APPLYING A LIFE CYCLE APPROACH IN DESIGNING FLEXIBLE HOUSING

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Abstract

In designing a house it is usual to be focused on the current needs of clients and users. However, soon those initial needs will change for reasons such as family growth, aging and changing lifestyle. Various solutions for this issue have been suggested by architects. 'Flexible Housing' is a type of dwelling design that has the ability for a house to adjust to the changing needs of its occupants. Although all the qualitative research indicates that this type of dwelling is an economic and sustainable solution, there is little quantitative data to support that argument. The real financial benefit of Flexible Housing will only be recognisable when, rather than the routine design approach, based primarily on immediately available expenditure, life cycle costing is taken into account.

The term Life Cycle Costing (LCC) is used to describe a process in which all costs relating to a property over its whole life cycle would be systemically calculated and evaluated. LCC is a significant task in a life cycle approach to buildings. This research aimed to indicate the financial advantage of Flexible Housing through designing a flexible house applying a life cycle approach.

To achieve the purpose of this research, first, a literature review was undertaken to determine the main features of a flexible house. Among varying techniques that have been applied by architects to achieve flexibility, 'slack space' was chosen for the present research project. This concept allows for adding flexibility to design by preparing some unprogrammed spaces to be occupied by users to address their new needs in the future. These phases will be done through a Building Information Modelling-based design process, using its features especially in cost estimation and documentation. Building Information Modelling (BIM) is a recent approach in the architecture, engineering and construction (AEC) industry. Applying BIM potentials in the design process could help the architect to make better architectural decisions at the outset where there are enough quantitative data to support the financial analysis of the design.

Key Words: Flexible Housing, Life Cycle Costing (LCC), Building Information Modelling (BIM), slack space

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Abbreviations

AEC: Architecture, Engineering and Construction

AUP: Auckland Unitary Plan

BIM: Building Information Modelling

LCA: Life Cycle Assessment

LCC: Life Cycle Costing

POS: Private Open Space

WLC: Whole-life Cost

Introduction

Chapter One

1.1. Introduction

In designing a dwelling, it is common to be focused on the current needs of the intended occupants. Any changes in the intended residents' demographics, lifestyle or preferences might affect the effectiveness of design. The design would remain suitable to the residents as long as no changes occurs within their needs, lifestyle and the dwelling functions considered for the project initially. These kinds of changes might confront the owner with later costly renovations or even require owners to relocate, which could be either expensive or impossible. Although there has been a tendency in the traditional residential design process to ignore the possibility that the users' needs might change (Friedman, 2002), there are architectural solutions for this issue.

Many housing building practices, especially during the 20th century, have tried solutions for this issue, such as flexible housing, open building and adaptable housing, and these approaches have been well reviewed (e.g. Friedman, 2002; Kendall & Teicher, 2000; Schneider & Till, 2007). Several other practices have been introduced internationally during recent decades under the concepts of 'lifetime homes' and 'incremental architecture'. These solutions address different aspects of the idea of adding flexibility and adaptability to residential architecture and indicate the increasing demand for this type of dwelling in the market. This movement is in contrast to the short-term view that sees housing as "a disposable commodity that can be moved on from once the surface has lost its attraction" (Schneider & Till, 2007, p. 37).

'Flexible housing' is a type of residential architecture that can adapt itself by evolving to the changing needs of occupants over their lifetime, so that there would be no need to move to another house or do costly renovations if the building's initial design is no longer appropriate to needs. Realistically, some changes will happen over time in occupants' needs and their expectations of their home, so that some features must be accommodated in the building's layout to address those inevitable changes. Housing design needs to be sufficiently flexible to respond to a range of changes in occupants' needs as they become older and potentially less physically able, as well as changes in family structure as it expands and then contracts (Schneider & Till, 2007).

According to Schneider and Till (2007), the potential of flexible housing as an economic and sustainable solution, in terms of increasing user satisfaction, reducing maintenance costs, avoiding obsolescence, and limiting users' need for relocation, seems to be obvious; however, there is little quantitative data to support this argument. The real financial benefit of flexible housing will only be recognisable when, in contrast to the typical process of construction cost calculation where investment appraisal is based on immediately available expenditure, life cycle costing is taken into account (2007). If the life cycle cost of a building, including all related costs (construction costs, operating costs, maintenance costs, and demolition and disposal costs) was calculated and considered in the initial investment appraisal of a building, "then building-in flexibility would be clearly an economic and sustainable benefit" (Schneider & Till, 2007, p. 44).

A current obstacle in consideration of flexible housing as an economic solution for issues in housing design systems is the lack of enough quantitative data for changing from the current, short-termist process of financial assessment, to a life cycle approach, and replacing common cost calculation procedures with life cycle costing. Thus, this research aimed to design a flexible house through a life cycle approach and identify the benefits of building-in flexibility in terms of reducing life cycle cost of the dwelling. For this purpose, a new design procedure was needed that can handle costs and energy requirements as well as the life cycle assessment of a building (König & Schoof, 2010). König and Schoof believe this new design process - 'integrated design' - has this ability to link the design process with cost information by applying Building Information Modeling (BIM).

Moreover, according to Schneider and Till, another common issue in flexible design is that, without proper documentation of layout and features, a flexible design would be a waste of money. Documentation can be accessible and easy to use for non-experts, especially the building's end-users, so all parties are aware of the features accommodated in the building's design (2007). This issue could also be addressed by using BIM as a tool for integrated design, to prepare a comprehensive view of the "project by including everything in a single-source model" (Krygiel & Nies, 2008, p. 32).

1.2. Research Question

- How can flexible design reduce the life cycle cost of a house?

1.3. Aim and Objectives

- Aim:
  - To design a flexible house using a life cycle approach.
- Objectives:
  - To define the main features of Flexible Housing;
  - To apply Building Information Modeling (BIM) as a tool for integrated design;
  - To provide a building information model to be used during building's life cycle;
  - To calculate life cycle cost (LCC) of the design;
  - To compare the proposed flexible design with the counterfactual non-flexible design in terms of economic benefit.

1.4. Research Rationale

During recent decades Auckland has experienced a housing affordability crisis (Auckland Council, 2018). According to Auckland Plan 2050, the city has one of the least affordable housing markets in the world (Auckland Council, 2018). Furthermore, as Auckland's population is aging, the available housing supply does not sufficiently address the demands of older occupants (Auckland Council, 2018). The city's future plan is that the housing supply system needs to change so as to design and build affordable houses for everyone. It is also important to prepare accessible housing for older citizens and people with disabilities (Auckland Council, 2018). Flexible Housing, as a type of residential architecture which considers different factors such as flexibility, adaptability, affordability, and accessibility, could be one solution for Auckland in coming years.

Applying BIM in designing a flexible house might make considerable improvement in design and address the aforementioned issues in flexible housing. The first benefit is that life cycle cost of the building can be calculated more easily and accurately, and information based on an economic analysis of design could facilitate the decision-making process for architects and owners. This can be done precisely, as BIM can consider the diverse aspects of a project through a database that is shared across all the stakeholders of a building project (Krygiel & Nies, 2008). So a second benefit of using BIM is the provision of a complete database of the building that can be used to show the proposed design features of the house for addressing possible changes.

1.5. Research Methodology

In this research, mixed qualitative and quantitative methods were applied, specifically a literature review, contextual and precedent studies, 'research by design', and financial analysis.

1.5.1. Research by Design

According to Roggema (2017), "any kind of inquiry in which design is a substantial part of the research process is referred to as research by design" (p. 3). In fields like architecture, where design is a fundamental aspect, this type of academic investigation can be applied as both method and outcome (Roggema, 2017).

	Methods	***Outcomes***
Theoretical Framework	*Literature review*	▪ *Design criteria, strategies and standards* ▪ *Life cycle approach* ▪ *BIM-based method*
Contextual Studies	*Using the statistical data*	▪ *Building programme*
	Using urban upstream plans, design and building codes	
	Site analysis	
Design	Adopting design criteria, strategies and standards	▪ Building Information Model (BIM) of a flexible house
	BIM-based method	
Economic Analysis	Life cycle costing (LCC)	▪ Life cycle cost of design

Table 1 Methods of data collection and analysis

1.5.2. Methods of Data Collection and Analysis

This research had four phases. First, the theoretical framework of research was shaped and most important references on flexible housing and life cycle assessment were reviewed. This stage's outcome was the design criteria. In the next phase, based on the contextual studies, the building's programme was formed. As this is a research by design project, the outcomes of previous stages were used in the design process. Finally, for responding to the research question, the proposed design was analysed economically.

1.6. Research Outline

Designing a flexible house through a life cycle approach is the aim of this research. This process is done in the shape of a detached house in Auckland. In order to do so, first, a site was identified that was suitable for this research's purpose. Next, with the help of scenario planning, the various stages of a typical family lifetime were defined. For this purpose three types of families in different stages of their lifetime were assumed: a couple with a new born baby or expecting one; a couple with two or three children in different ages (infants and teenagers); a retired couple whose children do not live with them anymore. Then, different scenarios about these types of families' needs and lifestyles were defined and ultimately formed the required brief and programme of the house. Finally, for answering the research question, the proposed flexible design needed to be compared with the counterfactual in terms of financial benefits. As mentioned earlier, flexible design consisted of three stages, so the design of the second stage was chosen as the counterfactual non-flexible design for economic comparison.

Literature Review

Chapter Two

Two groups of studies are related to the proposed topic:

The first of these are studies that deal with the notion of flexibility and adaptability in the residential design process. Three key references in this group are: *Flexible Housing* by Schneider and Till (2007), which defines flexibility in the residential design process and provides a comprehensive review of flexible housing projects since the 1900s; *The adaptable house: Designing homes for change* (Friedman, 2002), and *The Grow Home* (Friedman, 2014). The latter books are by one of the leading figures in this field, Avi Friedman and mostly focus on adaptable residential design concepts and strategies.

The second group of studies related to this research are about the life cycle approach to building generally and its design methods and tools in particular. König and Schoof's study, *A life cycle approach to buildings: Principles, calculations, design tools* (2010), is the most complete reference in this field. The *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors* (2018) and *Implementing Virtual Design and Construction Using BIM: Current and Future Practices* (2016) are also important references in the field of BIM and were relied on in the present research.

2.1. Flexible Housing

In this research, the concept of flexible housing is used as the overlap of all architectural responses (i.e. 'Lifetime Homes' in the United Kingdom (UK) and 'Grow Home' in Canada) to the problem of the changing needs of occupants. Design adjustments might be made in response to changes in family structure, lifestyle or outdated facilities, and could have a wide range from sliding doors and foldable furniture to moving internal partitions or external walls (Friedman, 2014).

As Schneider and Till (2007) point out, "flexible housing is housing that can respond to the volatility of dwelling" (p. 5). It uses flexibility or adaptability, or both, to achieve this aim. Flexibility is met through changing the physical structure of the building, while adaptability is the ability of the design to cover different types of needs within the original design. That is, flexibility considers issues of form and technique, while adaptability includes issues of use (Schneider & Till, 2007).

2.1.1. Definition

According to Schneider and Till (2007), flexible housing is "housing that can adjust to changing needs and patterns, both social and technological" (p. 4). These changing needs might be personal, like family growth, practical, such as the aging of the residents, or technological, like updating old services. Changing patterns could be demographic, economic or environmental (Schneider & Till, 2007). As Schneider and Till indicate with this deliberately broad definition, flexible housing serves its users in different ways and plays its role over the whole life of a dwelling. Prior to occupation, it enables future residents to make changes and also it allows them to design their home to their preferences and make alterations to it post-occupation (2007).

2.1.2. History

Throughout history, architects have tried to achieve flexibility and adaptability in their designs in a variety of ways and for various reasons. According to Cellucci and Di Sivo (2015), four main trends arising out specific demands that can be recognised are: “spatial flexibility in a fixed surface area; evolutionary spatial flexibility; technological flexibility related to construction techniques; technological flexibility related to the easy maintenance of the installations and building sub-systems” (p. 847). Schneider and Till (2007) note that three episodes in the development of flexible housing can be seen during 20th century.

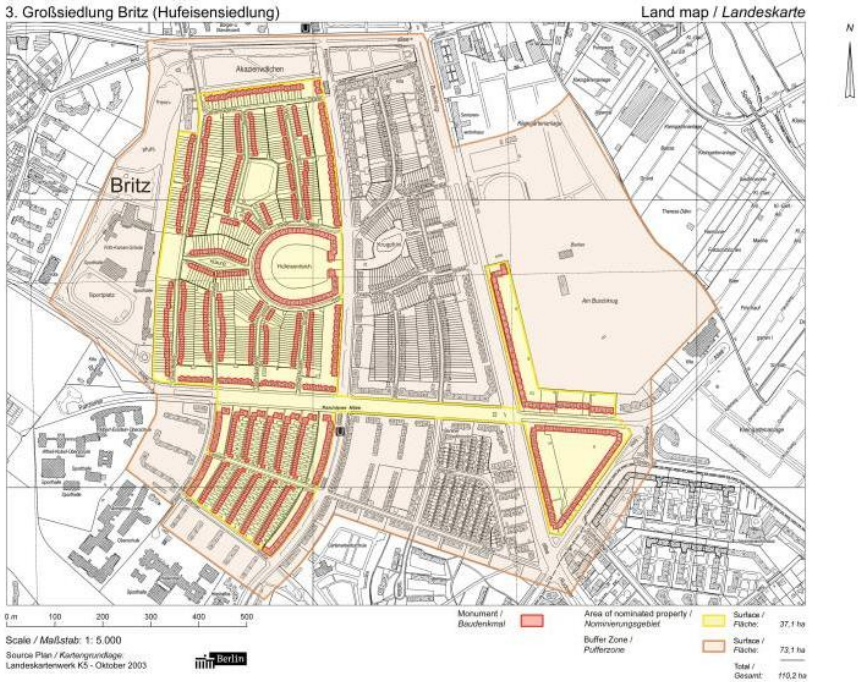


Figure 2 Hufeisensiedlung, Berlin, Bruno Taut, 1925

Figure 1 Hufeisensiedlung, Berlin, Bruno Taut, 1925

The first episode, in the 1920s, resulted from increasing demand for European social housing programs to build mass housing. That demand led architects to suggest new ideas to increase flexible usage of their designs regarding the new reduced spatial standards.

The second episode, from the 1930s and 1940s and continuing to the present, resulted from an idea that flexibility could be a key factor in new industrialised construction systems and prefabricated buildings. The third episode, in the 1960s and 1970s, arose out a movement towards engaging occupants in the design process, which caused a new consideration of flexible housing as an approach which provides user choice. It is interesting that all above demands are still available in the housing industry in many countries, so flexible housing is still an architectural response to those issues and a viable solution for contemporary housing problems (Schneider & Till, 2007).

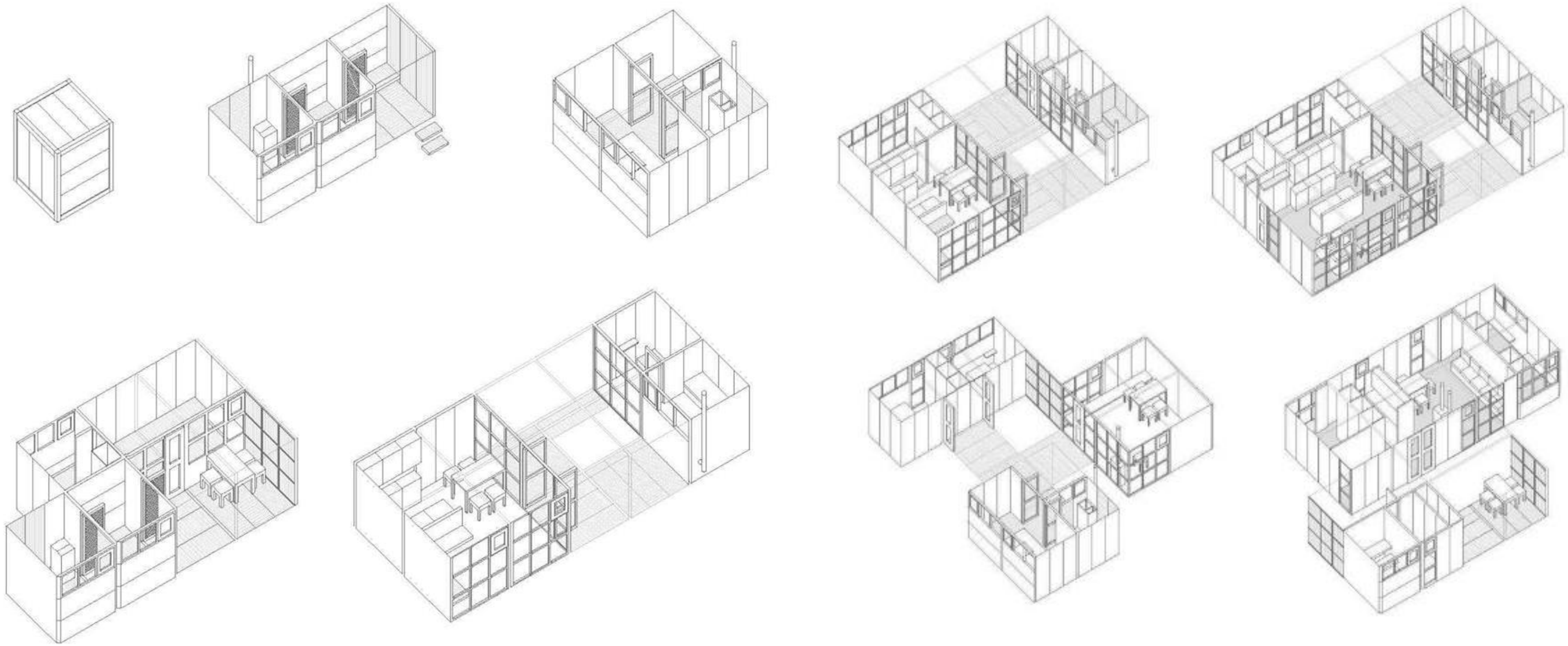


Figure 3 Moduli 225, Finland, Kristian Gullichsen and Juhani Pallasmaa, 1969-1971 (reference: Home Delivery)

2.1.3. Strategies

Schneider and Till (2007) categorize the various strategies in flexible housing based on being 'soft' or 'hard'. "Soft refers to tactics which allow a certain indeterminacy, whereas hard refers to elements that more specifically determine the way that the design may be used" (p. 7). So designing flexible housing depends on where we are on the soft/hard spectrum, it is important to be aware of the tension between indeterminate and determinate approaches (Schneider & Till, 2007). The present research tended to softer end of this spectrum as it is not the responsibility of architects to "control how a house is to be occupied, but rather to provide breathing space for change and adaptability" (Brennan, 2012, p. 2).

