University of HUDDERSFIELD

FLEXIBILITY IN USE IN VOLUMETRIC MODULAR HOUSING IN THE UK HOUSING INDUSTRY

SARA MOAYEDI

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ABSTRACT

The UK government encourages modern methods of construction to assist in reducing current housing shortages and minimise building costs. Housing should be adaptable to a family's changing needs and preferences over the course of their lifetime. Unfortunately, creating flexibility in volumetric modular housing, to meet customer needs over the house’s life, has been neglected.

It is essential for housing to be flexible, particularly during use, so that client needs can be met throughout the lifecycle of the house. As a result of the design and construction of the housing, residents and housing managers can make modifications over time due to the housing's flexibility. The spatial configurations of flexible houses can be modified in response to occupant behaviour and function changes, the addition of new users, and future renovations.

This study has defined principles that can increase flexibility in use. In addition, it was able to develop new steps for the DfMA Overlay to the RIBA Plan of Work that can assist designers in achieving flexibility in volumetric modular houses. This study provides a competitive framework that illustrates several steps to assist designers in incorporating flexibility in use into volumetric modular houses.

The target group of the study is designers and developers who want to know how to implement flexibility in volumetric modular houses that can increase customer satisfaction and add value to their product. The research has been conducted using two empirical cases and one in-depth casev followed by data collection using semi-structured interviews with designers, engineers, and developers, as well as documentary research, literature reviews, and workshops.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ABBREVIATIONS

VMH _ Volumetric modular houses

MMC _ Modern Methods of Construction

LTH _ Lifetime Home

FIU _ Flexibility in Use

EHS _ English Housing Survey

RIBA _ Royal Institute of British Architects

DfMA _ Design for Manufacture and Assembly

BoS _ Build offsite

HT _ House Type

OSM _ Off-Site Manufacture

EoT _ End-of-Terrace

Chapter 1: **INTRODUCTION**

1.1 Introduction

This chapter addresses the context and relevance of the research, as well as its aim and objectives. Additionally, the contribution, methodological approach, and for the sake of clarity, thesis structure is described.

1.2 Research context and relevance

While the construction sector is fragmented and slow to implement innovation and change (Ruparathna & Hewage, 2015), there is a noticeable shift toward offsite construction (Tsompanidis, 2018). Modern methods of construction (MMC) include a broad spectrum of advancements, significantly in the sector of residential building. Most of these innovations are offsite technologies, that entail shifting construction activity from the construction site to a manufacturing facility (Pan, Gibb, & Dainty, 2007; Pan & Hon, 2020; Wuni & Shen, 2019, 2020). They include prefabrication, modular construction, preassembly, offsite production, offsite manufacturing, industrialised construction, and a variety of onsite and offsite construction methods (British Urban Regeneration Association (BURA) 2005; National Audit Office (NAO) 2005; National House-Building Council (NHBC) 2006; Building Research Establishment (BRE) 2007).

The UK government supports modern methods of construction (MMC) to help alleviate existing housing shortages and reduce building costs. According to the most current results of the English Housing Survey, the United Kingdom needs 300,000 new houses each year (English Housing Survey, 2019-20).

Modern Methods of Construction (MMC) is a broad phrase that refers to a range of offsite and onsite techniques for home building that provide alternatives to conventional methods. The modern method of construction has seven categories such as (HFG, 2019):

1. Volumetric: Volumetric construction or modular construction is the process of manufacturing three-dimensional modules in a controlled industrial environment prior to delivery to site.
2. Panelised: This building technique includes flat panels manufactured within factory conditions. In contrast to volumetric construction, panels are constructed on-site or integrated into existing structures.
3. Hybrid: This is also known as semi volumetric analysis since it combines panelised and volumetric methodologies.
4. 3D printing: The printing of structural components in a variety of materials using digital design and manufacturing technologies on a remote, site-based, or final workforce basis.
5. Pods: This refers to the use of pre-assembled components that do not constitute part of the building's structure, but rather serve to condense materials and procedures that would have otherwise been provided on-site such as kitchens and bathrooms.
6. Traditional construction materials have evolved to make installation faster, simpler, and safer. This may often be accomplished via the use of big format versions of classic materials or by the development of materials that are simpler to install and require less on-site labour (internal walls, external walls, roofing finishes).
7. The use of technologies and procedures on-site to increase productivity by eliminating unnecessary work steps, allowing more accurate and strategic installation, and enhancing health and safety (measures to protect, productivity tools, use of BIM connected to on-site workflows, standardised temporary work, autonomous plant, digital verification, and robotics).

Volumetric modular homes (category 1) have the highest level of pre-manufacture (MHCLG, 2019). It may also help to improve the housing shortage in the United Kingdom by decreasing the building time and cost. In contrast, developing flexibility in volumetric modular homes to assist in satisfying client demands throughout the course of the house's lifespan has been overlooked. One of the reasons why flexibility while using the house is ignored is that developers do not think of a way to gather consumer feedback (Schmidt III & Austin, 2016). In addition, they do not take advantage of the elements and principles that can bring flexibility in use (Schmidt III & Austin, 2016) to volumetric modular houses.

Flexibility in housing is beneficial, especially during use due to customer needs being met over the life of the house. Flexibility in use enables tenants and housing managers to make changes over time as a result of the design and construction of the housing (Hatipoglu & Ismail, 2019; Sema, 2021; Till & Schneider, 2016). A flexible building allows for shifting spatial arrangements in response to changing tenant behaviour, functions, the addition of new users' needs, and prospective renovations (Geldermans, Tenpierik, & Luscuere, 2019).

According to Schneider and Till (2007, p.37), one of the issues with housing as a fixed design element is the lacking capability to adapt for unexpected and uncertain demographic changes. Therefore, some authors claim that "a combination of units that satisfies current demand may be unsuitable in thirty or even one hundred years".

According to the most recent public survey of the English housing market in 2019–20, 307,000 people out of 15.4 million moved into owner-occupied housing, while 99,000 moved into private rented housing and another 8,000 moved into social rent housing. There are many causes for this movement, but one of the most common is that homeowners are obliged to relocate and replace their houses when their circumstances, space requirements, family structure, or family growth change. Figure 1 shows the survey conducted by English housing market in 2019-20. According to Öst (2012), changes in family lifecycles are one of the reasons why residents' perceptions of their home change (Öst, 2012; Popovic, Elgh, & Heikkinen, 2021).

Furthermore, the cost of modifying houses for disabled users in the United Kingdom is already £350 million each year (Abo Kanon, 2017, p.148). This number is expected to increase rapidly as a result of an ageing population if dwellings are not designed to be flexible from the beginning (Schneider and Till, 2007, p.41).

According to Ichendu and Amadi (2021), "it is often difficult to physically adapt to shelter and modify the existing dwellings. This leads to waste and environmental burdens. Understandably, individual spaces in the house may become obsolete at times due to changes in users' needs". Furthermore, the same authors claim that the inflexibility of present housing has resulted in users' moving to different locations to suit their new status.

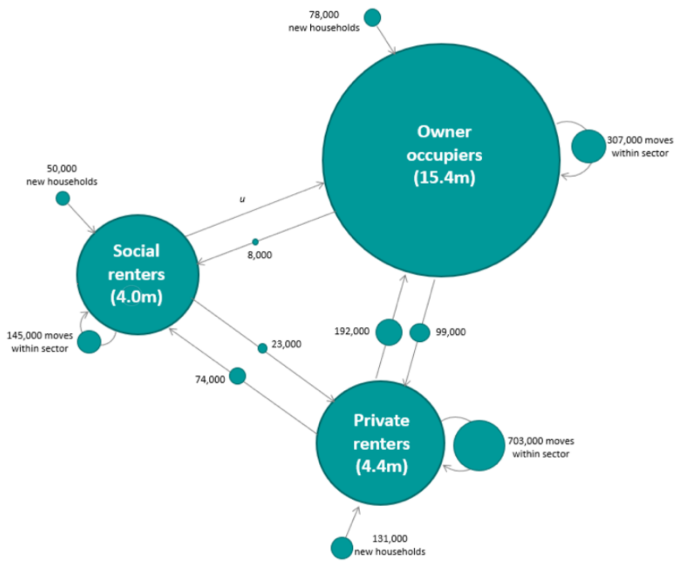

Figure 1: Household moves, by tenure, 2019-20 (English Housing Survey, 2019-20)

Azhar, Lukkad, and Ahmad (2013) have done a survey of critical factors and constraints for selecting modular construction that illustrates six constraints on modular houses.

1. Key decisions about construction methods made by the designers without involvement of contractors.

2. Owner’s wrong conception about modularity.
3. Restricted site layout (i.e., difficult to transport large modules).
4. Carrying out on-site modifications is difficult.
5. Decreased flexibility for design changes later in the project.
6. Non-availability of prefabrication unit in the project vicinity.

As this survey indicates, there are six issues described, two of them are related to flexibility in use, such as carrying out on-site modifications is difficult and decreasing flexibility for design changes later in the project. This needs to be solved in order to allow for flexibility for design changes later in the project's life cycle. Therefore, this research can close this gap.

In addition, Giuliana (2019) states that new models must be developed to suit changing lifestyles throughout society (Giuliana, 2019; Jensen, 2014; Popovic et al., 2021). Nowadays, customer requirements for configuration go beyond this type of offering as adjusting the geometry of houses is often required (Bianconi, Filippucci, & Buffi, 2019). Moreover, the families' requirement setting constantly challenges predefined designs in this respect during projects (Viking & Lidelöw, 2015).

Every person deserves more than just a roof over their head, they deserve an affordable place to call their own that makes them feel safe and secure. Volumetric modular houses can offer all of these things while focusing on individual needs rather than financial status of their occupants. In general, there are three ways for implementing flexibility in modular houses:

1. Flexibility of a modular system and the design unit to respond to differing needs and requirements of customers when the house is being designed. So design flexibility in modularity in design is one alternative to implementing flexibility. Modularity in design refers to the division of the product into modules to create a manageable set of activities. (Sako & Murray, 1999).
2. Flexibility of the modular production system to accommodate changes in requirements while production is underway. Modularity in

production refers to the division of the product into modules that may be produced independently and then assembled on the main line through a simple and small variety of tasks (Sako & Murray, 1999). Thus, modularity in design and modularity in production are concerned with simplifying processes (design and production, correspondingly)(da Rocha & El Ghoz, 2019).

3. Flexibility of modular housing in use to meet a change in tenant demands. In terms of usability, the product should be segmented into parts that may be customised or replaced during use to satisfy the needs of various users (Sako & Murray, 1999).

This study examines the third type of flexibility inherent in modular houses. It can create flexibility in volumetric modular houses based on customer needs over the lifetime of the house and prevent obsolete houses. However, it has to be noted that this type of flexibility is especially created during design, but also when the modular system is being developed.

1.2.1 Choice of research focus

The review of past and present national planning for developing dwellings indicated limited reference to principles for flexible housing. Despite the fact that the policies require the relevant parties to respond to the different needs of people in their homes and to consider future demographic trends in the regional and local contexts and housing markets, their recommendations were limited to the support of a mix of housing. This policy responds only to immediate household needs while ignoring people's future needs in dwellings (Abo Kanon, 2017).

This study investigates the creation of flexibility in the use of volumetric modular houses. In fact, the effort is to meet the users' needs over the lifetime of houses. Hence, the research question is: *what has to be done during the design phase to ensure that users have flexibility throughout the lifetime of the house?* as a result, this study seeks to bridge the research gap in this area by reviewing flexibility principles and identifying elements that can increase flexibility during use.

1.3 Research Aim and objectives

1.3.1 Research Aim

This research develops a framework to support designers of volumetric modular houses to implement flexibility in use. The definition of the framework in this research is an adding new roles or steps to the DfMA Overlay to the RIBA Plan of Work to implement flexibility in use. It presents several steps, and each step examines different principles that can bring flexibility in use for end users. It should enable customers' needs to be better considered by designers.

The framework could be competitive. It could provide comprehensive benefits for an organisation. Furthermore, for the government or local council, flexibility in social housing can add value in a way that keeps the houses from becoming obsolete. Hence, the average tenancy duration would be longer.

1.3.2 Research Objectives

1. Better understand the needs and the challenges around flexibility in use.
2. Identify the principles that can increase flexibility in use for the context of volumetric modular houses.
3. Define the stages in which designers should consider principles to implement flexibility in use in the volumetric modular houses.

1.4 Methodological approach

This research is conducted by using case studies and a literature review. Accordingly, the research included four stages.

Stage one of the research involved a literature review, with the aim of finding a problem and gaining a deep understanding of the problem in the first place. This literature review focuses on flexibility and identifies principles that can increase flexibility in use. Simultaneously, previous studies are looked at to find important features in housing that can be changed and features that have been found to be good in the literature. The second stage identifies principles that can increase flexibility in use for the specific context of volumetric modular houses. Two empirical cases and one in-depth case followed by data collection using semi-structured interviews with designers and engineers and develop the first version of the framework.

The third stage of the research defines the task to add flexibility in use for volumetric modular houses by using cross-case analysis of case studies, flexibility principles, analysis finding, and the analysis of the DfMA Overlay to the RIBA Plan of Work.

The fourth stage identified stages in which designers should consider principles to implement flexibility in use in the volumetric modular houses. Furthermore, the final version of the framework was developed.

1.5 Thesis Structure

This research is divided into six chapters. The second chapter reviews the literature on flexibility and the principles of flexibility. The third chapter discusses the methods used in this research, such as a literature review, case studies, etc. The fourth chapter analyses the data collected via case studies and interviews. The fifth chapter proposes a final framework and evaluates the framework's usefulness from the viewpoint of the designers. Chapter six includes a discussion and conclusion and offers suggestions for further research.

1.6 Summary

This chapter reviews the research background, relevance, and scope of the research and also explains the aim and objective. This chapter summarise the contribution of this research. Also it explains Methodological approach used in this research. In addition, it demonstrates the thesis structure.

Chapter 2: **LITERATURE REVIEW**

2.1 Introduction

This chapter reviews literature that has examined flexibility and the history of flexible houses, and issues around end users. Also, it explains the principles that can help to increase flexibility in use.

2.1.1 Volumetric modular housing and users' needs

Volumetric modular houses are category one of modern method of construction. This houses are manufactured off-site, while the assembly phase takes place on-site (Gosling, Pero, Schoenwitz, Towill, & Cigolini, 2016). Volumetric modular houses are developed by elements. These elements are building components that may be connected to make whole structures without the inclusion of a superstructure. These modular units are appropriate for any kind of construction but are especially popular in the education, healthcare, and student housing sectors. Hotels, commercial offices, and MEP plant room solutions are among the possible applications (Bayliss & Bergin, 2020; Gosling et al., 2016; Srisangeerthanan, Hashemi, Rajeev, Gad, & Fernando, 2020).

In addition, these modular units are appropriate for construction houses as well. The British Social Housing Authority attempts to solve underlying housing shortages and improve overall housing quality, through the municipal landlord (Cartigny & Lord, 2017). The adoption of modern technology, products, and procedures for the delivery of the built environment, generally referred to as "Modern Methods of Construction" (MMC), offers a partial answer to this difficulty (MHCLG, 2019). Houses England is devoted to assisting in the delivery of homes in the United Kingdom in order to close the housing shortage. They are also in favour of increasing the use of MMC in the building of these houses, claiming that it will assist the construction industry's limited production efficiency (Bayliss & Bergin, 2020).

The modern method of construction is revolutionizing the housing industry today, using cutting-edge technology to offer much-needed houses that are greener, safer, and more affordable (Bayliss & Bergin, 2020; MHCLG, 2019). These modern housebuilding procedures, which include prefabricating buildings and assembling them on-site, enable homes to be constructed in days rather than months (MHCLG, 2019).

The repeatability of units and design is critical to the success and attractiveness of volumetric module manufacturing (Srisangeerthanan et al., 2020). Modules are available in steel or timber construction and are pre-fitted with, heating, plumbing, windows, doors and finished interiors. They are commissioned before to leaving the manufacturer, assuring few flaws and stringent quality control. After transporting the units to the site, they are carefully lifted into place on the prior constructed foundations (Bayliss & Bergin, 2020; MHCLG, 2019).

Volumetric Modular houses may significantly reduce project timelines and costs while effectively preserving or boosting the final product's quality by shifting a portion of site-based work to an off-site fabrication company (Wu et al., 2019). Volumetric Modular projects have a mixed record of cost reductions; they are routinely finished 20%–50% quicker than conventional onsite construction (MHCLG, 2019). Volumetric Modular houses may also greatly contribute to sustainability by minimising site interruption, minimising waste, increasing movability and reusability, generating less dust and noise pollution, and decreasing the likelihood of equipment loss, theft, or damage (Bertram et al., 2019). Design companies are pursuing the development of modular libraries for manufacturing processes that may be speed up and simplified by automated design, hence shortening the design duration (Gosling et al., 2016). One client identified a nearly 15% reduction in design time by utilising modular libraries (Bertram et al., 2019).

Whereas the project planning of a volumetric design process can accommodate almost any bespoke features or changes required to meet the requirements of a specific project, once designs are finalised, they can be extremely difficult to change without incurring significant additional costs and reducing overall efficiency (MHCLG, 2019). Due to the increased savings associated with larger production scales, it may be very difficult to implement changes to plans after designs are finalised and modular manufacture begins. Thus, "design freeze" is a critical component of volumetric construction (Charlson & Dimka, 2021).

Instead, humans have been interested in changing their built environments from the beginning of human life. These changes were caused an increase or decrease in the number of people who lived in the building, and the changing requirements of those people through time. Changes in family size, age of household members, and physical ability, are examples of demographic changes that often occur within families over time.

Cultural aspects relate to the household's social conventions and views of the physical living environment which arise from the cultural values of the group or community. In this regard, Abo Kanon (2017) investigated socio-cultural characteristics such as cultural variations between households in their personal interactions, including relationships between household members and social connections with family, friends, and neighbours. In addition, the household's social roles and activities system, lifestyles, and feelings of privacy, congestion, identity, and comfort were taken into account.

On the other hand, economic considerations, in terms of changes in economic situations, such as a household’s income and job status, that may impact home design. Lastly, technical considerations linked mostly to household demands resulting from new technology advancements and shifting safety and security standards.

Numerous authors have stated that in light of the increasing complexity of product development in the construction industry, additional efforts should be made to manage customer requirements. These efforts should include capturing customer needs, making them explicitly available to the product development team, and ensuring that the requirements of various stakeholders are properly balanced (Bailetti & Litva, 1995; Barrett, Hudson, & Stanley, 1999; Kamara, Anumba, & Evbuomwan, 2002; Koskela, 2000; Shen, Li, Chung, & Hui, 2004).

In general, housing should be capable of meeting the different requirements of individual residents even while improving the end product's value without affecting delivery time or costs (Rocha, 2011). Due to the lack of customizability in present housing units, occupants prefer to move to different property depending on their changing demands throughout occupancy changes (Noguchi & Hernàndez-Velasco, 2005). Although some changes are unpredictable. For example, the pandemic has raised demand for residential office space. As a result, current residences may be inappropriate for working remotely, teaching remotely, or attending school remotely.

Additionally, a house is often the largest investment in a person's life. It is a meeting space for family members to socialise, and engage in bonding activities. Moreover, it is an investment in one's physical, psychological, social, and economic well-being (Zairul & Geraedts, 2015, p. 2). As a result, it is essential that the house is constructed in accordance with the end-users' requirements. This is in contrast to the normal approach, in which house developers buy a piece of land and construct a standard design.

Ball (1999) claimed that in order to be more successful in the housing industry, innovative business principles must be used. Additionally, Barlow (1999) said that the house building company must take a more proactive principle in terms of technology development while lowering costs, improving quality, and increasing efficiency. Thus, a designer should not just design for a particular time period or user, but also design a house for different users. The inclination to create structures that are only acceptable for a certain kind of housing at a particular time reveals a short-term economic mind-set (Khalili-Araghi & Kolarevic, 2020; T. Schneider & Till, 2005). However, despite many attempts by both policymakers and users to promote acceptance of the concepts, flexibility in housing design has never been broadly accepted (T. Schneider & Till, 2005). Flexibility is seen by Abo Kanon (2017) as a value method that not only increases productivity but also reduces waste associated with post-occupancy renovation.

2.2 The concept of Flexibility

Flexibility is a characteristic that is regularly encountered in everyday life but is difficult to describe due mainly its wide variety of applications. Hertzberger (1991, p. 146) argues that architectural issues may be resolved via flexibility. According Priemus (1993) , flexibility is the capability to reorganise in response to potential changes, on the other hand, Karni (1995), defines it as the ability to adapt to new situations. Thus, transformations, modifications, and configurations practised in many types of use and space come through flexibility (Diker & Akbulut, 2021, p. 184).

Flexible housing is defined by Schneider and Till (2007, p. 5) as housing that provides for several design possibilities, both in terms of social use and construction, or that is structured to develop through time. They argue that the idea of flexibility entails a nearly instantaneous capacity for movement and transformation. They argue that flexibility has a direct correlation with development, based on the notion that a movable object will emancipate itself from conventional constraints, and something that can be changed is new forever.

Similarly, Kizmaz and KOŞ (2015, p. 116) define the goal of using flexible approaches in architectural design as the capacity to control diverse conditions and the necessity to identify problems before they arise throughout the design process. According to Diker and Akbulut (2021, p. 185) one of most common definition of flexible design in the context of housing is a house that combines flexibility in its design and is adaptable to changing environmental conditions, demands, and requirements.

Furthermore, flexible homes must be able to accommodate new technology and even population fluctuations, as well as shift from one housing design to another(Hatipoglu & Ismail, 2019). Additionally, Hatipoglu (2016, p. 97) believes that homes must be flexible to fluctuating living conditions. If the user is granted flexibility, he or she will modify the environment to the greatest extent possible. Otherwise, the user will have difficulties adapting to their new environment and living conditions. Table 1 shows different definitions of flexibility.

