City As A Food Forest

Urban Agricultural Kitchen Interventions in the Urban Environment

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CITY

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Figure 0.1. *Ceramic model*

Acknowledgements

To Heather Mellor for encouraging me to follow my passions and aim high.

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Research Question:

How can urban agriculture be integrated into residential interior environments?

Abstract

Increases in urban density, the need for lower carbon solutions and a developed understanding of the importance of nature in cities have highlighted the importance of indoor environments and the need to rethink food production methods. This research thesis seeks to question whether hydroponic indoor urban agriculture could be part of the solution. By developing effective architectural solutions for indoor urban agriculture, it explores the integration of indoor greenery as a union of the built and natural which offers opportunities for improvements in urban food supply and contributions to occupant wellbeing.

Existing research indicates that the benefits from plants in building interiors could be extensive and research in this area is still developing. This work established the potential effectiveness of food production within apartments through a comparative analysis of existing interior applications of urban agriculture, concluding that kitchen hydroponic systems may be the most effective solution for indoor growing of edible plants. The research has investigated the use of natural materials to facilitate exploring methods of making with ceramics to reduce material toxicity.

The work explores the integration of a functional model of food production into the interior realm of residential architecture. This is proposed through creating an architectural intervention to support urban agriculture, employ natural materials and integrate biophilic design.

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Figure 0.2. *'Earthwood' adobe passive solar house (my family home)*

Personal Positioning

My upbringing on a self-sufficient life-style block in the rural South Island was a pivotal time that shaped my view of the world. Involvement in building our family home from natural materials instilled in me an appreciation of the importance of sustainable architecture ('Earthwood' Fig. 0.2.). My understanding of where food comes from was innately linked to what was available in the garden and which vegetables were in season.

Personal observations of the urban disconnect from the natural environment and food production have influenced my interest in the field of urban agriculture. This has informed my observations of the lack of productive spaces within architecture and led me to ask; how can architecture adapt to support a lifestyle that encourages resiliency and health. I felt that this thesis could best respond to this question by investigating how urban agriculture can be integrated into interior environments to target apartments as a built typology that is often significantly removed from the natural environment.

Chapter One

~Introduction

1.1 Introduction

Urban agriculture is defined as 'the production of crop and livestock goods within cities and towns, generally integrated into the local economic and ecological systems' (Lin et al., 2017, p. 156). Food production within cities has always been a challenge, and the densification of the urban population has been rapidly exacerbating this, with 60% of the world's global population expected to be urban dwellers by 2030 (Lal, 2020, p. 871). A greatly increased farm-to-table distance since the Industrial Revolution and the ecological impact of imported foods has led to higher carbon footprints for produce. Fig. 1.1. illustrates the top 100 global food trade flows from food transportation. Some cities are now regarded as 'food deserts' in which access to food has become severely restricted, with croplands located far away from urban centres. Globally, fruit and vegetables constitute over one-third of global food-mile transportation emissions, with transport of these products producing up to 200% more emissions than their production (Li et al., 2022, p. 450). The impacts of climate change and Covid-19 have highlighted the need for change in supply chains and food sourcing to mitigate the risk of shortages and to minimise carbon outputs globally.

Implementing planting and regenerative farming techniques throughout the urban environment promotes biodiversity, reduces pollution levels and lessens the heat island effect often found in cities (Goldstein et al., 2016, p. 994). By increasing local production of food within cities through small and diverse urban agriculture interventions, food resiliency is improved and there are less land requirements for large scale mono-crop conventional agriculture, which has led to a depletion of biodiversity and soil fertility on a wide scale. In recent years, many cities have experimented with urban agriculture as a solution to the lack of space and outdoor interventions can range from individual allotments to

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Figure 1.1. *Top 100 bilateral flows of international food-miles emissions per capita (Li et al., 2022, p. 447)*

larger shared rooftop gardens (Thomaier et al., 2015, p. 3). Yet, commonly, these have been developed by residents as an afterthought to the built environment or are implemented on macro or micro scale that are not suited to architectural kitchen integration. However, purpose-designed indoor urban agriculture solutions provide the potential to more positively enhance architecture to support active inclusion of agricultural interventions in urban areas, thereby, promoting resilience.

The health benefits of time spent outdoors and interaction with the natural environment can lower stress levels and improve mental health (Cobb & Jones, 2018, p. 231). The lack of interaction with the natural environment in urban centres is exacerbated by typical apartment and inner-city housing design, reducing the access to vegetation for many inner-city dwellers. An environment with indoor plants has been shown to lower stress levels of subjects compared to an indoor environment with no plants (Yeom et al., 2021, p. 9).

Existing research indicates that the benefits from plants in building interiors can be extensive if applied correctly, with a range of interventions and indoor vegetated solutions being established. The implications of indoor vegetation in the form of green walls or other planted installations have also been documented to have a significant effect on the wellbeing of the occupants of a space (Oh et al., 2011, p. 321) (Moya et al., 2019, p. 298). Increased air purification from plants has been linked to improved air quality and improved physical health, reducing the risks of respiratory diseases. This is especially relevant at the time of increased reliance on artificial ventilation which unavoidably requires ongoing operational energy consumption and often is constructed from materials high in embodied energy. (Beatley, 2018, p. 87). Vertical planted interventions indoors can help mitigate stress, fear, anger and blood pressure; they also contribute to increased workplace productivity, which is even more relevant in the home now, as in the world since the spread of Covid-19 people are often working from home in less suitable conditions (Weerasinghe et al., 2020, p. 2). Jointly, discussions of this nature present drivers and motivators for urban agriculture indoors, and shows a real increase of interest in recent years in the opportunities for development in this space.