Friedman (2002) identified four main areas of action to achieve flexibility and adaptability in a house: "manipulation of volumes; spatial arrangement; growth and division; manipulation of subcomponents" (p. 16). To achieve flexible housing, an indeterminate approach is needed to design, deciding in which areas and through which strategies action is needed. Across all design strategies and tactics to achieve flexible housing, three were selected for the present research design:

1. **Slack Space** is not just any space. This is space designed by the architect, but its function is not finally determined. "Flat roofs that can be built upon and courtyards that can be filled in" (Schneider & Till, 2007, p. 136) are good examples of external slack spaces and internally it is found on for example a balcony that can be turned into an additional room.

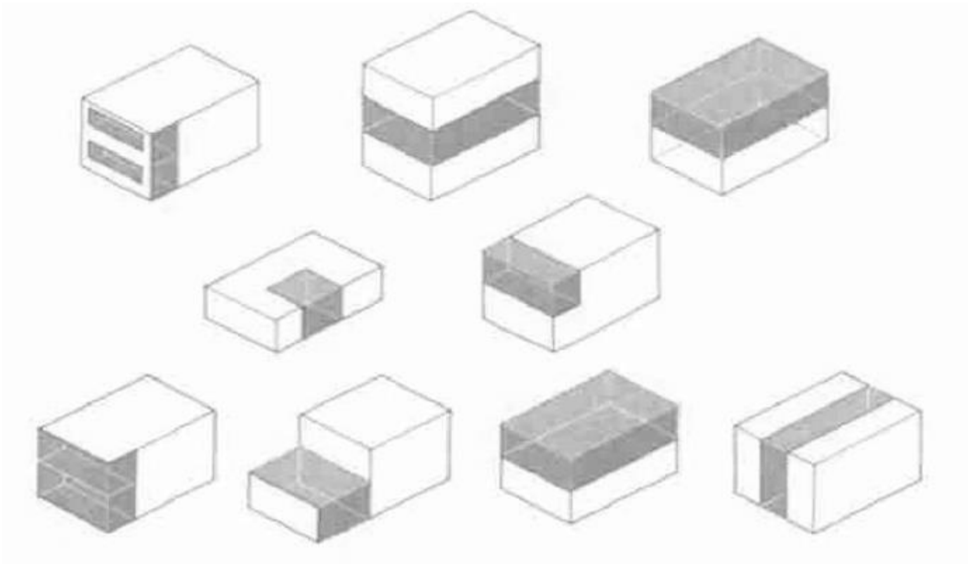


Figure 4 Slack Space (Schneider & Till, 2007, p. 185)

2. **Adding-on** is a method that enables people to become homeowners with a smaller initial investment and to expand their house at a later date as the need arises for extra space (Friedman, 2014). As Schneider and Till (2007) state "whether soft or hard, the ability to extend is a key part of flexible housing design" (p. 139).

3. **Dividing up** is another technique to adding flexibility to design. Although any dwelling can in principle be split up, it is more economic to do this task appropriately.

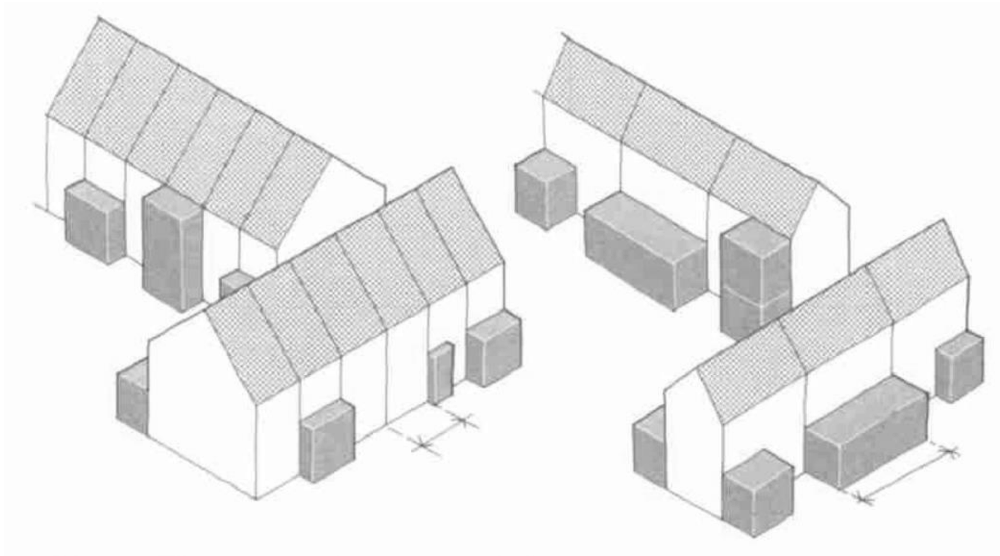


Figure 5 Horizontal additions (Schneider & Till, 2007, p. 183)

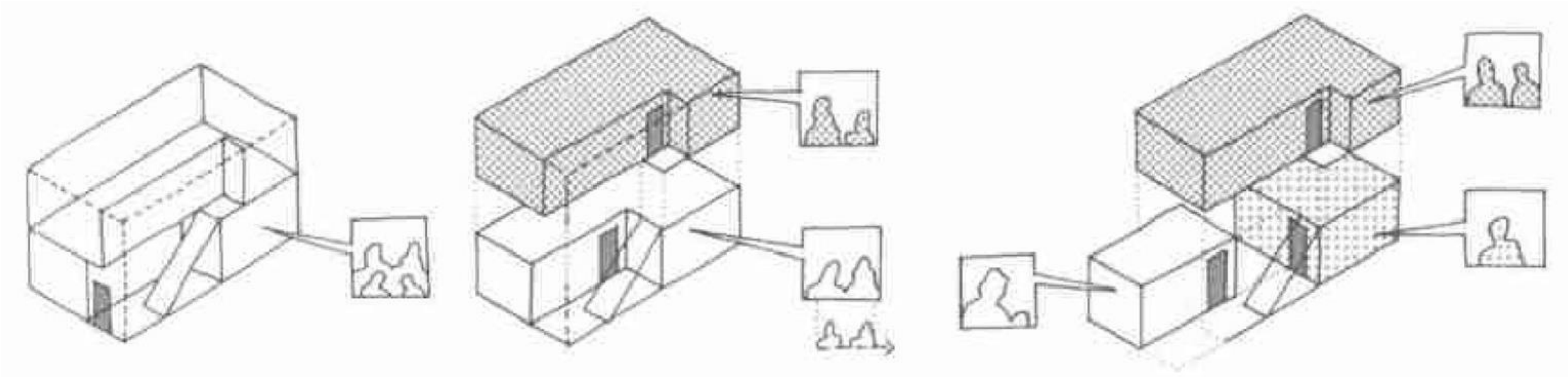


Figure 6 Joining and dividing (Schneider & Till, 2007, p. 188)

2.1.4. *Benefits and Gaps*

According to the World Commission on the Environment and Development, "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs" (Krygiel & Nies, 2008, p. 10). In the context of sustainable housing, Jon Broome considers "flexibility as an inherent part of a sustainable system, a basic and fundamental premise to do with buildings having a long-term future, being capable of changing, and being capable of responding to changing aspirations and needs" (Schneider & Till, 2016, p. 49).

In the housing sector, applied technology in construction and facilities is going to become obsolete and periodic renovations are essential. To preempt this issue, designing buildings that allow for and facilitate required refurbishments is a useful solution and can extend the home's lifetime (Friedman, 2002).

The adoption of flexible housing clearly has many benefits, as it meets issues of finance (by being more economic in the long term), participation (by encouraging user involvement in the design process), technology (by utilizing and progressing in construction technology), and use (by accepting different usage over time) (Schneider & Till, 2005). However, some arguments remain about how economic and sustainable this type of housing is. Two main issues in considering flexible housing as an economic and sustainable solution which were studied in this research are financial analysis and documentation. As Schneider and Till (2005) report, economic analysis has not been well studied in this area due to the lack of essential quantitative data. Although all the qualitative research to date indicates that this type of dwelling is an economic and sustainable solution, there is little quantitative data to support this argument. The reason is that the real financial benefit of flexible housing will only be recognizable when life cycle costing is taken into account, rather than planning based largely on immediately available expenditure.

Moreover, according to Schneider and Till (2007), another common issue in flexible design is that without proper documentation of layout and features, a flexible design would be a waste of money. Documentation can be accessible and easy to use for non-experts, especially the building's end-users, so all parties are aware of the features accommodated in the building's design (2007). This documentation is common for non-residential projects but it usually is not available for small-scale residential buildings.

2.2. Life Cycle Assessment (LCA)

Studying buildings over their whole lifetime to evaluate the real costs and benefits is a new approach in architecture. According to König and Schoof (2010), Life Cycle Assessment (LCA) depicts "a systematic analysis of the resources drawn from nature and the environmental effects of a product over its entire life cycle" (p. 13). Four main life cycle phases can be determined:

1. **New build,** which starts when the client decides to begin the project and finishes with handover of the building;
2. **Usage,** which comprises use, operation and maintenance;
3. **Refurbishment,** which involves partial or complete renewal and might be repeated several times;
4. **Deconstruction,** which starts when the owner decides to stop using the building, and covers the process of demolition and disposal (König & Schoof, 2010).

2.2.1. Scenario Planning

As it is almost impossible to anticipate the actual life of a property, in life cycle design it is common to employ 'scenario planning' as a tool to predict and model the jobs to be executed, like planned maintenance, renovation and change of use over building's life cycle (König & Schoof, 2010). It is the architect's responsibility to predict the future needs of occupants and to design based on those needs. The architect does this task through the "process of predicting and forecasting events in the life of a household and responding to them by creating potential scenarios that relate to particular solutions" (Friedman, 2002, p. 13). Two ways of scenario planning are:

- **Trend projection,** which imagines a regular succession of phases. The phases' length and the planned alterations for each phase have to be declared clearly in this method (König & Schoof, 2010);
- **Scenarios with options,** which is "a very promising approach to adopt with uncertainties in a building's life cycle" (König & Schoof, 2010, p. 16).

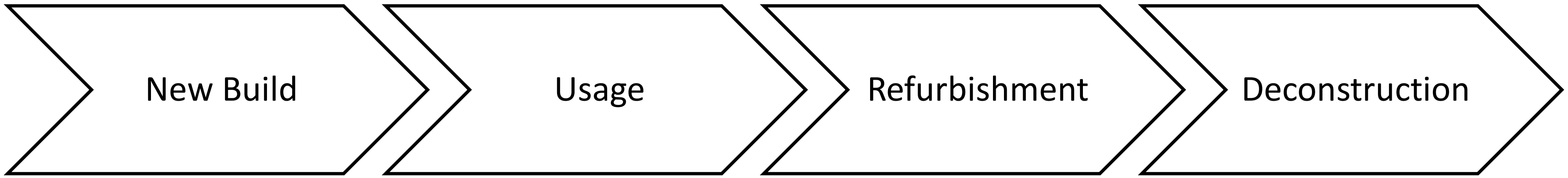


Figure 7 Life cycle phases

2.2.2. Life Cycle Cost (LCC)

As König and Schoof (2010) explain, "life cycle costs, or whole life costs or total cost of ownership, are considered to include all relevant costs linked with the acquisition or ownership of a good and are systemically recorded in the cost calculation" (p. 13). The term 'life cycle costing' (LCC) is applied to explain the systematic calculation and appraisal of a property's costs over its entire life cycle or a specified period of time. In life cycle costing in the wider sense (whole-life cost, WLC), in addition to life cycle costs (LCC) that include exclusively expenses (payments out), any income or revenue (payments in) are taken into account (König & Schoof, 2010). According to König and Schoof, whole-life cost "can be interpreted as a life cycle-oriented calculation of economic efficiency. Its outcome is also described as the life cycle result" (pp. 59–60)

The 'net present value' method, where all payments in and out are associated to their cash or present value at the time of the initial investment, is applied as the basis for assessing the life cycle cost of a building. Only investments with positive net present values or the alternative with the higher net present value are acceptable in this appraisal (König & Schoof, 2010).

<table>
<tr><td rowspan="39">Life cycle costs in the wider sense (whole-life cost, WLC)</td><td rowspan="26">Life cycle costs in the narrower sense (life cycle cost, LCC)</td><td rowspan="6">Building costs (construction)</td><td>Costs of design and technical consultancy services</td></tr>
<tr><td>Costs of plot</td></tr>
<tr><td>Construction costs</td></tr>
<tr><td>Costs of first modification or renovation</td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Miscellaneous costs</td></tr>
<tr><td rowspan="6">Operating costs</td><td>Rent</td></tr>
<tr><td>Insurance</td></tr>
<tr><td>Costs of external monitoring</td></tr>
<tr><td>Supply and disposal service (including fuel for heating, cooling, electricity, lighting, fresh water and waste water charges)</td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Miscellaneous costs</td></tr>
<tr><td rowspan="9">Cost of cleaning, care, and maintenance</td><td>Costs of care and maintenance management</td></tr>
<tr><td>Costs of modification or renovation during building operation</td></tr>
<tr><td>Costs of repair and refurbishment of minor components and parts of systems</td></tr>
<tr><td>Costs of renewal of systems replacement of major components</td></tr>
<tr><td>Costs of building cleaning</td></tr>
<tr><td>Costs of care and maintenance of external facilities</td></tr>
<tr><td>Costs of internal refurbishment, incl. redecoration, refit etc.</td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Miscellaneous costs</td></tr>
<tr><td rowspan="5">Costs at the end of the service life (end of life)</td><td>Costs of technical reports</td></tr>
<tr><td>Costs of demolition and disposal</td></tr>
<tr><td>Costs of reinstatement to the contractually agreed state</td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Miscellaneous costs</td></tr>
<tr><td rowspan="7">Other costs not directly attributable to the building (non-construction costs)</td><td colspan="2">Costs of the land and preparation of the plot</td></tr>
<tr><td colspan="2">Finance costs</td></tr>
<tr><td colspan="2">Costs of strategic property management</td></tr>
<tr><td colspan="2">Utility charges</td></tr>
<tr><td colspan="2">Administration costs</td></tr>
<tr><td colspan="2">Taxes</td></tr>
<tr><td colspan="2">Miscellaneous costs</td></tr>
<tr><td rowspan="5">Income and revenue (income)</td><td colspan="2">Income and revenue from sales</td></tr>
<tr><td colspan="2">Salaries of third parties during operation (rent)</td></tr>
<tr><td colspan="2">Taxes to be paid on income and revenue</td></tr>
<tr><td colspan="2">Interruptions in operation</td></tr>
<tr><td colspan="2">Other income and revenue</td></tr>
<tr><td colspan="3">Costs in conjunction with external effects (externalities)</td></tr>
</table>

Table 2 Whole life cost (reference: A life cycle approach to buildings: Principles, calculations, design tools)

2.2.3. *Integrated Design*

"Integrated design is a process in which the acquisition of knowledge and its optimization take place in alternate steps" (König & Schoof, 2010, p. 78). Applying integrated design tools that can manage costs and energy requirements, as well as the life cycle assessment of a development, enables the architect to link the various pieces of information and to prevent the flaws of individual mono-functional programs for cost estimating, energy requirement and life cycle assessment. In this process the building information model (BIM) performs as a shared interface and a digital tool that links the design process with cost information (König & Schoof, 2010).

2.2.3.1. Building Information Modelling (BIM)

Building Information Modelling (BIM) is an almost new approach in architecture, engineering and construction (AEC) industry. Since the beginning of 21st century BIM methodology has become an essential section of constructing new buildings (Briscoe, 2015). According to Krygiel and Nies, the BIM methodology targets a comprehensive vision of the project through a single-source model which includes almost everything (Krygiel & Nies, 2008). According to Garber (2014), "[T]his database – or information model – contains specific three-dimensional geometric information such as sizes, areas and volumes as well as: cost data, material and component quantities, zoning analysis, environmental performance and instructions for fabrication and construction" (p. 17). The BIM Industry Training Group (2016) notes that "[T]he building information model is not a single 3D object but an assembly of digital information. It is made up of three main parts: graphical model; non-graphical model; and documentation" (p. 15).

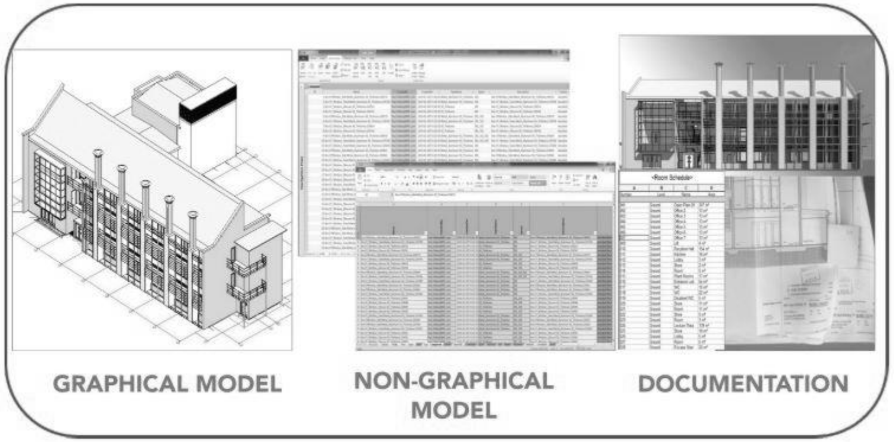


Figure 8 Three main components of a building information model (BIM Industry Training Group, 2016, p. 15)

2.2.3.1.1. BIM-based Design Process

BIM is a significant shift from the traditional way of design that has been applied by architects for years (Levy, 2011). As Garber (2014) notes, BIM as a new methodology has a great impact not only on buildings' construction, but also on their design process. Design is a knowledge-based activity and making informed decisions is better than making uninformed ones. Applying BIM in design process helps the architect to make better architectural decisions in the first place, as there are enough quantitative data to support the cost-benefit analysis of the design. According to Kensek & Noble (2014), "BIM affords the architect (and client) an opportunity to include life-cycle assessment as part of the design process" (p. 4).