Table 1: Definition of flexibility according to its types

NO.	Definition of Flexibility	Type of flexibility	Reference
1.	Flexibility is able to be reconfigured to accommodate abrupt changes in user needs, and it is also well-suited to manage short-term fluctuations.	Flexibility in use	(Radha, Tayib, Mohammed, & Rehabilitation, 2021, p. 23)
2.	Additionally, flexibility must be sensitive to the environment and end users.	Flexibility in use	(Chima Ichendu & Dennis Ejike Amadi, 2021, p. 3)
3.	Extending building lifetime and sustainable consumption that complies with recycling and waste management are the foundations of housing flexibility.	Flexibility in use	(De Paris & Lopes, 2018; p. 82)
4.	Flexibility is often used to the separating of dry and moist areas, use industrial goods and modular components in architectural design, and integrate many systems into a single workflow.	Flexibility in design	(Cellucci & Di Sivo, 2017, p. 114)
5.	Flexibility is the system's capacity to adjust to user requirements and surroundings, regardless of physical or cultural obstacles.	Flexibility in use	(Hassan Estaji, 2017, p. 37)
6.	Flexibility is the capacity of a system to adapt to dynamic environmental changes while yet being simple to modify.	Flexibility in use	(Cellucci, Di Sivo, & Architecture, 2015, p. 75)
7.	Flexible housing may transform to better suit a user's changing requirements. Flexibility provides the choice and the opportunity to choose between various living arrangements before the previous need is needed and to shift focus as necessary.	Flexibility in use	(Zairul & Geraedts, 2015, p. 3)
8.	A flexible construction may be modified as the requirements of the occupant change.	Flexibility in use	(Zairul & Geraedts, 2015, pp. 3-4)
9.	Flexibility is one of the physical characteristics of materials and geometrical shapes, which enables the implementation of repetition, balance, resemblance to create flexible space.	Flexibility in design	(Abdulpader, Sabah, & Abdullah, 2014)
10.	A flexible housing concept is a dwelling unit that will quickly and easily adapt to change, including technological and societal changes.	Flexibility in use	(Schneider & Till, 2007; T. Schneider & Till, 2005, p. 5)
11.	Flexibility is described as altering and adapting a building to various activities by implementing dynamic elements into the building itself as well as into the structure and administration.	Flexibility in design	(Greden, 2005, p. 65)
12.	The attribute of flexibility implies that the building's design allows for different physical layouts throughout the course of its life cycle.	Flexibility in use	(Groak, 2002)
13.	The versatility of space allowed it to offer many choices, combinations, and personalization options.	Flexibility in design	(Groak, 2002; A. Rabeneck, D. Sheppard, & P. J. A. D. Town, 1973)
14.	flexibility" is based on two contradictory roles: "it has served to extend functionalism and so make it viable" and "it has been employed to resist functionalism."	Flexibility in design	(Forty, 2000, p. 148)
15.	Flexibility refers to a system's capacity to adapt to changing purposes and occupants, as well as the ongoing work and resources needed to maintain stability throughout the course of a building's existence.	Flexibility in use	(Rush, 1986)

2.2.1 Flexibility and Adaptability

Flexibility and adaptability are often used interchangeably in the literature. Steven Groák makes the clearest difference between the two, defining adaptation as 'capable of varying social uses' and flexibility as 'capable of varying physical arrangements' (Groak, 2002). Adaptability is done by creating rooms or units in such a manner that they may be used in a number of ways, most notably via the organisation of rooms, circulation patterns, and room identification. Thus, adaptability includes 'polyvalency' and theories to refer to spaces that may be utilised in a number of ways without requiring physical modification (Schneider & Till, 2007).

According to Schmidt III and Austin (2016) the capacity of a building to adapt effectively to changing demands in its surroundings aids in maximising its value throughout its useful life. Adaptability is a term that refers to the advantageous impacts on the supply side during design and construction. According to some authors, flexibility refers to both short-term modifications to buildings such as interior layout alterations, and adaptation refers to more significant long-term changes such as a change of use (Leaman and Bordass, 2004).

Flexibility, instead, according to Groak (2002) is accomplished by modifying the building's physical fabric by connecting rooms or units, expanding them, or by folding or sliding walls and furnishings. Thus, flexibility includes both exterior and internal alterations, as well as temporary and permanent modifications, by being able to move a wall or door more internal configurations can be achieved. Whereas, adaptability is concerned with issues of use, flexibility is concerned with form and technique (Avi, 2002; Groak, 2002). In this research, flexibility in use has been investigated, which can be said to be consistent with adaptability.

2.3 History of flexible housing

Historically, the concept of flexible housing has emerged in two ways. According to Schneider and Till (2007), the concept of flexible housing has emerged through the development of the vernacular home in addition to the external forces that have compelled architects to incorporate flexible design solutions for housing. In the first instance, the roots of flexibility may be linked to the vernacular house's inherent ability to adapt to the changing demands of its residents. Oliver (2003) notes the vernacular's contribution to the introduction and development of flexible housing. Here, the roots of flexible building are evident in the adaptability of vernacular buildings to modifications, additions, and expansions. The flexibility of vernacular housing stands in stark contrast to the rigidity of the modern housing system. In the latter case, the concept of flexibility was conceived as a result of the post-World War I union of two social and ideological forces: the mass housing crisis and modernist ideals. In this regard, flexibility may be linked to how European countries were compelled to adapt to the growing demand for housing after World War I.

Schneider and Till (2007) split their consideration of flexible housing into three parts that correspond to three major drivers of flexible housing development: "*Modernity and the Minimal Dwelling*," "*The Industrialisation of Housing*," and "*Participation and User Choice*." This discussion has focused on notable examples that illustrate a variety of design objectives (Schneider & Till, 2007, p. 15).

2.3.1 Modernity and the Minimal Dwelling

The concept of flexibility in the context of domestic architecture is offered under two headings: "external pressures that have prompted housing designers and providers to develop alternative design solutions, including flexible housing" and "evolving conditions of the vernacular" (Schneider & Till, 2007, p. 13). The first, in the 1920s, came from the necessity for European social housing programmes to offer affordable homes. As a consequence of the downward shift in space regulations and new building techniques, architects developed designs that allowed for flexible use, liberating users from the new minimum standards.

On the other hand, flexibility becomes a social, and in the opinion of modernists, moral obligation as well as a pragmatic answer to the strong demands of the housing crisis. The issue in mass housing supply required the replacement of old housing models with new ones that emphasised the minimization of expenses and space. Designers at that time had started to recognise the need to provide apartments that meet the diverse demands of their occupants by examining the processes of use, the changeability of usage, and the efficient and flexible utilisation of spaces.

By combining these ideas architects were able to revolutionise housing and living patterns with the introduction of new housing models including variable floor plans. "versatile is the house: just like men, flexible yet solid" (Schneider and Till, 2007, p. 17) is not just a representation of the new housing models, but also an ideologically charged statement that represents the new freeing tendencies and dynamism of modernity. Architecturally, any house, despite of how finished it may be, is still in the construction process. In this connection, Lissitzky said, "every form it might take at a particular time is a frozen momentary image of a process....it is a moment of becoming and not a solidified end" (Schneider and Till, 2007, p17).

These new house types that emphasize cost reduction and space reduction were known as minimum dwellings (Teige, 2002). This period was seeing a simultaneous emergence of flexibility in minimum dwellings: social/non-architectural and physical/architectural (Schneider and Till, 2007). In the former, flexibility may be accomplished by the provision of rooms with uncertain uses, but in the latter, greater internal variability can be achieved through the use of foldable furniture and other movable elements.

Carl Fieger (1931) built an apartment as a prototype for a 40m^2 minimum dwelling in Berlin, Germany that can be transformed from a two-bedroom apartment at night into a living room, dining room, and study area during the day. Figure 2 shows flexible architecture that can adjust to meet varying demands within the same area of the building.

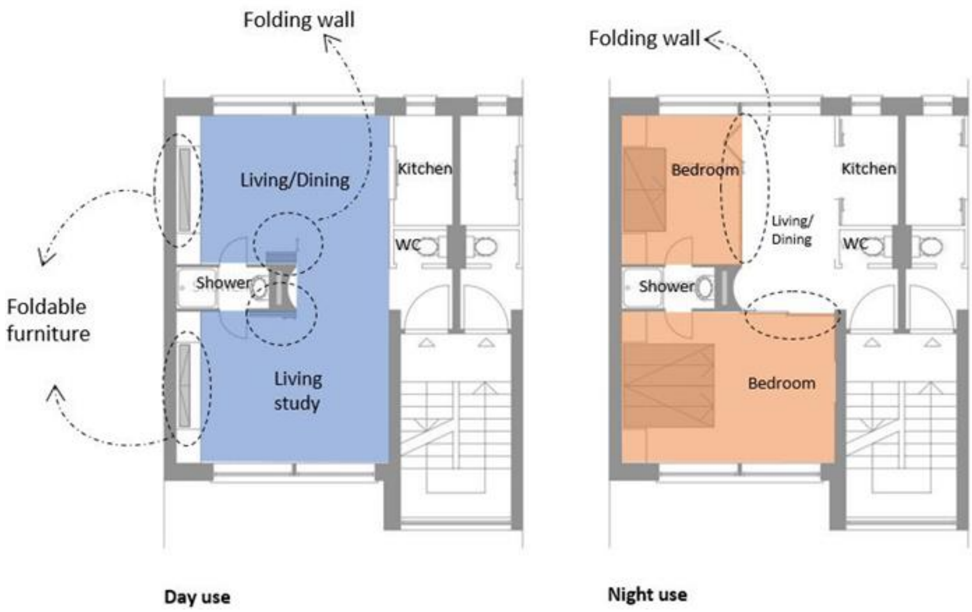

Figure 2: Kleinwohnung, Germany (Carl Fieger, 1931)

In relation to these early modernist endeavours and many those that followed, the word "flexibility" often suggests more than it can provide. The struggle between flexibility as an imposition of architectural control and flexibility as a relaxation of the architect's grip on the project is also visible in these projects. In conclusion, the positivist inclinations of early modernism favour the harder, more deterministic approaches to flexibility, a tendency that continues into the second phase. (Schneider & Till, 2007, p. 22).

2.3.2 The Industrialisation of Housing

According to Schneider and Till (2007), the first phase of flexible housing was driven by social and economic factors, but the second phase is being driven by technical forces, namely the adoption of industrialised housing supply solutions. The relationship between the first episode, which started with an analysis of the first period's existing housing patterns, and the third episode, which featured "user engagement" in the design process, was facilitated by new construction techniques and technology. The second driving force, which started in the 1930s and 1940s, and has continued to the current day, was the belief that prefabrication and emerging technology should and could provide solutions for mass housing supply. In terms of flexibility, it was anticipated that industrially manufactured and systematised buildings and their components would be self-sufficient.

The "standardisation" approach has resulted in the development of "modular" and "prototype" home designs. Standardisation and modularity provided a basis for creating formal clarity and order in the form of a succession of hierarchically organised components, each of which was clearly stated as an element. The architect Walter Gropius regarded the standardisation of individual building components as an opportunity to construct floors with the greatest potential variety (figure 3) (Ludwig, 1998, p. 132; Tafel, 1924, p. 78).

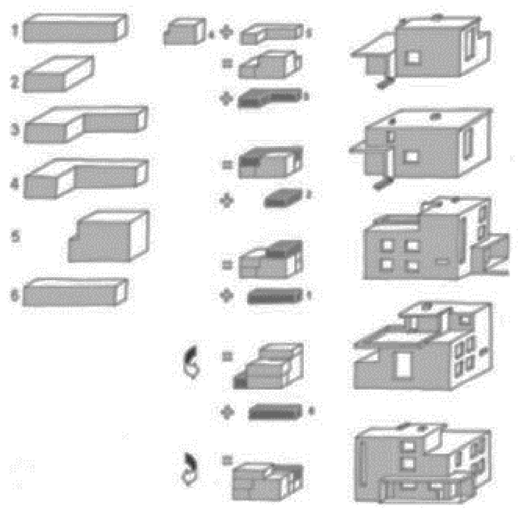

Figure 3:Haus Auerbach, Walter Gropius + Adolph Meyer, 1924. Diagram of components

Industrialisation began in the mid-1920s and early 1930s (in Germany), continued through the early and mid-1940s (in the United States), went up again in the 1960s and early 1970s (in France, the Netherlands, and Germany), and has recently resurfaced in the United Kingdom with the emphasis on modern construction techniques. When it comes to prefabricating dwellings, the idea of flexibility is predicated on the placement of components in an infinite number of possible configurations. This has clear advantages for the designer of flexible housing, particularly during the planning phase. According to Gropius' 1910 note on mass manufacturing, the flexibility to customise the home is a crucial feature of prefabrication. Gropius proved this in the design of a detached house for the Weißenhofsiedlung (Figure 4), which introduced a number of the essential characteristics of the prefabricated home (Kirsch, 1987, p. 59).

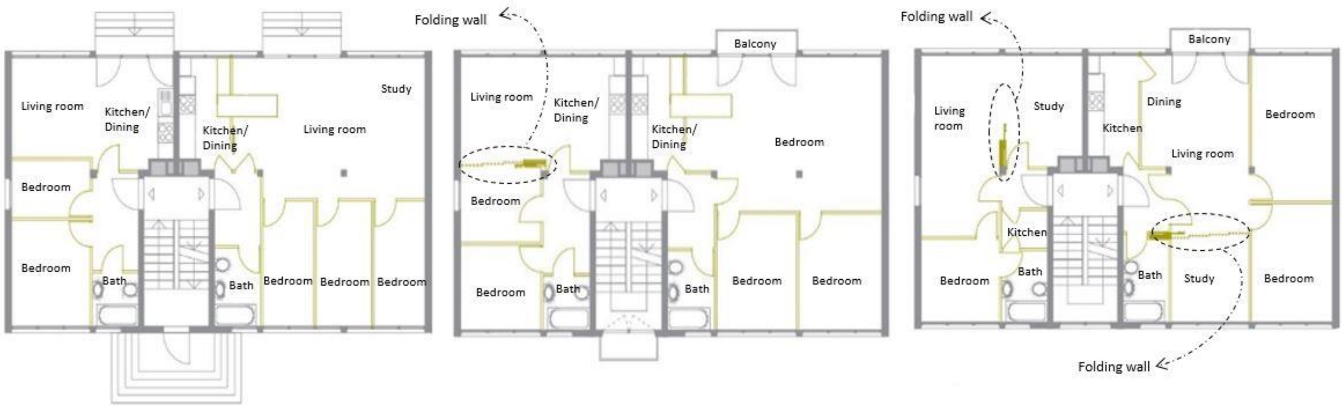

Figure 4: Weißenhofsiedlung Multi storey apartment block, Germany in 1927

Based on the evidence obtained during this period of flexibility, it is possible to conclude that the architectural ambitions for the construction of a new number of residences were not intrinsically flexible, both during the design phase and over time.

The flexibility of use often comes at the expense of long-term adaptability. The capability of prefabricated components and factory-assembled houses may seem to provide the customer with a wide range of short-term options, but may restrict long-term change. Long-term, prefabrication had lost its intrinsic flexibility in the meaning indicated by Walter Gropius; full home types could still be built, but they were not necessarily broken down into, let alone represented as, component elements that were readily added or modified in the past (Davies, 2005, p. 17).

In their book ‘flexible housing’, Till and Schneider (2016) give a clear warning that technology alone does not result in inherent flexibility. It must be linked to a consideration of the housing's actual use, as well as user choice and engagement.

2.3.3 Participation and User Choice

The "Support and Infill" theory of Herbert (1984) developed to "participation and user choice" in home design, refuting Rabeneck, Sheppard, and Town's critiques of mass made housing. Thus, Habraken heralds a move toward user participation in the design and subsequent modification of housing elements, which, according to him, are overlooked in traditional mass housing, which tends to see inhabitants as standard consumers.

By reviewing the history of flexibility in the home, it is reasonable to infer that the first period, or modernism, places more emphasis on flexibility of usage. While the next step studied during the standardisation or modularisation of the home was the utilisation of design flexibility, Although, in the end stage, both forms of flexibility were included via user engagement in the design process and the display of flexibility options. However, the housing industry has not been able to attain the same degree of flexibility in use as it has in design (Till & Schneider, 2016).

In reality, the three fundamental dynamics explored by Schneider & Till (2007, p. 30) have all converged on the housing agenda. *First*, the strain on housing supply, along with the need to minimise space requirements, is particularly intense in the United Kingdom and should drive a rethinking of home design, including consideration of flexibility in use. *Second*, there is a great deal of discussion over the necessity to modernise construction processes to match industrialised exemplars; once again, this gives an opportunity to develop flexibility in housing models. *Thirdly*, the inclusion of user participation in future housing supply has become a political goal in many countries. Flexible housing is a direct response to and solution for all of these needs (Diker & Akbulut, 2021; Ramirez-Lovering, 2013; Schneider & Till, 2007).

2.4 How can designers take into account the needs of end users?

By operating efficiently in the background, the designer may take into account the needs of end users while still providing them with a degree of control over their layouts. Indeterminate design allows individuals to occupy their houses in a number of ways without being confined to the details of room classifications, and it also allows them to make adjustments to their homes as their needs change (Hatipoglu & Ismail, 2019; Schmidt III & Austin, 2016; Till & Schneider, 2016).

If one approach to flexibility may be based on expanding the control of the architect, another way seems to be based on seemingly dissolving it (Schmidt III & Austin, 2016). Architects, such as Hertzberger (1991), are viewed as those who can contribute to the creation of an environment that provides far more opportunities for people to make personal markings and identifications in such a way that it can be appropriated and annexed by all as a space that "belongs" to them.

Buildings, on the other hand, can only be tested after they are constructed, since there are no prototypes(Schmidt III & Austin, 2016). However, Building Information Modelling (BIM) enables the virtual creation of buildings, and simulation may be used to evaluate solutions before construction begins. Consequently, it is crucial to incorporate BIM as an important approach to be considered spatially during the design phases. In this case, future users will be able to interact with the generated BIM model in order to, among other things, validate the detailed design choices.

In the other hand learning from existing buildings is something that is chronically underappreciated in the construction sector (BIS, 2013). However, although post-occupancy assessments and other performance monitoring approaches have grown more common, feedback from buildings in use is still unusual, and most of the time it is provisional and informal, including via meetings with customers or by revisiting the same building. Understanding how people adapt to their surroundings is a key part of learning about what works and what doesn't in terms of flexibility in a given facility. This is due to the fact that (Schmidt III & Austin, 2016):

- a building is merely an estimate as to how users will go about utilising the building after it has been filled
- user demands are not universal (they differ from person to person)
- and user needs are not static (they change over time)

Users may be quite adaptable, and they will often alter their structures in ways that were not originally intended by the designers. However, by constructing buildings with the ability to be flexible, the process of user appropriation can be encouraged (Hatipoglu & Ismail, 2019). Nevertheless, although some architects encourage user appropriation, others are uncomfortable with (and even hostile to) it since they consider 'their' design to be 'complete.' This is really about one's attitude toward change - how a person or organisation views change and to what degree they are receptive to it or closed to it (or both) (Schmidt III & Austin, 2016).

According to Scalbert (2004), "the important thing for me is to allow everyone the opportunity to express that which is not determined, but which remains latent in terms of the use of space". In this context, flexibility is seen as something that provides the user with the ability to choose how they want to utilise space rather than predetermining their life via architecture. Schneider and Till (2007), "flexible housing" is "a private domain that will fulfil each occupant's expectations." It is not about developing purportedly "excellent" or "right" layouts, but rather about creating a place that can withstand the ups and downs of normal life over an extended period of time.

Designing for flexibility necessitates a shift in viewpoint, requiring people to consider buildings in a much more open way and to recognise that they are far more complicated when seen from the perspectives of other users. When it comes to issues of user appropriation, the question of whether it is preferable to complete a speculative area to a certain specification or to leave an empty canvas is often brought into question.

On the other hand, users may not possess the necessary knowledge or attention to detail to comprehend how a structure operates. One example from a developer who discovered that renters would continue to set their workstations right over a floor grill and complain about the temperature of the room despite the fact they were informed about correct occupancy behaviour. A contented user is significantly more likely to be **a)** tolerant of inefficiencies and **b)** to have a higher appreciation for the building and how it is designed and built (Schmidt III & Austin, 2016). In general, designers need to consider the stimuli for flexibility to meet users' needs in the long term.

2.4.1 Recognising demand

Change is continuous and one of the most influential drivers of design. However, not all changes are equal; some are "sharp and striking" (radical), but the majority are progressive (Baldwin and Clark, 2000). Consequently, the type, size, and frequency of alterations will vary, some will be external, and others will be internal. Many are poorly monitored, although others are more obvious. Changes are often complicated, so they hardly occur in isolation; they usually propagate, making change management more challenging (Eckert et al., 2004). According to Douglas, 2006; Frenandez, 2003; Blyth and Worthington, 2001, there is a consensus that the rate of change is growing, which has contributed to an increase in uncertainty in the future.

There has been a tendency to categorise the types of change in the built-environment. Slaughter (2001) distinguishes between change in building performance, change in building use, and user or environmental changes, while Gann and Barlow (1996) distinguish between physical difficulties, and financial issues. Physical, functional, technical, social, economic, and legal obsolescence are the six categories of obsolescence described by Langston et al. (2008). These six types of obsolescence account for the majority of the changes documented in the literature.

During the change process, social shifts (causes) often need a physical response (effect), resulting in a mismatch between supply (building capabilities) and demand (user preferences). However, not all changes need a physical reaction, since some may be handled organizationally, individually, or within the building's latent capacity. The incorporation of time and the unravelling of change starts to perceive a building not as a static object in space, but as a dynamic interaction between context (users and environment) and form (building) (Schmidt III, 2016).

2.5 Principles related to flexibility in use

Housing flexibility at the design, construction, and finishing stage gives the household a good short- and long-term investment that makes a good fit with their special needs (Hershberger, 1999). In their book Schmidt III and Austin (2016), *adaptable architecture theory and practise,* offer a theoretical framework of concepts and strategies for adaptability in building by which to understand the principle of flexibility in use. Regarding their book, this research shows 9 principles that can be used to support designers during the design stage. The 9 principles were grouped into three areas, such as *physical elements*, *spatial aspects,* and *building character*.

