Adaptable Prefabricated Interiors in Urban Dwellings

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Post-Professional Master of Architecture: Urban Design and Housing
McGill University, Peter Guo-hua Fu School of Architecture.
Supervisor: Professor Avi Friedman
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Abstract

Exacerbated by accelerating population growth, housing shortage has become one of the most pressing social-economic crises in the 21st Century, especially for those living in metropolitan areas. To resolve this dilemma, architects and designers should shift their focus beyond the provision of mass-produced housing that fulfill immediate needs. It's time that they take seriously the vital fact that living spaces are never static, and that people's housing needs are always influx subject to the influence of myriad and evolving social, demographic, and environmental factors. Housing designs need to adapt to their dwellers, not fix them in one pattern of life. Static housing designs cannot support a diverse population and their evolving needs. In a world marked by major population shifts, communal diversification, urbanization, and growing sustainability awareness, the demand for adaptable design will continue to expand, transforming a formerly niche approach into the solution to the housing needs of the world's urban population.

The goal of this research is to understand the concepts and applications of adaptable design in urban apartment buildings. It will also investigate how adaptable design can benefit from prefabricated manufacturing practices. Firstly, this research reviews the theoretical framework of both adaptable design and prefabrication in urban dwellings. This is followed by a thorough analysis of ten contemporary designs and projects, including their adaptable strategies and prefabrication methods. Lastly, a design proposal will present the design of three prefabricated interior elements that will transform a typical one-bedroom apartment into a flexible living space.

This research found that for the North American housing market, the optimal design should be a free-standing modular unit that incorporates new technology. Due to their flexibility and cost-

efficient features, assemble-to-stock and made-to-order are the two most prevailing prefabrication methods.

Résume

Exacerbée par l'accélération de la croissance démographique, la pénurie de logements est devenue l'une des crises socio-économiques les plus pressantes du XXIe siècle, en particulier pour les habitants des régions métropolitaines. Pour résoudre ce dilemme, les architectes et les concepteurs doivent détourner leurs attentions sur les choses plus importantes au lieu de la fourniture de logements fabriqués de série répondant aux besoins immédiats. Il est temps pour eux de tenir dûment compte d'un fait essential que les espaces de vie ne sont jamais statiques. Les besoins en logements des personnes sont affectés inéluctablement par une myriade de facteurs sociaux, démographiques et environnementaux. Les modèles de logements doivent s'adapter à leurs habitants au lieu de se limiter d'un mode de vie particulier. Les modèles de logements statiques ne peuvent pas satisfaire les besoins évolutifs d'une population diversifiée. Dans un monde marqué par d'importants mouvements de population, la diversification des communautés, l'urbanisation et une prise de conscience croissante de la durabilité, la demande de design adaptable ne cesse pas d'augmenter, qui transforme en une approche autrefois axée sur des niches en une solution aux besoins en logement de la population urbaine mondiale.

Le but de cette recherche est de comprendre les concepts et les applications du design adaptable dans les immeubles résidentiels urbains. Il étudiera également comment un design adaptable peut profiter des pratiques de fabrication préfabriquées. Premièrement, cette recherche passe en revue le cadre théorique du design adaptable et de la préfabrication de design intérieurs résidentiel en analysant dix designs et projets contemporains, y compris leurs stratégies adaptables et leurs méthodes de préfabrication. Secondement, une proposition de design présentera le design de trois

éléments intérieurs préfabriqués qui transformeront un appartement d’une chambre typique en une espace habité flexible.

Cette recherche a révélé que, pour le marché de l'habitation nord-américain, le design optimal devrait consister en une unité autonome modulaire intégrant une nouvelle technologie. En raison des flexibilité et fonctionnalités rentables, l'assemblage sur stock et la fabrication à la commande sont les deux méthodes de préfabrication les plus répandues.

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Chapter 1: Introduction

1.1 Rationale of the Study

Housing designs have maintained a focus on the functional, spatial, and experiential aspects of built spaces, often to the exclusion of the vital fact that living spaces are never static, and that people's housing needs are always influx, subject to the influence of myriad and evolving social, demographic and environmental factors. Housing designs need to adapt to their dwellers, not fix them in one pattern of life.

Current architectural literature on adaptable design identifies four main characteristics of building adaptability: the capacity for change, reduced mismatches between building and users, maximized productivity, and enduring time (Schmidt, Eguchi, Austin, & Gibb, 2010). A housing design that accounts for time and takes the necessity of change as a critical aspect. It is centered around the concept of adaptability—it accommodates, in advance, changes in how occupants use, navigate, and experience their place of residence over time. In a world marked by major population shifts, communal diversification, urbanization, and growing sustainability awareness, the demand for adaptable housing design will only grow stronger especially in the urban living environment.

1.1.1. Brief Review of Adaptable Interior Design

The concept of adaptable design derivate from an enduring history that can be dated back to early human settlement. In prehistoric shelter often accommodated a variety of activities within a single structure. Over centuries, architecture gradually evolved from temporary structures towards permanent and robust settlements. In the pre-modern western world, generous dimensions and well-proportioned spatial designs created ambiguity in space to allow different functions and activities (Schimdt & Austin, 2016).

Eastern architecture's emphasis on simplicity and flexibility left a profound mark on architecture history and further inspired advances in modern architecture. For instance, the philosophy of adaptability is embodied by traditional Japanese housing design. Inspired by Chinese wood-framed architecture, a standardized 90cm x 180cm modular system known as Ken is adopted for interior design(Schimdt & Austin, 2016, pp. 12-13). Since the length is twice the amount of its width, the

structure can be easily extended within the modular framework. Moreover, eliminating the use of load-bearing walls by wood columns as the primary structures create an open floor plan, maximizing the flexibility of interior space. The interior of a room (Washitsu) usually remains empty so that occupants can define the function of the space (Schimdt & Austin, 2016). Tatami mats are designed based on the module size and tightly fitted inside the room. A two-inch-thick fine straw-mat is suitable for comfortable walking. Such a room can facilitate different daily activities such as organizing, working, dining, and sleeping. Light sliding partition fusumas are used as space dividers and can be uninstalled and stored easily. Shelves and storage rooms that fit between structure columns also function as walls. Given the capabilities for occupant customization, it is rare to find the same shelf arrangement from any two houses (Morse, 1961).

In the contemporary era, the concept of "form follows function"—the prioritization of spatial efficiency—has taken hold, limiting rooms to their monolithic functions, resistant to the possibility of change over time (Till & Schneider, 2007). Post-war brutalist housing projects are a case in point, favouring functionality, durability, and effective management over occupants' unique, shifting living needs (Kendall & Teicher, 2000). To counter this trend, the open building movement promoted flexible, user-oriented designs to improve the adaptability and efficiency of built spaces. In response to massive, indistinct housing developments, John Habraken developed the Support/Infill (SI) system to empower occupants to make autonomous changes in their living environments. All these momentous steps architects and designers took in history were propelled by the continuous evolution of human life and society (Schimdt & Austin, 2016).

1.1.2. Nature of Life Changes

Adaptable architecture has emerged gradually as the response to the dynamic nature of human lifestyles in time. As Schmidt suggested, time can be linear or cyclical. Cyclical time, such as night and day or seasons, recurs (Schimdt & Austin, 2016). Throughout the day, people make minor adjustments to furniture based on their habits, activities, and changes in sunlight. During the weekday, room layouts are guided by efficiency, while they tend to spread out during weekends for family gatherings. As the sun's angle moves across seasons, the location of furniture will be adjusted accordingly to ensure thermal comfort.

There are also transformations that occur over longer stretches of time. Significant life events such as marriage, child-rearing, and relocation are the leading causes of changes in family structures. *figure 1.1* demonstrates a scenario that depicts the changes in a typical nuclear family over time. Accordingly, these potential divergences in family structures necessitate the design's capacity to alter these lived spatial arrangements. Adaptable design allows residents to make both linear and cyclical modifications to their lived spaces without interfering with current building usage or requiring costly and intricate renovation process. In addition to complex life cycle changes, societal transformations are redefining the notion of family—and its housing needs—as well.

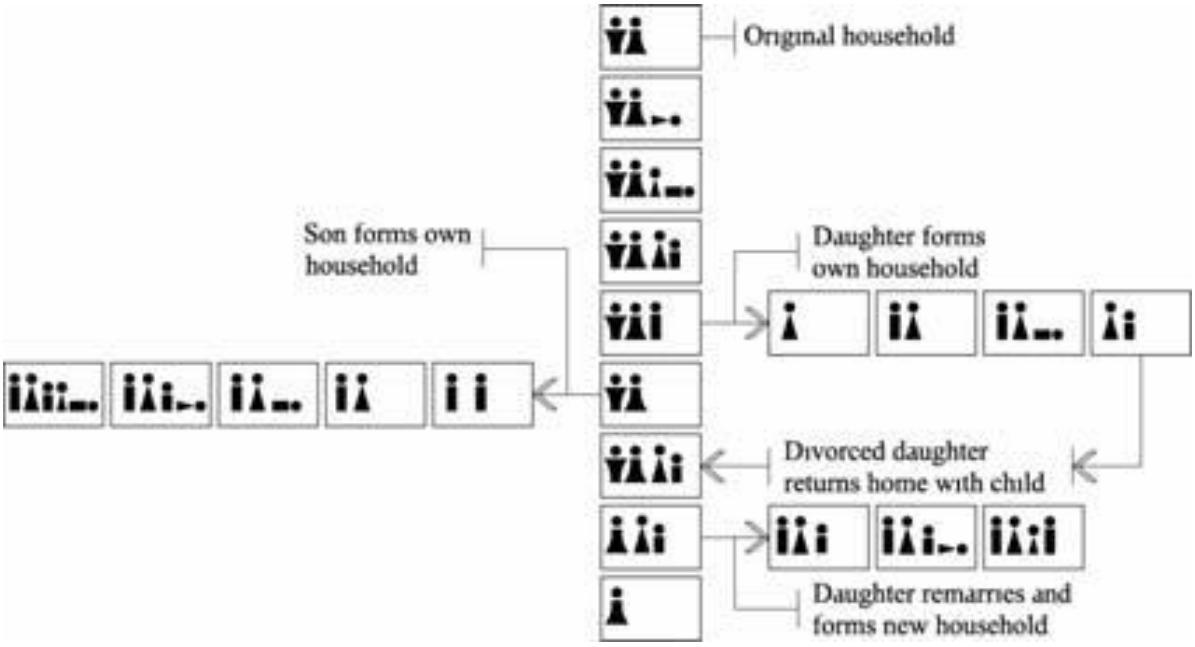


Figure 1.1: A scenario of evolving of family structure, "The Adaptable House: Designing Homes for Change", by: Friedman (pg.6), 2002, New York: McGraw-Hill.

1.1.3. New Style of Life

The "typical" family structure is evolving. According to the 1991 Census, married couples accounted for over 62 percent of all households in Canada, However, this percentage dropped to 52 percent in 2016. In 1991, married couples with children made up over 37 percent of all households in Canada, but after 2011, the nuclear family stopped being the main family structure in Canada. Instead, it should be noted that one-person households has grown 5 percent over the last two decades and reached 28 percent, becoming the new main household type of Canada and ending half a century of a lead maintained by the nuclear family. Among single households, 36

percent are 65 years old and above (Norris, 2017). A number of social and economic factors such as pensions, ageing population, and longer life expectancy also contributed to this phenomenon (Statistics Canada, 2017).

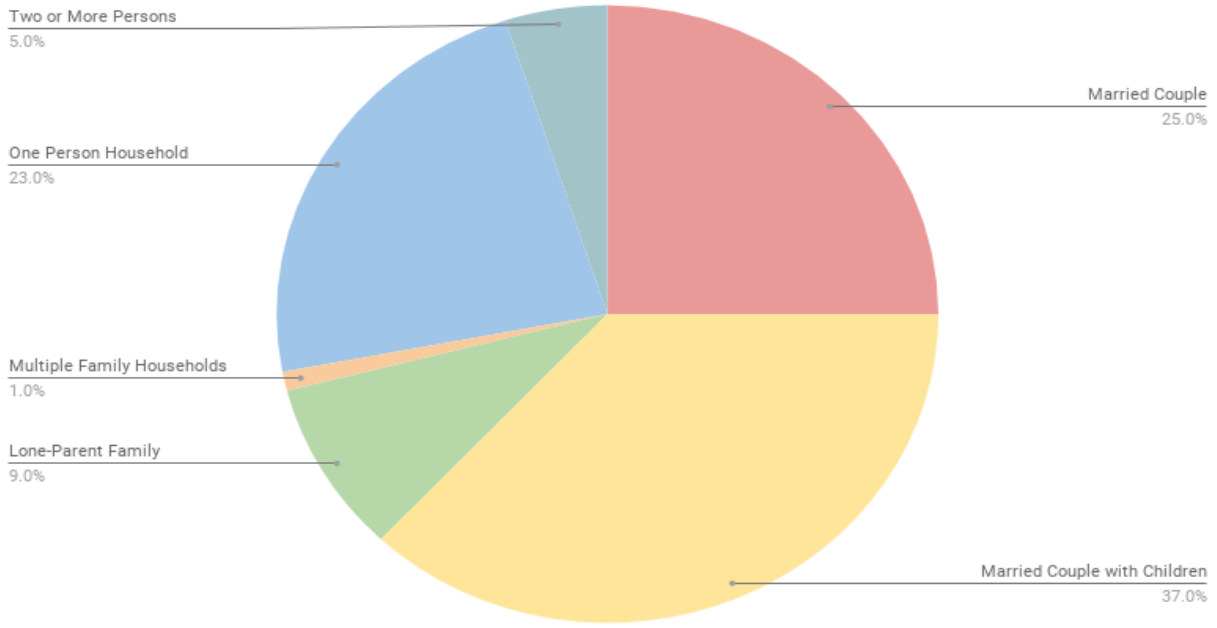


Figure 1.2: Portrait of Canada Household, 1991 Data Source: Statistic Canada, Census of Population 1991.

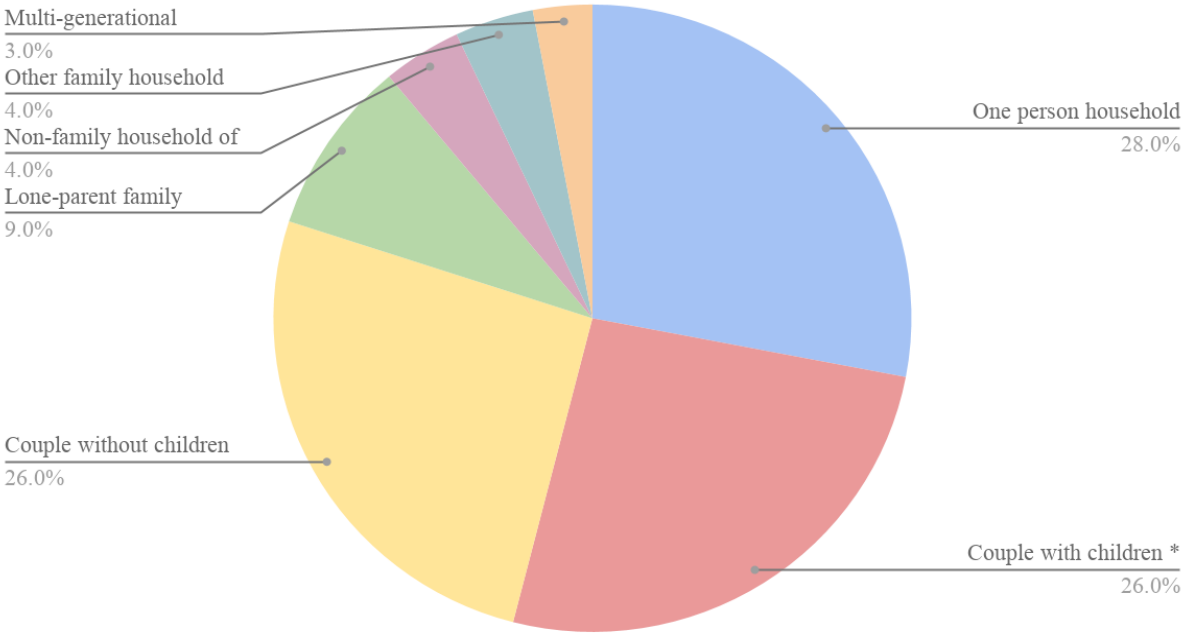


Figure 1.3: Portrait of Canada Household, 2016. Data Source: Statistic Canada, Census of Population 2016.

Major societal changes, as the concept of family has been enriched and expanded, same-sex marriage, changing divorce rate, the emergence of empty-nesters, and immigration, are also reshaping family structures in modern society. Over the years, Canada Census program has been extending its parameter to include more diverse households and families. In 1981, common-law unions were measured for the first time in history, followed by the inclusion of same-sex couples in 2001 and foster families in 2011 (Statistics Canada, 2017). The most recent census in Canada includes seven types of households, where only five categories were represented in the 1991 Census. In Short, the social transformations are influencing households and family's structure in Canada. Housing design needs to respond to such changes. A universal design no longer suffices for today's diverse family structures. To meet their demands, architects, manufacturers, and developers should turn to adaptable residential design to satisfy evolving housing needs.

1.1.4. Dense Urban Living

Another key to the ongoing transformations is urbanization. Over 55 percent of the world's population now reside in urban and metropolitan areas. This number is projected to reach 68 percent by 2050, according to *the 2018 UN World Urbanization Prospect Report* (United Nations, 2018). Compact living allows cities to accommodate larger populations. In recent years, there is a clear transition in the housing sector from the single-detached home to the multi-family apartment. As *figure 1.4* shows, after the 2008-2009 recession, multi-family dwellings experienced four years of continuous ascent. In 2010, the planned construction of multi-family dwellings (103,469) surpassed that of single-family dwellings (91,908) (Statistics Canada, 2018).

This market shift can also be attributed to land scarcity in urban and metropolitan areas. The single-detached home is less and less affordable when land prices continue to skyrocket. Furthermore, in recent years, policymakers and urban planners have been advocating high-density mixed-use homes to address urban intensification (Howley, 2009). In Canada's three largest cities—Toronto, Montreal, and Vancouver—apartments account for 54 percent, 75 percent, and 67 percent of constructions of their housing markets respectively (Statistics Canada, 2018). Given apartments' dominance, it is essential to have a flexible and adaptable interior design so that a diversity of families can rearrange and modify their limited interior space at home to meet their changing living

necessities. Beyond the challenge of increasing density in the urban environment, diminishing resources and escalating environmental crises are pressuring industries to explore sustainable design solutions for future development.

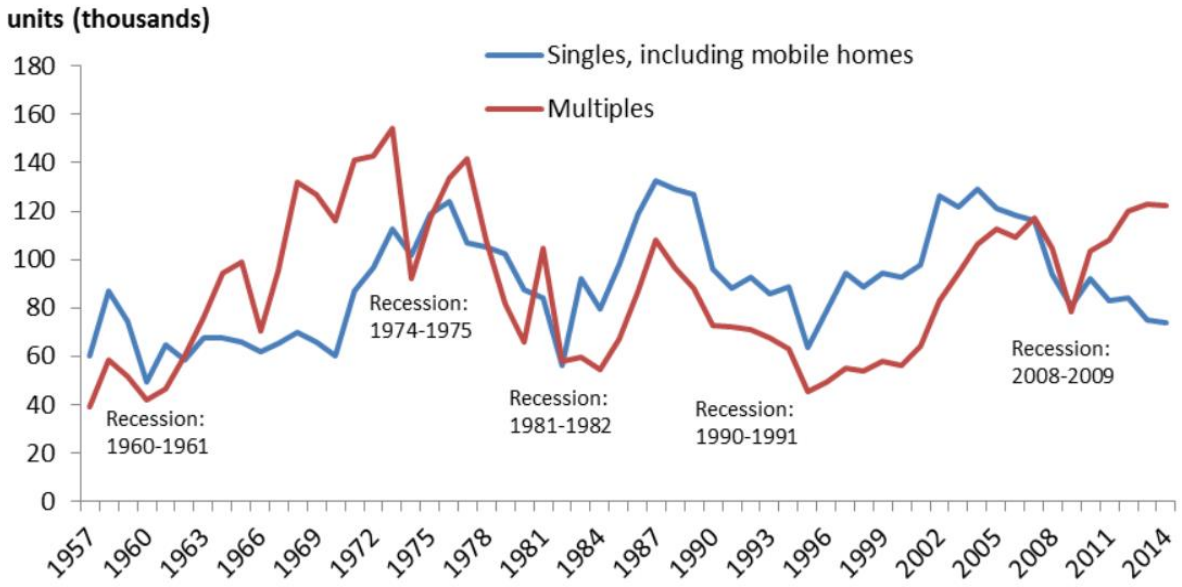


Figure 1.4. Type of Dwelling has Changed Over Time- Building Permits, Single-family and Multi-family Dwelling Units, Canada, 1957 to 2014. Source: Statistic Canada, "Evolution of housing in Canada, 1957 to 2014", 2018.

1.1.5. Sustainable Impact

With increasing global awareness of the catastrophic impact of environmental degradation such as excessive greenhouse gas emission on viable human life, government and policymakers are demanding all fields of industries to pursue sustainable developments. According to the *2017 UN Environment Global Status Report*, building and construction industries (including building material manufactures) were responsible for 36 percent of global energy use and 39 percent of total carbon dioxide emission (UN Environment , 2017) In response, the Canadian government actively too the initiative to prevent environmental deterioration. According to the 2019-2022 Federal Sustainable Development Strategy Plan, by the year of 2028, $26.9 billion will have been allotted for green infrastructure initiatives in Canada to reduce greenhouse gas emission and establish a climate-resilient environment (Environment and Climate Change Canada, 2019).

Building energy consumption can be categorized into operational and embodied energy. Operational energy can be monitored and effectively reduced by introducing energy-efficient

plants and appliances (Szalay, 2007). Embodied energy, however, is less tangible and trackable due to its ambiguous definition and the lack of a consistent measuring system. One of the widely adopted definitions of embodied energy is the sum of the energy involved in a product from production to demolition (Grinnell, 2011). Adaptable design focuses on enabling occupants to effortlessly make physical and functional changes within short refurbishment periods, thus prolonging the life-span of built structures. The energy generated by renovating the adaptable building is also far less than the energy produced by building demolition and construction processes required to replace obsolete buildings.

Architecture evolves with time and those who are occupying it. Shifts in lifestyle, society, and the environment will make adaptable designs more valuable than ever. Guided by this insight, this study intends to explore the concepts and applications of adaptable design in the urban living context. It will investigate, in particular, how adaptable design can benefit from prefabrication manufacturing practices.

1.2. Research Question

Based on the rationales discussed above, this research is leaded by one main research question with five sub-questions to provide a comprehensive understanding.

Main Research Question:

What kind of prefabricated interior system can be incorporated in the design of apartment units to facilitate occupants' configuration and efficient use of the space based on their evolving needs over time?

Sub-Questions:

1. What are the adaptable strategies applied in the design of interior systems?
2. What are the strengths and limitations of each system?
3. What prefabrication methods does this design/product utilize?
4. How is this design/product relevant to the North American context?
5. Is it feasible to integrate these systems into a residential home?

1.3. Theoretical Framework

This research intends to demonstrate that prefabricated adaptable interior design can help residents to adapt their living condition to both short and long-term changes in their family. The adaptable theoretical framework is mainly based on the theory proposed in John Haberken's 1972 classic *Supports: An Alternative to Mass Housing*, where he argued for support and infill system that empower tenants to manage their own living space in response to massive housing needs. *Adaptable Architecture Theory and Practice* by Simon Austin and Robert Schmidt (2016). provided a foundation for architects and students to understand the fundamental framework of adaptable architecture. Furthermore, they also explored diverse approaches to adaptable architecture design through over 30 contemporary practices and design proposals.

The evaluation framework of adaptability is based on Beisi Jia's article called "*Adaptable Housing or Adaptable People*?" (1995). He delineated four categories of adaptability based on the post-occupancy evaluation of adaptable houses in Switzerland—uses of adaptability, technical approach for creating adaptability, distribution of knowledge of adaptability, and management for adaptability. In addition, Voordt's article "*Building Adaptable Housing - From Theory to Practice Current Developments in the Netherlands*" raised a valuable insight on adaptable housing—that it should be for everyone and that design proposals must accommodate different age groups, ranging from the elderly to young couples(1990).

Two pieces of literature are reference in the discussions of prefabrication theory and methodology, particularly in the interior setting. "*The Prefabricated Interior: Defining the Topic*" by Deborah Schneiderman (2011) was the first paper to review the history of interior prefabrication and explicitly define the various approaches that have been adopted. Schneiderman showed that interior prefabrication practices range from elements (panel wall, furniture, the kitchen counter) to complete assemblages such as bathroom units, which mainly organize the undefined space with coherent programs within the built environment. Moreover, Smith and Quale's "*Offsite Architecture - constructing the Future*" noted four manufacturing methods of prefabricated system construction. These four systems— Made-to-Stock, Assembled to-Stock, Made-to-Order, and Engineered-to-Order—were categorized based on the cost, complexity, and flexibility of the construction process (Smith, 2010).

1.4. Goals and Objectives

This study aims to examine, investigate, and design an integrated interior system that can help inhabitants in adjusting their compact domestic spaces to their needs over time. The research comprises three main parts: a literature review of key theories, a comprehensive inspection of existing designs, and finally, an adaptable interior system proposal that employs flexible furniture with interior elements. The specific objectives of this study include:

- To research existing prefabricated versatile interior systems in the market.
- To investigate the main adaptable design strategies utilized in these systems.
- To propose a new prefabricated design solution that can help users adjust their living space effortlessly.

1.5. Intended Audience

This research can be of interest to three primary audiences:

1. Architects and design professionals. This research can function as a design guide to inspire efforts towards adaptable designs.
2. Manufacturers. The research may help bolster interest in the adaptable interior market, explicate current trends, and orient manufacturers' business strategies.
3. Developers. The research aims to demonstrate the value of adaptable interior design, and by extension, investment in such projects.

1.6. Methodology

The research begins with a literature scan of adaptable architecture theories and prefabrication research, with an emphasis on interior design, followed by an empirical study of ten samples of existing adaptable interior systems around the world. This research relies on both primary and secondary sources. The primary sources utilized here consist of essential product information obtained from the manufacturers' websites. Secondary sources provide reviews and commentaries on the product to enrich the analysis offered in this research. Based on the information gathered, the author will conduct an in-depth evaluation of the strengths and weaknesses of the various

adaptable strategies and prefabrication methods in the North American context. These findings will shape the adaptable interior system proposal, one that facilitates apartment occupants' adjustment of their compact living spaces to changing life scenarios.

The methodology for the study is based on several research frameworks. The main references are:

Residential Open Building (2000, pp. 196-218) by Stephen Kendall and Jonathan Teicher: Based on a survey of thirteen infill products, the study teases out the intentions and applications of various infill systems, accompanied by a visual representation of the products.

"Prefabricated wall systems and the North American home-building industry" (1993) by Friedman and Camilleri: This study evaluates the strengths and weaknesses of 55 manufactured prefab panels using 6 factors—cost, craftsmanship, technical performance, durability, flexibility, and ease of assembly. These factors can be utilized in the current research to assess a range of existing interior systems.

1.7. Scope and Limitations

This research explores a small sample of adaptable furniture systems and conducts an in-depth review of each product. Due to time constraint, only ten sample products are selected to represent its category and evaluated. Furthermore, this research focuses on adaptable interior design strategies that can be applied in the dense urban environment. Therefore, the value of the research findings and the design proposal can only be optimized in a typical apartment unit model. Although the selected products are selected from all over the world, their feasibility of applying to the North American context are evaluated in this research. Moreover, this research will only exam the adaptability of the design, the cost is not included in scope of this research.

1.8. Research Outline

This research consists of four parts:

- Chapter One: Introduction

  This chapter addresses the rationale of the study, offers a brief history of adaptability in other contexts, and presents the goals, objectives, methodologies, and other fundamental information related to this research.

- Chapter Two: Theoretical framework

  This chapter has two sections. The first section includes a literature review of the theory of adaptable architecture, clarifying its foundational concepts and providing a taxonomy of existing approaches. The second part of this chapter will concentrate on reviewing the literature on interior prefabrication and manufacturing methodology.

- Chapter Three: Case studies and their analyses

  This chapter offers market research and a thorough evaluation of existing interior systems in a compact living environment. The designs will be categorized based on the typology of adaptability presented in the last chapter. Each design will be evaluated base on the following features: function, material quality, spatial requirements, customization, and installation and maintenance.

- Chapter Four: Design proposal

  Taking inspiration from the case studies in Chapter Three, this paper will propose an integrated, prefabricated interior system to help apartment residents adjust their living environments.

Chapter 2: The Theory and Literature Review

The previous chapter discussed the rationale and the necessity of adaptable design in urban housing. This chapter will explore the theoretical framework of adaptable interior architecture and prefabrication in interior design, and there are two main sections. The first half will focus on the evolution of adaptable architecture theories since early 20th century, particularly the theories and strategies of flexible interior design. The second half will inquire into the conventional approaches to interior prefabrications and the technology influences on the prefabrication industry.

2.1. Early Adaptable Approaches: From the 1920s to 1940s

The contemporary discourse of adaptable architecture began in the early 20th century, as existing housing models could no longer keep up with soaring demand created by the working-class influx into the city. In addition, the existing urban housing models could no longer keep up with the scale of surging market demands. To accommodate the growing population, the housing sector had to reduce housing size standards. Held in Frankfurt in 1929, the second Congrès Internationaux d'Architecture Moderne (CIAM) congress conference - "The Minimum Dwelling" was organized around the theme of Subsistence Dwelling. This forum aimed to tackle housing shortage issues in metropolitan areas and debate the ideal design solution to ensure quality of life in shrinking housing spaces (Schneider & Till, 2007).

A series of empirical studies were conducted to gain a broad understanding of the internal dynamics of the modern lifestyle. For instance, Van den Broek and Heinrich Leppla documented how families occupied the standardized built domestic space differently. Mart Stam examined each family member's daily routines at home and how the household would interact and inhabit the domestic space. Based on these studies, Stam argued that the interior space should eliminate immobile and fixed installations and replace them with a rearrangeable design to meet users' varied and evolving needs throughout the day (Schneider & Till, 2007). These analyses demonstrated that the growing complexity of emerging modern life required housing designs capable of adapting to their inhabitants' daily activities and evolving circumstances, and in response, the notion of interior flexibility was proposed.

According to Schneider (2007), there were two general approaches to flexible dwelling design in the early modernist movement. One approach was driven by the desire to liberate rooms from functions predetermined by the architect. Instead, use-neutral floor plans comprised proportional

rooms of similar sizes and all with direct window access to external view. This strategy permitted the rooms to take on various functions based on the needs of dwellers, who gained more control over how their domestic space would be utilized. Meantime, another group of designers fascinated with the mechanical system explored the physical adaptability of interior architectural elements such as space divider and furniture system.

A number of architects were experimenting with versatile mechanical designs ranging from foldable furniture to removable panels for the spatial arrangement. Le Corbusier employed flexible interior elements such as sliding walls, foldable, and movable furniture in his Maison Loucheur proposal, creating 71m^2 of usable space in a 46m^2 house (Schneider & Till, 2007). Erich Mendelsohn used revolving stage devices with three different sets—including the dining table, seating, and piano—to transform the living room's function (*figure 2.1*).

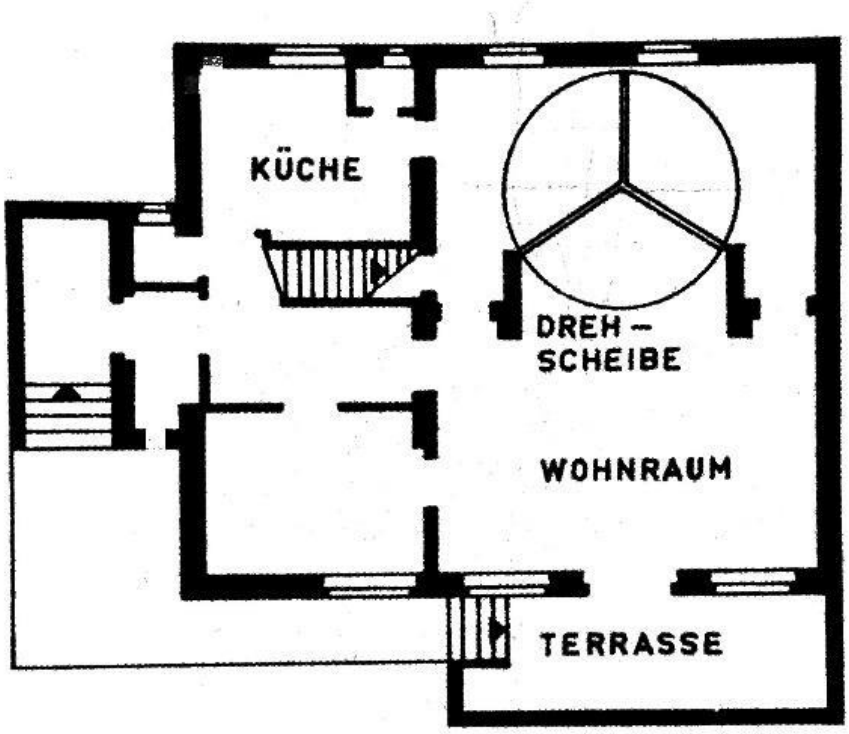


Figure 2.1: Single-detached houses in Berlin-Zehelendorf use revolving stage devices to provide interior flexibility, Richard Neutra+ Erich Mendelsohn. Source: "Flexible Housing", pp:19, Tatjana Schnerider, Jeremy Till 2007

Dutch architect Gerrit Rietveld also designed one of the most influential projects that incorporate flexibility into the residential dwelling design—the Schroder House. The Schröder House's design sought to achieve flexibility through the integration of hinged movable screens into the dwelling

space. Based on client participation, the design took into consideration the various activities that would happen throughout the day. As the floor plan shows in *figure 2.2*, the house is laid out around the central staircase. During the daytime, the movable panels fold towards the exterior wall and create a continuous open space for the family's daytime activities. At night, the panels unfold and divide the floor into four rooms, including one living room and three bedrooms. Considered a modernist architecture masterpiece, the Schroder House ingeniously combines a use-neutral floor plan and mechanical elements to achieve interior flexibility.

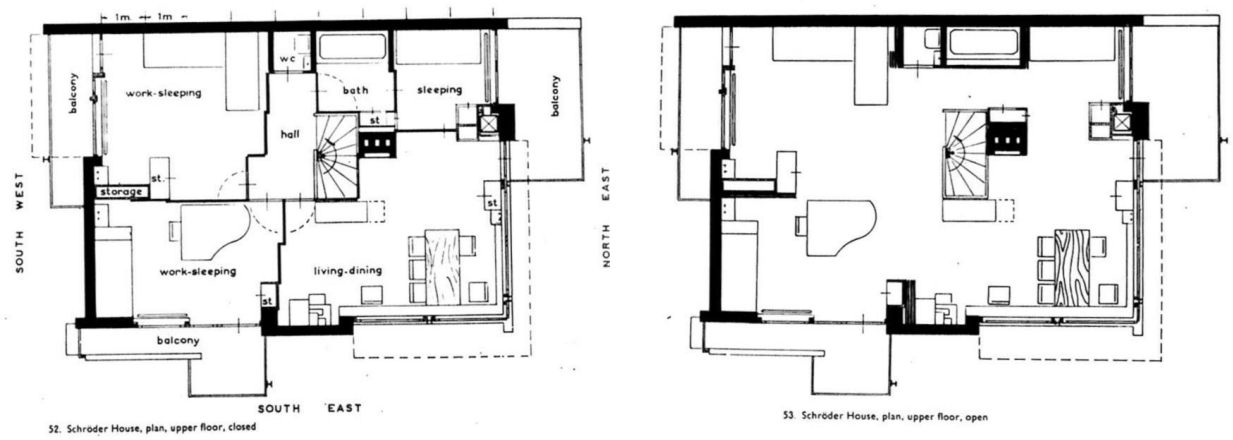


Figure 2.2.: Schröder Huis upper floor comparison.
Retrieved from: https://histarq.wordpress.com/2011/12/18/aula-5-de-stijl-1918-1927/

In North American, inventor William Lawrence Murphy (1856-1957) built a contraption to stow his bed into the closet in his one-bedroom apartment unit in San Francisco. He would later patent this invention, which became widely adopted in large cities throughout the country (Caputo, 2009). Overall, the first wave of adaptable movement recognized the internal variability in dwellings and attempted to develop tactics for flexibility within the fixed building shell, a concept that continued to develop throughout the later 20th century.

2.2 Response to Postwar Mass Housing: The 1960s

Shortly after World War II, countries in Europe began an extensive process of reconstruction. An anticipated population boom led to skyrocketing demand for housing. As part of its national post-war reconstruction program, the Dutch government promised to construct new housings for its entire population (Bosma, et al. 2000). However, restricted by a lack of skilled labour, building

materials, and means of transportation, only a number of housing developments with limited variation and minimum standards in dimensions and quality were selected for mass production. Although the construction of standardized housing resolved the immediate issue, the monolithic housing design, with standard components and layouts, was often replicated regardless of the tenants' family structure and their preferences. Opponents of mass housing argued that the indistinguishable housing units completely neglected residents' identities, humanity, and freedom (Bosma, et al. 2000).

