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Research Article

Flexibility Approach in Sustainable Architecture

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Abstract: In developing and changing societies, it has become inevitable to provide flexibility in sustainable architecture due to different needs. Thanks to the sustainable flexible designs, the emerging requirements are met. Flexible design in sustainable architecture; responding to the demands and needs of users, it gains importance in terms of sustainability in the life cycle process, in terms of their positive effects on the environment with the natural resources they consume during the construction, use, maintenance, repair and recovery stages and the waste they generate. In this study, the concept of flexibility and flexible architectural approaches were theoretically dealt with in a wide range and flexibility criteria were set up in sustainable architecture. Strategies for providing flexibility in sustainable architecture were identified and "flexibility criteria" were explained through examples. In determining the flexibility criteria, the approaches of many leading architects who are well-known in the historical process have been evaluated by evaluating the approaches to flexibility and flexibility criteria in sustainable architecture; four criteria, namely "spatial flexibility", "functional flexibility", "structural flexibility" and "aesthetic flexibility" were determined by evaluating them in terms of adaptiveness, movableness, interactivity and transformability perspectives.

Keywords: *Flexibility, Sustainable architecture, Flexible architecture, Flexibility criteria*

I. INTRODUCTION

Flexibility and adaptability have become central topics in contemporary architectural research, as buildings are increasingly expected to remain functional under changing social, environmental, and technological conditions. Recent literature indicates that adaptability is no longer considered a marginal design feature but rather a fundamental performance attribute associated with long-term building value, lifecycle extension, and the capacity to respond to change (Askar et al., 2021; Mlote et al., 2024). Within this perspective, buildings are understood not as static objects but as dynamic systems capable of accommodating evolving user needs, shifting functions, and future uncertainties.

This transformation is closely linked to the concept of sustainability. Current studies emphasize that building adaptability contributes to sustainability by reducing premature obsolescence, extending service life, and increasing the potential for reuse, transformation, and circular material flows (Askar et al., 2022). In other words, buildings that are capable of effectively absorbing change are less likely to require demolition or resource-intensive interventions. Accordingly, adaptability is increasingly addressed not only as a spatial or technical issue but also as a strategic component of circular economy and sustainable built environment approaches (Hamida et al., 2023).

Recent research also highlights the necessity of addressing adaptability through structured design frameworks. Askar et al. (2021) argue that adaptability has evolved into a multi-dimensional concept encompassing physical, functional, and temporal aspects, while their subsequent work establishes a direct relationship between design for adaptability and circularity-oriented assessment models (Askar et al., 2022). Similarly, the systematic review conducted by Mlote et al. (2024) demonstrates that contemporary research converges around key themes such as modularity, disassembly, reuse, resilience, and lifecycle extension. These studies collectively suggest that adaptability can be examined through a systematic set of design parameters rather than through isolated case-based interpretations.

Another important aspect emphasized in recent literature is the need to translate adaptability into tangible architectural characteristics. Watt et al. (2023) explicitly question what an adaptable building should look like and argue that adaptability must be reflected in observable architectural features and design decisions. This perspective is particularly significant for sustainable architecture, as the effectiveness of adaptability depends on its integration into spatial organization, building systems, and future transformation capacity from the early stages of the design process. In this sense, adaptability functions as a bridge between theoretical sustainability goals and architectural implementation.

Despite the growing body of literature, the relationship between flexibility and sustainable architecture remains

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insufficiently structured. Existing studies provide strong theoretical and empirical support for adaptability and circularity; however, the translation of these concepts into a clear architectural classification remains limited. Therefore, there is a need for a systematic framework that defines flexibility within the context of sustainable architectural design.

In response to this need, the present study examines the concept of flexibility through recent literature and proposes a structured classification based on four main criteria: spatial flexibility, functional flexibility, structural flexibility, and aesthetic flexibility. This framework aims to contribute to both theoretical discussions and practical design processes by clarifying how flexibility can be interpreted as a sustainability-oriented architectural strategy rather than merely a technical or formal concern.

II. MATERIAL AND METHOD

A. Sustainable Architecture

Sustainable architecture has been developed with the aim of reducing the significant consumption of energy and materials that occurs throughout the life cycle of buildings. When a building is designed in accordance with existing conditions and user needs, substantial savings in energy and materials can be achieved. Therefore, one of the fundamental challenges in the field of architecture is the rapidly changing needs and demands. To accommodate these dynamic demands, buildings must possess a flexible structure and spatial configuration (Estaji, 2017). Fisher (1993), defines sustainable architecture as an approach that conserves energy, utilizes renewable or recyclable materials, seeks to reduce dependence on fossil fuels, and aims to create more scalable buildings and communities.

Mollison and Slay (1994), define the purpose of sustainable architecture as the development of systems that are ecologically resilient, economically feasible, capable of meeting their own needs, and free from exploitation and pollution. These characteristics collectively contribute to long-term sustainability. Today, sustainable architecture has evolved as a synthesis of the various perspectives, objectives, and concerns mentioned above, ultimately reaching a more generalized understanding. This concept reflects an awareness of building design that is climate-responsive, energy-efficient, sensitive to social and cultural contexts, economically oriented toward the conservation of natural resources, and intended to minimize environmental impact (Williamson et al., 2003). Although sustainable architecture is a frequently discussed goal within architectural practice, its scope remains vaguely defined and lacks a universally accepted definition (Baweja, 2014).

Sustainable architecture aims to shape the living environments of the future starting from the present, by combining traditional architectural culture with the principles of sustainability. This is achieved through collaboration with various disciplines such as civil engineering, mechanical engineering, and electrical engineering, with the goal of transforming existing buildings into sustainable ones and ensuring that newly constructed buildings possess both flexible and sustainable qualities.

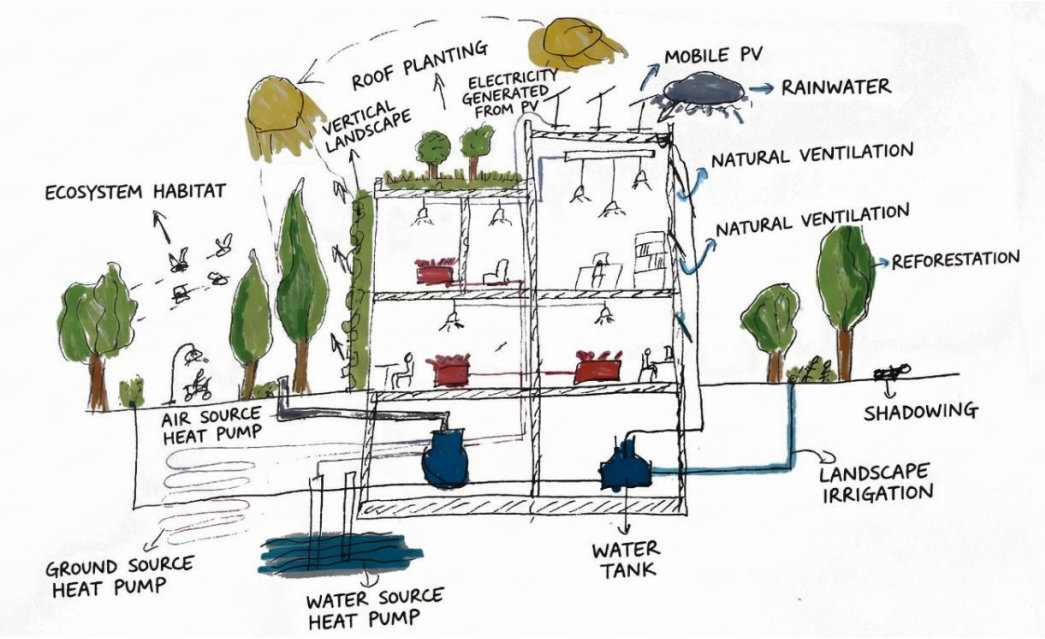


Figure 1. Living spaces in sustainable architecture (Sketch by Halil Yılmaz).