This work specifically focuses on challenging the traditional approach to food production and the carbon footprint associated with the transportation of food; and asks what would happen if urban agriculture interventions were incorporated into architecture to become an integral part of the kitchen. By focusing on dense apartment dwellings there is a meaningful opportunity created to include food production indoors, improving the wellbeing of occupants in a space that typically has a minimal connection to nature. The work covers a range of elements and contributing factors in the development of an urban agriculture intervention and addresses a series of significant gaps in existing knowledge.

Research Question:

How can urban agriculture be integrated into residential interior environments?

1.2 Aim

To contribute to a developing body of knowledge of how to more effectively integrate growing edible plants in the indoor environment.

1.3 Objectives

Establish the potential effectiveness of food production within apartments.

Articulate the most effective solutions for indoor growing of plants.

Articulate the key areas of consideration.

Test through design an outcome that is reflective of the sustainable values of the project.

Develop recommendations that can be further implemented and deployed in research or knowledge within this space.

1.4 Scope

An analysis of existing solutions showed that hydroponic growing methods appear to be the most ideally suited to the urban environment and will meet aims to develop a sustainable outcome for the application of indoor urban agriculture. The intent is to integrate the elements of visual food storage with an architecturally-designed hydroponic growing system, aiming to evaluate the way in which a visual and physical connection to food can be used to transform the way the kitchen working triangle operates and redefine the way that architecture is used to inform occupation and usage. The scope of the research is to implement an action design process, utilising the existing body of knowledge in the field to establish gaps and inform a design outcome and potential future applications of the work.

1.5 Methodology

This study provides a systematic overview by compiling the existing literature and available solutions to form an organised system of understanding to evaluate the range of interior green interventions. The study aims to identify the areas which could generate greatest improvement through further development in relation to urban agriculture indoors. In order to achieve this, the research explores what is currently possible, what is aspired to, what is currently known in existing literature, and also what is on the market. To situate the work within the existing body of knowledge, the research method initially consisted of compiling existing reviews and products and reviewing these through a comparative analysis lens using research for design (Frayling, 1993, p. 5). It was established that more development is needed in understanding and categorising the interior green intervention potentials, identifying that there was the need for a focus on developing architecturally-integrated systems.

The categorisation for the comparative tables follows a similar methodology and framework to earlier studies by Mir (2011) and el Menshawy et al. (2022) which highlight the difference between indirect and direct greening. This was applied to the frame of research, altering the framework to instead be divided into system types to analyse hydroponics and living wall systems within the interior context.

During the preliminary compilation of research, a key discovery was made that a gap in the exploration of hydroponic systems was the potential for implementation of natural materials for system construction. This led to a shift in trajectory for the research into the second stage to adopting practice-led research to employ an action research approach of research through design, with an emphasis on system and material testing (Frayling, 1993, p. 5). Findings from the earlier comparative analysis of existing knowledge were applied to inform relevant design decisions to form a reciprocal relationship between the two key methodologies of the work, with action research strategies and research for design working in parallel.

The literature review and comparative analysis of products situated the work within a current gap in knowledge. Iterative design processes employed problem-space planning methods to structure the problem space and establish knowledge-based decisions (Rowe, 1994, p. 65). Defining the work within a broad architectural context is established by integration of research findings into the kitchen design through natural material-based hydroponic systems.

1.6 Chapter Outline

In this work it is impossible to fully separate research for design and design for research because much of the design influenced a need for further research due to the technical nature of the work. Because of the need for much of the work to occur simultaneously, Chapter Two and Chapter Three will contain elements of both design decisions and further research and literature/precedent reviews.

Chapter Two introduces the general context of the existing broader body of knowledge and explains where the work is situated. Following on from that, Chapter Three involves more of the literature review content which needed to be included alongside design decisions for clarity, making it difficult to separate the two sections as the work was developed in parallel. The reader should consider that the literature review and design process flows through both chapters due to the intertwined nature of the methodology.

Chapter Two

~Context and Problem

2.1 Introduction

This chapter summarises currently available technological solutions for urban agriculture indoors through a literature and product review to ascertain the gaps in knowledge and areas requiring further research. Vertical greenery can be broken down into several key categories for use in dense urban environments to maximise vegetation while taking up minimal space. Vertical planted interventions can achieve different results in a space and include hydroponics, wall mounted growing bags, planter boxes and living green wall systems, which are further discussed in sub-section 2.3.1 (Avgoustaki & Xydis, 2020, p. 3; Manso & Castro-Gomes, 2015, p. 864). Indoor vertical planting is space efficient and maximises the productive area of the planting, while the vertical nature of the intervention may improve the environmental impact of indoor-plant systems as the system is maintained in stable growing conditions in a controlled indoor climate (Agra et al., 2021, p. 4).

Interpretations of existing knowledge such as the analysis of green facade types by Mir (2011, p. 14) show that by grouping literature into categories such as; green facades, wall vegetation and living wall systems, grouping can be used to develop sub-categories and guide frameworks. Contributing to the existing knowledge, for the purpose of this study, existing groupings were refined into a new system of alternative categories applicable to interior interventions, such as baseline/ traditional, green wall and hydroponics. This has allowed existing solutions for interior green interventions to be assessed with greater specificity. These categories have been established due to their recurrence in existing literature and prevalence as the primary existing internal greenery solutions that can be utilised for urban agriculture purposes and for further identification of areas where the greatest contributions may be made (Benke & Tomkins, 2017; el Menshawy et al., 2022; Francis et al., 2014; Manso & Castro-Gomes, 2015).