Eastman, Teicholz, Sacks and Lee (2018) identify the benefits of applying BIM through design process as follows:

- Earlier and More Accurate Visualizations of a Design;
- Automatic Low-Level Corrections When Changes Are Made to Design;
- Generation of Accurate and Consistent 2D Drawings at Any Stage of the Design;
- Earlier Collaboration of Multiple Design Disciplines;
- Easy Verification of Consistency to the Design Intent;
- Extraction of Cost Estimates during the Design Stage;
- Improvement of Energy Efficiency and Sustainability.

As mentioned in the introduction in this research, what is being sought is using the potential of BIM in terms of cost estimation and documentation.

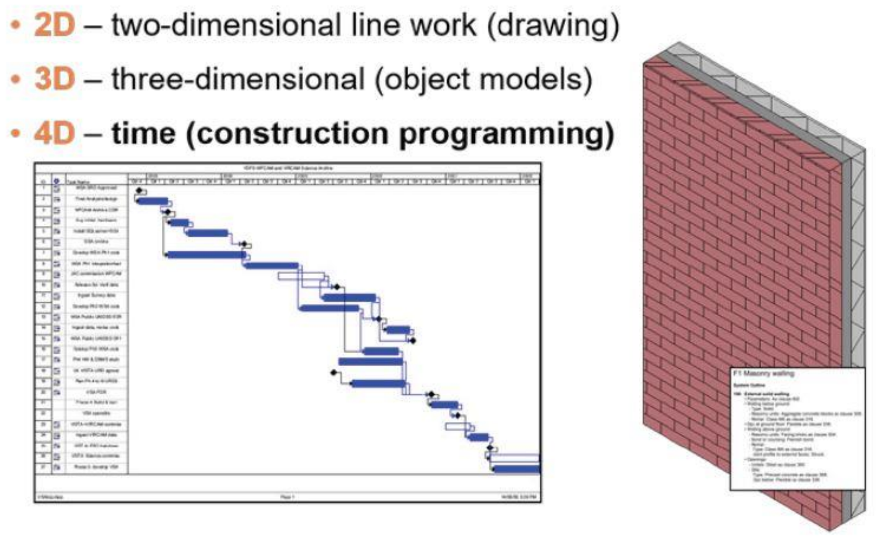


Figure 9 BIM dimensions (BIM Industry Training Group, 2016, p. 22)

2.2.3.1.1.1. *Cost Estimation*

An information model of building produces quantities that can be connected to a cost database so a cost estimate is calculable. This method of cost calculation is totally different from usual estimation methods, which mostly contain manually counting elements and areas from incomplete drawings (Andersson, Farrell, Moshkovich & Cranbourne, 2016). A 4-D model is created by adding time to a 3-D model. 4-D scheduling tools link scheduling activities with the information model to visualize the progress of project. If the cost information derived from the information model is connected to a 4-D schedule, expenses can be traced during building life cycle and the result is a 5-D model (Andersson, et al., 2016).

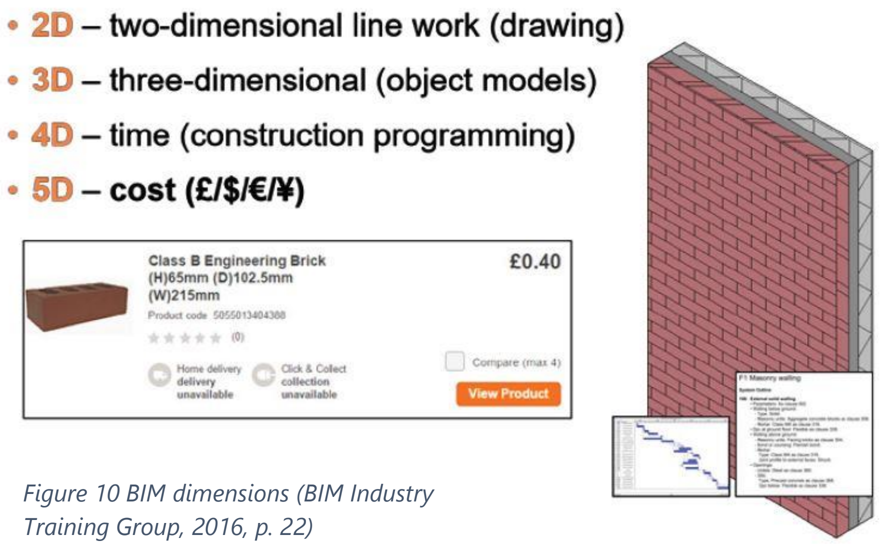


Figure 10 BIM dimensions (BIM Industry Training Group, 2016, p. 22)

2.2.3.1.1.2. *Documentation*

Documentation is possibly the best known benefit of BIM. In the traditional way of handover the design, all required documentation and information is delivered in physical format (printed documents) or digital format (Pdf files). In contrast, the information model of building as a spatial database "is the perfect vehicle for hosting and transferring critical data needed for operations into operations software" (Andersson, et al., 2016, pp. 33–34). Moreover the visualization of the information model enables everybody involved in the project, especially non-experts who may not be familiar with 2-D documentation and specifications such as the end-user of the building, to understand the design and different parts of the project. As Kensek and Noble (2014) comment, building information models can assist in properties' management, maintenance and operation particularly along with mobile technologies like an augmented reality platform.

Modeling (authoring) software programs such as Autodesk Revit, Vectorworks, Tekla BIM, ArchiCAD, Catia and Microstation BIM are applied to model geometry and much of the associated data. There are certain software for applying a range of specialized tools including quantity takeoffs, scheduling, energy analysis and visualization to the model built in the authoring software as well. Rhino Grasshopper, Autodesk Navisworks and 360, Synchro, 3-D Max, Innovaya, and VEO are examples of this kind of software (Andersson, et al., 2016).

2.3. Summary of Literature Review

The literature reviewed for this research included two types. Flexible housing is now well known as an architectural solution which answers existing concerns about the changing needs of occupants. Different aspects of this type of housing were studied to form an overall view of it and the project's design criteria. To address the current gaps in the field of flexible housing, it was necessary to choose a different approach. Accordingly, the second part of the literature review examined the life cycle approach to buildings in general and its suggested processes and methods for design in particular.

Precedent Studies

Chapter Three

3.1. Projects

Precedent studies reviewed here were chosen based on the strategies they applied to achieve flexibility in their design. Several tactics exist for flexible housing in terms of design and construction. Slack space, adding-on and dividing up are chosen strategies for review here.

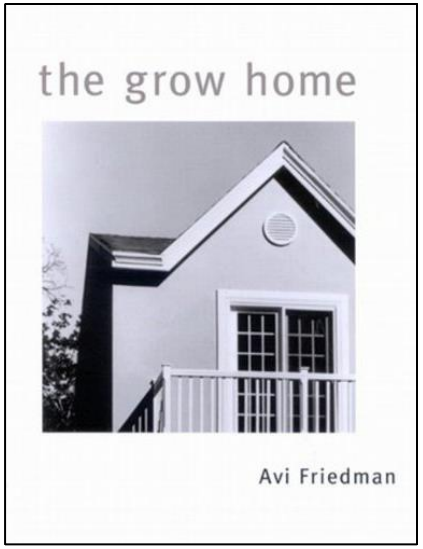


Figure 11 Book cover

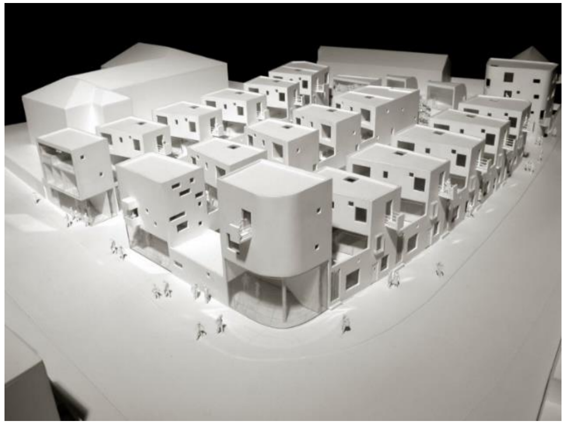


Figure 14 Donnybrook Quarter model

Figure 15 Street view of CMHC FlexHouse

Figure 12 Street view of WholeLife House

Figure 17 Next Home project, Avi Friedman, Canada, 1996

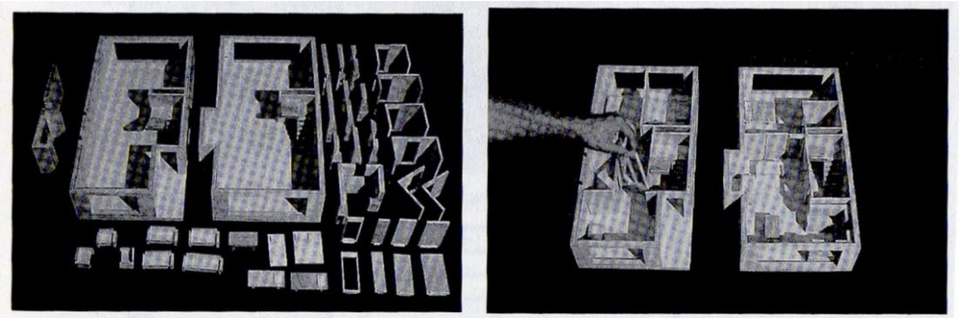


Figure 16 Next Home design offers the occupants the possibility of choosing their required components.

Next Home

Year: 1996

Country: Canada

Architect: Avi Friedman

As Schneider and Till (2007) point out "the Next Home in particular is a manifestation of an approach that enables greater choice for the occupants during the buying process as well as throughout the building's lifetime" (p. 112). The design has the potential to be constructed as a detached, semi-detached or row house. As a three-storey building, the house can be inhabited by one family or by three different families. To convert the building from a multi-storey house to up to three separate units is possible due to the position of the vertical circulation core, and the easy removability of the joists between levels allow the separation of those as well as the installation of internal stairs (Schneider & Till, 2007).

Design strategies:

- Flexible housing: dividing up;
- Building in narrow lots;
- Pre- and post-occupancy adaptability.

Donnybrook Quarter

Year: 2006

Country: England

Architect: Peter Barber Architects

Donnybrook is a low-rise, high-density street-based city quarter in East London. The architect, Peter Barber, who suggested the term 'slack space', designed the project like an accident waiting to happen. In this development, large courtyard spaces on the first floor that act as slack space are unprogrammed and invite the occupants to adjust them according to their evolving needs. Only when the occupants respond to the invitation and customise those spaces will the design accomplish a richness of occupation that was always intended (Schneider & Till, 2007).

Design strategies:

- Flexible housing: slack space

Figure 18 Aerial view of Donnybrook Quarter

Figure 19 Court yards as slack spaces

Figure 20 Street view of Donnybrook Quarter

WholeLife House

Year: 2010

Country: Scotland

Architect: John Brennan

In this project, the architect used the concept of Soft Flexibility to design a demonstration building for Scotland's Housing Expo 2010. The WholeLife House - an award winning project at the Scottish Housing Awards 2011 - "looks beyond technological understandings of environmental design towards addressing social and economic sustainability through adaptation strategies over its life" (Brennan, 2012, p. 1). The house is formed from two parts - a main building, and an annex block. The main building consists of a living area, kitchen and some bedrooms, while the functions of the annex are deliberately not specifically determined. The annex can be used, for instance, as extra bedrooms for a large family, a home office, or a separate unit for a young adult or elderly relative (Brennan, 2012).

Design strategies:

- Flexible housing: indeterminacy

Figure 22 3d model of WholeLife House

Figure 21 WholeLife House target types of families (right)

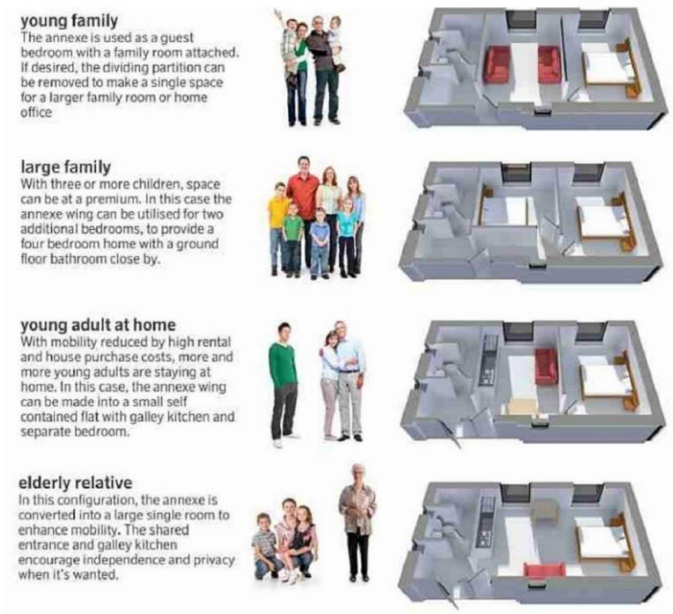


Figure 23 Street view of WholeLife House

CMHC FlexHouse

Year: 2016

Country: Canada

Architect: Ron Wickman

This building is an award-winning project based on the concept of FlexHousing. As Wickman (2017) states, "design had to produce housing that could be easily adapted to meet the present and future needs of the occupants". In this project, the architect tried to design a single detached house that was adaptable, accessible and affordable, to address the present and future needs of occupants. The design uses its land in an efficient and effective way, as the building has been located on a small lot. At the beginning, the building is small, but when it is necessary it can grow and even be subdivided or some additional spaces can be added to it. Varying types of families can be accommodated in the building. The design also has this potential to accommodate young couples with children, single parents, seniors, and persons with disabilities. It is designed to house a nuclear family, an extended family or two separate families (Wickman, 2017).

Design strategies:

- Flexible housing: adding-on

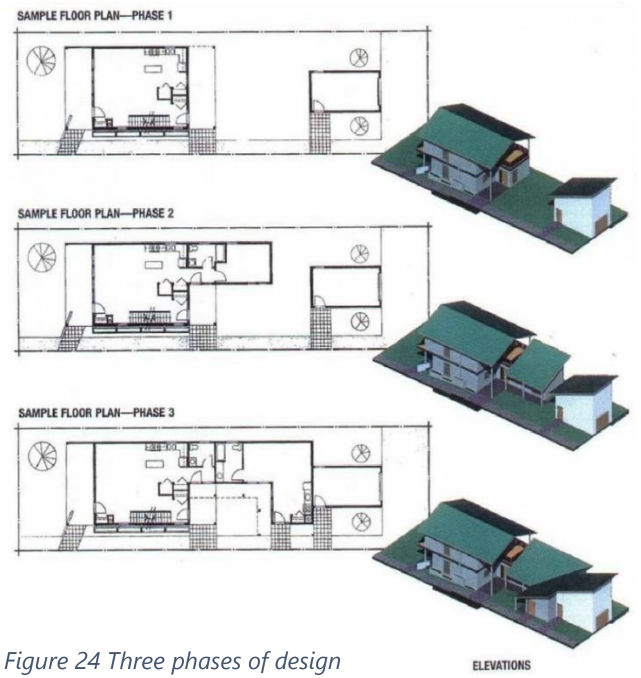


Figure 24 Three phases of design

Figure 25 Street view of CMHC FlexHouse

3.2. Summary of Precedent Studies

Through studying several projects around the world (though only four of them are described in this chapter), the main purpose was to figure out how flexible housing concepts and strategies have been implemented in diverse contexts. The selected projects had employed the flexible housing principles chosen for the present research, that is, slack space, adding-on and dividing up, and each one had proposed its understanding of flexible housing in a unique way.

Design Process

Chapter Four

4.1. Site

The selected site for this project is in Hobsonville Point, where has been developed on the site of a former Air Force base. This northwest Auckland township was planned to accommodate 4,500 homes and 11,000 residents up to its completion in 2024.

Figure 27 Hobsonville Point was the site for sea and land based aviation (1924).

Figure 26 Site location (Base map, Auckland Council GeoMaps, 2019)

There are several military properties, such as officers' houses in Sunderland and Cochrane Avenues, Mill house and Sunderland hangar that as heritage buildings enhance the identity of the neighborhood.

Figure 29 Mill House

Figure 30 Sunderland Hangar

Figure 28 Sunderland and Cochrane Avenues

Hobsonville Point, as a master-planned development, has been divided into precincts. Each precinct is also planned and designed in detail. The resulting document is called a ‘Comprehensive Development Plan’. The lot chosen for the present research is located in the Sunderland neighborhood and this north-facing precinct’s CDP was the main reference for site information and design regulations (Table 3 and Table 4).

Figure 31 Sunderland precinct in Hobsonville Point development

Figure 32 Illustrative precinct masterplan

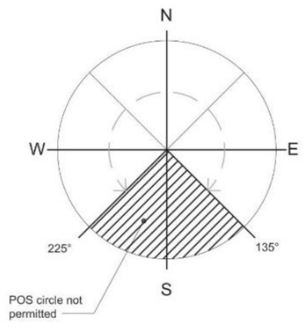
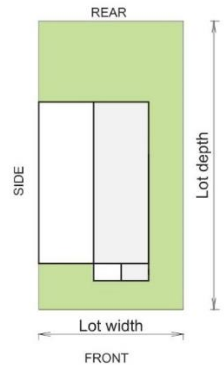
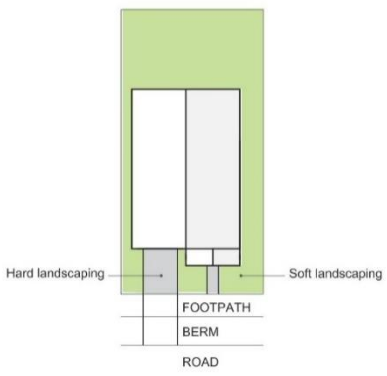
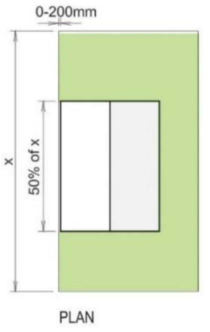
Location of private outdoor space	Lot boundaries	Front yard landscaping	Zero lot
			

Table 3 Definitions

Building typology	Detached housing	Zero lot condition
Maximum height	Wall height (external): 7.5 m	
	Overall height: 10.5 m	
Site coverage	Building: 55% max	
	Impermeable: 80% max	
Building separation	Primary outlook: 6 m min	
	Secondary outlook: 3 m min	
	No outlook: 0 m min	
Private outdoor space (POS)	3B: 50sqm	

Table 4 Land use and activities condition

The selected lot, with northeast-southwest orientation and a 150sqm area, is located on Neville Road, Sunderland. Figure 35 shows the passage of the sun over the site. For the most use of sun light the building was located on southwestern part of the lot.