2.5.1 Physical elements

In this area, the three principles of flexibility in use; modularity, design in time, and simplicity & legibility are examined.

Modularity: Modularity is a concept to support flexibility in modular houses. Walz (1980) defined modularity as "the construction of predefined units of dimensions for flexibility and variety in usage". Modularity is a concept that has been used to define a wide variety of fields that deal with complex systems. A productive solution to managing a complicated approach is to break it down into component pieces that may disintegrate “naturally” without compromising the system's integrity. At the core of this “natural” break concept is the principle that parameters and tasks are dependent inside modules but independent across modules. (Baldwin &

Clark, 1997, p. 35). A module definition says that modifications to one module do not affect other modules in the overall product. Nor do such modifications impair the product's overall performance (da Rocha & El Ghoz, 2019; Sako & Murray, 1999).

Chen (1994) introduced the concept of modularity as a result of the relationship between establishing functional independence and limiting module interactions. The importance of modularity is underlined as a technique for responding to changes in end-user requirements (Chen, 1994). Walz (1980) describes modularity as a construction strategy which creates an opportunity for the implementation of flexibility and diversity. Modularity has also been utilised to add value to products by offering customised dwellings or units that match the needs of inhabitants (Barlow, 1999; Barlow & Ozaki, 2003; Frutos & Borenstein, 2003; Hofman, Halman, & Ion, 2006). Additionally, it has been used to streamline the production process in projects involving the construction of customised dwellings (C. G. da Rocha & Kemmer, 2013; C. G. da Rocha, Kemmer, & Meneses, 2016). In addition, modularity requires the segmentation of a product into a set of physical parts to achieve the intended goal (da Rocha & El Ghoz, 2019; Pandremenos, Paralikas, Salonitis, & Chryssolouris, 2009; Sako & Murray, 1999).

This principle when it comes to physical bits is concerned with how they are specified as functional entities and constructed, as well as their ability to be detached later on. Schmidt III and Austin (2016) defined the four building characteristics related to modularity that are listed in table 2.

Table 2: Building characteristics related to the modularity (Schmidt III & Austin, 2016)

MODULARITY	**Reversible**	Ability of a structure to be disassembled into its constituent elements (with minimum if any damage).
	Moveable Components	Equipment, furniture, or fixtures that can be moved freely within the building.
	Component accessibility	The building's components are easily accessible; no other components are damaged in the process (like service element via suspended ceilings or raised floors).
	Functional separation	Division of functions into constituent components (like infill and support elements).

Design in time: The ability of the physical components to present options for users in time (Schmidt III & Austin, 2016). When it comes to design in time approach, it is concerned with the capacity of physical elements to present alternatives for users in a timely manner. For example, the illumination might be spread equally across a room at one point and then concentrated on certain areas at another point in the space (Configurable paraphernalia). Another way services may be zoned is by floor, with each level having its own dedicated on-floor plant that allows mechanical services to be added or removed to meet the demands of a tenant. Schmidt III and Austin (2016) defined the five building characteristics related to design in time that are listed in table 3.

Table 3: Building characteristics related to the design in time (Schmidt III & Austin, 2016)

DESIGN IN TIME	**Service zones**	Control and delivery of services are separated into distinct regions to improve user control.
	Configurable paraphernalia	Equipment, and furniture etc.
	Multifunctional components	Does not move or change state, but is capable of performing a variety of functions.
	Not precious	often low-cost, temporary solutions that can take some level of knockability.
	Extra components	Provisional inclusion of components that go beyond the building's minimal functional requirements.

Simplicity and legibility: Numerous designers believe that buildings have become too complex, resulting in increased construction and maintenance expenses. The principle's notion of a basic, uncomplicated building is closely related to the repetitive nature of standardised components, the intelligibility of off-site solutions, the promotion of a single, simple design concept, and the reduction of financial limitations. Simplicity and legibility are characterised by straightforwardness, basic concepts, and an awareness of how things fit together (Schmidt III & Austin, 2016).

This approach is seen in a variety of flexible housing plans, many of which use the layering concepts of open construction but in a more flexible and less deterministic way (Schneider & Till, 2007). Thus, 'Anpaßbarer Wohnungsbau', in the Genter Strasse scheme (in Munich) designed by Otto Steidle with Doris and Ralph, a prefabricated frame may be filled according to the customers' requirements and desires. These solutions are even more fundamental in housing than in the office sector, and developing a layered approach does not need specialised expertise but rather innovative ideas (Hatipoglu & Ismail, 2019). Schmidt III and Austin (2016) defined the two building characteristics related to simplicity and legibility that are listed in table 4.

Table 4: Building characteristics related to the simplicity and legibility (Schmidt III & Austin, 2016)

SIMPLICITY AND LEGIBILITY	**Standardised components**	Standard off-the-shelf components and/or the widespread usage of a component specifically designed for construction
	Simple construction method	Simple, comprehensible structural system

2.5.2 Spatial aspects:

In this area, five principles of flexibility in use such as loose fit, spatial planning, unfinished design, maximise building use, and increased interactivity examined.

Loose fit: This principle varies from modernism's efficient treatment of spatial dimensions in order to produce a "loose" relationship between programme and space (Cellucci & Di Sivo, 2015). The presence of open space enables it to be split in any manner that is necessary (Raviz, Eteghad, Guardiola, & Aira, 2015). A common principle is to eliminate permanent barriers inside the area in order to create a more universal atmosphere. A longer span often requires broader columns and deeper beams, which are both considered in relation to cost and other spatial characteristics. In a constrained application, the distribution of open space between floors is not necessarily uniform (Schmidt III & Austin, 2016). Frequently, the top level has less constraints than the lower floors, owing to the lower structural stresses.

Additionally, open floor layouts benefit from larger, double-height parts that heighten the sense of openness and comfort. Additional or unused space that is not often addressed in the brief might give options for spatial adaptation. Circulation space is often seen as a chance to offer more than just a path for movement. These are the places that can be improved by human contact, with the room's usage dictated by how people meet, engage, and communicate. Storage is an example of a soft-use space—a strategically situated section of support space that is readily shifted to accommodate development in a core functional area(Schneider & Till, 2007). Exterior spaces are typically the least expensive components of a structure but are also the most visible and remembered. They are, however, often underutilised in terms of increasing the building's utility. The primary impediment to oversizing space is cost, since adding more floor-to-floor height or square metres to the layout always raises the capital cost. Schmidt III and Austin (2016) defined the three building characteristics related to loose fit in table 5.

Table 5: Building characteristics related to the loose fit (Schmidt III & Austin, 2016)

LOOSE FIT	**Open space**	A large area that has remained mostly untouched by human activity and is impenetrable by immovable impediments (e.g. columns).
	Support space	Spaces that are not described in the brief that are required for functional support.
	Oversize space	A space that is bigger in plan or section than the market norm or functional need.

Spatial planning: Spatial planning is a frequently used design method that provides occupants with spatial alternatives for using a structure in a variety of ways. Consideration of space arrangement, its borders, dimensions, and relationships to other spaces (Bayliss & Bergin, 2020; Estaji, 2014; Schmidt III & Austin, 2016). Schmidt III and Austin (2016) defined the three building characteristics related to spatial planning that are listed in table 6.

Table 6: Building characteristics related to the spatial planning (Schmidt III & Austin, 2016)

SPATIAL PLANNING	**Typology pattern**	Designed according to a typology or a predefined use/spatial pattern.
	Joinable/Divisible space	A place that may be connected or separated in order to accommodate a variety of spatial layouts.
	Modular coordination	Coordination of spatial relationships between systems that have physical implications.
	Connecting buildings	Capability of connecting or separating buildings.
	Standard room size	A sequence of equally sized rooms.
	Spatial variety	A range of room sizes to accommodate a range of uses and group sizes.

	Spatial ambiguity	Through the use of soft boundaries or closeness, the boundaries between internal and/or outside spatial usage are dissolved.
	Spatial zones	Spatial separation of several sorts of functional spaces into defined zones.

Unfinished design: The unfinished design of the principle raises problems about the link between where the designer ends and where the user starts in order to produce a solution that may be appropriated without unreasonably restricting space alternatives (Schneider & Till, 2007). User customization may be ignited by material, space, and solution selections, providing the user with a feeling of ownership and identity in the building and the ability to make modifications. The effectiveness of a project may be determined by the users' capacity to customise and operate in the area as required (Barlow, 1999).

Speculative office development illustrates the two options: space may be finished to a specified level and given a market value, or space can be left unfinished, necessitating an extra phase of construction to complete. The former is called user customisation, since it only requires the addition of goods (furniture, equipment); however, the latter is considered phased, as it requires the user to employ a contractor to complete the area (stuff, services, and space plan) (Schmidt III & Austin, 2016). Schmidt III and Austin (2016) defined the three building characteristics related to unfinished design in table 7.

Table 7: Building characteristics related to the unfinished design (Schmidt III & Austin, 2016)

UNFINISHED DESIGN	**Space to grow into**	Allows for the addition of more space (non-existing) horizontally or vertically.
	Phased	Make it useful by completing the 'unfinished' area that needs extra effort to make it useable.
	User customisation	'Usable' area that has been 'completed' and is intended to be decorated or claimed by the user

Maximise building use: This design concept aims to increase the efficiency with which and for how long the building is utilised. A multifunctional space is a wide open area with moveable furniture that may be used for a range of activities, such as an atrium or courtyard that functions as a large, undefined space for gatherings (Diker & Akbulut, 2021). Additionally, new technology often allows for the addition or removal of physical and/or spatial dependencies inside a structure, since reducing spatial dependencies enables room functions to be changed more easily (Raviz et al., 2015). Schmidt III and Austin (2016) defined the three building characteristics related to unfinished design in table 8.

Table 8: Building characteristics related to the maximise building use (Schmidt III & Austin, 2016)

MAXIMISE BUILDING USE	**Multifunctional spaces**	A space that may be utilised for a variety of uses.
	Use differentiation	Inclusion of a variety of uses.
	Mixed demographics	Serves a broader population than a specific demographic.
	Multiple/Mixed tenure	Inhabited by a number of tenants who may or may not be bound by the same lease agreement.
	Isolatable	A space or wing that could function separately from the other parts of the building.
	Multiple access points	Supply of several access points capable of serving a variety of purposes or users.

Increased interactivity: Increased interactivity encourages the creation of physically and aesthetically connected spaces, which expands their potential uses. A strong physical connection generates legible, efficient, and many connections that encourage development which is often more than a method of movement and should contribute to the accessibility of spaces, as well as the building and its setting (Schmidt III & Austin, 2016). Similarly, visual connections facilitate communication, engagement, and the creation of flexible workspaces. For instance, informal breakout spaces near a staircase that get natural light from above might eliminate the requirement for formal conference rooms. Schmidt III and Austin (2016) defined the two building characteristics related to increased interactivity in table 9.

Table 9: Building characteristics related to the increased interactivity (Schmidt III & Austin, 2016)

INCREASED INTERACTIVITY	**Physical linkage**	The physical links that connect spaces
	Visual linkage	Linkages between indoor and external environments on a visual level.

2.5.3 Building character

In this area, aesthetics, which is a principle of flexibility in use, is examined.

Aesthetics: Aesthetics, as a principle, uses the building's appearance, shape, and storey to create positive responses from users and society. It demonstrates how colour may be used to gently emphasise design aspects, identify circulation pathways (way finding), identify different areas of the building, designate ownership, improve accessibility, and ultimately offer value by just adding a little of additional brightness (Schmidt III & Austin, 2016). Schmidt III and Austin (2016) defined the five building characteristics related to aesthetics in table 10.

Table 10: Bbuilding characteristics related to the aesthetics (Schmidt III & Austin, 2016)

AESTHETICS	**Attitude and character**	The use of colour and images to infuse the structure with personality.
	Spatial quality	A different spatial character.
	Building image	An outside picture shows a sense of familiarity or unpredictability.
	Quirkiness	Spatial or physical irregularities that contribute to the building's character.

	Time interwoven	A narrative built into the design or revealed via ageing material.

2.6 Discussion

The British Social Housing Authority attempts to solve underlying housing shortages through volumetric modular houses, which is category one of the Modern Methods of Construction. However, creating flexibility in use in volumetric modular housing has been neglected in consideration of addressing client demands throughout the span of the house's existence. It is said by Azhar, Lukkad, and Ahmad (2013) that making design changes later in volumetric modular houses is less flexible and makes carrying out on-site modifications more difficult.

According to Schneider and Till (2007), the housing shortage, along with the need to minimise space requirements, is especially severe in the United Kingdom and should stimulate innovative thinking regarding house design, including consideration of flexibility in use. Nevertheless, based on the findings of similar studies, a more plausible explanation is that flexibility is seen as something that provides the user with the ability to choose how they want to utilise space rather than predetermining their life via architecture. Flexibility in use often comes at the cost of long-term adaption. The ability to manufacture increasingly larger modules and, eventually, entirely prefabricated and manufactured dwellings seems to provide the buyer with a tremendous variety of approaching choices but severely limits future modification. However, if the consumer or buyer participates in the initial stages, then they can customise their houses. On the other hand, customising houses limit the house's flexibility in use by taking into account a consumer's personality and interests, in such a way that subsequent users will be unable to make modifications to the property. As a result, a flexible modular house can meet the needs of users over time by using flexibility principles. Designers should think about these changes during the design process and even when they make customization options.

Therefore, creating options that can be constantly changeable according to the users' needs has not been designed yet.

These results demonstrate that when using flexibility principles during the design phase it can aid in closing this gap in knowledge. In this research the principles were grouped into three areas: physical elements, spatial aspects, and building character. Using flexibility principles at the design, construction, and finishing stages allows the house to respond to changing user requirements, over both the short-term and the long-term, which improves the level of suitability for different users over time.

2.7 Summary

This chapter establishes the overarching definition of flexibility for the context of this research. It then reviewed volumetric modular housing and the requirements of the end users. In addition, it summarised the history of flexibility and explained the matter of flexibility in use. Also, this chapter reviewed 9 principles for implementing flexibility, which is divided into three areas which can help to implement flexibility in use in volumetric modular houses. In addition, it introduced the building characteristics of each principle.

Chapter 3: **RESEARCH METHOD**

3.1 Introduction

The previous chapter defined the research area and defined the research elements, effectively outlining the "what" of this study. This chapter focuses on the design and implementation of the research methodology in order to generate new useful guidelines, essentially outlining the "how" of this research. The chapter is structured around four topics: the "nested" method to research methodology, the research philosophy, the research approach, and the research techniques.

Research methodology is viewed as Morgan and Smircich (1980) stated that the systematic, formal, rigorous, and precise process used to solve problems and/or discover and interpret new facts and relationships; its design is viewed as Bickman et al, (2009) stated that "... the architectural blueprint of a research project, linking data collection and analysis activities to the research questions and ensuring that the entire research agenda will be addressed." For the design and execution of this study, an integrated, "nested" research methodology approach was utilised. The following section examines the necessity and character of this methodology.

3.2 Research method

The researcher has access to a wide variety of research methodologies. Despite the fact that there are a variety of options available, it is essential that the researcher adopt a methodology that is applicable and pertinent to the study area (McNeill, 2006). The term "research" refers to a sequence of deliberate and planned enquiries aimed at expanding existing knowledge and forming new facts (Ahmed, Opoku, & Aziz, 2016). The research methodology is a collection of rules for doing research that establishes a logical plan for achieving the study's objectives and goals. Indeed, the suitability of research methods is determined by the character of the objects to be investigated (Azungah, 2018; Morgan & Smircich, 1980). Flexibility is, by its very nature, a varied and complex issue. Consequently, the study methodology was created to be sensitive to the topics under investigation, with the objective of "... suit the method to the problem and not the problem to the method " (Fowles & Fowles, 1978). The main components of research methodology, as well as how they combine, must be clearly understood in order to produce a suitable connection between the methodology and the study area. These components include the research philosophy, approach, and techniques (Yin, 2014).

First, it is beneficial to delineate among research approach and research technique. A research approach is comprised of 'dominating theory development' and testing procedures, i.e., the approach taken to data collection and analysis in order to extract information from the data, while research techniques are mostly comprised of data gathering and analysis tools (Sartori, 1970).

The research approach and research technique also shouldn't work in a philosophical vacuum, since this would deliver the methodology and the technique completely lacking of any philosophical context; indeed, "...a methodology is not simply a collection of these elements. Generally, it is founded on a philosophical perspective; otherwise, it is solely a method, like a recipe"(Avison & Wood-Harper, 1991). The following argument captures the risk associated with perceiving research methodology solely in terms of its constituent elements. Although philosophical foundations are not strictly a methodology, they guide and illuminate it. Consequently, an unexamined and poorly defined epistemology can result in methodological confusion, just as methodological obscurity renders even the most sophisticated technique ineffectual (Sederberg, 1972).

As a result, there is an obvious need for a comprehensive, combined research methodology. To meet this need, the 'nested' research model in was developed in this research. Sexton (2000) suggest a 'nested' strategy that generates a framework that "provides the researcher with a research approach and techniques that benefit from epistemological level direction and cohesion" (Sexton, 2000, p. 74). The nested approach used in this study, as seen in Figure 5, is explained in more detail in the following sections.

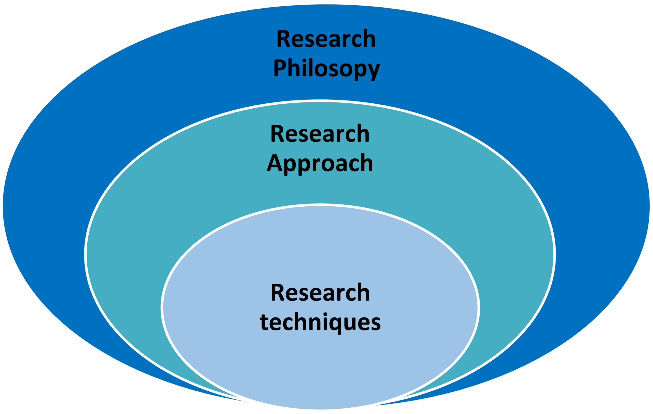

Figure 5: Research methodology 'nesting'

3.3 Research Philosophy

The term "research philosophy" relates to the researcher's conception of information's nature and connection to the natural reality (Duignan, 2016). It relates to both the process of producing and developing knowledge and the kind of information that is acceptable in studies (Saunders, Lewis, & Thornhill, 2016).

All scientific research aims at generating theory (Tzortzopoulos, 2004). Every method of research is predicated on certain underlying assumptions about the nature and sources of knowledge (Sexton, 2000, p. 76). To conduct research effectively, it is necessary to understand these assumptions. The most significant philosophical assumptions for our purposes are those that pertain to the underlying epistemology that leads to research. The term "epistemological foundations" refers to the beliefs that people have about how they get their knowledge (Hirschheim, 1985).

There are two major schools of thought that have shaped the epistemological dispute about the optimal way to do research, each articulating a distinct and opposing paradigm of inquiry. Positivism encompasses "all approaches to science that believe that scientific knowledge can be derived solely from sense data that can be directly experienced and verified between different observers" (Susman & Evered, 1978, p. 583), including rigorous observational methods for generating scientific knowledge. Thus, it primarily uses quantitative and experimental methods to examine theoretic generalisations (Blaikie, 1993). Positivism seeks causal explanations and underlying rules, which is often simplified to make analysing easier (Li, Easterby-Smith, & Bartunek, 2009; Remenyi, Williams, Money, & Swartz, 1998).

On the other hand, the interpretive research method is more concerned with description and observation. According to Saunders et al. (2016), interpretative research assumes that reality is only accessible via social creations such as language, awareness, and shared meanings. According to Ryan (2018), the researcher's values and perspectives will always influence how data is gathered, processed, and interpreted. Thus, this work contributes to interpretivism philosophy by relying on interpretations, new understandings, and worldviews. Its value-based research and researcher interpretations contribute significantly to the study's impact. This type of inquiry mostly uses qualitative methods to comprehend and explain phenomena.

Within the field of construction management research, both paradigms of inquiry have been criticised. On one hand, phenomenological research has been criticised, with the argument that a “inductivist” approach makes it impossible to develop generalizable theory, as two individuals observing the same phenomenon may reach divergent conclusions due to their disparate preconceived notions and background beliefs (Harriss, 1998). On the other hand, Seymour, Crook, and Rooke (1997) criticise the use of positivist methodologies in the field of built environment management, arguing that a closer connection between researcher and real-world issues is necessary. Susman and Evered (1978, p. 583) made a similar critique of the positivist model of science as applied to organisational research: "By limiting its methods to what it claims is value-free, logical, and empirical, the positivist model of science as applied to organisations produces knowledge that may only inadvertently serve and sometimes undermine the values of organisational members."

The purpose of this research is to construct a study in a real-world organisational setting, as it will focus on the application of flexibility in modular housing companies. As a result, the interpretive school of thought is used as the epistemological foundation for this study. Qualitative approaches are used to inductively and holistically comprehend human experience in context-specific circumstances. As Silverman (2020) notes, a "distinctive strength of qualitative research... is its capacity to concentrate on real practise in situ, examining how organisations are habitually performed." Thus, the researcher analyses the implementation process, placing a premium on meanings, facts, and words, in order to get a more comprehensive knowledge of the phenomenon.

3.4 Research approach

A research strategy is a term used to describe how a researcher approaches the process of doing research, developing a distinct style and using a variety of methodologies. According to Yin (1994) the following criteria should be used to choose the most suitable research strategy:

- The investigation's scope and the sort of questions asked
- The investigator's degree of control over real behavioural occurrences
- The level of emphasis placed on current events

The research approach specifies the sorts of evidence to be gathered and their sources, as well as the technique of interpretation to arrive at suitable answers to the given questions (Li et al., 2009). Numerous factors were evaluated in selecting the most effective way to achieve the research's goals and objectives, including the following:

- The study is centred on current occurrences, with minimal control over the factors being analysed

- The aim of addressing 'how' and 'what' type questions
- The need for extensive primary data to facilitate implementation knowledge, as well as the extent, sensitivity, and type of data needed

These reasons make it a good idea to utilise a case study method to learn how flexibility can be implemented into modular housing companies, to understand the context of flexibility in use, and to find out which factors lead to the success of flexibility implementation. Yin (1994) describes a case study as an empirical investigation of a current phenomenon in its real-world environment, particularly when the distinction between phenomenon and context is not immediately apparent.