Sustainable architecture, as shown in Figure 1, allows to extend the life of buildings, save energy and resources, improve waste management and material use processes, respond to changing user demands, adapt to environmental and climatic conditions, and increase the quality of housing and life.

B. Sustainable Architecture Criteria

Sustainable architecture addresses environmental issues not only within the framework of ecological concerns but also by considering economic and social dimensions. From the design phase of a building onward, achieving sustainability goals requires the integration of these three dimensions through a holistic approach (Erengezgin, 2003). Environmental, economic, and social aspects constitute the three fundamental pillars of sustainability. Implementing these pillars is made possible through strategies such as energy conservation, efficient use of water, material management, optimal resource utilization, low maintenance and operational costs, design considerations that prioritize human health and comfort, and the preservation of social and cultural values (Gültekin & Yavaşbatmaz, 2013; VanGeem, 2006; Yeang, 2012).

Sustainable architecture adopts the principle of constructing a sustainable society and environment by placing environmental, economic, and social factors at its core. Therefore, many developed countries have established green building certification systems to ensure sustainability. BREEAM, LEED, GREENSTAR, CASBEE, and DGNB are among the most widely used sustainable green building certification systems in the world. These systems employ a range of evaluation criteria that vary according to the geographical, social, and economic conditions of the countries in which they are implemented.

C. Flexible Architecture Approaches

In order to meet the evolving and diversifying needs of housing users, it is necessary to transform both housing functions and technical systems. In this context, concepts such as flexibility, convertibility, adaptability, and expandability have gained prominence in the field of architecture. In line with social changes, residential buildings must be open to physical transformation and flexible design approaches to allow users to adapt to their living environments (Forty, 2000; Onat, 1993; Schneider & Till, 2007; Yılmaz, 2006; Yürekli, 1983).

Flexibility refers, in one sense, to the ability of a structure to expand or contract by adding or removing elements without compromising its integrity. In another sense, it involves the modification of building components and their relationships. This is made possible through strategies such as the use of movable partition walls and spatial organizations that eliminate the need for fixed dividing walls (Norberg-Schulz, 1963). According to Schneider and Till (2005/2007), flexibility is defined as negotiated change, focusing on a range of issues aimed at addressing both current and future user needs. Flexibility first involves the provision of diverse unit configurations within architectural layouts. It also includes the potential for these units to adapt and be transformed over time. Furthermore, it allows the building to accommodate new functions. While Habraken (2008), describes flexibility in terms of modification, adaptation, usage diversity, and freedom, Kronenburg (2007), identifies adaptation, mobility, transformation, and interaction as key concepts associated with flexibility.

D. Flexible Architecture in Historical Process

The origins of demountable and reassemblable architecture can be traced back to traditional structures such as the "tipi" used by Native Americans in North America, the "tent" commonly found in the deserts of North Africa, and the "yurt" used in Asia (Kronenburg, 1997). These shelters, constructed by attaching textile materials to a load-bearing frame, are considered the earliest examples of portable and rapidly assembled/disassembled structures in history (Topham, 2004).

One of the earliest examples of the flexible design concept is Le Corbusier's "Maison Domino" project, designed in 1915. This project is regarded as a precursor to the flexible planning approach. The Domino system is based on the principle of integrating columns, floors, walls, and stairs into a cohesive system that combines structural materials and functional requirements in the most optimal way (Risselada, 1991). Ludwig Mies van der Rohe, one of the pioneers of modern architecture, also worked on flexible architectural designs in the post-war period. His 1927 apartment design for the Weissenhofsiedlung is notable for its completely open plan, with only one or two interior load-bearing columns. Habraken, 2008) advocated for the open-plan system to enable flexibility in architectural design and argued that inflexible designs lacking user participation result in monotonous buildings. Norberg-Schulz (1963), emphasized that flexibility can be achieved in two ways: first, by allowing the structure to expand or contract through the addition or removal of elements while preserving its integrity; and second, by enabling changes in the building components and their interrelations. While developing a user-centered planning approach, Hertzberger (1991), contributed to the discourse on flexibility, and Kronenburg (2007), highlighted key aspects such as accessibility, multifunctional spaces, open-plan configurations, movable furnishings, the interaction between interior and exterior spaces, and the integration of technology.

E. Flexible Architecture and Flexibility Criteria

According to Sinclair et al. (2012), static spaces designed within rigid and predefined physical parameters tend to resist adaptation to different uses over time. These fixed spaces are typically designed to serve a single function, making them inflexible and structurally rigid. However, over the lifespan of the built environment, user needs often change, making modifications to buildings or their surroundings necessary. Sinclair et al. (2012), evaluate the potential of buildings to adapt to such changes under three main categories:

- ✓ Spatial flexibility,
- ✓ Functional flexibility,
- ✓ Aesthetic flexibility.

The literature presents various definitions and approaches by different architects regarding flexible housing. Based on Cavalliere et al. (2019), and other approaches proposed throughout architectural history, the factors and strategies related to building flexibility have been compiled and presented in Table 1.

Table 1. Building flexibility factors and strategies (Askar et al., 2021; Cavalliere et al., 2019; Cellucci & Sivo, 2015; Goncikowski, 2023; Hamida et al., 2023; Israelsson & Hansson, 2009; Kronenburg, 2007; Latif & Shahin, 2023; Li et al., 2025; Ratsou Staehr et al., 2025; Slaughter, 2001; Till & Schneider, 2005; Watt et al., 2023; Živković & Jovanović, 2012).

