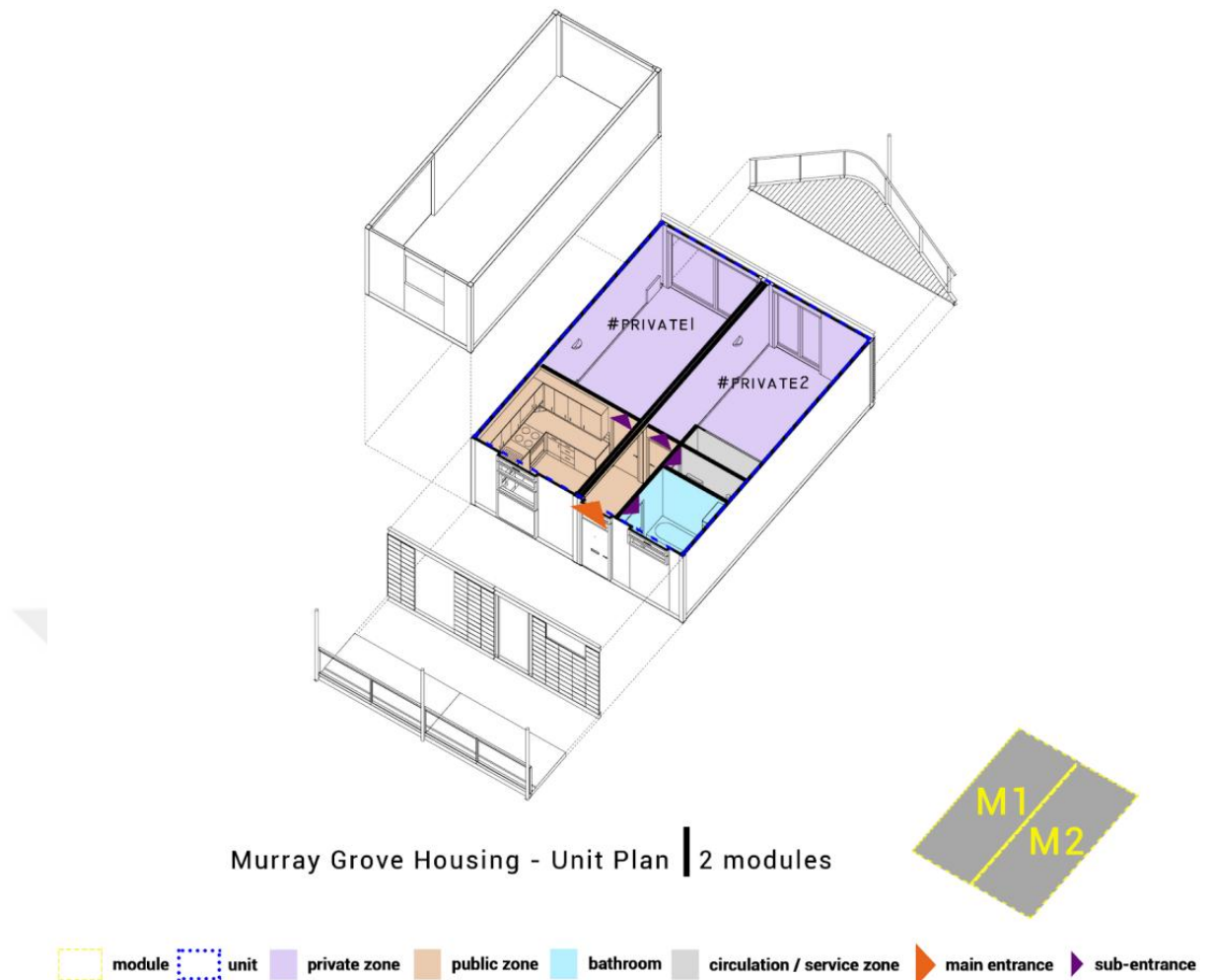


Figure 4.27: Diagram of Murray Grove Housing's 3D View¹⁸

4.13. Urban Splash (hoUSE)

Urban Splash is located alongside the canal New Islington and comprises 43 prefabricated houses (Frearson, 2016). The most distinctive part of the project is the layout options presented for the customers. Even though each house looks the same from the exterior, the interior layout of each house might be organized by customers divergently (Frearson, 2016). Placement of the spaces in the plan and location of the floors are alterable features of the Urban Splash. The layout that is preferred for the first floor of one house might be placed on the third floor in another (Frearson, 2016).

¹⁸ Diagram was generated by me. 3D axonometric view was taken from <https://www.cartwrightpickard.com/housing/murray-grove/>



Figure 4.28: Photos of Urban Splash Project (Frearson, 2016)

4.14. B2 Tower

B2 Tower, designed by SHoP, was completed in 2016 (SHoP, n.d.). It is shown as the tallest modular high-rise building of its time (Thai et al., 2020). The initial aim of the company behind the decision of using modular systems is to decrease the construction costs and wastes (MG McGrath Inc, n.d.).

For the project; both modular and conventional construction techniques were utilized (Thai et al., 2020). The conventional construction method is used for podium-based concrete structures (Thai et al., 2020) and the ground floor of B2 Tower that hosts commercial facilities (Honyak, 2018). The modular construction method is utilized for the residential floors. Each module is structured by a braced steel frame that increases the stability of the structure against horizontal loads (Thai et al., 2020).

The project comprises 930 modules that create 350 accommodation units (Sezer, 2015) based on 23 varied interior layouts (SHoP, n.d.). These numbers make this project dissimilar from other modular buildings because it is one of the modular high-rise cases that have 23 different apartment types.



Figure 4.29: B2 Tower (MG McGrath Inc, n.d.)

4.15. Carmel Place NY (My Micro NY)

Carmel Place, an affordable housing project, was designed for getting maximum efficiency from a small construction site (Çolak, İlerisoy;2018). 55 housing units, which comprised of 6 varied module types ranging from 23 to 34 sqm, were placed on a 3250 sqm project area within nonequal vertical volumes (Brake, 2016). Based on getting maximum performance from a relatively small area; nArchitects -designer of the project- bring convertibility to bear on the interior layout (Brake, 2016). To illustrate, by employing same area for both living room and bedroom, it is aimed to get maximum performance from the micro-unit and provide capaciousness (Brake, 2016). Utilizing a single room for multiple purposes to obtain multiple functions enhances the potential of the unit.



Figure 4.30: Carmel Place (Brake, 2016.)

Carmel Place (as known as My MicroNY) has seven different unit types that are prefabricated as fully-finished modules. For the analysis, four of these seven units

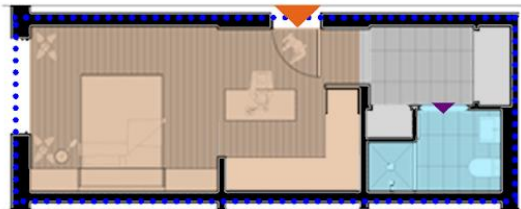
are examined. Apart from the exceptions, the space flows of the apartments are similar; there are only dimension differences between the units. Except for Unit A and Unit F, all units are open to the public zone. As it can be seen in Figure 4.20, an additional transition area, which blocks the direct entrance to the public zone, is provided for Unit A. While this transition zone is increasing the privacy level of the unit, there is not any private zone like other unit types of the project. Briefly, all units have a public zone and a bathroom as the main spaces. However, there are some additional service or circulation areas in some unit types.



Carmel Place or My Micro NY - Unit 1 Plan | 1 module

M1

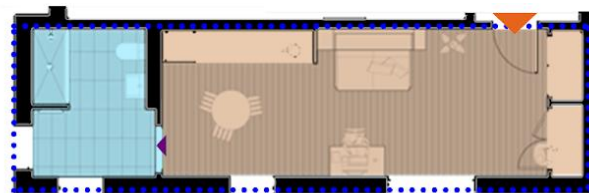
Figure 4.31: Diagram of Unit 1 Plan, My Micro NY



Carmel Place or My Micro NY - Unit 3 Plan | 1 module

M1

Figure 4.32: Diagram of Unit 3 Plan, My Micro NY



Carmel Place or My Micro NY - Unit 4 Plan | 1 module

M1

Figure 4.33: Diagram of Unit 4 Plan, My Micro NY

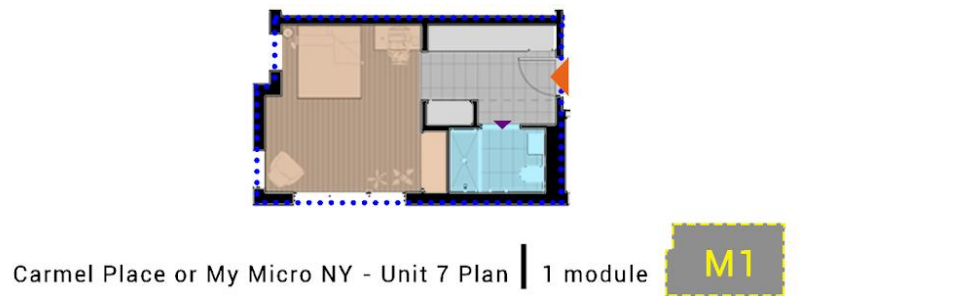


Figure 4.34: Diagram of Unit 7 Plan, My Micro NY¹⁹



4.16. Union Flats

Union Flats is a 4-story modular housing project, in Union City (Duffy, n.d.). The project comprises 243 accommodation units from 408 modules (Guerdon Modular Buildings, 2020). Modular construction is chosen by the company because of the desire for time, cost, and construction waste reduction (Lee, 2019).

All equal-sized modules were produced off-site; only exterior walls and circulation shafts were constructed on-site while the modules were placed (Duffy, n.d.). Although being identically-sized modules, they are able to create various layouts by nesting differently (The Union Flats, n.d; Duffy, n.d). As it is seen in the Figure 4.36, a similar strategy is followed by the project and 3 modules generate 2 housing units by combining the modules within the housing units. Therefore, this joining process of wooden-framed modules should be done studiously to have a hassle-free on-site construction process (Duffy, n.d.).

Compared to other modular projects where modules are placed repetitively, this project presents an alteration in terms of housing layouts. Based on the Tetris-like shape of units, a dynamic inner circulation is provided for residents.

¹⁹ Diagrams were generated by me. Unit plans were taken from <https://www.dezeen.com/2016/02/01/carmell-place-micro-apartment-tower-new-york-city-narchitects-photos/>



Figure 4.35: Union Flats²⁰

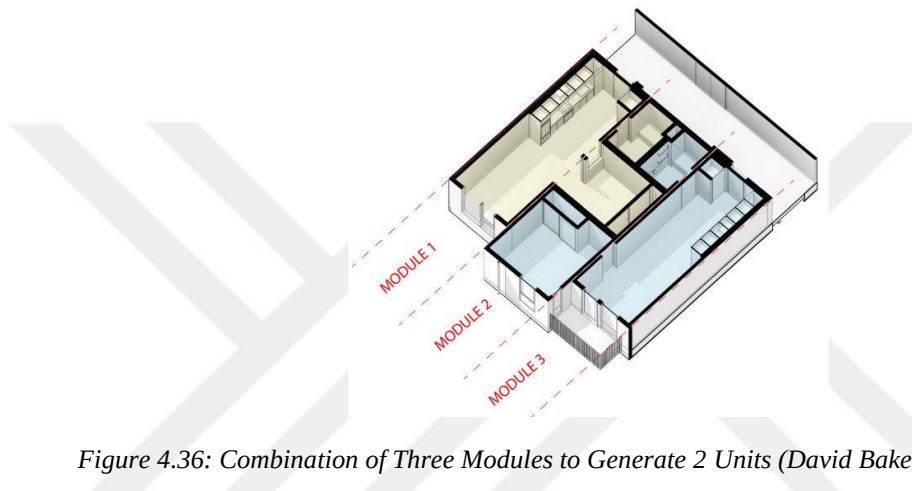


Figure 4.36: Combination of Three Modules to Generate 2 Units (David Baker Architects, n.d.)