When addressing the integration of food sovereignty and emphasising resilience in the urban environment, often vegetation and housing are approached as disparate fields. Discourse around the integration of urban agriculture and the benefits it provides to cities has been documented across a range of interventions at varying scales and typologies and examined in a range of publications; (Hardman & Larkham, 2014; Lin et al., 2017; Thomaier et al., 2015, p. 3). Urban agriculture can be seen to have a wide scope of benefits, addressing issues from community and wellbeing in the urban environment; to climate change and local resilience through food sovereignty (Traian & Oana, 2020, p. 78). For urban dwellers, improvements to air-quality and individual or localised food production creates autonomy and security for a resilient future, with long-term wellbeing benefits.

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Figure 2.1. The Farmhouse

2.2 Precedent Projects

A series of precedents have been selected to assess existing solutions and conceptual proposals that employ urban agriculture and vertical greenery within an architectural context. The projects selected range from high-rise apartment blocks to small-scale indoor interventions. Observations note the architectural integration rather than the technical system specifications used.

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Figure 2.2 - 2.3. The Farmhouse

The Farmhouse

Designed By: Precht Architects

Year: 2017 (conceptual project)

A mass timber construction apartment block with residential units and urban farming areas integrated throughout living spaces. Each residential space has a balcony along the exterior of the building, which opens to the interior and acts as a link to nature and as a productive food growing space (Fig. 2.2.-2.3.). The productive growing areas can incorporate a range of different methods of vegetated systems to enable food security, improved air quality and aims to develop a built environment that simulates an eco-system (Precht, 2017).

ReGen Villages

Designed By: EFFEKT

Year: 2016 (ongoing)

Glasshouse-style envelopes around the buildings in this project fulfill multiple purposes by insulating homes, extending the growing season year-round and allowing for outdoor space to be functional in winter (Fig. 2.4.-2.6.). The integration of high-yield aquaponic farming for localised year-round food production, along with renewable energy and circular waste systems is intended to manage resources and reduce waste. The concept illustrates the way that an integrated agriculture and residential approach to building can improve access to food and encourage a connection to nature for inhabitants.

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Figure 2.4. - 2.6. ReGen Villages

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Figure 2.7. - 2.8. Bosco Verticale

Bosco Verticale

Designed By: Stefano Boeri Architects

Year: 2014

Located in Italy, this project acts as the urban equivalent to a forest, extending vertically along the building. The design enables trees and vegetation to be planted on the balconies and façade panels and creates a massive scale green intervention in the middle of the city (Fig. 2.7.-2.8.). The design concept has pushed the boundaries of what architecture is capable of and is a prime example of what can be achieved in vegetating urban environments.

Save Food From The Fridge

Designed By: Jihyun Ryou

Year: 2009

This precedent project aims to shape traditional oral knowledge about food storage methods used before the advent of refrigeration (Ryou, 2022). By creating spaces for fruit and vegetable outside of the fridge (Fig. 2.9.-2.10.), the need for toxic refrigeration chemicals is reduced by minimising the volume required for a fridge. The project uses timber joinery to develop aesthetic and functional food storage shelves, which are purpose-designed for different vegetable uses (Fig. 2.11.). By keeping food out of the fridge, the nutrients are preserved, maintaining more nutritious and healthy produce for consumption.

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Figure 2.9. Apple storage bowl

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Figure 2.10. Cruciferous vegetable stand

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Figure 2.11. Overview of 'Save Food From The Fridge'

Micro Intervention

Designed By: Tzen-Ying Ling, Guo-Zua Wu and Ju-Sen Lin

Year: 2018

Designed for research purposes, the micro-scale intervention is intended for retrofit application into existing spaces. The modular form in Fig. 2.12. creates an adaptive design that employs elements of circular economy and allows it to be adapted to fit into any range of different sized rooms or buildings. The 'micro-unit' can be used to grow crops of fruit, vegetables and herbs, but potentially requires a higher level of maintenance than non-edible plants (Ling et al., 2018, p. 153). Modular units are able to fulfil a range of uses due to the flexibility of shape and potential to be used indoors or outdoors as required.

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Figure 2.12. Micro Intervention

2.2.1. *Precedent Outcomes*

The review of several different precedents highlighted the range of potentials that technology has enabled within architecture, and the possibilities that it presents for further development of research. Many more projects have explored the integration of plants into the built environment, from small-scale interventions such as living green walls; to utopian city-wide vertical farms (Blanc & Lalot, 2008; Despommier, 2010). Planting interventions can also enable an increased exposure to greenery and vegetation for the indoor environment. In a post-pandemic world, the importance of healthy homes has increased, with the longer periods of time spent indoors and a lack of natural stimulation.

The precedent project, 'Save Food From The Fridge', provides an example of incorporating traditional methods of food storage back into modern spaces. Through a series of food waste audits across New Zealand, the 'Love Food Hate Waste' project has estimated that nationally 157,389 tonnes of food are thrown away each year, with vegetables making up nearly 1/3 of the total wasted food (Love Food Hate Waste, 2022). By creating visual connections to food and displaying produce, food waste can be reduced. The visual connection of food within a space and the minimisation of refrigeration requirements addresses a new typology for the modern kitchen, creating direct connections between growing food, storing food, and cooking food.