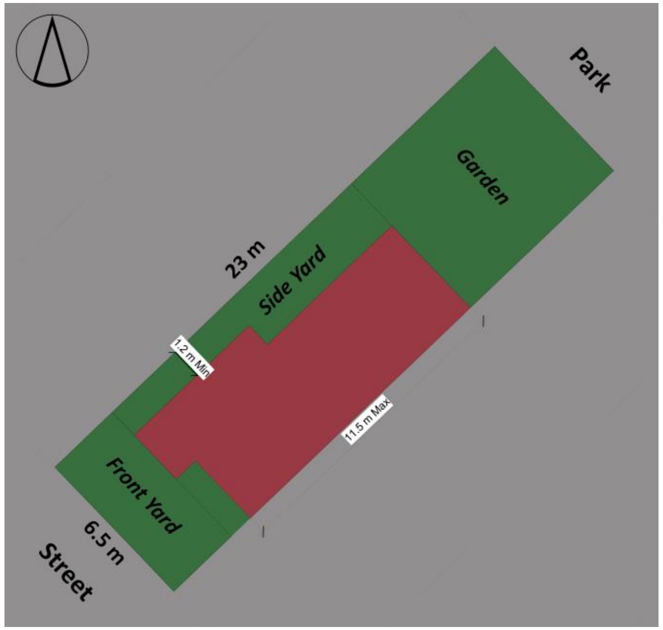


Figure 33 Massing plan

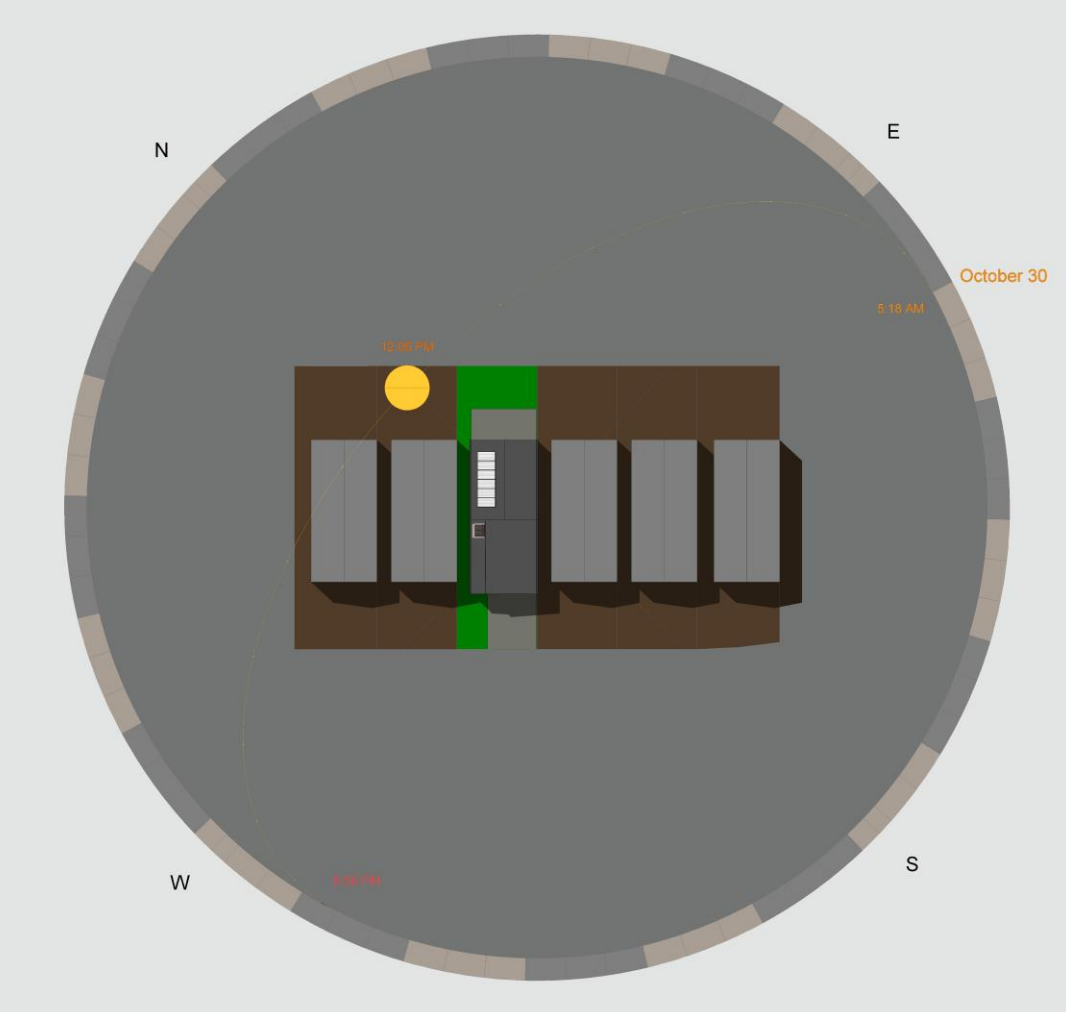


Figure 35 Sun path diagram

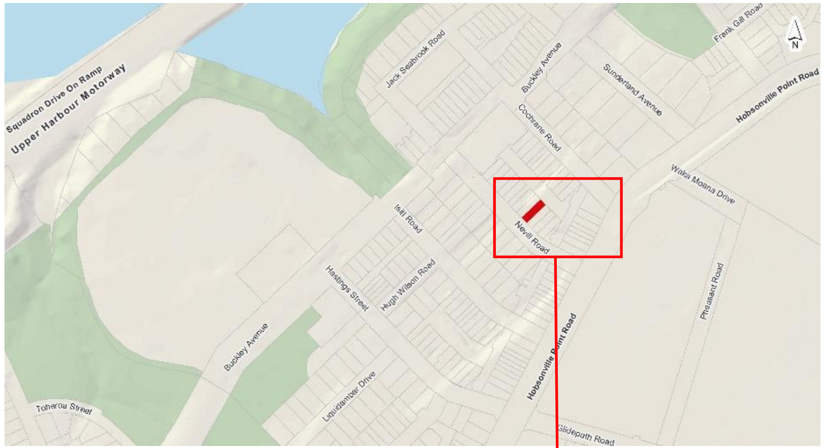


Figure 34 Location of site in Sunderland precinct

Figure 36 Selected lot on Neville Road (Lot 91)

Figure 37 indicates different types of houses that have been built in this area. The current built dwelling on the selected lot belongs to a group of houses that are called 'Park Terraces', as their back sides face a linear park. This attached, two-storey scheme (Figure 38) with 158sqm total floor area has occupied nearly all of the permitted site coverage and has not provided any breathing space for future growth.

Figure 39 Street view of lot 91 from Neville Road

Figure 40 Street view of lot 91 from park

Figure 38 Layout of current building on the chosen lot

Figure 37 Sunderland houses

4.2. Programme

To reach a suitable programme for a flexible house and based on the life cycle approach, first, with the help of a scenario planning method called ‘trend projection’, the building lifetime was divided into three 15-year stages. Then, an imaginary family was defined as the flexible house user and predictions made of those occupants’ evolving needs during each life stage. In the first stage, the family consists of a young couple with one child. They need a two-bedroom house with at least 70sqm total floor area. In the next stage, the family expands to the form of parents with two or three children (infants to teenagers), so the family needs at least three bedrooms with a minimum total floor area of 90sqm. Ultimately, at the third stage, the family contracts to a retired couple whose children no longer live with them. In this stage they prefer to live on the ground floor and a 50sqm one-bedroom unit is enough.

Based on this scenario, two sequences of alterations in the house’s design were predicted. First, the layout needs to be expanded to address the family’s changing conditions and demands. Thus, the two-storey building is divided into two separate units. The types of space required and the minimum size of each space (Table 5) were drawn from *R6: Unit Layouts & Room Sizes* which is part of *Residential Design Element* - “a non-statutory guide created to assist developers, designers and planners achieve policy outcomes under the Auckland Unitary Plan (AUP)” (Auckland Council, 2018, p. 1) - and Sunderland houses’ layouts. The following table represents the proposed programme for this project. According to Friedman (2014), efficient planning of the layout results in less construction and energy costs in the design of the Grow Home, where “the design objective was to provide a smaller house with the maximum usable floor area so as not to disrupt the occupants' living comfort” (p. 149). Thus, in the present research, the size of the unit was planned at the minimum standard.

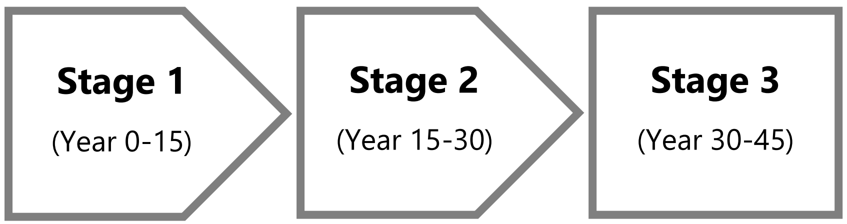


Figure 41 Three stages of the programme

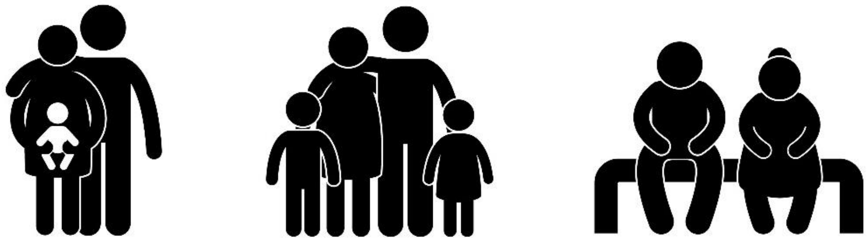


Figure 42 Family evolution

Stage one		Stage two		Stage three			
Space	*Min Size*	*Space*	*Min Size*	*Space*	*Min Size*	*Unit 1*	*Unit 2*
Bedroom 1	9.00	Bedroom 1	9.00	Bedroom 1	9.00	✓	✓
Bedroom 2	9.00	Bedroom 2	9.00	Bathroom	3.00	✓	✓
Bathroom	3.00	Bedroom 3	9.00	Car pad		✓	-
Car pad		Bathroom	3.00	Entry	0.36	✓	✓
Entry	0.36	Car pad		Garden		✓	-
Garden		Entry	0.36	Hot water cylinder		✓	✓
Hot water cylinder		Ensuite	3.00	Kitchen + Dining	10.80	✓	✓
Kitchen + Dining	13.20	Garden		Laundry	0.84	✓	✓
Laundry	1.26	Hot water cylinder		Living	20.00	✓	✓
Living	24.00	Kitchen + Dining	16.20	Patio		✓	-
Patio		Laundry	1.26	Storage		✓	✓
Storage		Living	28.00	Stairwell		-	✓
Stairwell		Patio		Terrace	5.00	-	✓
Terrace	8.00	Storage		Wardrobe	1.00	✓	✓
Wardrobe	2.18	Stairwell					
		Terrace	8.00				
		Wardrobe	3.18				
Min Total Floor Area	70.00	Min Total Floor Area	90.00	Min Total Floor Area	50.00		

Table 5 Proposed programme

4.3. Flexible House

At the beginning of the design part of this research, the following subjects were considered as design concepts and principles.

- ***Detached building***

  To have private outdoor space and a dwelling open on all faces where the passage of the sun can be felt throughout, so that detached is still the dominant ideal form of living (Pfeifer & Brauneck, 2015). According to the Auckland Design Manual, this type of dwelling is very common in Auckland and "avoids the potential complexity of having a wall on a neighbour's boundary" (Auckland Council, 2019).

- ***Flexible strategies:*** slack space/adding-on/dividing up

  As it can be seen in Figure 45, first, the flexible house is a 90sqm two storey unit with two bedrooms and some slack spaces, where the function is not exactly determined. Then, at stage two, with the help of those slack spaces, the house expands and transforms to a 123sqm two storey building with three bedroom, one extra bathroom and bigger kitchen and living room (Figure 46). Finally, at the third stage, the house divides up to two separate 50sqm units (Figure 51).

- ***Narrow lot***

  At just 6.5m wide, the chosen lot is quite narrow that was both restriction and opportunity for designer (Figure 33).

- ***Smaller house***

  As affording a home is a big challenge especially for first-time home buyers, any opportunity is valuable to reduce the initial investment by adopting cost-reduction strategies of flexible housing, like building a smaller unit which can be expanded over time.

- ***Private open space (POS)/ yards***

  Court yards provide some breathing spaces in the layout for expecting alterations in the future. For instance, the side yard plays an important role as slack space in the proposed flexible design (Figure 33).

4.3.1. Stage One

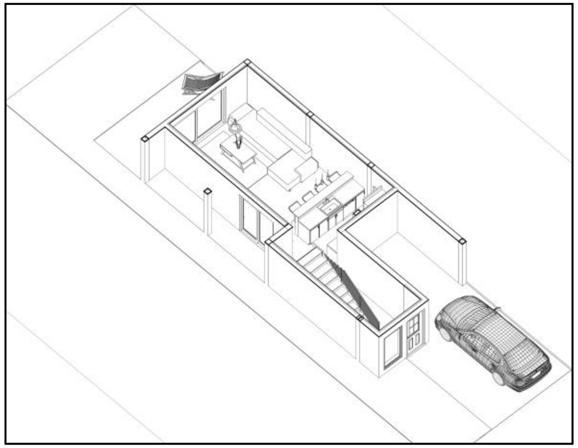


Figure 43 Ground floor 3D plan in stage one

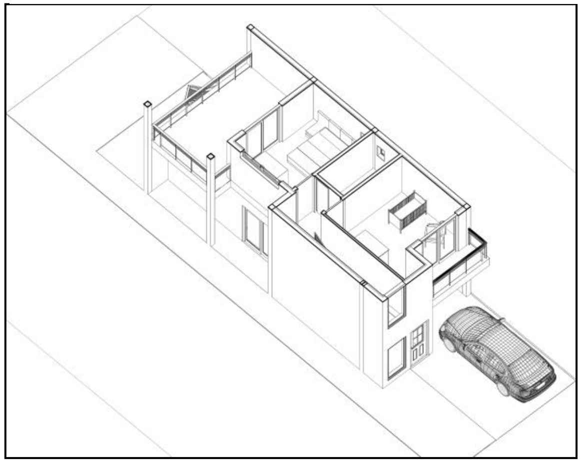


Figure 44 First floor 3D plan in stage one

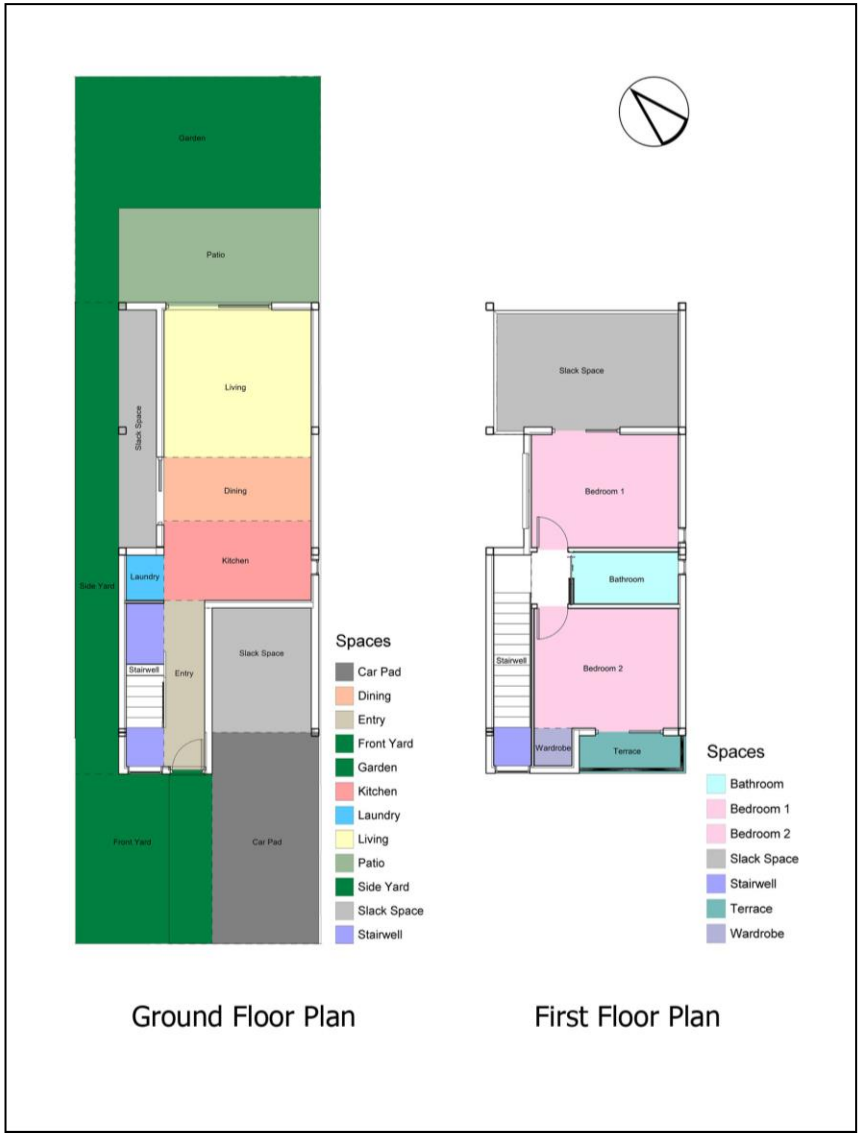


Figure 45 Distribution of spaces in the layout – stage one

4.3.2. Stage Two

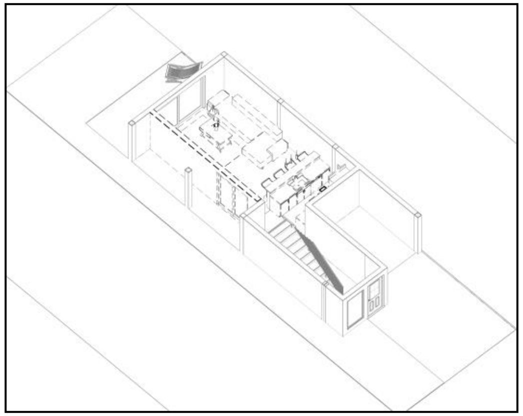


Figure 49 Ground floor 3D plan in stage two – dashed lines show demolished elements