2.2.1 Introducing the Support/Infill Theory

One of the most prominent critics of the mass housing movement is the Dutch Architect John Habraken. In his 1961 book *Supports: an Alternative to Mass Housing*, he argued that the traditional process of—and human attachments to—habitation was hardly considered in the post-war mass housing movement. In mass housing, dwellers were unable to express themselves or cultivate a sense of affinity with the house due to physical constraints it imposed. As a result, there were high rates of residential mobility during that period. “Could the fact that a conflict exists between man and the method chosen to combat the half-century-old housing shortage mean that there is a connection between these two?” asked Harbraken (1972). He believed housing should not be treated as a commodity; rather, it should embody a natural relationship between humans and buildings. The process of housing design should balance rational consideration and human decisions based on the particularities of different people. The actual issue, Harbraken argued, was not industrialization but the institutionally controlled housing approach, which he considered inadequate to the inhabitants’ complex needs (Kendall & Teicher, 2000). In Habraken’s proposal, the built environment should consist of some form of support system, which provides the primary structure to sustain the occupants; while the infill or the interior fit-out systems will be customized based on the user’s choice and fit in the structure frame. This support/infill system efficiently divides the building into two autonomous sections—the technology and logistic bundles—with a distinct hierarchy system applied to it (Bosma, et al. 2000; Kendall & Teicher, 2000; Schneider & Till, 2007).

2.2.2. The Layers

One impediment to change is the intricate relationship among building layer systems, such as cast in place plumbing and electric wiring in the wood frame wall. The more layers a design entails , the more significant the efforts and costs associated with adaptation will be (Schimdt & Austin, 2016). To clearly define the function of the support and infill system, architects attempted to review them from different scales. The layer system was introduced before the support/infill system, where each layer is associated with one scale. There are two general approaches to the layering system.

In 1994, Stewart Brand proposed the model for building decomposition in *How buildings learn: what happens after they are built (figure 2.3*). Taking into account future changes, he categorized the building into seven layers with a distinct hierarchy of scale—site, structure, skin, service, space plan, stuff, and space. Each layer has its services life expectancy. The services layer (e.g., water

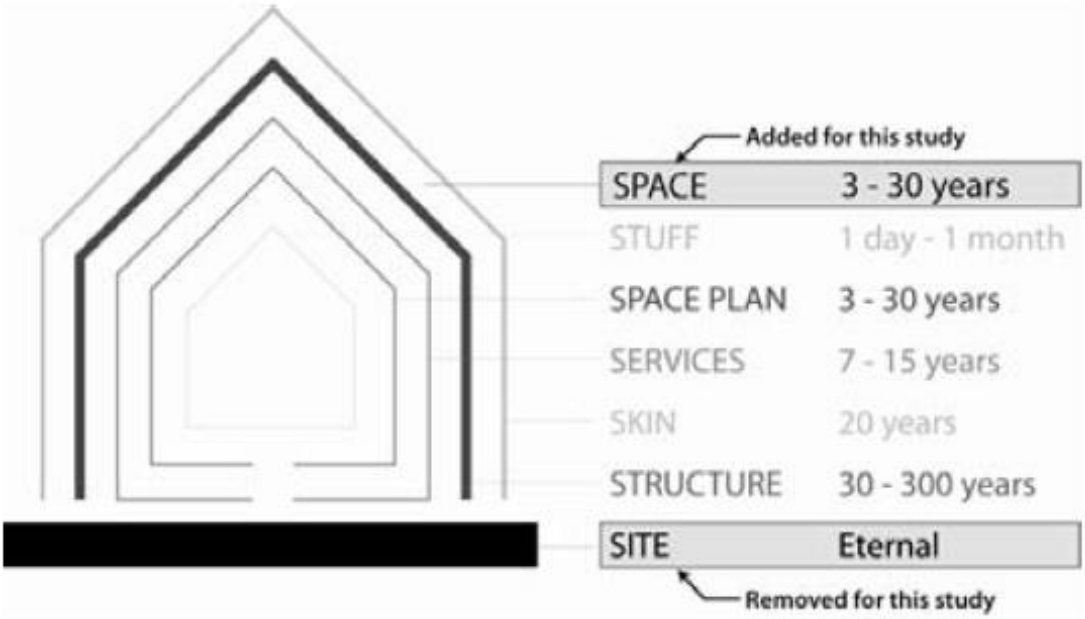


Figure 2.3: Brand's 1994 Layer Model. Source: "Understanding Adaptability Through Layer Dependences", pp.3, Schmidt, Deamer, & Austin, 2011.

and electricity), for instance, has a life-span of around 7-15 years, while the structure layer (e.g., Columns and beams) can last for 30 to 300 years. Separating the internal layers allow the ones

with shorter lifespan to be updated autonomously within the other layers. Therefore, the building lifespan is mainly determined by the structural layer and external site condition.

Later, Kendall & Teicher (2000) integrated Brand's layer system and Habraken's support/infill theory to offer a level of decision-making sufficient for Residential Open Building. From urban-level considerations such as land-use and neighbourhood fabric to building-level ones addressing structural support and interior layouts, each level has its territory, size of parties it can serve, and changing cycles. The subsystems fit inside each level should be interchangeable with similar products from different manufacturers.

2.2.3. The Support

The support structure is built for the unforeseen future and allows the infill units to grow and transform independently. Like the car and the highway, the support and the fill are distinct yet rely on each other to exist. The support is the highway system, intended to serve various types of vehicles. It is made of permanent and durable materials embedded with technical systems to provide services for each infill unit. when the vehicle mode updates, the robust highway system can continuously support the transportation system. In term of housing development, the most primitive form of support is the building, with columns, beams, and foundations transferring the load from the plane above to the ground. However, Habraken disagree with the skeleton model proposed by Le Corbusier in Dom-Ino House. Habraken argued that it is superficial to consider skeleton as the support structure, even if they appear to be similar (Habraken, 1972). The support structure encompasses all the essential infrastructure elements such as public access, circulation, structure frames, and sewage systems. They directly connect to each subdivision, commonly referred to as "the lot." He envisioned that the support structure should maintain its simplistic form with minimum details and finishes. As the social shifts and technology advances occur, the support structure can act as the basis to accommodate perpetual changes (Kendall & Teicher, 2000). Moreover, the support system could only be completed with infill occupation.

2.2.4 The Infill

The infill system is developed based on an individual's preferences and needs, as Habraken illustrated in *figure.2.4.* Within the independent skeleton, each family can personalize how the space is occupied, while they can be updated independently without interfering the function of other infill systems. Kendall and Teicher further defined the internal system in their publication: *"Residential Open Building."* They pointed out that its wide adoption in the commercial building market, where infill applications ranged from furniture systems to "slab-to-slab" fit-out systems. However, in the residential context, the structures, mechanics, and services systems were often mixed up together. In North America's home-building industry, each subcontractor team specialized in a single task to increase efficiency. Although it boosted on-site productivity, the single-minded approach limits the integration of different building systems. Furthermore, the lack of effective communications between different decision-makers turned the construction site into an assembly line, where each team uses the fastest way to finish their work without consulting with other stakeholders. This method of construction can lead to the entanglement of pipes, ducts, wirings in the building system, complicating future renovation processes (Friedman, 2002; Kendall & Teicher, 2000).

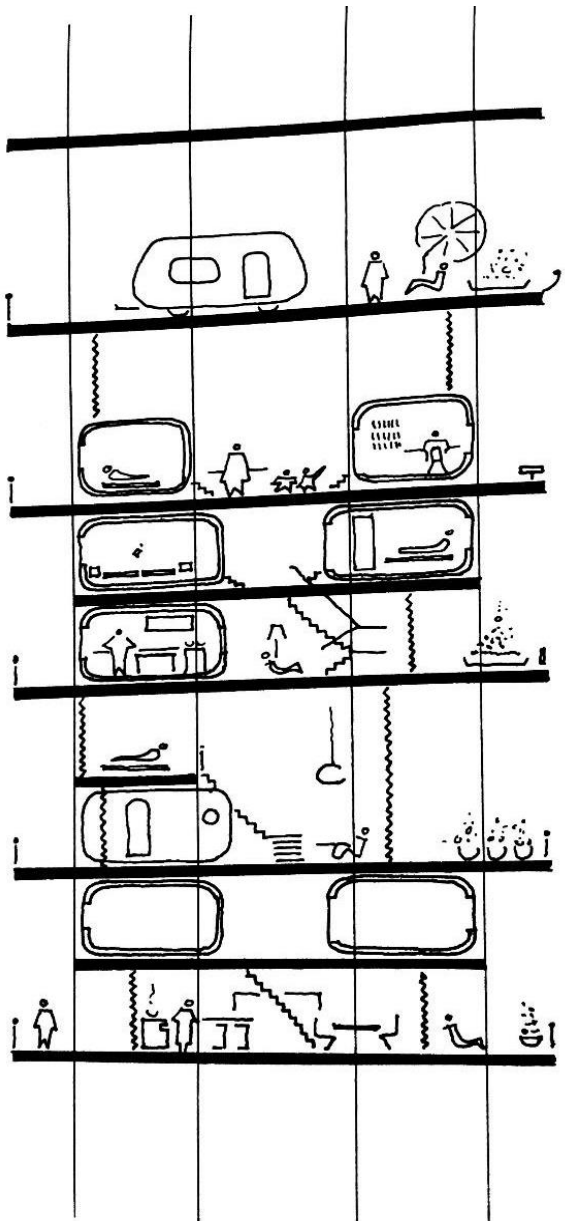


Figure 2.4: Habraken's sketch of the support structure in 1963. Source: "Housing for the Millions: John Habraken and the SAR 1960-2000", pp 112, *Bosma, Hoogstraten, & Vos, 2000.*

Instead of the disorganized interior assemblies, Habraken envisioned the infill system as a well-integrated pre-fabricated set available for dwellers or general contractors to install in the structural

support frame. Multiple suppliers are involved in the production of the infill system, and coordination occur in advance to ensure minimum on-site modification. This approach facilitates communications between suppliers and helps dwellers participate in the design process, which empower them with greater control over their future homes (Bosma, Hoogstraten, & Vos, 2000).

2.2.5. Molenvliet Housing Project

The Molenvliet Housing complex was one of the first dweller participatory projects designed by Dutch architect Frans Van der Werf and Werkgroep KOKON in Papendrecht. This project provided 124 dwelling units with 67 different design types. Habraken commented it was the first full-blown project designed based on his support/infill theory (Habraken, n.d.). The overall design is organized into four building levels based on scale: the over the urban plan, district master plan, the support structure, and the interior infill.

At the urban planning level, one-third of the sites are occupied by building constructions with an overall density of 90 dwelling/ha, while the rest of the site is left for landscaping (Kendall & Teicher, 2000, p. 83). At the master planning level, the low-rise urban fabric consists of an open courtyard in the center and buildings surrounding the yard (*figure 2.5*). Small passage tunnels in the ground floor function as the main circulation paths between the courtyards and connect them to the main street. Based on a series of capacity studies, architects developed an ideal 480cm square grid system and placed the 20 cm x 140 cm parallel piers on the grid (Werf). The cast-in-place concrete structure framework embodied mechanical chases and stairs into the system. As part of the support system, the central shafts bring all the primary services, including water, energy, sewage pipes, and wires, into the free-standing central shaft (*figure 2.6*). The shaft space can be accessed from different directions and allocated in a diagonal place (Werf)Lastly, the infill unit layout is designed based on the parcellation of the main structure. Each infill unit contains all the essential interior elements including interior walls, space dividers, doors, finishes, bathroom and

kitchen cabinets, fixtures, and appliances (Kendall & Teicher, 2000, p. 84). To make the design adaptable to different families, a participatory design approach was adopted in this project.

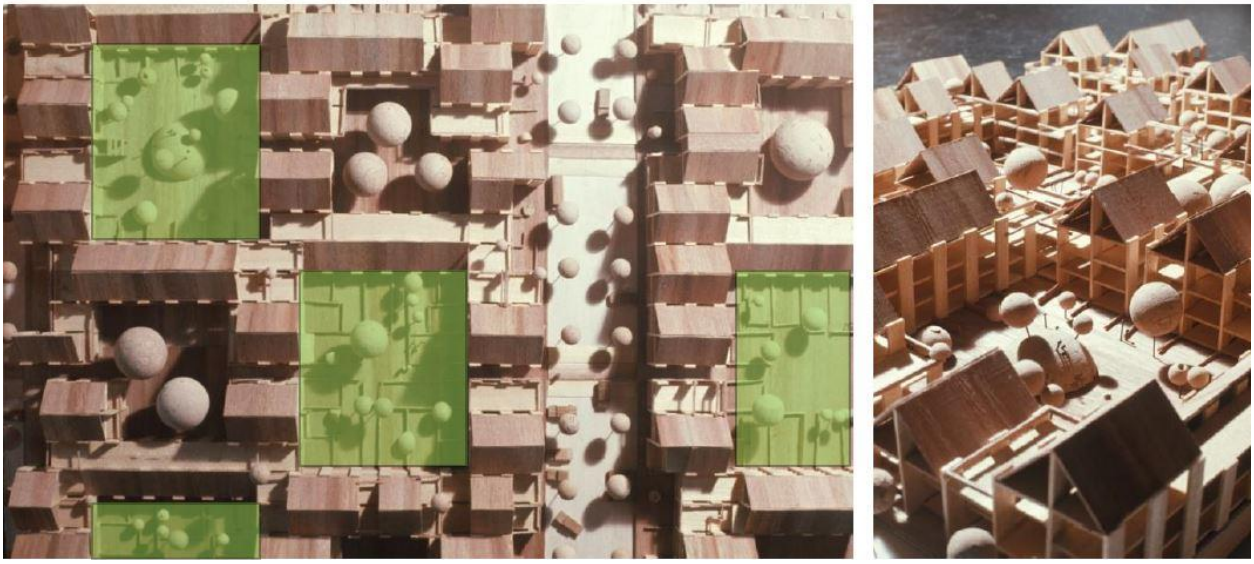


Figure 2.5: The master planning model indicating the relationship between the courtyards, buildings and main street. Source: Habraken, Open Building- Molenvliet, n.d.

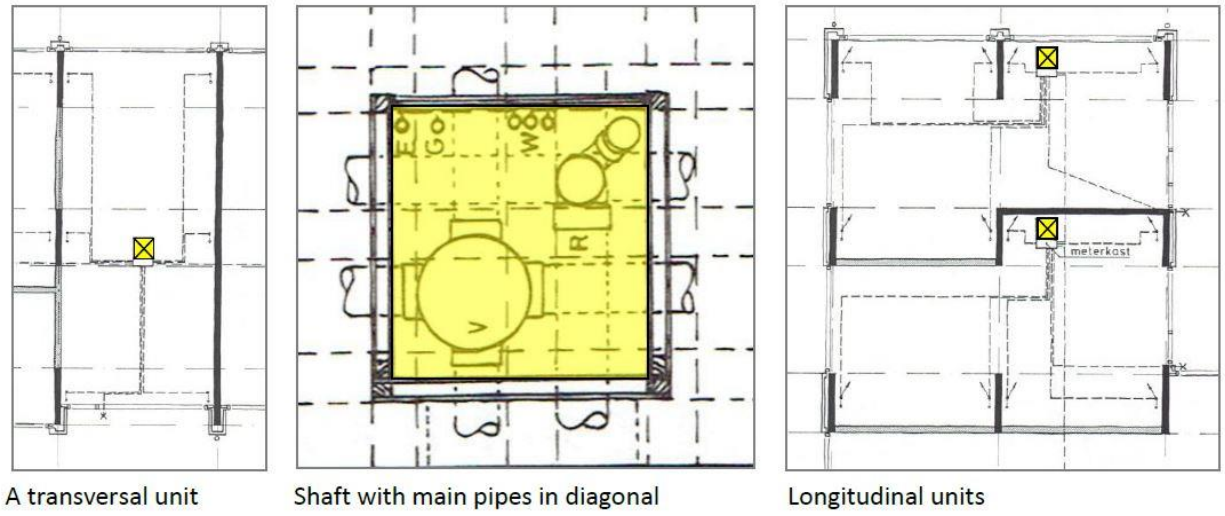


Figure 2.6: Central shaft plan details and their location for different unit type. Source: Habraken, Open Building- Molenvliet, n.d.

2.2.6. Involvement of the User

Under the influence of opposition to housing commodification in the 1970s, Austrian architect Ottokar Uhl explained that users should have the right to engage in the design process with architects and urban planners instead of remaining consumers who simply purchase the end products (Steger, 2004). During the initial design phase of Molenvliet housing, two infill consultating meetings were set up with future residents so they could participate in the design of their units (*figure 2.7*). During the first meeting, architects discussed the spatial layout with clients based on their family structure, each member's age, habits, and preferences. The second meeting was to finalize the floor plan with some minor modifications based on user feedback (Habraken, n.d.). Meanwhile, according to the interior layout, user can engage in their unit facade design by choosing the window patterns and finish colours (*figure 2.8*).

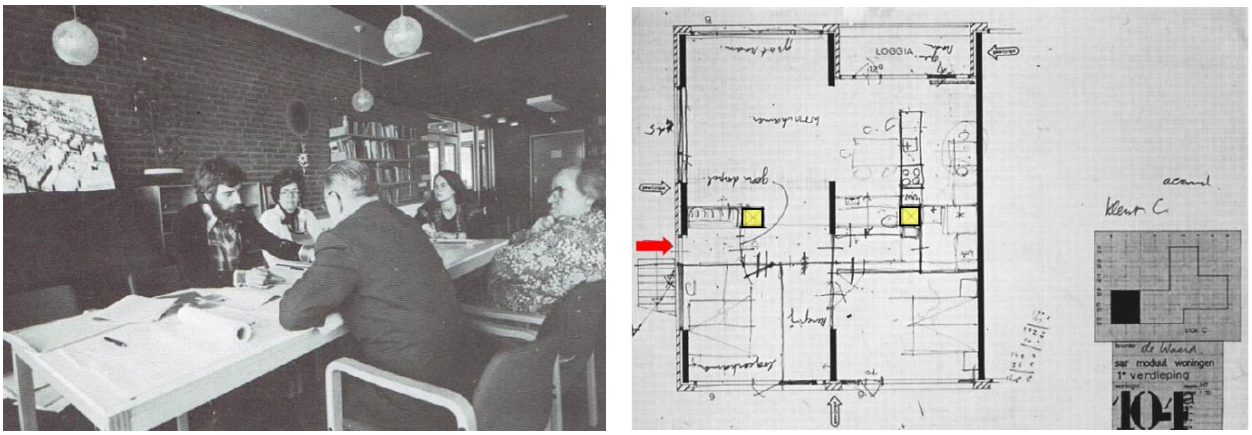


Figure 2.7: (a) Molenvilet Housing project client consultant meeting; (b) Interior sketch after user consultation. Source: The Molenvliet Project, Werf.

Figure 2.8: (a) Illustration drawing for color choices by users during the user consultation; (b) The built façade with variation for each unit. Source: The Molenvliet Project, Werf.

Gotink, a social and behavioral science researcher from Utrecht University, followed all consultation meetings and conducted post-occupancy interviews with dwellers who had participated in the design process and those who had not to assess the levels of their satisfaction with the housing layout. Gotink found that more than 43 percent of the residents who were not involved in the design process were unsatisfied with their current dwelling layouts. In comparison, the unsatisfaction rate for those who participated in the design process percent was as low as 14 percent(Gotink, 1979) This study indicated that end-user engagement in the design process has a positive impact on user satisfaction. In addition, Schneider and Till (2007) explained that the dweller's satisfactions levels are not only based on the space's fulfillment of functional needs, but also a sense of ownership over their home. They argued that the architect should dictate housing designs according to their desires and create homes that reflect the dwellers and their unique needs.

2.3. Contemporary Six Adaptable Architecture Approaches

Influenced by the aforementioned architects and theorists, multiple strategies and approaches have emerged in the past few decades to center adaptability in housing design. In Schmidt and Austin's 2016 book Adaptable Architecture Theory and Practice, they summarized six ubiquitous adaptable design strategies in modern architecture practice: Adjustable, Versatile, Refitable, Convertible, Scalable, and Movable.

Adjustable

Adjustable strategies are associated with the elements and equipment inside the building, such as furniture, equipment, and other installations. The strong flexibility of these elements support end-users in accomplishing their constantly changing tasks without complicated upgrading procedures. Multifunctional property and the degree of user control over the product are the two keys to adjustability. The consideration and integration of potential needs related to product and its usage, such as the movability of furniture would enable the end user to perform simple physical modifications to achieve greater comfort without necessarily adding or switching to other products.

Versatile:

Another common approach to adaptable building design is the versatility of the physical room layout—whether it can adapt to changes in occupants and the purpose(s) of the lived spaces. A space's versatility is determined by the space's physical parameters including permanent load-bearing structures location, size and proportion of the space, location of subsystems and service access, and movability of space dividers. Based on the building layers model Brand established (discussed in 2.2), multiple layers of building are introduced, with a range of versatility ranging from stuff, space plan, services structure, and skin—the more independent each layer becomes, the more convenient it is to modify a space.

Refitable

Refitable design often entails the alteration of the performance of a building. Even though buildings are permeant structures, they require constant modifications to keep up with functional changes or updates to regulations on energy performance. The retrofitting process affects the normal functions of multiple building layers, and the intricated building system will lead to complication and extra expenses. Therefore, assessing the different lifespans of building components and their maintenance processes can help the users choose the right products. Moreover, an independent layer system with minimum connections between layers can avoid interrupting the functions of other building layers during the renovation process.

Convertible

A building's function is driven by multiple factors such as the market and social demands, building ownership, and city planning regulations. For instance, office-to-residential and factory-to-restaurant are commonly seen building repurposing approaches nowadays. These changes are predetermined by the physical properties of the building, such as the floor to ceiling height, circulation locations, structure integrity, facade fenestration, floor capacity, and fire rating capacity. Ensuring a more generous floor to ceiling height, great floor space, and window openings are a few common tactics to attain building convertibility.

Scalable

Scalable refer to a building's capacity to accommodate volume increases. It can be implemented both horizontally by attaching a room to the building or vertically by adding/ subtracting floors to the original building. The original structure and the complexity of the building geometry determine the feasibility of a modification process.

Movable

Movable is the least seen form of adaptable approach. In temporary events and conditions, a portable structure that can be easily set up and deconstructed is required. Movability is tied to construction type, the scale of the components, and the building's materiality.

Among the six approaches, adjustability, versatility, and refitability are the three tactics affiliated with interior adaptability. Adjustability deals with furniture system adaptability, and versatility is concerned with interior floor plan flexibility by finding the right location for the permanent structure and utilizing movable interior components. Refitability design focuses on technical issues by isolating the service system from the main structures to avoid restriction during the building retrofitting process.

In conclusion, adaptable interior design has experience three critical stages of development in the past decades. In the early modernist period, the concept of floor plan indeterminacy and experiments with the mechanism of movable architecture components were the leading themes for adaptable interior design. The second phase was guided by John Habraken's infill and support theory, where the interior and the main structure act as independent systems to avoid creating complications for dweller as they adjust the interior based on their needs. Various theroies have emerged in the wake of this theory. Austin and Schmidt, for example, proposed six adaptable strategies, in which adjustable, versatile, and refitable designs specifically attended to interior adaptability. Among all these approaches, prefabrication is constantly involved in the manufacturing process, which will be discussed in the following part of the chapter.

2.4. Interior Prefabrication

To ensure a comprehensive understanding of the prefabricated adaptable interior design, the second half of the chapter will zero in on contemporary discussions of interior prefabrication. The

first part of the section reviews the three main approaches to interior prefabrication, cross-referencing them with pioneer projects for each approach. Relevant topics such as delivery concerns, end user's adaptability, and project scheduling issues are also included. The last part of the chapter is devoted to different manufacturing methods as well as their respective advantages and disadvantages.

Prefabrication architecture is also known as offsite construction. Unlike conventional onsite construction, its manufacturing process occurs in a controlled factory environment. The finished building products and/or its components such as panels, modules, or units will be delivered to site for installation. This project delivery system facilitates a radical evolution in architecture and construction industries, profoundly improves the efficiency, quality, and safety of building construction (Smith, 2010). In recent years, technology advancements have further advanced the deployment of the prefabrication process. For instance, the introduction of Building Information Modelling systems facilitated communication between project teams, thus avoiding unnecessary misunderstandings between different parties. Moreover, utilizing computer-operated machine tools such as CNC, Laser printing, and 3D printing technology improves precision in manufacturing. Not surprisingly, in the last twenty years, an increasing number of developers, architects, and clients have begun to explore innovations prefabrication, creating many high-profile projects around the world.

Despite continuous technology advancements and the substantial industry attention prefabrication architecture has drawn, the application of prefabrication in interior environments has received, at best, a muted response. In 2011, Deborah Schneiderman, Associate Professor of Interior Design at Pratt Institute, published "*The Prefabricated Interior: Defining the Topic*" the first paper to review the history of interior prefabrication and explicitly outline the approaches that have been explored till today. Schneiderman explained that interior prefabrication practices range from elements (e.g., panel wall, furniture, the kitchen counter) to complete assemblages such as bathroom units. The prefabricated elements organized and undefined space with coherent programs within the built environment (Schneiderman, 2011). Interior prefabrication explores not only the construction techniques of interior components, but also the critical locations and their role of space-making. Similar to all the other forms of offsite construction, interior prefabrication

offers benefits such as affordability, cost efficiency, and end-user adaptability. Based on the historical review, Schneiderman classified interior prefabrication construction into three basic types: Planar Construction, Modular Construction, and Unit Construction.

2.4.1. Planar Construction

Planar component such as the fundamental architectonic element is one of the most commonly seen prefabrication systems. The history of the domestic interior prefabricated panel can be traced back to the traditional Japanese house as mentioned in Chapter One, where the Shoji (screen) functions as a solid wall, a sliding door, and a partition at once. In the 20th century, modernist movement screens were widely adopted by prominent architects such as Gerrit Rietveld, who introduced sliding walls into the Schroeder House to make the interior space adaptable for daily uses. In North America, the earliest appearance of the panelized prefabricated system was introduced by the British, who brought the prefabricated, panelized wood house from England to Cape Ann, Massachusetts in 1624 and established a fishing community near the coast (Hearn, 2018). Today, panelized system accounts for approximately 43 percent of the prefabricated home construction market in the United States (Smith, 2010).

The production of light wood or light gauge-metal-framed wall assembly is known as panelization, which effectively speeds up the wall delivery process compared to traditional onsite framing (Smith, 2010). The size of the prefabricated panel—within 8 ft 6 in (2.6 m) in width and 14 ft height (4.3 m) in height—is determined by the maximum size that a standard shipping truck can legally carry and deliver (Smith, 2010). Open and closed are the two types of prefabricated panel systems available in the market. The Open system only provides the structural frame and exterior sheathing while leaving the rest of installations, such as plumbing, insulation, and interior finishes, completely onsite. This method allows for greater flexibility in onsite modifications to the original design. In the Closed system, however, all the components are installed in place at the plant (Friedman, 2002). This method requires precise integration and coordination between architects and M.E.P. engineers during the design phase of the project. Although it limits onsite flexibility, it does make up with fast installation and less labour requirement.

In the interior residential setting, prefabricated panels are mainly used as space dividers and wall finishes. Beyond physical space division, interior partition panel can distribute services by embedding utility systems such as plumbing, electrical wirings, and cables into the wall cavity. Interior space, the most ephemeral part of a building system, requires a strong capacity to accommodate changes. Therefore, interior partition manufacturers have developed serval tactics to allow tenants to adjust an interior space according to their needs, while avoiding the interruption of routine activities and operations within the space. For instance, the open panel system used in the DIRTT partition (*figure* 2.9) allows user to switch panel materials. Integrating the cords and

Figure 2.9: Top Left: DIRTT interior partition system; Top Right: Cable Raceway; Bottom: DIRTT Floor mounted panels, Sources: Smith, 2010, pp.158.

plugs into the wall cavity allows convenient access to electricity. The baseboard raceway is another tactic that was developed in response to the constant needs of wire upgrades at home (*figure 2.9*) (Friedman, 2002). The demountable covers, modular jacks, and switchable outlets simplify future wiring system upgrades for the user in the future. The floor-mounted panel allows the wall to be relocated, and the leveller is adjustable so the panel can be fit into spaces with different floor-to-ceiling heights (*figure* 2.9) (Smith, 2010).

2.4.2. Modular Construction

The emerging of tatami modules in traditional Japanese architecture, , where the size of a room is measured by the number of tatami mats that can be fit in the existing space, was one of the earliest

Figure 2.10: The Storagewall Demonstration and plan below. Source: LIFE, 1945, pp. 65-67.

forms of modular system in interior design (Morse, 1961). In the 20th century, the furniture industry began to experiment with modular construction methods. Sears and Roebuck used the modular system to mass-produce bookcases in 1909 (Schneiderman, 2011). In 1944, George Nelson published his masterpiece the Storagewall, which was later highlighted on the cover page of LIFE magazine in 1945 as a prototype for modern interior design. A 12in-deep modular storage system replaces the old wall of the room and contains almost all the paraphernalia of a family including shelves, a desk, and a closet as illustrated in *figure 2.10*. The storage wall could be installed in all the rooms of the house; the modular design makes it possible to assign different functions to the storage wall by allowing changes to its composition (LIFE, 1945).

In response to post-WWII housing shortage, U.S. companies like Lutron Corporation introduced the prefabricated mass-produced home. In 1948, they announced the first prefabricated house model— "Westchester Two Bedroom," which was later deemed a milestone in the development of interior prefabrication (Bergdoll & Christensen, 2008). The interiors of the Westchester house were built-in and integrated with enamel-encased prefabricated modular panels. The partitions not

Figure 2.11 : Lustron Home Interior, Photograph courtesy of the Library of Congress.

only divide the space but provided functional programs such as shelving, cabinet, closet, and vanities as illustrated in *figure 2.11* (Bergdoll & Christensen, 2008)

The module was the subdivision of a modular system, which is designed, manufactured independently, and assembled to form a complete structure. The functional integrity of a modular system is achieved by the repetition of modules in a given space (Schneiderman, 2011). . Standards such as forms and dimensions are introduced to guide the production of the module and ensure each discrete can fit into the entire system. In addition, module variations enable the entire modular system to support multifunctional usage. A variety of modules can be attached, detached, switched, and rearranged quickly to create alternative combinations for different users (Gu, Xue, & Nee, 2009) In residential interior design, modular systems are frequently used in kitchen and furniture design, and Schneiderman pointed out that the kitchen's role as the vehicle for exploring prefabrication in interior design (2011).

The first attempt at the prefabricated kitchen was designed by L.H.De Koninck, and it was known as the Cubex System (*figure 2.12*). The basic module of Cubex is four standardized cupboards with ten different variations, which can be arranged into 200 kitchen layouts (Heynen &

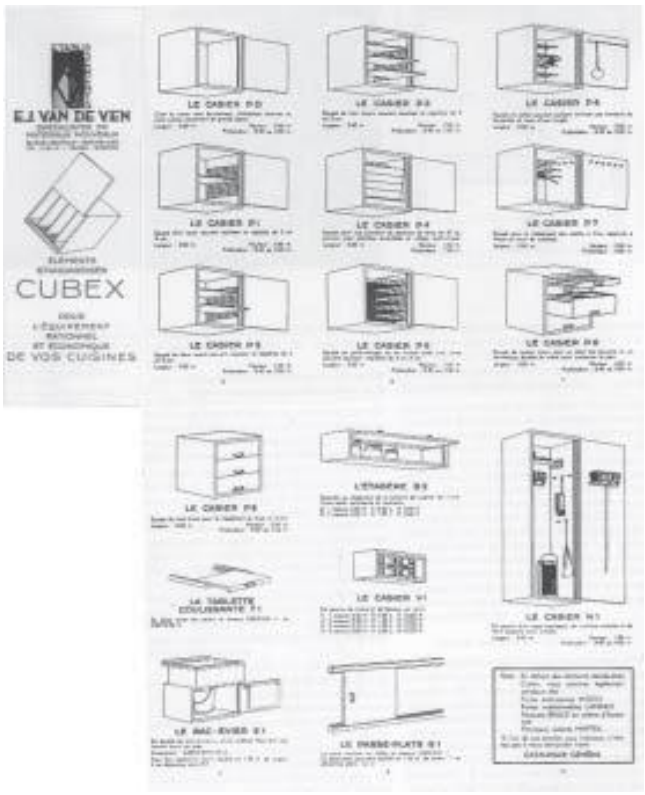


Figure 2.12. List of standardized Cubex elements from brochure published by the Van de Ven company, 1935. Retrieved from: Heynen & Caudenberg, 2004

Caudenberg, 2004). This experiment foreshadowed the prefabrication approach to the modern kitchen design. In 1946, Cornell University Housing Research Center designed the modular kitchen prototype based on rigorous research study, which was known as the Cornell Kitchen. Five fundamental functions of the kitchen Mixed, serve, range, sink and equipment formed five prefabricated movable centers. Each center had adjustable height, with a self-supporting structure and identical base cabinets. Moreover, the centers could be disassembled into a flat package that could be transported easily (Schneiderman, 2010). This modular prototype became the precursor of contemporary prefabricated kitchen designs.

2.4.3. Unit Construction

In interior prefabrication field, the term unit refers explicitly to an all-inclusive interior appliance For instance, the factory-produced free-standing kitchen dresser emerged in the 1890s is one of the earliest forms of a prefabricated interior unit (Smith, 2010). The manufacturing of prefabricated units coincides with the on-site construction process, which substantially reduced the on-site construction time of the project. The coordination between manufacture and the construction manager at the early stage of the construction is imperative to ensure the products delivery time corresponding the construction phases. Furthermore, in sustainable aspects, the remaining construction materials can be efficiently recycled and reused for other projects in the factory environment, thus effectually reduce the vast construction wastes (Smith, 2010). One of the successful unit inventions is the prefabricated bathroom pod, which was introduced to the market to simplify the on-site construction process of a bathroom.

In 1947 the Architectural Forum magazine introduced the first standard prefabricated bathroom developed by Bertrand Goldberg. The pod can fit through a typical door, which facilitates the process of the delivery the pod into an interior space (Schneiderman, 2011). After years of development, the bathroom pod consolidated all the bathroom fixtures, piping, lightings, finishes, cabinets within a structural frame and ready to connect to the services onsite as shown in *figure 2.13*. It is critical to schedule the bathroom pod delivery time before the exterior installation. Since the pod size is oversized to fit into any conventional door or elevator, the preferred delivery method is to hoist the pod into the designated floor through the facade opening. Once the pods craned into the building, installers can immediately move them to the right location by using rollers or air

casters (Smith, 2010). he prefabricated bathroom pods offered an efficient alternative to the typical scattered bathroom design and construction, which inspired designers like Joe Colombo to investigate the all-inclusive prefabricated interior design.

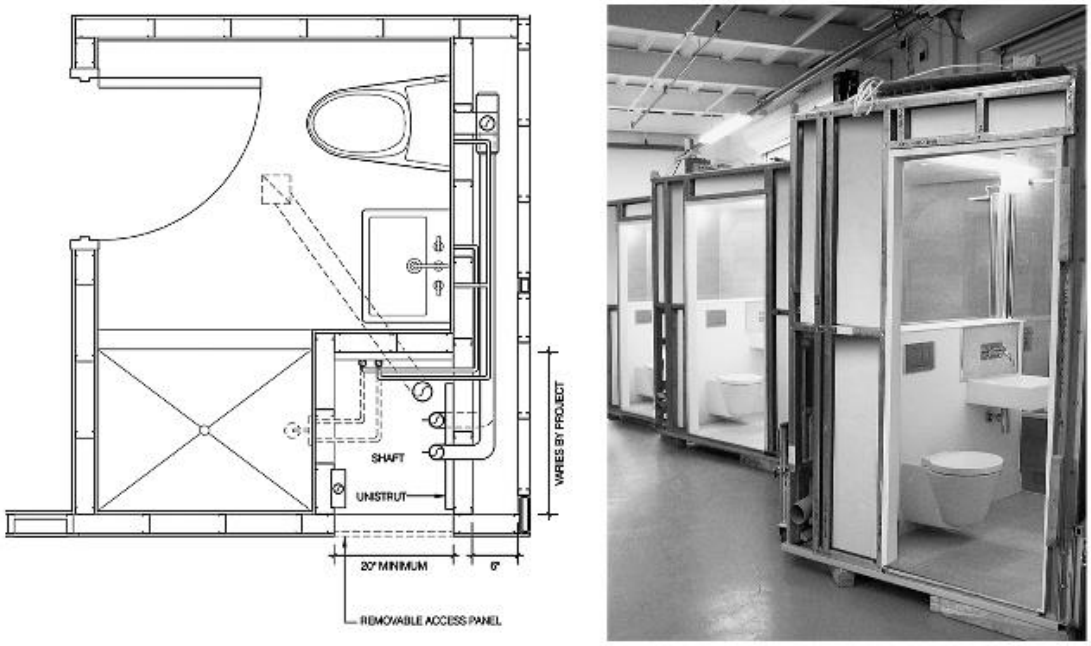


Figure 2.13. Bathroom pod, source: Smith, 2010. pp. 173.