2.3 Vertical Interventions

Indoor vertical planting is space efficient and maximises the productive area of the planting as illustrated in Fig. 2.13.-2.14. By being vertical, the intervention may improve the environmental impact of indoor-plant systems as stable growing conditions are maintained by being indoors (Agra et al., 2021, p. 4). Vertical planted interventions indoors can help mitigate stress, fear, anger and blood pressure; they also contribute to increased workplace productivity, which is even more relevant in the home now, as people are often working from home in less suitable conditions (Weerasinghe et al., 2020, p. 2). Psychological and physiological effects of the green wall on occupants is shown to be beneficial through a VR study testing the scale of green wall interventions in an interior space (Yeom et al., 2021, p. 9). Stress levels were higher with a large green wall when the levels of greenness were over 80%, and were reduced by a small green wall. This stems from biophilic theory; biophobia is a fear of nature elements, especially in a small room or dark space, and the savannah hypothesis that humans prefer an open space with some trees rather than a dense forest due to natural survival instincts.

Green walls can be used to maximise building performance and create healthy environments reducing building energy costs and HVAC requirements by improving ventilation, humidity and overall sustainability (Torpy et al., 2017, p. 576). Biowalls or other planting interventions can be connected to HVAC systems as natural air purification systems, to complement mechanical systems (Moya et al., 2019, p. 304).

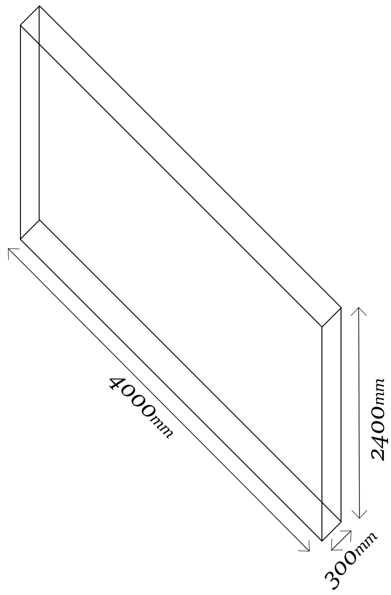

Figure 2.13. 1 sqm floor area = 2880 cubic meters productive space

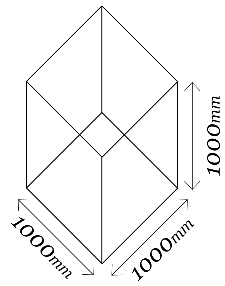

Figure 2.14. 1 sqm floor area = 1 cubic meter productive space

In an active green wall system (using active botanical bio-filtration), mechanical air induction draws polluted air in, which allows for faster metabolisation by the microbes to degrade contaminants (Fleck et al., 2020, p. 1). This research has shown that botanical biofilters are capable of reducing indoor concentrations of VOCs, CO and CO_2, which most conventional systems cannot remove. There is the potential for introduction of harmful fungal bioaerosols in the case of both active and passive green walls, however, the risk has been found to be very low and within the limits outlined by the World Health Organisation for immunocompetent people (Fleck et al., 2020, p. 4).

Active Green Wall System

Green wall plants reduce indoor CO_2 levels and affect indoor humidity (Agra et al., 2021, p. 5). The plant root zone (rhizosphere) is an effect area for removing Volatile Organic Compounds (VOCs) from the air, particularly when used with activated carbon filters (Moya et al., 2019, p. 299). Vertical gardens are useful at reducing VOCs and Sick Building Syndrome (SBS) through the bio-filtration effect of leaves and roots, particularly if the planting system is maximised as an active green wall for optimal air purifying outputs (Weerasinghe et al., 2020, p. 3). Active green walls are more effective than passive green walls for improving Indoor Air Quality (IAQ), as active green walls push air through to maximise the air improvements. Air-cleaning rates are overall more effective when using active fan-assisted hydroponics technology instead of passive vegetation systems due to more air passing through the root rhizomes of the plants, which removes VOCs (Moya et al., 2019, p. 303). Active atmospheric pollutant filtering through the incorporation of assisted aeration to the plant walls has been shown to reduce ambient indoor CO_2 (Torpy et al., 2017, p. 576). The active module operation is a positive addition to a green wall and can be implemented with a fan system at the back of the wall, in which the speed of the fan impacts the efficiency response of different plants (Torpy et al., 2017, p. 581).

2.3.1 Categorisation

Fig. 2.15. illustrates the categorisation of green interventions, which allows for a more specific literature review of the existing knowledge based on the three categories.

Baseline/Traditional

Plants in pots are the most common form of indoor planting intervention and can range in size/volume from countertop herbs to indoor trees. These have been included in the study to provide a baseline of common existing interior greenery to contrast against the results from larger-scale vertical interventions. The benefits of potted plants as a form of natural inclusion can impact both the physical and mental aspects of holistic wellbeing. With potted plants, an increased pot volume is linked to an increase in the overall biomass production, with a larger pot volume resulting in a higher carbon sequestration capability (Agra et al., 2021, p. 5). The benefits of potted plants have been shown to be primarily for wellbeing, as the productive capacity of potted plants and the quantity required for significant air quality improvements is impractical for urban settings (Torpy et al., 2017, p. 575). Additionally, the low natural light levels experienced in many indoor environments means that the CO2 phytoremediation would be less efficient, so the number of potted plants required to make a significant difference would be impractical (Pennisi & van Iersel, 2012, p. 475). The practicality of potted plants as an effective indoor intervention is, therefore, limited due to the restrictions of space in typical urban settings, encouraging the utilisation of vertical vegetated interventions for use in urban interiors.

Living Green Wall

The green wall system is more complex than potted plants and has been developed in a varied range of applications, and it can be primarily categorised by modular or continuous systems. (Hopkins & Goodwin, 2011, pp. 23–27). These systems are made up of a framing backing and are typically direct-fixed to walls, with the growing substrate panels or planters attached.