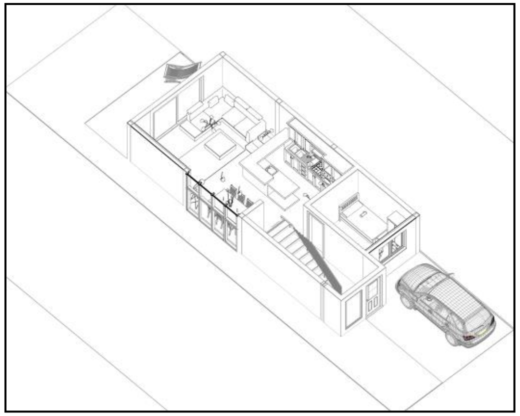


Figure 48 Ground floor 3D plan in stage two – bold lines show created elements

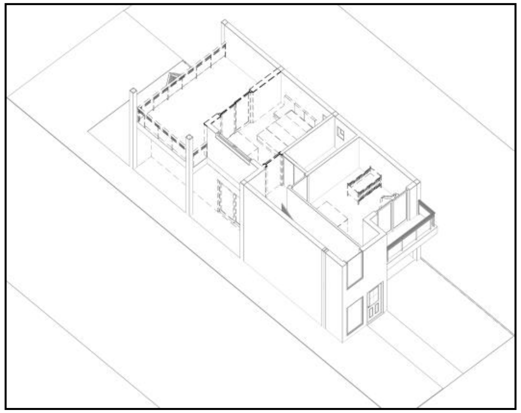


Figure 50 First floor 3D plan in stage two – dashed lines show demolished elements

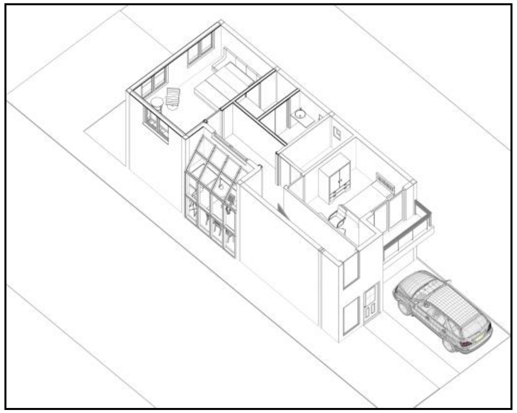


Figure 47 First floor 3D plan in stage two – bold lines show created elements

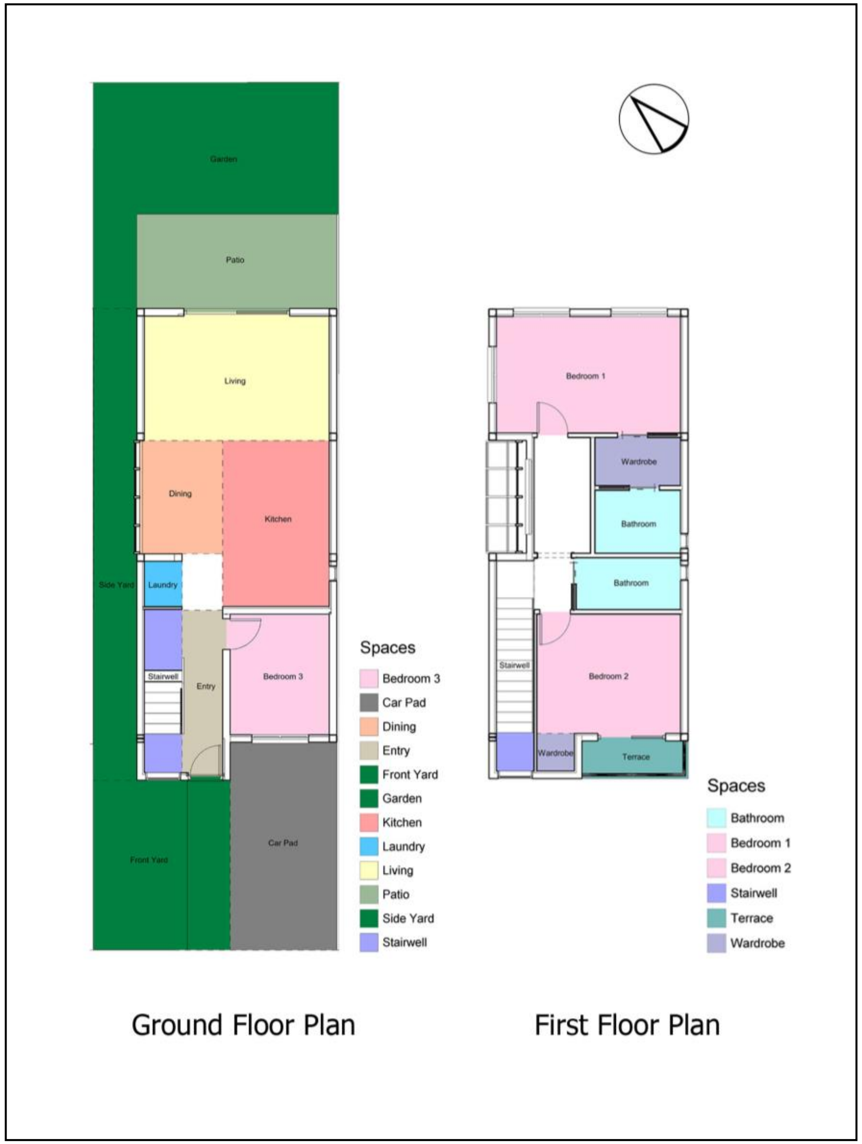


Figure 46 Distribution of spaces in the layout – stage two

4.3.3. Stage Three

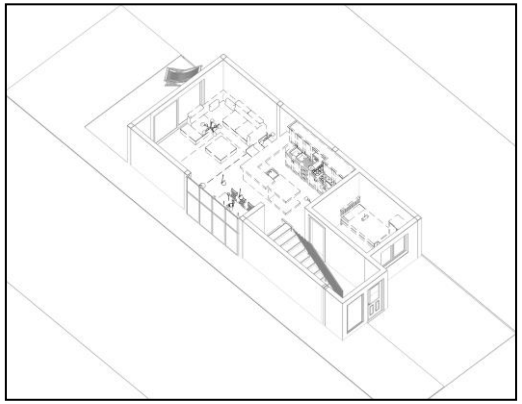


Figure 53 Ground floor 3D plan in stage three – dashed lines show demolished elements

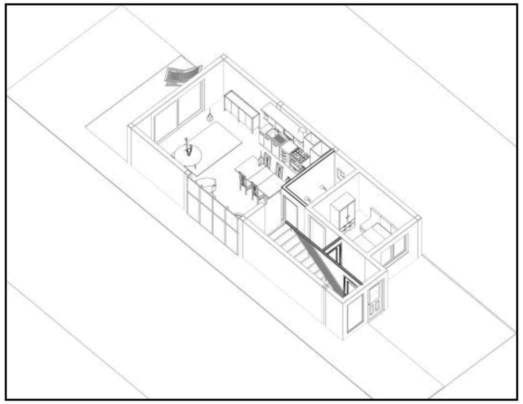


Figure 52 Ground floor 3D plan in stage two – bold lines show created elements

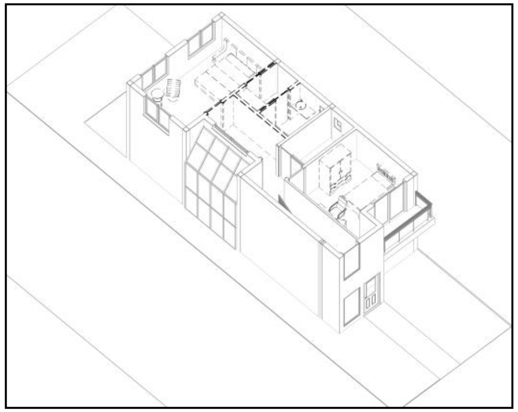


Figure 55 First floor 3D plan in stage three – dashed lines show demolished elements

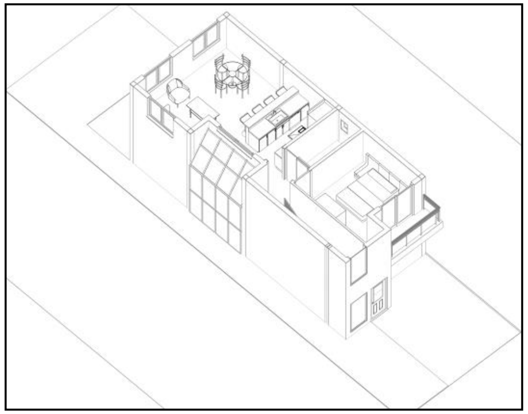


Figure 54 First floor 3D plan in stage two – bold lines show created elements

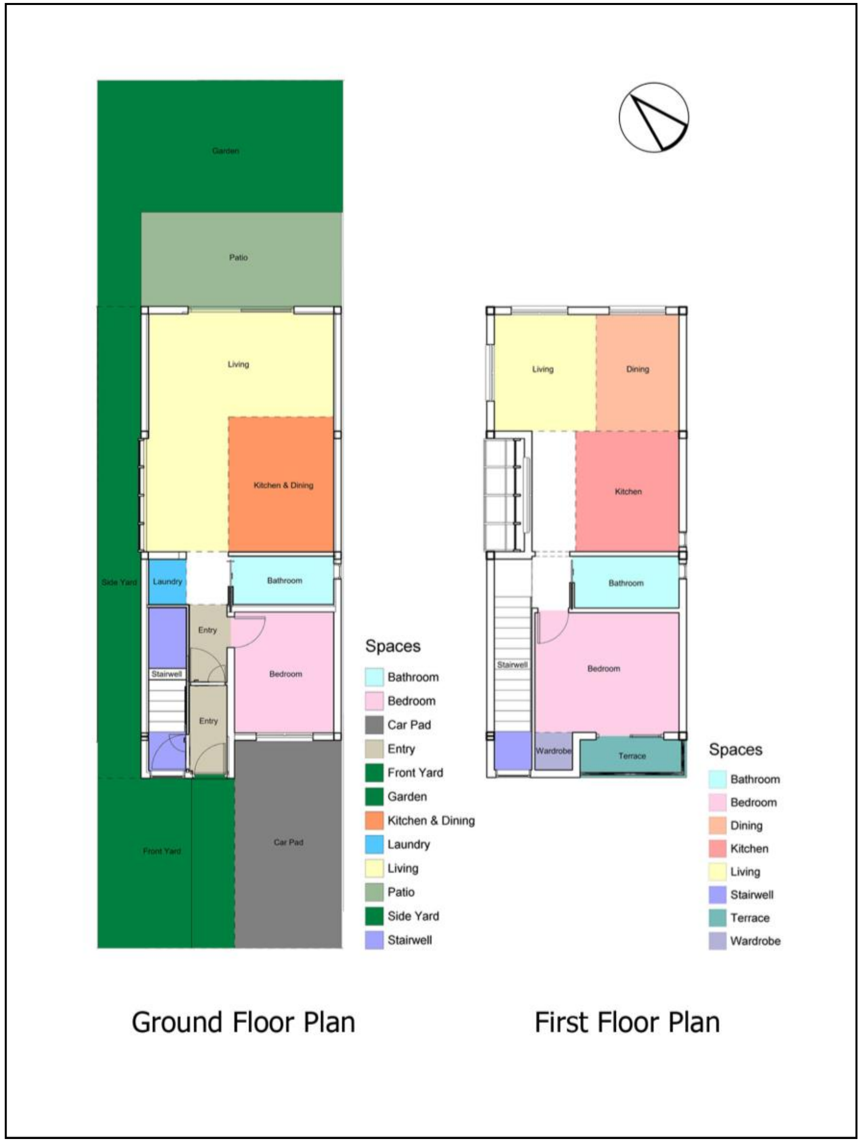


Figure 51 Distribution of spaces in the layout – stage three

4.4. Developed Design

Figure 56 Exterior 3D view – from Neville Road (stage one)

Figure 57 Exterior 3D view – from park (stage one)

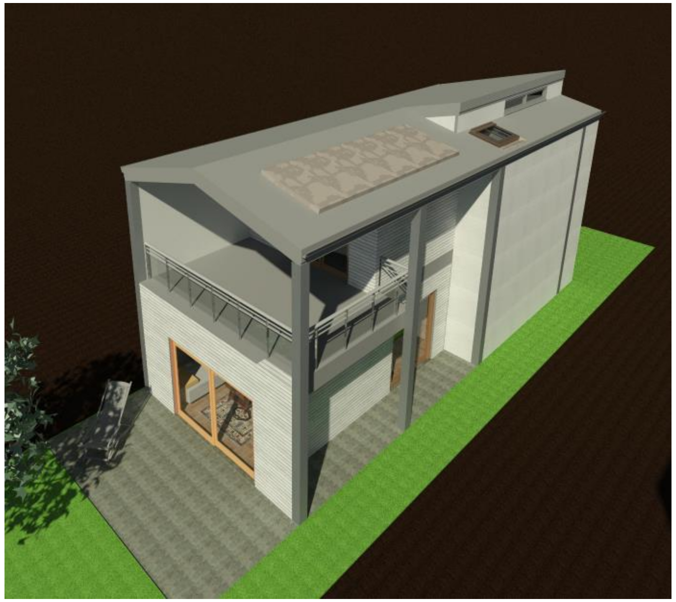


Figure 58 Exterior 3D bird view (stage one)

Figure 61 Exterior 3D view – from Neville Road (stage two)

Figure 60 Exterior 3D view – from park (stage two)

Figure 59 Exterior 3D bird view (stage two)

Figure 64 Exterior 3D view – from Neville Road (stage three)

Figure 63 Exterior 3D view – from park (stage three)

Figure 62 Exterior 3D bird view (stage three)

4.4.1. Stage One

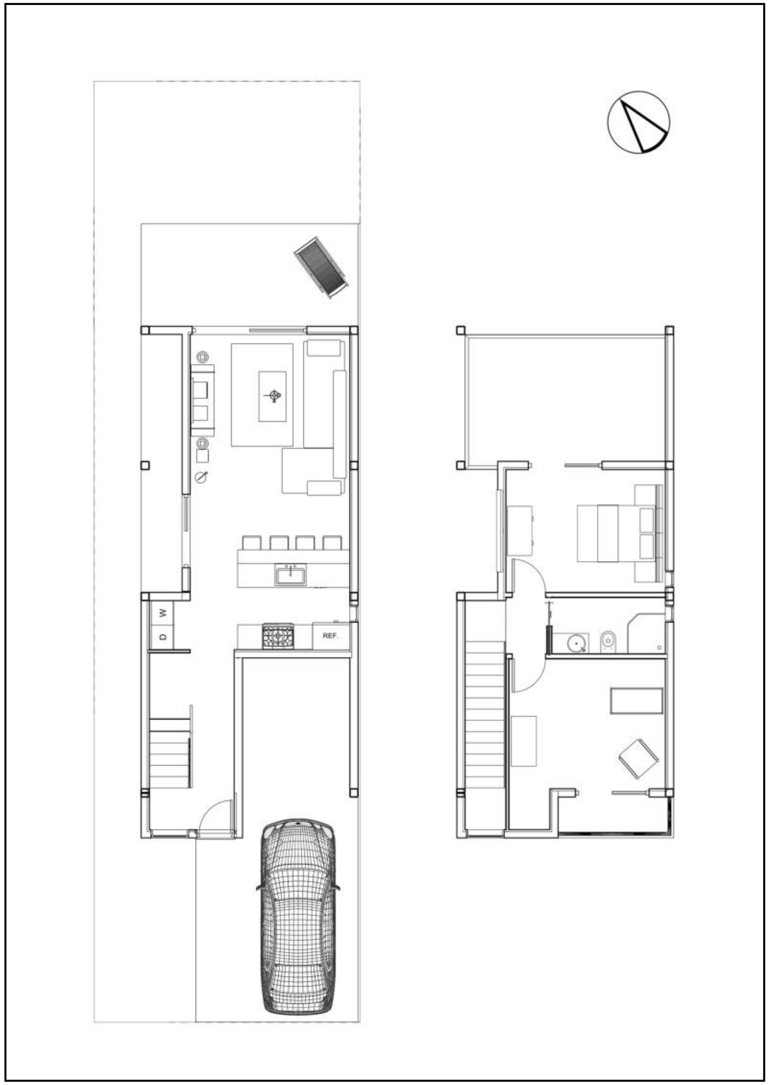


Figure 66 Ground floor furnished plan (left), first floor furnished plan (right)