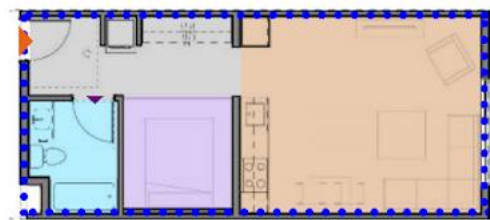
Case 16 is a residential project that has 4 different unit types. This case study shows the possibility of spatial variations in the units although using the module(s) which have the same dimensions.

When the plans are analyzed based on module-unit relation; it is achieved that;

- The first unit which is named as “Chillpod Studio” is composed of a single module and it uses all the area that is provided by the module. The unit opens to a circulation zone that has access to other spaces in the unit. The bathroom is placed next to the entrance while the public zone is stated at the end of the circulation zone. Unlike other cases, the public zone is divided into two spaces by a partition wall which creates additional space in the same area.

²⁰ Image is taken from <https://www.ekoyapidergisi.org/hem-prefabrik-hem-ekolojik>.

- The second unit, named with “Corner”, is composed of two modules and uses all area that is provided by the modules. The circulation zone of the unit, two bathrooms, and the second private area are placed in module 1 (M1) while there are the first private zone and the public zone in module 2 (M2). Similar to the first unit, there is a circulation zone at the main entrance and the users are carried to the bathroom, private zones, and the public zone by the corridor. However, unlike the “Chillpod Studio”; “Corner” has closed areas that can be used in various functions as private zones. For the third unit, “Flex 1BR”, two modules are assigned and half of the second module (M2) is wielded for it. The first module (M1) is utilized by the bathroom and public zone while half of the M2 host the private zone. However, “Flex 1BR” differentiates from the first two units by not having any circulation or service zones. The user directly enters the main space without passing through a transition zone and can access the private zone from the public area.
- The last unit of the project, the “Flex Studio”, has almost the same plan as the “Flex 1BR”. In contrast to “Flex Studio” has no private space and consists of a single module that is identical to the first module of “Flex 1 BR”.



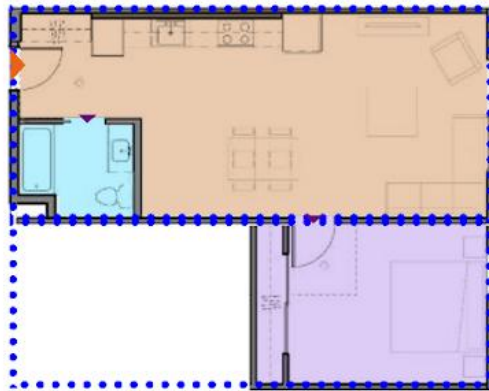
The Union Flats - 'Chillpod Studio' Plan | 1 module 

Figure 4.37: Diagram of Chillpod Studio Unit Plan



The Union Flats - 'Corner' Plan | 2 modules

Figure 4.38: Diagram of Corner Unit Plan



The Union Flats - 'Flex 1BR' Plan | 2 modules

Figure 4.39: Diagram of Flex1Br Unit Plan



The Union Flats - 'Flex Studio' Plan | 1 module

Figure 4.40: Diagram of Flex Studio Unit Plan²¹

 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ▶ main entrance
 ▶ sub-entrance

²¹ Diagrams were generated by me. Unit plans were taken from https://www.dbarchitect.com/us/news_blog/340/The%20New%20Multifamily%20Modular.html

4.17. David H. Koch Childcare Center

David H. Koch Childcare Center was projected by MIT for the need of its members (Arup, n.d.) and scheduled in a little while (Triumph Modular, 2021). Therefore prefabricated modular systems were found appropriate to meet expectations (Triumph Modular, 2021). Totally, 21 prefabricated modular units were brought to the site as fully-finished systems and used for the construction. 11 of them were placed on the pad foundation for the ground floor and the rest of them were placed on top of the first group (D. W. Arthur Assoc. Architecture, 2015). Two modules for each floor were slid back and three modules of the first floor were rotated to generate semi-open subspaces (D.W. Arthur Associates Architecture, n.d.). On the website of the architecture of the project, it is mentioned that all these movements were done by virtue of features of steel-framed modules (D.W. Arthur Associates Architecture, n.d.). Herewith, instead of designing a simple building; diverged and dynamic spaces were obtained.



Figure 4.41: David H. Koch Childcare Center (Triumph Modular, 2021)

David H. Koch Child Care Center is a two-story nursery project that comprises 21 modules. 10 modules are assigned to the ground floor while 11 of them are charged for the first floor. When the project is compared to other examined cases it is

- The ground floor consists of 11 modules that are fabricated as the divided cells to design the floor by attaching each other. There are 9 large-sized and 2 relatively small private areas on the ground floor. Smaller ones are placed near the public zone while the private areas are dwelling on either side of the circulation zone. The floor is dominated by private zones and there is a single public zone apart from the private zones, bathrooms, circulation, and service areas. The public zone hosts the main entrance and provides access to the circulation and service areas.
- The first floor comprises 10 modules and similar functions as the ground floor with an exception. Private areas and bathrooms are placed around the circulation and service zones. Although the first floor has larger individual spaces, they are coded as private zones because of being fully closed and have no direct connection with circulation areas.

4.18. Vignes Street Interim Housing Project

Vignes Street Interim Housing Project is a residential complex that was designed as a solution to the increasing housing population of Los Angeles during the COVID-19 pandemic (McKnight, 2021). The project consisted of three main parts (McKnight, 2021): social areas for laundry, kitchen, and dining room facilities; single-story temporary shelters, and three-story housing blocks (Smith, 2021). Single-story units are made of wooden trailers while the multi-story part is comprised of shipping containers (McKnight, 2021). To interconnect the shipping containers and link them to the circulation volume (stairs and open corridors); additional structural elements were utilized (McKnight, 2021). Each 25 sqm housing module and trailer hosts a

two-bedroom with its own bedroom; a total of 232 bedrooms was gained to the city for the homeless people (McKnight, 2021).

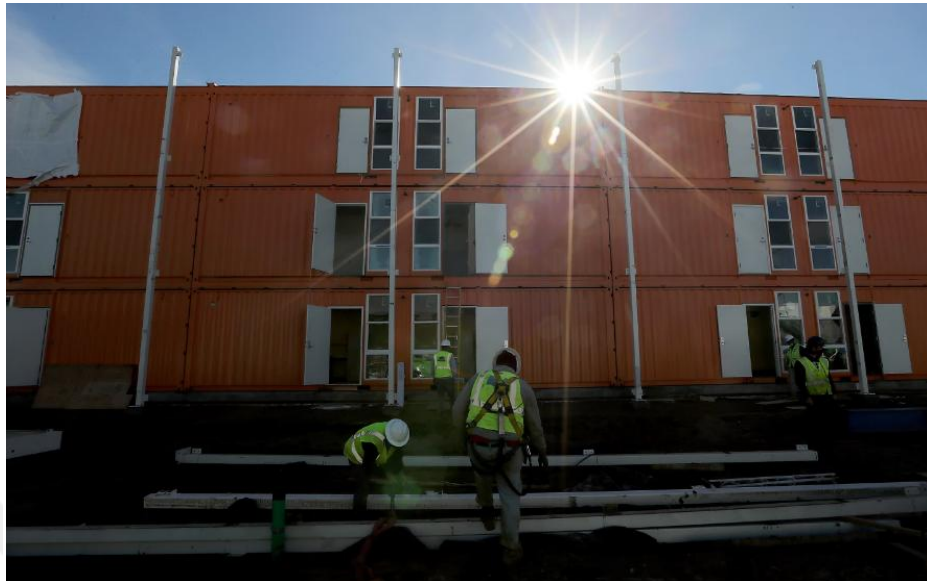


Figure 4.43: Photo from Construction Process of Vignes Street Interim Housing Project (Smith, 2021)

4.19. The Stack Broadway

“The Stack”, the first modular apartment building located in Upper Manhattan (The Harman Group, 2016), was built in 2014 (González, 2020). The building comprises 7-story and 28 housing units (The Harman Group, 2016). Totally 56 modules were fully fabricated off-site and placed on top of a steel-framed podium on-site (The Harman Group, 2016).

the architect of the project mentions that the building was planned on a small and disadvantageous site (González, 2020) and designed to get maximum efficiency from a small site for the affordable housing complex (The Harman Group, 2016). This approach was utilized also for the unit and module dimensions; because of the transportation limitations and risks (The Harman Group, 2016). Therefore prefabrication means more than an off-site production process for them (Blahut, 2015).



Figure 4.44: Module Combination and Image of The Stack (GLUCK+, n.d.)

The Stack is another residential project that is constructed by using a modular system. For the analysis, a full plan of the second floor of the project is chosen. There are 5 distinct unit types and 9 modules are assigned for the second floor. 6 of the 9 modules are occupied by both a unit and circulation core of the building or two units while 3 of them are assigned for a single unit or building.

Basically;

- M1, M5, and M6 are occupied by Unit 1, the main circulation core (MCC), and Unit 3.
- M2 and M3 are shared by Unit 1 and Unit 2.
- M4 is assigned for both Unit 2 and the MMC.
- M7 is shared by Unit 3 and Unit 4 and M8 is used by Unit 3, Unit 4 and the MCC.
- M9 is assigned for both Unit 5 and the MCC.

When the plans are analyzed based on module-unit relation; it is achieved that;

- Unit 1, Unit 2, and Unit 3 have similar space flow and function distribution. At the main entrance, the user is welcomed by the public

zone and carried to the circulation area to access private zones and bathrooms.

- Unit 4 is smaller than the first three units. It has one private area and one bathroom. However, it has a similar space distribution with an exception. At the main entrance, instead of entering directly the public zone, it is first accessed to the first circulation area. The user reaches the public zone by passing it. The flow after this area is the same as the other units.
- Unit 5 is the smallest unit of the project. It is made up of a single unit and hosts a public zone and bathroom accessible from the circulation area on the main entrance part.

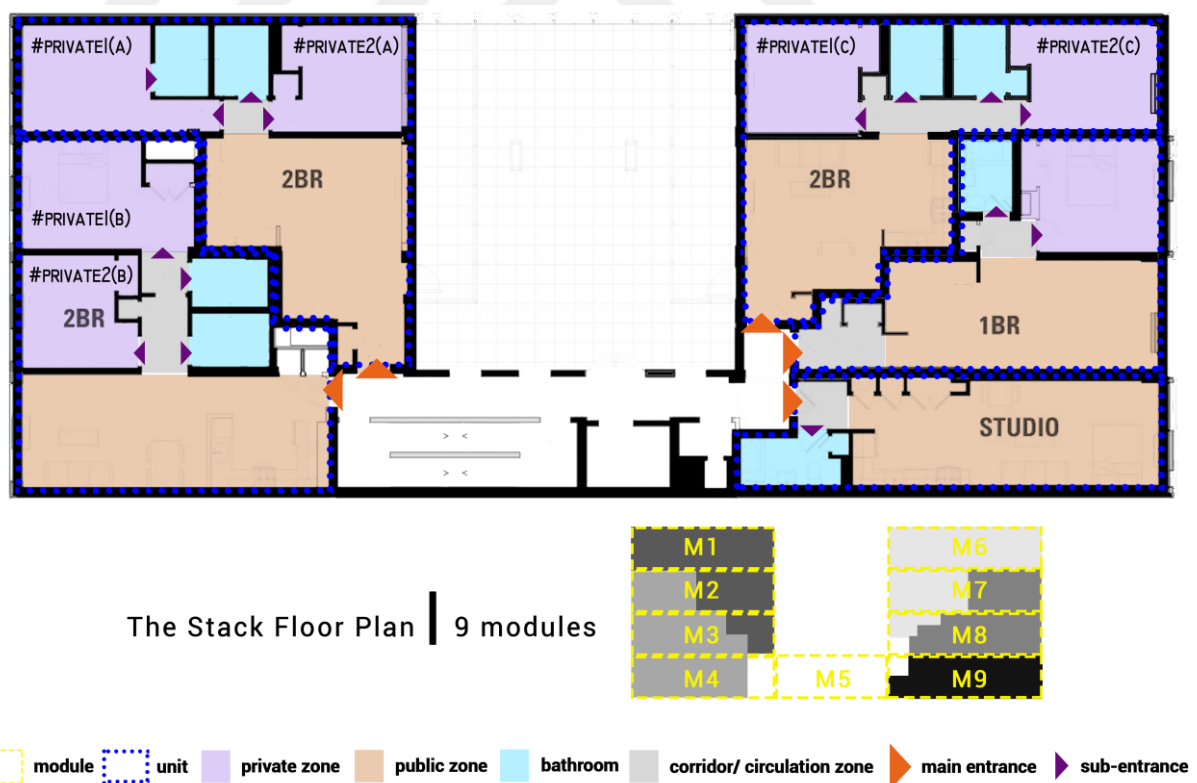


Figure 4.45: Diagram of The Stack's Floor Plan²³

²³ Diagram was generated by me. Floor plan was taken from <https://gluckplus.com/project/the-stack>

4.20. Nakagin Capsule Tower

Nakagin Capsule Tower is one of the early examples of modular buildings (Laovisutthichai et al., 2021). It was built as a residential building in 1972, in Tokyo (Kim, 2017). 140 modular units, which were produced by the shipping container factory and named as “capsules” (Laovisutthichai et al., 2021), were stacked on two core towers by high tension bolts (Kim, 2017). For the project, a single fully-furnished module type was used (Laovisutthichai et al., 2021). However; an option, which makes modules more flexible, was provided to connect modules for a larger household population (Kim, 2017).