According to Gummesson (2007), the purpose of case studies is to develop a basic knowledge of structure, process, and people. Thus, case studies may be used to generate new ideas or to test established phenomenon, which may be single or multiple, whether purely qualitative or a combination of qualitative and quantitative data. (Silverman, 2020; Yin, 1994).

The implementation dynamics were examined in three companies that specialise in modular houses. Yin (1994) used the phrase "embedded multiple case" to refer to this approach. The term "embedded design" refers to different units of analysis. Three layers of analysis were used in this study: (a) the company; (b) the process; and (c) the project.

Numerous case studies were used in this research because they allow for the examination of data from multiple companies, which allows for the determination of different context-specific principles used by companies. As Miles and Huberman (1994) point out, several examples, with an acceptable sample size, contribute to comprehension and explanation by pointing out particular circumstances, under which a discovery may occur, and also by forming more general categories of how these factors may be connected. Thus, a multiple-case design enables a replication logic in which each case study helps to validate or refute earlier findings (Yin, 1994). In summary, the use of case studies was deemed acceptable for this study topic since they allow for the examination of implementation in a real-world setting. The examples chosen have a significant impact on the outcome of this research. As a result, the next section discusses the rationale for picking the particular situations.

3.5 Data gathering

The steps developed during this study are shown in Figure 8. The process for this study is as follows: formulation of the research problem, design of the research method for data collection and analysis, data analysis, and finally, development of a framework.

The **first stage** defined the research problem, which required a thorough literature search to identify knowledge gaps, followed by deciding on a research focus and approach. The first stage led to a better understanding of the subject and the development of research questions. In addition, the research was based on a review of the literature on modular home flexibility as well as the ideas and principles stated by volumetric modular houses inside the MMC framework. The first step of the study was exploratory in nature, with the objective of discovering and better understanding difficulties surrounding flexibility. It began with the following research question: "*What must be done during the design process to ensure that users have flexibility throughout the duration of the house's lifetime*?" Additionally, it emphasised the need for greater knowledge about how flexibility is implemented in volumetric modular houses. As a result, the literature revealed that there were no frameworks for implementing flexibility in modular houses.

The **second stage** is divided into two phases. The *first phase* started with a semi-structured interview and continued with exploratory case studies with two companies that have sought to implement flexibility. Through semi-structured interviews, the variables that affected each company's design process and implementation process were determined (three in the design team and two in DFMA). The questions were factually accurate and focused on the respondent's opinions (figure 7).

The findings underscored the need to comprehend the flexibility approach and the stated RIBA stages. These results prompted a further evaluation of focusing on the flexibility principle, DfMA, and knowledge transfer between them. The *second phase* is an extended version of the first phase. It is started with choosing an in-depth case study, gathering data, and figuring out how likely it is that the results of the research on flexibility will be in alignment with the data gathered from the case study. In addition, the role of the researcher was to be an observer of the process to better understand the design process. Also the researcher conducted a semi-structured interview with designers and engineers to find out the needs of end users of modular houses from company C. In Figure 6, a case study design is shown.

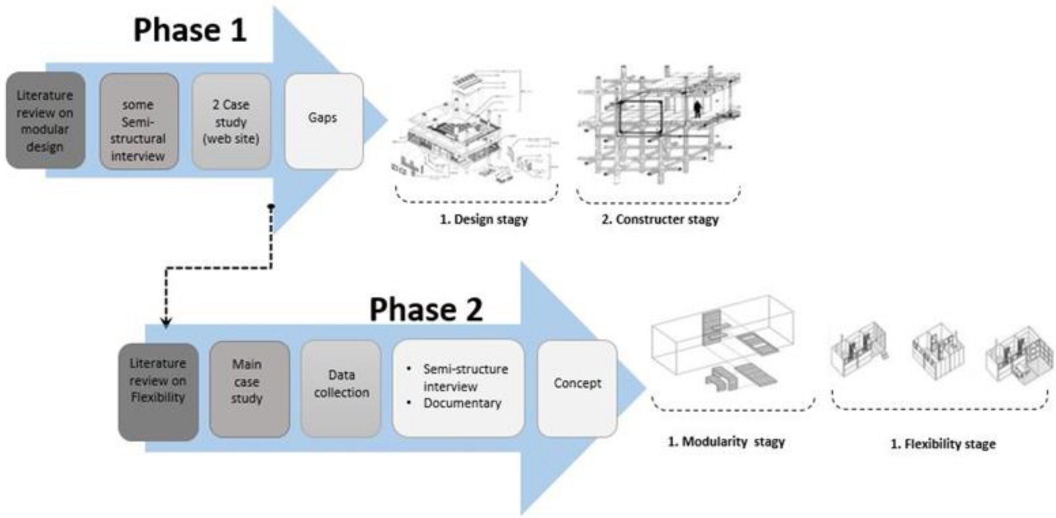

Figure 6: Case study design

The **third stage** is to analyse the data to highlight the data analysis techniques utilised in this study, which include content analysis and a description of the problem around flexibility. In addition, interviewees' stories were taped and transcribed, and then a qualitative approach was used to look for important categories of ideas.

In the **last stage** a framework developing flexibility was designed. However, the framework was not adopted in the company due to time restraints during the study phase. Figure 7 represent a research methodological design.

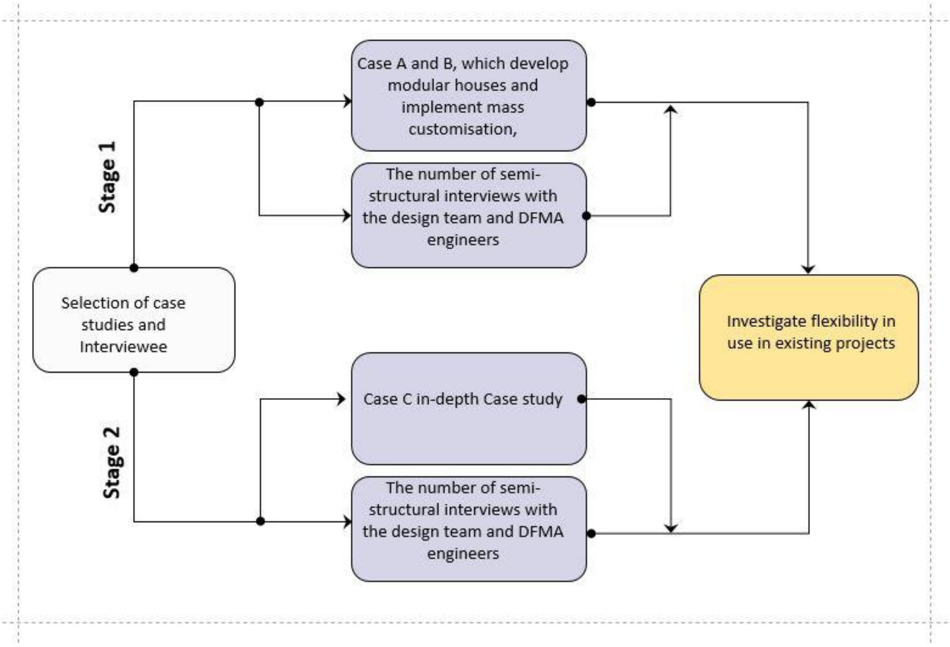

Figure 7: Zoom in of the research method for stage 2

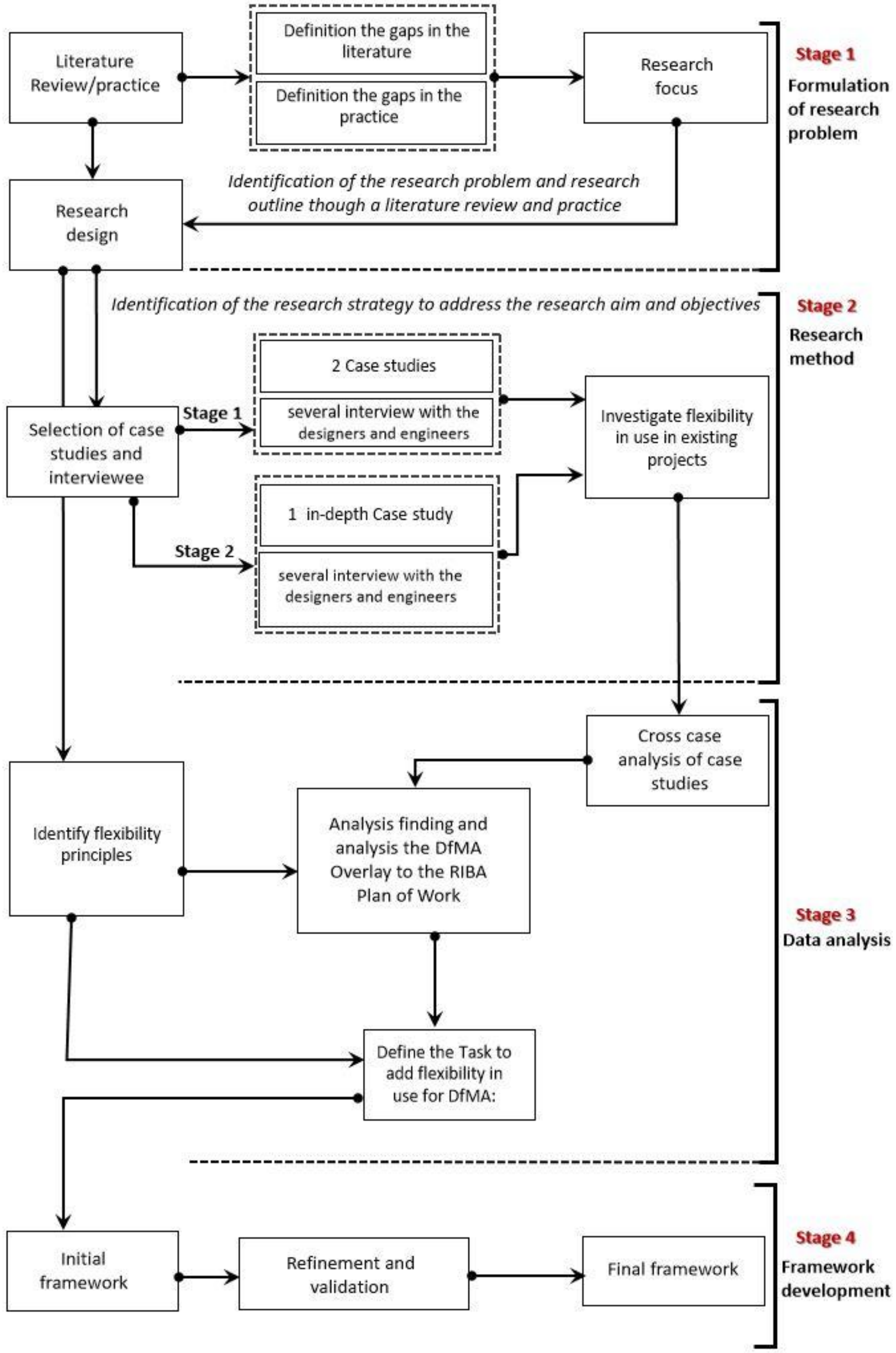

Figure 8: Graphical representation of research methodological design

3.6 Research techniques

This section discusses principles for generating raw data or collections of information that may be used as a foundation for more study. Yin (1994) defined the following six data gathering techniques and processes for case study strategy: document examination, archival records, interviews, direct observations, participant observations, and physical artefacts. Regarding the generation of data, it may be gathered and recorded in a way that is appropriate for the research (Yin, 1994). The data collection approach, as described in the research design section, was a mix of processes. Guetterman and Fetters (2018) discovered that when many data collection techniques are employed in conjunction with their distinct characteristics, the study becomes more dependable and accurate.

3.6.1 Literature review and synthesis

The early phases of every research effort include a review of relevant literature on the subject under investigation. The task begins with a review of the literature and continues throughout the process of systematic development of conceptual analysis (Jankowicz, 2000). According to Winchester and Salji (2016), literature reviews are an important component of any research endeavour since they foster constructive critical thinking while also providing a wealth of information for context development.

Baker (2016) and Walliman (2017) consider that doing so validates and confirms previously stated notions, as well as assists in detecting gaps in current research and conceptualizations. In other words, Saunders et al. (2016) states that literature reviews provide a varied pool of early-stage resources for substantiating any study's assertions (Saunders et al., 2016). It is a continual process that is employed throughout this study, most notably in the very early conceptualisations of research, such as the development, explanation, and evaluation of conceptual framework elements. Perhaps more importantly, a literature review is still essential for generating a study concept and theory, as well as for filling in gaps in research needs for describing the research problem using flexibility in modular houses. Recognizing the modularity and flexibility inherent in design processes exacerbates these inconsistencies. Thus, the extensive investigation aided in laying the groundwork for:

- the researcher to establish what was previously known about the topic area
- and enabling the researcher to draw on the experiences of both academics and practitioners

The research collected data from a variety of sources, including books, research papers, and journals, academic texts and reports, review articles, reference databases, and publicly available data sets. These sources include both print and electronic media. Based on the research and current data, three high-level functional objectives are created. There are three steps in this process: 1) defining modular homes that can be changed, 2) setting design requirements, and 3) coming up with adaptable solutions, like flexibility principles.

3.6.2 Semi structure interview

Semi structure interviewing is the most fundamental of all qualitative methodologies (Bernard, 2017). Its significance came from the fact that the technique may result in a detailed description of the interviewee's experiences, knowledge, thoughts, and perceptions that may be recorded (Alvesson, 2003). Bernard (2017, p. 165) believes that interviews enable the researcher to uncover fresh clues, revealing additional facets of an issue via human experiences.

The term "qualitative interview" has been used to refer to a wide variety of interview types, ranging from completely open-ended to those in which the researcher asks more controlled questions, similar to those in a formal questionnaire (Li et al., 2009; Yin, 1994). A semi-structured interview format was used in this study.

As Robson (2002) points out, semi-structured interviews use predefined questions, but the sequence of the questions may be altered according to the interviewer's assessment of what seems most suitable. Thus, they enable the interview to have a broad aim and emphasis while being sufficiently flexible to developing difficulties. Given the exploratory and explanatory character of the interviews conducted in this study, this was deemed the most suitable method to use, since it focused the interview and enabled the researcher the freedom to investigate new problems.

Van Teijlingen (2014) contend that, although interviews are often touted as the most effective way of information collecting, their intricacies are sometimes underestimated. Powney and Watts (2018), argues in favour of this position, claiming that the interview scenario should be seen as "socially, linguistically, and subjectively rich". Yin (1994, p. 80) identified the primary shortcomings of interviews as follows: (a) bias caused by poorly crafted questions; (b) answer bias; (c) inaccuracy caused by poor recollection; and (d) reflexivity (the interviewee gives what the interviewer wants to hear). To mitigate the consequences of these limitations, a plan was implemented that included tape recording and accurate transcription of all interviews, as well as supplementary data collection approaches. By recording the audio, the issue of unreliable data was resolved which enabled analysis and evaluation to be conducted. Appendix 1 contains an example of an interview questions.

3.6.2.1 Identification and Selection Criteria of Interviewees

As defined by Maxwell (2012), sampling and participant selection are the ideas and principles used to discover, select, and get access to relevant data sources for a research project. In order to get the most up-to-date information on modular building and flexibility, the author interviewed nine people who work in the modular housing industry. They were either prominent figures in the house building sector or members of the Build Offsite organisation who were responsible for making business decisions on the construction strategy for their projects.

A person who is an expert in a certain field or has a unique skill or expertise may be able to answer questions about "factors" or "opinions" (Chynoweth, Knight, & Ruddock, 2008; Döringer, 2020). Build Offsite (B0S) is a leading organisation in the UK's off-site industry. BOS helps the off-site construction industry and tells people about the benefits of this new way of building.

Nine semi-structured interviews were conducted with prominent housing practitioners and BOS members and stakeholders. The interviews included design managers, clients, consultants, contractors, project managers, and construction managers; all were senior managers or directors responsible for construction strategy-related decisions.

The interviews were designed to collect information on the general facts and opinions of industry practitioners about the use of flexibility in modular homes. Each interview was carefully transcribed for analysis, and all interviews were recorded. In line with the study's objectives, a list of interview questions was prepared and sent to research participants in advance to give them time to think and prepare more thoughtful responses. Due to the UK COVID-19 lockdown, all interviews were conducted using Microsoft Teams.

3.6.2.2 The aim of the questionnaire

The purpose of the interviews was to investigate and establish the present knowledge of the flexibility of modular homes as well as to investigate how companies offer flexibility in use in their products. It was also used to figure out which factors and motivations had the biggest impact on the flexibility of volumetric modular homes.

The semi-structured interview was designed to complement and build upon the facts and issues uncovered by the literature review, necessitating two primary studies. Interviews were used to get data because they were a good way to gather important information for the following reasons:

- It helps the researcher understand some of the significant issues that are discussed in the literature, such as how the building industry thinks about implementing flexibility in volumetric modular housing.
- Those who want to learn more about volumetric house construction, especially in terms of the need for flexibility in use.
- It gives the researcher more information about a subject and the chance to keep looking into it.

3.6.2.3 Description of interviews

The interview questions have been divided into two parts. In the first part, modular houses, and the drivers for using modular houses were discussed. In the second part, flexibility in modular houses was discussed. The gathered data gave further information on the design approach and the motivations for flexibility in a design, as well as the developing opportunities and limits throughout the design phase. The qualitative data collected was carefully analysed to highlight the frequency of keywords that were mentioned in Tables 11 and 12.

Regarding the first part of the interview, table 11 illustrates the main drivers for using modular houses. For instance, shortage in housing supply is one of the drivers. Reducing on-site construction time, in addition to revising the building regulations to support modularity, are others drivers for using modular housing. Each driver shows a level of implementation, however, the main focus is typically towards minimising on-site activity and reducing overall project life cycle cost.

Table 11: Drivers for using Modular houses

Modularity	
Drivers	**Implementation**
Shortage in housing supply	Housing supply rate needs more efficient methods for building new dwellings.
	Obtaining government and industry objectives
	Rising home prices in multiple locations
Reducing on-site construction duration	Time savings accruing to overlap between on-site operations and off-site production
	Rapidity of installation units on-site
	Reducing on-site activity
	Reducing time spent on non-construction activities
	Applying latest regulations and standards
Revisions to Building Regulations to support modularity	Cover all building performance
	Introduce new rules and regulations
	Reduction of errors and enhancement of performance
	Considering every facet of off-site construction
	Meeting Housing Corporation Policy agenda
	Agenda for housing supply
	Using the most recent standards and codes to support OSM
	Deliver new dwellings with off-site technology
	Reducing total project life cycle costs
	Achieving carbon agenda target

Based on statistical evidence, the majority of housing being created in the United Kingdom is not fit for purpose in terms of anticipating household change. Data collected by Ichendu and Amadi (2021) about reasons to move shows that 43% of people have moved or thought about moving because their current homes no longer meet their changing needs and goals.

Despite the architects' use of statistical data that highlighted certain families' changing demands in this circumstance, their flexible design did not prioritise any specific set of households' changing needs since "all buildings are predictions and all predictions are wrong" (Brennan, J. and Brennan & Wilson Architects, 2010, p. 22).

In this regard, the architects explain, "Prediction is difficult since, in a poorly regulated housing market, there are few barriers to purchase other than financial means." Therefore, the real intentions for flexible housing in terms of shifting family demands are the household's more significant societal needs.

The second part of the interview discussed flexibility. Table 12 shows the drivers for using flexibility in modular houses. For instance, products and end users are one of the drivers for flexibility in modular houses, which address four implementations. The main driver is the response to changes in household needs, which typically involves the need to create space.

Table 12: Drivers for using flexibility in Modular houses

Flexibility	
Drivers	**Implementation**
Product and end users focus	Consider the input of end-users while designing new initiatives
	Low households' billing
	Indoor and outdoor environment quality of the facility
	Maintenance issues
Quality of the product	Changing in household makeup
	Personalisation
	Sustainability
	Customer satisfaction
	Capacity for change
Response to changes in household needs	Create space joining together two attached units
	Improving the living space to accommodate the different activities of family members
	Creation of two separate units on each floor
	Accommodate new social activities and changes in lifestyle

3.6.3 Documentary evidence

According to Yin (1994), documented evidence is likely to be significant in every case study. Documents are generally used to find new evidence and supplement existing evidence, offering fresh insights. The primary benefits of using documentation as a source of evidence is that it is stable, can be read often, is unobtrusive, and that it typically covers a large amount of time, events, and situations (Yin, 1994).

Documents were mostly employed in this study to offer precise facts about the design process of modular homes inside the companies. Additionally, the documents included supplementary information on the phases of modular housing design and their practises. A researcher gathered and analysed a variety of documents, including research documents on design, and different stages of design, for volumetric modular houses, internal e-mails, and publicly available information on the companies on the Internet.

3.7 Selection of the cases

There is no consensus in the literature on the optimal number of cases to use when using the multiple case study approach (Tzortzopoulos, 2004). There was one main case study and two preliminary case studies in this research. The companies provide customisable houses and use flexibility approach in their products to investigate flexibility in use in existing projects.

As a consequence, the author evaluated these variables to collect reliable and legitimate results. It should be noted that access to the modular house design process had a significant role in the case selection process, most notably in the primary example. Additionally, analysing the design with DFMA professionals afforded the researcher an excellent chance to gain knowledge about the design process. Figure 9 summarises and illustrates the study's selection criteria. The evidence was gathered using a variety of research techniques, which are detailed in the section on data collection.