Figure 65 Interior 3D rendering – living room

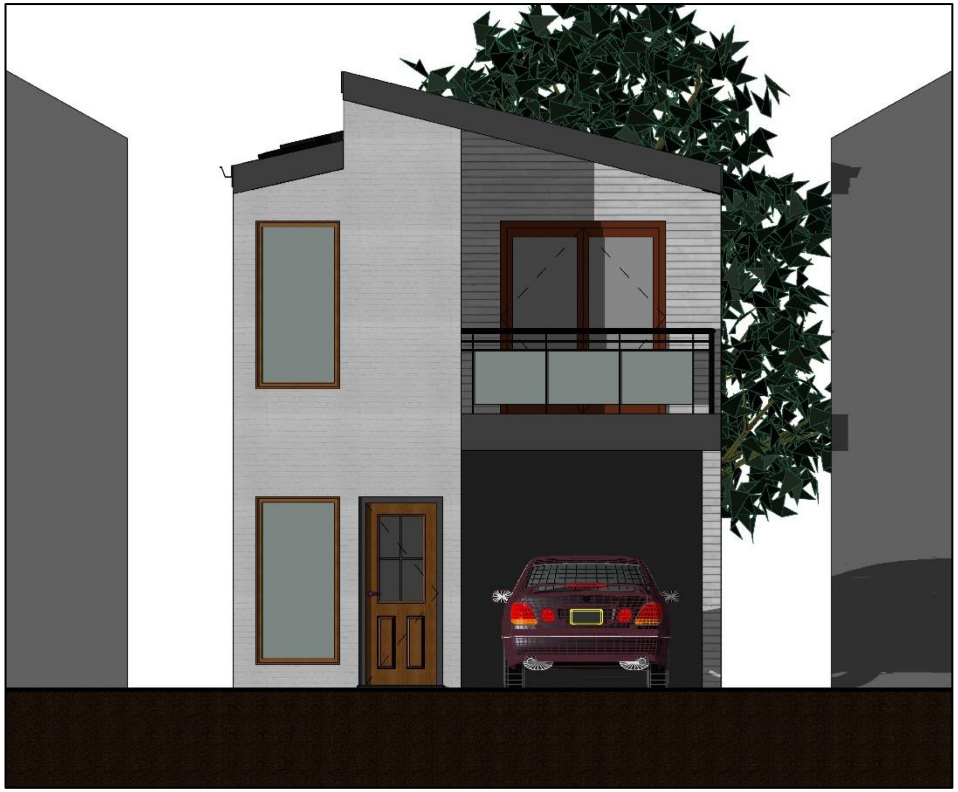


Figure 68 South elevation

Figure 67 North elevation

4.4.2. Stage Two

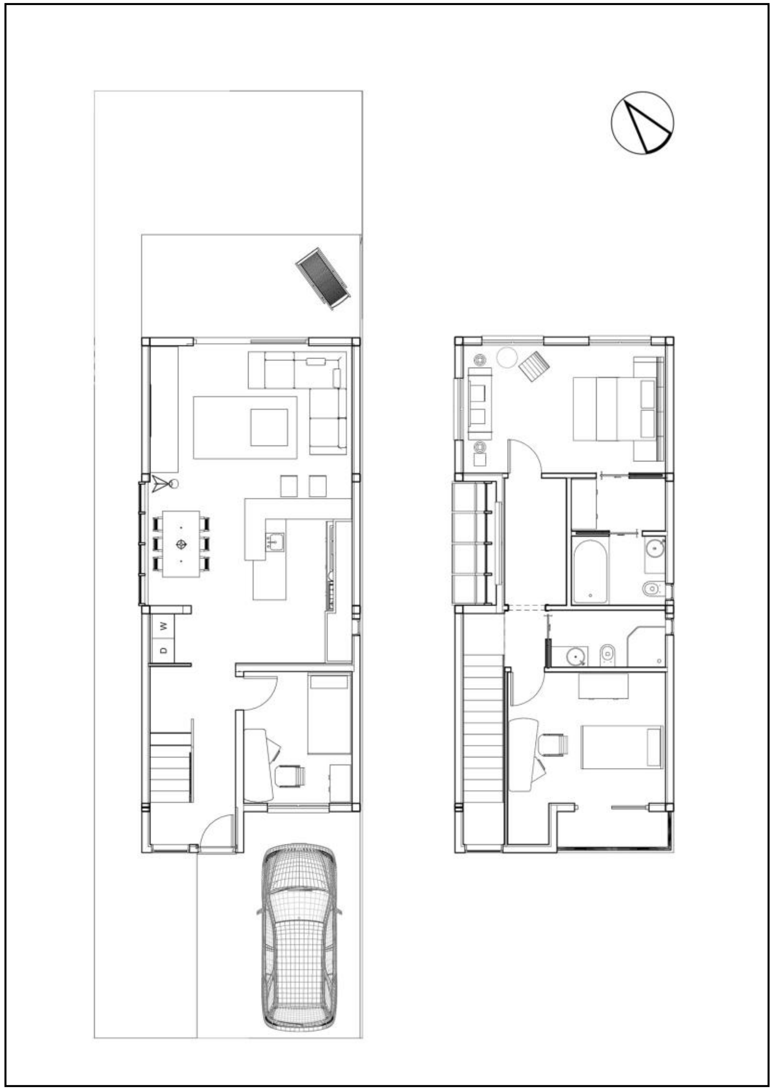


Figure 70 Ground floor furnished plan (left), first floor furnished plan (right)

Figure 69 Interior 3D rendering – living room

Figure 72 South elevation

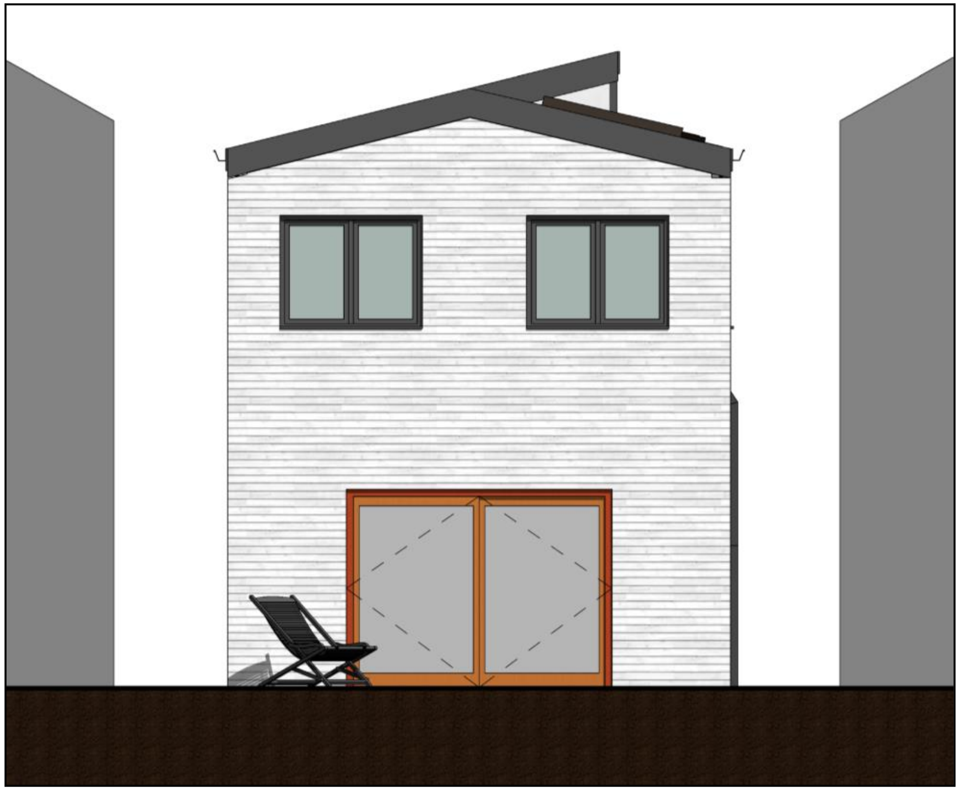


Figure 71 North elevation

4.4.3. Stage Three

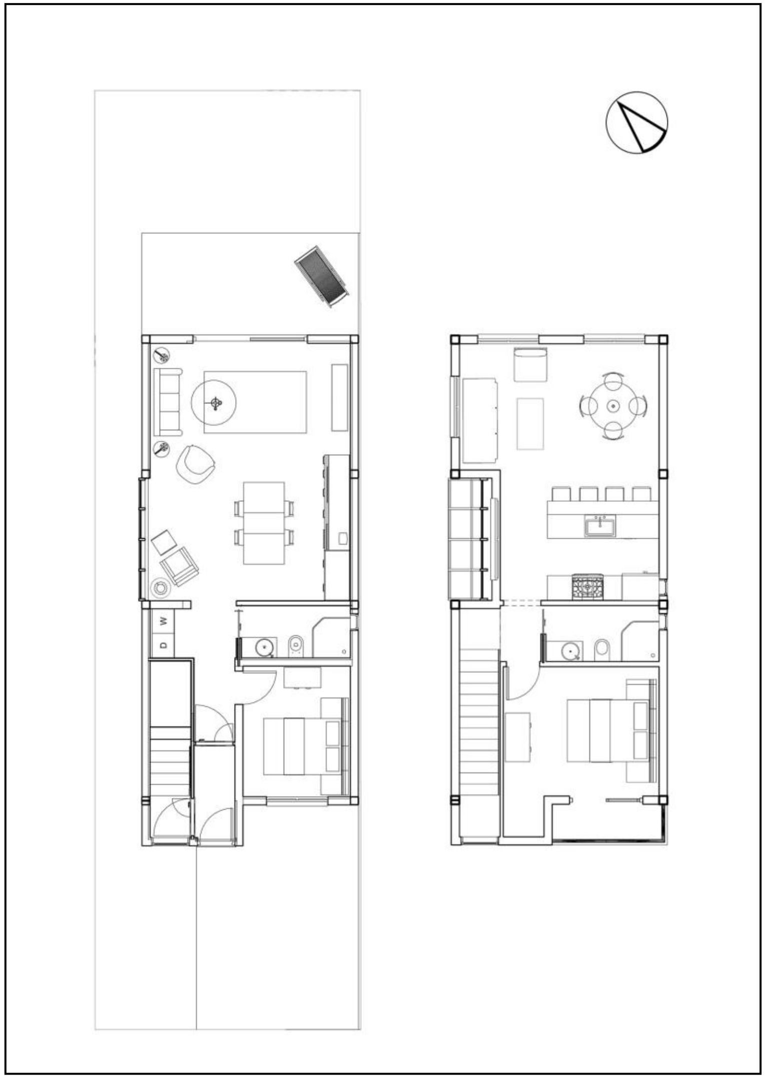


Figure 74 Ground floor furnished plan (left), first floor furnished plan (right)

Figure 73 Interior 3D rendering – living room

Figure 76 South elevation

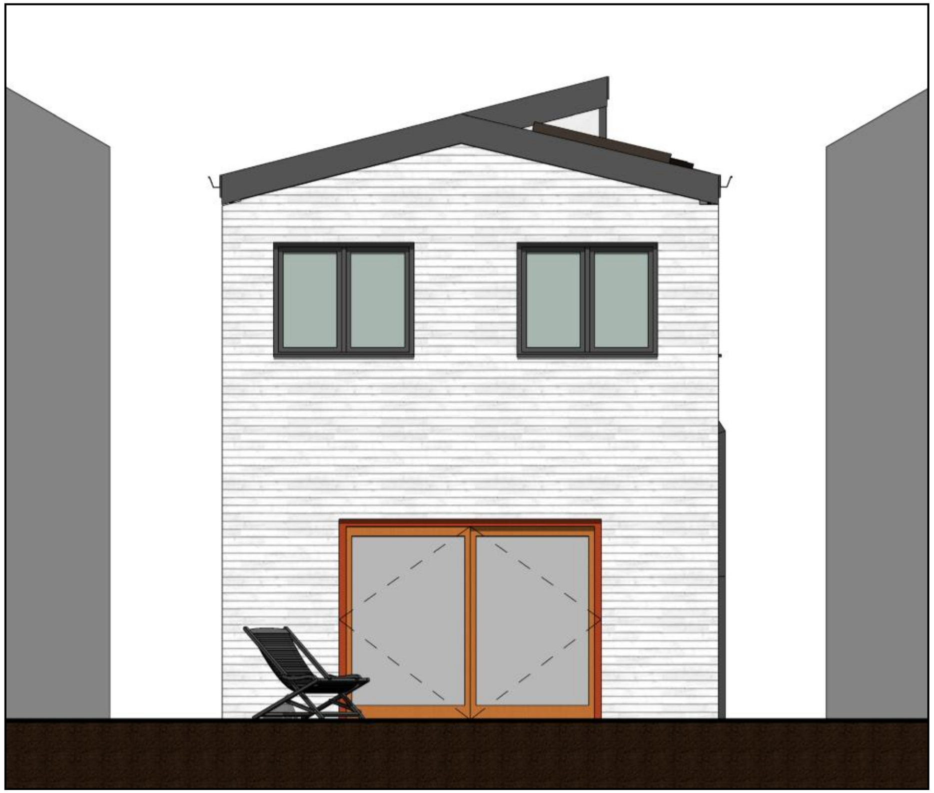


Figure 75 North elevation

Economic Analysis of the Design

Chapter Five

This section discusses the economic efficiency of the flexible design compared to the counterfactual option. In assessing the economic efficiency of the design, two distinct methods - static and dynamic - could be pursued. In static processes, the economic efficiency is evaluated based on comparing the expenditures and/or utilities of an investment without considering the point in time when they occur. In contrast, dynamic processes consider the exact points in time of payments in and out in the timeline of the investment (König & Schoof, 2010).

The question in the present research is whether flexible design can reduce the life cycle cost of a house. Answering this question requires comparing the life cycle cost of our proposed flexible design with the life cycle cost of a non-flexible scheme. In this research, the static process is chosen based on the following factors:

1- The dynamic method requires accurate economic estimations of inflation rates and discount rates for each element of costs and revenues. These precise data were not available for the next 45 years to enable pursuing the dynamic method.
2- Considering the same inflation rate, estimating the future costs and discount rate, to calculate the present value of future costs, will eventually result in the same outputs as with the static method.

5.1. Comparable Design Alternatives

The financial comparison should be based on two comparable options in terms of time period and the state that the building is in. The first option is the flexible design, which comprises the initial build and two alteration stages at years 15 and 30. It is assumed that in 15 years the family needs in terms of space and number of residents will reach to its peak, and therefore the counterfactual option was chosen to be the design of stage two.

Alternative 1: Flexible design

The building will be built as indicated at stage one, where at year 15 the building will be transformed to the stage two design, and at year 30 it will convert stage three.

Alternative 2: Non-flexible design

Comparing to the flexible alternative in this option, design includes only one stage. The building will be built at stage two scheme and will not change during the next 45 years.

5.2. Cost Estimation for Two Design Alternatives

As discussed in chapter two, many items can be calculated for a whole-life cost estimation. To answer the research question through comparing two flexible and non-flexible options, it is simply necessary to estimate those parts of whole-life cost that are different between the two options, such as the costs of construction, finance and operations. Other items of the whole-life cost, like cost of the land and costs of demolition and disposal, are the same in both options and therefore can be ignored. Table 6 indicates the items of whole-life cost that need to be considered in the economic analysis of two design alternatives.

Although there might be a slight difference between the costs of energy and costs of building cleaning in the two design alternatives, in the present research we have not calculated those as they are assumed to be the same in both options. It should be noted that the possible difference in the mentioned costs would be in favour of flexible design, as the building is smaller in this option during stage one and stage three. The planned alterations at the beginning of stages two and three in the flexible options have been considered as renovation costs.

Building costs, renovation costs, finance costs and possible revenues (income) are the main costs and revenue that were calculated in this research. These four factors will form the major part of whole-life cost, as follows:

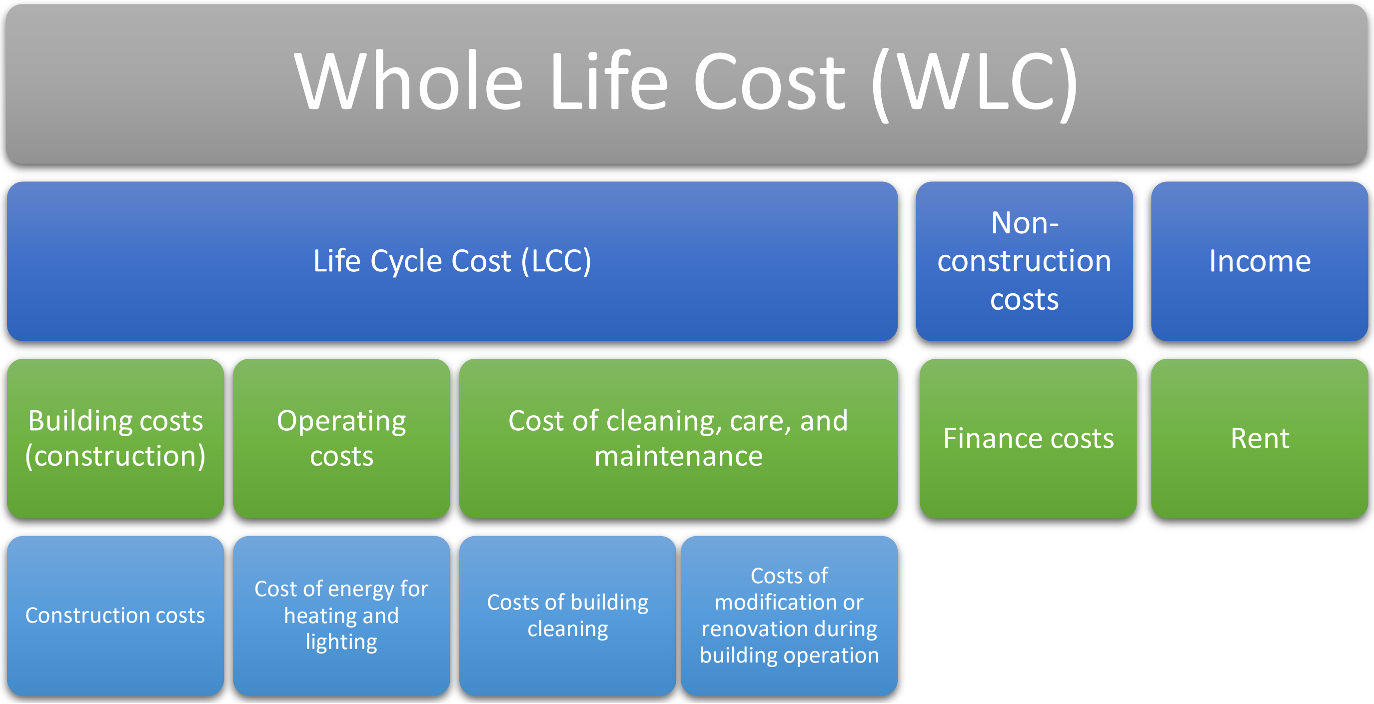


Table 6 Main components of the whole life cost of a building

5.2.1. Construction Costs

This item is the most important feature of life cycle costing. For calculating this group of costs *QV cost builder* was used as the most comprehensive reference to New Zealand building costs. This database provides:

1. Building costs per square metre;
2. Elemental costs of buildings.

The construction cost of the non-flexible option was calculated using the first section of *QV cost builder,* as follows:

Non-flexible option construction cost *= building area (square metre) × unit cost ($ per square metre)*

Where:

Building area for non-flexible option = 123.85sqm

Unit cost = 2500 $/sqm

Therefore:

Non-flexible option construction costs = $309,625.