On the other hand, Kim also claims that the modularity of Nakagin Capsule Tower also has caused some negativeness in terms of refitment of technical equipment (Kim, 2017).



Figure 4.46: Nakagin Capsule Tower (Block, 2021)

Nakagin Capsule Tower is made up using identical modules. Each floor comprises 14 modules that are connected to the main circulation towers and each module is utilized to create units. When the plan of a single unit is examined, it is seen that

there is no partitioning other than the bathroom. Each unit of the project that is relatively smaller than the other cases, is dominated by the public zone except for the bathroom. This feature decreases the privacy level of the unit if there are multiple users because all activities are needed to be done in the public zone.

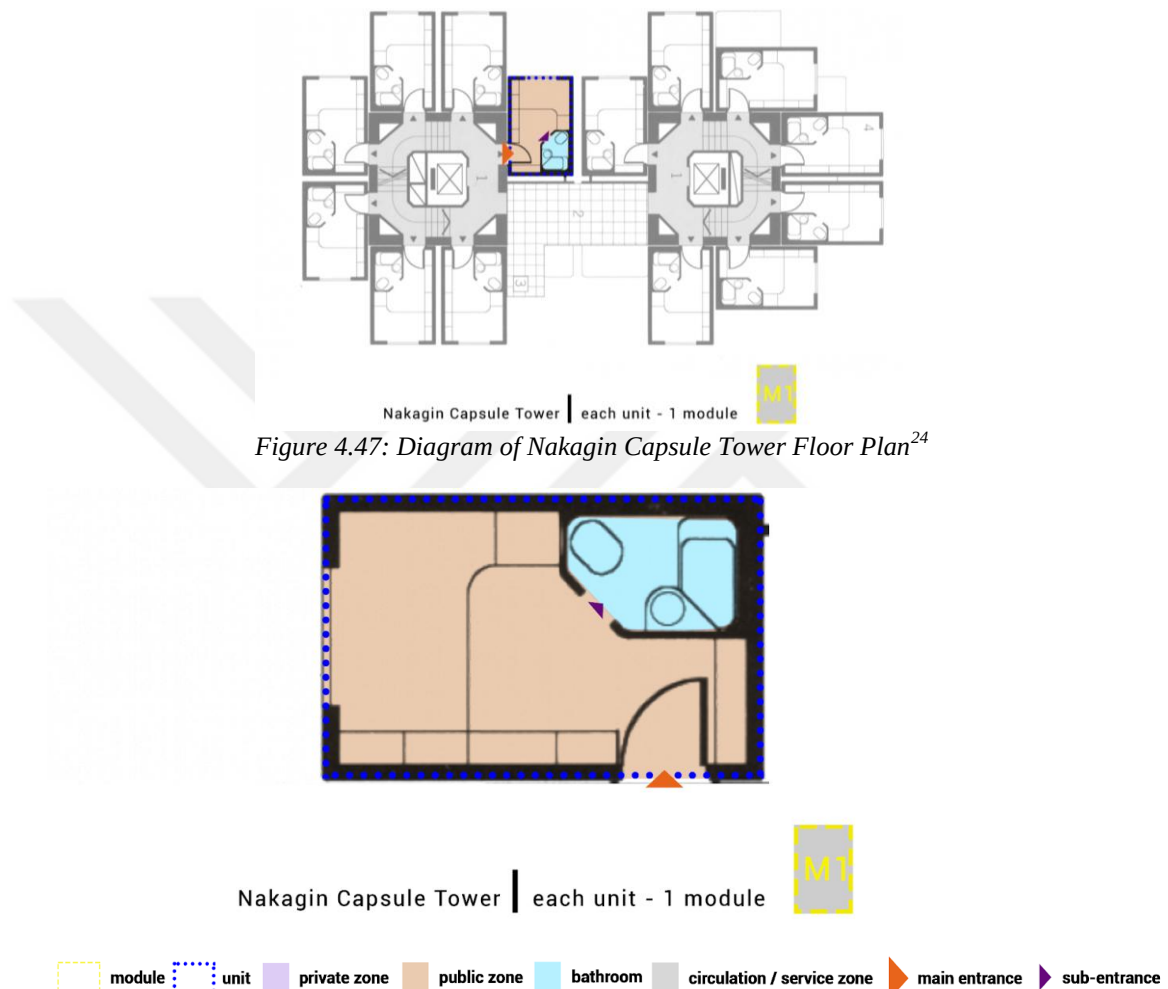


Figure 4.48: Diagram of a Unit Plan, Nakagin Capsule Tower²⁵

4.21. Ogura Asahi Kindergarten (OA Kindergarten)

Ogura Asahi is another modular project (Freda, 2018) that is separated from other cases by its function. It is comprised of shipping containers that are structurally reinforced against earthquakes (Stevens, 2016). By reusing shipping containers,

²⁴ Diagram was generated by me. Floor plan was taken from <https://plans.arch.ethz.ch/archives/project/nagakin-capsule-tower>

²⁵ Diagram was generated by me. Image of unit plan was taken from floor plan above.

Hibinosekki + Youji No Shira architects - designers of the project- want to give a message to students and families about environmental sustainability (Freda, 2018). Therefore the metal appearance of the container was preserved on the exterior facade (Weller, 2016) while wooden panels were used to cover interiors and provide a warmer school environment (Freda, 2018).



Figure 4.49: Photo of OA Kindergarten (DiStasio, 2016)

Ogura Asahi Kindergarten is a nursery complex for children. For this research, one of the project's buildings that is built by using modular containers is examined. As can be seen in Figure 4.30, the building has two stories and each level consists of 7 modules. Modules are identical in terms of size except for three of them on the ground floor.

When the plans are analyzed based on module-unit relation; it is achieved that;

- On the ground floor, three main spaces are obtained by using 7 modules, and each of them might be evaluated as individual units because of having separated areas and entrances. Two of them are defined as public zones because of having both visual and physical access from the outside. The main entrance, represented with an orange arrow, is placed on the right side, where the first public zone is positioned, taking users inside from the outside of the site. This area uses the M7 and a part of the M6. The rest of the M6 with M3, M4, and M5 are assigned for the second public zone that is split off from the

first one with a wall. This area has no direct access to the first public zone and bathrooms that are constructed by using M1 and M2.

- On the first floor, there are two sub-spaces that can be defined as circulation and services areas and three main zones. Compared to the ground level, these main zones are defined as private areas because of being enclosed spaces and having no direct access for users it is needed to pass through a circulation zone except for the second private zone (#PRIVATE2). Since, there is a single path that is passed through the “#PRIVATE2”, to reach the first private area (#PRIVATE1). This transition leads to the questioning of the privacy of the #PRIVATE2 even though it is a closed area.

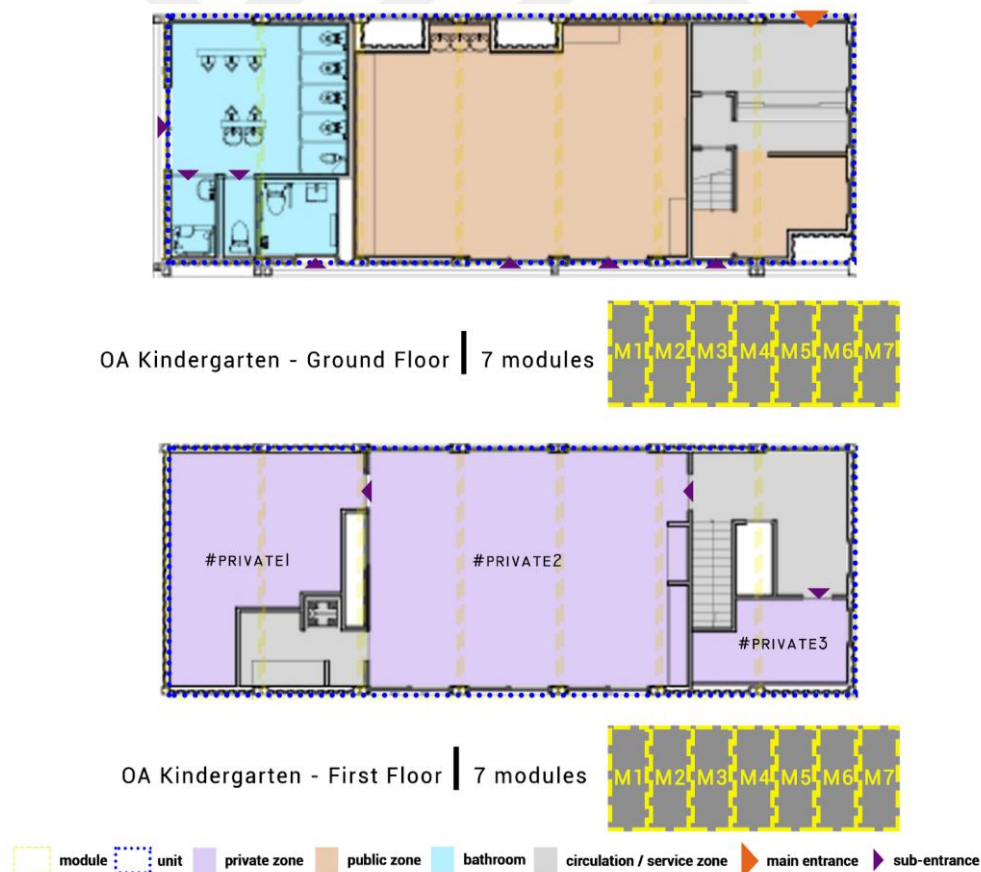


Figure 4.50: Diagram OA Kindergarten Floor Plans²⁶

²⁶ Diagram was generated by me. Floor plans were taken from <https://www.designboom.com/architecture/hibinosekkei-youji-no-shiro-oa-kindergarten-shipping-containers-saitama-japan-06-20-2016/>

4.22. Habitat 67

Habitat 67 is one of the first examples of modular architecture. It was built in 1967, in Montreal as a solution to the increasing population and limited housing problem (Keçeci, 2020). Moshe Safdie, the architect of the building, aimed to show the possibility of designing larger spaces for city-center, not only suburbans (Keçeci, 2020). When the project construction was completed, in 1967, it had 158 apartments comprised of 354 identical modules (Merin, 2013). But for today's version, there are 146 apartments because of combining some smaller units to convert them into larger ones (Merin, 2013; Keçeci, 2020). Totally, there are 15 different unit types that were obtained by the combination of multiple modules. The number of modules changed from 2 to 8 depending on the apartment type (Bayram, 2021).