In 1972, Colombo exhibited his integrative design, the Total Furniture Unit, at the museum of modern art in New York. In his proposal, kitchen appliances, bathrooms, storages and beds were all integrated into the unit design. In addition, the versatility and adaptability of this unit design can fit into multiple interior configurations (Schneiderman, 2012, p. 23). With minimum fieldwork for on-site services connection, the unit can instantly provide a habitable environment. Besides Colombo, a group of students from MIT later developed a similar all-inclusive unit for 200 square feet (18.6 m^2) micro-unit *figure 2.14*. The unit incorporated catering kitchen, folding bed and chair, table and storage inside and placed at the center of the room divided the space into three zones. The entire unit can slide to access shower room in the back. With simple adaptable folding and sliding techniques, each side of the unit can transform the space into various programs, which allows the apartment function two to three times as its original size. Furthermore, designers embedded motion and voice sensors to control the movement, lighting and sound system of the

unit (MIT City Science, 2012). Gradually the all-in-one prefabricated unit started to draw developers' attentions due to its convenience and flexibility.

Figure 2.14: Four scenarios of MIT City Home. Source: https://www.re-work.co/blog/connected-home-hasier-larrea

2.5. Manufacturing

Building prefabrication range from standardized elements to customized systems. Ryan Smith (2010) concluded that the prefabricated system could be categorized into four forms based on the level of cost, complexity and flexibility of the production process including Made-to-Stock, Assembled to-Stock, Made-to-Order and Engineered-to-Order.

- Made-to Stock (MTS): Highly standardized products without intricated details for mass production. These products can be easily obtained from the warehouse shelves, for example, lumber, wood, gypsum board and plywood.
- Assembled to-Stock (ATS): The building products developed based on the building code and standards. Certain degrees of customization is provided by a wide range of inventories, where customer can choose the products out of the available in stock, for instance, numerous types of kitchen counters, restroom vanities.

- Made-to-Order (MTO): The production of these products are based upon order; therefore, more options for customization compared to ATS products. However, since the customization is predetermined during the initial stage of the prefabrication process, MTO products have less degree of onsite flexibility compare to ATS products. Examples include prefabricated stairs, doors, and other elements can be manufactured in the same assembly line.
- Engineered-to-Order (ETO): These products are design, engineer and manufacture based on the particular scenarios. The high degree of complexity can be achieved with these systems. However, the price and production time is higher than any other forms of prefabricated products. In some cases, specialists are required for ETO installation. Examples include precast elements and custom furniture.

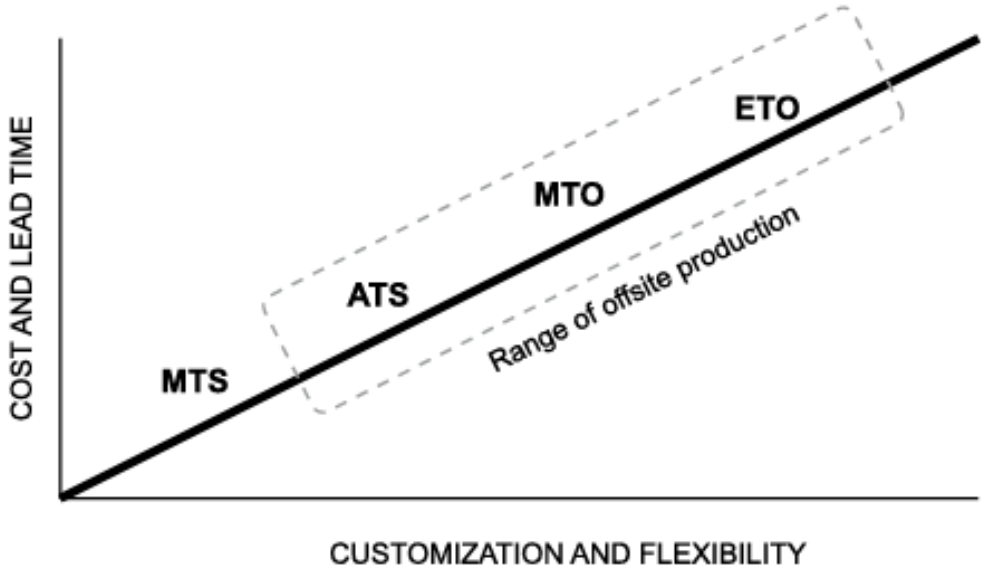


Figure 2.15: Considered proportional to the cost and lead time necessary for production. Source: Smith, 2010 pp 122.

As Smith (2010) illustrated in *figure 2.15*, the more complex of design, the more resources in term of time and cost is needed. MTS is the cheapest but less flexible option, whereas the ETO as the most expensive but entirely custom-made product. In some occasions, the classification can be simplified into the standardized off-the-shelf products and customized Made to Order product (Smith, 2010). The coordination between designers, engineers, fabricator and installer are critical since miscommunication among the team members might lead to extreme costly errors and failures

of building. Therefore, the advancement of technology effectively limited variations and reduced unnecessary errors during the production process.

The widespread of computer integrated technology into both design engineer phases and manufacturing phases has improved the accuracy, efficiency, and productivity of architecture prefabrication industry. For instance, introduction of the Building Information Modeling (BIM) system established a platform to encompass all stages of projects and the products' information into a digital model, which can be shared among all project stakeholders. This interoperable technology provides an efficient and productive path for teams to collaborate. In manufacturing fields, emerging of digital automation prefabrication tools such as CNC machine, laser cutter, 3d printers and water-jet cutters are capable of dealing with complex geometries and mass-producing the product with a high level of accuracy (Smith, 2010). In general, both design and manufacturing are benefiting from the integration of technology.

2.6. Conclusion

In general, despite the raising interests of architecture prefabrication, the discussion regards interior prefabrication remained whispering. There are three interior prefabrication approaches summarized by Deborah Schneiderman, which are Planar, Modular and unit. In addition, four forms of prefabrication products can be generally classified as in-stock products and made to order. The more complex and customized product generally require more time and investments. As the technology application of prefabrication industry advance, the overall quality of the final product improves due to better communication between stakeholders and more precise manufacturing methods.

Chapter 3: Case Studies

3.1 Introduction

In this chapter, the product research will be conducted with in-depth investigations of each of them based on the literature review from the previous chapter. Ten cases of contemporary adaptable interior approaches, including concepts and products, from around the world, will be selected and analyzed. These products are selected based on the following premises. First and foremost, the approach must be prefabricated and provide users with a certain degree of adaptability to their interior environment. Secondly, the concept must be innovative and leading-edge to provide an innovative insight into the residential interior design. Thirdly, the product or project approach should be applicable to the North American housing market, especially in a dense urban context. Namely, compact studio, urban apartments and other similar housing typologies can adopt this method in cities. Lastly, all the concepts or designs should be invented or continuously developed and modified within the last twenty years. Thus, to ensure the validity and relevance of this research to current market trends.

This research is aimed to identify adaptable design approaches and evaluate them based on the parameters highlighted in literature studies. A collection of applications at all different scales will be incorporated in this research, which attempts to inform potential audiences a comprehensive market study. Therefore, the case studies will be divided into four categories based on the scale of the product, including micro-scale accessories, mesoscale space divider and furniture systems, the entire house design at the macro-scale. Each case study will first describe the basic project information and rationale of the design. Follow by a thorough explanation of the design emphasis on the adaptable strategies applied to the design. After project introduction, the method of adaptability will be interpreted according to two adaptable theoretical frameworks introduced in the first part of chapter two – Steward Brand's building later theory and the six adaptable approaches by Schmidt and Austin. In addition, the method of prefabrication will be examined based on categories identified by Schneiderman and the manufacturing catalogue summarized by Ryan Smith. Thirdly, the application process of the product will be reviewed by investigating the delivery, installation and maintains, potential constraints and their pertinence to the North American context. Lastly, a short conclusion to summarize the system recapitulates the adaptable concept of the product.

In addition, a point-based rating system is introduced to evaluate the product. This system intends to offer an intuitionistic and pellucid conclusion to readers and assist them to compare products based on the scores. The rating system analysis three critical features of the product – Adaptability, the feasibility of application and suitability to the North American context. The Numerical rating system used the Likert rating scale with a maximum of five points, where each point indicates a degree of satisfaction. One denoted with completely disagree, and five represent completely agree.

The research starts with micro-scale accessory (cs 1), which can be incorporated in the furniture system and facilitated interior adaptability. The second category includes two types of space dividers (cs 2, cs 3); these case studies demonstrate two distinct approaches that assist dweller to achieve interior flexibility. The third category consists of five unique, adaptable furniture systems (cs 4, cs 5, cs 6, cs 7, cs 8) with different prefabricated methods. Lastly, two systematic approaches of entire house design (cs 9, cs 10), provide two precedents to achieve adaptability at the macro scale.

This market research intents to find the prefabricated interior designs that can facilitate dweller to adapt their living environment on both daily basis and long-term life changes. One of the preoccupations of the research is to identify the potential users of these innovative design. Based on product functionality, the feasibility of application and aesthetic features, a list of a potential customer will be highlighted in this research.

Lastly, the research is established based on both primary and secondary sources. The primary sources provide the basic product information, design intention, and principals, which is obtained from manufactures product's descriptions and documentation available on their website, photos and diagrams, videos representations, speeches and interview. In addition, secondary sources, including architectural review platform, online blogs, publications, news reports, will be reviewed to assist the analysis process.

3.2.1. Accessories: Case Study 1

Key Words: kitchen accessory, home office, living room, modular approach

Basic Information

- Product Name: EasyRack Kitchen Flat
- Designer: Decoma Design
- Company: Domusomnia, Italy;
- Product Feature: an adaptive stainless-steel counter track provides practical functions to help client personalize their kitchenware.
- Launched in: 2013| Source: (Domusomnia, n.d.) (Architonic, n.d.)

Figure 3.1: Top: Application on island kitchen worktop; Bottom: Variety applications illustration. Source: Domusomnia website, http://www.domusomnia.com/

The EasyRack Kitchen Flat system is an innovative and flexible kitchen design solution that provides additional utilitarian functions to the kitchen counter. Instead of working with limited counter manufactures, this system can adapt to all kinds of conventional kitchen system, including both wall-mounted and island counter scenarios. There are two main parts included in the product: a stainless step/flat frame and Corian accessory modules that fit in the track, as illustrated in *figure 3.2*. The frame served as a based that can fit into the hole on the kitchen countertop or mounted on the wall with special tools. The frame has 15 different sizes range from 900 to 3000 mm to fulfill the various situations. Drainage is embedded at the bottom of the track which can connect with the drain manifold.

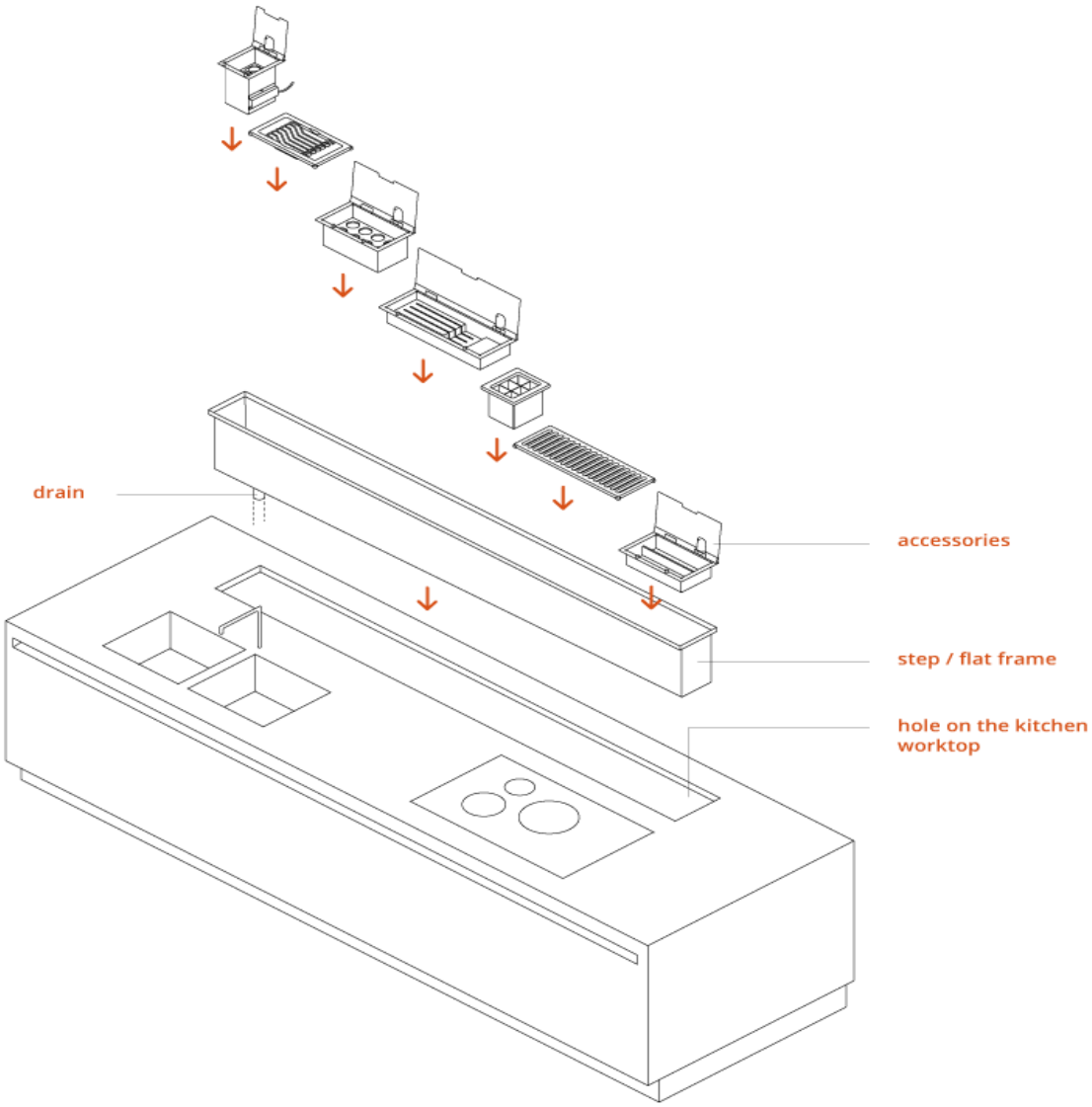


Figure 3.2: EasyRack Kitchen Flat System axonometric diagram.
Source: Domusomnia website, http://www.domusomnia.com/

The prefabricated accessories trays come with four modular lengths: 150, 300, 450, 600 mm and evolve into various functions to serve the kitchenware. Each module can be replaced and rearranged easily, which helps to divide the courter space into different functional zones. Besides regular functions like cutlery tray and dish racks, the accessory tray also included electrical appliances into the design such as docking station for electronic devices, sockets, and weight scale. Altogether 15 different trays are included in this product for the user to personalize their kitchen top.

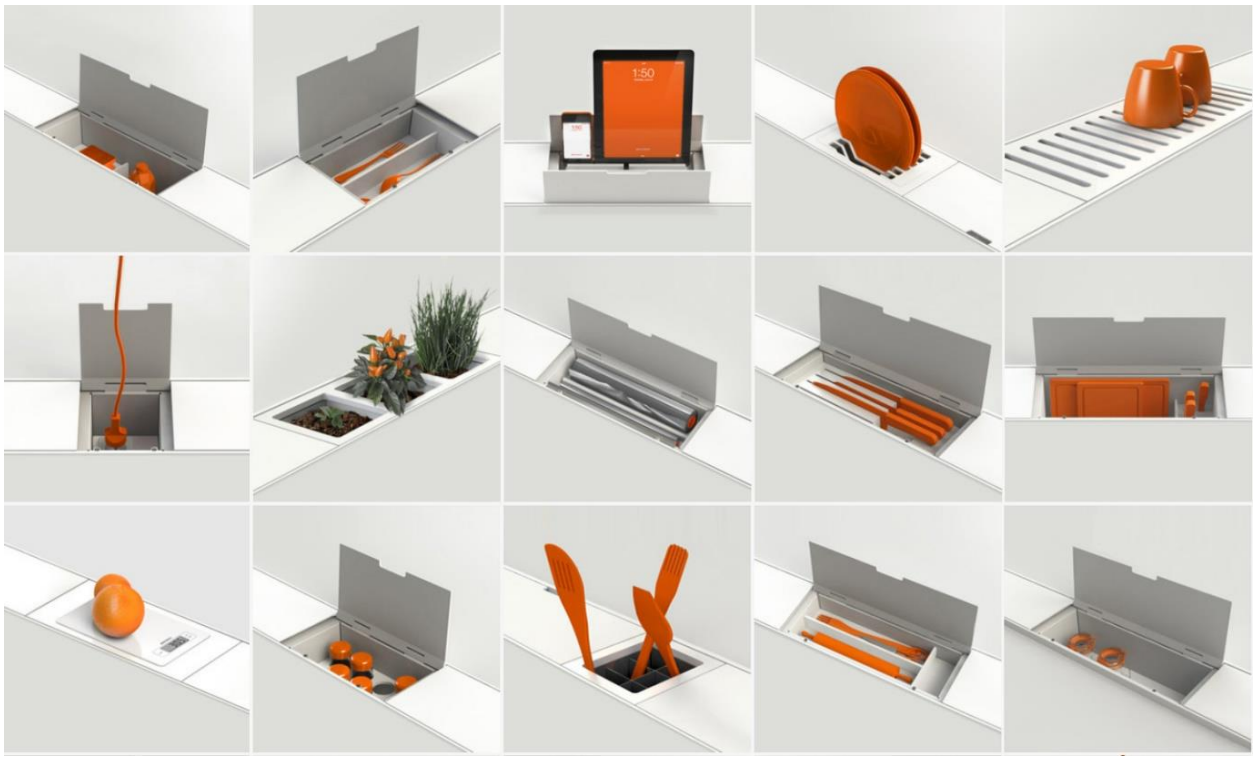


Figure 3.3: 15 variation of accessory trays
Source: ARCHITONIC, https://www.architonic.com/en/products/domusomnia/3104682/0/1

In addition to the kitchen counter flat, designers employ the vertical wall space under the wall unit. EasyRail Leaf (*figure 3.4)* reinterpreted the traditional kitchen rail and redeveloped fix accessories, which help clients to customize the kitchen space further. Similar to the EasyRack flat system, an aluminum triangular profile rail is nailed to the wall, which acts as a hook to hold the accessories. Four standard lengths are available from 900 mm to 2000 mm. The accessories equipped with diverse functions including shelves, glass holders, hooks, paper towel holder, table stand for electronic devices and knife holder. Users can easily install the rail, choose the accessories based on their demands and organize them along the rail according to their preference. Moreover, this

concept is not limited to kitchenware design; Domusomnia expands the EasyRack design to office space and living room design. As shown in *figure 3.4*, the design is flexible to adapt to the system to other scenarios by update accessories based on a specific case.to other scenarios by simply update accessories based on specific case.

Figure 3.4: Top: EasyRail Leaf for Kitchen; Bottom left: EasyRack Office product sample; Bottom right: 15 variations of accessory trays. Source: Domusomnia website, http://www.domusomnia.com/

Adaptable Strategies

- Layer integration: As an accessory product, the EasyRack products involved with the stuff layer and structure layer among all the other building layers. Most products are directly installed on the tabletop, and users can frequently reorganize the tray modules daily. However, it can only provide adaptability in a micro-scale, which is limited to the working surfaces. For the wall-mounted scenario, the system can only provide short term adaptability.

- Adjustability: User can purchase the prefabricated tray based on the function they need and their ability to adjust the layout. The accessory trays provide versatile functions to the conventional countertops. Additionally, integration of sockets and WiFi router avoid consumer to install intricate wiring system by themselves, while allows for more device plug to the system directly.

Prefabrication:

- Method of prefabrication: This accessory system is prefabricated modularly. Four sizes modules with 15 different functions allow the user to choose the module accordingly and fit the rack base, as shown in *figure 3.3*. Moreover, the track system also comes with 17 modular lengths from 600 to 3000 mm with 150 mm increment.

- Manufacturing: this product can be categorized as assembling to stock. The consumer can choose the track base length and accessories types based on their needs. The online system assists in customizing their Easy track system with a visual display (*figure 3.5*). According to the order, the modular unit will be assembled in the factory with prefabricate components in stock within four working days.

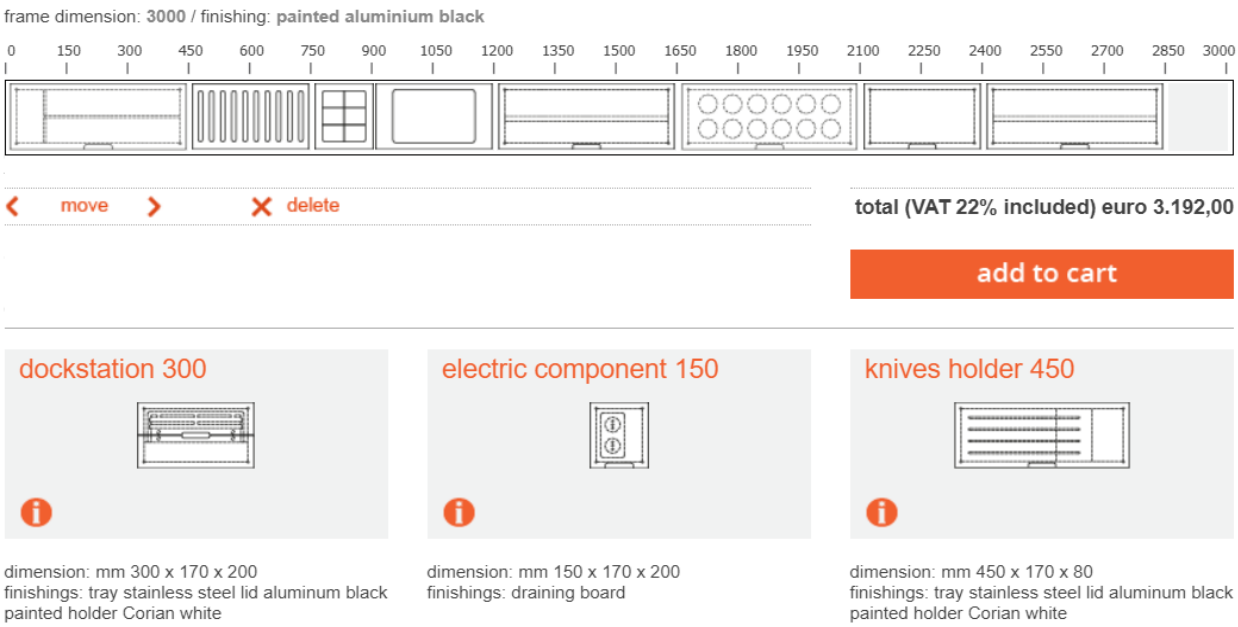


Figure 3.5: Shopping online system help consumer visualize their selection. Source: Domusomnia website , http://shop.domusomnia.com/domusomnia/easyrack-bordo.html

Applications

- Installation and maintenance: The EasyRack kitchen product can apply to both wall-based kitchen and island kitchen. For the island kitchen, a square hole with the precise size is required on the countertop to fit the frame into it. As the wall-based kitchen, a special wall mounting kit is available to create a shelf to set the frame. The next step is to connect the drain with original sink drain. Lastly, the end-user can drop the accessory tray into the frame. Since the product is targeted to design professions and carpenters, the installation process requires particular carpentry skill and tools such as the table saw, screwdriver and measuring tools. For maintenance, unless it involves relocating the rack, the accessory trays can be easily rearranged and replaced without requiring any special tools and skills. A short well-illustrated installation demonstration video is available online. It provides a step by step tutorial without any language description, which avoid language barrier for clients around the world.

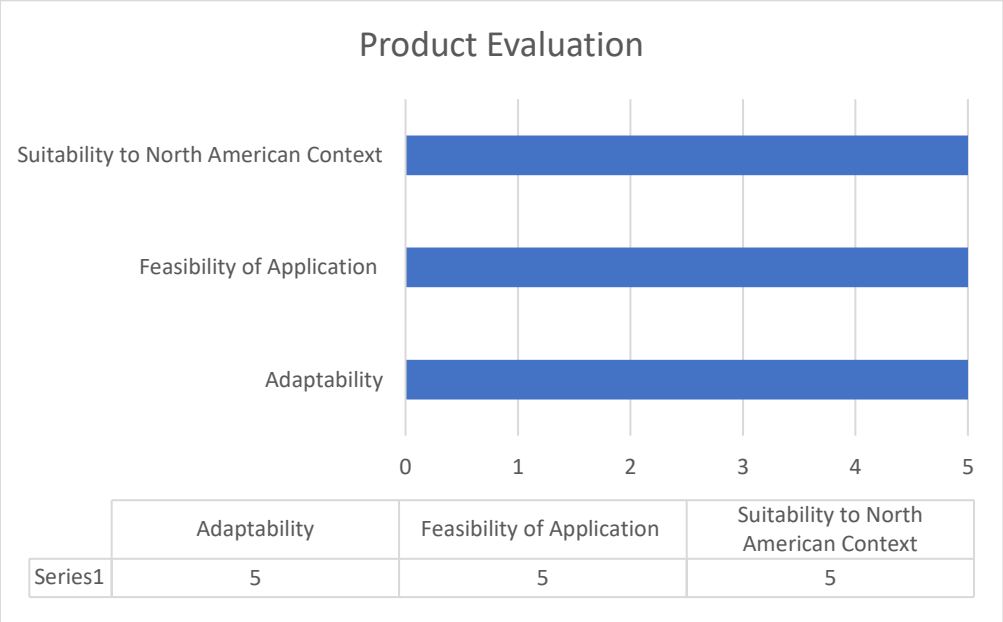
- Limitation: This product can only apply for linear condition. Another restriction is the location for the electric component and Dockstation. Since the electrical plug is wired to the mains, the user needs to specify the location in the order.

- Potential User Group: This product is applicable to all kinds of user groups. It can apply to both new construction tenant fit-out project and interior innovation project.

- North American Context: It is suitable for all kinds of construction systems since the system is relatively independent of the main structure and services system. For the wall-mounted case, the client needs to ensure the wall is suitable for installation.

Conclusion:

The EasyRack kitchen and the entire product series developed based on an innovative and flexible concept. This system consists of a rack that can adapt to various situations and prefabricated tray modules equip with multiple functions. Since the product requires a certain degree of skills in carpentry and special tools for installation, extra spending is needed to hire a professional to help the client set up the product. Regarding the fitness to north American context, the product only connects with the furniture system, and it can quickly adapt the interior fit-out in any countries around the world. Well illustrated installation videos diagrams and handbook achieve mutual understanding and remove the language barrier between the manufacturer and consumer.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series1	5	5	5

Table 3.1. Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS1.

3.2.2. Space Divider: Case Study 2

Key words: flexibility, partition, furniture, environmentally friendly, modular approach.

Basic Information

- Product Name: Softwall + Softblock modular system
- Designer: Stephanie Forsythe and Todd MacAllen
- Company: MOLO Design, Canada.
- Product Feature: a dynamic solution for interior space divider and furniture system made by 100% recycled Kraft paper.
- Launched in: 2003-2006 | Source: (MOLO Design)

Figure 3.6: Textile Softblock modular room divider, Source: Molo website, https://molodesign.com/collections/space-partitions/

MOLO Design introduced a freestanding interior partition design to provide a brand-new approach for space divider. Distinguish from conventional partition wall with rigid linear form, which also requires tracks to hold the panels in place; the flexible honeycomb geometry enables the Softwall to create both straight and snaking partition patterns without any track to support. The Softwall module comes with three different lengths 6 ft (1,829 mm), 8 ft (2,438 mm) and 10 ft (3,048 mm)

and the height can be customized or cut on-site to fit in the room. Two thicknesses are available 9.25 in (235 mm) and 13.3 in (338 mm), which provide stability for the product to stand alone without other structural support. Similar to the Softwall system, the Softblock provide three different heights 1 ft (305 mm), 2 ft (609 mm) and 3 ft (914 mm) to create a dynamic pattern of the wall surface. For instance, 2 and 3 ft tall block can provide seating for people. The blocks can stack on top each other form a dynamic wall surface, as shown in *figure 3.6*. With consideration of shipping and storages, the Softwall can be packed into flat box maximum 3 in (72 mm) thick. Two persons can carry the packed wall to site and unfold it up to 15 ft (4.5m) length. Moreover, Clients can customize the wall surface with special cuts to form shelves on the surface *figure 3.7*.

Figure 3.7: Top: Benchwall with high backed seating; Bottom left: Customised shelf space on softwall; Bottom right: Optional LED ribbons can light the honeycomb cell,
Source: Molo website, https://molodesign.com/collections/space-partitions/

With consideration of environmental impacts, the Kraft paper integrated recycled fibres or non-woven polyethylene textile with new paper fibres. This material with the sturdy matrix structure provides strength to hold up to 68kg per linear foot weight on top. In addition, the kraft paper is a non-flammable material, which meets the NFPA 701 fire rating test standard. The pleated pattern of the wall creates a desirable uneven finish to prevent parallel reflecting surfaces in the room; and the kraft paper absorbed the noise as well, to further enhance the acoustic quality inside the room and sound insulation between spaces.

At two ends of the block, magnetic panels are embedded in the wall to help the panels connect to each other, at the same time enhance the vertical structural stability of the product. Accessories such as handles and steel anchor strip are available to help the installation process. Another unique design characteristic is the integration of light in the soft wall and block system. The LED kit transforms the product not only serves as a space divider but also become a light source for the room (*figure 3.7*). Due to the flexibility of both products, there is no limitation for application; it can be used in several circumstances such as the museum, office, and residential.

Adaptable Strategies

- Layer integration: The Softwall and block series as free-standing space dividers, it engages with the space plan building level. Completely separating the space divider with the main structure, the self-standing feature maximizes end-users freedom to their room layout at any time of the day.

- Versatile: The flexibility and mobility of the wall provide dweller versatility to change the spatial layout of the room. It has well acoustic performance and fire ratings to ensure the quality of the room. With flexibility in height, people can create different spatial relationships. For instance, a floor to ceiling height wall can provide an isolated room in space, while the non-full height wall can create a semi-private space.

- Refitable: The Softwall and block system as a free independent product has no physical connection with other layers. This feature avoids interrupting the function of other building layers while rearranging the room layout.

Prefabrication:

- Method of prefabrication: The Softwall and Softblock system took the modular approach in prefabrication. There are two modular thickness and three different heights for Softblock. Two height modules for Softwall system.

- Manufacturing: This product can be categorized as the made-to stock highly standardized product. Limited size options are available in stock and consumer can choose to add the steel anchor strip on each end.

Applications

- Installation and maintenance: With five easy steps, a two-person team can install the wall effortlessly. First of all, before installation, people need to clean the floor, then two persons stand at both ends of the wall by holding the circular handholes and left the product 1in (25mm) above the ground. Pull handle accessory is available for purchase. Keep lifting the ends while stretching Softwall and repeat the stretch action several times until the wall reaches its maximum potential. Since the Kraft paper is a stiffer material, people need to hold in place for a few minutes. Follow by stretching is to fold the magnetic end to stabilize

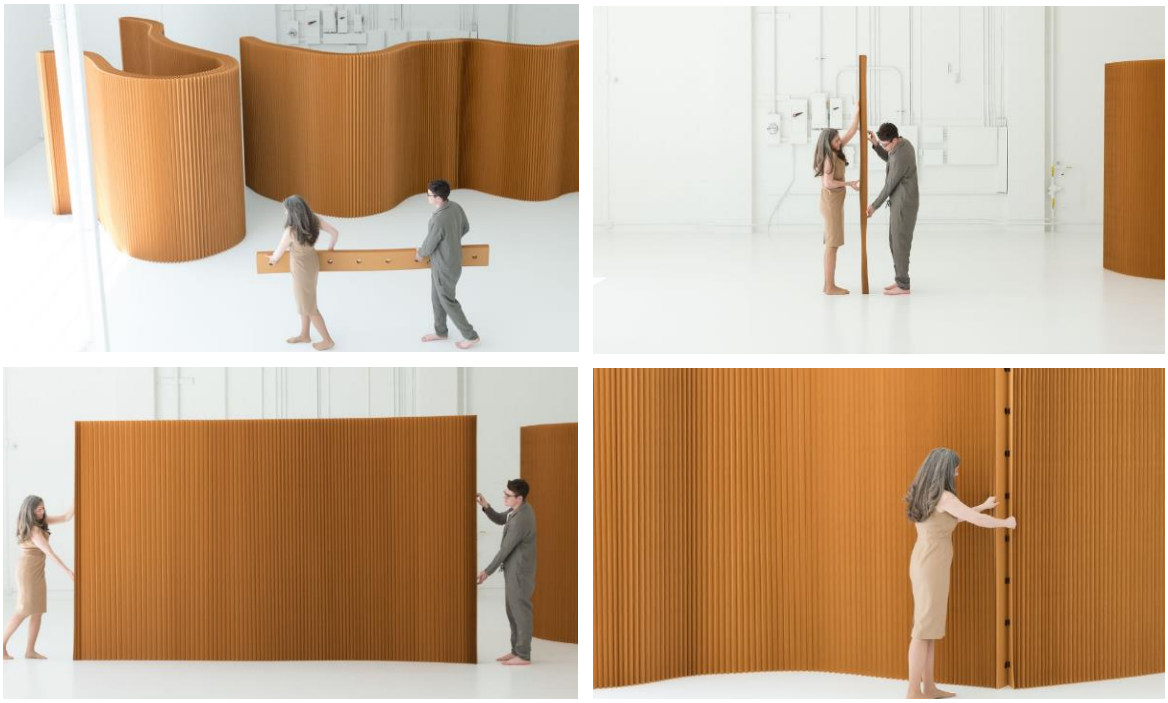


Figure 3.8: Softwall installation process,
Source: Molo website, https://molodesign.com/collections/space-partitions/

the panel. Lastly, the user can freely rearrange and shape the wall to the desired position. The installation can be done without any additional tools. The wall can be folded back to the original position when the room needs to adapt to a different layout. In terms of maintenance, the wall should avoid wet and humid conditions. Once in a while, the user needs to close the wall and left it compressed for a few days to regain the shape memory. Moreover, the Krafted paper is a 100% recyclable material. At the end of its life cycle, user can recycle the product simply removing the magnetic strips at two ends

- Limitations: Although the Kraft paper can hold up to 68 kg per linear foot weight, its still a delicate material. It requires constant maintenance and avoids using it in humid and wet condition. since the product is made by delicate material, the product is only suitable for indoor environment

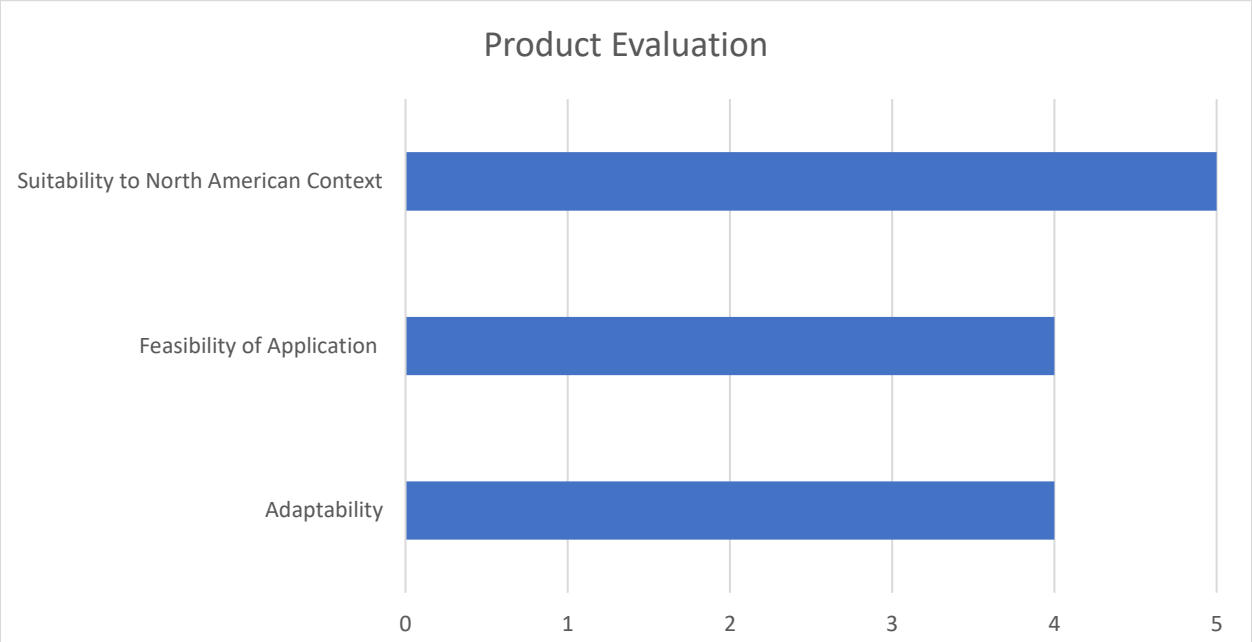
- Potential User Group: This flexible space divider is particularly suitable for families who are expecting to growth in the near future. In addition, the compact apartment can benefit from compressible features of the product, since dweller can pack the partition wall into a 3 in (76 mm) box and store.

- North American Context: This product is suitable for all kinds of construction systems, since it is entirely independent of the main structure and services system. It does not require any tracks installations. The variety of panel height option can fit the product into different room height designs.

Conclusion:

The Softwall system is a practical and dynamic interior space divider designed for providing users with the maximum flexibility to arrange their interior space. It achieves adaptability through versatility and refitability. Since it is a freestanding system, the product can fit different construction environments. Beside function as a space divider, the wall can become a light fixture by integrating the LED light strip into the wall. By changing the profile of Kraft paper, the Softwall system can branch out into other variation products, for instance, Softblock, Benchwall, thin acoustic wall, and shelf wall (*figure 3.9*).