Reference	Principles/Factors	Definition/Strategies	Flexibility Factors
Slaughter (2001)	Interactions within the system	Reducing connections/interactions between components	**SPATİAL**
	Interactions between systems	Reducing dependencies on other systems to simplify maintenance	**SPATİAL**
	Interchangeable parts	Providing economies of scale in material ordering and facilitating replacements	**SPATİAL**
	Increase plan predictability	An organized layout can signal how to reduce time and locate components for demolition work	**FUNCTİONAL**
	Specific system area	Keeping certain areas or volumes away from other components and systems.	**FUNCTİONAL**
	System access proximity	Increasing the physical proximity of access points to specific systems to reduce the need for significant renovations	**FUNCTİONAL**
	Increase flow	Improved flow achieved by strategic placement of components can simplify replacement	**FUNCTİONAL**
	Phase system installation	Using components designed to accommodate growth in a specific system can eliminate all or part of the system.	**SPATİAL**
Till & Schneider (2005)	Area	Less defined use of space	**FUNCTİONAL**
	Construction (Building)	Buildings that allow for easy intervention in the future	**FUNCTİONAL**
	Design for adaptation	Forecasting future scenarios and plan adaptations	**FUNCTİONAL**
	Tiers	Clearly defining the building layers from structure, surface, services, interior partitions to completion	**FUNCTİONAL / AESTHETİC**
	Typical plan	General and indeterminate space	**SPATİAL**
	Services	Locating services that allow for future change and upgrades	**FUNCTİONAL**
Kronenburg (2007)	Adaptable	Ability to adapt to different situations and users by changing function, surface, or form	**AESTHETİC / FUNCTİONAL**
	Transformable	Changing the spatial, structural, or material impact of a building through building components and fittings	**SPATİAL / STRUCTURAL**
	Mobile	Moving a building at the scale of its environment, structure, or components	**FUNCTİONAL / SPATİAL**
	Interactive	Interaction between the user and the building, and between architecture and other disciplines, using intelligent automation systems	**AESTHETİC / FUNCTİONAL /SPATİAL**
Israelsson & Hansson (2009)	Material standards	Materials with a lifespan suitable for current and future operations	**AESTHETİC / SPATİAL/ FUNCTİONAL**
	Manufacturing	Prefabrication leads to more flexible production techniques	**FUNCTİONAL**
	Installation	A high degree of planning is required due to the difficulty of changing installations	**FUNCTİONAL**
	Planning for changes and service life	determines the functions of a building can adopt in the future	**FUNCTİONAL**

Table 1. (cont) Building flexibility factors and strategies (Askar et al., 2021; Cavalliere et al., 2019; Cellucci & Sivo, 2015; Goncikowski, 2023; Hamida et al., 2023; Israelsson & Hansson, 2009; Kronenburg, 2007; Latif & Shahin, 2023; Li et al., 2025; Ratsou Staehr et al., 2025; Slaughter, 2001; Till & Schneider, 2005; Watt et al., 2023; Živković & Jovanović, 2012).

Živković & Jovanović (2012)	Orientation of the housing unit	Single-sided, two-sided, or three-sided orientation	**FUNCTİONAL**
	Geometry of the plan	Dispersed or compact housing units	**FUNCTİONAL**
	Size and structure of the apartment	Relationship between the structure and size of the apartment and the family structure	**SPATİAL / FUNCTİONAL**
	Location of technical services	Central or peripheral position, grouped or individually arranged	**FUNCTİONAL**
	Building structure	Masonry or skeletal structure	**STRUCTURAL**
Cellucci & Sivo (2015)	Spatial flexibility within a fixed surface area	Redundant access; customization of privacy and social needs	**SPATİAL**
	Spatial flexibility	Increasing surface area within existing support	**SPATİAL**
	Technological flexibility techniques related to construction	Adjusting and adapting the building envelope; structural regularity and adaptable floors	**AESTHETİC / SPATİAL / FUNCTİONAL**
	Maintenance-related technological flexibility	Integrating home automation systems; equipment redundancy and control	**FUNCTİONAL**
Askar et al. (2021)	Multidimensional Adaptability Framework	Developing a holistic design approach that integrates physical, functional, and temporal dimensions to manage future uncertainties.	**FUNCTIONAL / SPATIAL**
Goncikowski (2023)	Hard-Soft Portion Optimization	Establishing a rational balance by decoupling the permanent core structure (hard portion) from market-responsive, reconfigurable residential units (soft portion).	**FUNCTIONAL / STRUCTURAL**
	Standardized Facade Modularity	Utilizing optimized facade modules that allow interior partition walls to be placed on different axes, increasing the variety of possible apartment combinations.	**AESTHETIC / SPATIAL**
Latif & Shahin (2023)	Decoupling of Main and Secondary Structures	Physically separating the rigid primary load-bearing frame from the lightweight secondary structure to allow for aesthetic freedom and dynamic load management.	**STRUCTURAL / AESTHETIC**
	Dynamic Joint and Load Management	Implementing flexible joints between structural components to absorb energy from impulse loads, preventing damage while enabling system movement.	**STRUCTURAL**
Hamida et al. (2023)	Circular Construction Determinants	Integrating demountable and reusable components into the design to facilitate circular material flows and minimize early obsolescence.	**FUNCTIONAL / STRUCTURAL**
Watt et al. (2023)	Observable Architectural Attributes	Ensuring that adaptability strategies are manifested in concrete, visible design features such as spatial organization and flexible structural systems.	**SPATIAL / FUNCTIONAL**
Li et al. (2025)	Component-Based Adaptability	Incorporating modular technical shafts and separable structural systems that can be easily modified to meet the changing physical and social needs of aging populations.	**FUNCTIONAL / STRUCTURAL**
Ratsou Staehr et al. (2025)	Scalable Infrastructure and Systems	Adopting a strategy of over-designing technical shafts and service capacities to accommodate future technological shifts and functional conversions.	**FUNCTIONAL**
	Internal Layout Fluidity	Enhancing the building's capacity for interior reconfiguration during the use phase through the application of lightweight, removable partition materials.	**SPATIAL**

From the 1960s to the present, the concept of flexible housing has been addressed by many architects, drawing on various principles and developing various strategies. Table 1. presents the principles identified by some architects who have worked on flexibility, along with the definitions and strategies they have developed to achieve these principles. In

light of these definitions and strategies, flexibility criteria have been defined as spatial flexibility, functional flexibility, aesthetic flexibility, and structural flexibility.

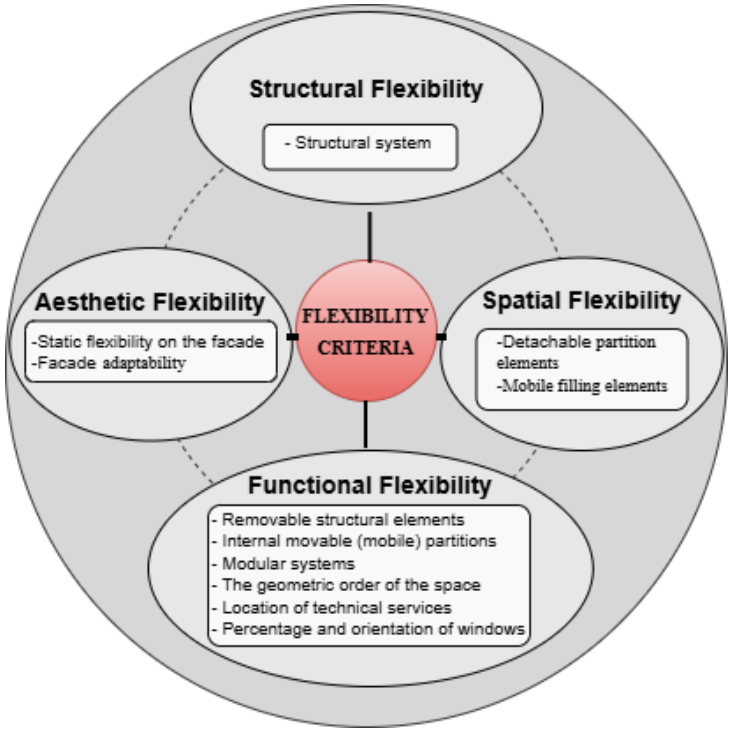


Figure 2. Flexibility criteria (Askar et al., 2021; Cavalliere et al., 2019; Cellucci & Sivo, 2015; Goncikowski, 2023; Israelsson & Hansson, 2009; interpreted by İslamoğlu & Usta, 2018; Hamida et al., 2023; Kronenburg, 2007; Latif & Shahin, 2023; Li et al., 2025; Ratsou Staehr et al., 2025; Slaughter, 2001; Till & Schneider, 2005; Watt et al., 2023; Živković & Jovanović, 2012) (Figure: Halil Yılmaz).