Modular System – planter boxes: Planter boxes with pre-vegetated plants installed in soil are made at a sufficient depth for plant roots to grow and are hung from metal framing with a dripping irrigation pipeline system (el Menshawy et al., 2022, p. 8).

Modular System – pockets: Plants grow in a soil or similar substrate within fabric pockets hung on a frame with a waterproof backing. As the plants grow, the root network strengthens the fabric and creates a robust system (Francis et al., 2014, p. 84).

Continuous system – felt system: This living wall system was designed by Patrick Blanc and can be applied to either building exteriors or interiors (Blanc & Lalot, 2008, p. 100). This plant wall system is made up of a light metal frame fastened to the wall, with a felt substrate for plants to be rooted into (Manso & Castro-Gomes, 2015, p. 866). The walls can effectively be any scale due to the light makeup of the structure.

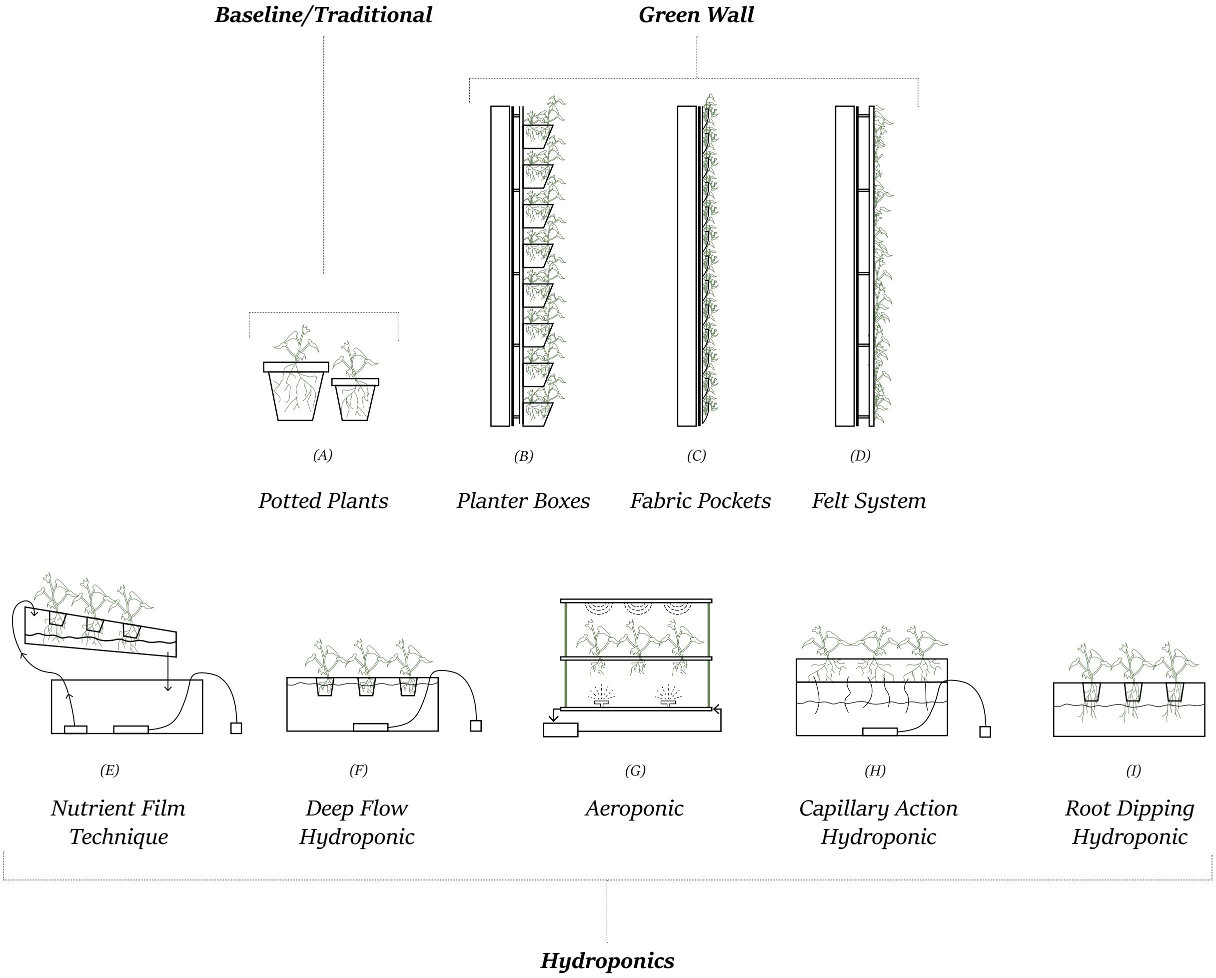

Figure 2.15. Diagram of green interventions

Practical availability of these green wall systems can be seen as one of their additional features. Fabric pocket systems are easily available on the market as products at a range of scales, however, most planter box walls or felt living walls are available as custom designs by specialised companies, limiting accessibility.

Hydroponics

Finally, hydroponics can be viewed as a whole separate system. Agriculture uses a large quantity of water, which is a resource that is rapidly becoming scarce and hydroponic systems involve growing plants with mineral nutrients in a controlled amount of water instead of soil. Hydroponics uses much less water, with 1kg of lettuce grown in an indoor hydroponic farm only needing 3% of the water required compared with a lettuce grown in a traditional outdoor farm (Tavan et al., 2021, p. 2). Most hydroponic systems with mixed crops can use 85-90% less water than standard farming methods and are able to be grown in high density units with controlled conditions, enabling consistency of harvesting (Sharma & Singh, 2019, p. 369). Plants grown under an intense light show a high level of Vitamin C and mineral substances in the edible portion of the plant with a good yield and quality, while simultaneously producing a significant amount of O_2 (Guo et al., 2014, p. 1556). Lettuce plants in a controlled environment and grown in a nutrition solution under light-emitting diodes have been shown to have an oxygen-generating capacity of 1473 g.day-1 during the later growth stages, which is enough oxygen for 1.75 person per day (Guo et al., 2014, p. 1553). When plants are in drought conditions or not getting sufficient water, the photosynthetic activity is reduced because the stomata of the plant close through a process known as photorespiration which leads to less CO_2 supply (Tavan et al., 2021, p. 10).