To calculate the construction cost of the flexible option, the construction cost of the second stage, where the demand is at the peak in terms of total floor area, was calculated using the same procedure as for the non-flexible design. Here flexible design at stage two and non-flexible design are the same.

Considering stage two construction costs as the basis, the costs of changing elements will be subtracted from the stage two costs to calculate the construction costs at stage one.

Flexible option construction costs *= construction cost of stage two – construction cost of all elements that are created in stage two + construction cost of all elements that are demolished at stage two (all elements that were available in stage one but not available at stage two)*

Where:

Construction cost of stage two = building area (square metre) × unit cost of each square metre

Construction cost of stage two = 123.85sqm × 2500 $/sqm = $309,625

Construction cost of all elements that are created in stage two = $69,798 (for detail refer to Appendix)

Construction cost of all elements that are demolished at stage two = $11,758 (for detail refer to Appendix)

Therefore:

Flexible option construction cost = $309,625 – $69,798 + $11,758 = $251,584.

5.2.2. Renovation Costs

In the flexible option, planned renovations will occur at the beginning of the second and third stages. To estimate the cost of these refurbishments, it is necessary to quantify the amount of those elements that are going to change (be demolished or be created) during the renovation process. The element's quantification, obtained from the building information model and elemental cost rates extracted from *QV cost builder,* were all that was needed to calculate the renovation costs of flexible design. While the non-flexible house probably also needs some retrofitting over its lifetime, calculating those expenses was neither possible nor useful, since similar retrofitting will also be required for the flexible option. Stage two and stage three renovation costs are as follows:

Stage two renovation cost = $69,798

Stage three renovation cost = $48,449

5.2.3. Finance Costs

Buying a house with a home loan is a conventional approach, especially for first-time home buyers. Depending on the repayment amount that a family can afford, finance costs may affect the whole-life cost of a property dramatically. To estimate these costs based on the initial amount of money that the owners need for construction, the ANZ home loan repayment calculator was applied. The repayments are shown in Table 7.

5.2.4. Income

From year 31 onward, the flexible house will be divided into two separate units and the first floor unit can be rented. Assuming a typical $300 per week rent for similar one bedroom units in the area, $15,600 annual income could be earned.

	Required loan for construction	Min Required Deposit (10%)	Return period	Interest rate	Annual repayment
Non-flexible option	$309,625	$30,962	20 years (year 1 – 20)	5.19 floating	$24,912
Flexible option	Stage 1: $251,584	$25,158	15 years (year 1 – 15)	5.19 floating	$24,168
	Stage 2: $69,798	$69,798	5 years (year 21 – 25)	4.85 fixed	$15,744
	Stage 3: $48,449	$4,845	5 years (year 31 – 35)	4.85 fixed	$10, 932

Table 7 Repayment amount for the home loan of each option

5.3. Cash Flow and Total Costs

Figure 77 demonstrates the project's timeline and description of all costs and incomes for both flexible and non-flexible options. As depicted in Figure 77, at the end of year 20, both options reached a similar status in terms of building and paying off all loans. So year 20 would be a perfect time to compare the costs of the flexible house with the counterfactual. Another suitable point would be at the end of the building's life cycle, year 45.

5.3.1. 20 Year Cost Comparison

At year 20, the two alternatives are at the same condition. The design of flexible house at second stage was suggested as a non-flexible option (for the whole 45 years) and the flexible option has been renovated on year 15 to transform to stage two; thus, at this time, the scheme options are the same. In addition to the similar condition of the building in both options, home loans are also all paid off. Figure 78 shows the cash flow diagram for the first 20 years of the house life cycle (for simplicity, each five years have been aggregated).

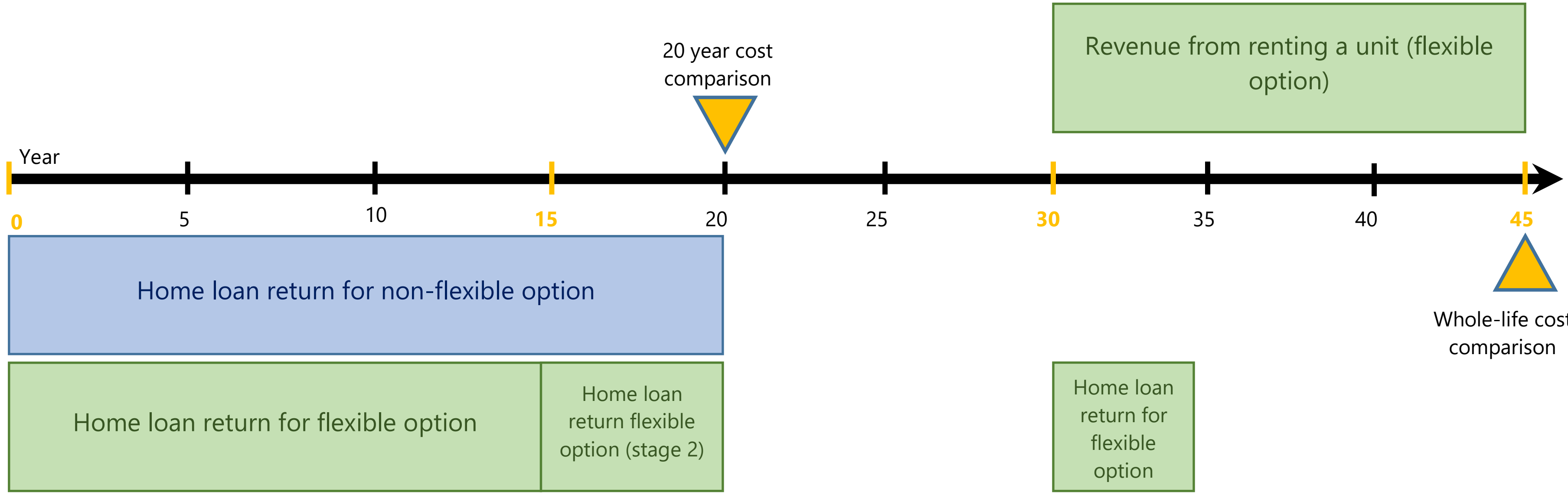


Figure 77 Timeline of building costs (home loan repayment) and revenues

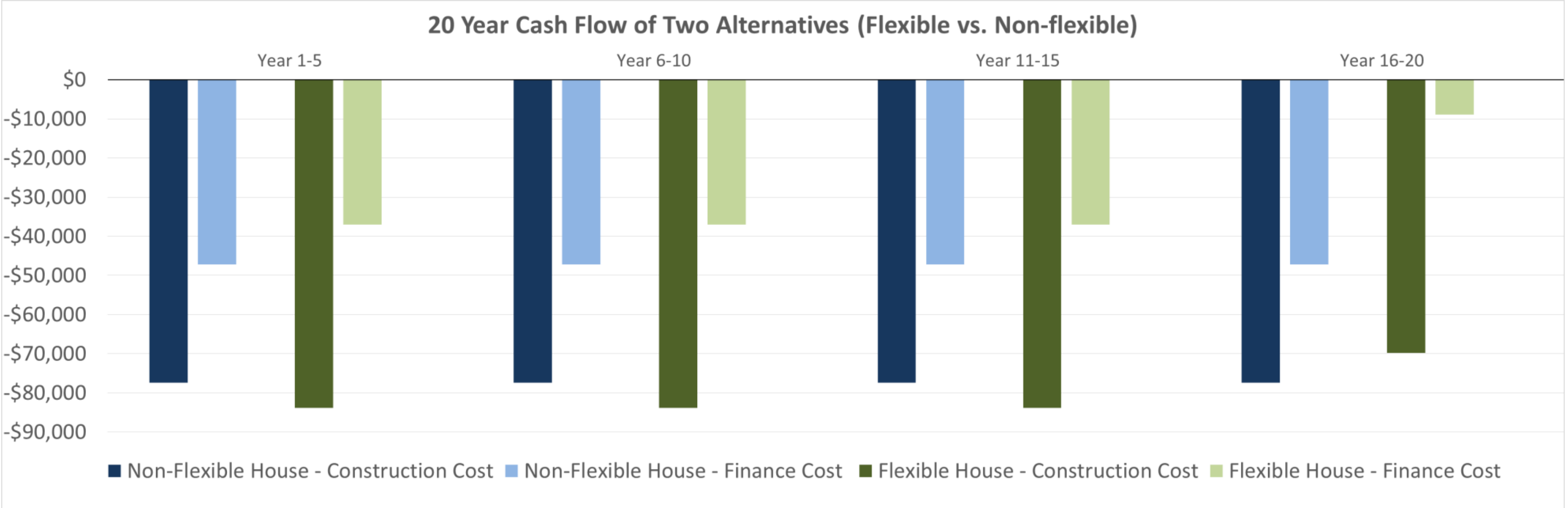


Figure 78 20 year cash flow of two flexible and non-flexible alternatives

Having a similar annual repayment amount in both flexible and non-flexible options, the flexible option home loan will take 15 years to be paid off, due to lower amount of the loan compared to the non-flexible option, and therefore the finance costs would be less than for the non-flexible house.

Figure 79 shows the comparison between the total costs of the two flexible option and the non-flexible option for the first 20 year of building life.

As shown in Figure 79, in the first 20 years of the house's life cycle, a ***$57,000 (11.4%) cost reduction*** is achieved through the flexible design option.

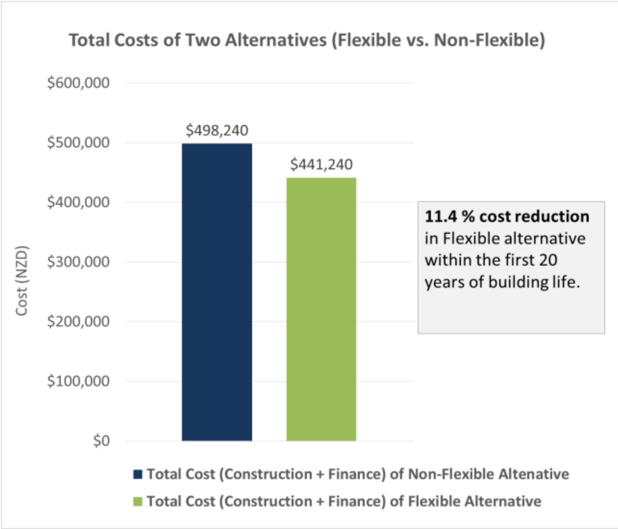


Figure 79 Total cost of two alternatives for the first 20 years

5.3.2. *Whole-life Cost Comparison*

The whole-life cash flow of two options is shown in Figure 80. The values depicted in the figure are the aggregation of a five-year period. Similar to the 20-year economic analysis, costs are shown as negative values and incomes are shown as positive values. Figure 81 shows the comparison between the total costs of two flexible options and a non-flexible option for the whole life of the dwelling. Taking into account the income from renting one unit, the flexible option will result in a **$236,340 (47%) cost reduction**. It should be noted that this cost reduction mainly stems from the income from renting one separated unit that the flexible design enables.

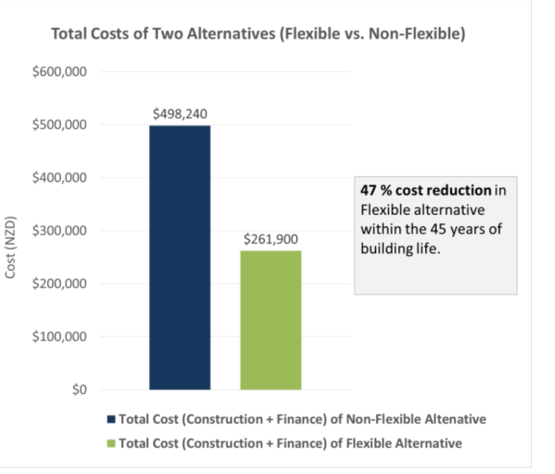


Figure 81 Total whole-life cost and income of two alternatives

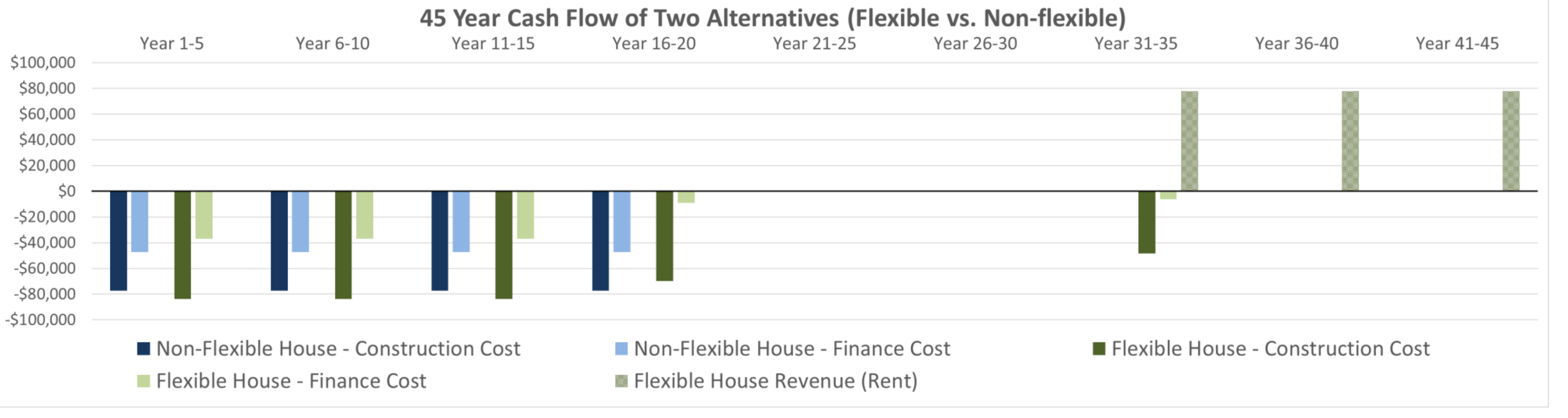


Figure 80 45 year cash flow of two flexible and non-flexible alternatives

Conclusion

Chapter Six

Through this research, the researcher tried to investigate the field of flexible housing and to address some recognized issues in the field with the help of a life cycle design approach. A significant achievement of this research was in answering the research question:

- How can flexible design reduce the life cycle cost of a house?

To answer this question, a life cycle approach was chosen. As a research by design project then based on flexible housing criteria, a flexible house was designed for a site located in the Sunderland neighborhood at Hobsonville Point, Auckland. Slack space, adding-on and dividing up principles were applied as flexible housing strategies to design a flexible house with the ability to be customised and expanded over time as its occupants' needs evolve.

The integrated (BIM-based) design process enabled analysis of the flexible design approach financially and to see the consequences of the decisions made about design. Using the provided building information model made the process of quantification and estimation easier and more accurate.

The financial analysis of design revealed that a 47% reduction is possible in the whole-life cost (life cycle cost in a wider sense) of a flexible option in comparison to a non-flexible alternative. As explained in chapter five, studying the period of the first 20 years of the building's life cycle indicated an 11.4% decrease in construction and finance costs of a flexible house compared to the required budget for constructing a non-flexible alternative.

Another significant result of the BIM-based design process was the provision of the project's building information model, which produced all required data and documentation. So the user has all the information about the flexible features of design and planned alterations simply by accessing the provided model.

A key accomplishment of this research is applying a life cycle approach to flexible housing that is not common, particularly in Auckland housing system. Applying a life cycle approach and the BIM-based design method assisted the researcher to address flexible housing issues in terms of financial analysis and documentation. The advantage of flexible housing as an economic and sustainable solution for current issues in housing sector such as lack of adaptability, affordability and accessibility was demonstrated.

If architects and architectural researchers are involved more in the process of financial assessment, hopefully, the amount of quantifiable data which is necessary for economic analysis of flexible housing will increase so that more complete and precise appraisals will be feasible. The life cycle approach as described aims to change the dominant short-termist approach to building that is currently common in housing sector to a long-term and more sustainable approach. This goal might be achieved by increasing the use by architects of Building Information Modelling (BIM) as an integrated design method.

Further research in this field could usefully explore the economic advantage of different types of flexible housing such as medium density housing. Life cycle costing through dynamic processes applying net present value method may be another valuable topic to research.