Figure 3.9: Other applications of Molo product, Source: Molo website, https://molodesign.com/collections/space-partitions/



	Adaptability	Feasibility of Application	Suitability to North American Context
Series1	4	4	5

Table 3.2: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS2.

3.2.3 Space Divider: Case Study 3

Key word: home office, planar construction, movable partitions

Basic Information

- Project name: Switch
- Designer: Yuko Shibata
- Company: Yuko Shibata Office
- Project Feature: an interior space divider enables the dweller to renovate and transform their home between living and working mode.
- Published: 2010 | Source: (ArchDaily, 2010) (Shibata, 2015) (Etherington, Switch by Yuko Shibata, 2010)

Figure 3.10: The switchable book shelf. Photo Credit: Ryohei Hamada. Source: Archdaily, https://www.archdaily.com/83661/switch-yuko-shibata

Telecommuting is one of the ongoing trends has attracted people, especially young professional's interest in the past decade. According to the Census, in 2016 there was 7.4 percent population in Canada who chosen to work from home (Statistics Canada, 2017). Home office as a niche market in the housing industry is constantly seeking for design solutions to adapt existing residential space into working office without diminishing and interrupting the quality of the living space. One of the precedential project designed by Japanese architect Yuko Shibata effectively transformed an

87 square meter (940 sq.ft) three-bedroom apartment into a Home office, which allows the owner to switch their home between living and working during the day.

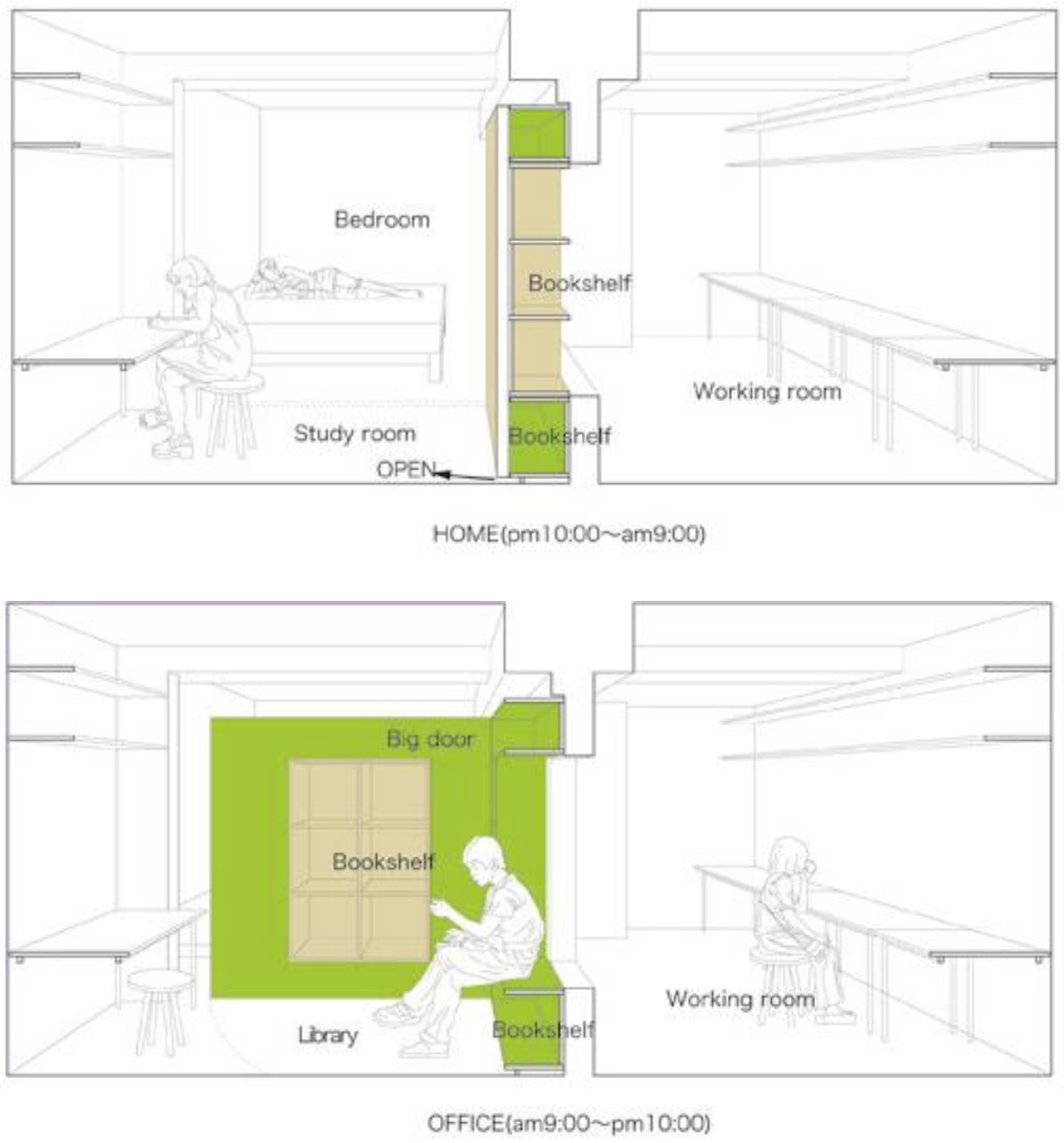


Figure 3.11: Bedroom/ work room perspective during different time of the day, Top, home 10:00pm-9:00am; Bottom: 9:00am-10:00pm. Source: Archdaily, https://www.archdaily.com/83661/switch-yuko-shibata

The apartment is a typical concrete box frame structure, which limits the architect to demolish any wall during the renovation process. Therefore, Shibata introduced two movable partitions in the house to define the space for a different function. The first partition located along the existing

dividing wall between in the bedroom, an opening is added to the existing wall as a passage to allow access to the study room without entering the private living space. During the daytime, the partition will open, which subdivided the bedroom into a sleeping zone and a reading space. At night the panel will be closed to give the study room back to the bedroom and provide privacy from the working room, as illustrated in *figure 3.11*. The bookshelf attached on the panel can be used in both study and working rooms. Furthermore, the wood finish on the bedroom side creates a warm living environment, while on the other side, the bright green finish makes the room seems spacious visually.

Figure 3.12: Space transformation in bedroom. Photo Credit: Ryohei Hamada, Source: Archdaily, https://www.archdaily.com/83661/switch-yuko-shibata

The other innovation effectively switched the in the dining room into a multifunctional space, with bookshelves built against the wall between the kitchen and dining room. A track was installed on the ceiling to hang a full-height partition panel the track. Multiple openings are cut out from the panel create a passage doorway and viewing hole. During the working hours, the panel can slide open and divide the space into two zone-a library space and a meeting room. After work, the panel will be put against the shelf wall leaving the entire room for dining and living purposes.

By understanding the cyclical properties of our human lifecycle and ingeniously utilising the simple mechanical system, the architect was able to integrate both functions coexisting in one space. Shibata took advantage of the lifecycle and design the space according to the potential needs associated with these two functions. With these two additions, the dweller can adapt the apartment from home to office with a simple move.

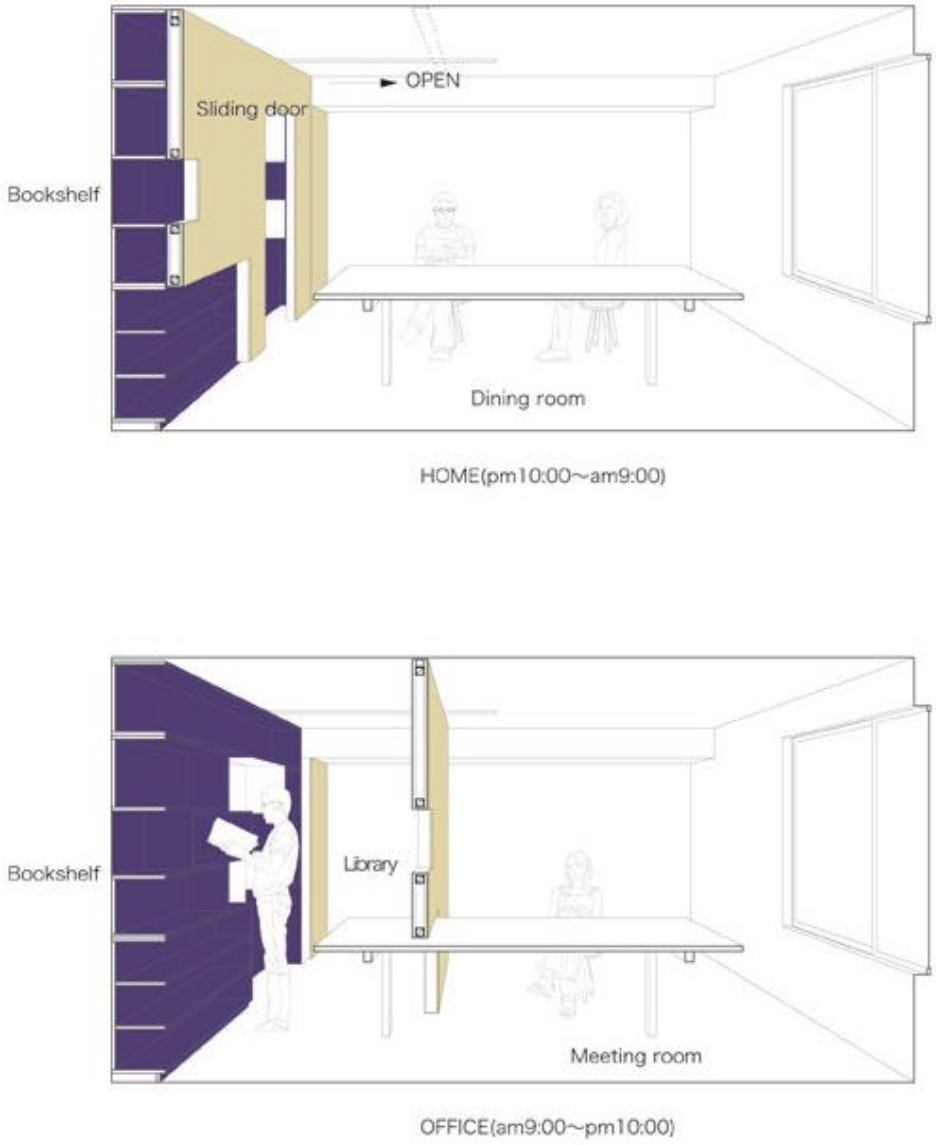


Figure 3.13: Dining/ Working space perspective during different time of the day, Top: Home 10:00 pm- 9:00 am Source: Archdaily, https://www.archdaily.com/83661/switch-yuko-shibata

Figure 3.14: Space transformation in the dining/working space. Left: dinning space, Right: Library/ Meeting room Photo Credit: Ryohei Hamada, Source: Archdaily, https://www.archdaily.com/83661/switch-yuko-shibata

Adaptable Strategies

- Layer integration: The Switch project involves both space and stuff building layers. These two space dividers can be slide or open to subdividing the space into other functions. The prefabricated space dividers intelligently fit into the existing room without making changes to the load-bearing walls. However, there are minor modifications of the existing non-load-bearing wall to cut more opening for access and visual connection.

- Adjustability: In the dinner /meeting room, the movable sliding panel can be move along the track, which allow dweller to decide how much room they need to occupy for each function.

- Versatile: Both partitions are versatile to be able to change the physical space plan within the load-bearing structural frame. Castors and sliding tracks provide partition movability to adapt the space.

- Convertible: This project using movable partition and simple mechanical tactics to enable both living and working coexist in the same apartment. By taking people's daily schedule

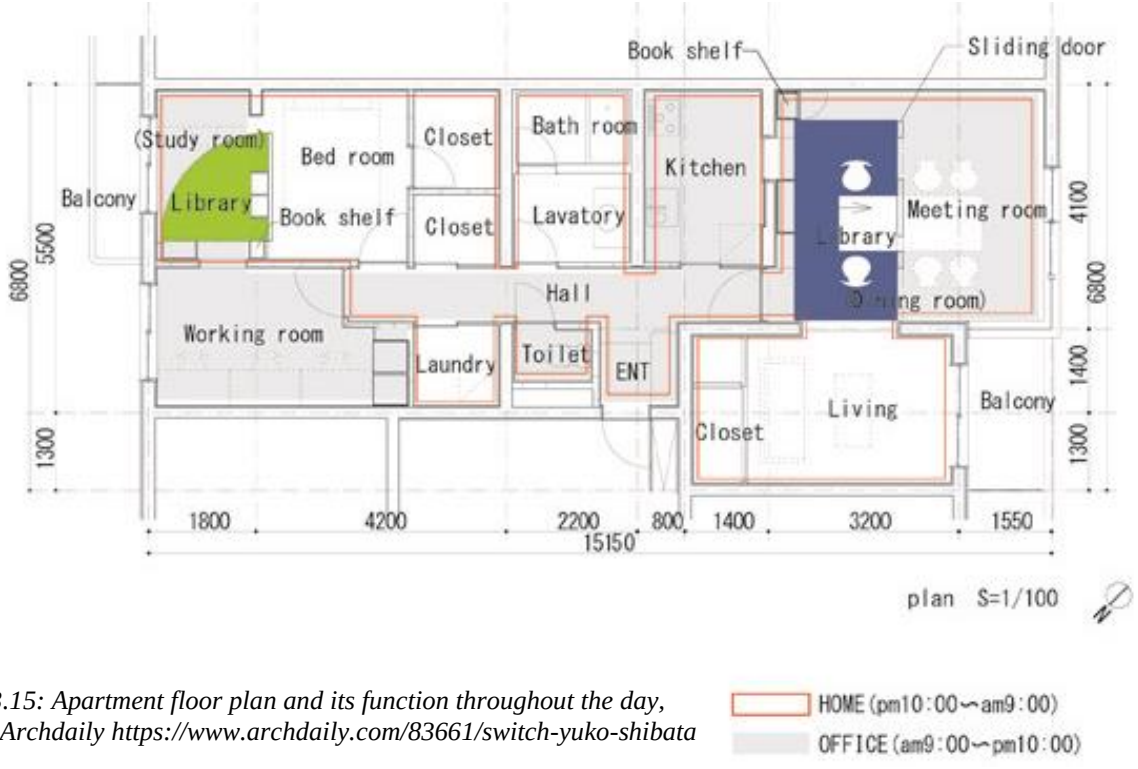


Figure 3.15: Apartment floor plan and its function throughout the day, Source: Archdaily https://www.archdaily.com/83661/switch-yuko-shibata

into account, the design created function neutral spaces to provide flexibility for different settings. As for highlights in *figure 3.15*, the entire house can be categorized into two zones- working and living space, where the working/dining room and study room in the bedroom are the flexible neutral zones that can be used for both day and night. This concept also avoids wasting space or renting another office for the owner, which eventually save them money on operating their business.

Prefabrication:

- Method of prefabrication: These two prefabricated panel partitions are closed systems, which are pre-assembled in the factory and delivered to site. As mentioned in chapter two, this approach avoids the complication of onsite installation.

- Manufacturing: These two panels are designed and customized specifically for this apartment unit and clients needs. This manufacturing approach is engineered-to-order.

Applications

- Installation: The partitions might be prefabricated different pieces and shipped on-site for assembling since both partition wall does not seem fit into a typical door opening. The entire renovation process requires professional interior contractors to prefabricate the components and install them.

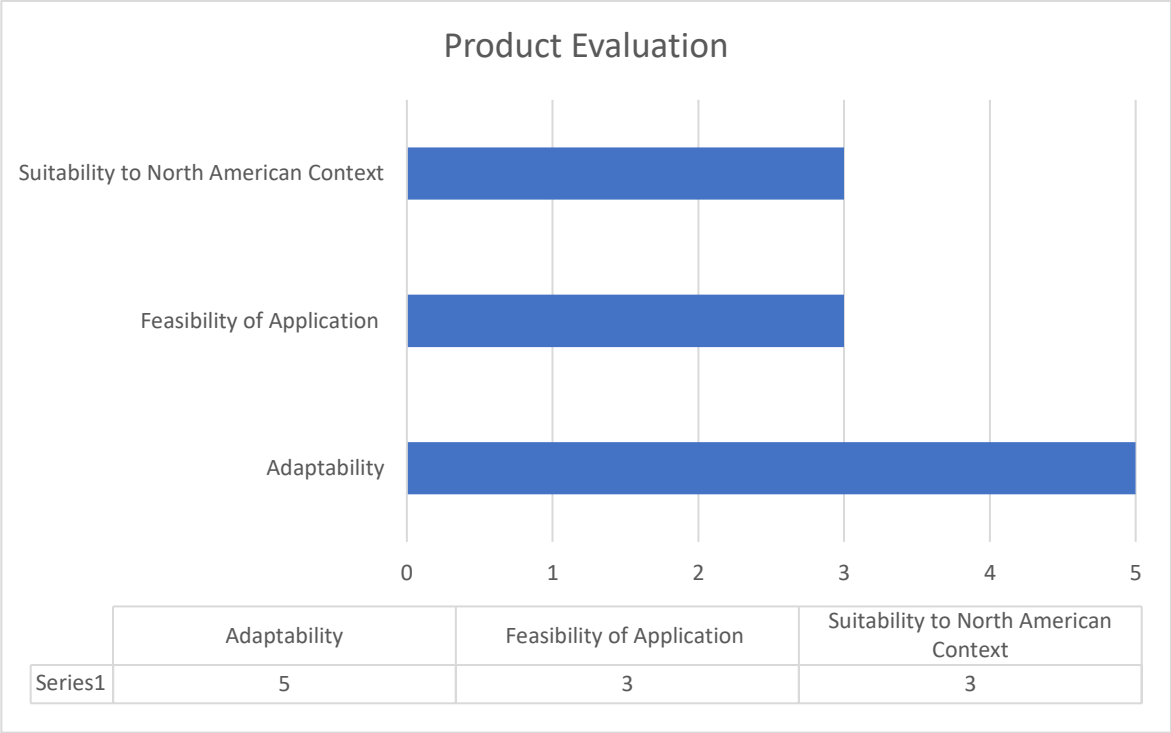
- Limitation: Since both panels are Engineered-to order, it requires professionals to design, manufacture, and install the system. Based on the architect's design intention, additional openings on the wall is necessary to provide a shortcut for people to access another room without interfering the privacy of other spaces.

- Potential User Group: This project provides insight for dwellers who are seeking a flexible design solution for their demand for working at home. Beside work at home scenario, the concept can provide spatial flexibility, and temporary subdivide a room for different functions.
- North American Context: This concept could be easily adapted to North American homes since the space divided can be installed without changing any load-bearing structures.

However, the partition in the working/dining room requires a track system, which might not be feasible in some scenarios.

Conclusion:

The Switch project intelligently provides a new perspective for home office design. By understanding the nature of lifecycle, the architect was able to use the same space for different function throughout the day. This concept provides a cost-effective alternative than renting an office space for the business.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series1	5	3	3

Table 3.3: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS3.

3.2.4. Furniture System: Case Study 4

Keywords: panelized space creator/furniture, planar approach

Basic Information

- Product Name: 90 degree furniture | FLSK(flex) workspace
- Designer: Louwrien Kaptein (interior architect) and Menno Bolt (designer).
- Company: Kapteinbolt, Netherlands
- Product Feature: a panelized system creates a dialogue between space and furniture.
- Published: 2008 | Source: (Kapteinbolt, n.d.) (Etherington, 2010)

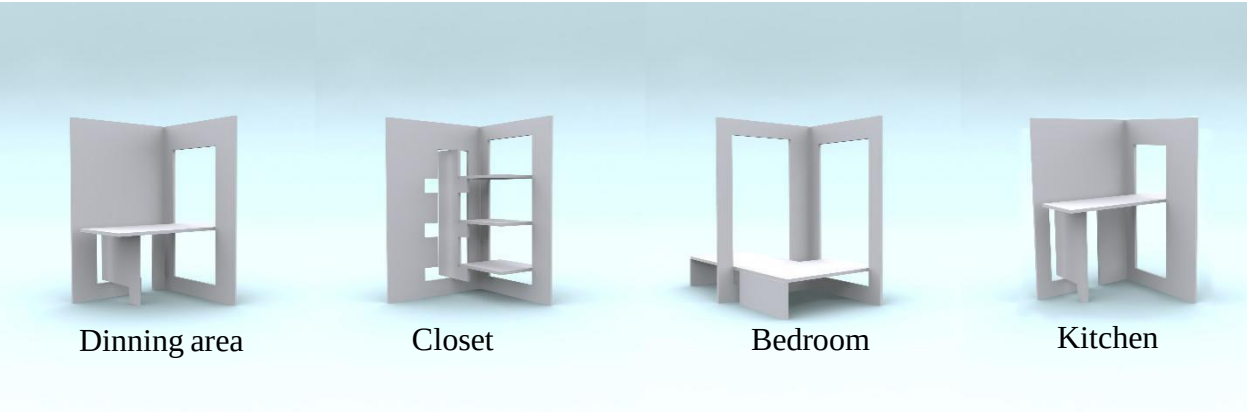


Figure 3.16: Four conceptuses illustrations of 90 Degree Furniture set. Source: Kapteinbolt website, https://kapteinbolt.nl/projects/90degreefurniture

90 Degree Furniture is an interior furniture concept developed by Dutch interior design firm Kapteinbolt. Designers aimed to create a dialogue between furniture and they believed the essence of furniture is the creation of space. This system utilizes two simplest gestures: unfolding, rotating to transform a 2D panel into a 3D space with specific internal functions. There are four assemblages introduced, including a working unit, a sitting and sleeping unit, cooking unit and storage unit, as shown in *figure 3.16*. Each unit is established based on a folded plywood panel broad. Geometry was pre-cut on the panel and secured by stainless steel pins during transportation. The horizontal and vertical planes are formed by unfolding and rotating the pre-cut panels. The size of the panel is 44 in x 72 in (1,117 mm x 1,829 mm), which is designed based on Le Corbusier's modular concept of human size. Ultimately, by arranging these four units together and create a sense of enclosure with different functions interact with each other. Users can decide to

use the unit individually or combine them in a different arrangement; therefore, create multiple spatial compositions (*figure 3.17*).

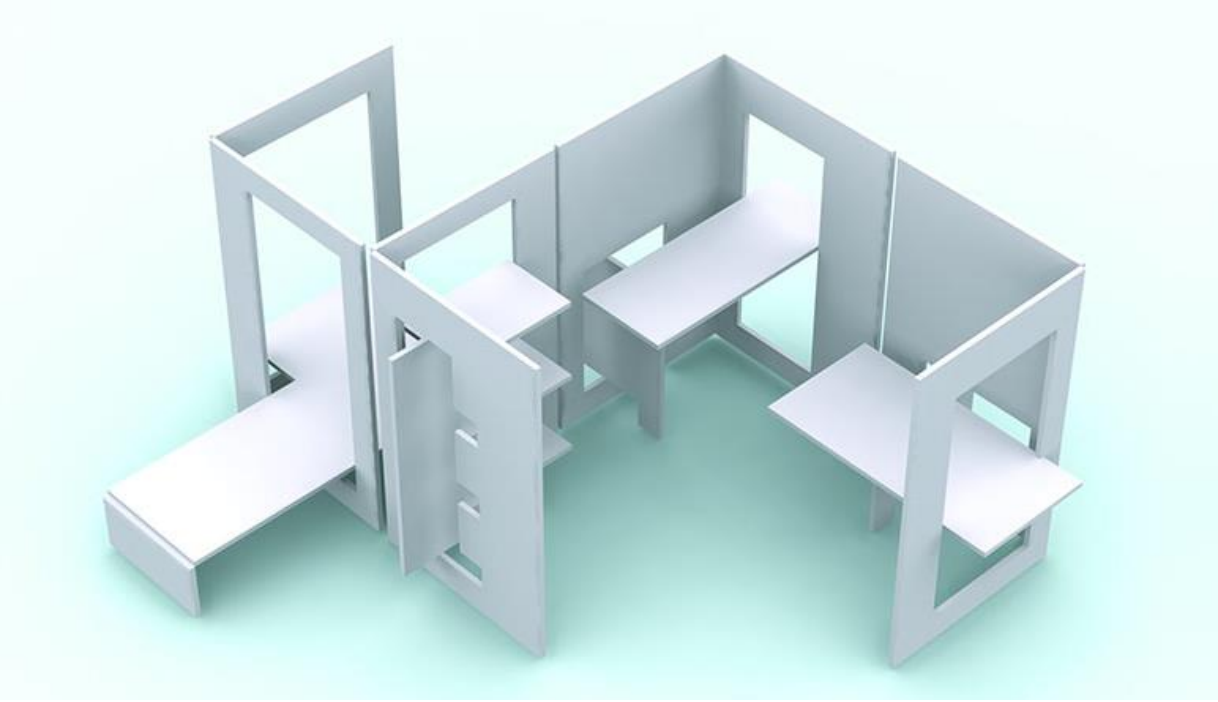


Figure 3.17. Combination of these four furniture sets. Source: Kapteinbolt website, https://kapteinbolt.nl/projects/90degreefurniture

One of the first built up prototype is the closet assembly. As shown in *figure 3.18*, the assembly delivered a double folded panel with pre-cut profiles. The transformation begins with unfolding

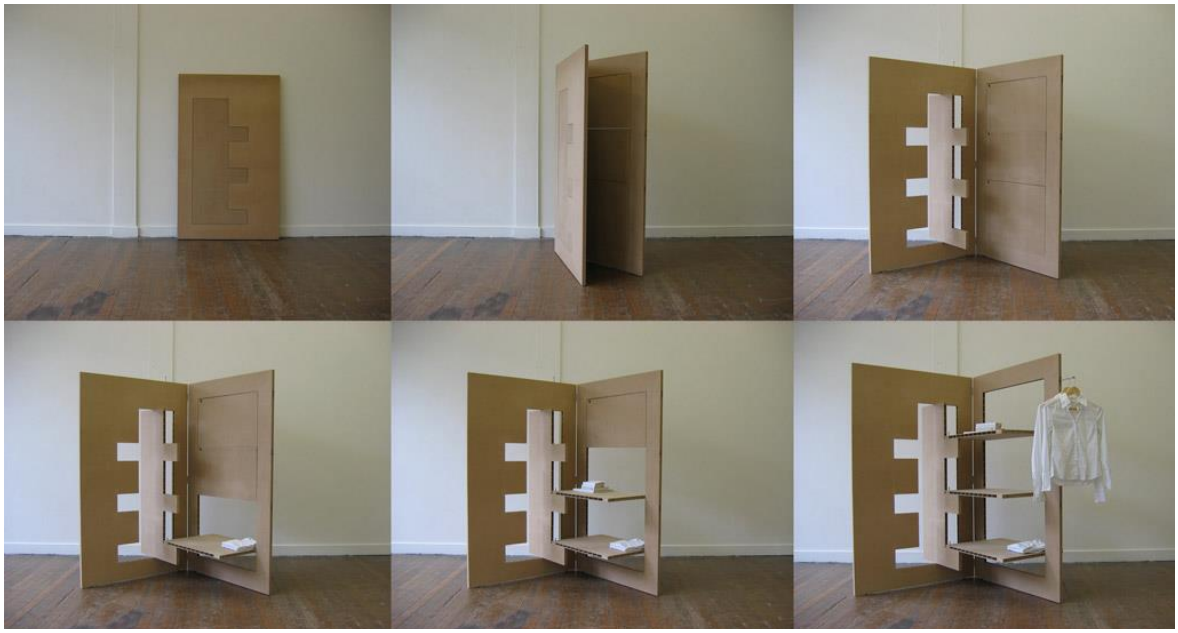


Figure 3.18: Process of setting up the closet system. Source: Kapteinbolt website, https://kapteinbolt.nl/projects/90degreefurniture

the double panel to 90 degrees and starts to create a discrete space in the room. Follow by rotating the pre-cut panel perpendicular to the main panel and unfold the shelf planes down. The steel pins used for secure panels during shipping can be reused here as a hook to hang cloth. Designers intentionally left the product unfinished to enable the client to decide the finishes as they want. Another built prototype is the FLKS (flex) workspace. This design intends to serve clients, who are seeking flexible home-office design solutions. The panel is made by birch plywood and similar technique applied in this product. The system consists of a folding desk, a chair and a frame to define enclosure in space (*figure 3.19*).

Figure 3.19: Process of setting up FLKS workspace.
Source: Kapteinbolt website, https://kapteinbolt.nl/projects/90degreefurniture

Adaptable Strategies

- Layer integration: The 90 Degree system as free-standing furniture system is completely isolated from other building layers besides the stuff plan layer. The self-standing feature maximizes end-users ability to set up the room with the different unit set.

- Adjustability: This system achieves adjustability through developing variations of units based on the simple folding and rotating concept. The design team introduced four furniture units with unique functions and allowed users to choose the combination and arrangement of these units.

- Versatile: The flexibility and portability of these furniture sets provide dweller versatility to change the spatial experience of the room. As the designer highlighted, these products

use furniture to define discrete space. The panel package provides convenience during shipping and saves space for storage.

Prefabrication

Method of prefabrication: A 2D planar board makes this funiture system. By cutting the profiles on the board and drilling holes for the pins, this 2D plane can be transformed into a 3D space.

Manufacturing: Currently, since Kapteinbolt is a Startup company, all the product is handmade upon order. However, this concept has the potential to be mass-produced as the company grow. It can be either Made-to stock for standardized types or made-to-order for more special occasions.

Application

- Installation and maintenance: Regarding to the installation, the prefabricated panel include all the necessary kits and parts that is required for setting up the units. The steel pins that used to secure the panel in shipping will also be used for installing the panels or function as a hook. Since the product is portable no special delivery method is required. The installation procedures are straight forwards and no special tool or skill seems required.

- Limitation: Although the designers started prototyping the design by introducing the first Flek workspace product line, the product could be optimized in multiple ways. Functionality wise, this product only provides basic planer surface without out integrating any appliances into the design. for instance, the kitchen unit only provide a table surface without considering employment of stove, sink those basic kitchen appliances, which limited the kitchen only suitable as a snack bar space. Despite the multifunctional strategies, lack of adjustability of each unit affect the user experience with the product. Specifically, users cannot adjust the table and chairs height to reach comfort. Therefore, to further develop this product, designer should take consideration of the practical function relate to the product and allow flexibility for both macro and micro level.

- Potential User Group: The FLSK Workspace is an ideal product for home office situation especially for apartment dwelling unit with limited space. Since the system is a temporary setting, it can be packed and stored after working without requiring a room for it. This allows user to adapt their room for multiple functions.

- North American Context: As a free-standing furniture product, it is suitable for all kind of construction system. In addition, the prefabricated panel size can fit through typical residential doors, this avoids complication during delivery process.

Conclusion:

The 90 Degree furniture and FLEK workspaces using simple movement transformed the prefabricated panel into a 3-dimentional space. Four furniture proposals were introduced including working, sleeping, cooking and closet. The entire system is pre-assembled and self-supporting to ensure the product maximum adaptability. Since the design is at early stage of development, integration of appliances and product adjustability requires further research and refinement. This product has the potential entering north American market due to its flexibility and independency from other building layer system.

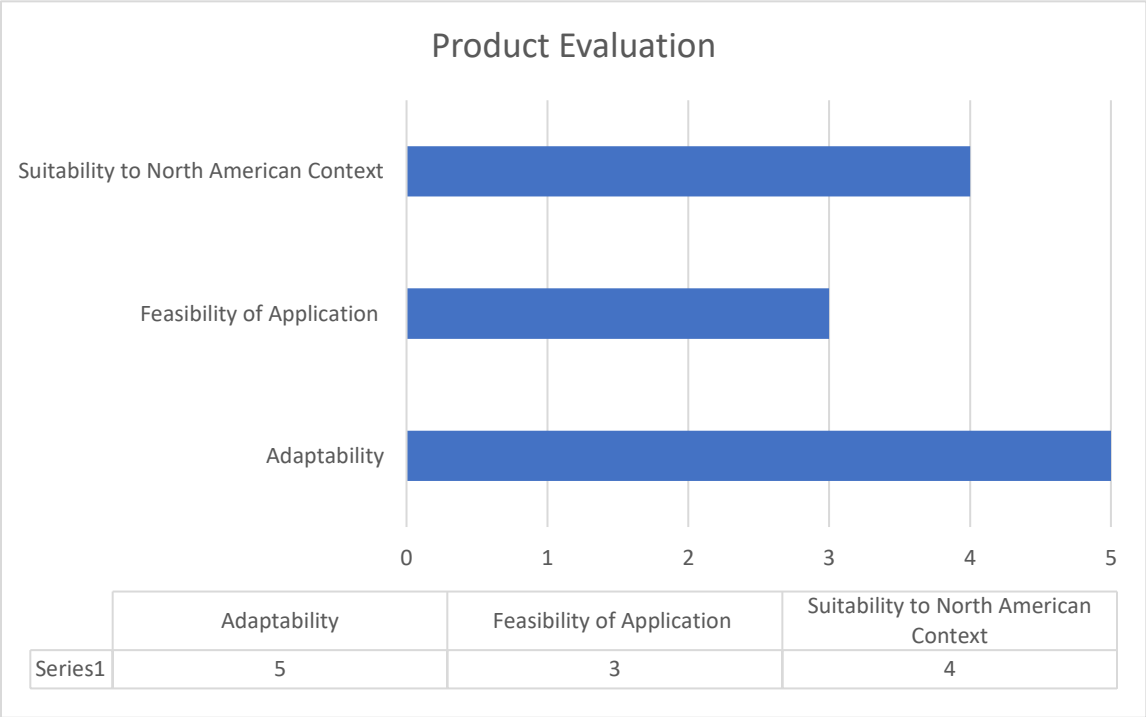


Table 3.4: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS4.

3.2.5. Furniture system: Case Study 5

Key words: Modular approach, kit of part, storage system.

Basic Information

- Product Name: Haller & Haller E system
- Designer: Architect Fritz Haller and engineer Paul Schärer
- Company: USM, Swiss.
- Product Feature: A modular approach system empower the user to customize and individualized the interior shelves.
- Originally designed in 1963, the new Haller E system introduced to the market in 2017.

Figure 3.20: UNStudio designed USM's Salone del Mobile booth. Source: Dezeen, https://www.dezeen.com/2019/04/18/usm-unstudio-milan-design-week-video/

In 1963 Swiss architects and engineer Fritz Haller and Paul Scharer collaboratively designed the first version of Haller shelving system. In the original design, they introduced a modular system assembled by three kits of parts: an around-shaped joint adaptable in six directions, adjustable connection inserts connect with the joints and hollow steel tube act as the main grid structure of the shelf (*figure 3.21*). With seven different lengths of the steel tube range from 4 in (102 mm) to 30 in (762 mm), the system can reconfigure into ninety kinds of combinations, where each module configuration associated with a unique possible function. Inside the modular grid, there are wide ranges of infill panels and accessories available for the customer to define the function of each module. For instance, they can choose the profile of the panel, which side to install the panels, extension shelves, drawers and the colour of each module. Furthermore, USM tailored twenty-five types of accessories intent to generate an evolving system that can assist its customer to define the infill modules.

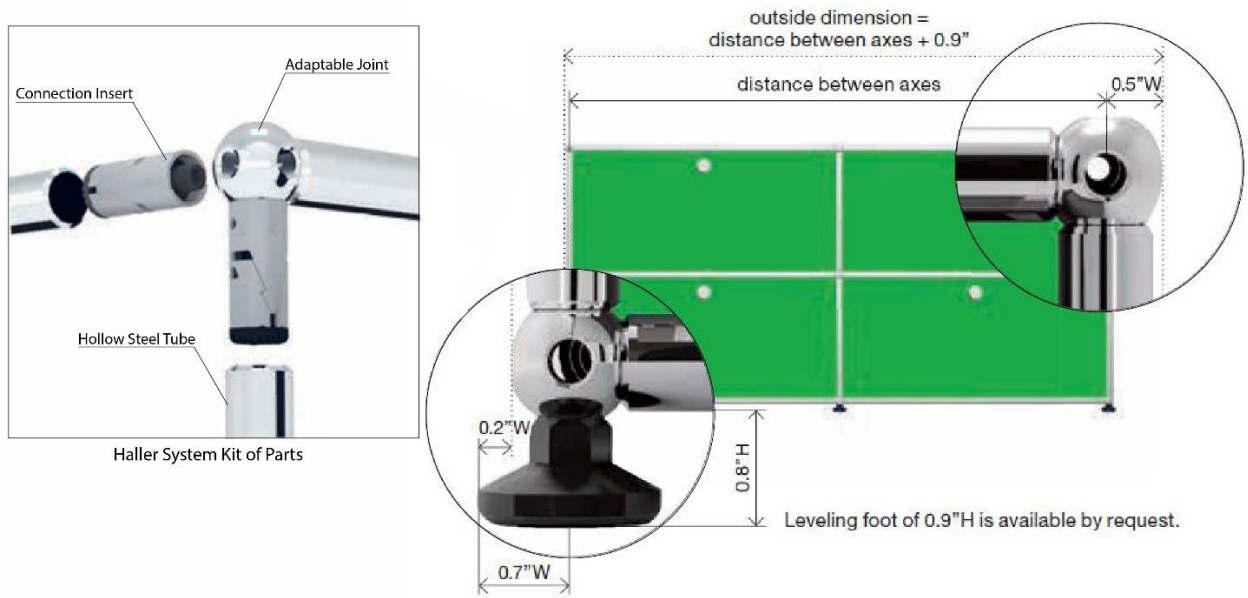


Figure 3.21: Kit of parts for USM Haller system. Source:USM website, https://www.usm.com/en-us/modern-home/

With different compositions of modules, this kit of parts system can create all kinds of furniture suitable for both office and residential interior environment, including shelf storage, workspace, closet, credenza and coffee table (*figure 3.22*). This flexible system is capable of not only as a piece of furniture, but also it holds the potential to build a unique interior spatial experience.