Closed System – nutrient film technique: The nutrient film technique is an active recovery hydroponic system which uses a tube with no growing substrate other than the nutrient solution. The nutrient solution is run through a slanted channel while the plants are suspended above, with the roots consistently being moistened by a thin film of solution running along the channel (Rosenbaum, 2020, p. 8).

Closed System – deep flow technique: Deep flow hydroponic systems use an aerated nutrient solution with plants set on a tray above a reservoir with an air pump and air stone providing aeration (Rosenbaum, 2020, p. 7). This method does not use a growing substrate and maintains a higher level of solution in the growing tray than the nutrient film technique.

Aeroponic: An aeroponic system is an active system that uses minimal water and no growing substrate, instead using a mist to spray nutrient solution onto plant roots to maintain moisture levels (Lakhiar et al., 2018, p. 4).

Open System – capillary action: Capillary action hydroponics, also known as wicking, are a passive system in which the plants sit in a growing medium above a reservoir of nutrient solution. Wicks are suspended between the two and draw the nutrient solution up to maintain substrate moisture (Mariyappillai et al., 2020, p. 82). The growing medium can easily become oversaturated with this method, causing plants to rot or die if not maintained correctly.

Open System – root dipping: Plants are suspended in individual units of growing substrate so that roots hang in the air to be exposed to oxygen and are dipped into nutrient solution at the bottom (Mariyappillai et al., 2020, p. 81). As the plants grow, the nutrient solution is absorbed and the root level grows down with the water level. This is a passive hydroponic system that does not require much maintenance.

2.3.2. Conclusion

The opportunities presented by each of the green planting interventions provide a range of potentials and barriers that require further exploration to ascertain the path for further development for the research. An analysis of the characteristics of each system will show the advantages and disadvantages across a spread of parameters.

Chapter Three

~Proposal Articulation

3.1 Comparative Analysis

To ascertain the most effective system to apply to high-density urban interiors, a comparative analysis of existing categorisations of interior green interventions has been completed. Compiling literature to identify the key characteristics of the interior green interventions enabled a comparative assessment of the advantages and disadvantages of the solutions based on a scale of low, moderate and high. The identification of important drivers for change and key barriers to implementation were highlighted through a review of existing solutions.

The diagram in Fig. 3.1. shows a breakdown of the major common green interventions applicable to interior spaces and establishes a baseline/ traditional category for comparative analysis. By identifying traditional systems for comparison, the socially accepted perception of typical interior greenery, such as potted plants, is able to be contrasted to green interventions that are less commonly applied, allowing the fundamental differences to be assessed.

The baseline system has shown a low level of inputs and maintenance when compared with the more technical living wall systems and hydroponics. However, the lesser requirements also correlate to a lower output and less advantages comparatively. Table 3.1. has identified hydroponic systems as an applicable method for residential buildings to have effective impacts in interior urban agriculture application.

Therefore, hydroponics appear to offer a range of clear technical and performance advantages for interior agricultural application over the traditional/baseline and living green wall systems. Along with the range of available systems and the lower maintenance requirements, the hydroponic systems have a range of documented research on food production capabilities and are purpose-designed for efficiency and density of planting.

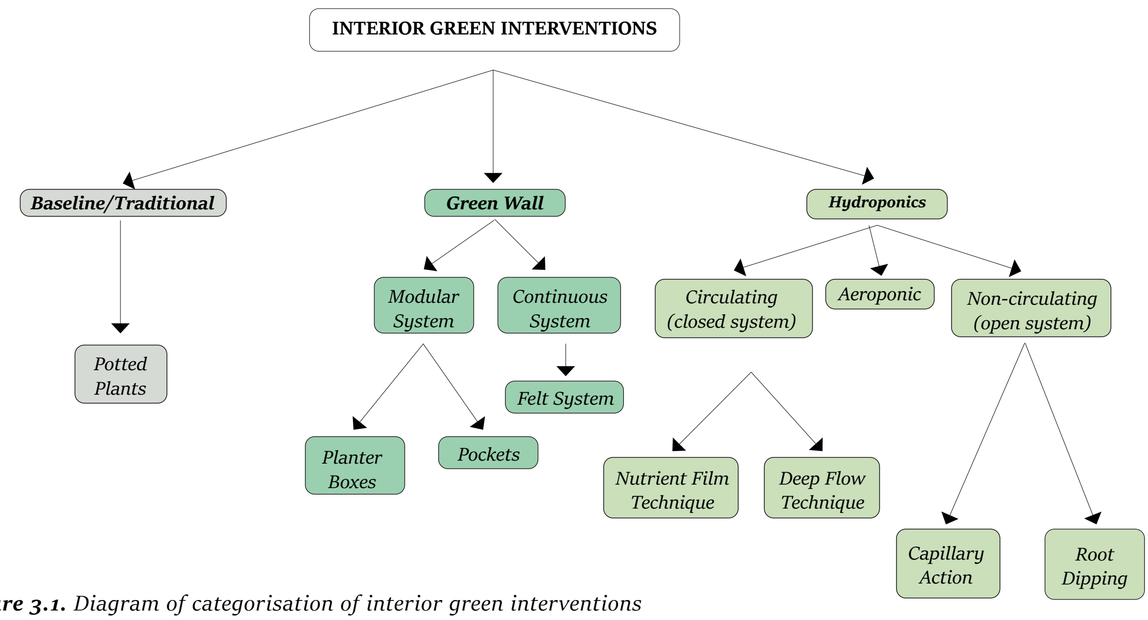

Figure 3.1. *Diagram of categorisation of interior green interventions (adapted from Mir, 2011)*