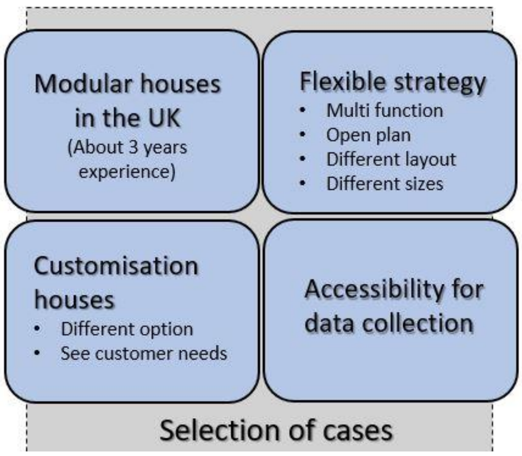

Figure 9: Case study selection criteria

3.8 Summary

This chapter describes the research method in detail. In this qualitative study, interpretivism philosophies were selected. This research also mentions the amount of case studies and interviews to be conducted. For data collection, the researcher used documentary, literature review, and semi-structural interviews. The case study is constructed of two sections: one that looks at cases in the construction and design phases of the house, and the other that focuses on the main case, which looks at the design and building stages of the company. The whole case study discussion in this chapter has all a reader would need to know about case study design and data collection methods. The next chapter extensively examines the first two phases of case studies.

Chapter 4: **DATA ANALYSIS**

4.1 Introduction

As described in the chapter on research methodology, the case study design process is divided into two phases: Phase 1 consists of two primary case studies and semi-structured interviews. Phase 2 is applicable to the main case Study (Company C). Phase 1 is an analysis of two companies in the United Kingdom, including information gathered from the company's website and various interviews with design teams. Additionally, nine semi-structured interviews were conducted to understand how they create volumetric modular homes and to analyse the flexibility of modular houses. Then follows Phase 2, which includes research for the primary case study. This chapter discusses the qualitative information and how it was analysed to gather the answers to the research questions.

4.2 Phase 1

4.2.1 Description of Company A

Company A is a modular housing company based in the United Kingdom that was created in 1994 to produce affordable homes in cooperation with the Homes Association. They claim that they are carrying out their social role by producing housing for as many people as possible. They provide a variety of dwellings that may be customised to the customer's specification. The company has developed an online design tool that offers a variety of customisation choices to assist clients in personalising their houses. They produce four types of modular houses. After picking a house type from four standard options, clients may personalise almost every aspect of their new home, from the outside aspects such as the facades to the layout of their living area. The following are Company A's major competitive criteria for this business opportunity:

- **Design:** The client has complete control over every aspect of the house, from the smallest details to the main features.

- **Delivery**: Products should be supplied to clients with a diverse range of options.
- **Market-competitive prices:** Indeed, they seek to deliver a customised product in terms of sustainability and design while keeping prices competitive with other industry participants.
- **Innovation:** Company A is an early adopter of home customization tools. In addition to making changes to the way things work, the company gives this online software to its customers as an asset.

4.2.1.1 Description of the Company A product

The company constructs three and four bedroom dwellings, with the majority of its variations based on the three-bedroom design, which is available in four different floor plans. They believe modular homes are an appropriate solution address housing requirements. The company wants to create homes to the highest standards and to be fully adjustable, allowing purchasers to customise their homes exactly how they wish. This covers the interior layout, the inclusion of additional rooms or a conservatory, and the selection of both internal and exterior finishes (Figure 10). Once the buyer's customizations are complete, the order is sent to the manufacturing facility for production. The customization possibilities available to customers are shown in Figure 11.

Figure 10: Facade customization at company A

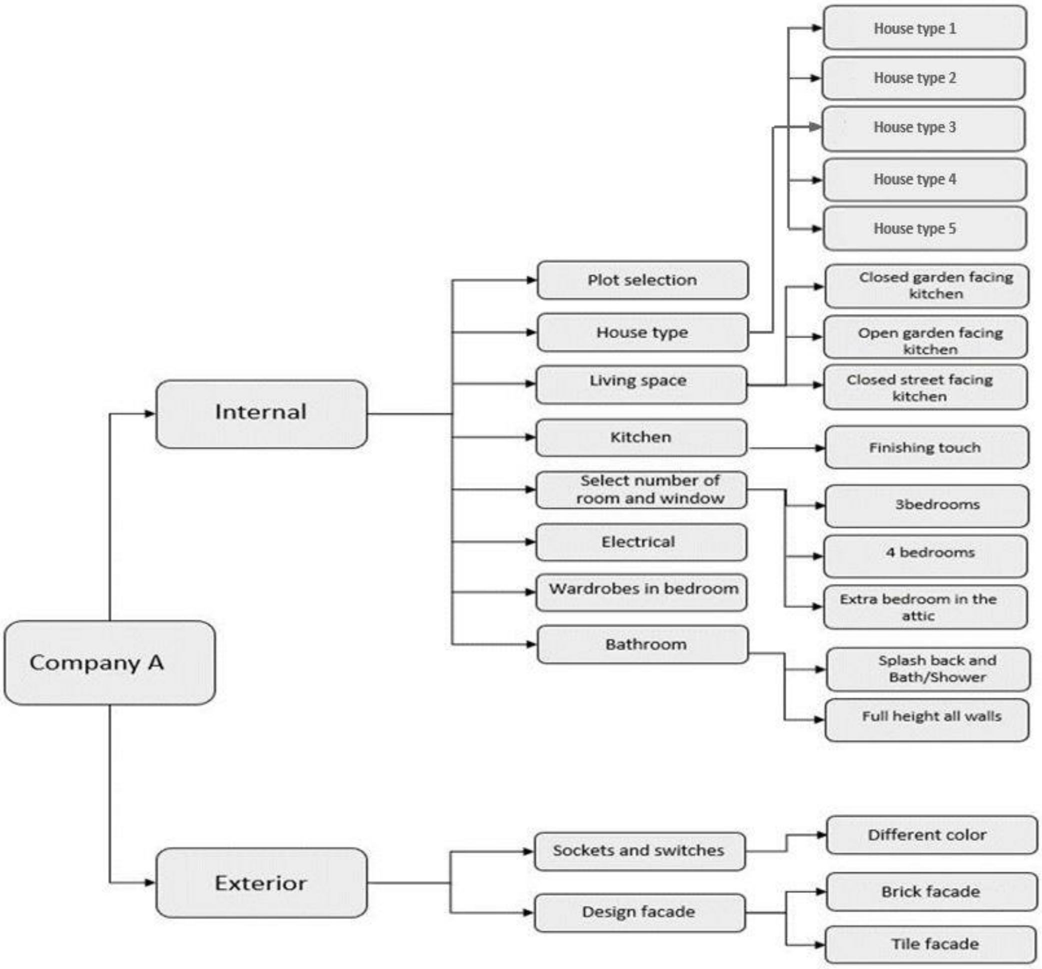

Figure 11: Customizable options of company A

The production process will begin with shaping the panels and cutting out the windows and doors. The panels are integrated to meet stringent acoustic and heat insulation requirements, making the dwellings more sustainable. It is connected and plumbed and may be completed with any kind of interior decorating. When modules are built, they are lifted onto transport vehicles and delivered to site, where they are assembled. Afterwards, the roof and outside fittings are added to make a new home that looks just like a traditional house when it's done. Figure 12 shows Modular house development process at company A.

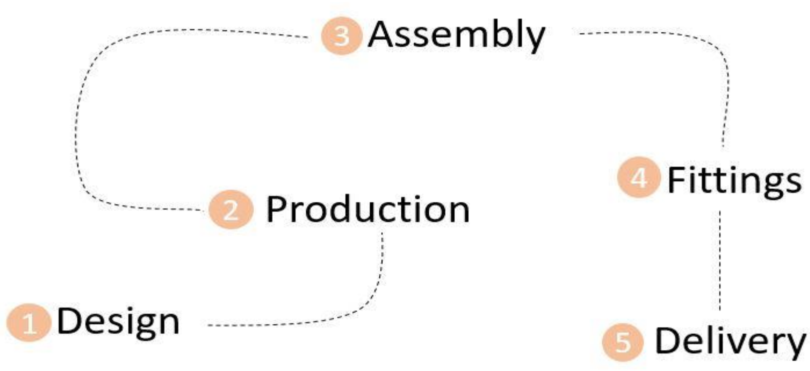

Figure 12: Modular house development process at company A

4.2.1.2 Identification of flexibility options

Each company's products were looked at and evaluated based on the three categories listed in chapter two. These categories are physical elements (section 2.5.1), spatial aspects (section 2.5.2) and building character (section 2.5.3) (Table 13).

Table 13: Analysis of company A based on categories

Categories		**Products**				
		House type 1	House type 2	House type 3	House type 4	House type 5
Physical elements	Modularity	x	x	x	x	x
	Design in time		x			x
	Simplicity and legibility	x	x	x	x	x
Spatial aspects	Loose fit		x			x
	Spatial planning					
	Unfinished design				x	x
	Maximise building use					
	Increased interactivity					
Building character	Aesthetics					

The corporation has provided some possibilities to its clients via the use of customisation software. According to the data gathered from this company, the company has not provided many flexible houses. For instance, in the majority of customization options, the company decides to move toilets or bathrooms from the ground floor in order to maximise customisation for its clients. Although having different layout is not a sign of flexibility, the company is trying to keep most of its customers satisfied. Therefore, buyers can customise their products or homes in the design process. However, as discussed in Chapter Two, Section 2.6, customising dwellings reduces the property's flexibility by considering the consumer's personality and preferences in such a manner that future users will be unable to modify the property. Figure 13 shows the three layers that the company envisions for their clients.

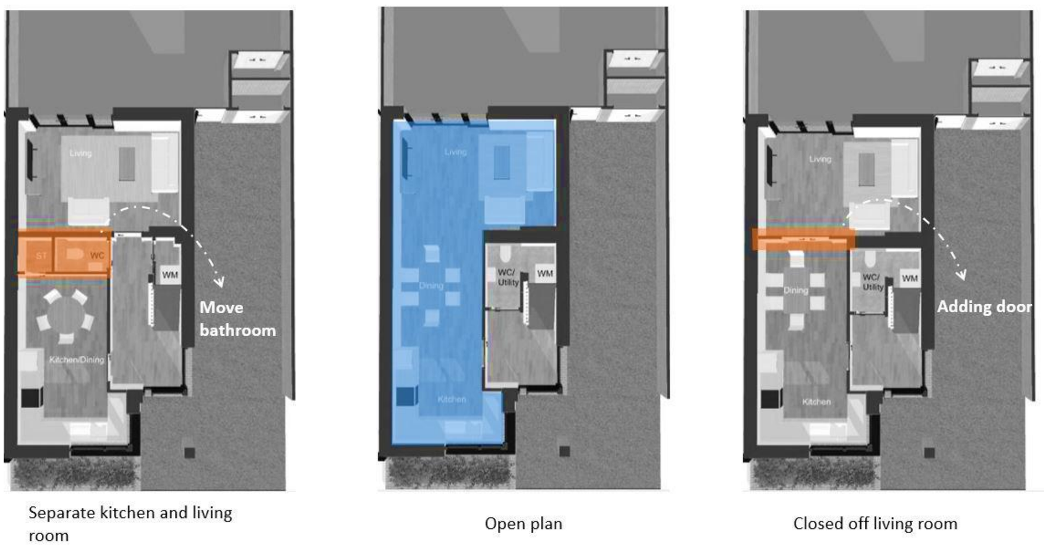

Figure 13: Three ground floor layouts in company A

One of the layouts separates these two areas by using the door. The provision of an additional door between the kitchen and the living room allows the client to prevent the smell of cooking from the kitchen reaching the rest of the dwelling. The interior partition and the door is demountable and can be readily replaced in the future, the bathroom's location on the side may be considered as significantly freeing up internal space and enabling the kitchen to be increased or opened up over time. Another layer attempts to establish a separate dining area from the living room by relocating the bathroom. However, as discuss in Chapter Two (section 2.5), the degree of flexibility may be improved via the use of flexibility principles. The location of service spaces and service cores may be seen as a factor of how the primary spaces are configured. Service units may be integrated into the structural system or developed independently. The placement of services, particularly the bathroom, in the middle zone of this layout reduces the capacity to vary the plan arrangement. Schneider and Till (2007, p. 294) emphasise the critical role of service spaces in house design for flexibility in use.

- Strategic placing of service areas to allow for the temporary placement of kitchens and bathrooms inside designated zones
- The ability to access services in order to update them in the future
- The distribution of services in the floor zone in such a way that they are accessible from any design configuration.

Another layout is an open-plan configuration that blurs the lines between the living, circulation, dining, kitchen, and front and back gardens, and can be readily partitioned to offer a number of spatial and functional options facilitated by a ground-floor height of 2.9m. Each room has a window and is big enough to provide a variety of furniture arrangements.

Every residence is required to have a parking space by planning regulations. The design of the outdoor parking is linked to direct and wide access, which allows for a wide range of uses.

4.2.2 Description of Company B

Company B is one of companies that is developing modular houses. This company has a number of branches around Italy and the United Kingdom. Their major concentration is in residential construction. According to the company's website, a developed society requires a contemporary lifestyle. They assert that their efforts would revolutionise the building of flexible houses that respond to customers' requirements. This company makes an effort to think about social changes when they design their homes, as well as the cost-effectiveness of their products for everyone.

The company's efforts are guided by a philosophy. In this approach, they see a project as a source of difficulty, opportunity, and adventure. The difficulty comes in determining an offer that satisfies the customer's expectations. A chance to utilise, modify, and enhance their customer's quality of life is an adventure since it is an unexpected occurrence that brings its own risks. Simultaneously, the design of these goods is fascinating. Anticipating that construction companies would not prioritise the creation of configured houses in the market, the business has concentrated on building modular homes with the primary goal of maximising customisation in its products. The company's competitive criteria were determined via participant interviews and the company website.

- **Design:** The client has control over of the house during the design stage.
- **Delivery:** Products should be supplied to customers within the timeframe specified in the contract.
- **Market-competitive prices:** The company's goal is to deliver this flexible product at a price level comparable with current market trends.
- **Innovation:** Buyers can configure their houses on the company website.

4.2.2.1 Description of the Company B product

They provide five distinct house types, ranging from a 30 m^2 studio to a 110 m^2 three-bedroom house, that all are based on the notion of standardisation and modularity. This company allows buyers to personalise the exterior and interior layout of their apartment (module composition, residence size), as well as other optional features like various materials for the façade. This company designs each part of the house as a module (Figure 14). Typically, this includes a bathroom module and a kitchen module etc. By assembling these modules together, it produces a complete modular house.

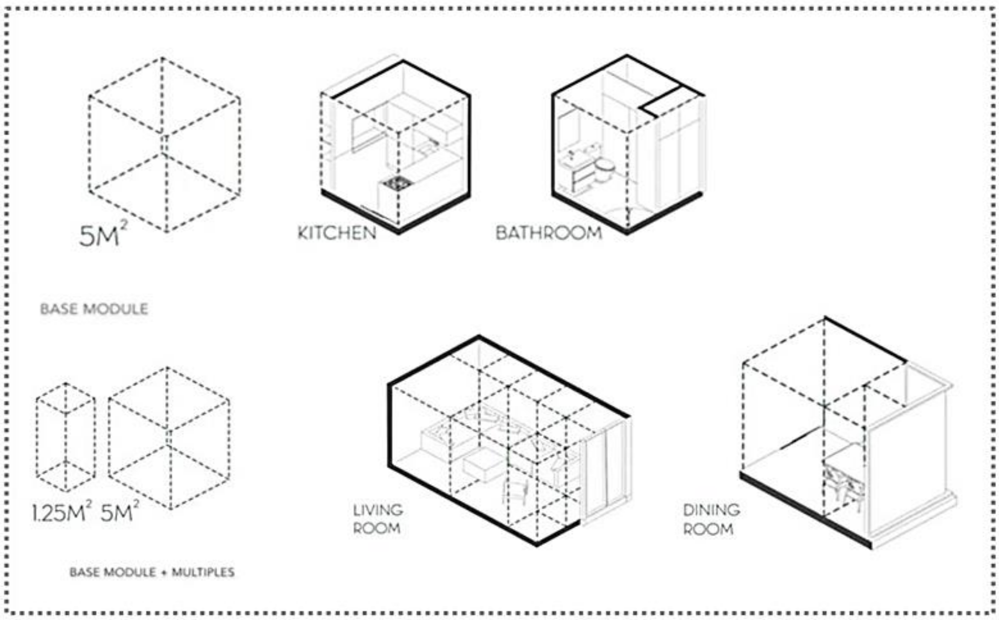

Figure 14: Develop standard module in company B

The stages that company B takes to create a standard and modular house are as follows:

Stage one (design based on standard size): The company uses this to determine the standard size of the house's wet areas, such as the kitchen and bathroom, which is 5m2 for their product. That is the main module in their products. They mentioned that they came to this size as a result of their experience investigating a variety of different types of houses (Figure 15). They create a separate module that is a quarter of the size of the main module to combine with the base module. Thus, the company has many modules at this level that can be used as specific parts of the houses, like a dining room, bedroom, bathroom, kitchen, and living room.

Stage Two (assembly of numerous modules): Using the various modules obtained in the first stage, company B can design different layouts with their modules. By adding and moving modules, they can construct a wide variety of housing designs. The organisation is able to create dwellings ranging in size from 30 m^2 to 110 m^2. In addition, due to the high cost of transportation, they only deliver the houses once they have been fully pre-assembled.

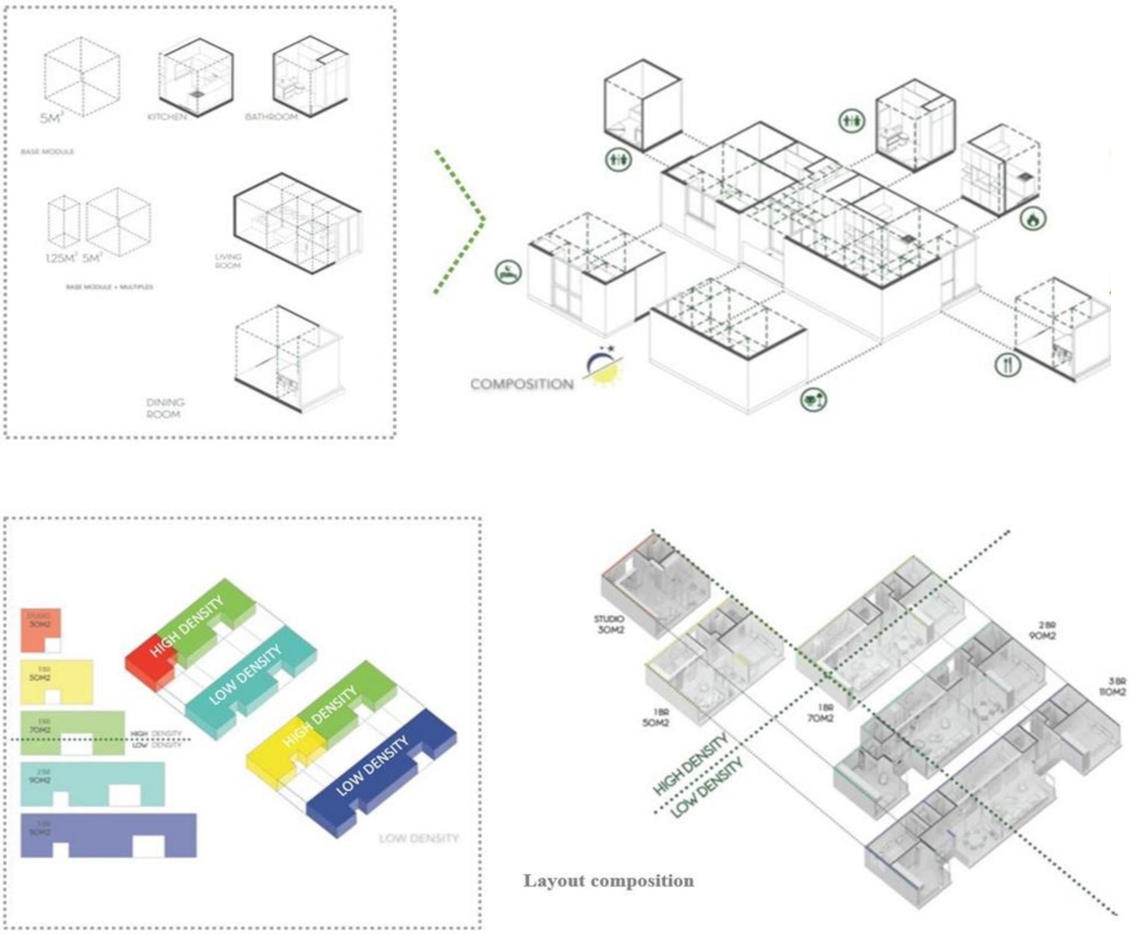

Figure 15: Different layouts of Company B

The house is divided into different modules. However, by configuring these modules, buyers can create different layouts, but each area has a specific function. Also, there are tight, lengthy corridors in some of the largerscaled layouts (Figure 16). In reality, the availability of space and the size of the land have driven these designs.

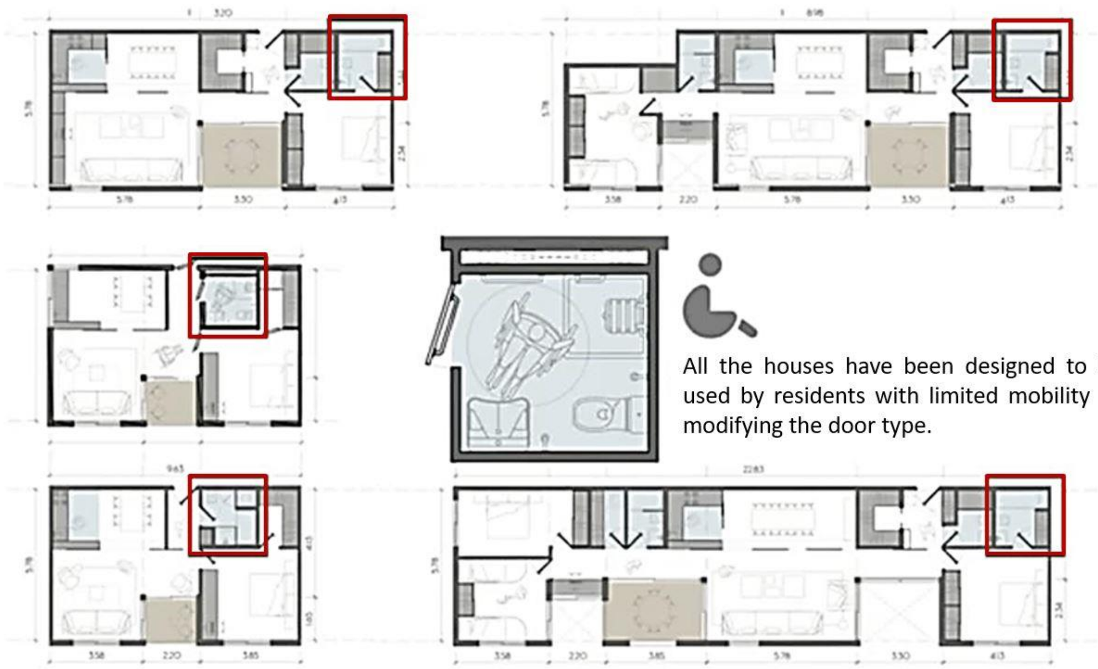

Figure 16:Different types of modular houses in Company B

4.2.2.2 Identification of flexibility options

Each company's products were looked at and evaluated based on the three categories listed in chapter two. These categories are physical elements (section 2.5.1), spatial aspects (section 2.5.2) and building character (section 2.5.3) (Table 14).