Figure 3.22: Various application of USM system Source:USM website, https://www.usm.com/en-us/modern-home/

In the modern home environment, the demand for electrical appliances drives the classic Haller system move forward. In 2017 USM introduced the new Haller E collection, where electrical wiring, USB charging port, and lighting fixture are embedded into the hollow metal tube. Taking advantage of the hollow steel tube, designers able to seamlessly integrate the electrical system into the grid and only require a simple plug to the main outlet. Moreover, the dimmer switch allows the user to control the brightness and the lighting temperature for a different purpose. In terms of adaptability, the charging portal and lighting fixture are modularized and can fit into a standard power outlet socket. User can easily switch the elements by following the instruction (*figure 3.23*).

Figure 3.23: Haller E collection. Top Left: USB charging port; Bottom Left: LED lights; Right: Haller e kit of parts. Source: USM website. https://www.usm.com/en-us/modern-home/

The kit of parts approach allows USM to mass-produce the Haller product. Furthermore, with understanding the privilege of mass customization to the product marketing, USM developed an interactive online-shopping interface to help consumers to customize their Haller unit, as shown in *figure 3.24*. The interface starts with designing the size of the shelf by choosing the number of

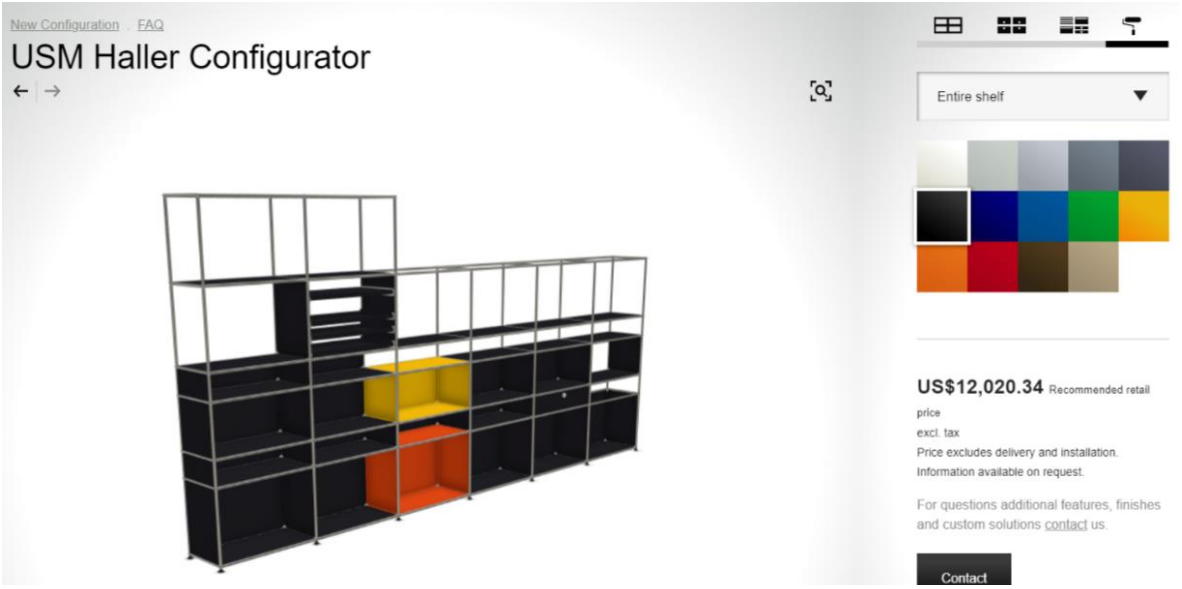


Figure 3.24: Online shopping portal. Source: USM website, https://www.usm.com/en-us/modern-home/configure-your-own/

modules. Once the shelf size is decided, the user can modify individual module configurations and then chose the infill system into the grid. Follow by that is personalize module by selecting accessories such as extended shelves and drawers. Lastly, the customer can pick the colour for decoration. While customer making selection of the product, a real-time 3D viewing portal on the left allows the user to rotate, zoom in and manipulate the configuration. This system allows customer better visualized the product they choose

Adaptable Strategies

- Layer integration: The Haller system falls into the stuff building layer. Besides the electrical plug for the Haller E product, it has no physical connection with the main structure and services systems. Thus, the module can be located anywhere in the room.

- Adjustability: The Haller E series provide adjustability to control the lighting brightness level. In addition, the kit of the part system can build a variety of functional assemblies. This system can be used for both office and home environments. The collections of 25 accessories elements, empower users to adapt and personalize the shelving system.

- Refitability: Along the building lifecycle, the user needs to retrofit the room to meet their current needs. The kit of part gird structure enables users to change the configuration or function of Haller product. User can uninstall the original parts and rearrange them into different layouts since the Joint ball can adapt the tube in six directions.

Prefabrication

- Method of prefabrication: The Haller product is a modular prefabricated system, assembled with three kit-of-parts — the flexible joint, connection insert and hollow steel tube. In Haller E collection, LED light fixture and the USB charging plug are modularized and fit into the standard power outlet socket.

- Manufacturing: The Design Your Own online shopping portal guide the user to customize their Haller system based on their requirements. Consumers can select the modular size and accessories among the serval dimensions predetermined by the manufacturer. In order

to meet as much client's demand as possible, USM provides seven different lengths of the hollow steel tube to build over ninety kinds of shelving units. The production will be processed based upon order, which is known as Made-to-order. Therefore, once the product is manufactured, it will be hard to modify the assembly on site.

Applications

- Installation and maintenance: The installation process requires professional USM authorized specialist assistant, there will be an additional cost associated with it. User can only replace the e-inserts (the lighting elements and USB portal) independently.

- Limitation: Since the product equipped electrical appliances in the steel grid structure, the Haller E product require precaution for short circuit by avoiding contact metal object with the E-Ball (the joint ball).

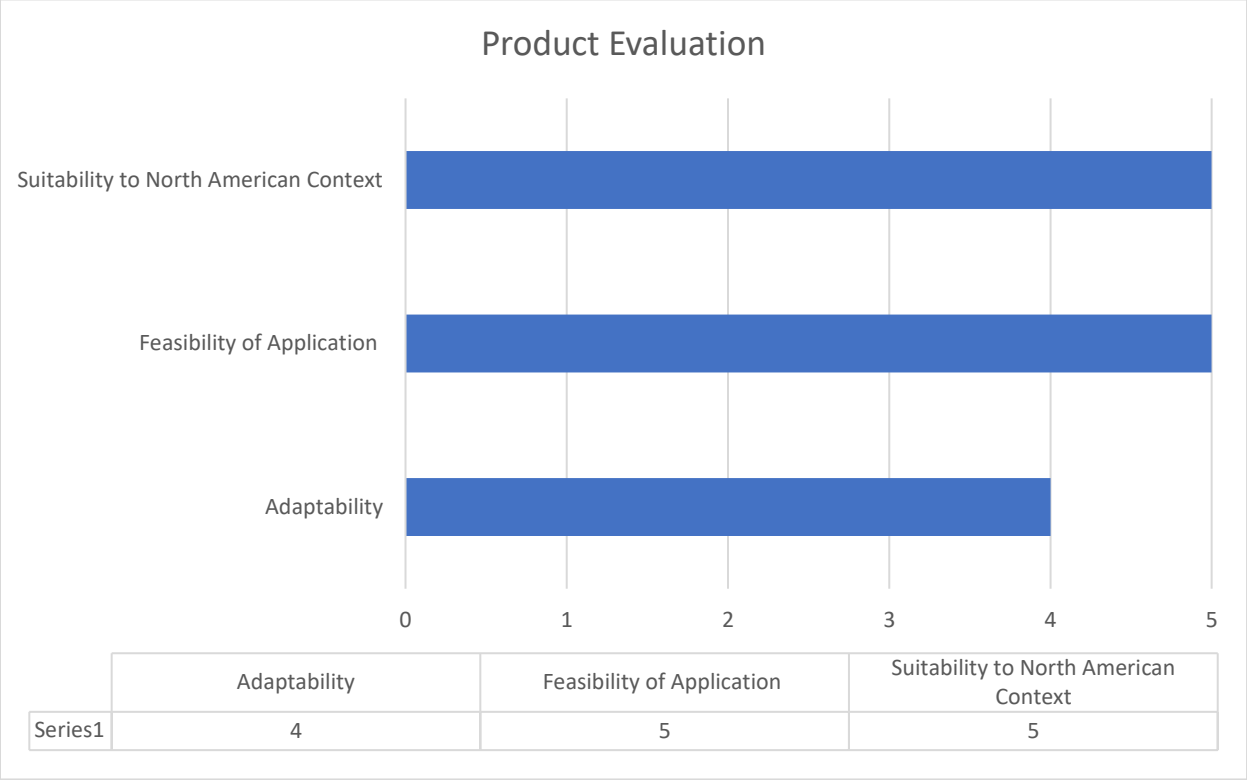
- Potential User Group: This system applies to all kind of user groups. It can apply to both new construction tenant fit-out and interior innovation project. As previously mentioned, this product can provide all kinds of storage solutions to living, bedroom, kitchen and home office space.

- North American Context: Similar to all other free-standing interior furniture pieces, the Haller system is suitable for all construction system.

Conclusion:

USM uses the kit-of-part modular approach to create a highly flexible and adaptable interior storage system. The Haller system can be adapting to serve for multiple residential interior spaces including kitchen, living room, bedroom, home office and restroom. Along with the building life cycle, the Haller product can be reconfigured to meet users' need over time without interfering the normal building functions. Integration of lighting and charging portals further equipped the system with the trend of demand for new technology in home design. Moreover, Introduction of the online shopping system allows for mass customization of the product. Instead of buying standardized shelves, customer can design their own storage space based on their preferences and personalize

it with different sizes, accessories and colours — all these flexible features based on on the kit of parts structured grid system.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series1	4	5	5

Table 3.5: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS5.

3.2.6. Furniture System: Case Study 6

Key words: kitchen unit, modular approach

Basic Information

- Product Name: A la Carte II
- Designer: Oliver & Linda Krapf
- Company: Stadtnomaden, Germany
- Product Feature: Modularized kitchen system provide customer high degree of flexibility. Made by Beech plywood panel with high pressure laminate, white shock strength, scratch an abrasion resistant cover.
- Launched in: 2014 | Source: (Architonic, n.d.) (Huene, 2012) (Stadtnomaden, 2017)

Figure 3.25: Top: the entire A La Carter II Set; Bottom left: the basic unit; Bottom right: the magnet connector. Source: Stadtnomaden catalogue.

The A La Carter II system took the modular approach breakdown and simplified kitchen design into different modular units. Similar to the Cornell Kitchen approach (discussed in chapter 2), each function formed individual modular units, including cleansing, cooking, baking, refrigerating, and storing. The standard module unit, as shown in *figure 3.25* with the size 95 cm x 74 cm x 60 cm (height x width x depth), are divided into three portions. The upper and lower parts contain drawers for storage or sink. The middle portion of the unit can fit various core functional appliances with maximum 45 cm height such as compact dishwasher, oven, cooler, waste disposal and additional cabinets for storage. The notches from the side and back provided space for wires and pipes to connect with in-house services core, at the same time, allow ventilation to cool the electric appliances. In addition, the built-in electrical socket allows the use of other equipment.

The units can form different combination layouts based on clients' future needs and spatial condition. Magnets join units at four corners on the side *figure 3.25,* which results in an active avoid space in between. As *figure 3.26* illustrated, the layout can form adapt for three types of layout including freestanding, wall-related and block, which is flexible for all kitchen layouts. The sequence of the unit arrangement can be easily switched around based on the end user's preferences and habits. This modular approach allows the user to choose the kitchen components based on the tasks they need range from simple coffee kitchen to more complex full kitchen. The unit is elevated above the ground by the levelling modules to allow the robotic vacuum cleaner to pass. The levelling feet can switch to castors, which assist the user to move the units around effortlessly.

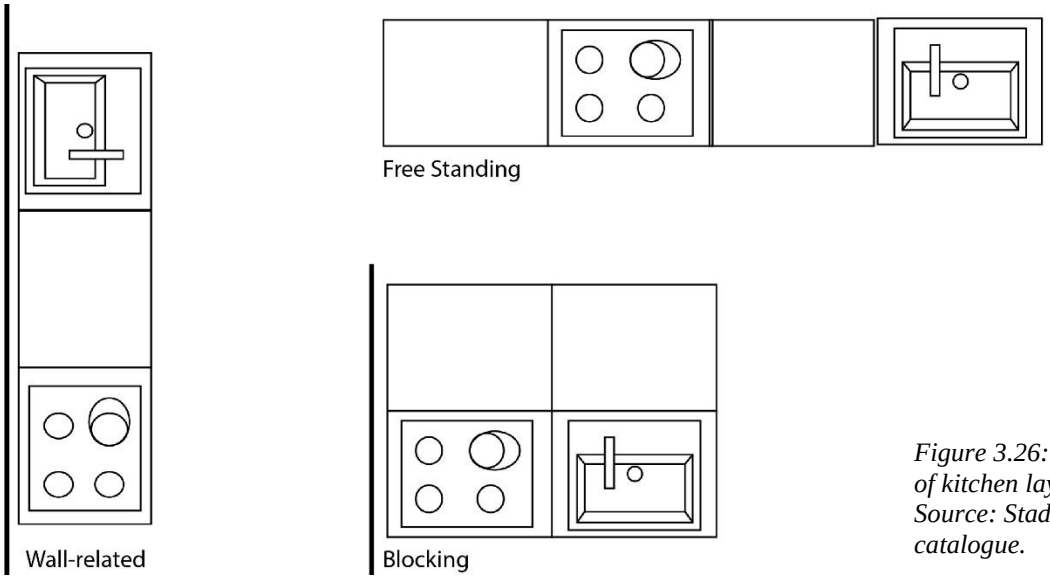


Figure 3.26: Three types of kitchen layouts plan. Source: Stadtnomaden catalogue.

The gap between the units is filled by selection accessories, including chopping board, shelf, dish racks and trivet, or the simple plain basin as shown in *figure 3.27*. These various inlays not only provide different functions between the active zone and assist kitchen operation, but also smartly define the function of the counters space.

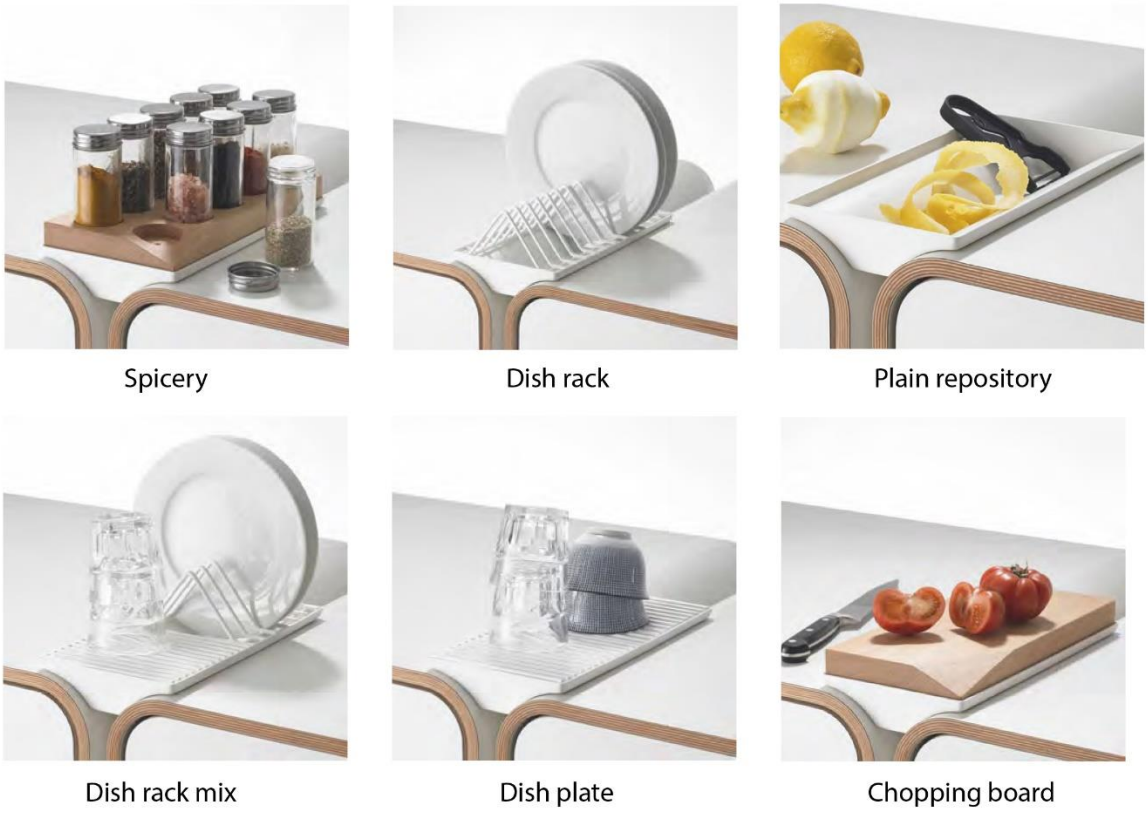


Figure 3.27: Various samples of inlays between the units. Source: Stadtnomaden catalogue.

Adaptable Strategies

- Layer integration: According to Stewart Brand building layer of dependency theory discussed in chapter two, this product mainly associates with two building layers: stuff and space plan. The interchangeable inlays modules considered as the stuff layer, which constantly require changes in a daily to monthly bases. The entire kitchen layout is adaptable by rearranging or adding extra modules. Depends on the durability of the product, the life-span of the space plan level is around 3-30 years. The tasked based modular approach allows the product to make changes without interfering the other layers' normal

function such as service and structural layers. Therefore, maximize adaptability through layer independency.

- Adjustability: The modularized kitchen design approach achieves adaptability in different scales. In a larger scale, the tasks based modular kitchen units are selected by the user based on their needs. Each prefabricated standard module can convert into different function by switching the core appliances in the middle part. In addition, the various combination of modules allows the kitchen better to fit into different interior spaces with a preferred layout sequence. In a micro-scale, the interchangeable castors provide mobility to allow user rearranging the layout. Moreover, the inlay accessories include all the kitchen related tasks into the module design, for instance, cutting broad, dish racks and spicery holders. Besides the prescribed inlay module client can fit other functions on the plain basin such as the planter box shown in *figure 3.28.*

Figure 3.28: Other accessories of a la carter II, Left: Planter Box on the inlay module; Right top: built-in socket; Right bottom: castor. Source: Stadtnomaden catalogue.

- Versatility: Besides the three typical arrangement the company specified, the modularized unit can form several kitchen layouts, such as galley kitchen, peninsular kitchen. Since individual unit embodied function with it, each unit can be used independently. Under circumstances like family gathering events, the modules can be set aside and immediately convert the kitchen space into open space. This maximizes the freedom for the tenant to adapt their living space to their needs.

Prefabrication:

- Method of prefabrication: As mentioned before, this product modularized the kitchen function into different modules. The prefabricated base module is shown in *figure 3.20,* where the user can switch the infills in the middle section of the module to define the unit function. Besides units are modularized, the accessories also consist of two modular kit of parts- the adapter filling between the gaps and functional module fit on top of the adapter.

- Manufacturing: This product can be categorized as assembling to stock. The consumer can choose the appliances, accessories, and sub base system with additional charges. Based on the consumer's order, the modular unit will be assembled in the factory with prefabricate components in stock.

Applications

- Installation and maintenance: The module is delivered on a one-way pallet to the nearest shipping company access point. Therefore, an additional cost will be associated with renting a forklift truck to load the product or hiring an assistant to move the product. Since the product is pre-assembled, the installation does not require special tool or technician. For rearranging the layout with castor installed on the subbase, one person can easily rearrange the layout as indicated in *figure 3.29.*

Figure 3.29:User rearrange the kitchen layout Source: Stadtnomaden catalogue.

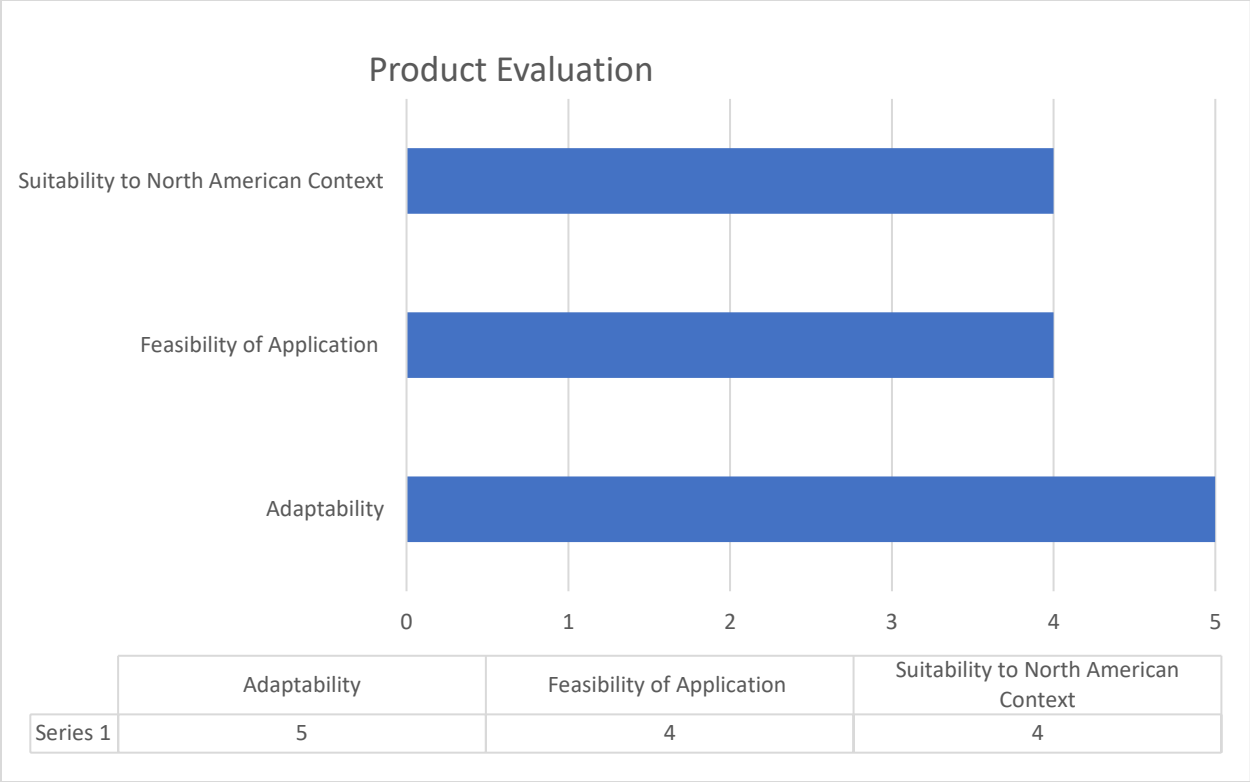
- Limitation: There are two potential constraints of the product. The kitchen can not form an L shaped layout due to the unit is only designed to be accessible from front and back and no corner unit available. Another limitation is that the kitchen system does not have an air exhaust system, which might impact the indoor air quality while cooking.

- Potential User Group: This product is suitable for customers from all stage, especially career-driven families/individual type who only require mini kitchenette. Moreover, for younger families who are seeking growth in the short future, the user can purchase more units to expand the space and function of the kitchen as they needed.

- North American Context: This product is suitable for all kind of construction system since its relatively independent from the main structure and services system. However, since the product is manufactured in Europe, the special request needs to be made to ensure product adaptability to North American standards, such as the appliances electricity capacity, drainage hole size, and other interior standards.

Conclusion:

The A la Carte II kitchen design achieved adaptability through modularizing the kitchen design into task-based cores. User can purchase the unit according to their needs and easily arrange the layout with assistance from castor and magnet joints. Although the design tends to be flexible to various type of spatial layout, the L-shaped layout is not applicable since none of the units is capable function at the corner. Besides the modular unit, the inlay accessories between the unit allow for additional functions on the countertop. In terms of application, A la carte II can be used in any kinds of construction types without requiring special technical support for installation and maintenance. An additional cost is associated with limited options for appliance products from a few high-end manufactures, the size for the interchange part should consider more products line. Therefore, customers have more options at lower costs.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series 1	5	4	4

Table 3.6: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS6.

3.2.7 Furniture system: Case Study 7

Keyword: minimum kitchen, all in one unit.

Basic Information

- Product Name: Pop-up kitchen Pia
- Designer: Darko Špiljarić
- Company: Dizzconcept, Croatia
- Product Feature: A all-in-one approach of kitchen design intend to save valuable space in by providing all functions a typical kitchen has.
- Launched in: 2014 | Source: (Architonic, n.d.) (Ambista, n.d.) (Dizzconcept, n.d.)

Figure 3.30: Pia nova kitchen in space illustrati. Source: Dizzconcept website, https://www.dizzconcept.com/pop-up-kitchen-pia

Kitchen as part of the interior fit-out often requires a wall, and specific sized room to properly function. In cases like compact living environment, to support a full kitchen will take too much precious space and impact other function in the room. In addition, other ongoing concepts such as shrinking kitchen phenomenon discovered by LABC Warranty and the “kitchenless” house concept raised by architect Anna Puigjane indicate the trendy of minimizing the kitchen size at

home (Mahdawi, 2018; Bestard, 2016). Dizzconcept noticed the need for flexible space for urban living and shrinking kitchen trends; they are pursuing an alternative design solution to provide full kitchen function without taking much space in the room.

Instead of requiring a separate room for kitchen, PIA compressed a fully equipped kitchen in a closet style prefabricated module, which only occupying 1.6 m^2 of the room. The unit can be placed against a wall or free-standing in a space with access to electricity, water and network connection. The cabin can remain closed when it is not in use. The cabin can function as a TV stand for the living room. To use the unit, the user can open the closet doors and expand the space into a cooking space.

The PIA kitchen has integrated 180 cm long counter with sink and faucet. The base of the counter contained a compact size dishwasher and refrigerator, waste disposal, shelves and drawers for storage. In the upper cabinets embedded Electrical socket, LED lighting, ventilator and microwave. Besides the main cabinet, the two 15 cm deep door can provide extra storage or function as a

Figure 3.31: Pia nova kitchen unit. Source: Dizzconcept Website. https://www.dizzconcept.com/pop-up-kitchen-pia

pantry. The door can open from 90 to 120-degree angle to allow user to create different spatial layouts and adapt the unit in the environment accordingly.

To better serve for various client's need for the kitchen, Dizzconcept tailors the PIA kitchen into five different models. The models range from fully equipped kitchen to snack bar and can fit in all kind of environment including apartment, micro-studio unit, student housing, vacation rental and office space. In some cases, the PIA unit can serve for both kitchen and a space divider illustrated in *figure 3.32*. Moreover, the small unit footprint can save space from accommodating other

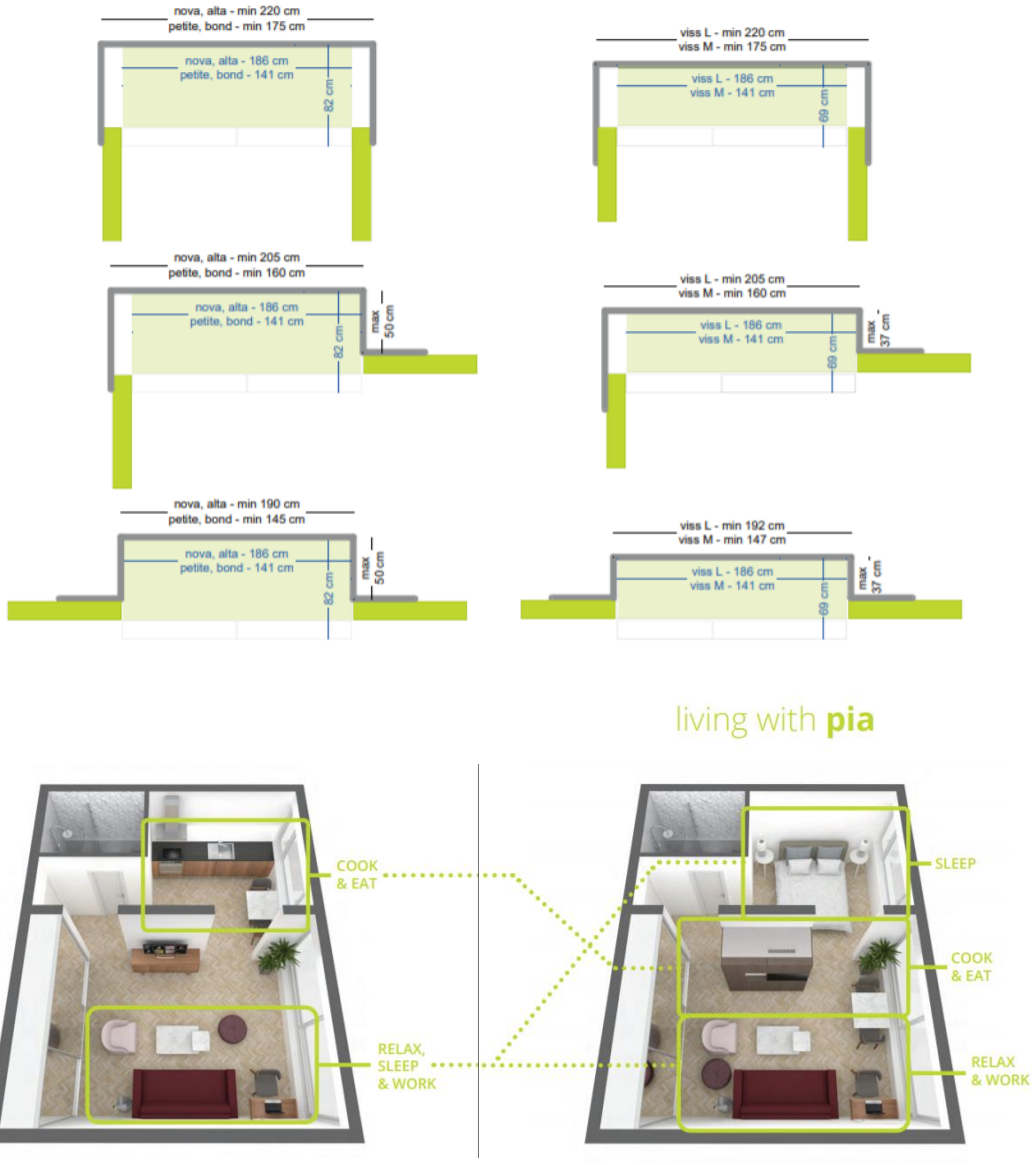


Figure 3.32 Top: Various door type of Pia system; Bottom: comparison between conventional room layout with kitchen and Room layout with Pia kitchen unit. Source: Dizzconcept Website. https://www.dizzconcept.com/pop-up-kitchen-pia

functions in the room. For instance, in the studio unit, the PIA unit can replace the conventional kitchen and save the room. By placing the unit in the middle of the room, intelligently divide the space into two zones, one side becomes a private bedroom, the other side is a living room.

Adaptable Strategies

- Layer integration: The Pop-up kitchen integrates three-building layers into one unit including services, space plan and stuff. It is a free-standing unit that can be located anywhere in the room function as a kitchen, living room TV stand and space divider simultaneously. This unit requires plugin with electricity, water supply, and drainage to provide its full functions. The small footprint saves room space from accommodating other functions.

- Adjustability: PIA integrates flexibility into the product to empower the user to adjust the system according to their need. For instance, the rotatable TV allows the user to adjust the screen to a different angle and achieve comfort. The door can be open to a different angle, which helps the unit fit into all room layout.

- Versatility: Although the PIA kitchen cannot be moved around, the unit itself can free stand in a space and subdivide the space into zones. Moreover, the cabinet door will provide additional flexibility to help dweller create their kitchen space. *figure 3.33* illustrates three application of PIA unit that transforms the space with more functions.

Prefabrication:

- Method of prefabrication: The PIA kitchen is an all-in-one prefabricated system, that integrates all appliances and functions into a compact unit.

- Manufacturing: The PIA kitchen is prefabricated-to-order. The customer will choose the type, appliances, colour and materials first. The manufacturer will fabricate the unit based on the order.

Figure 3.33: Different layouts with PIA kitchen units. Source: Dizzconcept Website. https://www.dizzconcept.com/pop-up-kitchen-pia

Application

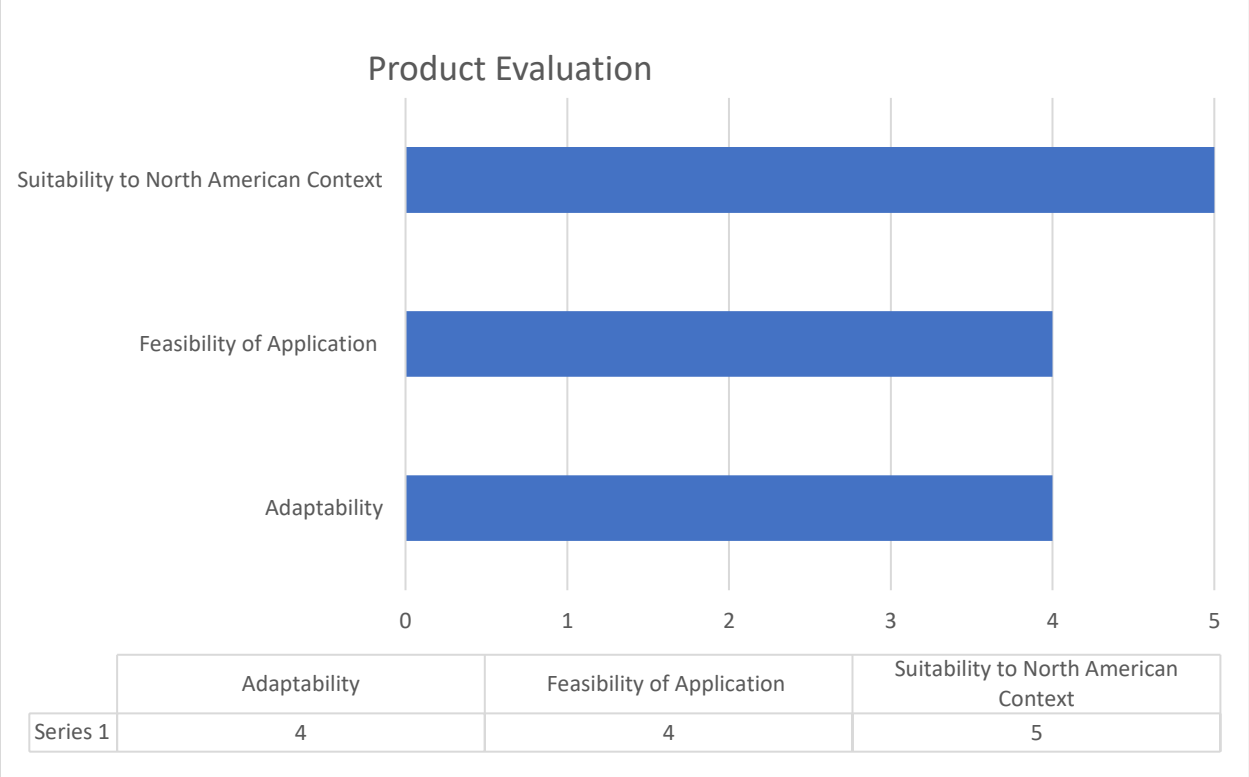
- Installation and maintenance: The product comes with three prefabricated modules can be easily assembled on-site, plugin services and ready to use in merely 30 minutes. The delivery package is 110 x 100 x 210 cm box, which can fit into a conventional passenger elevator. The whole system can be disassembled and transported to another location.

- Potential User Group: It is an ideal product for an apartment building in a dense urban environment. In addition, PIA introduced five other variations with different size and functions to maximize its market adaptability. For instance, the short-term rental and tourist apartment, the kitchen can only equip with basic sink, microwave and shelf.

- North American Context: The PIA product is a free-standing kitchen unit; it can be easily fit into a different environment, including North American homes.

Conclusion:

PIA introduced an alternative design solution of the kitchen; It intends to provide the same kitchen functions as a conventional kitchen with minimum space. Within a 1.6 m^2 footprint, the unit can expand into a fully equipped kitchen by open the door. While the kitchen is not in use, the cabin unit becomes a TV stand and transform the rest of the room into a living room. In this case, the PIA unit helps dweller to use the same space for multiple functions. The PIA unit does not require a designated room to function. It can be placed anywhere in the room and leave the original kitchen space for other function. For Shipping and installation, PIA divided the unit into three components, which can fit into any passenger elevator. This shipping method avoids the additional cost involved for delivery. Multiple models of PIA kitchen are available to broaden the potential user group from urban apartment unit flat to short term and holiday rent home.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series 1	4	4	5

Table 3.7: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS7.