All construction processes, even the prefabrication of concrete units were done on-site (Merin, 2013). The prefabricated concrete modules, structured by “reinforced steel cage”, were connected by steel cables (Merin, 2013).

Dynamic arrangement of both modules and units, instead of putting one on top of another separated Habitat 67 from other modular projects (Merin, 2013). By applying rotations, pop-outs, and pop-ins on the design; roof gardens, better natural ventilation, and light were provided for each unit (Merin, 2013).

Habitat 67 is a residential project that is constructed by using multiple module types. The project provides public and private areas on both inside and outside of units (Morah, 2019). This feature is derived from the property of assigning separate module(s) for each unit. In the project, there is not any module that is shared by multiple units. Users can meet in common public areas on the outside of

accommodation units. Therefore, it is shown as a successful example of providing privacy in a populous project (Morah, 2019).



Figure 4.51: Habitat 67 (Merin, 2013)

For this research, Duplex Unit A, which consists of two modules, is examined. Each module is prefabricated separately to create the ground and first floor of the unit. As can be seen in the figure, the ground level has an open plan and is designed as a public zone except for the bathroom. After reaching the upper level, the circulation zone welcomes the user to distribute the user to two separate private areas and a bathroom.



Figure 4.52: Plan Diagram of a Unit Type in Habitat 67²⁷

²⁷ Diagram was generated by me. Unit plan was taken from <https://www.archdaily.com/404803/ad-classics-habitat-67-moshe-safdie>

Compared to other examined cases in the research, “Habitat 67” shows the fabricability of the modules for the project that has multi-story units. Each module of the project was fabricated as the floor of a single unit.

4.23. Dorteavej Residence

Dorteavej Residence is a modular project designed with the scope of affordable social housing (Hernández, 2018). There are 66 accommodation units at the 5-storey Dorteavej building (Frearson, 2018). Although being an affordable housing project; 3,5 m height and floor area changing between 60 to 115 sqm were provided for units (Frearson, 2018). Additionally, on the south facade, modules are popping-in to have a dynamic facade and create balconies for the houses (Hernández, 2018).

There is not any information about the convenience of using a module to combine or connect another module for the post-construction process to vary unit types. However, the project provides the variety via different-sized units which were combined during the construction phase.



Figure 4.53: Photo of Dorteavej Residence (Frearson, 2018)

Dortheavej Residence is designed by using modular systems. Unlike other examples, the modules are not connected to each other. As can be observed on the elevation diagram of the project (Figure 4.54); they are placed with a module-sized space between them.

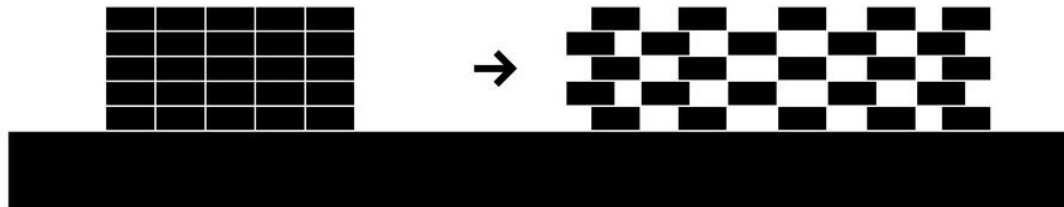


Figure 4.54: Elevation Diagram of Dortheavej Residence (Hernández, 2018)

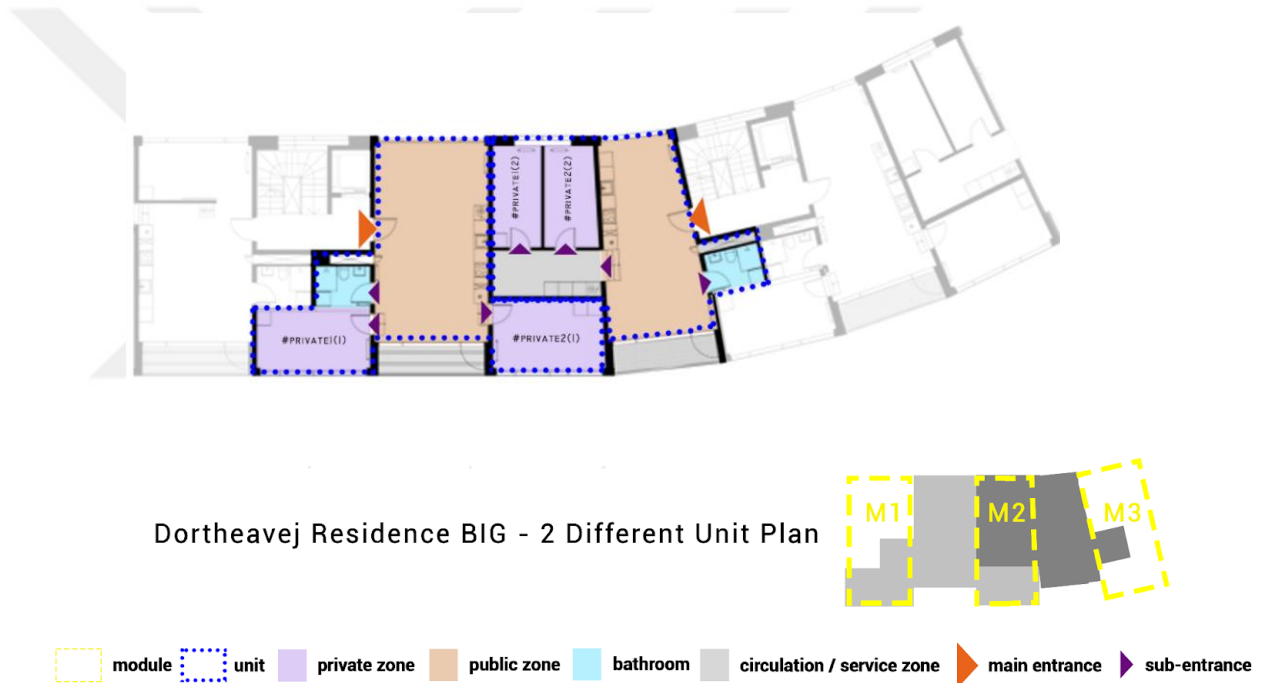


Figure 4.55: Diagram of Two Units in Dortheavej Residence

A module-free area uses the walls of the modules on its sides as walls, the ceiling of the one below it as a floor, and the floor of the one above it as a ceiling. To analyze the unit-module relation, a part of the second floor which is composed of two types of units is examined. As shown in Figure 4.55, each unit comprises a public zone, a bathroom, and two private areas. The main entrances of the units are placed in the public zone and the public zone of the units is located in module-free areas while private areas, bathrooms, and circulation elements are dwelling on the modules. To

exemplify, “Module 1” (M1) hosts the first private area (#PRIVATE1) and bathroom of the first unit but the second private area of the unit is placed on the M2 with private zones of the second unit (#PRIVATE1(2), #PRIVATE2(2)).

This project shows the possibility of building design and construction that is established by using half the number of modules instead of arranging them side by side. This feature might affect the time, amount of material, workforce, and budget that is required for the construction.

4.24. Modular Concrete Housing / Vale de Cambra (VDC)

VDC is a modular mixed-used project which was built in 2019 (SUMMARY, 2020). On the ground floor; prefabricated 2D precast concrete building components such as slab and structural wall are used to obtain an open area for assigning different functions variously (SUMMARY, 2020). In other words, the ground floor was designed as a reorganizable space depending on the user's wish (SUMMARY, 2020).

On the other hand, the first floor was planned as a group of modular accommodation units that were made from “GOMOS system” (Architectuul, n.d.). Each module that has a 45 sqm floor area, was craned on top of the mixed-use floor as a combination of four fully-finished submodules (Stinson, 2020; BUILDING PICTURES, 2019). To lower environmental effects and construction time, precast concrete elements were utilized for both structure, insulation, and cladding (Architectuul, n.d.).

This project differs from the other cases with modules' appearance because the inclined roof forms of modules made VDC visually unique by obstructing new floor and module additions on top of existing units. Similarly, the module was not directly

attached to another module on the horizontal plane (Figure 4.57) because of the aim of separating the acoustic of each unit (Architectuul, n.d.).

Vale de Cambra is a small-scale project that comprises 6 identical units. Each unit is designed as a separate concrete module. On the examined unit plan, it is seen that there are a bathroom and public area in the open-plan unit. By using a separation wall, it is aimed to obtain a sub-space for different functions but because of not having fully-closed spaces that area is defined as the public space. On the plan, it is directly entered into the public zone without passing through a circulation zone. Therefore, it is needed to use the same space for all functions except for the bathroom. This feature breaks the privacy of the interior.



Figure 4.56: Vale de Cambra (Architectuul, n.d.)

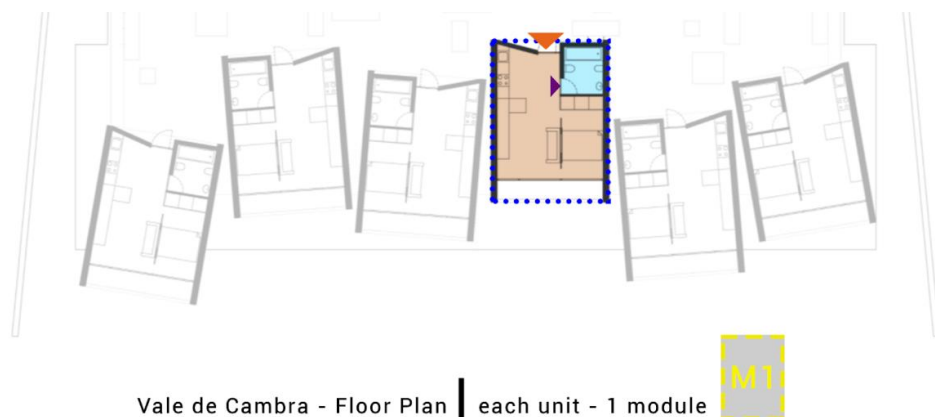
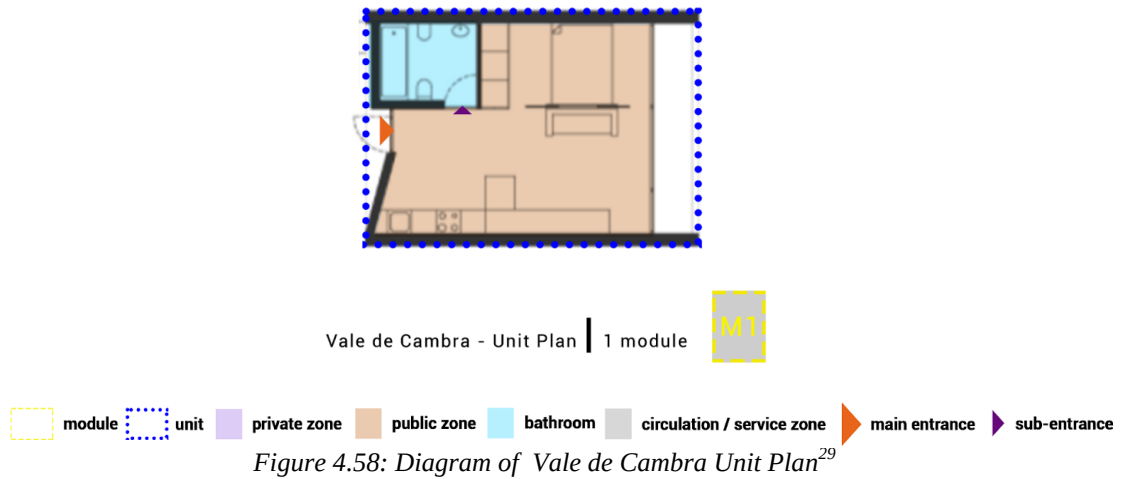


Figure 4.57: Diagram of Vale de Cambra Floor Plan²⁸

²⁸ Diagram was generated by me. Floor plan was taken from <https://summary.pt/works/valedecambra/>.