Spatial flexibility is achieved with "detachable partition elements and mobile filling elements", functional housing flexibility with "removable structural elements, internal movable partitions, modular systems, geometric layout of the space, location of technical services, percentage and direction of windows", aesthetic flexibility with "static flexibility on the facade and facade adaptability", and structural flexibility is achieved according to the characteristics of the "structural system of the building" (Figure 2).

E.1. Spatial Flexibility

Spatial flexibility allows for the solution of different functions within a single volume, responding to short- and long-term changes in users' needs and desires. In this system, the plan should be divided into variable and fixed areas. Areas that can be rearranged according to user needs are separated using sliding, folding, retractable, and movable walls (Sinclair et al., 2012). This arrangement allows for flexible reconfiguration of the space.

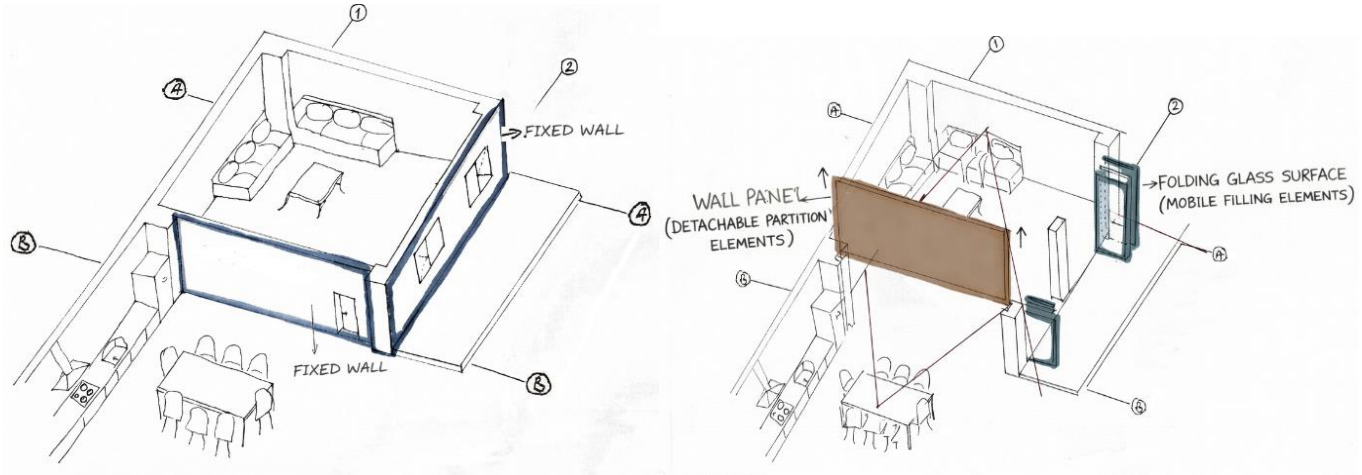


Figure 3. Spatial flexibility (Sketch by Halil Yılmaz).

As seen in Figure 3, spatial flexibility is achieved through specific strategies. The first drawing utilizes fixed walls and furnishing elements, while the second drawing utilizes removable walls, foldable glass surfaces, and movable infill elements, allowing for spatial flexibility by expanding or reducing volumes. Two fundamental strategies stand out in achieving spatial flexibility: the use of removable partitions and mobile infill elements.

E.1.1. Detachable Partition Elements

Detachable partition elements are elements, usually made of lightweight materials, that physically separate spaces and create distinct areas. These elements are generally based on modular design principles and can be easily repositioned according to user needs (Karni, 2008). Installation and dismantling of these elements are generally quick and easy (Mateus et al., 2013).

Detachable partition elements are a key element in providing spatial flexibility. These elements provide significant interior space savings. When necessary, significant spatial changes can be made within the existing structure. Furthermore, infill elements visually blend in with the building's interior without taking up too much space.

E.1.2. Mobile Filling Elements

Another important element in terms of spatial flexibility is mobile infill elements. Thanks to their mobility, these elements adapt to the changing needs of users in the short and long term, allowing for the creation of different spatial arrangements simultaneously.

Mobile infill elements are generally movable structures or furniture used to enhance the functionality of spaces. These elements, thanks to their non-fixed, portable features, allow users to use spaces more effectively (Habraken, 1998).

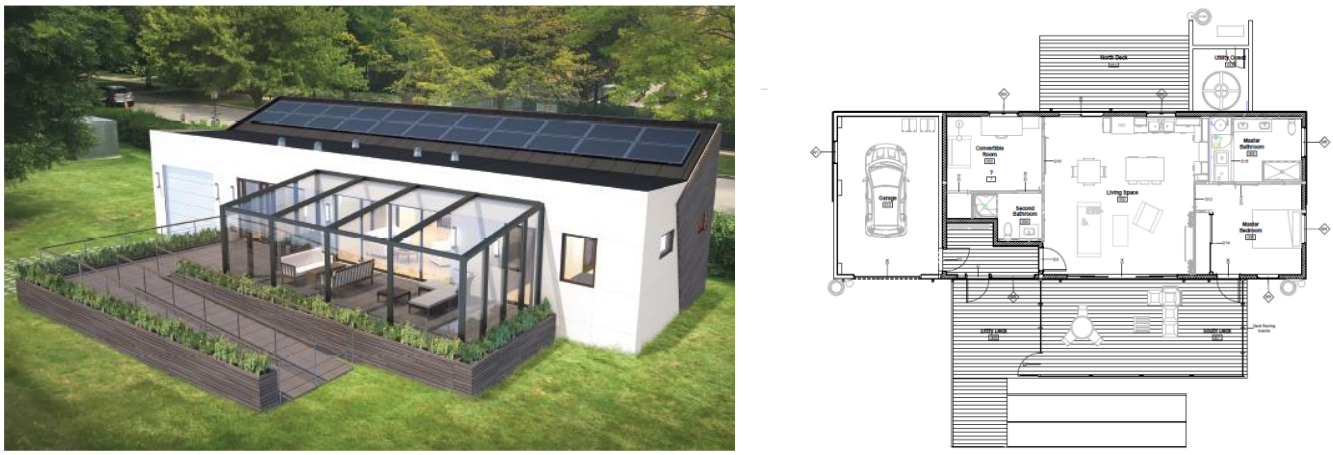


Figure 4. Northwestern house (U.S. Department of Energy, 2017c).

In Figure 4, the "Northwestern house" developed by Northwestern University in Visual 1, spatial flexibility was achieved by creating a structure that allows for different lifestyles with pre-fabricated, color-changing, removable and sliding movable walls.