3.2.8 Furniture system: Case Study 8

Key words: All-in-one Unit, high-tech, compact living

Basic Information

- Project: CityHome | Ori System
- Designer: Kent Larson(Research Principle) & Hasier Larrea(Research Affiliate), Yves Behar.
- Company: MIT Media Lab | ORI | IKEA
- Product Feature: A robotic controlled all-in-one unit system introduce a brand-new way of urban living into a smart, compact and adaptive experience.
- The CityHome Launched in: 2011| Source: (Larrea, 2015) (Lee, 2019) (IKEA, 2019) (Pownall , 2019) (ORI, n.d.)

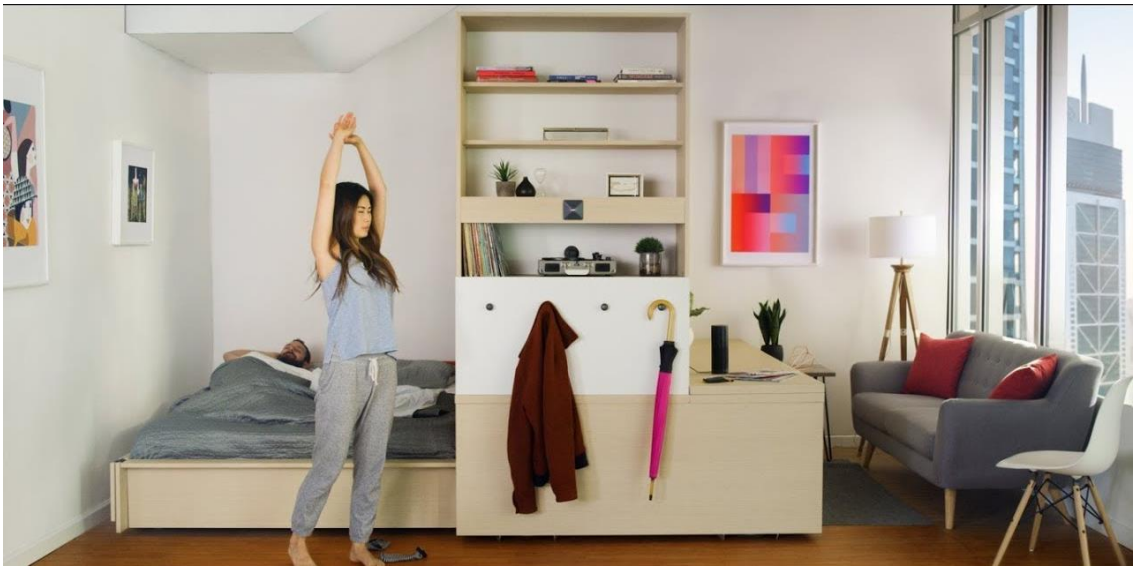


Figure 3.34: Ori Studio Suite. Source: Ori website, https://oriliving.com/ori-studio-suite

In the past 2000 years, along with all the evolving design concepts and technology advancements, yet architects were taught and trained to design buildings by assigning specific functionality with discrete spaces called room. In the current residential dwelling design, we have a clear definition of a room with specific size, functions and appliances that should be included. For instance, the bedroom includes a bed and a closet; the living room has a sofa and tables. Although it seems reasonable to have all the furniture to support the room's functionality, the problem is that we

cannot occupy all these spaces simultaneously. In another sense, these spaces are wasted when they are unoccupied. Hasier Larrea designer from MIT considered these room and furniture as the space killer. After years of research and designing, The MIT Media Lab announced the first version of CityHome. This project was guided by two main concepts: space perception and space augmentation. Under the premises of redefining people's perception about living, the design integrated serval interior spaces into one piece of furniture system. This unit could function the same as space three times as it occupies.

The prototype of CityHome was built in 200 square feet (19 m^2) micro-unit apartment in Boston. The units located at the center of the room. On one side of the unit, a single bed, full-size table and a folding bench chair are tidily fit into the unit. Dweller can pull the bed out from the unit when

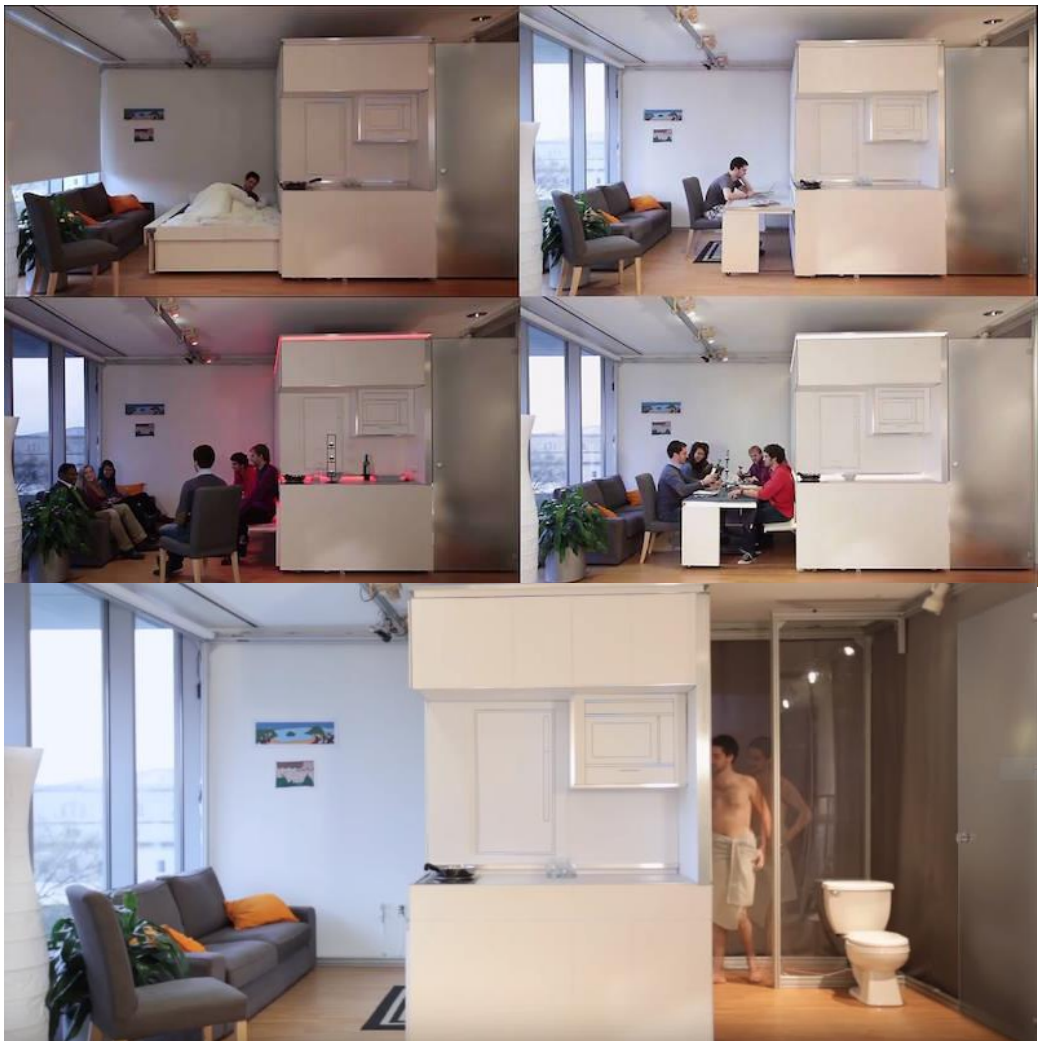


Figure 3.35: Cityhome prototype design by Hasier Larrea. Source MIT Media Lab Achieve, https://www.media.mit.edu/projects/OLD_cityhome2/overview/

they sleep and switch the room to a workspace by sliding the desk out. For friends gathering and dining, the table can extrude further out and serve as a dining table. The folding bench can provide additional seating to the crowd. On the other side of the main living/resting space, functions require a certain degree of privacy function are including closet, shower and toilet. The entire unit is set on a track and can slide back and forth, as shown in *figure 3.35*.

In recent years, it is growing market interest in adaptable interior design. Companies have proposed numbers of prototypes that include similar adaptable strategies CityHome incorporated in their design. One unique feature makes CityHome stands out from the other that is the incorporation of motion and voice control system into the unit design. Although there are many skeptical comments regard the concept of dependent out life on robots, Larrea argues that our modern life has already been unconsciously transformed by the convenience robotics system such as elevator, garage door, Vacuum cleaner. The Cityhome intends to assist people in transforming the space effortlessly by using the robotic machine. After the announcement of CityHome, this concept attracts many companies and manufactures interest, which including ORI and later IKEA.

The MIT Media lab started their outreach by collaborating with designer Yves Behar and introduced the ORI system series. Based on CityHome concept, Ori further developed around three scenarios, a pocket closet, studio suite and cloud bed, with a robotic system to control the movement of the units. To control the system user can push the button on the side or use the APP on the phone (*figure 3.36*) to choose the mode and robots will transform the space automatically.

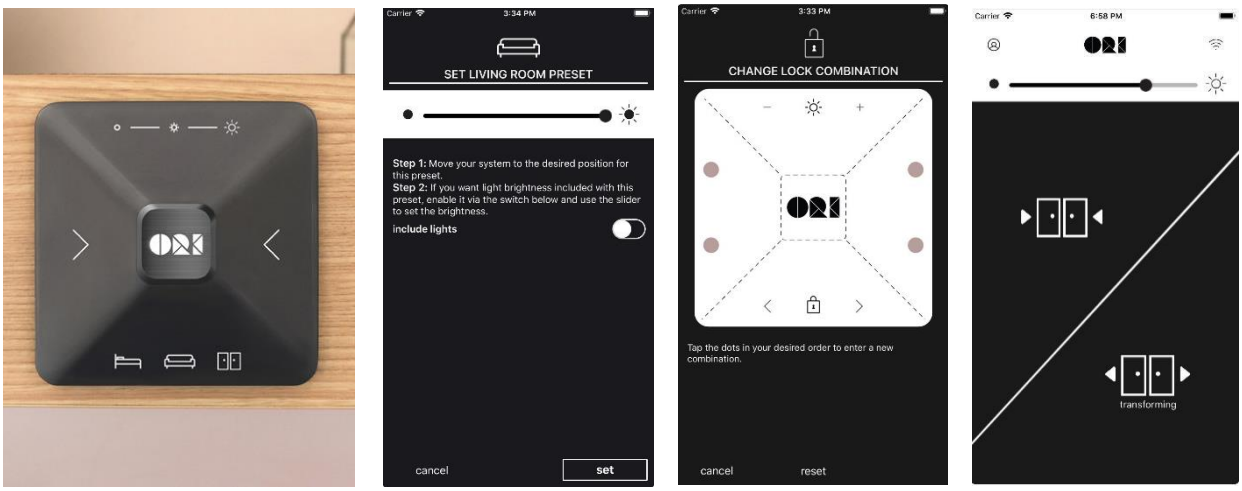


Figure 3.36: Ori Living control system and Phone APP. Source Ori website and its phone application user interface,

- The Pocket Closet: by setting the closet on a track system, this system can double the capacity of storages and create a walk-in wardrobe. The pocket closet can be used not only as a closet in the bedroom, but it can also apply to other spaces in the house, including a pantry in the kitchen and a storage room for the home office. Three sizes modules are available for different scenarios from 4 ft (1219 mm) wide to 8 ft (2438 mm) for both double and single storage. For installation, it requires a 71 in (1803 mm) clear wall to place the track on the wall. The flooring needs to be levelled within +/-1.5 degree.

Figure 3.37: Ori pocket closet and its potential applications in an apartment unit. Source Ori website. https://oriliving.com/ori-pocket-closet

- Cloud bed: Another ongoing developing product. It combines the living room and bedroom under a single system. During the daytime, it functions as a living room with sofa, at night the bed will drop down from the ceiling. This design provides efficient usage of the space and decorates the living/bedroom with warm wood finishing.

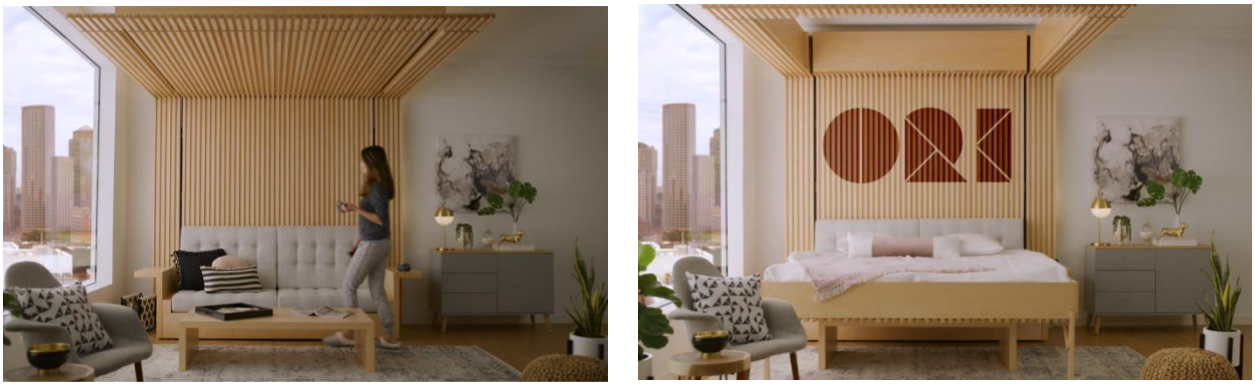


Figure 3.38: Ori Cloud bed. Source Ori website. https://oriliving.com/ori-cloud-bed

- Studio Suite: This system is designed targeting to the compact urban living scenario. It consolidates all the essential architectural elements from the living room, bedroom, dining and home office into one unit. Same as the Pocket closet, this product has two different models: original and slim-fit to better fit in different studio units. It can provide both full and queen size bed. For installation, it requires a 118.5 in (3,010 mm) wall space for the track, and the minimum floor to ceiling height is 87 in (2,210 mm).

Figure 3.39: Ori studio suite. Source Ori website, https://oriliving.com/ori-studio-suite

In Summer 2019, Ori and its partner IKEA together launching their new product Rognan at Democratic Design Days. Rognan joint the Ori's Studio Suite and the robotic control platform with IKEA's PLATSA modular storage system. The unit contains a walking closet, a living sofa, tucked-in bed and working desk. By touching the button, the user can adapt their space into the function they need. Cooperating with IKEA can transform this idea into mass production, which provides a truly affordable compact dwelling solution for the growing urban population. The IKEA plan to trial the Rognan system in Hong Kong and Japan market in the coming year and expand the territory by tailoring the design to the local living habits.

Figure 3.40: Rognan unit. Source: IKEA website, https://newsroom.inter.ikea.com/news/ikea-and-ori-team-up-to-develop-rognan-robotic-furniture-for-small-space-living/s/edd8a80b-e570-4c62-943a-5c20543bc23e

Adaptable Strategies

- Layer integration: From the original CityHome to recently unveiled Rognan, this all in one unit integrate with both space plan and stuff building layers. The wall-mounted track and the entire unit can shift along the track to help the user change the space plan on a cyclical basis. While the folding table and tucked-in bed provide adaptability for the user to move their stuff around. This prefabricated system allows the user to explore different spatial layout more frequently compare to conventional interior fit-out the cycle is around 3 to 30 years. However, this system requires the right size room to function properly, which might not be the case for every scenario.

- Adjustability: The high degree of flexibility in the design ensures user be able to find comfort with a simple adjustment. For instance, the Pocket Closet design, the closet can adjust to different rooms and provide the function accordingly. Moreover, built-in outlets, USB ports, LED lighting and connection with digital assistant Alexa and Google home ensure users' control much more straightforward and precise than before.

- Versatile: The movability of the product redefines the way home are designed. In a compact living environment, the user can avoid unnecessary space killers and efficiently use space with comfort. The robotic machine user can effortlessly any make changes.

Prefabrication:

- Method of prefabrication: The concept of Cityhome provides an all in one design solution for the compact living environment.

- Manufacturing: The Ori living series the units are made-to-order. The customer will choose the type, appliances, colour and finishes, and the manufacturer will fabricate the unit based on their choice. Similar methods of production can apply to Rognan in Ikea.

Applications

- Installation and maintenance: For Ori Pocket Closet, the component will be shipped, and the user can self-assemble the system within 3 to 4 hours. However, the Studio Suite requires unique shipping methods and technicians to install with additional charges.

- Limitation: This unit system has a specific spatial clearance to perform properly. For instance, the Studio Suite units, as illustrated in *figure 3.41*. 126.5 in width x 160.5 in length x 91 in height (3,213 mm x 4,076 mm x 2,311 mm) for a full-size bed unit.

- Potential User Group: Although all the products are targeted to compact urban apartment dwellers, it can also serve for families and senior users, since the robotic system can assist them to move things around. It can fit in both micro-studio units as well as a single-detached house.

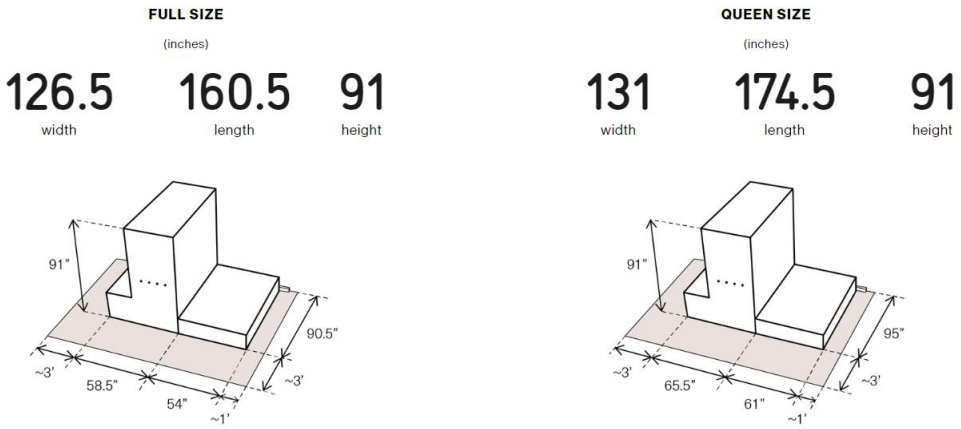
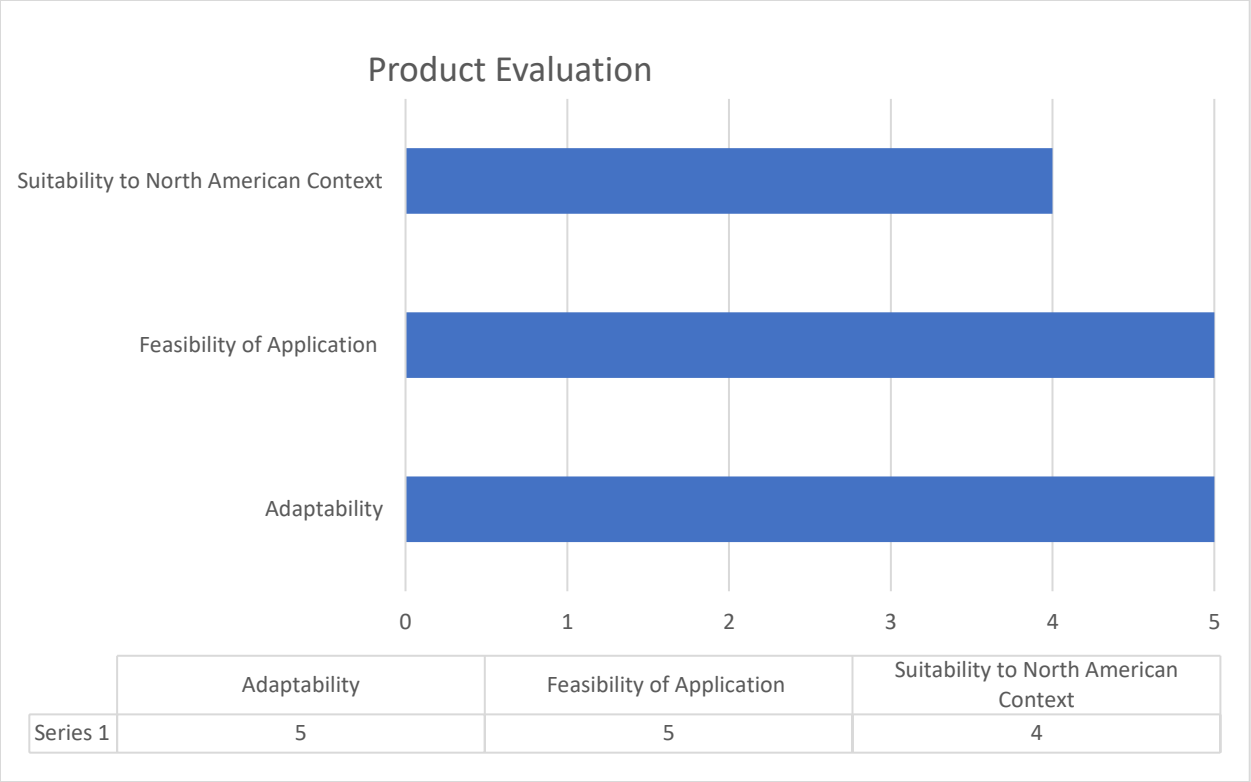


Figure 3.41: Spatial requirement of ORI Studio suite. Source Ori website, https://oriliving.com/studio-suite-fit-guide

- North American Context: Besides the specific spatial requirement, this system requires might need further adjustment to fit in all North American homes perfectly. Since in the North American housing market, wood and timber are the main construction methods. The level of accuracy of a typical wood frame construction is comparatively lower than concrete and mass timber construction. In general practice, wood frame construction can accurate to one-eighth of an inch. However, the Ori system requires the flooring to be 1.5 degrees, which might limit some user with wood frame construction house.

Conclusion:

Introduction of CityHome provides a new vision towards the future urban living. Urbanization is urging cities to use their land sources more efficiently. By avoid wasting space and compact all the functions into an all-in-one unit, The CityHome effectively reduce our existing footprint without compromising the quality of life. The flexibility of the design allows the user to switch the bedroom to the dining room and party room within the same space. This concept allows the user to control the space as they need. Moreover, Integrating the furniture system with cutting edge technologies, such as digital assistant system and robotic machine, and phone apps, ensure the transformation process effortless and bring more conveniences to our daily life. With the concrete conceptual foundation, The CityHome soon developed into a real marketable product Ori system. Recently, the collaboration with IKEA provides the opportunity to mass-produce this product and be able to benefit more population around the world.



	Adaptability	Feasibility of Application	Suitability to North American Context
Series 1	5	5	4

Table 3.8: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS8.

3.2.9 Entire house design: Case Study 9

Basic Information

- Project name: Drawer house
- Size: 1,744 square feet (162 m^2)
- Designer: Oki Sato
- Company: Nendo, Tokyo, Japan
- Project Feature: A housing project intelligently condenser and store all the interior function behind the wall., The dweller can change the interior spatial arrangement by pulling each functional component out like a drawer.
- Built in: 2003 | (Lam & Thomas, 2007) (Nendo, 2003)

Figure 3.42: Drawer house exterior view and small outdoor space. Source: Nendo website. http://www.nendo.jp/en/works/drawer-house/?

This private residence situates in one of the most crowded cities on earth, Tokyo, Japan. Under this compact living environment, it is commonly seen that the families are sharing the living room for all their activity besides sleeping. Interior flexibility provides dweller with the privilege to accommodate all kind of events in their daily life in a small building footprint. The concept of the house design is the drawer, by storing all the function inside a cavity to provide free open space. As illustrated in *figure 3.43*, designers condense all the functions of the house one side of the house and left the other side a spacious open room. All functional components including, dining space, bed, chairs, bathtub and entire kitchen can be pulled out from the wall and set up different venues according to dwellers needs. This concept effectively uses one space for multiple functions and reduce the building footprint without cramp the room with all the furniture. It is a three-story tall single-family house with a basement and two tiny front and back yards.

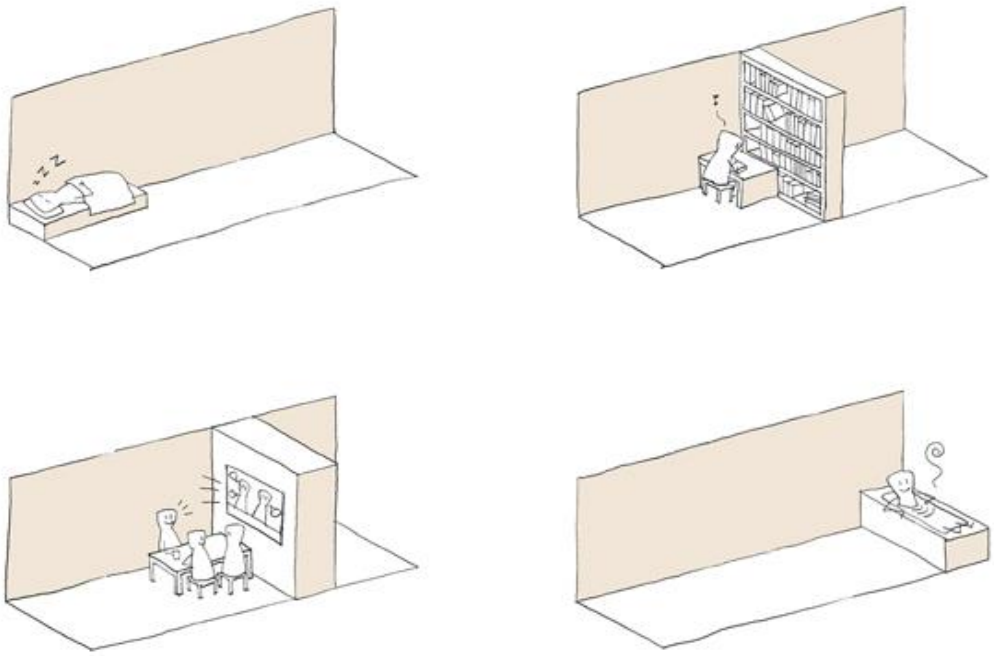


Figure 3.43: Drawer house conceptual design diagram. Source: Nendo website, http://www.nendo.jp/en/works/drawer-house/?

The ground floor served as the main living space for the family, the second floor served for a more private function, while the basement provides additional bedrooms and storages. The right side of the house remains open with both sides connected to the yards. The left side of the house finished with series floor to ceiling doors and drawers.

Following pictures demonstrate the transformation of drawer house. In the ground floor, the doors open to reveal the restroom hide behind. Adjacent to that is a stair goes up to the second floor. Additional drawers are hidden under the first riser of the stair. The drawer on the left side can open from both sides of the room. During the dinner time, the folding door will open and unveil the hidden kitchen behind. By pulling out the multimedia wall next to the kitchen not only serve the dining space with TV, but also divide the guest bedroom from the dining space. In the guest

Figure 3.44: The ground floor adaptable strategies. Source: Nendo website, http://www.nendo.jp/en/works/drawer-house/?

bedroom, a murphy bed can be unfolded. A curtain track is embedded in the ceiling, to allow the guest to close the curtain create a private space at the corner.

On the upper floor, the drawers carry more private functions such as trucked in bunk beds, bookshelf and tables. Some closet units can be pulled out from the wall served as a temporary space divider. The bookshelf drawer slides open and puts next to the desk and chair unit. Together these two components create a working area in the middle of the space, divide the second floor into three zones-two bedrooms on both ends and a home office space at the center.

Figure 3.45: Second floor adaptable strategies. Source: Nendo website, http://www.nendo.jp/en/works/drawer-house/?

The concept of "drawer" extends to the exteriors space. The large glass panel door opens blur the edge between the indoor and outdoor. A hot tub can be slid out to create an outdoor spa on the balcony. Simple mechanical tactics such as folding door, tracks, sliding walls and caster ensure the mobility of all furniture components, thus bring flexibility to the drawer house.

Figure 3.46: Right image: transition between interior and exterior; Left image: Basement adaptable strategies. Source: Nendo website, http://www.nendo.jp/en/works/drawer-house/?

Adaptable Strategies

- Layer integration: The left side of the house consolidate service, stuff and components form a space plan together and remain the right side of the house open. This concept modularized the space plan into movable components. When the house requires upgrading, dweller can change the individual module to other functions without the need to refit the entire room. Furthermore, the drawer house took a similar strategy as typical office building practice, to maximize the flexibility of the space by locating services such as kitchen, restroom and stair core together. This concept avoids spatial restrictions during the refitting process.

- Versatility: Tactics including, caster and tacks provide movability to the components. User can pull out the functions and arrange the room layout based on their need. This concept allows people to use the same space for varies activities.

Prefabrication

- Method of prefabrication: The entire house took a modular approach. The furniture system is modularized into a draw unit and fit on the left side of the house.

- Manufacturing: The drawer unit in this house is engineered and manufactured unique to this project. It has a high degree of complexity, with specialist involved in the design, prefabrication, and installation process.

Applications

- Potential User Group: The concept of concentrating services and internal functions modules together can be applied in all kinds of residential building types including apartments, duplex, semi and single-detached house. This strategy can effectively reduce building footprint by eliminating unattended space in the room. It can be an ideal solution for a building situated in a dense urban context.

- North American Context: One potential constrains of implementing the concept in North American residential building is the limitation of wood frame construction. For instance, the span of wood joist and beam is smaller than steel or concrete. For structural integrity

addition, vertical support is required, which might obstruct free plan and movability of modules.

- Limitation: Besides the wood frame construction is a potential limitation. Another restriction is the HVAC system. Since the majority of households depend on the HVAC system to cool and heating the space, drop ceilings might exist, if the flooring structure is I-joist rather than Open web joist. Drop ceiling might limit floor to ceiling height modules to move around.

Conclusion:

The Drawer house provides an elegant design solution for a family to use their space effectively. With all the functions, services and circulation on one side of the house, where the other half open and free are remain open to accommodate different function throughout the day. All the interior component can be pulled out like a drawer from the shelf. Dwellers can use the same space for different activity by switch the module.

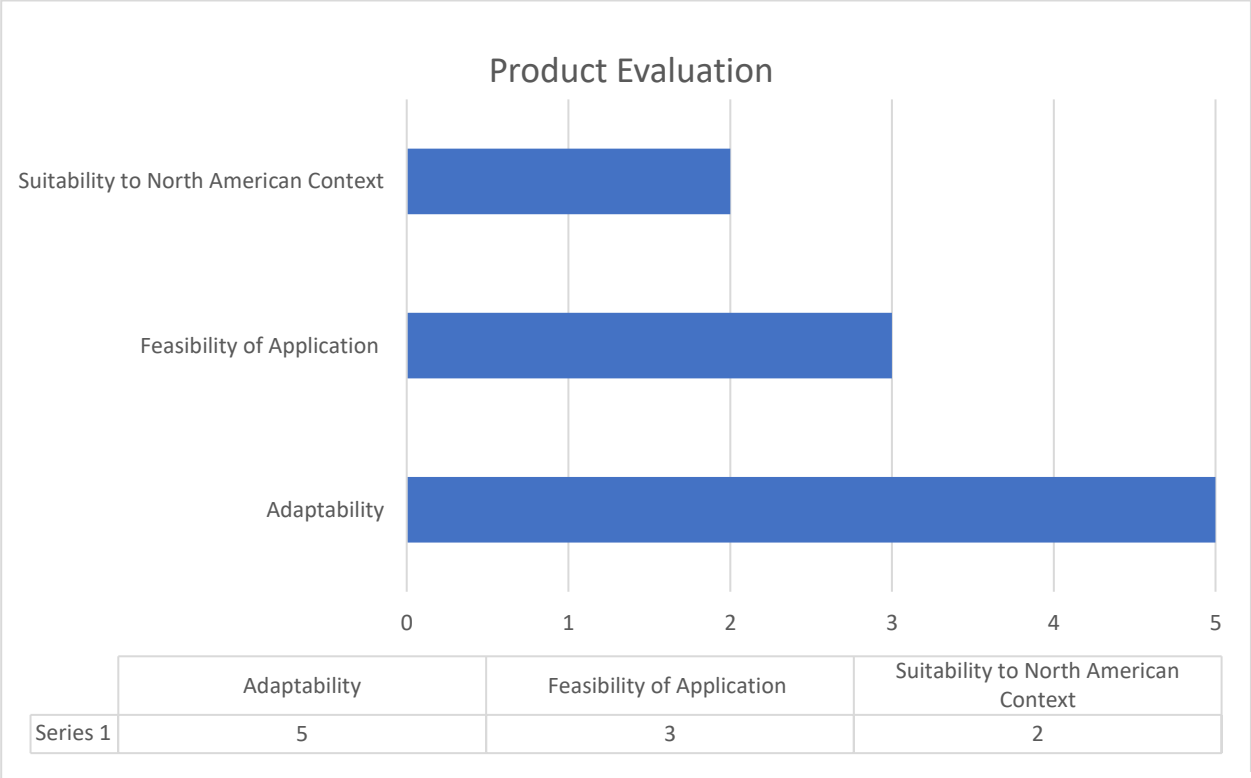


Table 3.9: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context CS9.

3.2.10. Entire house design: Case Study 10

Basic Information

- Project name: Furniture House Series
- Size: 116 m^2
- Designer: Shigeruban
- Company: Shigeruban Architect and Muji, Japan
- Project Feature: A house assemble by prefabricated full-height unit, which serve for both functional and structure purposes.
- The Furniture house 1 was built in 1995, The Post Hurricane Reconstruction house used similar approach was built in 2009. | (Shigeru Ban Architect, 2009) (RE ESTUDIO, 2016)

Figure 3.47: Furniture House 1 exterior view. Source: Shigeru Ban Architects, http://www.shigerubanarchitects.com/works/1995_furniture-house-1/index.html

In 1995, Architect Shigeru Ban experiment, a unique construction methodology built the prototype of the furniture house near a lake in Yamanashi, Japan. Unlike typical housing approach walls and columns are used to support the roof and create space and fill in with the furniture wall system. Ban proposed the "furnishings as structural support" concept to integrate structure and function. This design intends to express the simplistic style and functionality quality of modern architecture. The house set on an almost square foundation and bolstered by floor to ceiling height structural furniture unit. The house contains one bedroom, a living room and kitchen, and an outdoor terrace. As the floor plan illustrates, room are divided by row of furniture units with different types and thicknesses.