CHARACTERISTICS OF INTERIOR GREEN INTERVENTIONS

Green Intervention Type	Traditional System	Living Wall System			Hydroponic System				
					circulating		*non-circulating*		
system type	*modular*	*continuous*	*modular*	*modular*	*modular*	*modular*	*modular*	*modular*	*modular*
	potted plants	planter boxes	pockets	felt system	nutrient film technique	deep flow technique	aeroponics	capillary action	root dipping technique
prefabricated/in-situ	prefabricated	prefabricated	prefabricated	in-situ	prefabricated	prefabricated	prefabricated	prefabricated	prefabricated
passive or active fan system	passive	passive	passive	passive	active	active	active	passive	passive
natural/artificial lighting	natural	combination	combination	combination	artificial	artificial	artificial	artificial	artificial
plant species	rooted or leafy plants	climbing, rooted or leafy plants	climbing or leafy plants	shallow root systems	herb/leafy greens	herb/leafy greens	herb/leafy greens	herb/leafy greens	fruiting and leafy plants
supporting system	for plants	for module	for module	for module	for module	for module	for plants	for module	for module
manual/automated watering	manual	automated	combination	automated	automated	automated	combination manual/refill	automated	combination manual/refill
maintenance	--	pruning/ replacement	pruning/ replacement	pruning	plant/nutrient replacement	plant/nutrient replacement	plant/nutrient replacement	plant/nutrient replacement	plant/nutrient replacement
growing substrate	soil	soil	felt/soil	felt	nutrient solution	nutrient solution	air/misted nutrient	nutrient solution	nutrient solution
electricity (other than lighting)	no	yes	yes	yes	yes	yes	yes	no	no

ADVANTAGES AND DISADVANTAGES OF INTERIOR GREEN INTERVENTIONS

improving the aesthetic value	*xxx*	*xxx*	*xxx*	*xxx*	*xx*	*xx*	*xx*	*xx*	*xx*
visual experience in absence of plants	*xx*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
improving the insulation property	*x*	*xx*	*xx*	*xx*	*x*	*x*	*x*	*x*	*x*
system cost	*x*	*xxx*	*xxx*	*xxx*	*xxx*	*xxx*	*xxx*	*xx*	*xx*
maintenance cost	*x*	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	*x*	*x*
irrigation system requirement	*x*	*xxx*	*xxx*	*xxx*	*xxx*	*xx*	*xxx*	*x*	*x*
moisture problems	*x*	*xx*	*xx*	*xx*	--	--	--	--	--
technical expertise needed to maintain	*x*	*xx*	*xx*	*xxx*	*xxx*	*xx*	*xxx*	*xx*	*xx*
replacement of panels	--	*x*	*xx*	*xx*	--	--	--	--	--
food production output	*x*	*xxx*	*xx*	*x*	*xxx*	*xxx*	*xxx*	*xx*	*xx*

Key: *x: Low* *xx: Moderate* *xxx: High* --: Non applicable

Table 3.1. *Characteristics and advantages/disadvantages of interior green interventions*

3.1.1 Existing System Analysis

To further narrow the field of the research, a specific range of residential-scale hydroponic products currently available in a New Zealand context have been compiled and reviewed to gain an overview of the spread of existing product types and scales available. It was possible to evaluate the existing spread of each type of intervention, with 21 products assessed overall (See Appendix 1). In bigger markets internationally, it can be estimated that there would be a wider spread of products available, due to a higher density of market saturation.

Table 3.2. looks at products that are readily available in New Zealand at an existing fixed price, and the data spread identifies the green interventions available by cost of product against the cubic meter volume of the total product. The size of the product typically relates to the volume of food production capacity of the product. The data shows a correlation between lower cost and smaller systems/products, such as benchtop planters. The accessibility for interior application with affordable solutions is restricted by the capacity for retrofitting larger solutions into existing buildings.