Table 14: Analysis of company B based on categories

Categories		Products				
		House type 1	House type 2	House type 3	House type 4	House type 5
Physical elements	Modularity	x	x	x	x	x
	Design in time					
	Simplicity and legibility	x	x	x	x	x
Spatial aspects	Loose fit					
	Spatial planning					
	Unfinished design					
	Maximise building use					
	Increased interactivity	x	x	x	x	x
Building character	Aesthetics					

Company B gives the buyers an opportunity to configure their houses. However, these kinds of houses do not have flexibility in use due to pre-determined functions.

4.3 Phase 2

4.3.1 Description of Company C

Company C is one of the companies engaged in the development of modular homes. The company developed housing-across the UK, mainly in London. Currently, Company C has three sites and 185 houses. They are building modular family homes with two to four bedrooms. In response to the housing shortages in the United Kingdom, this company is one of the small developers of low-rise volumetric modular houses in the country. They believe that each home should correspond to core elements or principles that bring home design and delivery into the twenty-first century. These factors include design, the ability to make changes, affordability, and sustainability. They said that the market designs with cost in mind, but we design with the client in mind, so there are different drivers. One of the company's developers stated:

"*We acknowledge that family lifestyles are not the same as they formerly were. Increasingly, children are leaving home later, a phenomenon known as "boomerang kids," and parents are staying with their children and grandkids. Clearly, traditional two-up, two-down home designs do not support all lifestyles. This is why we have chosen to create designs that enable customers to distribute space inside their houses as they see fit*."

The company's competitive criteria were evaluated from participant interviews and its website.

- **Design:** The product must perform comfortably in any environment and satisfy the needs and requirements of both current and future generations.
- **Delivery:** Assisting in the reduction of the planet's carbon and preserving it for future generations.
- **Market-competitive prices:** To produce a mass impression similar to 'Grand Designs'. Another goal is to make homes that can be changed to meet the needs of different customers.
- **Innovation:** this company has an innovative roof design that integrates the roof into the first-floor module. Also, the capping stone at the top of the roof is customisable.

4.3.1.1 Description of the Company C product

Company C developed four products for the market, which cover 2–4 bedrooms. The layouts of the company's homes are made on purpose to offer a variety of design options, giving people a range of ways to live that can be adapted to meet their changing needs. The concept behind the open-plan design is that users benefit from the freedom their house provides them with by allowing them to modify their living environment to their particular requirements. In addition, they utilise the loft as a living space in their products. Loft living provides an additional living area, increasing vistas and natural light and allowing multigenerational families to have a variety of activities. In their products, loft living also includes a bedroom and an en-suite shower room, allowing users to have their own independent space from the rest of the house.

Nevertheless, the business decided to design two new products, HT5 and HT7. This company, for its products, has developed platforms with different dimensions that were based on experiments and studies of various types of houses. Therefore, the company needs a different platform with a different size to produce new products. The interviews provided information on the size of these platforms which vary according to market needs. Typically, the company is able to diversify its products with increased attention to consumer needs. The products of this company are:

HT1: Is a two-story residence with two bedrooms. The gross interior area is 82 m^2. This form of residence contains two rooms, two bathrooms, and an open-plan kitchen and living area. The target of this product is young couple with or without children. HT1 is made up of two modules and utilises Platform 1. The ground floor is one module, and the first floor is one module which also includes the roof (Figure 17).

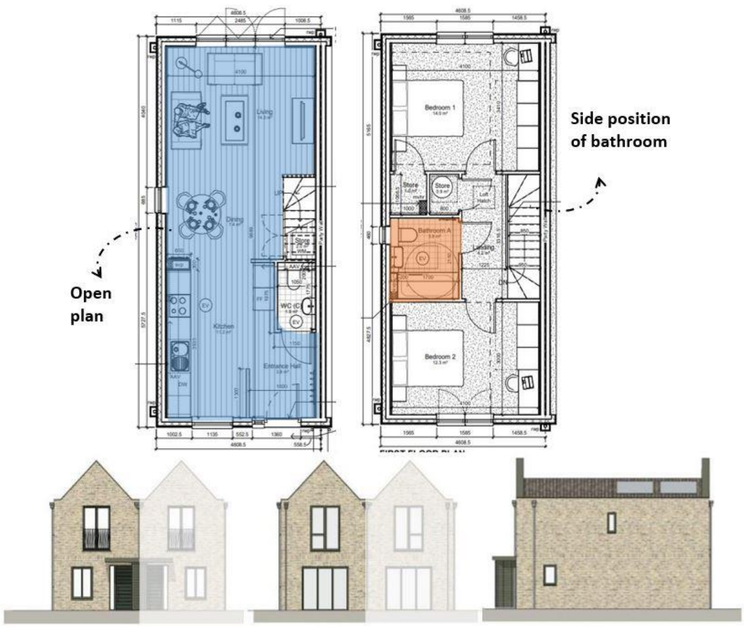

Figure 17:HT1 one of the company C's houses

Moreover, this business has an innovative roof design that integrates the roof into the first-floor module. So, by integrating the roof and first-floor modules, the height of the first floor is 3.60 metres. Also, the capping stone at the top of the roof gives buyers a chance to customise the house externally (Figure 18).

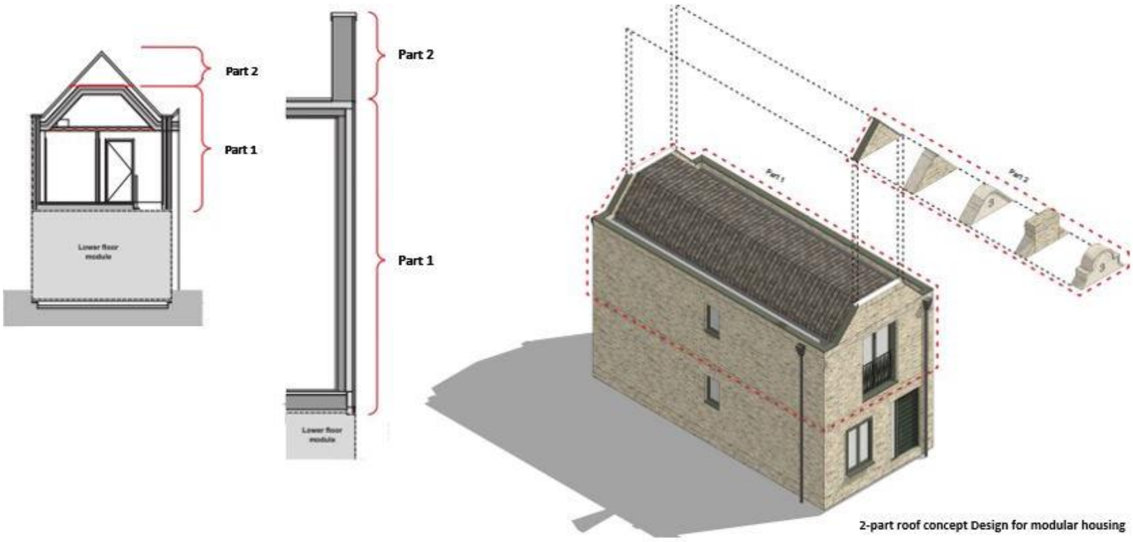

Figure 18: Innovation roof design and customization capping stone

HT2: This product offers two-or three homes with a GIA ranging from 89 m^2. Typically, these residences include three bedrooms and an open-plan kitchen with a living area, and dining room. In these sorts of dwellings, Platform 2 is used because it is larger than platform 1. The home consists of two modules, a ground floor module, and a first floor module which includes the roof. This product is suitable for families consisting of two people, up to medium families with two or three children (Figure 19).

Figure 19: HT2 one of the company C's houses

The only difference between HT2 and HT1 is that HT2's size is suited for a medium-sized family and is an affordable house.

HT3: Typically, this residence contains three bedrooms and two or three bathrooms, one of which is a 'Jack-and-Jill' bathroom. The GIA is 106 m^2 and includes a kitchen, dining area, laundry room, and storage space. This product is suitable for small families, to medium sized families with two or three children (Figure 20).

Figure 20: HT3 one of the company C's houses

HT4: Has four bedrooms with storage, a laundry room, a bathroom, a kitchen, and a living room. The GIA is 132 m^2. This kind of property is targeted by investors and large families with three or more children. They offered these items with adaptability. Adding an additional external door creates the opportunity for the space to be used independently from the rest of the home, which provides an opportunity for an alternative living situation for family members. (Figure 21).

Figure 21: HT4 one of the company C's houses

HT5: The company was seeking to complete the architectural design of its 2.5-story, 3-bed house. The researcher was involved during the design process. The company's request was that HT5 was to be designed using the HT1 chassis. They wished to expand the floor and convert the existing design to the larger (wider) HT2 platform. From HTA's original layout to the new layout, which is shown on the marked-up floor plan (Figure 22), the ground floor's internal layout had to be changed. The first floor and second-floor internal layouts are largely finalised and only require some minor adjustments. A design for a new GF contemporary front bay window was required. The existing gambrel roof profile requires some minor remodelling. The roof had no dormer windows. The company asked for a new, modern dormer window to be added to the front of the building (Figure 22).

Figure 22: The design process of completing HT5

The design process was concluded after a series of meetings with designers and DFMA engineers and workshops. Figure 23 shows the end result of the new houses for the company. The next section describes the design process.

Figure 23: HT5 one of the new houses at company C's

HT6: This is another product where the company was seeking to add a new house type to its product line. The scope of HT6 was that this new house type was required to be a "corner turner" unit for future larger developments. It must fit into the suite of their house types while offering a difference in design and external appearance. The semi-detached (semi) or end-of-terraced (EoT) versions must complement HT1's and HT2's front façade. The company also covered flexibility in design. They asked for the new house type to be a flexible unit that is capable of being presented as a 3 bed (HT6) or 4 bed (HT7) 2 storey house. HT6 & 7 will have two variants: detached (double fronted) or semi/EoT. Design work is focused on HT6, but the architectural and DfMA skeleton must be in place to progress HT7 at a later date. Therefore, architects' floorplans for HT7 should be fixed at this stage. They also mentioned that the new house types seek to respect the best of the UK's housing heritage (traditional housing in shape and form) and bring them into the 21st century.

Figure 24: HT6 one of the new houses at company C's

4.3.1.2 The design process of HT5 and HT6

Several stages were involved in the design process of HT5 and HT6, which are outlined below:

1) In the first stage, company C conducted research and gathered information from end customers in order to build new products for the market based on their demands. This phase assisted the business in determining the platform to be used. Figure 25 illustrates all product platforms.

2) In the second stage, the corporation selected a design/DfMA company to design the homes. Therefore, they preferred to collaborate with the previous team because they were familiar with the company's products and strategy.

3) In the third stage, multiple workshops were conducted between the company, the designers, and DfMA engineers. Because the design team knew what DfMA's limits were, most of the workshops were between the design team and company C.

4) In the fourth stage, designers provided two different layouts for HT6 to cover different customer requirements.

5) In the fifth stage, all regulations were covered. The project was then ready for RIBA planning control. After some editing, they received RIBA stage 2.

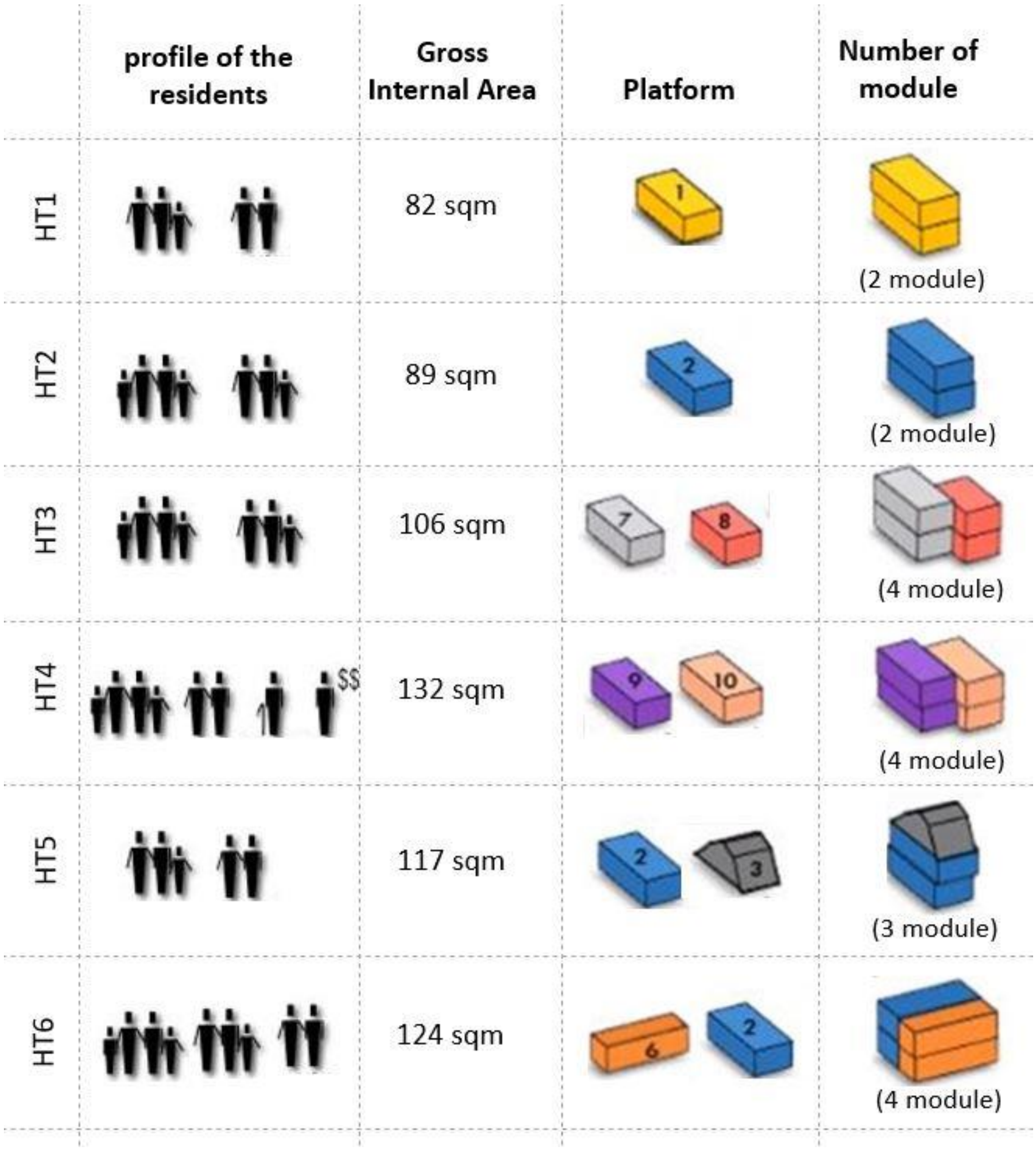

Figure 25: Platforms for Company C's products

4.3.1.3 Identification of flexibility options

Each company's products were looked at and evaluated based on the three categories listed in chapter two. These categories are physical elements (section 2.5.1), spatial aspects (section 2.5.2) and building character (section 2.5.3) (Table 15).

Table 15: Analysis of company C based on categories

categories		Products					
		House type 1	House type 2	House type 3	House type 4	House type 5	House type 6
Physical elements	Modularity	x	x	x	x	x	x
	Design in time				x		x
	Simplicity and legibility	x	x	x	x	x	x
Spatial aspects	Loose fit	x	x			x	x
	Spatial planning				x		x
	Unfinished design				x	x	x
	Maximise building use				x		
	Increased interactivity						
Building character	Aesthetics	x	x	x	x	x	x

The company has provided few flexible houses. For instance, in **house type 4**, we can observe that the architect attempted to develop flexibility. By including a bedroom and a bathroom on the ground floor, the company was able to design a space that could adapt to the changing demands of the customer over time. The flexibility of this sort of adaptable design to provide more bedrooms in the future might be seen as a response to other demographic changes in the household, such as the requirement to provide children of different genders with separate sleeping areas at a certain age. This also allows the design to meet the privacy needs of young people by offering greater room for youngsters to pursue their own activities independently. In addition, the possibility to establish separate sections on the ground floor, so offering an en-suite room with its own entrance, gives the design the flexibility to provide the elderly space for their needs.

The location of service areas is an essential factor in designing flexibility. Plumbing and electrical wiring are two of the most challenging components of modifying a home's design. Therefore, only a subset of company C's products included a level of flexibility.

In addition, the designs for **house type 5** include an extension onto the roof space, which adds circa 50 square metres to the total floor area. The architects anticipated future access to the area by extending the staircase to the roof space, as well as the provision of two dormer windows and adequate height in the attic space at both the verge (1.5) and the ridge (2.5) to make it usable. These expansion principles are recommended specifically by the design regulations for flexible houses (Figure 26).

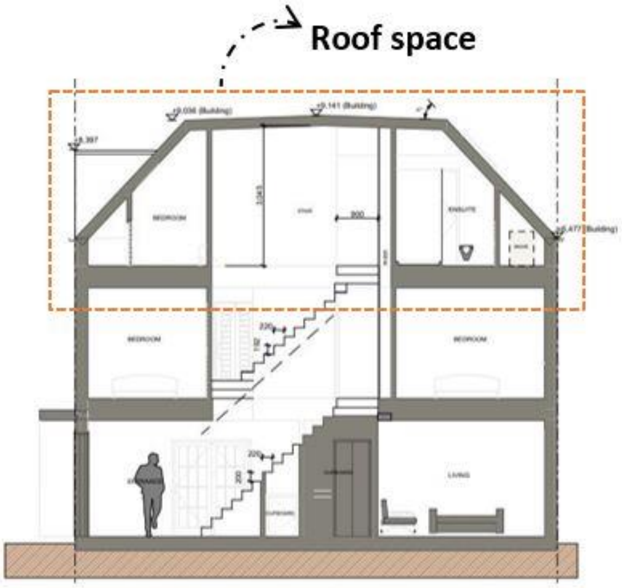

Figure 26: Roof space at HT5

The relationship between housing structures' fixed and variable elements impacts flexibility. The architectural arrangement is made flexible by addressing the structural system and location of service space. In this regard, the main indeterminate area outside the service zone allows for a variety of ways for creating flexible housing, thus enabling an architectural plan that is practically successful. By including removable partitions which is shown in **HT6**, an indeterminate area is created which increases the level of flexibility of the house (Figure 27). This room can be named according to any function.

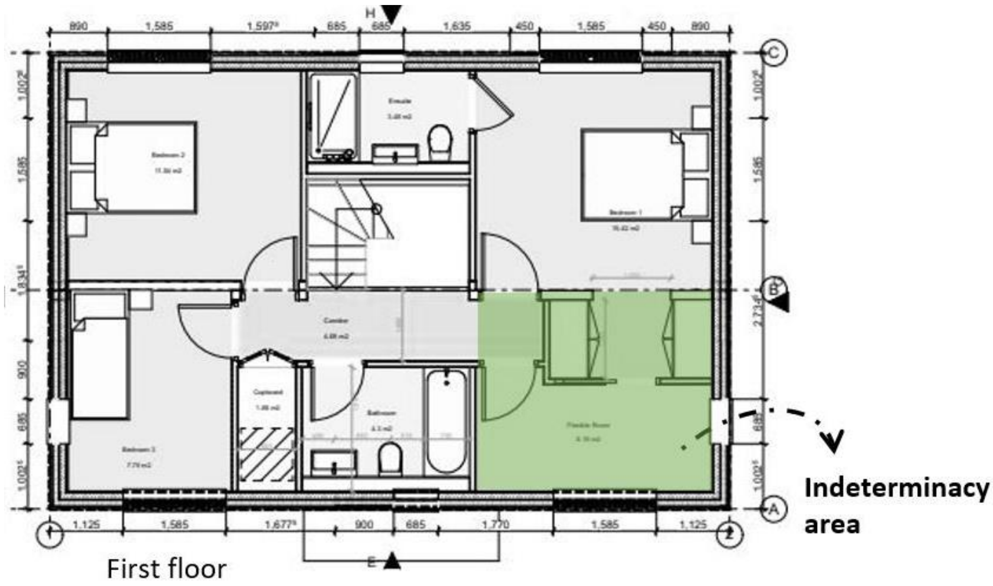

Figure 27: Undefined room at HT6

The flexibility of this sort of adaptable design, to provide more bedrooms in the future, might be seen as a response to other demographic changes in the household. In house type 6, the designer placed the rear double door on one side of the wall to create a larger space on the rear facade for a future extension.

4.3.2 Description of interviews with Designers and Engineers

In the past, people believed that they should live in their houses as they were originally built. However, this view is no longer prevalent as users now consider it their right to have a house that meets their demands. The market attempts to satisfy these requirements by implementing mass customisation, which is different to flexibility in use.

Designers determined that one of the requirements of the end users is to offer temporary or permanent bed space on the ground floor or access level for elderly household members who cannot reach the upper floors. Another aspect is the possibility for exterior walls to accommodate future openings and alterations to the infill components. The designers have stated that the clients and end users have previously sought to extend the buildings, however, the construction of modular homes include structural columns that cannot be removed, thus limiting its extendibility.