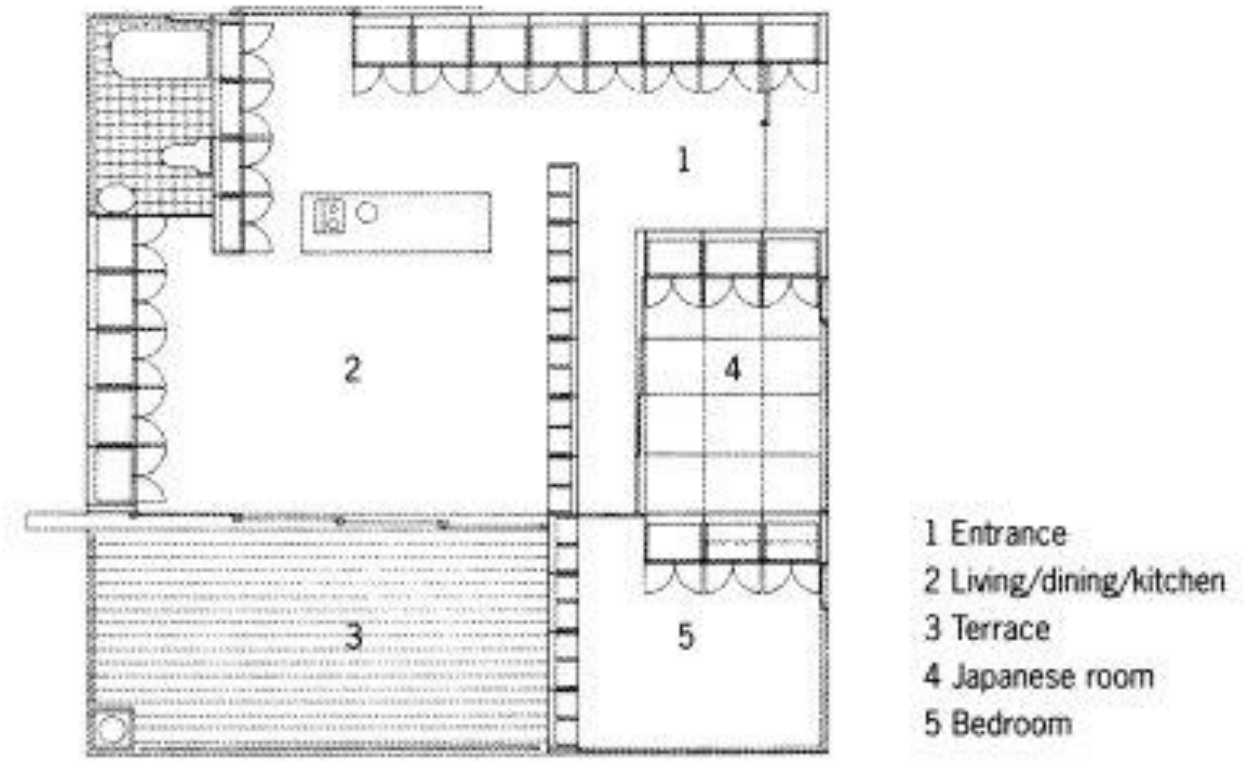
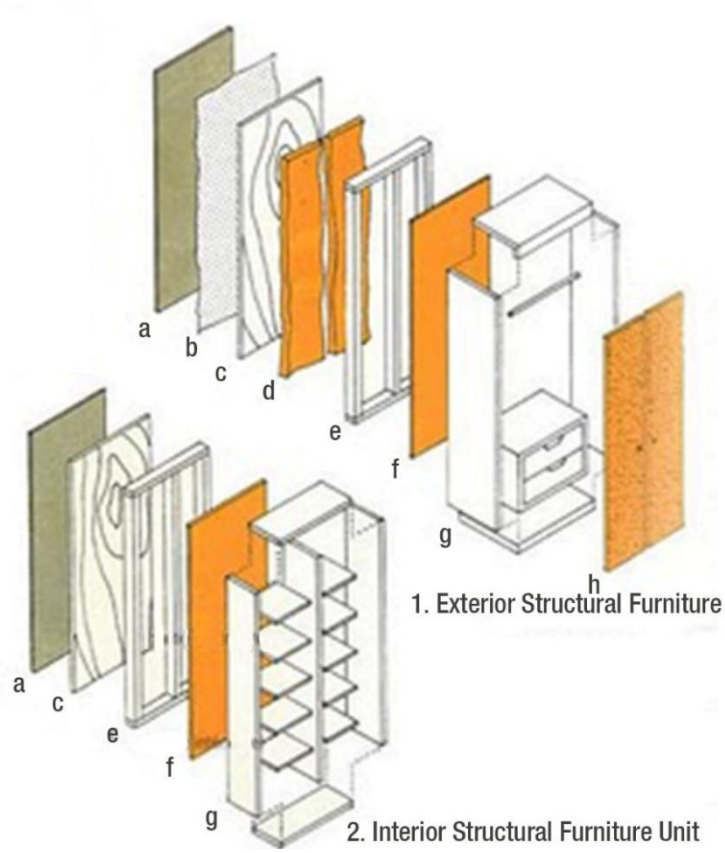


Figure 3.48: The Furniture House 1 floor plan. Source: Shigeru Ban Architects, http://www.shigerubanarchitects.com/works/1995_furniture-house-1/index.html

To reduce the construction cost, the structural furniture units were prefabricated in the factory. Instead of inventing a brand-new system, Ban modifies the current wall assembly practice, by attaching furniture modules with the typical 2 in x 4 in (38 mm x 89 mm) timber frame and 12 mm thick structural plywood. This concept adapts to both interior and exterior condition. For exterior

unit, water barriers and insulation are embedded in the unit assembly. The backboard on the outside provides a nailing surface for varies exterior finishes and furniture cabin on the inside can install different door finishes. By integrating furniture unit with the wall structures, it leaves more flexible open spaces for dwellers to occupy. Moreover, the diverse types of the unit, including a wardrobe, cabinet, pantry, bookcases and kitchen counters, allows people to adapt the furniture unit for different scenarios. Each unit is 2.4 m tall, 0.9 m wide, and the thickness depends on different functions. Since the unit weight is about 79.2 kg, during construction, it can be easily moved around by a few labours.



a. Finished backboard, any exterior and interior finish can be selected and applied. The application method for exterior finishes is adjusted according to requirements
b. Water barrier membrane. Necessary if a. (above) is used for exterior.
c. Structural plywood board: 12mm thick.
d. Insulation. Necessary if a.(above) is used for exterior.
e. Timber Frame 2 in x 4 in (38 mm x 89 mm) Lumber.
f. Backboard of interior storage
g. Interior storage: varies according to unit.
h. Door: any finish can be selected and applied.

Figure 3.49: Furniture unit exploded diagram. Source: Shigeru Ban Architects (edited by author).

After the success of the first trial of the furniture house in 1995, Ban keeps exploring the furniture house design and integrate other concepts into housing design. The second version of the furniture house (*figure 3.50*) built-in 1996 experiment with two stories structure with the same construction method. Rug-screws were used to install the furniture in place. In addition, new kinds of furniture units were added to the module family including, sinks, kitchen, staircase, and interior air conditioner.

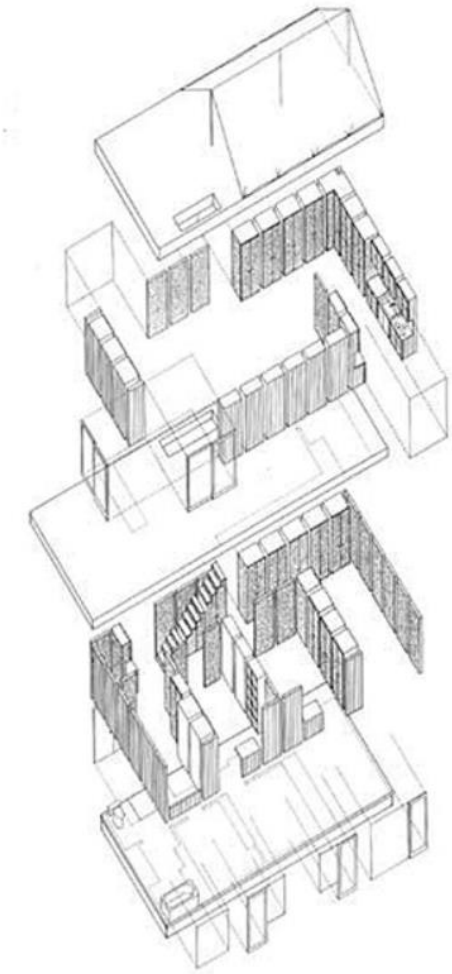


Figure 3.50: Furniture House 2. Source: Shigeru Ban Architects, http://www.shigerubanarchitects.com/works/1996_furniture-house-2/index.html

One year later, another project built known as the Nine-square grid house. In this house, steel studs replaced the wood frames, and full-height sliding partition can divide the space into a different zone. These sliding partitions provide dweller adjustability to change the spatial layout (*figure 3.51*).

Figure 3.51: Nine square gird house. Source: Shigeru Ban Architects, http://www.shigerubanarchitects.com/works/1997_nine-square-grid-house/index.html

After Hurricane Karina, SBA was commissioned to rebuild the Lower Nine Ward community with affordable and safe housing. The concept of furniture house was selected due to the cost-benefit and mass-producible feature of the structural furniture unit (SFU). In order to better fit with the surrounding context, architects adapt the furniture system with vernacular "Shortgun" style housing. The entire house sits on elevated plane support by pile foundation. The 8 ft tall (2.4m) SFU act as the main structural element, storages and spatial partition. To provide extra strength and rigidity to resist future extreme weather, additional 2 in x 2 in (38 mm x 38 mm) hardwood cleats are added to the inside.

Figure 3.52: Furniture House 6. Source: Shigeru Ban Architects http://www.shigerubanarchitects.com/works/2009_post-hurricane-reconstruction-housing/index.html

Adaptable Strategies

- Layer integration: Unlike all the other cases studies that products segregate from the main structure, SFU integrated the structure with furniture component, it integrates five main building layers, including structure, skin, services, space plan and stuff. Although this concept provides adaptability through creating an open floor plan, it limits the user to alter the overall layout of the house over time.

- Open Floor Plan: By integrating the functional components, structure and space partition into one system, creating a flexible open floor plan for dweller to adapt the space according to their needs.

Prefabrication

- Method of prefabrication: The construction of furniture house is based on a modular prefabricated system. All furniture modules are manufactured and assembled in the factory. After that, all modules will be delivered to site on construction. Based on the floor plan, each unit will have a unique function associated with it.

- Manufacturing: All the component in the house is Engineered to order. This approach allows for different variations of the furniture unit. It is a highly customized manufacturing system, with high cost and efforts involved.

Applications

- Construction Process: Construction of the house began with a concrete foundation with flooring lay on top, the rest two exposed concrete parts are for entrance and restroom. The highlighted part indicates where the wall units will stand. Then the prefabricated furniture unit's delivery to site by a crane and labours moved them to the right place. Workers installed the unit by nailing the structural frame down to the ground. For exterior wall, insulation is stuffed between the wood studs same as the typical wall frame construction. After all, units were placed in place, and the prefabricated roof can be put on top and finish up the house. Compare to the conventional construction process. It is noteworthy the simplicity of SFU construction. Since all the units are prefabricated offsite with a high

degree of precision, less time and efforts are required for onsite construction. Furthermore, the lightweight well-integrated unit can be moved around and easily installed by single labour. Altogether, the SFU requires less specialist and high skilled labour during the construction process.

Figure 3.53: Construction process of the Furniture House 1. Source: Shigeru Ban Architects, http://www.shigerubanarchitects.com/works/1995_furniture-house-1/index.html

- Limitation: Like all the wood frame construction, the structural furniture unit is only suitable for low rise construction.

- Potential User Group: Developers who are seeking for low-cost, mass-produced housing development are potentially interested in Furniture house concept, due to the benefit of prefabrication. In addition, as Katrina housing demonstrated, it can also be applied to reconstruction and re-habitation projects after natural disasters.

- North American Context: The structural furniture unit concept developed from conventional wood frame construction. Instead of separating infill furniture with structure, this concept modelized furniture system into units and assembled the units with the existing wood-frame structure. Ban understands the resistant to innovations in the construction field, he incorporated prefabrication technology to provide a cost-effective method of constructions, which attract developers around the world. After years of practicing in both Japan and the United States, the Furniture house concept has adapted itself to meet the code and standards in the North American context.

Conclusion:

From the prototype of furniture house built in Yamanashi to Katrina rehabilitation project. Furniture house introduces a new construction system intended to provide an affordable, efficient and adaptable design solution for increasing housing demands around the world. The SFU system provides an all-in-one solution to housing industry by providing structure support, interior storage and spatial partition simultaneously, which reduced the complexity of housing construction and interior fit-out process. Moreover, with prefabrication technology, all the unit can be prefabricated in a controlled environment and delivery to site for installation. Developers can benefit from both the high building quality and less labour involvement, especially skilled experts. All in all, followed by years of Research & Design development, the concept of furniture house has successful rooted itself in both Japan and the United States low-rise housing market.

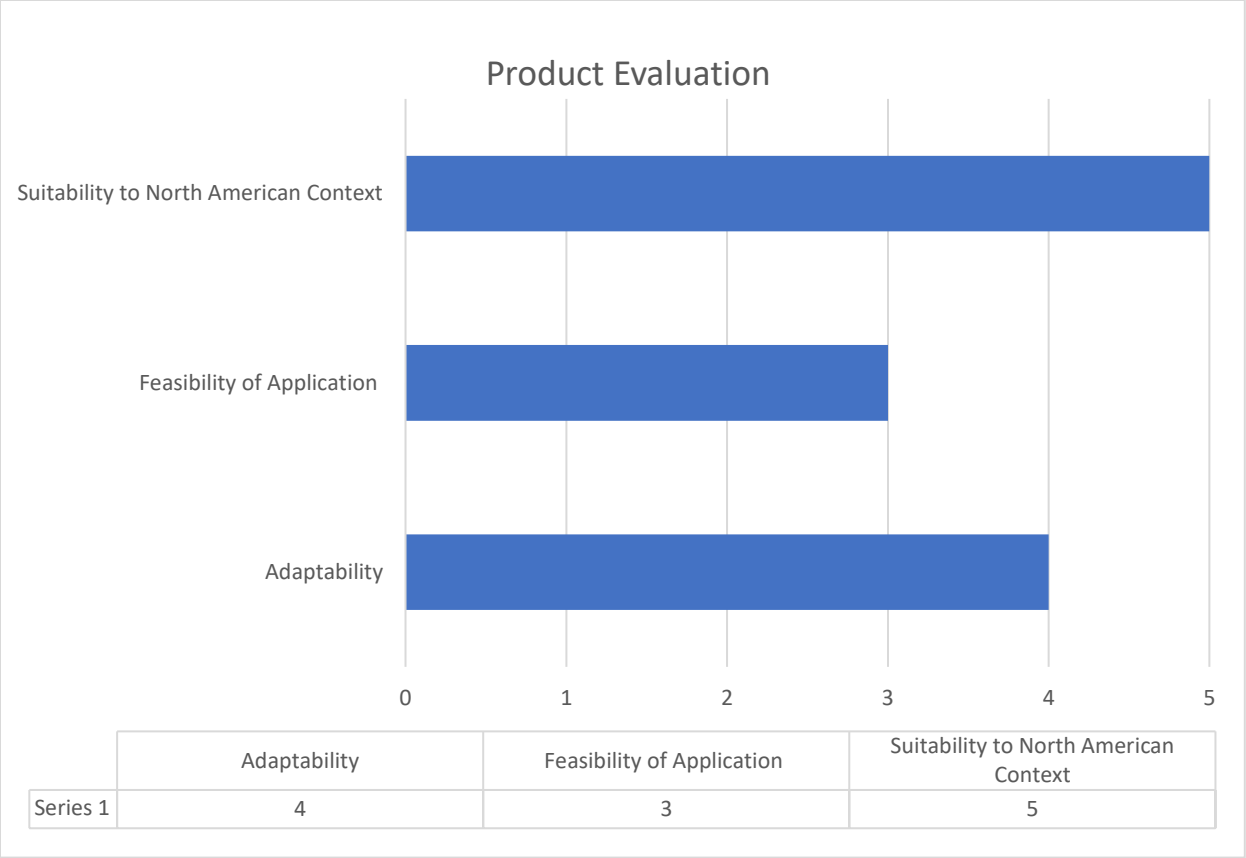


Table 3.10: Evaluation of the Adaptability, Feasibility of application, and Suitability to North American context

3.4 Conclusion

Based on the case studies, seven strategies are integrated into the design of multiple products and concepts

- **Multifunctionality:** Besides the actual role and feature of the design itself, providing auxiliary tasks in the unit brace the functionality of the product. It is a cost-effective approach for dweller to use the same interior space for various activities. For instance, in case study 7, the Pop-up kitchen not only provides a fully equipped kitchen space but also incorporated TV on the folding door. This design permits the system works for both kitchen and TV stand in the living room.

- **Integration with technology:** The advancement of technology is gradually changing the way of our daily life. In the home industry, practices such as embedding wiring into furniture, garage door and ongoing interest in smart homes intent to provide convince to our life. One common approach is to provide the electrical charging station in the furniture design to enhance the functionality of the design. This strategy has implemented in several cases studies including EasyRack system (cs1), Haller e Storage by USM(cs 5) and Modularized kitchen system (cs6). Another progressive approach is developing machinery to easy the process of adapting room configuration. As the CityHome and Ori home system (cs8) demonstrated, integration of mechanical machine, motion sensor and phone APP allow dweller to adapt their interior layout effortlessly. By simply pressing a button, the machine can transform the space for dweller automatically. This technology is not only attractive to the young generation, but it can also benefit the elderly users with a disability to control the interior space smoothly without and laborious work.

- **Customization:** Instead of developing different product series to meet customer's changing needs, the ability for customer to configure the product during purchasing empowers them to adapt the product to their needs. Interactive online purchasing interface facilitates to visualize their choice. In both case study 1 and 5, the company developed an online shopping program to allow the customer to select the components and visualize their final product simultaneously.

- **Movability:** To achieve an adaptive interior space requires elements with a certain degree of movability that can facilitate user to adjust the layout according to their need. Tracks and castors are two typical accessories have been used in several cases studies — cs 6 , cs 3 cs8 and cs9. Besides rearranging the location of the element, movability also includes adaptability of elements physical form for other functions. The space divider in the switch project(cs3), by opening the door panels the dweller can subdivide the bedroom space into two-room.

- **Minimize fixed installation:** This approach avoids restriction in the interior environment and saves spaces for other usages. For instance, the and all-in-one kitchen discussed in case study 7, introduced an alternative kitchen with occupying minimum space in the room. This concept allows dweller to occupy the original kitchen space to a bedroom or living room.

- **Utilizing ceiling and wall surfaces:** In most of the time, not all the interior surfaces have been utilized effectively. In this research, there are few cases that attempted to use the wall and ceiling spaces for storages and other functions. For instance, the furniture house design integrates wall storages with structural wall assembly, which efficiently use the wall surface and leave a spacious room for other uses. Another trial is the furniture house, where all the functional components are stored in the wall. The dweller can pull units out and use the same space for different activities. The Ori bed concept intended to store the bed in the ceiling and space below can serve as a living room during the day time.

- **Avoids "space killer":** Since people tend to use a space for particular activity at a specific time of the day, where the rest of the unused furniture and space are considered as "space killers." By considering the nature of the human life cycle and allowing the interior component to adapt our biological time can effectively save space in the room. The switch house(cs 3), the Pop-up kitchen (cs 7), Cityhome unit (cs 8) and the drawer house (cs 9), they all deliberately designed to adapt space for different functions throughout the day.

3.5 Insights to Chapter 4

Based on the case studies, there are few aspects should be taken into consideration for the design proposal in chapter 4.

Adaptability

To ensure the design adapt to wide range of users, It is essential to consider the user's life cycle from short term to long term changes. In addition, different age groups are expecting diverse functions and uses of space. Therefore, multifunctional design can facilitate the design to adapt to more scenarios. Moreover, to achieve a high degree of adaptability, the design strategies should include from micro to macro scales, which are identified in the hierarchy system established in chapter 3.

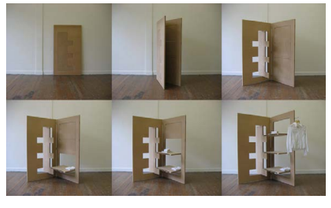
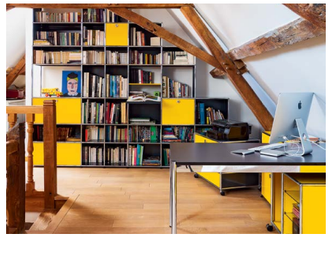
Prefabrication:

Among the four manufacturing methods listed in chapter 2, assemble to stock and made to order are the two most prevailing approaches in the market, due to its flexibility and cost-efficient features. Shipping as another essential aspect should be considered in the design to avoid complication during delivery.

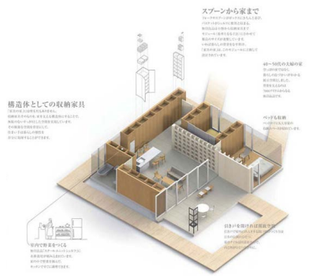
Design application:

Three facts should be acknowledged in the design to simplifying the design application process. First, as mention before, highlighting the potential user groups for the design. Second, the user's experience with installation, adapting process and future maintenance should be considered. Third, the design should evaluate its suitability in the North American context, especially for wood frame construction.

3.3 Case Study Summery

Project Name	Image	Adaptable Strategies	Prefabracation Method	Key Features*
Accessories CS1 : EasyRack Kitchen Flat		• Stuff layer and structure layer • Adjustability	• Modular Approach • Assemble to stock	• Multifunctionality • Integration with technology • Customization
Space Divider CS2 : Softwall + Softblock		• Space plan layer • Versatile • Refitable	• Modular Approach • Made-to stock	• Movability • Minimize fixed installation
Space Divider CS3 : Switch		• Space plan and stuff layer • Adjustability • Versatile • Convertible	• Planar Approach • Engineered-to-order	• Movability • Utilizing wall space • Avoids “space killer”
Furniture System CS4 : Switch		• Space plan and stuff layer • Adjustability • Versatile	• Planar Approach • Made to stock	• Movability • Avoids “space killer”
Furniture System CS5 : Haller storage system		• Stuff layer • Adjustability • Refitable	• Modular Approach • Made to order	• Integration with technology • Customization • Movability

Note *: Key Features are further explained in 3.4 conclusion section.

Project Name	Image	Adaptable Strategies	Prefabracation Method	Key Features*
Furniture System CS6 : A la Carte II Kitchen		• Stuff layer and Space plan layer • Adjustability • Versatility	• Modular Approach • Assemble to stock	• Multifunctionality • Integration with technology • Movability
Furniture System CS7 : Pop-up kitchen Pia		• Services, space plan and stuff layer • Adjustability • Versatility	• All in one unit Approach • Made to order	• Multifunctionality • Minimize fixed installation • Avoids “space killer”
Furniture System CS 8 : CityHome | Ori System		• Space plan and stuff layer • Adjustability • Versatile	• All in one unit Approach • Made to order	• Integration with technology • Movability • Utilizing ceiling and wall surfaces • Avoids “space killer”
Entire House Design CS 9 : Drawer house		• Service, space plan and stuff layer • Versatile	• Modular Approach • Engineered to order	• Movability • Utilizing ceiling and wall surfaces • Avoids “space killer”
Entire House Design CS 10 : Furniture house		• Structure, skin, services, space plan and stuff layer • Open Floor Plan	• Modular Approach • Engineered to order	• Utilizing ceiling and wall surfaces

Chapter 4: The Design Proposal

4.1. The Concept

In this chapter, three design proposals are presented as the conclusion of this study. These design proposals are derived from the theories featured in chapter two and the in-depth market research of chapter 3 and intended to provide an adaptable design solution that can benefit dweller in reconfiguring their interior space to meet their evolving needs. As chapter one noted, the housing shortage issue associated with urbanization leads to the tendency of shrinking family size in the past century. Therefore, the urban housing market interest shifts from the single-detached house towards high-density mixed-use development. To better meet the market demand, these designs are tailored to fit in typical apartment units in an urban context in North American. A 600 square feet (55 m^2) one-bedroom micro apartment unit is selected as a model to demonstrate the application of the design (*figure 4.1*).

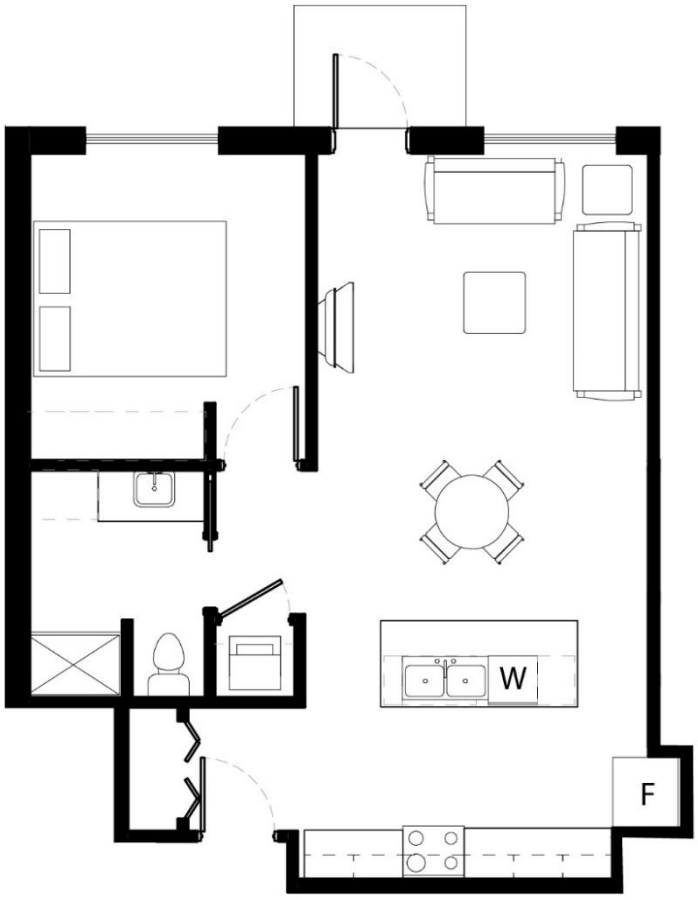


Figure 4.2: The sample one-bedroom unit floor plan.

This concept intends to minimize the installation of fixed elements in interior space that obstruct and restrict the adaptation process throughout the building life cycle. In this proposal, three units are developed to address adaptability in the kitchen, living room and bedroom. These units not only provide the functions with occupying minimum space, but also help occupants to create space to support their daily activities. Users can expand the units into a fully equipped space and compact them when they are not needed. Among the ten innovative case studies, the all-inclusive concept used in the CityHome project (cs 8) is referred to as the leading precedent in developing this design proposal. Besides that, several strategies appeared in cs 3, cs 4 and cs 7 were integrated into the design as well to ensure the design achieve adaptability in all scale.

In terms of prefabrication methods, these designs adopted kit of part assembly with modularized components for the user to choose according to their interior space and needs. User can choose the modular size based on their existing spatial condition and customize the product to fit their demands. Made to order will be the primary manufacture strategies, which based on the order the kit of parts will be customized delivery to site for assembling. A step by step installation manual with graphics demonstration will be provided to help the user with no expertise to assemble the product.

Objectives of all the designs

- To maximize the interior flexibility for dwellers to reconfigure their living environment.
- Intelligentially use the interior space for multiple activities by eliminating unnecessary fixed installations.
- Provide an affordable design solution for occupants.

4.2. Kitchen

Kitchen as the one of least adaptable space in residential homes, installations of fixed cabinet and counters limited its flexibility. The current market trend of shrinking kitchen size in homes are challenging the conventional non-adaptable kitchen design approach. In this proposal, the concept is to create a fully equipped kitchen within a minimum footprint. The design process initiated by analyzing the typical kitchen space and identify potential spaces can be reduced without compromising the normal kitchen functions. All the elements in the kitchen can be categorized into two parts based on their movability and flexibility. Stove, oven, sink, and dishwasher are considered as the immobile part of the kitchen. Counter, storage, pantry components are relatively flexible.

In this design, the immovable appliances remain fixed, where the other components integrate as one unit and can be moved around with castors on the base, as highlighted in *figure 4.2*. When the kitchen is unused, the unit will be placed against the wall; the user can still have access to the essential kitchen functions. When dweller needs more space for cooking, they can pull the unit out and expand it into a cooking island/working counter. Pegboard was used as the vertical finish; at the same time, it can be used to provide additional storage by pinning the element on the pegboard. For instance, counter broad, foldable chairs, shelves and other accessories can be stored on the pegboard.

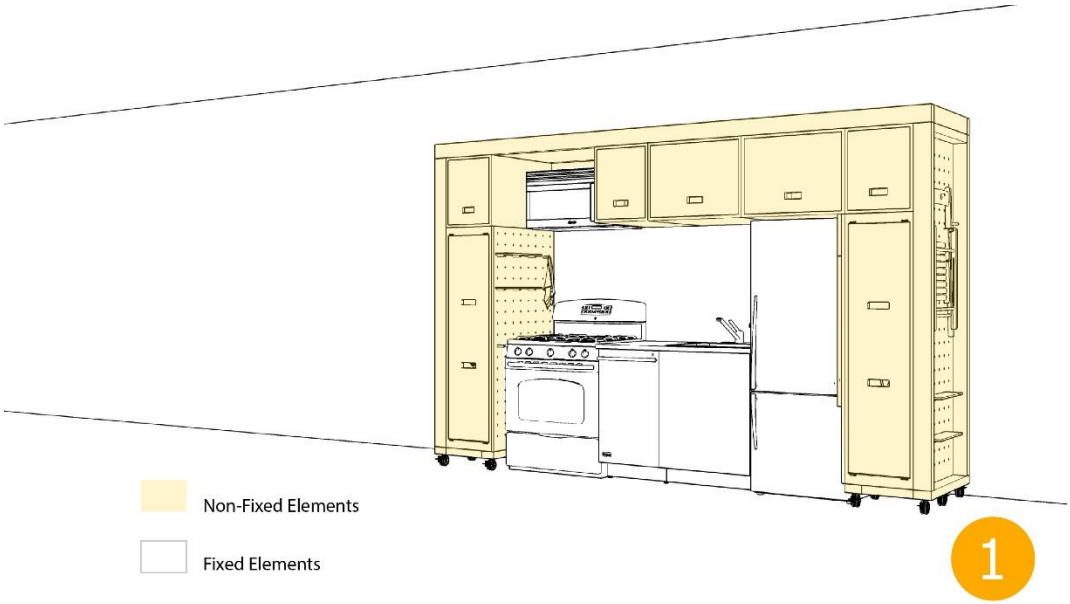


Figure 4.2： The unexpanded kitchen.

The cooking counter is adjustable to different heights that facilitate user to achieve comfort. In this case, the work station can function as a cooking counter, a bar area and a study table for kids while their parent is cooking.

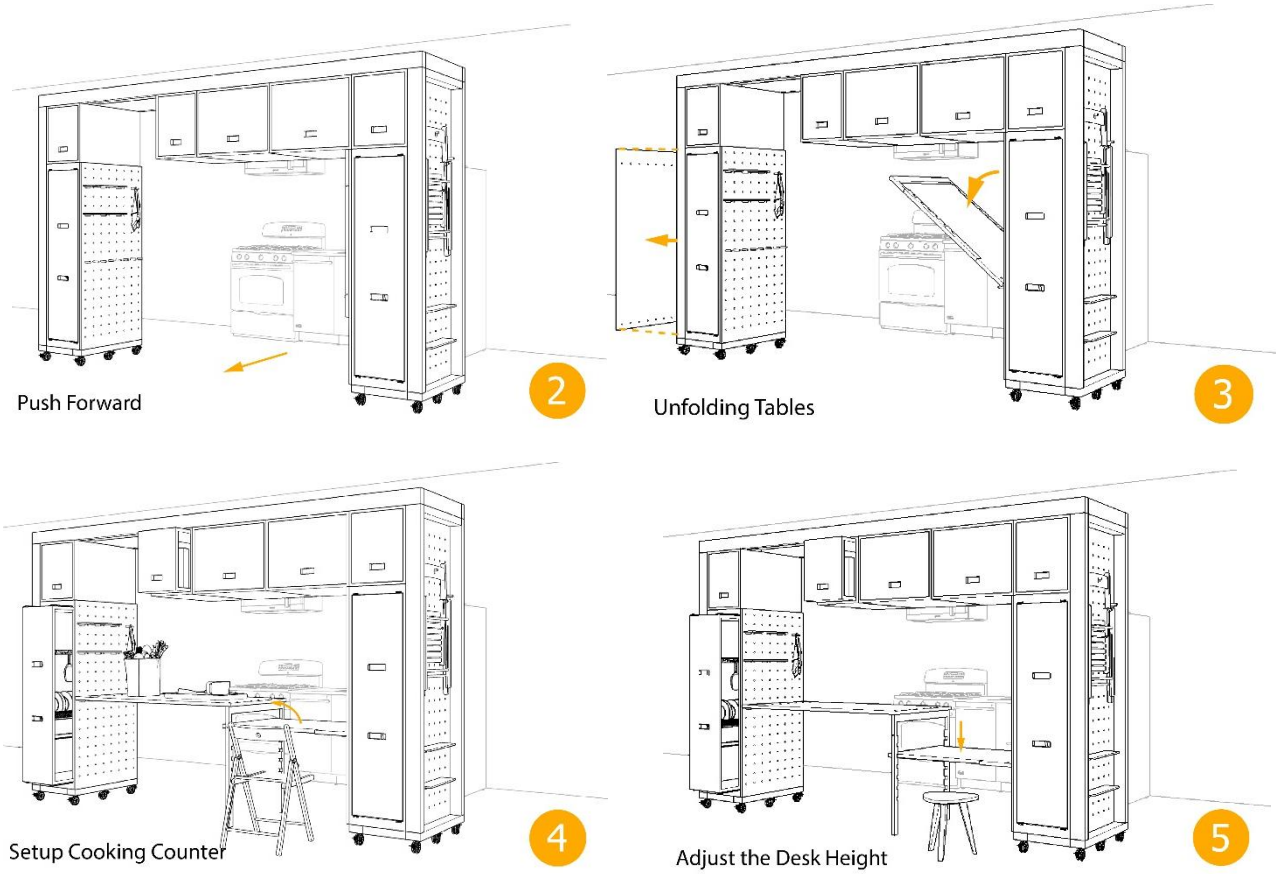


Figure 4.3: The process of expanding kitchen space.

Depends on the room layout, the unit can be moved around effortlessly and create different kitchen spaces. The storage drawers can be open from both side, which allow the user to use the unit from different directions.

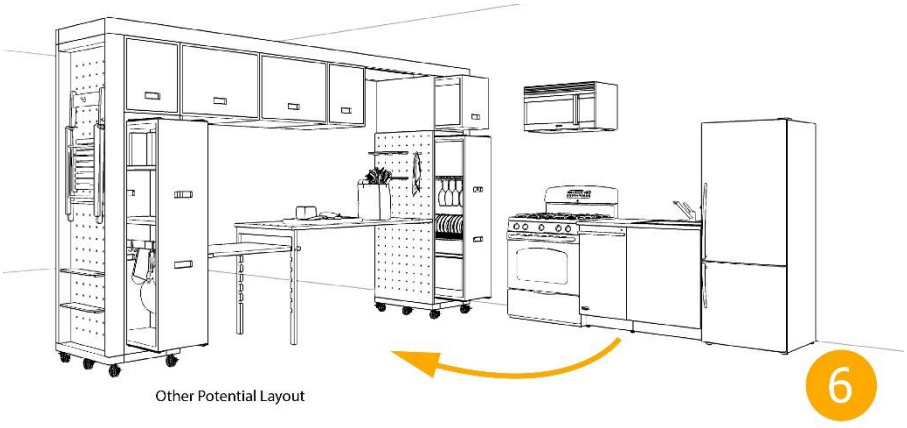


Figure 4.4: Alternative Kitchen Space layout.

Kit of parts:

The main structure is made by pre-cut 2 in x 4 in (38 mm x 89 mm) wood frames, which user can assemble them into the main structural frame.

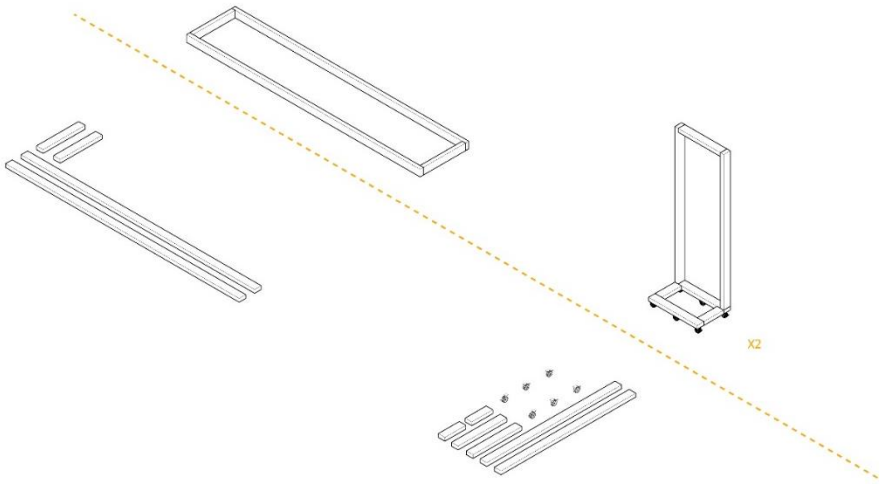


Figure 4.5: Kit of part for the main frame.

The drawers come with three modularized sizes with a sliding track built in the module and different infill shelving accessories including pantry rack, wine glass holder, hanger and standard shelves.

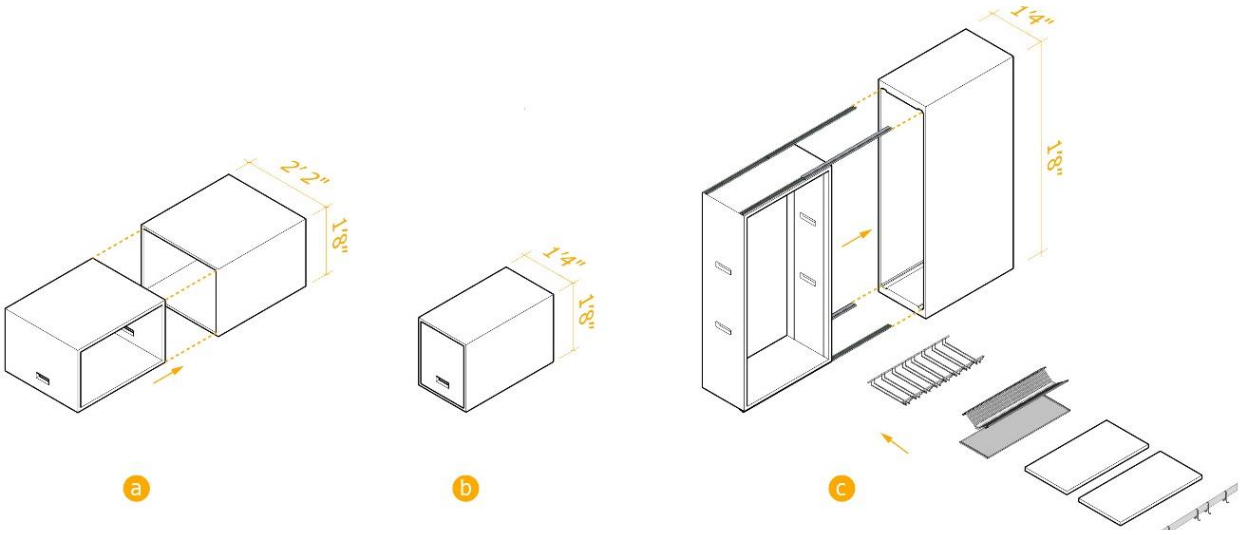


Figure 4.6: Kit of part for the drawers.

The countertops are made by dismountable panels with adjustable support legs to allow people to adjust the unit to accordingly and function as both cooking top and working desk simultaneously.

In addition, the vertical surface is made by pegboard with accessories designed to provide additional storages on vertical surface.