4.25. Keetwonen Student Housing

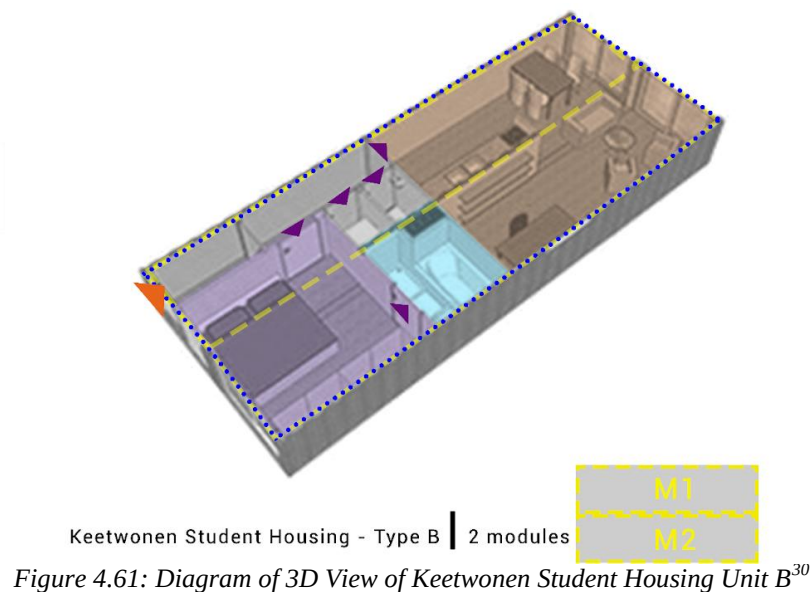
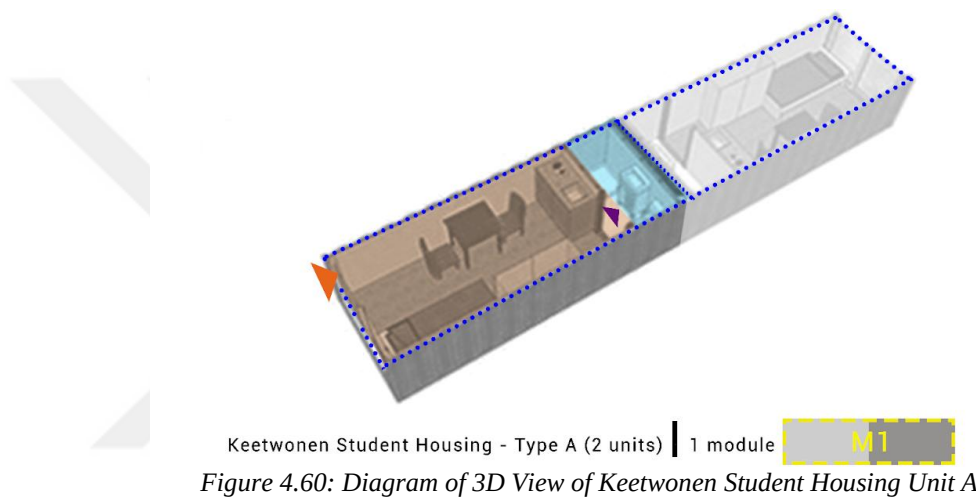
Keetwonen was declared as “the world’s first and largest container student campus” (Tempo Housing, n.d). The project emerged from the need for student accommodations in Amsterdam (Tempo Housing, n.d). Totally, 1034 container modules were assigned for both public and private functions of the student complex (Tempo Housing, n.d). For the production of containers; reused materials were used and all modules were fabricated at a factory in China (Alemdağ&Aydın, 2015). Both on-site and off-site construction processes were completed in 2006 (Tempo Housing, n.d).



Figure 4.59: Keetwonen Student Housing Unit (Tempo Housing, n.d.)

²⁹ Unit plan was taken from floor plan image.

Keetwonen is a student housing project that is used for a short-term period compared to permanent housing. For the research, two different unit types of the project (Type A, Type B) are analyzed. Half of a single module is utilized for student unit, Type A, while the director unit, Type B, comprises two modules. The territories of the units affect the space variations. To illustrate, Type B has a private zone, a bathroom, and a public zone that has entrances on the circulation part. However, Type A consists of a public zone and a bathroom by sharing a module with a neighboring unit.



 module
 unit
 private zone
 public zone
 bathroom
 circulation / service zone
 ▶ main entrance
 ▶ sub-entrance

³⁰ Diagrams of the project were generated by me. 3D views of the project were taken from <https://www.lowtechmagazine.com/2006/06/lego-for-big-bo.html>.

When the plans are analyzed based on module-unit relation; it is achieved that;

- Modules are planned and divided into spaces based on unit type. Accordingly, the areas created are differentiated and functions such as private zones; service, and circulation areas are provided for the user.
- When the relation between unit type and duration of use is considered, it is understood that the unit of director and student rooms differ in terms of the number of modules and the variety of spaces. Because of being used in the longer term, the director's unit has a larger floor area and private areas.

As a summary, Chapter 4 focuses on the analysis of case studies. Firstly, selected projects are introduced based on the literature; and secondly, the spatial analysis of plans are conducted to investigate the effect of modular building systems on spatial variety and design. Finally, results of the literature review and the plan analyses are tabularized (Table 4.1, Table 4.2, Table 4.3) to be able to access the specific information about the each project easily for the following chapters.

project name	function	numbers of unit types	analysed unit types	module number of each analysed unit	no-private zone	1-private zone	multiple private zones	entrance by passing circulation zone	direct entrance to the public zone
Post-earthquake Container Cities	emergency accommodation	3	U1 / U2 / U3	1 / 1 / 1	-	U1 / U2	U3	U3	U1 / U2
The Museum Hotel Antakya	hotel	2	standard	1	standard	larger	-	-	+
Little Hero	residential	1		1	-	+	-	+	-
Holon Apartment	residential	3	U1 / U2 / U3	2 / 0,5*2 / 0,5*2	-	-	+	-	+
Ten Degrees Tower	residential	12	a2 / a4 / a8 / b2	2 / 2 / 2 / 3	-	a2 / a4 / a8	b2	a2 / a8 / b2	a4
Apex House	dorm	17	Studio Type 11	1	+	-	-	-	+
Raines Court	residential	3	U1 / U2 / U3	2 / 2 / 3	-	U1	U2 / U3	+	-
Murray Grove	residential	1		2	-	-	+	-	+
Carmel Place/ My MicroNY	residential	7	A / C / D / G	1	+	-	-	A / G	C / D
Union Flats	residential	4	Chilpod Studio / Corner / Flex 1 BR / Flex Studio	1 / 2 / 2 / 1	Flex Studio	Chilpod Studio / Flex 1 BR	Corner	Chilpod Studio / Corner	Flex 1 BR / Flex Studio
David H. Koch Child Care Center	childcare	2 (as floors)	ground floor/ first floor	11 / 10	-	-	+	ground floor	
The Stack	residential	5	U1 / U2 / U3 / U4 / U5	shared modules	U5	U4	U1 / U2 / U3	U4 / U5	U1 / U2 / U3
Habitat 67	residential	multiple	Unit A	2	-	-	+	-	+
Nakagin Capsule Tower	residential	1		1	+	-	-	-	+
Ogura Asahi Kindergarten	childcare	2 (as floors)	ground floor/ first floor	7 / 7	ground floor	-	first floor	ground floor	-
Dortheavej Residence by BIG	residential	multiple	U1 / U2	shared modules	-	-	+	-	U1 / U2
Vale de Cambra	residential	1		1	+	-	-	-	+
Keetwonen Student Housing	dormitory	multiple	Type A / Type B	1 / 2	Type A	Type B	-	Type B	Type A

Table 4.2: Unit Variation Chart

	Unit Type	number of private zone(s)					public zone		circulation/ service zone		main entrance opens to		number of the modules utilized for each unit				
		0	1	2	3	3+	yes	no	yes	no	public zone	circulation zone	<1	1	2	3	*
Post-disaster Housings	1																
	2																
	3																
The Museum Hotel Antakya Standard	1																
Little Hero	1																
Holon Apartment	1																
	2																
	3																
Ten Degrees-Croydon Tower	a2																
	a4																
	a8																
	b2																
Apex House	1																
Raines Court	1																
	2																
	3																
Murray Grove	1																
Carmel Place	1																
	3																
	4																
	7																
Union Flats	C.S.																
	C																
	F																
	F.S.																
David H. Koch Childcare Center	1																
The Stack	1																
	2																
	3																
	4																
	5																
Habitat 67	1																
Nakagin Capsule Tower	1																
Ogura Asahi Kindergarten	1																
Dortheavej	1																
	2																
Vale de Cambra	1																
Keetwonen Student Housing	A																
	B																

*: exceptional cases

Table 4.3: Spatial Analysis Chart

CHAPTER 5

RESULTS & DISCUSSION

In the previous chapter, selected case studies are reviewed and analyzed to be able to interpret the effect of modular systems on the variety of spaces generated. Modular projects are observed to differ based on building functions, number of stories, and properties of modules that are adopted for their construction. Building functions of selected cases are diversified as 19 accommodation units that are divided into three as 15 residential, 3 container cities, and 1 homeless shelter project, in addition to 2 dormitories, 2 kindergartens, 1 hospital, and 1 hotel. It is observed that there is a variety in function distribution although the group is dominated by the residential projects which are occupied permanently by the users. Similar to the occupancy of residential case studies, hotel projects, kindergartens, and dormitories are permanent projects although the user of each function changes frequently. In other words; although users occupy dormitory projects for a certain period of time, they are reserved for other coming students. However, emergency buildings are demolished or updated after the necessity has been dispersed. These results reveal that modular systems are also utilized for permanent functions, considering the lifetime and changing potential needs. On the other hand; temporary building functions which

constitute 20% of the selected case studies, also have a substantial share. The presence of the pandemic hospital, post-earthquake containers, and homeless shelter project shows that the modular systems which were firstly utilized in response to emergency situations are still used for the same purpose today. On the other hand, there are other cases that show that the usage of modular systems can be adapted for functions that are not the result of emergency architecture. In addition, when the pandemic hospital, container city and homeless shelter projects- -which are products of emergency architecture- are compared; it is observed that their story numbers are similar and vary between 1 and 3. It is thought that the duration of usage and the requirement of being completed in a short time are the reasons for this situation, because the story numbers of the dormitory and housing case studies, which are permanent functions, change from one-story building up to 60-story high-rise.

Within the selected 25 cases, there are 21 projects which are mostly mentioned in the literature and also 4 other modular projects which are located in Turkey and included into the focused group to compare the place of modular systems in Turkey and other countries. Besides the 4 case studies in Turkey, it is observed that 5 of the selected cases are located in the United Kingdom, 6 of them are in the United States of America, 2 of them in Australia, 2 of them in China, 2 of them in Japan; and the rest of them are constructed in 4 different countries which are Canada, Denmark, Portugal, and Holland (Table 4.1). In addition, construction durations change from 28 hours 45 minutes to 2,5 years. While the project that was completed in the fastest time was built in 2021 (Holon Building), the building that took the longest time to complete happened in 1967 (Habitat 67). Habitat 67 is the oldest one among the selected cases, while the Holon Building, constructed in 2021, is one of the newest; it

is observed that the construction periods of modular buildings have decreased over time.