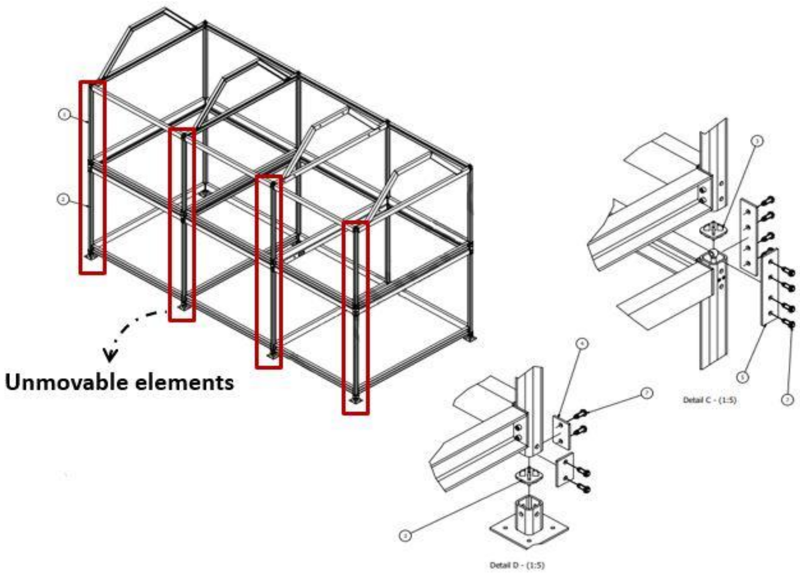

Figure 28: Structural of modules in company C

Among the demands of the users are natural light, the ability to change the size of the windows, an en-suite space, and more storage space, especially under the stairs. Furthermore, moveable partitions and furniture, for separating internal spaces, may also be used. Each of the previously mentioned options may satisfy customer demands.

In the next section, the examined companies are compared to determine their similarities and differences.

4.4 Cross-case analysis

After completing the empirical analysis of the companies, a cross-case analysis was conducted. The purpose of the cross-case study was to compare and contrast the differences and similarities between the companies (Yin, 2013).

The results of the comparison between the products of the three companies are shown in table 16. It was discovered that **Company C** provides more flexibility in use than the other two companies. One of the primary reasons is that this organisation is familiar with the definition of flexibility in use and employs principles to develop more sustainable houses. This company uses principles such as Aesthetics, unfinished design, and spatial planning during the design stage. This organisation also examines physical elements, but in order to increase flexibility it must also consider spatial aspects such as increased interactivity and multiple scales.

Modularity is not a basis for flexibility in use. In fact, modularity has been used to define a wide variety of fields that deal with complex systems. Modularity is the concept that breaks complex systems into component pieces. **Company B** hasn't been able to create flexibility because of the modularity concepts, which show different components with specific sets of functions. These components can't deliver different functions to meet the users' needs during the lifetime of the building.

However, there are only two elements that are common to all, which is modularity, and simplicity & legibility. These can be a common point when offering volumetric modular houses, therefore, companies implement different principles of flexibility. Whether the principles the companies have shown are logical internally, is an interesting question (not pursued in this research). For example, company B, which is unlike the other companies, could have more flexible elements with the inclusion of an indeterminate area. This company needs to develop flexibility in use by incorporating the principles of flexibility.

Company A offers buyers a variety of alternatives, including customizable houses rather than flexible houses. Therefore, this organisation must reassess its definitions of flexibility, which will allow them to comprehend the distinction between customization options during the design stage and flexibility in use. The main difference between these two concepts is the duration of their response to customer needs. Mass customization is a short-term concept for specific users; however, flexibility in use is a long-term concept that can respond to various types of users.

In addition, developers need to recognise the necessity to allow more flexibility over the building's lifespan. It is obvious that policies and practises in this field are changing fast and will continue to do so. This emphasises that the houses must essentially be flexible throughout time. There is a need for a deeper awareness of how to create flexibility in use. This might refer to a variety of aspects, including principles, building structure, room sizes, furnishings, and scheduling to maximize utilisation.

Furthermore, analysis of data demonstrates that designing flexible houses to allow for unanticipated change offers greater flexibility in use and user empowerment. On the other hand, plans based on a scenario approach, limit flexibility in use and user control over their residences. Additionally, the possibility for extra size provides for greater flexibility in use, although this is dependent on the degree of unpredictability in space use and independence in terms of access and services.

Based on the literature review and the empirical study, it can be seen that to design flexibility in use, the designer needs to develop an indeterminate area or tailor to no specific use. As illustrated in figure 29, relationships between the two areas are visualised in this research. It is constructed on two design spectrums, with the central grey indicator representing the push-pull relationship between buildings and human agency. For a well-designed space to be flexible in use, architects must consider users, not buildings, at the centre of the design, which leans towards a more indeterminate configuration. Also, it illustrated the position of the principles based on the level of determinacy and the level of end-user involvement.

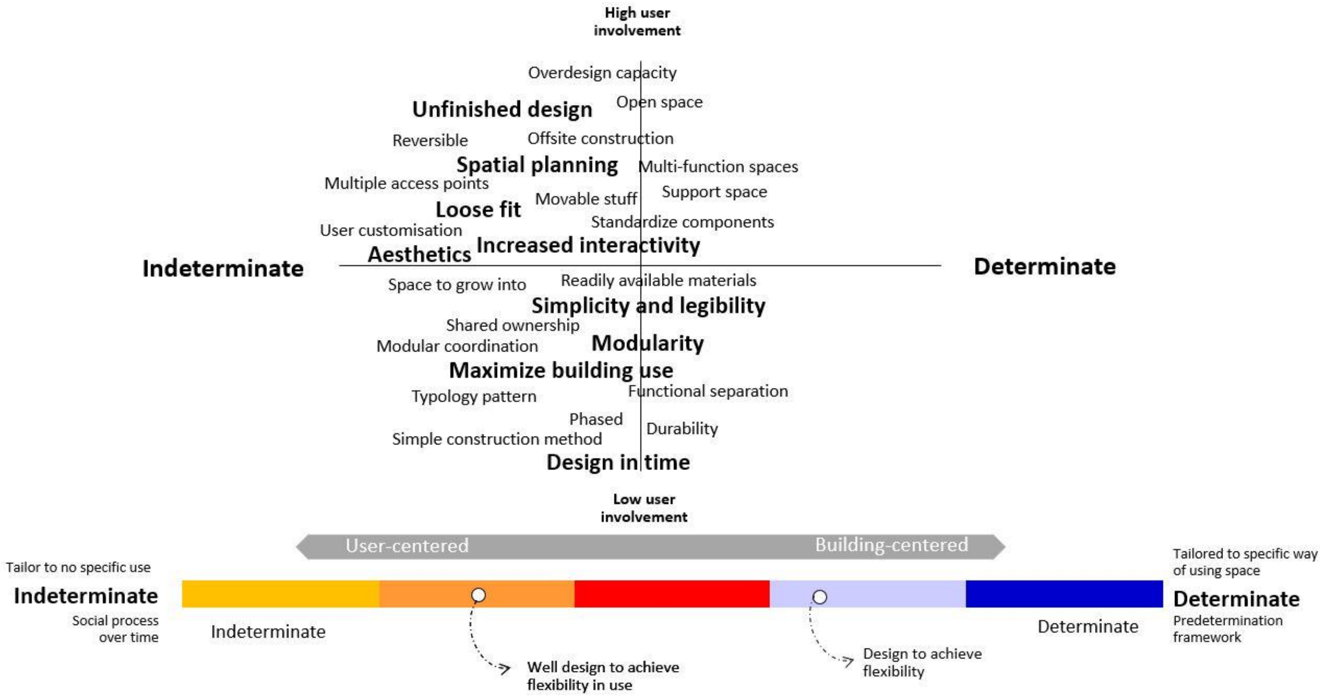

Figure 29: The relationship between the flexibility principles and the indeterminacy, as well as the involvement of users

4.5 Summary

This chapter analysed the data obtained throughout the progress of the study; each company's products were analysed. The interview description was presented. Additionally, the author highlighted the flexibility possibilities available to each company's houses. In conclusion, cross-case studies were used to demonstrate the contrasts and similarities between each company. The next chapter will discuss design steps that can create flexibility in modular housing.

Table 16: Comparison of companies' products based on the flexibility principles

Areas	Principles	Company A products					Company B products					Company C products					
		House type 1	House type 2	House type 3	House type 4	House type 5	House type 1	House type 2	House type 3	House type 4	House type 5	House type 1	House type 2	House type 3	House type 4	House type 5	House type 6
Physical elements	Modularity	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
	Design in time		**x**			**x**									**x**		**x**
	Simplicity and legibility	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Spatial aspects	Loose fit		**x**			**x**						**x**	**x**			**x**	**x**
	Spatial planning														**x**		**x**
	Unfinished design				**x**	**x**									**x**	**x**	**x**
	Maximise building use														**x**		
	Increased interactivity						**x**	**x**	**x**	**x**	**x**						
Building character	Aesthetics											**x**	**x**	**x**	**x**	**x**	**x**
Total	**16**						**15**					**30**					

Chapter 5: **DESIGN FRAMEWORK**

5.1 Introduction

Incorporating flexibility into the design of a residence improves its quality since it enables the building to adapt to the changing demands of the family. Despite this, the RIBA plan of work has not explored how modular housing may be made flexible. In order to apply flexibility in use, this chapter establishes a framework by adding new steps to the DfMA Overlay to the RIBA Plan of Work to implement flexibility in use as shown in Table 19. This chapter refers to the third objective of this study, which is to develop a framework which designers should consider flexibility principles to implement flexibility in use in volumetric modular houses. By analysing the DfMA Overlay to the RIBA Plan of Work, it could be figured out what steps need to be added to make flexible modular houses.

5.2 RIBA Plan of Work for DfMA Overlay

The DfMA Overlay is a supplementary project strategy included in the RIBA Plan of Work and serves as a companion to the Construction Strategy. It outlines the activities essential to accomplish a successful DfMA approach on a project and to properly execute the numerous new ways of construction. The project team will complete the duties once they have been assigned to the client team, design team, or construction team, as applicable, in accordance with contracts for professional services or construction. These task bars are included:

Stage Outcome: The stage outcomes are high-level descriptions of the intended results at the conclusion of each stage. These are derived from the RIBA Work Plan Template for 2021 (RIBA, 2021).

- ***Stage 0***: The best way to meet the client's needs was determined. If the result shows that a building is the best way to meet the client's needs, the client moves on to Stage 1.
- ***Stage 1***: The project brief is established based on client demands.

- ***Stage 2***: The customers' approval of the architectural concept ensuring it is in accordance with the Project Brief. During Stage 2, the brief stays active and is modified in accordance with the Architectural Concept.
- ***Stage 3***: The spatial coordination of architecture and engineering details.
- ***Stage 4***: On most projects, Stage 4 and Stage 5 will overlap. Complete all design information necessary for manufacturing and construction of the project.
- ***Stage 5***: Completion of manufacturing, construction, and commissioning. Other than replying to site queries, there is no design work in Stage 5.
- ***Stage 6***: Building delivered, aftercare started, and building contract ended.
- ***Stage 7***: Buildings are utilised, operated, and maintained with efficiency. Stage 7 begins simultaneously with Stage 6 and continues throughout the life of the building.

Core DfMA Tasks: These are the essential DfMA activities that should be done at each stage to enable the effective deployment of contemporary construction techniques throughout the life cycle of the project.

- ***Stage 0:*** Consider the applicability of the seven categories MMC across project portfolios and programmes. Consider how DfMA may affect the client requirements or business case, such as the repurposing of a building and the reuse or recycling of its components at the end of the building's life. Consider how different MMC techniques may impact the organisation of the project team.
- ***Stage 1:*** Consider methods to include the seven MMC categories into the project brief and project programme, and stimulate DfMA thinking, including the possibility of components recurring in future projects. Before commencing design, do research with manufacturers to determine the supply chain's capabilities. Consider DfMA solutions while performing feasibility studies, taking DfMA best practise

examples for comparable projects into consideration. Consider how several MMC categories influence the composition of the project team, including the responsibility matrix and professional services contracts that address intellectual property concerns.

- ***Stage 2:*** Integrate MMC categories appropriate to the architectural concept. Determine DfMA solutions for sustainable outcomes in the concept design. Ensure that the construction, sustainability, cost plan, plan for use, and health and safety principles take DfMA into account, coordinating as necessary with the supplier chain. Consider elements of strategic engineering, such as floor-to-floor heights, spans, space needs, and foundation design. Consider initiating early conversations with the planning and transportation authorities to protect the architectural concept.
- ***Stage 3:*** Revisit the construction strategy and cost plan, taking into account conversations with prospective contractors and the supplier chain. Consider buildability, including the influence of the erection sequence, fabrication or manufacturing procedures, and tolerances on interfaces, while developing the construction strategy. Verify the planned MMC system's warranty provisions.
- ***Stage 4:*** Consider the effects of DfMA on building systems, such as "plug and play" connections and interfaces. Develop the DfMA components with more precision, take into account interfaces and standards, such as structural, moisture/water/vapour penetration, and acoustic concerns. Consider prototyping and other quality assurance approaches. In the revised health and safety and construction strategy, evaluate the risks associated with manufacturing and assembly.
- ***Stage 5:*** Consider loading, handling, and transportation for each component and subassembly when revising the construction strategy to include a logistical plan. Monitor the quality of offsite production consider commissioning, optimising manufacturing acceptance testing use.

- ***Stage 6:*** Provide feedback on issues and how to prevent them in future projects. Provide comments on the DfMA approach for future project evaluation.
- ***Stage 7:*** Consider any required feedback. throughout the use phase to influence future developments. Provide feedback on the performance of standardised components, including replacement and maintenance. Provide feedback on what elements have been determined for reusing at the end of the building's useful life, as well as how the structure might be adapted instead of demolished.

Suggested Digital Tasks for DfMA: These new responsibilities assist the achievement of a DfMA strategy via the use of digital processes and technologies to increase efficiency and incorporate data-driven decision-making, in accordance with the UK BIM Framework. This category of tasks, referred to as "Suggested BIM Tasks" in the first edition, has been expanded to encompass all important digital processes, such as visualisation, data utilisation, and digital infrastructure outside of the project information.

- ***Stage 0:*** Analyse data from prior DfMA projects, including schedule and cost, in order to establish benchmarks.
- ***Stage 1:*** Using BIM for preparing feasibility studies. Consider using or building a digital library including DfMA objects and components, and determining how this might be used across many projects. Confirm information needs (or Exchange Information Requirements under the UK BIM Framework), including Asset Information Management (AIM) requirements, and build BIM implementation strategy.
- ***Stage 2:*** Develop digital information, including data-rich DfMA information, using a digital library of Stage 4-ready objects. Compare the model to the information requirements to determine its validity. Consider DfMA tolerances while constructing the BIM model. Utilize

digital tools and technology, such as VR, to enhance the customer experience.

- ***Stage 3:*** Update digital information comprising data-rich DfMA material, perhaps from a digital library of Stage 4-ready objects and evaluate the influence on the final specification. Evaluate the model to the information requirements to determine its validity. Utilize digital tools and technology in coordination exercises such as 4D (time).
- ***Stage 4:*** Update digital information, including supply chain information. Evaluate the model to the information requirements to determine its validity. Utilize 4D technology to simulate and rehearse the sequencing outlined in the construction strategy, together with manufacturing, assembly, and logistics, prior to the start work on-site.
- ***Stage 5:*** Use tools and technology to instruct site personnel and get access to digital data, such as site plans, method statements, and product manuals. Utilize digital technology to monitor the production, logistics, packaging, and delivery processes. Utilize digital technologies to assess actual against anticipated progress on-site and to verify the quality of construction.
- ***Stage 6:*** Ensure digital information relating to DfMA components, including lessons learned and possible reuse, is connected to Feedback.
- ***Stage 7:*** Consider using configuration management tools to update digital asset information over the building's lifetime. Consider using digital twin and smart building technologies that are connected with Internet of Things and cloud technologies in order to collect data on in-use activities.

Procurement Strategy: the procurement strategy task bar indicates the most important procurement choices inside the RIBA Plan of Work framework for normal procurement routes. The tasks are derived from the RIBA Plan of Work for 2021 and augmented by suggesting important activities required for the proper execution of the various MMC categories. The following stages are covered by MMC categories 1, 2, and 4.

- ***Stage 0:*** Ensure that the client team has the necessary expertise of MMC and DfMA to give the optimal solution.
- ***Stage 1:*** Consider possible manufacturers and subcontractors in relation to the contractor selection process.
- ***Stage 2:*** Consider possible subcontractors and manufacturers in relation to the contractor selection process.
- ***Stage 3:*** Consider possible subcontractors and manufacturers in relation to the contractor selection process.

5.3 Steps to add flexibility in use for DfMA:

The literature indicates that a plan for the building's lifespan established during the initial design phase should allow more flexibility (Moravek, 1996). Future planning establishes the roles to which a building may be modified in the future. Existing buildings are covered by a variety of regulations and norms, which cannot help buildings be modified throughout time. A building typically has a lengthy service life. The laws that exist at the time of construction can give buildings a chance to be more flexible over time.

Previous sections have examined the latest version of the DfMA overlay template, which included DfMA processes into the RIBA Plan of Work 2021. This section defines tasks that can provide flexibility in use in modular houses. It can help designers to design flexible modular houses. These stages offer some flexibility principles to implement flexible volumetric modular houses. Table 17 provides a summary of the stages.

- ***Stage 0:*** As mentioned in the second chapter, flexibility can be divided into three areas. In this stage of designing flexible modular houses, it is necessary to examine the definition of flexibility in use and the principles. Consider how the 9 principles of flexibility may be implemented across project portfolios. Consider how modularity, design in time, simplicity & legibility, loose fit, spatial planning, etc, can increase the flexibility of a building and respond to different users' demands over time. Also, consideration needs to be made towards the impact flexibility principles have towards the project.

- ***Stage 1:*** Consider ways to incorporate the 9 principles into the project brief and project program while also considering ways to introduce flexibility in use, including the possibility of principles recurring in future projects. Before the design process, carry out research and development with the manufacturers to examine the three categories of these principles; physical elements, spatial aspects, and building character. Consider flexibility in use while performing feasibility studies, taking into consideration flexibility principles and best-practice examples from similar projects. Consider the impact of these principles on the project, including a change in user requirements over time, professional services that address the requirements of customers over time, and the obsolescence of the building.
- ***Stage 2:*** Integrate flexibility principles appropriate to the architectural concept. Determine flexibility in use for sustainable outcomes in the conceptual design. Ensure that the construction, sustainability, cost plan, and plan for use coordinate as necessary with the stakeholders, clients, and supply chain. Regarding flexibility principles, consideration must be taken towards different functional elements and service areas in addition to the elements of strategic engineering, such as floor-to-floor heights, spans, space requirements, and foundation design. Consider initiating early conversations with manufacturing engineers to protect the architectural concept.
- ***Stage 3:*** Utilizing the first category of MMC, which is volumetric modular houses, stage 3 illustrates the building plan application, which requires a design freeze in order to get the most value from using offsite solutions. This is the last opportunity to design flexibility in use during the design stage. Although, by using flexibility

principles, end users have an opportunity to modify their houses based on their needs over time.

- ***Stage 6:*** Provide feedback on flexibility and how future projects might be improved. Provide feedback on the principles of the flexibility approach for future project review.
- ***Stage 7:*** Consider how feedback throughout the use phase may influence future developments. Provide feedback on the performance of different principles and their maintenance and replacement. Provide feedback on which principles have been determined to respond to end-users' needs during the building's useful life.

Table 17: Defined flexibility in use in DfMA Overlay to the RIBA Plan of Work (Initial Framework)

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
Stage Outcome	Client requirements	Project brief	Architectural concept approved by clients and project brief	Coordination between architecture and engineering	Complete design and construction required manufactory	Manufacturing, contraction, and commissioning completed	Building handover	Building use, maintenance
Core DfMA Tasks	Defined MMC category to respond to clients' needs	Opportunity for repeatability elements	Embed appropriate MMC into architectural concept	Coordination between designers and DfMA	How DFMA impacts on building systems	Update construction strategy (logistic plan, lifting)	Provide feedback	Provide input on highlighted reuse and recycling features
Suggested Digital Tasks for DfMA	Set benchmark	Establishing Digital library	Develop digital information	Update digital information from library	Update library information (supply chain…)	Utilize tools and technology to instruct site employees.	Ensure digital information relating to DFMA components (feedback)	Consider configuration management techniques
Suggested Flexibility in use	Well-defined flexibility principles and keep them under review	Defined building opportunity for flexibility based on principles	Embed right flexibility principles into architectural concept	Design freeze (last chance to increase the number of flexibility principles)	—	—	Arrange to receive feedback	Provide feedback on the performance of different principles
Procurement	MMC and DfMA collaborate to provide the optimal solution	Review potential subcontractors and analyse how manufacturers connect to contractor selection						

5.4 Validation of the framework

Various methods may be used to validate frameworks, depending on the character of the study, including the use of existing literature, expert opinions, case studies and surveys (Inglis, 2008). To validate the framework in this study, feedback was requested from specialists in the volumetric modular houses research domain, particularly those with experience in DfMA specially design for volumetric modular houses. A document summarising this research study (including the research problem, research methodology, findings, and conceptual framework) was provided to them for this purpose. Five experts were contacted for the validation of the framework; three agreed to participate, and two validated the framework. Table 18 presents the profiles of specialists who participated in the validation of the framework.

Table 18: Profile of experts in flexibility in volumetric modular houses

Expert no.	Description
V1	• Senior architectural Design in Volumetric modular houses • Expert in plan and design requirement
V2	• Professor of built environment • Expert in Building information modelling

The remarks and feedback of the specialists on the framework are presented in the flowing sections.

5.4.1 Comments from experts

V1 and V2 discovered the summarised document to be intriguing and well-structured, requiring no additional information to comprehend the framework. They made some observations regarding the How designers identify the principles of flexibility that are applied during the design process.