E.2. Functional Flexibility

Functional flexibility should be evaluated within the context of the transformation of the architectural program or the functional changes of residential spaces. Within this framework, an architect who is aware of the levels of change inherent in the flexible building approach can significantly contribute to the physical and functional sustainability of a building by anticipating how long the building can be used, when its lifespan will end, and what it can become once it has. Flexibility, based on adaptability to functional change, is also a significant element in terms of the interchangeability of functions within the building, the addition of new functions, or the removal of existing ones.

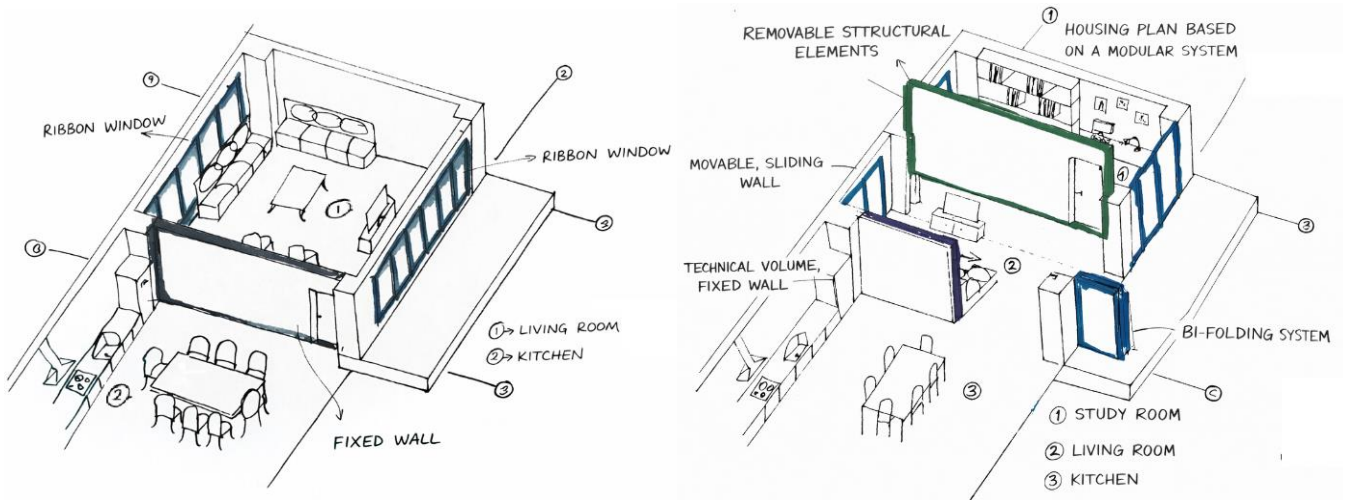


Figure 5. Functional flexibility (Sketch by Halil Yılmaz).

In Figure 5, the first image shows the use of fixed walls and strip windows. The irregular plan geometry of the building poses obstacles to future functional changes to the volumes and overall structure. In the second image, functional transformations can be achieved in volumes one, two, and three using removable structural elements and movable partitions. Furthermore, fixing the placement of technical services, opting for partitioned windows instead of strip windows, designing the plan within a geometrical order, and modular construction allow for functional changes in both the structure and the volumes.

In this context, six fundamental strategies are considered to ensure functional flexibility. These strategies include removable structural elements, movable (mobile) partitions in interior spaces, modular systems, the geometric layout of the space, the positioning of technical services, and window percentages and orientations.

E.2.1. Removable Structural Elements

Removable building elements are building components that can be easily modified and rearranged to meet the needs of spaces. These elements provide flexibility in design processes and allow for faster response to user needs (Gosling et al., 2013

Removable building elements offer many benefits, including the ability to disassemble subsystems, reconfigure spaces, and reduce maintenance and repair costs. The criteria for removable building elements are determined by structural elements such as removable walls, exterior walls, floor coverings, and load-bearing components (beams and columns). A notable aspect of this criterion is that the proportion of removable building elements is evaluated relative to the total amount for each category (Cavalliere et al., 2019).

E.2.2. Internal Movable (Mobile) Partitions

Internal movable partitions allow for more efficient use of space by allowing for changes to the interior layout. For example, movable partitions used in open office spaces allow for different work arrangements to be created based on team needs (Gerdenitsch et al., 2018). The mathematical formulation of this criterion is similar to the criterion for "removable structural elements." Therefore, the criterion for "internal movable (mobile) partitions" considers the ratio of mobile elements to the total area of the interior partition walls (Cavalliere et al., 2019).

Internal movable (mobile) partitions quickly respond to the user's changing physical and social needs, increasing the flexibility of the building, extending its lifecycle, and saving time and resources.

E.2.3. Modular Systems

Modular systems, related to the industrialization of building construction processes, are defined as the production of repetitive components or specific sections of a building in a factory environment and assembly on site. Modular systems consist of components that can be assembled within a specific design language. These systems can be easily customized and modified to meet user needs. Particularly in sectors such as education and healthcare, modular structures offer the possibility of rapid adaptation and expansion (Ferdous et al., 2019). These modular systems contribute to reducing energy and insulation costs in residential buildings, effective environmental waste management, and minimizing environmental damage. Furthermore, allowing for quick and easy structural modifications plays a crucial role in minimizing potential errors during modifications thanks to prefabricated production and standards.

E.2.4. The geometric Order of the Space

The geometric layout of spaces plays a critical role in interior design. The shape of a space directly impacts users'

experiences and interactions. Geometric layout can alter the perception of a space by establishing a balance between functional flow and aesthetic values. In this context, users' movement patterns and social interactions should be considered when organizing the space (Hillier & Hanson, 1984).

There is a direct relationship between the geometric layout of a space and the flexibility of the building. The ability to reposition rooms, particularly depending on the geographical conditions where the building is located, in terms of sunlight, heat, and light is critical for both meeting user needs and ensuring functional flexibility. A sharply defined plan is not desirable; instead, it should adapt to evolving and changing conditions, creating a dynamic structure. Increasing and diversifying surface areas impact flexibility. Designs should consider future needs, offering the building and the user the opportunity to make changes/modifications.

E.2.5. Location of Technical Services

The location of technical services within a space is a crucial factor in terms of user comfort and functionality. The layout of electrical, plumbing, and ventilation systems should be optimized according to the space's layout and intended use. This increases the space's efficiency, both aesthetically and functionally (Chadderton, 2013). Technical services often have a low level of flexibility, preventing functional changes in some areas. An effective design, thanks to its flexible structure, allows for various changes in many areas, extending the building's lifecycle. Furthermore, accurately determining the location of technical services simplifies intervention in the event of future malfunctions and maintenance/repair requirements, reducing costs.

E.2.6. Percentage and Orientation of Windows

The percentage and orientation of windows determine the lighting and ventilation conditions of a space. Natural light intake increases user comfort and contributes to energy savings. Orienting windows maximizes daylight, helping to make interior spaces healthier and more livable (Acosta et al., 2016). In this context, window placement and design are considered critical elements in sustainable architectural approaches.