In the second stage, within the 20 cases utilized, 4 of the selected projects are generated by repeating the same unit while 14 of the selected cases consist of multiple unit types whose number changes from 2 to 17. There are two more case studies examined which are the educational facilities as a kindergarten and a child care center. Because of employing modules to design a building that is occupied by the same user group, each preschool project is analyzed by counting the building itself as a unit (Table 4.2). 4 case studies, which employ single unit types, are diversified as Little Hero, Murray Grove, Nakagin Capsule Tower, and Vale de Cambra residential projects. On the other hand, 14 cases that are designed by combining multiple unit types, are listed as post-earthquake container cities, The Museum Hotel Antakya, Holon Apartments, Ten Degrees Tower, Apex House, Raines Court, Carmel Place, Union Flats, The Stack, Habitat 67, Dortheavej Residence, Keetwonen Student Housing. In this classification; Van, Elazığ, and İzmir Container Cities are accepted as one post-earthquake housing project, and the unit types for three of them are analyzed as one since each container city adopts the same type of modular arrangement and plan. Totally, 39 unit types which vary as 3 post-disaster accommodation units, 1 hotel room, 2 education facilities, 3 dormitory rooms, and 30 housing units are investigated.

After the data and spatial analysis are conducted in Chapter 4, the following results are achieved:

- 1. Numbers of the occupied modules change from unit to unit.**

A single module is utilized to generate 16 of the 39 unit types. 6 of the single module-based units are short-term accommodation facilities (varied as post-disaster containers, dormitory units, and hotel rooms) while the rest of them belong to housing examples (Figure 5.1). 14 of the 39 analyzed units consist of a single module and the borders of the units are identical with the relative modules. Exceptionally, despite being constituted of a single module, 2 units do not have identical borders with the employed module; they use the utilized modules partially (Figure 5.3).

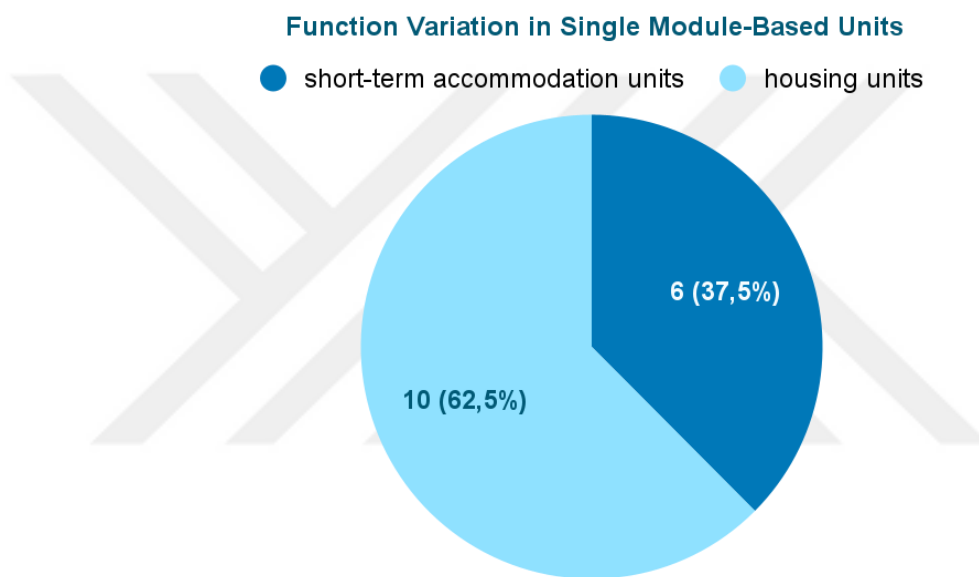


Figure 5.1: Function Variation in Single Module-Based Units

On the other hand, 23 of the 39 analyzed units are composed of multiple modules (Figure 5.2). 20 of them are example for housing units while one of them is a dormitory room as a short-term accommodation unit and 2 of them are education facilities. Educational buildings differ from other projects in terms of the number of spaces and the distribution of private and public zones due to their functions. For example, multiple modules are commissioned to create one of the private areas while a single module is utilized by a housing unit that comprises a private room, a public zone, and a bathroom.

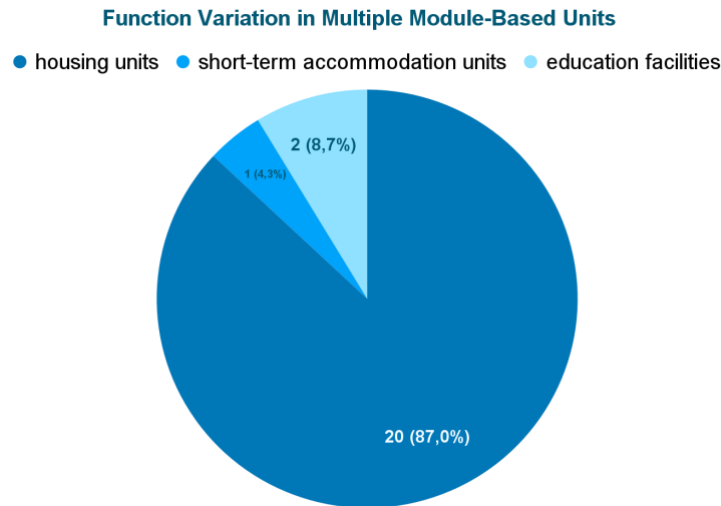


Figure 5.2: Function Variation in Multiple Module-Based Units

12 of the multiple module based units use all floor areas provided by the modules and unit borders are defined by the combination of utilized modules. However, 11 of them occupy modules partially and create disorganized plans as in the case of Dorteavej Residence (Figure 5.3).

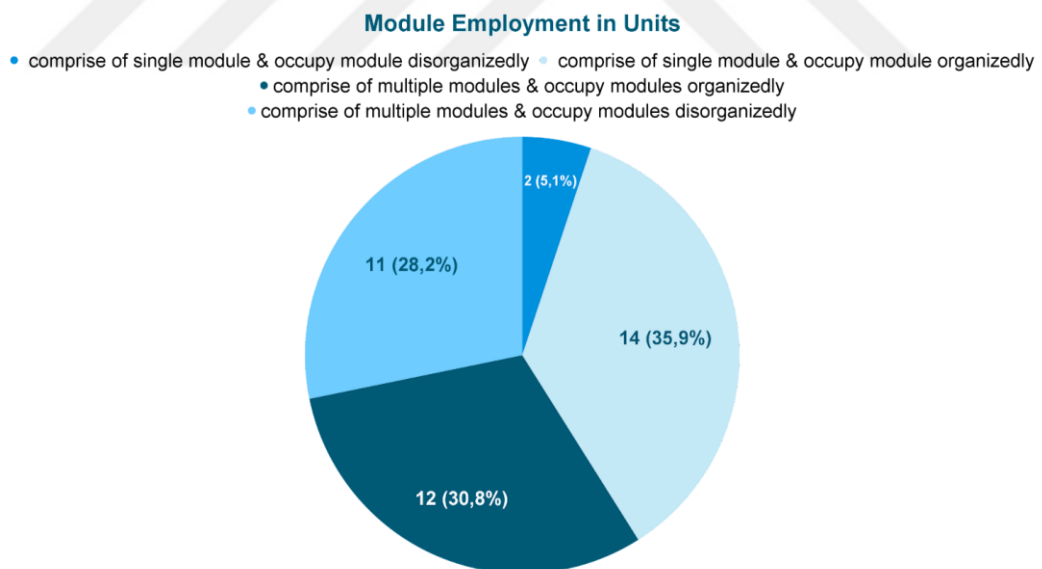


Figure 5.3: Module Employment in Units

The amount of utilized modules in design affects the layout of the units because larger floor areas provide different unit forms that can be achieved by increasing the number of modules. Briefly, multiple modules provide a potential for creating additional areas in the plan. Not only numbers of the utilized modules but also

module occupation strategies' of the units have a role on the layout design. Particularly, the units that are made up of more than one module might occupy modules in different ways. While this situation is seen in some examples as sharing a module by two distinct units (Figure 5.4), in some projects it has emerged by using the same module for both the unit and the main circulation volume of the building (Figure 5.5). In accordance with this observation, it can be mentioned that the occupation system of the modules affects the variety in projects which are built by utilizing modular systems. Instead of prefabricating a module to be used by only one unit, the possibility of having spatial variety in the units are enhanced by providing an option for a module to be shared with another part of the building.

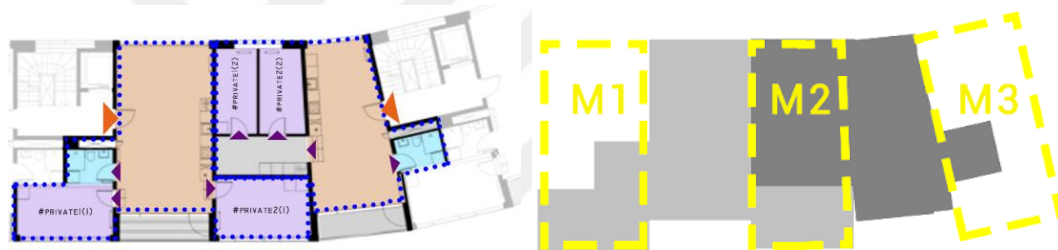


Figure 5.4: Occupation of M2 by two units (Dortheavej Residence)

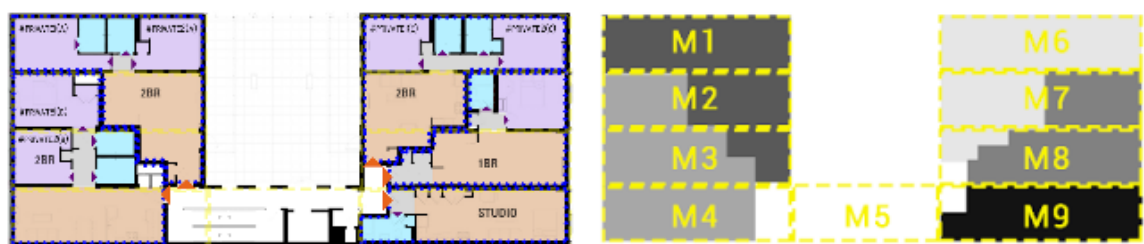


Figure 5.5: Collectivization of M9 by circulation core and unit (The Stack)

2. There are different space combinations in terms of possessing public-private spaces, circulation zones and bathrooms. Combinations vary based on different criterias such as function of the unit, number of the utilized modules etc.

It is achieved that all units have a public zone except one, that is the third unit of post-earthquake housing. However, private zones are distributed distinctly to all unit types. 11 (28,2%) of the modular-based unit types have no private areas; 10 (25,6%) of them have 1, 14 (35,9%) of them have 2, 3 (7,7%) of them have 3, and 1 of them has more than 3 private zones on their layouts. (Figure 5.6)

Program of the units in terms of space combinations changes depending on purpose and module number of units. Within the 39 selected cases, it is observed that there is a program difference between single module-based and multiple module-based units. Each group diversifies in itself, too.