- They pointing out that by using BIM (Building Information Modelling) allows enables the virtual construction of buildings and the use of simulation to evaluate solutions prior to construction. Consequently, it is necessary to include BIM as a significant methodology to be considered, as future users will be able to interact with the rendered BIM model, there by verifying the detailed design decisions, among other possibilities. They also mentioned that by creating digital library designer can use more principle during the design stage.

5.4.2 Analysis of experts' comments

To refine the initial framework using the feedback of specialists, classification and in this section, which follows, the comments are evaluated.

- The experts involved in the validation and refinement of the framework recommended that it would be useful to add which principles need to be used in each stage.
- Nearly all of the experts involved in the validation and refinement of the framework recommended incorporating BIM as a significant methodology and establishing a digital library.
- They also suggested that it would be helpful to increase the principle after stage three (requiring future research).

5.5 Final framework

After considering expert comments and suggestions, the final framework for this study is created and shown in Table 19.

5.6 Summary

This chapter reviewed the DfMA Overlay to the RIBA Plan of Work and it explained all the stages in different steps. Also, to add flexibility in use for DfMA, a new step demonstrating the task has been added which forms the knowledge contribution of this research. Furthermore, various stages of framework development are discussed, and the final framework has been constructed following validation and refinement. At the end, table 19 provided a summary of the stages.

Table 19: Defined flexibility in use in DfMA Overlay to the RIBA Plan of Work (Framework)

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
Stage Outcome	Client requirements	Project brief	Architectural concept approved by clients and project brief	Coordination between architecture and engineering	Complete design and construction required manufactory	Manufacturing, contraction, and commissioning completed	Building handover	Building use, maintenance
Core DfMA Tasks	Defined MMC category to respond to clients' needs	Opportunity for repeatability elements	Embed appropriate MMC into architectural concept	Coordination between designers and DfMA	How DFMA impacts on building systems	Update construction strategy (logistic plan, lifting)	Provide feedback	Provide input on highlighted reuse and recycling features
Suggested Digital Tasks for DfMA	Set benchmark	Establishing Digital library	Develop digital information	Update digital information from library	Update library information (supply chain…)	Utilize tools and technology to instruct site employees.	Ensure digital information relating to DFMA components (feedback)	Consider configuration management techniques
Suggested Flexibility in use	Design in time, Modularity and keep them under review	Spatial Planning, Loose fit, Maximase building use & Establishing Digital library	Unfinished design, Aesthetic	Increased interactivity, simplicity & legibility & Update digital library	—	—	Arrange to receive feedback	Provide feedback on the performance of different principles
Procurement	MMC and DfMA collaborate to provide the optimal solution	Review potential subcontractors and analyses how manufacturers connect to contractor selection						

Chapter 6: **DISCUSSION AND CONCLUSIONS**

6.1 Introduction

The overall aim of this research was to develop a framework that provides steps to aid designers of volumetric modular homes in implementing flexibility in use. It covers a step that examines various stages where end-user flexibility can be increased. Therefore, it should enable designers to evaluate the needs of clients more carefully. This chapter provides study findings and is split into two sections. The first section outlines how the research addresses objectives in light of the key results from the literature review and the analysis of case studies within the UK research area. The second section suggests future study areas.

6.2 Discussion of the main findings in relation to the research objectives and literature

This section presents the important study results that answer the aim and objectives given in Chapter 1.

Objective.1: Better understand the needs and the challenges around flexibility in use.

This objective, together with the identified research gap and a better understanding of flexibility in use constituted the first step of the study, which was addressed in Chapter 2 through a literature review. The research summarises the various definitions of flexible housing and the history of flexible housing.

Flexibility in use is beneficial, due to customer needs being met over the life of the house. Humans have been interested in changing their built environments since the beginning of human life. These changes were caused by an increase or decrease in the number of people who lived in the building and the changing requirements of those people through time. Changes in the size of the family, the ages of the people living there, the ages and genders of the children, and their physical abilities are all examples of demographic changes that can happen over a family's lifetime. Designing for flexibility necessitates a shift in viewpoint, requiring people to consider buildings in a much more open way and to recognise that they are far more complicated when seen from the perspectives of other users. When it comes to issues of users demands, the question of whether it is preferable to complete a speculative area to a certain specification or to leave an empty canvas is often brought into question.

However, although post-occupancy assessments and other performance monitoring approaches have grown more common, feedback from buildings in use is still unusual, and most of the time it is provisional and informal, including via meetings with customers or by revisiting the same building. Understanding how people adapt to their surroundings is a key part of learning about what works and what doesn't in terms of flexibility in a given facility.

A thorough literature review was conducted on housing design modifications and relocations in various contexts, as well as on flexible housing research and projects that have identified various drivers for flexible housing design in terms of changing household needs. In addition, this study has examined the challenges associated with the flexibility in use. One of the problems is the lack of integration between project/design process/building planning and the real estate market, which have neither a long-term perspective nor an organised approach to the various life cycles of building components. A further essential factor is to challenge building design, construction, and usage practices.

The literature review identified few approaches for analysing the capacity of flexible designs to adapt to the changing demands of various families. Nonetheless, several references were discovered in the works of Al-Dakheel (2007), Schneider and Till (2007), which offered some measures of cultural adaptability and flexibility to the changing demographic features of families.

In the housing context, the review highlighted two essential concepts: flexibility and adaptation. Flexibility as 'capable of varying physical arrangements' and adaptation as 'capable of varying social uses'. flexibility includes both exterior and internal alterations, as well as temporary and permanent modifications, by being able to move a wall or door more internal configurations can be achieved. Whereas adaptability is concerned with issues of use. In this research, flexibility in use has been investigated, which can be said to be consistent with adaptability.

Objective.2: Identify principles that can increase flexibility in use for the context of volumetric modular houses.

Chapter 2 explains some of the more cited principles for flexibility in use. It shows 9 principles that can support the designer during the design stage. The principles were grouped into three areas: *physical elements*, *spatial aspects,* and *building character*. Physical elements can be seen in existing products already, whereas spatial aspects and building character get less consideration throughout the design process.

Furthermore, each area contains several principles, each principle illustrating's different building characteristics related to the modularity. For a well-designed space to be flexible, architects must place the user at the centre of the design, not the building, which is shown in figure 29. To solve this issue, these principles need to be considered at the design stage in order to analyse human-centered via building-centered design, as per figure 29.

These principles give a framework for designers to consider flexibility. Consequently, the principles of flexibility are high-level terms for addressing flexibility and adaptability and are given as one of the numerous interconnected design concerns. The 9 principles may be seen as a menu of alternatives, each of which is individually different. One principle alone is not enough to achieve flexibility in use, instead, flexibility in use is achieved through the use of multiple principles.

The major scope of flexibility and related notions of adaptation in the context of housing were provided throughout the research indicating that Flexibility in use should be considered throughout the design process. Therefore, allowing users to modify and alter their homes in accordance with their changing desires and requirements throughout time.

During the twentieth century, there were two problematic approaches to flexible housing design, the first is characterised as an indeterminate method of design that allows unlimited modification, while the second as a determinate method of design that includes overly technical and complicated approaches. In addition, for a more effective housing design, it would be preferable to place flexibility in use in the background of the design process, rather than making it the primary focus.

Objective.3: Define the stages in which designers should consider principles to implement flexibility in use in the volumetric modular houses.

This objective identified stages to implement flexibility, which were covered in Chapter 5.

The literature indicates that a plan for the building's lifespan established during the initial design phase should allow more flexibility. Future planning establishes the roles to which a building may be later modified. Existing buildings are covered by a variety of regulations and norms, which cannot help buildings be modified throughout time. A building typically has a lengthy service life. The laws that exist at the time of construction need to be changed to give buildings a chance to be more flexible over time.

This research defines stages that can provide flexibility in use in modular houses. It can help designers to design flexible modular houses. These stages offer some flexibility principles to implement flexible volumetric modular houses. It presents several stages, and each stage examines how the use of principles can bring flexibility for end users. It can enable customers' needs to be better considered by designers. According to the framework, the earliest levels must understand the idea of flexibility and the importance of flexibility in application. During data collection, the researcher discovered that businesses are unaware of the distinction between flexibility and customisation strategies. The most evident distinction between flexibility and mass customisation is that mass customization responds to the owner or client demand in short term, but flexibility in use responds to the user demands in long term. Consequently, it is crucial for designers to comprehend these distinctions.

Every building has the ability to facilitate flexibility in use. The role of the designer is to identify or even generate new opportunities for the implementation of flexibility, which may be readily performed by using flexibility principles. Then embed the flexibility principles into the architectural concept. Before the design freeze, there is the last chance to increase the number of flexibility principles. In addition, for improvement, the flexible houses need to receive end-user feedback to find any issues. Also, it is important to provide feedback on the performance of different principles.

Each principle may accommodate various end-user requirements. Therefore, designers need to identify the possibility of designing a building based on principles. It would be more efficient if architects could design many flexible principles. In addition, by examining the framework shown in table 19, designers may determine when and how they might use the principles, and each step illustrates which data must be gathered to build flexible modular homes. In addition, the last two stages, which are arranged to receive feedback and provide feedback on the performance of different principles, may assist architects in determining which principles are applicable and efficient for certain sorts of dwellings. They may also categorise the principles depending on inputs from end users.

6.3 Conclusion

If housing fails to adapt to new circumstances, it is, at best, unpleasant and, at worst, outmoded. From this viewpoint, one of the most significant difficulties associated with house design in the world today is the perception of housing as a commodity with inflexible design parameters. It becomes more important to design residential buildings with the market's immediate requirements and expectations in consideration. So, the current housing market prefers to adopt short-term expediency over long-term wisdom (Schneider and Till 2007, 4). The housing issue is becoming increasingly significant in terms of its social, economic, and physical repercussions. The design of residential buildings that are inflexible cannot meet the changing requirements and desires of the users. However, users' desires and requirements may shift over time. The inflexibility of housing necessitates that when users' requirements change, as they eventually will, they need to move to a new home. This kind of house design based on predetermined principles is an illustration of the inflexible in residential architecture. Additionally, modern method of construction is not exempt from this difficulty, which is housing inflexibility.

Modern Methods of Construction (MMC) are encouraged by the UK Government to assist alleviate housing shortages and reduce building costs. Volumetric modular housing (VMH) is a subcategory of modular construction. Unfortunately, the creation of flexibility in volumetric modular housing has been overlooked in order to fulfil the demands of customers during the lifetime of the home.

During the twentieth century, there were two problematic approaches to adaptable home design, which Schneider and Till (2007) refer to as "the rhetoric of flexibility." The first is characterised as an indeterminate method of design that permits "endless modification," while the second as a determinate method of design that includes excessively technical and complex answers. The case studies from England illustrate these two problematic flexible home design concepts. They are created in a predetermined manner with "endless solutions" or in an architect-determined manner with excessively technical and complex solutions. However, for well to design flexibility in use, designers need to work in the background, which means designers giving some indeterminate area, then end users can use it based on their needs.

The purpose of this study is to develop several steps to assist designers in incorporating flexibility in use into volumetric modular homes. This study's objective is to provide recommendations that might aid designers of volumetric modular homes in considering flexibility in use. Also, the study shows principles that can increase flexibility in use. By analysing the DfMA Overlay to the RIBA Plan of Work, this research designed different steps that help designers have flexibility by implementing flexibility principles that need to be added to make flexible modular houses. The lessons learned from the case study contexts are as follows:

- Designing flexible housing for unanticipated change gives the design solution a greater opportunity for flexibility in use. Designs based on a scenario approach limit flexibility in use and user control over their residences.
- The possibility for additional size provides for greater flexibility in use, but this is dependent upon the degree of indeterminacy in space use and independence of services.
- In order for flexible design to make users more independent, architects should be encouraged to take a position that is based on giving up control over design and being aware that what happens in a space should depend on more than the architect's teams.
- The employment of hard technology to achieve flexibility affects both the initial investment and the cost of flexibility. Increasing the number of pods might reduce the flexibility in use as their will be fewer connections between areas (company B).

- Understanding the relationship between the upfront cost and long-term value of flexible design and explaining this to consumers in a transparent way is essential for flexible home delivery.
- It is essential to increase market knowledge of building performance in order to make flexible modular housing profitable.

It is important for housing to be flexible, particularly during use, so that client demands may be satisfied throughout the house's lifetime. As a consequence of the design and construction of the housing, residents and housing managers are able to make adjustments over time as a result of the housing's flexibility in use. The spatial arrangements of a flexible building may be changed in response to change in occupant behaviour and functions, the addition of users, and future renovations.

6.4 Further research

This research raises new possibilities for further research into flexible modular housing, particularly in terms of contexts similar to the UK. As the current study had limited opportunity to draw on the perspectives of users with regard to their flexible housing, it would be worthwhile for future research to conduct in-depth study of users' perceptions in order to understand the potential for flexible design to respond to users' changing needs. Moreover, as this research focused mainly on flexible housing as a product, further research in relation to flexible housing as a process is necessary to understand the impact of the incorporation of flexibility on governance processes throughout the different stages of development.

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APPENDICES

Appendix 1: INTERVIEW QUESTIONS

INTERVIEW QUESTIONS	
Section A	**Modularity**
1.1	Do you use modular design or modular construction?
1.2	Can you walk me through the process you use for modularity in your projects?
1.3	What type of information is essential to ensure that modularity requirements are met?
1.4	In what stage of the RIBA plan of work should such information be provided and by whom?
1.5	What are the issues faced when using modular construction?
1.6	How do you select projects to use modularity?
Section B	**Flexibility**
2.1	Do you offer a level of flexibility to your end-users? If yes, which type of flexibility do you offer to them?
2.2	When you wish to design flexibility, what boundaries/obstacles prevent you from doing so?
2.3	How does the project's flexible design meet the changing needs over time?
2.4	In what ways can modularity enable flexibility?
2.5	Who is responsible for coordinating the flexibility or design options provided to users? What is your approach?
2.6	How do you ensure that flexibility does not adversely impact the construction phase?
2.7	Can you provide any documentation that describes the modules and flexibility approaches/elements you use? or a sample of your modular designs?
2.8	Do you work with other companies to provide flexibility in a modular building? If so, could you please provide details and maybe help contact them for further data collection for this research.

Appendix 2: INTERVIEW'S TIMETABL

Role/Discipline	Propose interview		Actual interview schedule		Interview operation status
	Date	Time	Date	Time	
Land and Partnerships Director	12/10/2020	14:00	13/10/2020	09:30	Finished
Business management	12/11/2020	13:30	18/11/2020	10:00	Finished
Designer	04/12/2020	15:00	04/12/2020	15:00	Finished
Director	07/12/2020	9:00	07/12/2020	9:00	Finished
Manufacturing Mentor	8/12/2020	15:00	08/12/2020	15:00	Finished
Heads up the design team	03/12/2020	10:00	10/12/2020	11:00	Finished
Manufacturing Mentor	14/12/2020	9:00	14/12/2020	9:00	Finished
Designer	15/12/2020	9:00	15/12/2020	9:00	Finished
Preconstruction Director	4/01/2021	12:00	04/01/2021	12:00	Finished

Appendix 3: DfMA Overlay to the RIBA Plan of Work

DfMA Overlay to the RIBA Plan of Work

The MMC categories

Category 1: 3D primary structural systems
Category 2: 2D primary structural systems
Category 3: Non-systemised primary structures
Category 4: Additive manufacturing
Category 5: Non-structural assemblies and sub-assemblies
Category 6: Traditional building product-led site labour reduction/productivity improvements
Category 7: Site process-led site labour reduction/productivity/assurance improvements

Construction Strategy

A strategy that considers specific aspects of the design that may affect the procurement, buildability, manufacturing, assembly or logistics of constructing a project or that may impact health and safety aspects.

The **Construction Strategy** comprises items such as the craneage strategy, site access and welfare accommodation locations, reviews of the supply chain and sources of materials, and specific buildability considerations, such as the choice of frame (steel/concrete/timber) or the installation of larger items of plant.

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
		← Projects span from Stage 1 to Stage 6; the outcome of Stage 0 may be the decision to initiate a project and Stage 7 covers the ongoing use of the building →						
Stage Outcome at the end of the stage	The best means of achieving the **Client Requirements** confirmed If the outcome determines that a building is the best means of achieving the **Client Requirements**, the client proceeds to Stage 1	**Project Brief** approved by the client and confirmed that it can be accommodated on the site	**Architectural Concept** approved by the client and aligned to the **Project Brief** The brief remains 'live' during Stage 2 and is derogated in response to the **Architectural Concept**	Architectural and engineering information **Spatially Coordinated**	All design information required to manufacture and construct the project completed Stage 4 will overlap with Stage 5 on most projects	Manufacturing, construction and **Commissioning** completed There is no design work in Stage 5 other than responding to **Site Queries**	Building handed over, **Aftercare** initiated and **Building Contract** concluded	Building used, operated and maintained efficiently Stage 7 starts concurrently with Stage 6 and lasts for the life of the building
Core DfMA Tasks	← Developing a programme-level platform will follow Stages 0–4, concluding in a library of systems to technical design level information and the use of these systems on a project will provide significant optimisation of Stages 1–4 →							
	Consider opportunities for applying the seven MMC categories across portfolios or programmes of projects Consider how DfMA might impact on the **Business Case** or **Client Requirements** including repurposing of a building and reuse or recycling of components at the end of the building's life Consider how different MMC strategies might impact the set up of the project team	Initiate DfMA thinking including opportunities for repeatability of elements on future projects and consider how to incorporate the seven MMC categories into the **Project Brief** and **Project Programme** Undertake **Research and Development** with manufacturers to determine supply chain capability prior to design commencing Consider DfMA solutions when undertaking **Feasibility Studies** considering best practice DfMA exemplars from comparable projects Consider how different MMC categories impact the set up of the project team including the **Responsibility Matrix** and professional services contracts including intellectual property issues	Embed appropriate MMC categories into the **Architectural Concept** Identify DfMA solutions to **Sustainable Outcomes** in the **Concept Design** Ensure that the **Cost Plan**, **Construction**, **Sutainability**, **Plan for Use** and **Health and Safety Strategies** consider DfMA, liaising with supply chain as required Consider **Strategic Engineering** aspects including floor-to-floor heights, spans, space requirements and foundation design Consider early discussions with the planning and transport authorities to safeguard the **Architectural Concept**	Update the **Construction Strategy** and the **Cost Plan** taking into account discussions with potential contractors and the supply chain Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces in the **Construction Strategy** Check warranty provision for the proposed MMC systems	Consider how DfMA impacts on **Building Systems** including 'plug and play' connectors and interfaces Develop the DfMA components more accurately considering interfaces and specifications including structural, water/moisture/vapour penetration and acoustic issues Consider prototyping and other methods of quality assurance Consider manufacturing and assembly risks in the updated **Health and Safety** and **Construction Strategies**	Update the **Construction Strategy**, including a logistics plan, considering lifting, handling and transportation for each component and sub-assembly Monitor quality of offsite manufacturing Consider **Commissioning**, optimising the use of factory acceptance testing	Provide **Feedback** on defects and how these might be avoided on future projects Provide **Feedback** on the DfMA process for consideration in future projects	Consider any **Feedback** during the in-use stage necessary to inform future projects Monitor the performance of standardised components including maintenance and replacement and provide **Feedback** Provide **Feedback** on what aspects have been identified for reuse or recycling at the end of the building's useful life and how the building can be adpated rather than demolished
			Technical design activities may commence in Stage 2 in order to verify DfMA concepts					
Suggested Digital Tasks for DfMA	Analyse data, including cost and programme, from previous DfMA projects in order to set benchmarks	Use BIM for the preparation of **Feasibility Studies** Consider using or establishing a digital library including DfMA objects and components and how this may be used across multiple projects Confirm **Information Requirements** (or Exchange Information Requirements (EIRs) under the UK BIM Framework) including Asset Information Management (AIM) requirements and develop BIM execution plan	Develop digital information including data rich DfMA content possibly from a digital library of Stage 4 ready objects Validate the model against the **Information Requirements** Consider DfMA tolerances in the development of the BIM model Use digital tools and technologies including VR to improve client experience	Update digital information including data rich DfMA content possibly from a digital library of Stage 4 ready objects and consider impact on **Final Specification** Validate the model against the **Information Requirements** Use digital tools and technologies as part of coordination exercises including 4D (time)	Update digital information including information from supply chain Validate the model against the **Information Requirements** Use 4D technologies to scenario test and rehearse the sequencing set out in the **Construction Strategy**, including manufacturing, logistics and assembly, before work starts on site	Use tools and technologies to train site operatives and access digital information including setting out, method statements or product manuals Use digital technologies to track manufacturing, packing, logistics and delivery process Use digital tools to compare actual against planned progress on site and to inspect **Construction Quality**	Ensure digital information relating to DfMA components is linked to **Feedback**, including lessons learned and potential repurposing	Consider configuration management techniques to update digital **Asset Information** during the life of the building Consdier use of **Digital Twin** and smart building technolgies aligned to Internet of Things and cloud technologies to obtain data from in-use activities

Procurement Strategy

ER Employer's Requirements
CP Contractor's Proposals

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
Traditional	Appoint client team including MMC adviser	Appoint design team			Tender · Appoint contractor			Appoint facility and asset management team, and strategic advisers as needed
Design & Build 1 Stage					ER · CP · Appoint contractor			
Design & Build 2 Stage			ER	Pre-contract services agreement	CP · Appoint contractor			
Management Contract/ Construction Management			Appoint contractor					
Contractor-led			ER	Preferred bidder	CP · Appoint contractor			
MMC Categories 1, 2 and 4	Ensure client team has the requisite knowledge of MMC and DfMA in order to deliver the best solution	Review possible subcontractors and consider manufacturers and how they relate to contractor appointment						
MMC Categories 3 and 5			Consider specialist subcontractors and any constraints and embed into design					
MMC Categories 6 and 7					Low impact on procurement			

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Core RIBA Plan of Work terms are defined in the *RIBA Plan of Work 2020 Overview* and glossary and set in **Bold Type**.

Further guidance is included in '*Mainstreaming DfMA in Construction*'