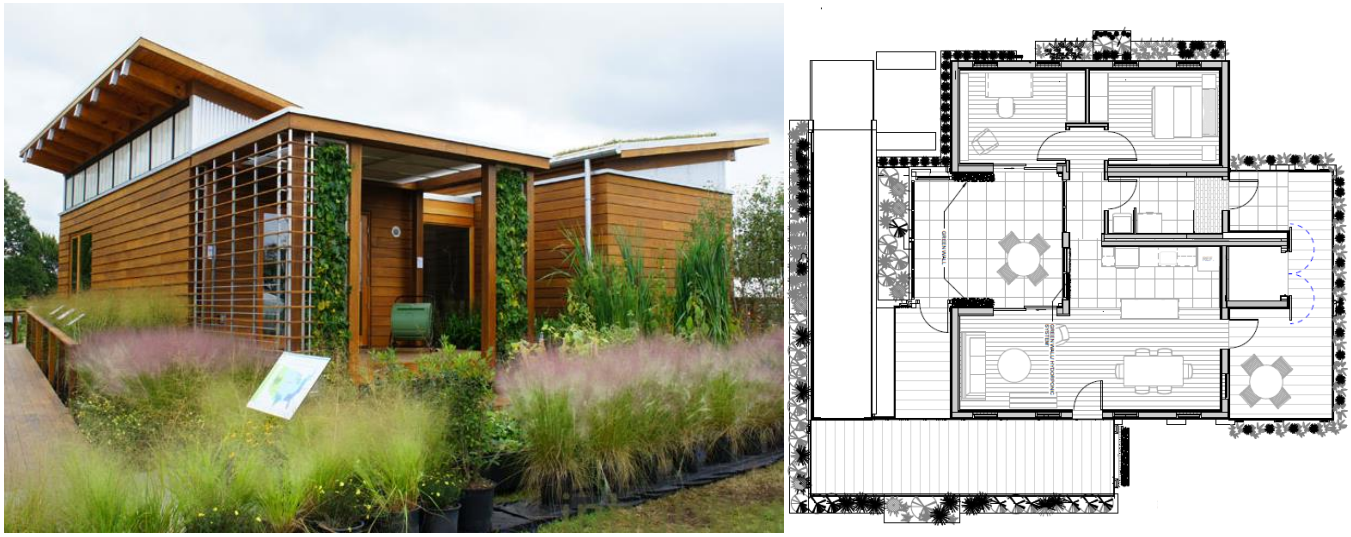


Figure 6. Maryland house (U.S. Department of Energy, 2017a).

In Figure 6, removable wall panels at the front of the building designed by the University of Maryland provide access to the mechanical, electrical, and plumbing systems within, allowing them to be separated from the structure. This allows for easy maintenance and repairs, and thanks to the movable and mobile elements, the interior of the building can be modified to meet different desired functions. Concealed fasteners are used on the wall panels to provide a simple and clean look, but they can also be easily removed with standard vacuum cleaners. Certain areas, such as the living room, dining room, bedroom, and study, can be added, or expanded or reduced as desired thanks to removable structural elements. This reduces unused space within the house, resulting in greater energy and space savings.

E.3. Aesthetic Flexibility

Building facades are both elements that determine the specific uses of interior spaces and surfaces that reflect the aesthetic preferences of shared users. These facades define privacy and transparency by establishing the space owner's interaction with the city in all sensory dimensions; they function as air conditioners and play a critical role in shaping the visual perception of a building. Within the framework of architectural approaches, the expression of the interior space can be considered in terms of its concealment, or, to a certain extent, solely in the context of aesthetic values, independent of the space itself. The user's lifestyle influences the space, and this influence can be observed through the façade.

The cultural values and characteristics of societies have a significant impact on living spaces (residences). Buildings are shaped by historical experiences and local conditions. However, when changes to the exterior, façade, and overall appearance of buildings need to be made over time, the lack of capabilities to allow for this can pose a problem. This is where the concept of aesthetic flexibility comes into play. It is important to design a structure that allows for the changes individuals desire to make to its exterior. These changes will not only meet the individual's personal desires and needs but will also contribute to the building's greater compatibility with the outside world.

Aesthetic flexibility is examined in two prominent ways, both between the designer and the user. The types of these methods are listed below:

E.3.1. Static Flexibility on the Facade

Static flexibility refers to the ability to achieve balance among the fixed elements of a building's façade design. This encompasses a variety of elements, from material selection to formal arrangements. Static flexibility plays a critical role in ensuring the continuity and aesthetic integrity of an architectural design (Vink, 2005).

The static flexibility of a façade stems not from the user's ability to intervene, but rather from the designer's well-thought-out support elements and functional and aesthetic values that satisfy both the user and the city. Numerous examples of static flexibility can be cited; these include double-skin façades, façade-extending floors, modular curtain walls, and similar methods. Functional modifications to a building's exterior also allow for static flexibility in the facade.

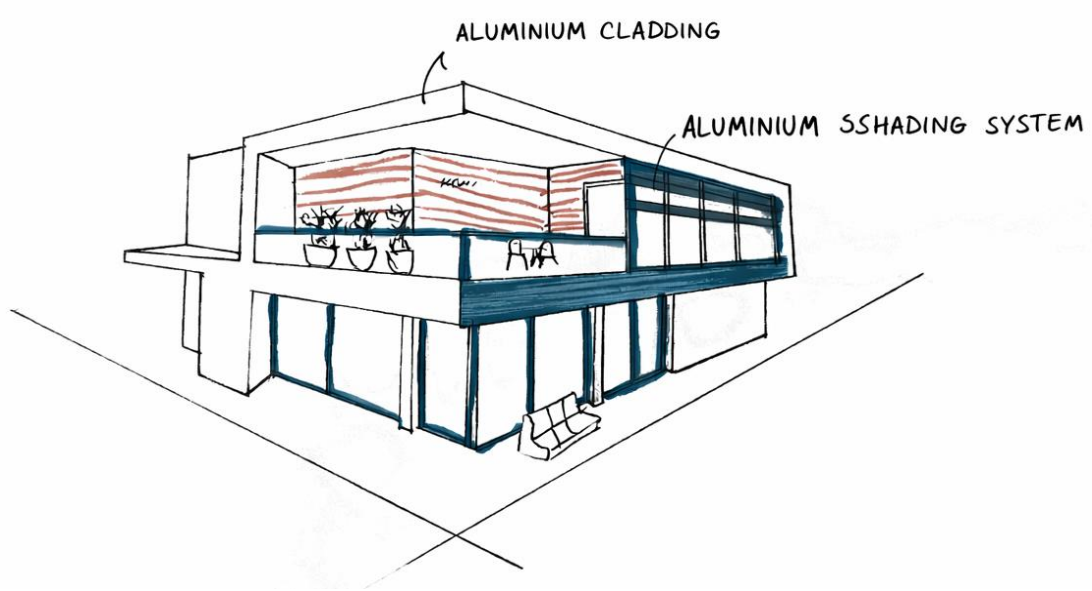


Figure 7. Static flexibility on the facade (Sketch by Halil Yılmaz).

Figure 7 shows an example of a façade designed using overhanging slabs, sunshades, and vertical landscaping. This design provides a user-friendly, user-friendly structure that is compatible with the aesthetics of the surrounding area.