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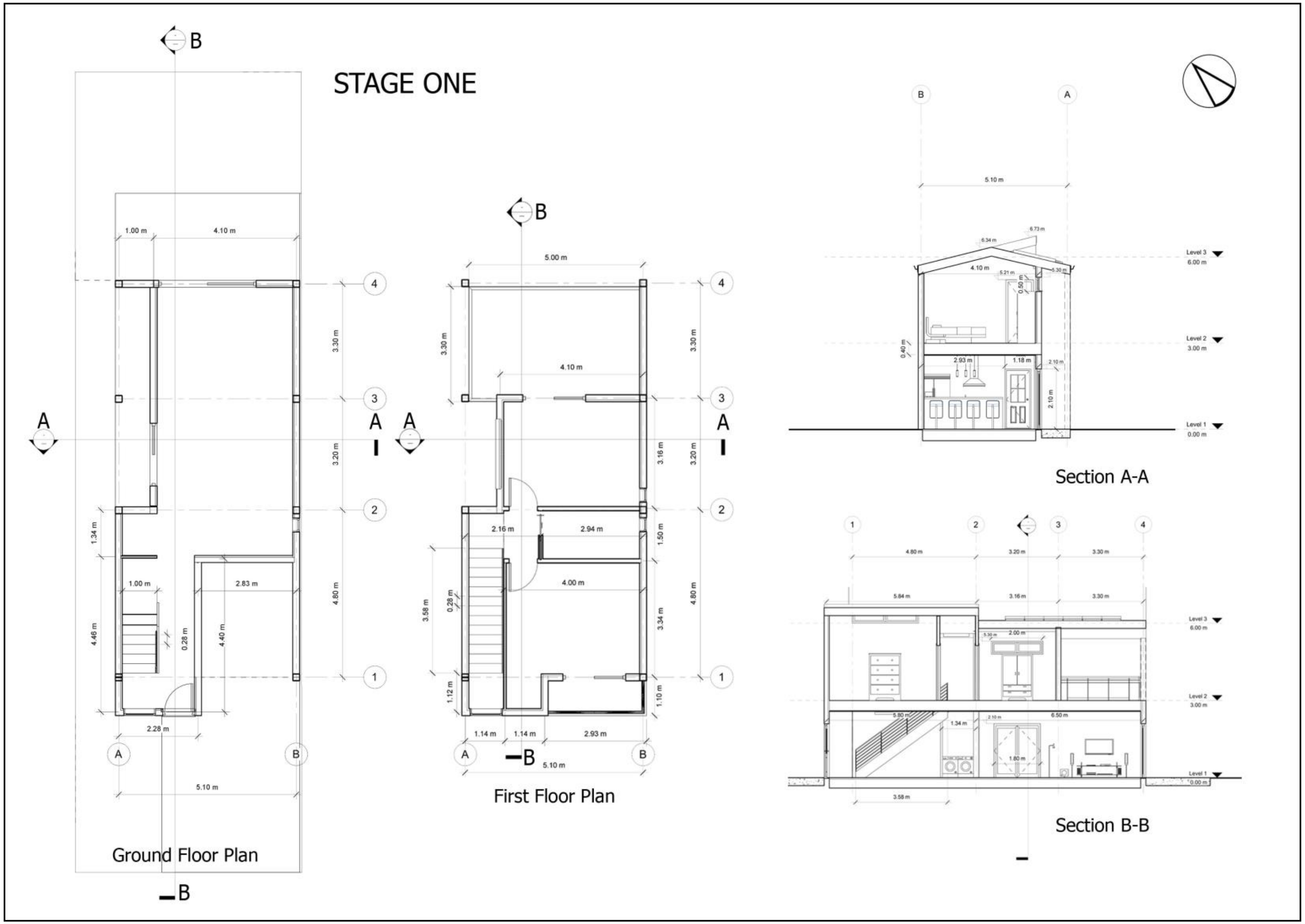
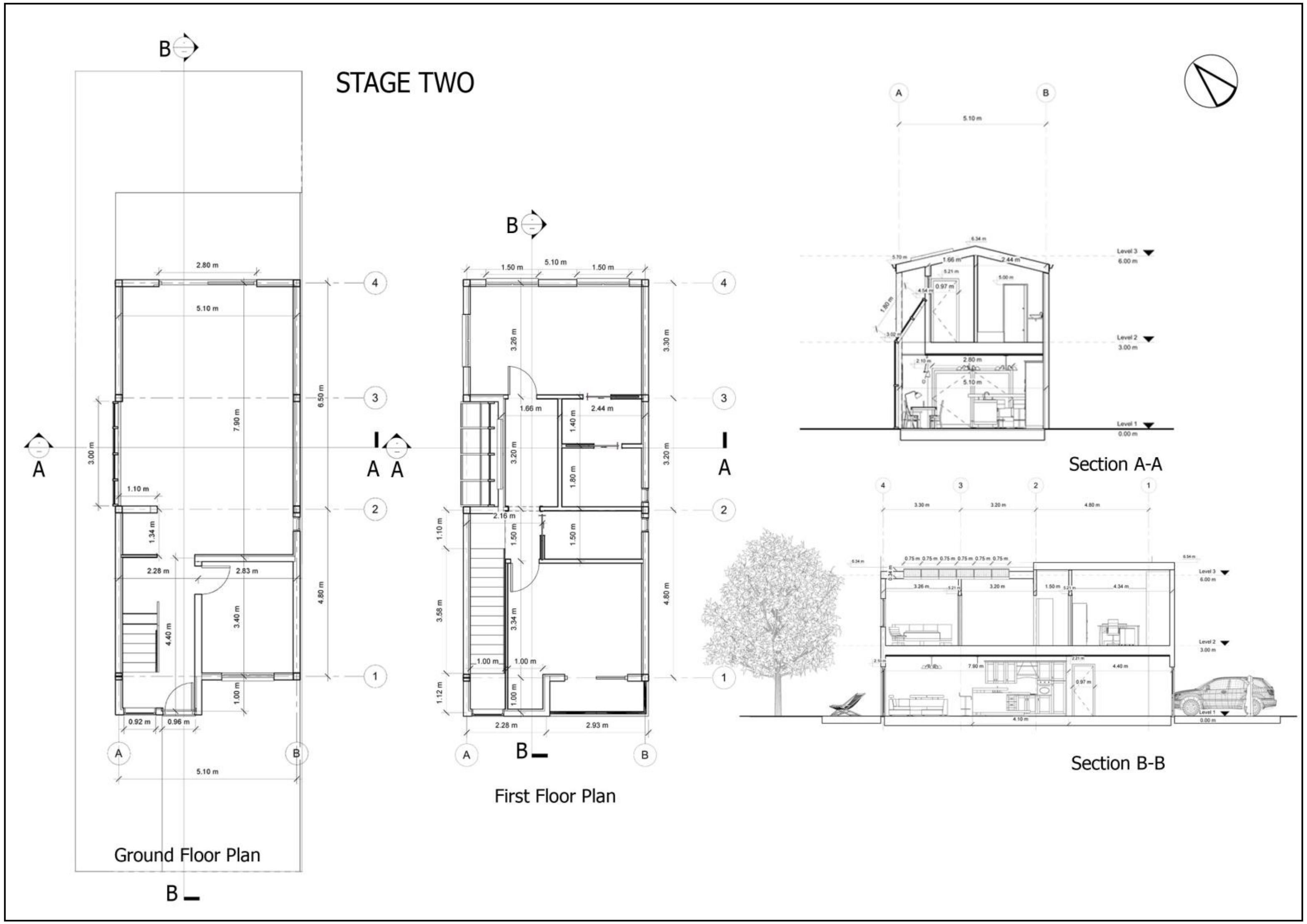
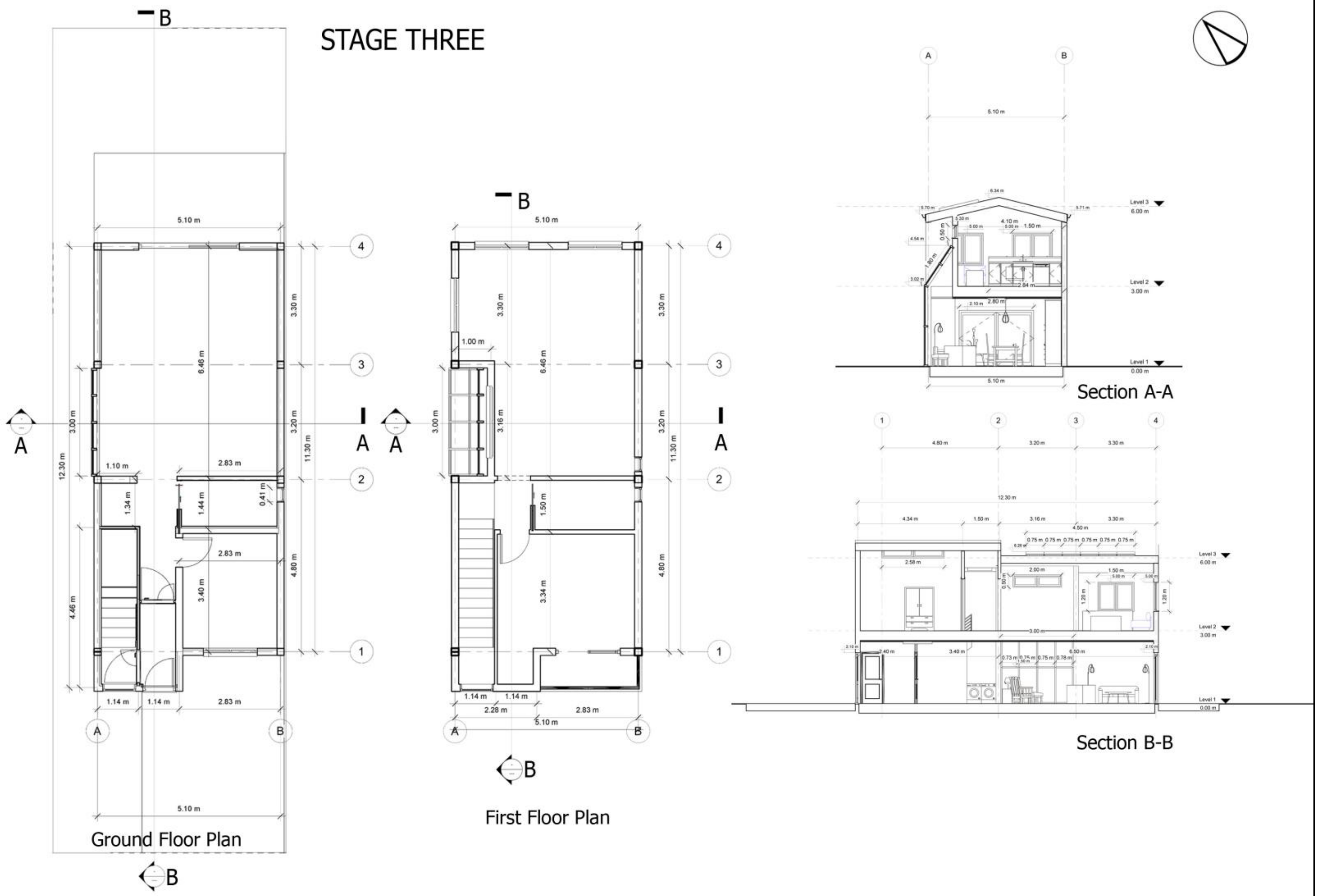
Appendices

Appendix A – Annotated documentation

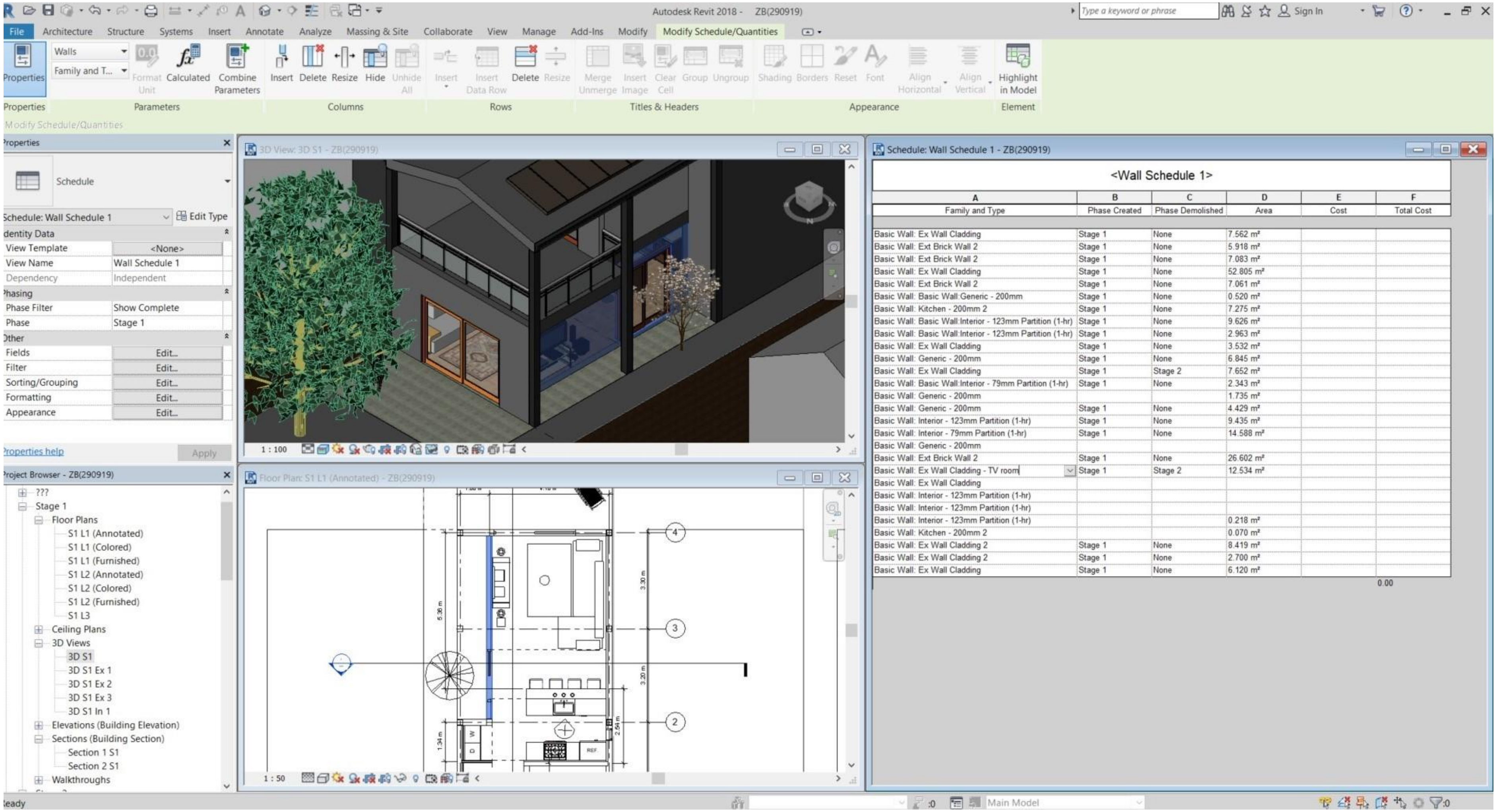



STAGE TWO
Ground Floor Plan
First Floor Plan
Section A-A
Section B-B

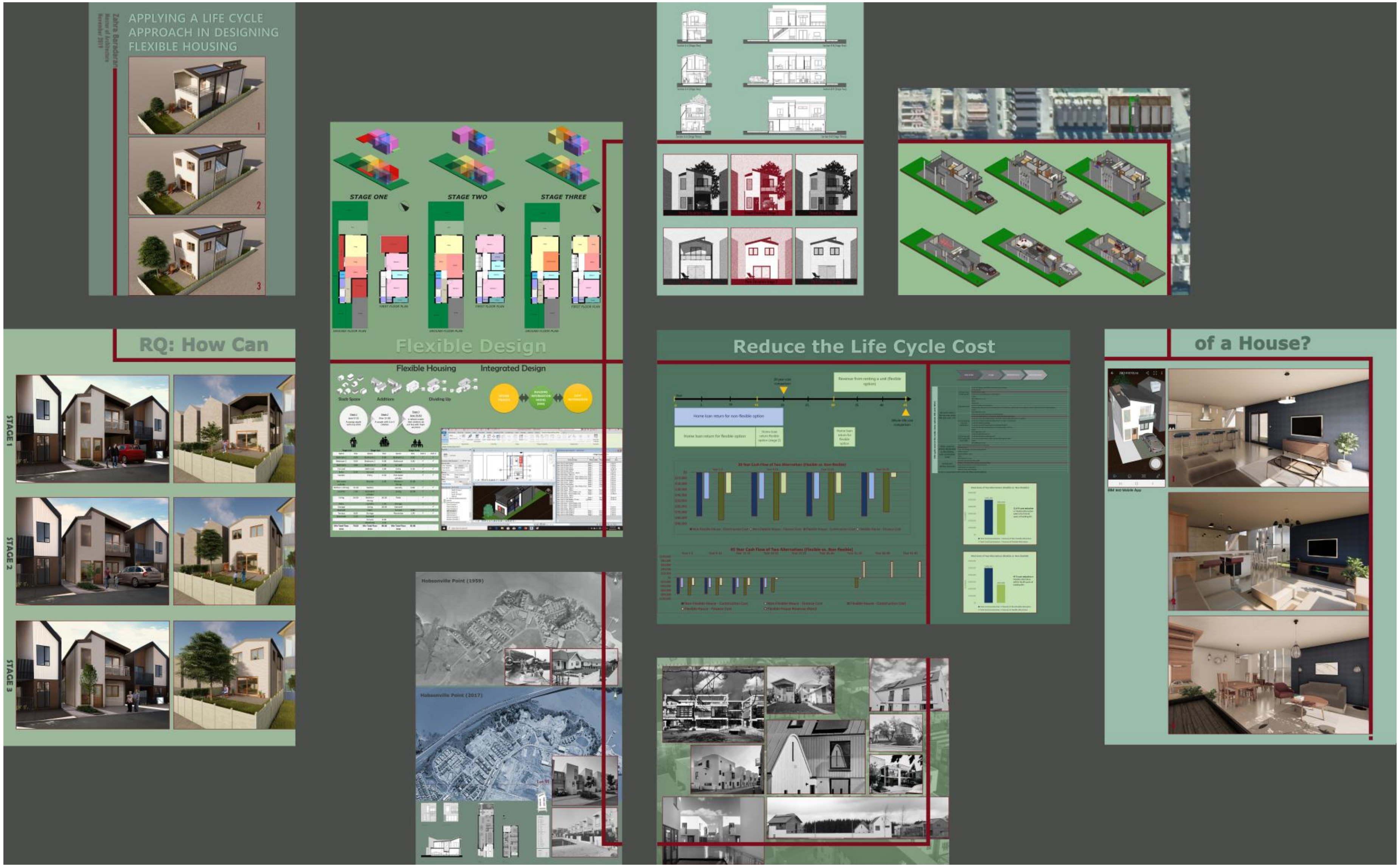
STAGE THREE



Appendix B – Quantification and cost estimation process in Revit 2018 software



Appendix C – Final presentation




year 1


year 15


year 30

Stage One

Stage Two

Stage Three

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Degree: Master of Architecture

Year of presentation: 2019

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Principal Supervisor: Nikolay Popov

Associate Supervisor/s: Peter McPherson

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