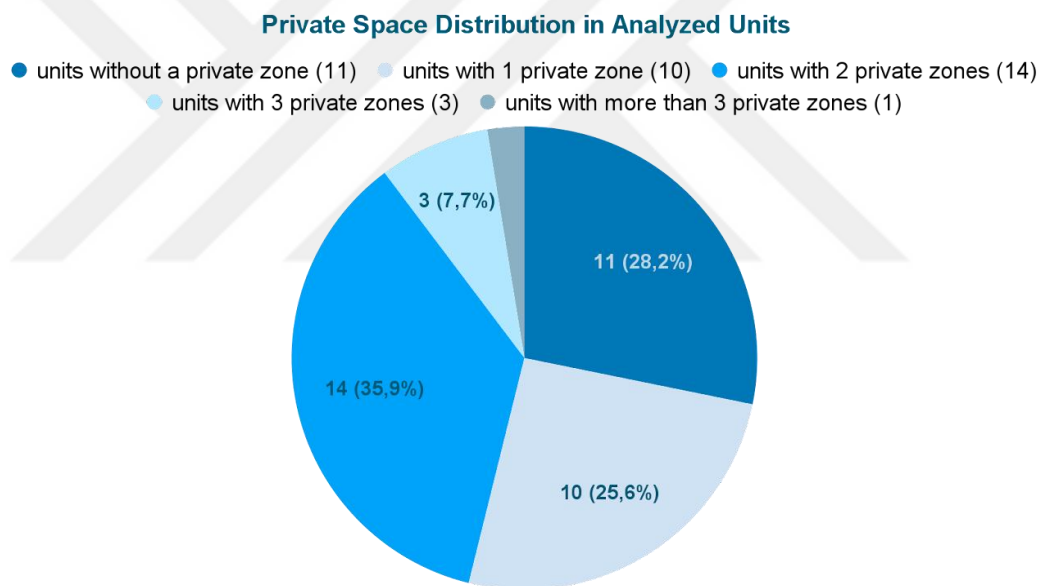


Figure 5.6: Private Space Distribution in Analyzed Units

Space combinations for single-module based units, are listed as (Figure 5.7):

- 2 of 16 are 1 private zone + 1 public zone + 1 bathroom
- 7 of 16 are 1 public zone + 1 bathroom
- 5 of 16 are 1 public zone + 1 bathroom + circulation zone
- 1 of 16 is 1 private zone + 1 public zone + 1 bathroom + circulation zone
- 1 of 16 is 2 private zones + 1 bathroom + circulation/service zone

Space Combinations in the Design of Single Module-Based Units

- 1 private zone + 1 public zone + 1 bathroom
- 1 public zone + 1 bathroom + circulation/service zone
- 1 private zone + 1 public zone + 1 bathroom + circulation/service zone

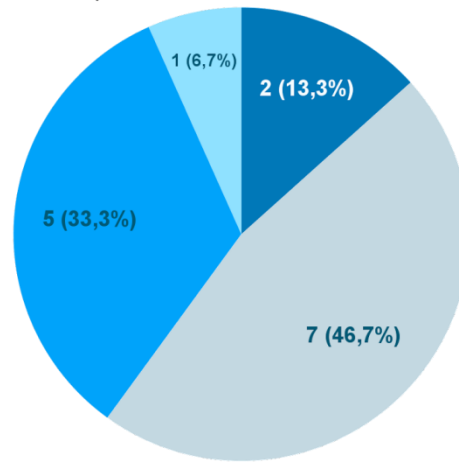


Figure 5.7: Space Combinations in the Design of Single Module-Based Units

Space combinations adopted in the second group, which consist of multiple module based units (Since two educational facilities are analysed as a building through their floor plans, David H. Koch Childcare Center and Ogura Asahi Kindergarten are not included this classification.), are listed as (Figure 5.8):

- 2 of 21 are 3 private zone + 1 public zone + 2 bathroom + circulation zone
- 4 of 21 are 1 private zone + 1 public zone + 1 bathroom + circulation zone
- 7 of 21 are 2 private zone + 1 public zone + 1 bathroom + circulation zone
- 6 of 21 are 2 private zone + 1 public zone + 2 bathroom + circulation zone
- 2 of 21 are 1 private zone + 1 public zone + 1 bathroom

Additionally, circulation and/ or service area utilization changes depending on the different unit types. The areas other than the bathroom, private, and public zones are named as circulation and/or service areas as they create additional spaces and/or provide access to the unit itself or the rooms in it. As a result of the examinations made by adhering to this perspective, it is observed that 30.8% of the analyzed units (12 out of 39) do not have spaces used for this function. On the other hand, 69.2% of these units (27 out of 39) employ these spaces at different points and purposes which

vary as service areas to create additional places for storage or installation, inner circulation elements as corridors, and circulation zone at the main entrance to block direct access to the main part of the unit. In the analyzed unit type;

- Murray Grove Housing is an example for having an additional area for the service zone.
- Also, there is an additional space at the entrance part to provide an anteroom in the plan of 5 units.
- There are 9 units that have additional space as corridors to circulate users between rooms.
- There are 12 units that utilize these areas for both anteroom and inner circulation.

It is observed that all unit types have bathrooms and public zones except the third unit of post-earthquake containers. However, in some units, the public spaces are used for multi-purposes because of being the only main space of the unit. On the other hand, as the area grows in the multiple module based units, the number of the owned main spaces increase and their usage purposes decrease.

Space Combinations in the Design of Multiple Module-Based Units

- 3 private zones + 1 public zone + 2 bathrooms + circulation/service zone
- 2 private zone + 1 public zone + 1 bathroom + circulation/service zone
- 1 private zone + 1 public zone + 1 bathroom
- 1 private zone + 1 public zone + 1 bathroom + circulation/service zone
- 2 private zone + 1 public zone + 2 bathroom + circulation/service zone

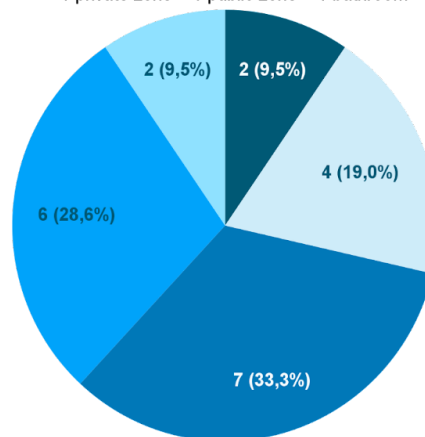


Figure 5.8: Space Combinations in the Design of Multiple Module-Based Units

3. Placement of the main entrance plays a role on the privacy level of the unit.

Employment of circulation and/or service areas is another critical specialty in modular-based units. Since, the number of the provided spaces is increased by adopting these areas; it affects spatial diversity in a positive way, too. The units that have circulation and/or service areas, constitute a majority (66.7%) in the analyzed case studies (Table 5.1). However, these zones are placed at different points with different functions in the unit plan. While only one unit is adopting this kind of space as a service area for storage or installations, the rest of them use these areas as anteroom or corridors for circulation in the unit.

circulation/ service zone		main entrance opens to	
yes	no	public zone	circulation zone
26/39 (66.7%)	13/39 (33.3%)	22/39 (56.4%)	17/39 (43.6%)

Table 5.1: Possession of Circulation/Service Zone&Position of Main Entrance

Working on the data by utilizing the information from the spatial analysis, provides evidence about the relationship between the main entrance and the area where it opens to. The main entrances of the 23 of the plans open to a public zone. They are diversified among themselves as 14 multiple module-based and 9 single module-based. However, a circulation zone is employed for 16 of them by placing partition walls and/or arranging place of other spaces in the plan to create a transition zone between the entrance and the public zone. Therefore direct access to a public area is blocked. The amount of module(s) does not have a big role in this group; they are divided as 9 multiple module-based units and 7 single module-based units (Figure 5.9).

Having both physical and visual direct access to the public zone decreases the privacy level of the unit. When the user opens the door, the visitor can see the interior of the unit directly if the main entrance is placed in the public zone. However, if there is an additional wall or arrangement on the main entrance, they create a secondary zone to protect the privacy of the unit and block direct access.

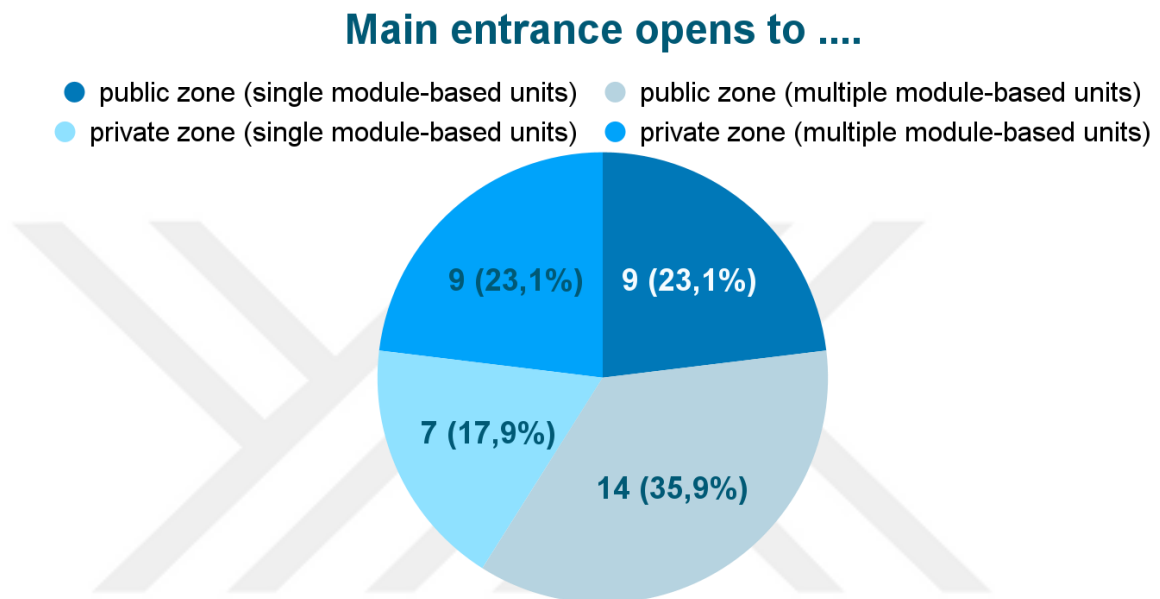


Figure 5.9: The Places Main Entrances Open

4. Function distribution is concentrated on the accommodation units.

Although modular systems can be utilized to construct buildings in several functions; it is seen that most of the case studies in the selected group are housing and short-term accommodation projects. There are also two kindergarten projects as education facilities. Although it shows that modular systems can be preferred for functions different from housing, the examples of these functions are quite low in number. When the selected modular buildings are analyzed, it is not only the scale of the project that changes according to the function but, the number of utilized modules, the sizes and numbers of the different spaces in a unit also change.

5. Varied module shapes and numbers are adopted to design selected units.

Another output of the analysis is related to the shape and number of the modules. In the creation of modular buildings, the modules that have different forms can be adopted. As it can be seen on the diagrams and statistics above, for the selected cases, rectangular modules are employed for 28 of the 39 unit types while 11 of them consist of irregular polygonal-shaped modules. Although rectangular shaped modules dominate the group, polygonal modules have 28.2%. It is observed that the uniformity formed by rectangular modules could be broken with different forms. Since, adoption of varied shapes for the units creates additional areas or divided zones; it might increase the potential of layout. However, the shape of the module does not have a big role in the design of units. The design and program of the unit are in large part influenced by the number of modules.

Module numbers that are employed to generate units affect the space variation and combination in the design. In the analysis, they are grouped as single module-based and multiple module-based units. The first group, single-module based units, is dominated by mainly two different combinations which are 1 public zone + 1 bathroom (43.8% of 16 cases) and 1 public zone + 1 bathroom + circulation/service zone (31,3% of 16 cases). There is just a circulation/service area distinction between the two unit programs. The second group, multiple module based units, is also dominated by two varied collaborations that are 2 private zones + 1 public zone + 1 bathroom + circulation/service zone (33,3% of 23 cases) and 2 private zones + 1 public zone + 2 bathroom + circulation/service zone (28,6% of 23 cases). Only, the number of bathrooms in the units makes the difference between these two combinations. It is clearly observed that single module-based units mostly have a public zone and a bathroom as the major areas in the design and thus, the majority of these units do not supply a private zone for the user. In addition, multiple module-

based units are predominantly generated by the 2 private zones and a public area with 1 or 2 bathrooms and circulation areas. However, different combinations could be provided depending on the number of modules and size of the units.

Basically, the vast majority was not provided by the one type of spatial collaboration. The sum of multiple types of spatial collaborations constitutes the vast majority of space combinations in both single and multiple module-based units. This situation shows that modular systems can be preferred for different spatial design alternatives, they do not allow only one type of building program.

Modular systems which are planned in detail, have helped to get maximum efficiency from a limited space. For instance, the fact that an apartment and a hotel room have distinct plan types explains this situation because they have different usage periods and they need different areas. In addition, since different sized areas are needed in kindergarten projects, which differentiate from other examples with their functions, utilized modules are planned dissimilarly. The existence of these examples has revealed that modular systems can also be used for functions that require large-scale interior spaces. On the other hand, the use of modules in different numbers and styles -in terms of occupation- can create additional spaces and offer the user the advantage of spatial variety. Thus, the user can obtain areas with different privacy rates that can be used for different purposes. In particular, the possibility of adding circulation areas such as corridors increases the spatial diversity of these projects. Considering the adaptability of the modular systems for various functions and ability of occupying modules in different ways, modular systems have been found useful to be utilized for building construction.