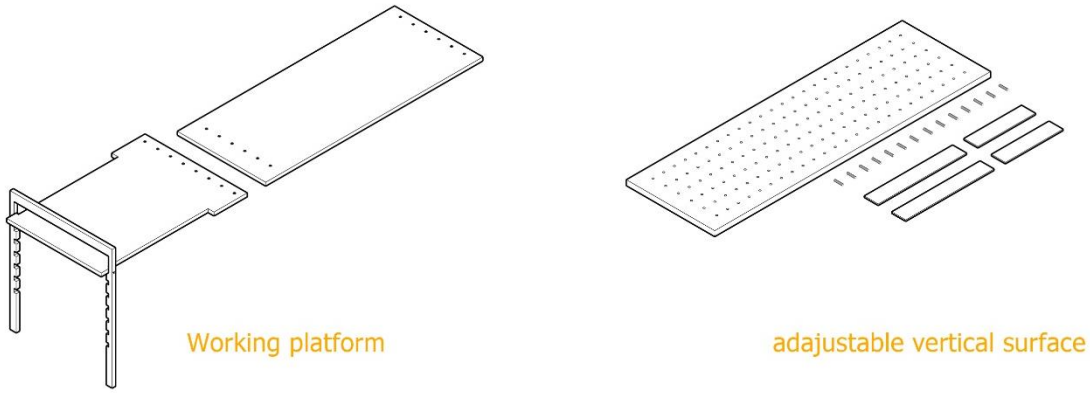


Figure 4.7: Kit of part for counter top and accessories.

Assemble:

1. Firstly, setting up the frame structures and install the castors at the bottom.
2. The Second step is to install the drawer frame to the main structural skeleton.
3. Thirdly, insert the drawer into the frame.
4. Lastly, attach the pegboard on the vertical surface and customize the vertical surface based on user's need

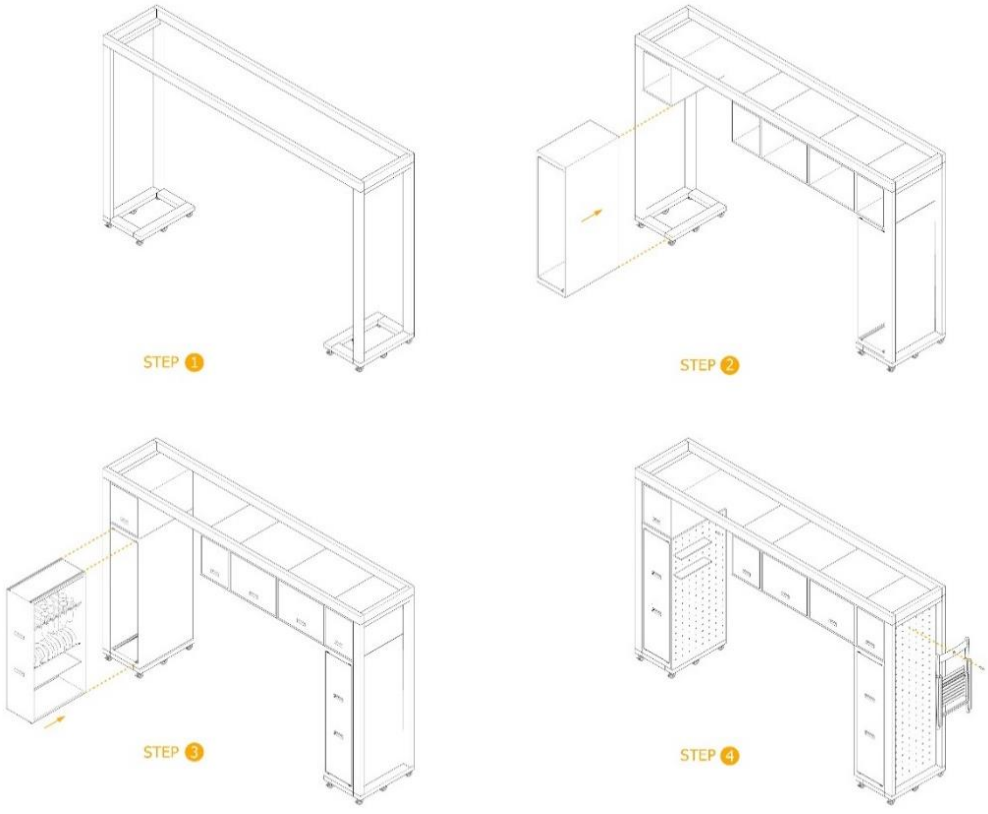


Figure 4.8: Kitchen unit assembling procedure.

4.3. Livingroom / Bedroom

In a typical apartment, the living room and bedroom are separated by space divider, which becomes a physical barrier restricting dwellers to rearrange their room layout. In addition, these two rooms are occupied during a different time of the day. The living room space is considered as waste, while the bedroom is in use. Therefore, this design eliminates the partition wall between these two rooms to allow occupants to use the existing two rooms as one undivided space. In this proposal, a list of six fundamental elements including bed, closet, TV stand, sofa, working station and storages are embedded into this unit design. Similar to the kitchen design, this all-inclusive unit can be freely moved in space. Several adaptable strategies are integrated into the unit design such as murphy bed, operable closet and table, pegboard vertical surface and castors.

The unit consists of two sides, on one side is the bedroom come with a murphy bed and a closet. Additional storages are hidden behind for bed necessaries and bookshelves.

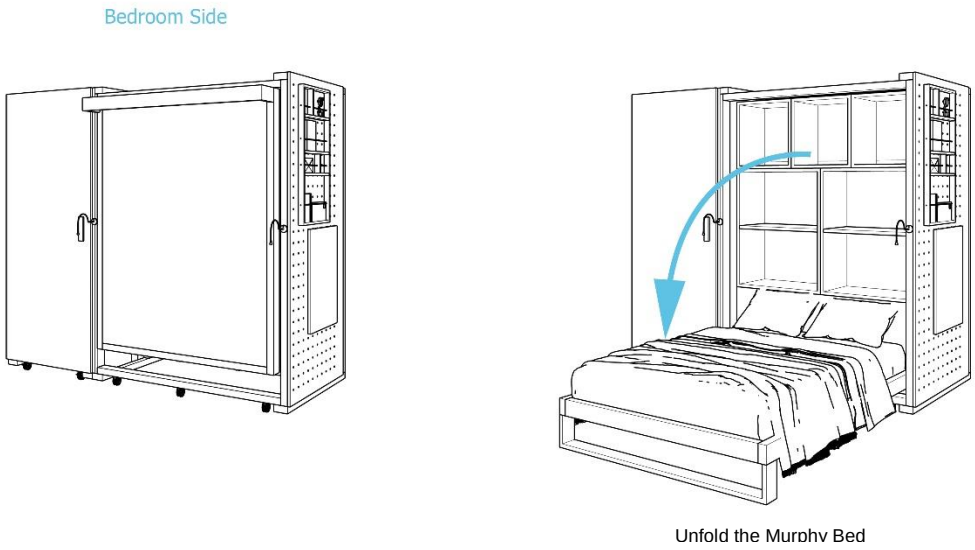
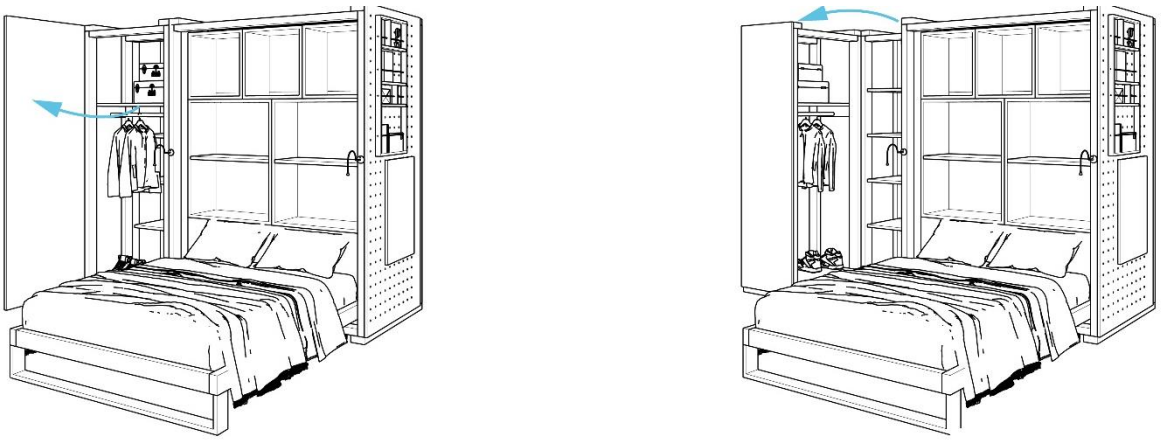


Figure 4.9: Bedroom/Living room unit- the Bedroom side.

The closet is set next to the bed and consist of both coat hanger and shelving sections. Usually, people can open the closet door and grab the cloth. It can also be expanded into a mini walk-in closet by opening the coat hanger portion of the closet, as illustrated in *figure 4.10.*

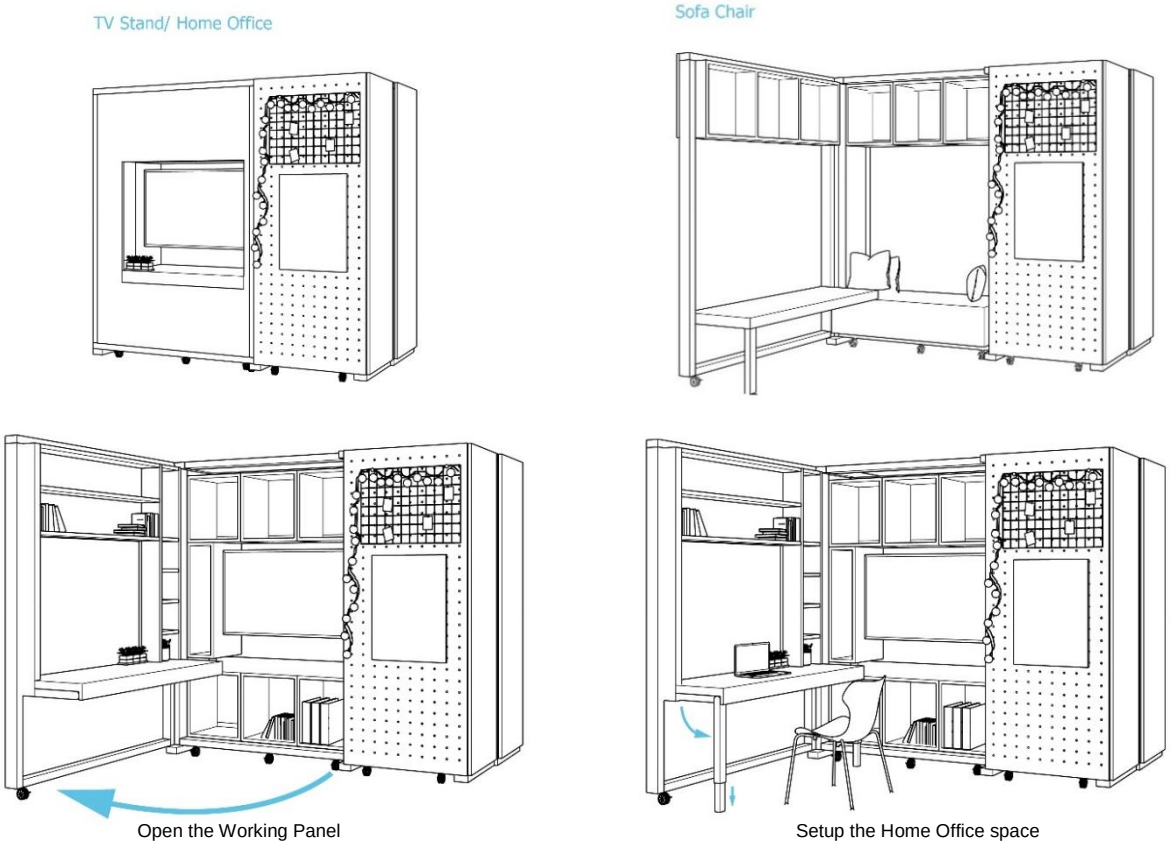


Open the closet door

Expand the closet into a
mini walk-in dressing space

Figure 4.10: Bedroom/Living room unit- the operable mini closet.

On the other side, the living room can switch between three modes: the TV stand, Sofa chair and a working desk. When the unit is closed, It can use as a TV stand in the living room. The user can



Open the Working Panel

Setup the Home Office space

Figure 4.11: Bedroom/Living room unit- the Livingroom side.

choose the between sofa chair and home office based on their need. To set up the home office, the user can open the cover panel and pull out the table support embedded in the table. This unit can adapt to different daily scenarios and facilitate all kinds of long-term spatial changes. Moreover, at the micro-scale, the vertical space finished with pegboard not only provide additional storages but also allow people to personalize the unit with their decorations.

Kit of Parts:

There are four main components in this unit. The following graphics intended to demonstrate assembly procedures of each part. The First component is the main structure frame made by pre-cuts lumbers. Castors are installed to provide unit movability within space.

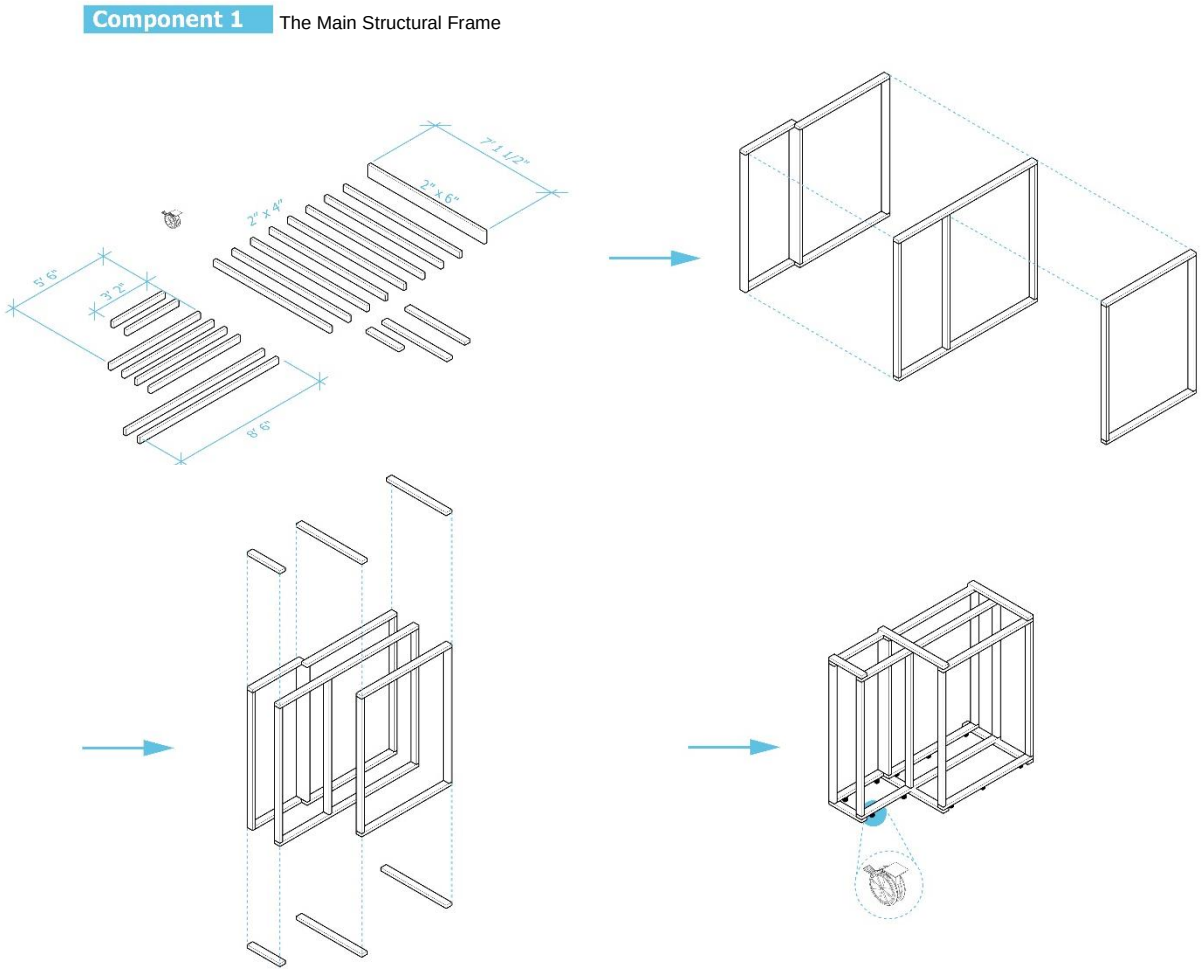


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Figure 4.12: Kit of parts for Bedroom/Living room unit- the main structural frame

The second component is the cover panel in the living room. It can switch between two options: work station and sofa chairs. The third part is a queen size murphy bed. Component four is the operable part of the closet.

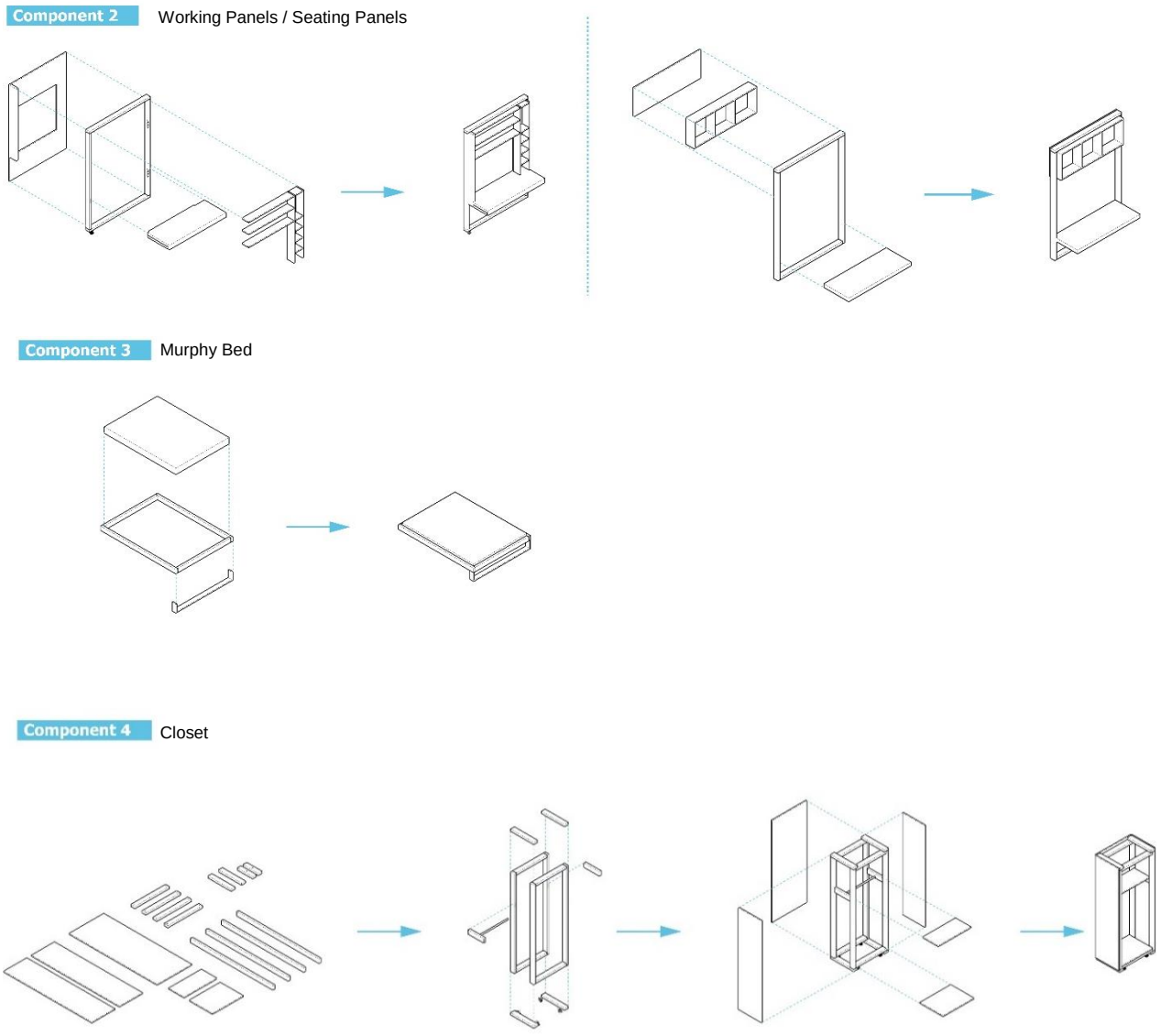


Figure 4.13: Kit of parts for Bedroom/Living room unit- the murphy bed, chair, workstation and closet.

Assembly:

1. After pre-assemble all the components, add storage units and shelves into the main structure.
2. Secondly add the rest pre-assemble pieces to the main structure.

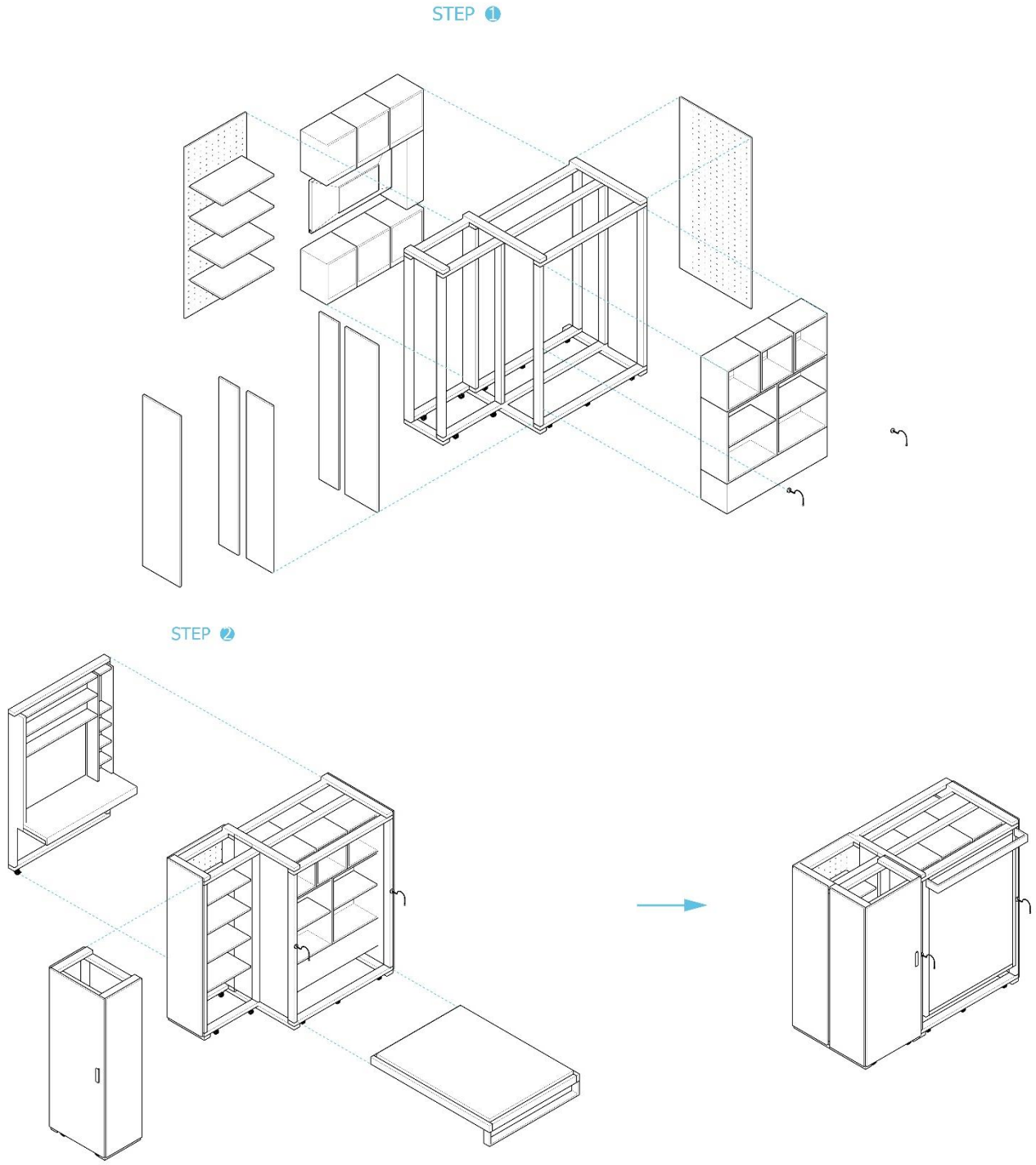
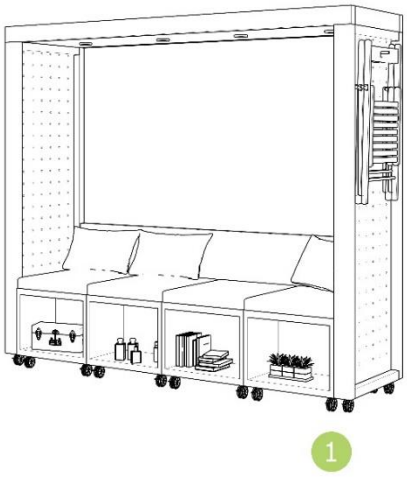


Figure 4.14: Bedroom/Living room assembling procedure.

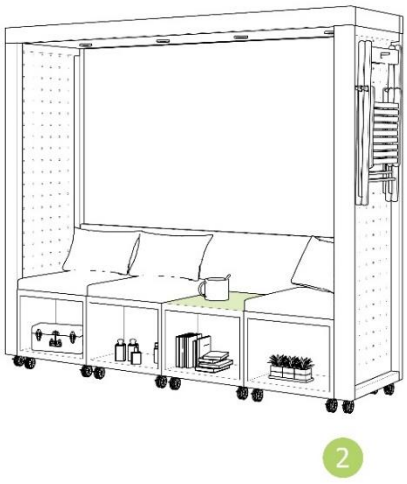
4.4. The Family Hub

In most of the home, the dining space and the living room are the social hub for family members gathering. Sofa and dining table are the two main elements in these spaces to support family relative activities. The third proposal combined these two elements as one unit. The design incorporates flexible tactics that occupants can switch the unit between two modes the sofa/seating and dining table.

In the new proposal, seating is shared for both dining and living space. A box module makes the seating with cushions placed on the top. The box can also provide additional storages under the seating. By removing the cushion, the chair can function as a coffee table for the living room. Like other elements proposal, castors are provided for each seating unit to allow flexibility for dweller to rearrange their living room space effortlessly. Furthermore, by rotating the back support of the sofa horizontally, the unit will alter into a dining table, and the sofa chairs become the dining chairs. To ensure the unit is completely free-standing without limited by the physical built environment, lighting fixtures and USB portals are integrated into the unit design. The occupant can simply plug the electrical core to any electrical outlet the room to provide power for lighting and phone charging. Again, pegboards are used in this unit to add extra vertical storage.



Sofa



Sofa with coffee table

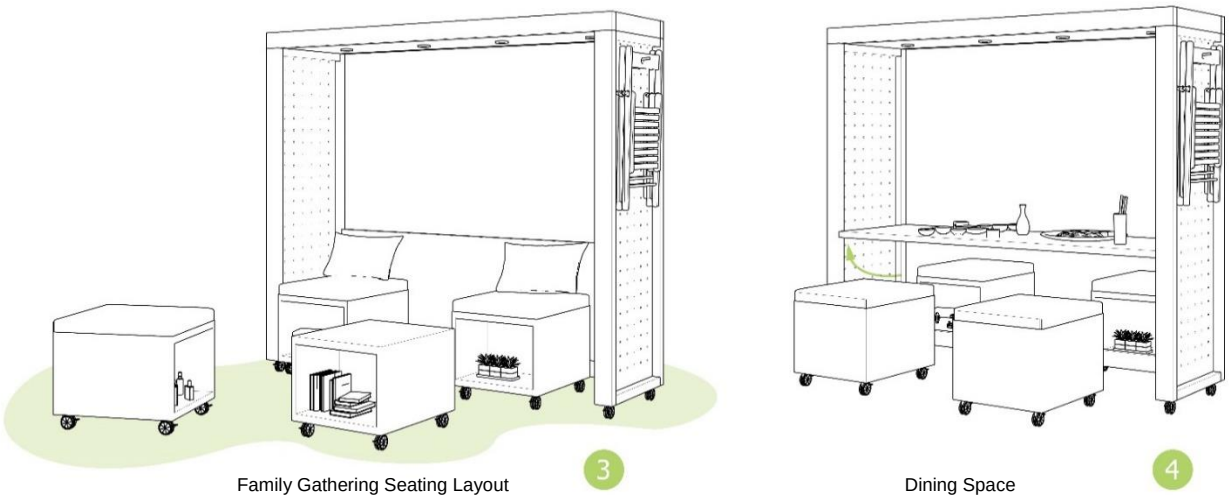


Figure 4.15: Living room/ Dining Unit

Kit of Parts

There are three components of this unit design. The seating module made by a storage box and four castors at the bottom. Occupant can choose the number of these modules based on their interior space. The second component is the side frame made by 2in x 4in (38 x 89 mm) lumber. Lastly the top frame is prepared based on number of seating modules the occupant chosed.

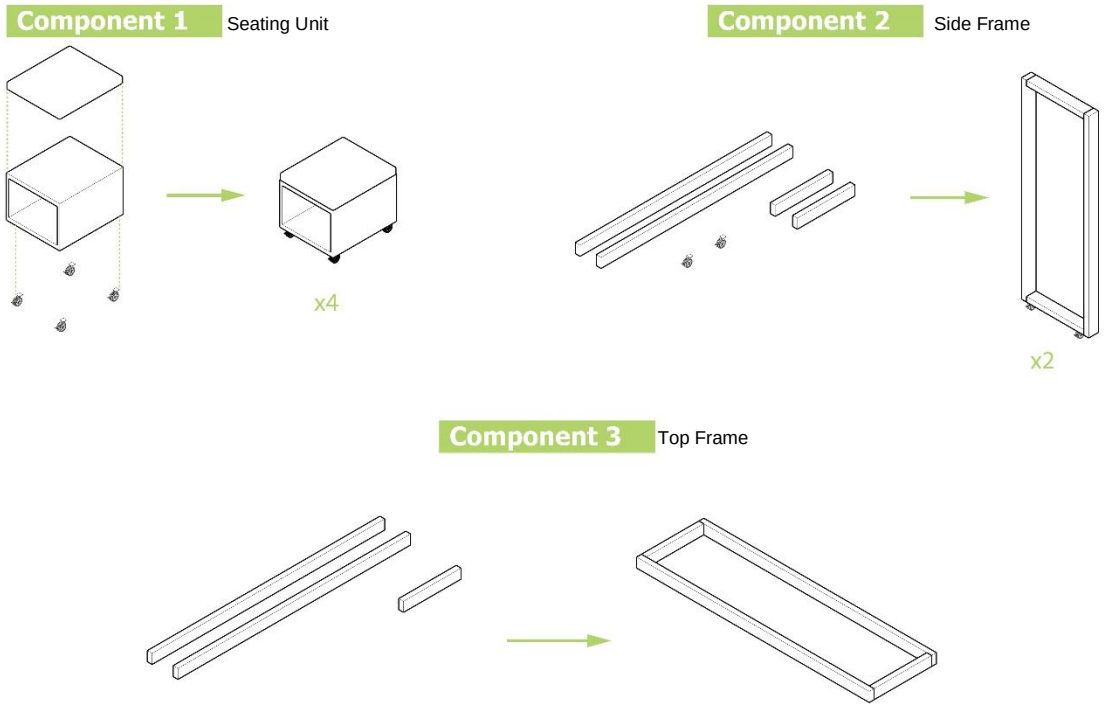


Figure 4.16: Living room/ Dining Unit, Kit of Parts

Assemble

1. Install the frame together with the pre-assembled frame pieces.
2. Add the pegboard and the table to the frame
3. Position the seating modules in place.

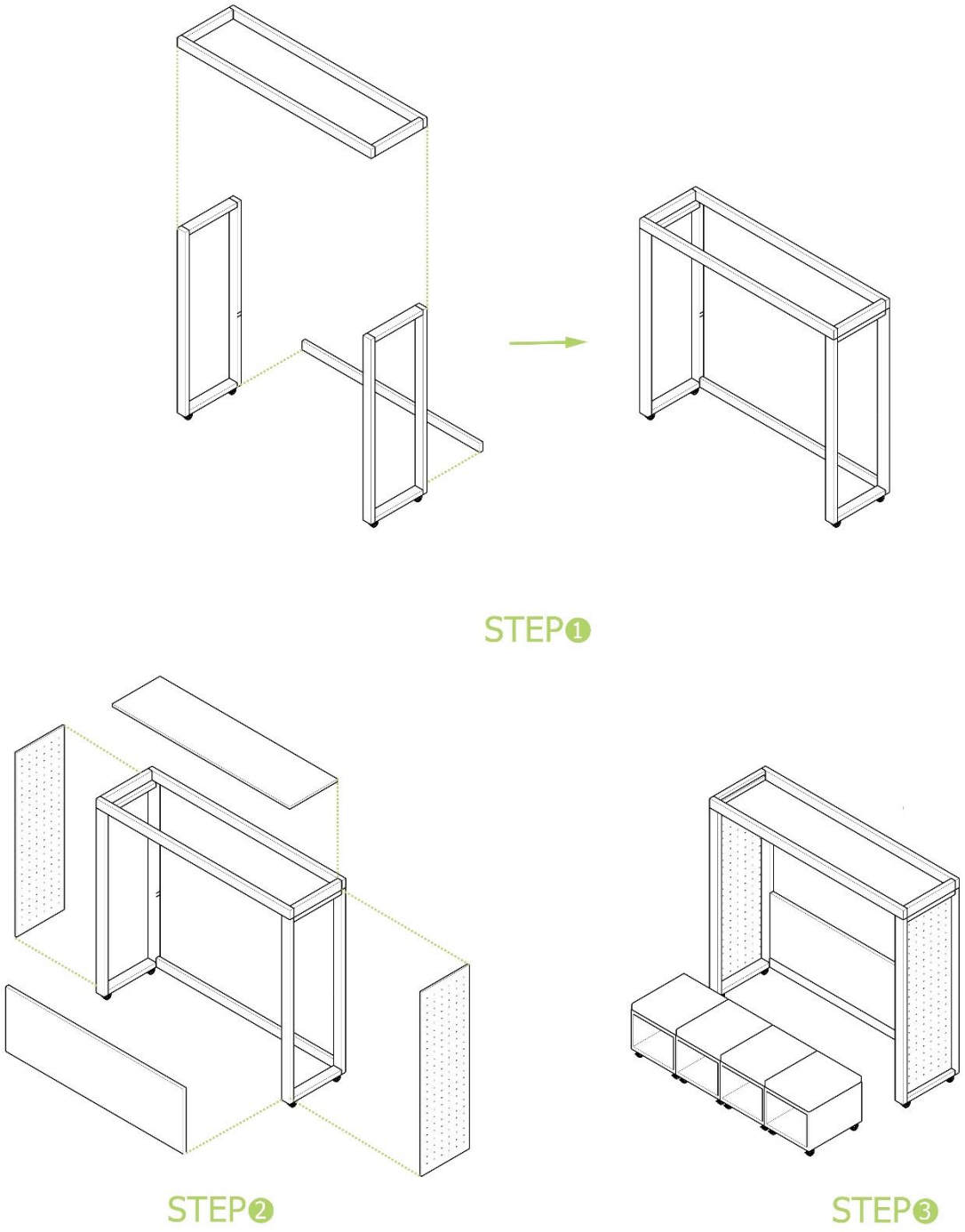


Figure 4.17: Living room/ Dining Unit, assembling procedure.

4.5. Design Application

To demonstrate these two unit can effective adapt the interior space for different scenarios, the following diagram intend to demonstrate utility of both units during different time of the day; and compare it with the original spatial layout.

Figure 4.18: Room layout during different time of the day.

4.6. Conclusion:

As Habraken envisioned the support and infill system should be able to function autonomously. The support provides the basic structural frame, while the infill is customized according to users' preference. When the society norm and user's needs change, the infill system can update independently without interrupting the normal function of the building. Following the infill and support theory as main design guideline, this design proposal isolates the interior fit-out with main structural element. This approach avoids potential intricate process in the future, when tenants want to reconfiguring interior space. This design proposal melds multiple functions associate with a space together, which minimize the spatial requirement to support all the activities. Moreover, with consideration of our nature life cycle, the unit can transform into different functions within a same space. As the current trend of urbanization and shrinking dwelling space in cities, this unit can ensure dweller to adapt their living space for different purposes without demanding enormous room for it. With these units, dweller can not only rearrange the overall room layout, but also make small adjustment to the unit such as table height.

All the unit is prefabricated based on order and delivery to site as kit of parts, user can assemble the unit together by following the instruction provide by manufacture. All the elements are designed to be able to fit through conventional door, which avoid unnecessary effort during delivery process. For future development, other unit can be designed and work together to help user to adapt interior space. Moreover, integration with cutting edge technologies such as motion sensor, robotic mechanical system, smartphone control platforms and potentially A.I. smart homes, the users can adapt the space effortlessly.

In conclusion, this research intends to understand the full spectrum of adaptable prefabricated architecture in residential interior space. This research identified seven adaptable design strategies are commonly applied in the market. For North American housing market, the optimum design should be free-standing modular unit that incorporate new technology into the design. In term of prefabrication methods, assemble-to-stock and made-to-order are the two most prevailing approaches in the market, due to its flexibility and cost-efficient features.

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