E.3.2. Facade Adaptability

Adaptability refers to how a building adapts to changing needs and aesthetics over time. This concept is of paramount importance today in sustainable architecture. Buildings should be designed to consider not only current needs but also future transformations (Manewa et al., 2016). They can be defined as structures where the user has the opportunity and control to make certain levels of changes to the façade. In this approach, the designer plays a crucial role in ensuring the preservation of the building's aesthetics and urban image.

This design approach, which allows users to make certain levels of changes to the building's exterior, enables the creation of dynamic structures that are compatible with urban aesthetics and meet user expectations. However, any changes made must be left to the user's discretion to a certain extent, and this must be carefully planned during the design process. Otherwise, if the user exerts absolute control, the harmony of the building's exterior with urban aesthetics is likely to be disrupted, negatively impacting the building. This is also crucial for extending the lifecycle of energy-efficient buildings that maintain urban aesthetics and ecological balance.

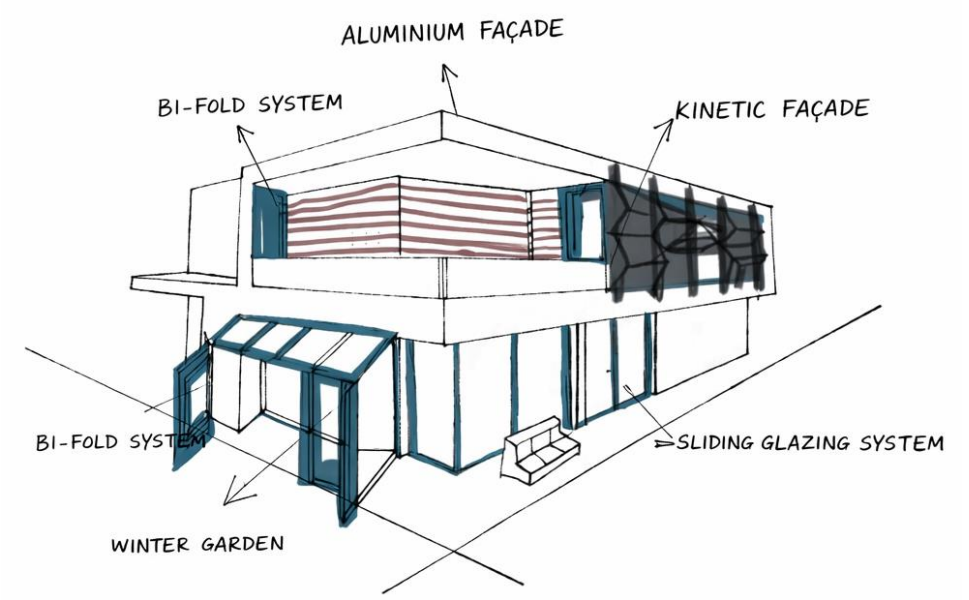


Figure 8. Facade Adaptability (Sketch by Halil Yılmaz).

Figure 8 presents an example of a facade designed using double-skin kinetic façades and folding joinery, giving users the opportunity and control to make changes at certain levels. Designed to preserve the urban image and aesthetics, these types of facades increase user satisfaction, reduce construction costs, and extend the building's lifecycle.

One example of aesthetic flexibility is the NeighborHub house, shown in Figure 9. This is an exemplary project where flexibility is implemented statically and in terms of flexibility in the exterior façade. As is well known, users' ability to modify the building's exterior surfaces is limited. However, this design allows users to meet their wishes and needs and achieve a high level of aesthetic flexibility.

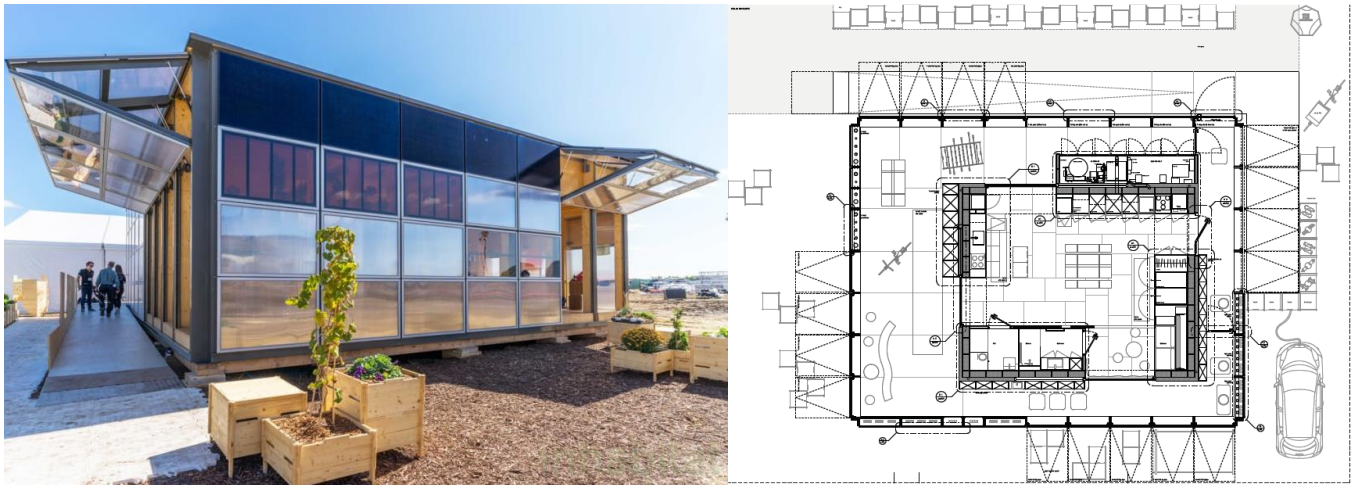


Figure 9. NeighborHub house (U.S. Department of Energy, 2017d).

The NeighborHub house project is a prime example of aesthetic flexibility, particularly in terms of its façade's adaptability to change. One of NeighborHub's most significant innovations is the placement of PV panels on the façades. Instead of traditional, optimized, sloped roof placements, a system of solar panels maximizes the use of solar energy throughout the day while also creating a variety of exterior designs.

E.4. Structural Flexibility

To enhance flexibility in housing, it is crucial to separate the "Structural elements" and "Infill elements" sections of the housing construction system, making these sections physically independent, and clearly defining the components of each section. Within this framework, structural flexibility is addressed from the perspective of the structural system.

E.4.1. Structural System

Structural system flexibility refers to the ability of a structure's load-bearing capacity and behavior to change according to the requirements of the architectural design and depends on many factors, from material selection to design

methods. While traditional buildings are generally constructed using rigid systems, the use of more flexible and dynamic systems has become widespread in modern architecture.

In masonry systems used in residential projects, walls serve both load-bearing and partitioning functions, preventing rearrangement after construction is complete. Considering that walls also contain plumbing connections, it's clear that such load-bearing systems will impose flexibility restrictions. In a flexible residence, the load-bearing system should, to the extent possible, avoid vertical space division, and permanent connections to vertical space division components should be avoided. Therefore, skeletal systems, where vertical load-bearing elements, non-load-bearing internal reinforcement, and building envelope components are functionally and physically separated, are considered suitable structural systems for flexible residences.