To conclude, selected modular case studies are briefly introduced and analyzed diagrammatically through the layout plans in Chapter 4. It is observed that modular systems are utilized for different functions however, accommodation projects constitute the majority of analyzed cases. Additionally, the amount and shape of occupied modules changes in different unit types. Associatively, they affect the space combination of units in terms of having public-private spaces, circulation zones, and bathrooms. Therefore, they present varied layout designs by being combined diversely. It is seen that, in these space collaborations, the placement of circulation areas has a role in unit privacy.

CHAPTER 6

CONCLUSION

Modular systems are defined as prefabricated elements that are mainly utilized to construct a building that has many advantages and disadvantages. In literature, modular systems are divided into three categories based on the physical properties of modules. Two-dimensional panels, structural framings and three-dimensional volumetric units represent these three categories. In this thesis, three-dimensional modular-based construction methods are varied according to material selection during the off-site production phase and construction technique to link modules on-site. Steel, timber, and precast concrete are the main materials to prefabricate modular volumes. The decision of which material to choose for modular building systems also affects the type of construction method. Based on material selection, building height, and scale of the project; the construction method is chosen from stacking method, core-based method or infilled frame systems.

The concept of modularity, from an architectural manner, is utilized to explain the case of using repetitive elements or volumes in construction. Although they have been utilized to respond to emergency needs, these systems have developed over decades, and today modular systems have found a prominent place in modern

architecture. Therefore, it has turned into an option for construction of different functions in various locations. On the other hand, modular systems are still mostly utilized for emergency projects in some countries such as Turkey. In this context, the problem is structured on the use of modular systems preferably for the emergency cases for some countries, although they have potential for more permanent cases. In accordance with the research problem, this thesis aims to investigate the effects of modular systems on spatial design and diversity through the layout analysis of selected case studies. For the analysis of plan layouts of case studies, two staged methodology is adopted. In the first stage case studies are analyzed based on basic characteristics and utilized modular system's properties; and collected information is tabulated. In the second stage, selected case studies that are built by adopting 3D volumetric modules are investigated by focusing on the plan layouts. For this investigation, unit or building plans are diagrammatized by coding each space according to its spatial properties. The spaces on each plan are coded as the bathroom, public, private, and circulation and/or service zones based on their functions.

In this context; 25 case studies are selected and each of them is investigated in the first stage. Plans of the selected 3 case studies are not accessible and 2 of them comprise 2D modular panels. Therefore, these 5 case studies are excluded for the second stage of the analysis which focuses on spatial properties. The rest 20 modular projects are analysed through multiple or single unit types. Totally, 39 unit types are investigated.

In accordance with the spatial analysis of the selected modular case studies, it is observed that; there is a relationship between the amount of utilized modules and the layout of the unit. Excluding the few exceptions, there is a direct proportion between

the number of spaces in the unit layout and number of the modules assigned to generate the unit. The typologies that utilize a single module, consists of public space and a bathroom mostly while other typologies that are formed by multiple modules provide more spaces compared to the single module-based units. There are multiple variations of spatial combinations that are obtained by analyzing the unit typologies although there are combinations that have a majority.

Utilization of the modules is another critical specialty of the modular systems. This is derived from the sharing modules with another unit or common areas in the building and shows that instead of adopting only a rectangular-based plan; different forms, like L-shaped, can be achieved by this occupation and help the creation of a dynamic plan in terms of inner circulation. This inference is an answer to a possible prejudice that may arise against the fact that apartments designed with modular systems should adhere to the limits of the module. There are examples similar to the analyzed plans in projects constructed with traditional building construction methods. By occupying another module partially or completely, additional spaces can be integrated to the single-module based units; therefore, the project might have more potential in terms of spatial design and diversity by avoiding repetition of the same module.

In addition, diagrams indicate that modular building systems are not generated by only rectangular cells, polygonal modules are also utilized in the analyzed examples. However, only 11 of the 39 modular cases consist of modules in polygonal-based shapes. Rectangular module based case studies have the majority. Since they create extensions or additional spaces, the potential of the project in terms of obtaining distinctive unit forms increases. Taking polygonal shapes (trapezoid-like forms can be shown as an example) as a reference affects the design of the project. In particular, because modular systems are prefabricated systems; modules are

transported to the field from the factory as being ready for assembly. Therefore, they are products of a more controlled process. However, both production and on-site installation steps of the polygonal modules might require more precise workmanship compared to rectangular modules because of having multiple sides and corners.

Another implication is the employment of modular building systems for the construction of residential projects mostly. The investigation shows that modular systems are not only adopted by a single function; they can be utilized for various building functions. However, accommodation projects, such as hotel, dormitory, post-earthquake housing and residential projects, are differentiated from other case studies in terms of how much they are utilized by constituting a majority. Being composed of repetitive units which is one of the major differences between accommodation units and other functions is thought as one of the reasons for the employment of modular building systems for this kind of projects. In this sense, although functional diversity is achieved by residential, hospital, kindergarten, hotel, dormitory and post-emergency housing functions; the increase in density in accommodation cases has led to the questioning of availability of modular building systems in different functions. Comparison of the projects by adopting an analysis method through the layout of each design indicates that units are dominated by the public zones and each of them has one. However, additional areas which are named as private zones are added to plan via utilizing extra modules in the design phase to enlarge the footprint of the units based on the required spaces.

In addition, there are layout similarities between a post-emergency container (Figure 4.1) and one of the single module-based housing units (Figure 4.12) in terms of space flow and combination. Although the duration of occupations are dissociated; temporary accommodation units supply a private zone together with a public zone

and bathroom for the user and permanent housing unit comprises public zone and bathroom.

Based on these observations, it can be mentioned that modular systems have potential in terms of providing spatial diversity. However, for this heterogeneity, it can be required to expand the space by increasing the number of modules or occupying another module partially. Since extension of unit floor area and increase in the utilized module number create additional spaces which can be evaluated as a circulation/transition zone, secondary bathroom, private and/or public spaces. These areas help to provide different experiences for the users in the unit by creating varied unit forms and space combinations. Therefore, as a response to the first research question, selected case studies show the potential of modular systems in terms of spatial design and diversity in a positive way.

Besides the spatial analysis of case studies, this thesis also presents data on the functions of the modular cases versus their usage period. The findings make it possible to comment on the distribution of the temporary emergency and permanent non-urgent functions in modular case studies based on the second research question. When the selected cases are analysed, it is achieved that they have divergent occupancy durations based on the function and the construction reason. 25 selected modular case studies are varied as 4 temporary emergency projects (pandemic hospital and container cities) and 21 permanent non-urgent buildings (residential, dormitories, kindergartens and hotel) based on building functions. Considering that 3 of the emergency projects, which are post-earthquake container cities, are added to compare the use of modular systems in Turkey with the world, it can be said that almost all of the case studies obtained in the literature review are permanent non-urgent projects. Briefly, it is achieved that modular systems are mostly utilized for

the permanent non-urgent functions but it does not give information whether these systems are advantageous or not for these functions. The observations highlight the potential of modular building systems to be used for not only temporary emergency cases but also permanent non-urgent projects.

These observations also show that modular buildings are employed in different locations which is the problem tackled in the third research question. Although locations are listed as USA, UK, Turkey, Japan, Australia, China, Denmark, Holland, Canada and Portugal. However, certain types of functions are used more in specific locations. This is clearly seen in the examples of the USA, UK and Turkey. While the case studies in the USA and UK are dominated by the residential projects, Turkey mostly utilizes post-emergency accommodation projects. It shows that there is an abstention of utilization of modular systems for permanent non-urgent projects in Turkey because while other countries such as UK and USA, prefer this technique for non-urgent buildings.

Additionally; it is observed that case studies have different numbers of stories. As demonstrated in Table 4.1, the number of stories of the modular buildings varied between 1 and 60. According to the results of this research, 4 of the analyzed buildings have 15 or more floors, while the number of stories of the remaining projects is between 1 and 14. When the seismic characteristics of the locations of the projects are examined, it was observed that 11 cases out of 25 were built in high-risk regions which are Turkey, China, Union City and Los Angeles in USA, Japan, Portugal and Holland (Table 4.1). The story numbers of these projects vary between 1 and 4, with two exceptions. The two exceptions are 10- and 14-story buildings. The 14-story project was constructed by adopting the core-based method in 1972, in Tokyo, one of the riskiest areas. These features set the project apart from others with

its modular system preference, even though it was designed 50 years ago and on the seismic belt. Three of the four selected case studies in Turkey are also added to the group which is generated by the projects in high earthquake risk zones, as the post-earthquake containers for disaster victims. Therefore, the decision of designing low rise projects is regional because of the location. Despite this, the fact that there is no variation in the number of floors in regions with low earthquake risk has created new question marks about the structural capacities of modular systems. Since the selected case studies, that have varied floor numbers, are constructed in different countries and cities, there is not a direct relationship between employment of the modular building systems and site locations.

To conclude, modular systems have potential in terms of spatial design and variation. However, the number of the employed modules in the projects affects this potential. In particular, the existence of modules in different shapes supports the spatial diversity. While spatial additions or form-based differences increase the number of spaces in the units, they also separate the projects from each other in terms of design. In addition, the analyzed projects show that the modules do not have to belong to a single unit, but can be shared with a building or another unit. The assignment or collectivization of multiple modules positively affects possible spatial variations. Single module based units mostly comprised a bathroom and a public zone but the projects that utilize or share more than one module provide spatial diversity because they offer large floor areas. However, it is observed that partially open modules are assigned for this kind of unit type. Being comprised of partially open modules allows obtaining units in different shapes such as L-like shapes. Thus, spaces that can be shaped independently from the module boundary can be designed in the units. This is another criteria for increasing the potential of the modular project in terms of spatial

design. Similarly, adaptability of the polygonal shaped modules have a positive effect on the position of the modular systems in architecture.

When the projects are examined in terms of location and function -apart from the spatial analysis- the following results are observed: Firstly, the specific locations host specific functions. Therefore, there is not functional diversity in these locations. The selected case studies are divided into two as temporary emergency and permanent non-urgent projects in terms of duration of usage although the examples vary as hospital, dormitory, residential and post-emergency accommodation functions in general distribution. While modular modular systems are utilized for permanent residential projects in the USA and UK, they are preferred for temporary container cities. Despite the similarity between post-earthquake container units and single module based residential units in terms of spatial design and diversity, they are utilized for different purposes.

For the future studies; firstly, it can be investigated how the added partitions to get a room affect the duration of the prefabrication phase and can be compared with conventional methods. This study will help to analyse modular systems in terms of time efficiency.

Secondly; as it is observed through the case study analysis, there is no modern example of modular building that is constructed by adopting curvilinear or organic shaped modules. The lack of a project built from round-shaped modules causes to question this potential in organic form projects. This might be the main focus of following research.

Thirdly, it has been observed that there is no direct relationship between utilization of modular systems and location of existing modular case studies. Therefore, the

structural performances of modular systems on different seismic zones can be analyzed through the constructed projects. Besides high-risk zones, no examples of modular buildings could be found in locations with low seismic hazards. In future studies, this issue can be discussed as a separate subject. The structural suitability of modular systems in low, medium, and multi-story buildings in regions such as Nevşehir, Konya, and Karaman, which have low seismic hazards, can be questioned.

In conclusion, an analysis method has been developed to investigate the spatial diversity and design in buildings that are built by utilizing modular systems in this thesis. By using this method, selected case studies have been analyzed based on private-public areas, circulation areas, and bathrooms. As a result of this analysis, it has been observed that the design is affected by the form and number of the modules used by the units; and the number, type, and location of the spaces the units have. Thus, a new spatial analysis method, which is shown over modular systems, has been contributed to the literature.

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