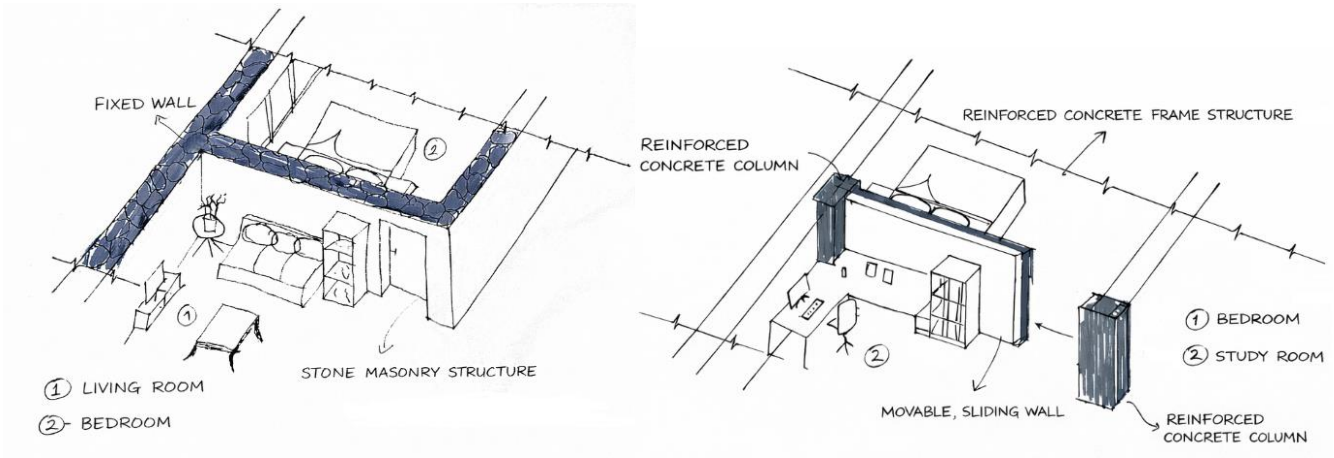


Figure 10. Structural flexibility (Sketch by Halil Yılmaz).

Figure 10 the first image, shows an example of a stone masonry system used as a load-bearing structure. In this system, the walls not only serve as load-bearing elements but also divide the volumes. The load-bearing properties of the walls limit the flexibility of the building's volumes. The second image shows an example of a reinforced concrete frame (skeleton) system. This system allows for horizontal flexibility in the sections of the building outside the load-bearing elements.

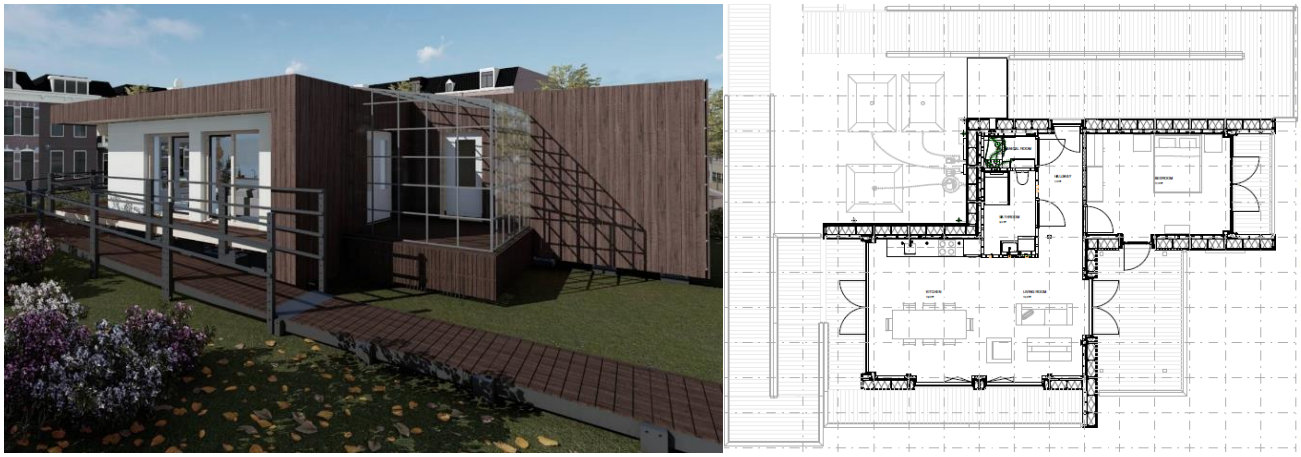


Figure 11. Self-sufficient house (U.S. Department of Energy, 2017b).

The Selfficient house, developed by the Netherlands University of Applied Sciences, shown in Figure 11, is designed almost like a Lego logic, allowing the house to be reduced or expanded according to user needs thanks to the ability to add or remove wall panels.

III. RESULTS AND DISCUSSIONS

The study demonstrates that contemporary housing models often fail to achieve targeted optimizations because they do not adequately respond to the evolving demands of users and market dynamics. This lack of adaptability hinders the achievement of environmental, economic, and social sustainability goals. Research findings indicate that architectural flexibility criteria are intrinsically linked to sustainability objectives through a multi-dimensional relationship. By

enhancing a building's capacity to absorb changes throughout its lifecycle, these criteria ensure resource efficiency and prevent premature demolition.

Impact of Flexibility Criteria on Sustainability Performance A primary finding of this research is that structural flexibility serves as a foundational prerequisite for achieving other flexibility types and broader sustainability targets. Utilizing skeletal systems allows for the independence of non-load-bearing elements, enabling horizontal spatial transformation and significantly extending the building's functional life. Furthermore, spatial and aesthetic flexibility were found to have strong correlations with nearly all sustainability indicators, with the exception of land use. Conversely, certain functional flexibility elements, such as the positioning of technical services and window-to-wall ratios, exhibited a comparatively weaker relationship with sustainability criteria.

Bridging Theory and Practice through Flexibility The need for "observable architectural attributes" highlighted in recent literature is operationalized through practical examples like the Maryland and Self-sufficient house projects. Features such as detachable wall panels and modular systems in these projects function as a "bridge" that translates theoretical energy conservation and waste management goals into tangible architectural solutions. Additionally, the results confirm that flexible design strategies support social sustainability by eliminating physical barriers for disabled users and accommodating modern lifestyle shifts, such as the increasing demand for home-based work environments.

IV. CONCLUSION

To ensure a sustainable society and future, it is imperative to extend the lifespan of the built environment by ensuring buildings remain responsive to shifting social and technological conditions. This study provides evidence that the integration of functional, spatial, aesthetic, and structural flexibility during the initial design phase positively influences a building's overall sustainability performance.

The core conclusions of the research are as follows:

- Structural flexibility is the cornerstone of sustainable design; achieving this criterion facilitates the implementation of all other flexibility and sustainability objectives.
- While spatial and aesthetic flexibility offer high efficiency across a wide spectrum of sustainability goals, elements like technical service placement and window orientation have a more localized and limited impact.
- Flexible design strategies provide strategic advantages, including the conservation of natural resources, effective waste management, and the creation of user-centered ecological living spaces that accommodate the needs of the elderly, children, and individuals with disabilities.

Ultimately, adopting the proposed flexibility criteria in residential design maximizes the building's lifecycle while reducing long-term maintenance and repair costs. Future research should focus on supporting these findings with quantitative data across diverse building typologies to further validate the impact of flexibility on sustainability.

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