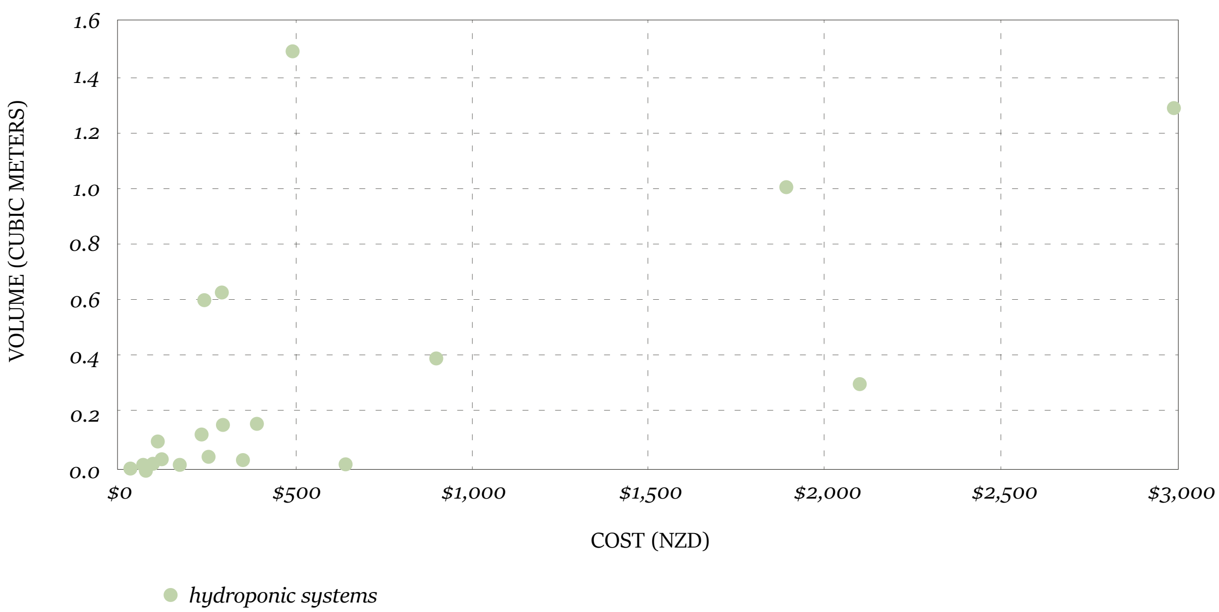

Table 3.2. *Spread of available products cost to volume scatter graph*

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Figure 3.2. Hydroponic system 'A'

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Figure 3.3. Hydroponic system 'B'

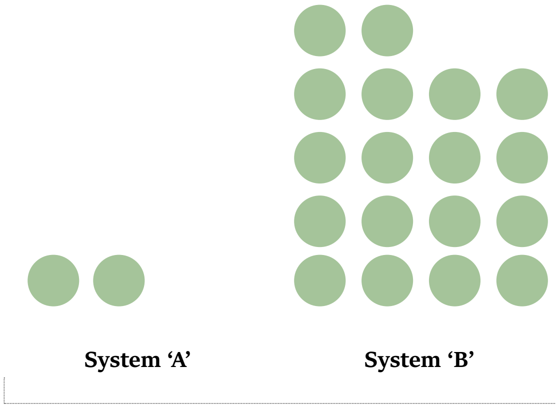

Figure 3.4. Estimated annual produce (kg)

Fig. 3.2. and 3.3. respectively show the smallest and largest hydroponic systems available which are compared to assess an estimated annual output of edible produce based on existing data (See Appendix 2). The calculations used a standard lettuce plant, *Lactuca sativa L.,* as the planted variable due to the existing detailed research on the performance of this species in hydroponic systems (Guo et al., 2014, p. 1556). Assuming a growth cycle time of 40 days, with 9.1 growth cycles occurring annually, and consistent indoor growing conditions, an annual output of produce *(Lacuta sativa L.)* can be approximated at 41.6kg for system 'A', and 374.8kg for System 'B' (Fig. 3.4.).

3.1.2 Hydroponic Growing

There are many drivers to implementing hydroponic urban agriculture solutions indoors. Among these are the lower water consumption of hydroponic systems compared with traditional farming, reduction of carbon emissions from food transportation, and improved resilience for urban centres. The uptake of interior greening interventions has been restricted by the primary identified categories of cost, space and feasibility. This was more pronounced by choosing to focus on the smaller and not especially central market of New Zealand. The barriers can be further categorised by exploring the requirements for a retrofitted intervention in an existing building. Social barriers to change include reluctance of uptake of new solutions, requiring a series of 'early adopters' to implement interior green interventions to normalise indoor vegetation and promote active agriculture in urban spaces. This is more pronounced in smaller markets, where it might take longer for a good range of early examples to become reasonably available through the efforts of the early adopters. The barriers to entry for the increased integration of advanced vertical green interventions are primarily cost and maintenance, which are the key concerns highlighted in some studies (Montacchini et al., 2017, p. 294).

Hydroponic growing methods for agriculture are ideally suited to the urban environment based on the information collated in Section 3.1. To aim for the most sustainable outcome of indoor urban agriculture application, a hydroponic system typically has small volume, low power requirements, minimal maintenance and the highest ratio of produce yield to system cost. The complexity of installation for large-scale retrofitted systems could be mitigated by integration into architectural design and implementation in newer construction projects. The integration of architecture and agriculture can be successfully executed through design solutions that implement vertical green systems from the project initiation.

The range of identified hydroponic systems involves different requirements for the running and maintenance, however, the general principles of hydroponic growing remain consistent. A water-based nutrient solution and a growing medium are the key elements required for plants to grow.

Hydroponics

Nutrient Solution

Hydroponic systems require a nutrient solution to provide the plants with the nutrients required for growth that would traditionally be sourced from the soil. A combination of essential macronutrients, micro-nutrients and non-mineral elements are combined in nutrient solutions to provide the full range of nutritional value for the plants (Son et al., 2020, p. 274). Fig. 3.5. shows a breakdown of the key nutrients by category (Asao, 2012, pp. 1–2).

The solution pH measures the concentration of hydrogen ions or relative acidity, with an optimal pH level for hydroponic vegetables illustrated by Fig. 3.6., typically within a range of 5.0 to 7.0 (Sánchez et al., 2020, p. 2). The solution is diluted into water, which must remain oxygenated to prevent the plant roots from drowning (Brechner et al., 2013, p. 16). This requires an air pump located in a reservoir for a closed-circuit reticulating system, or air pumps within the growing containers for an open system.

For more complex crops, such as fruiting and flowering plants, the pH and nutrient ratios are key to successful crops. However, for leafy greens and non-flowering crops, a nutrient solution mixture can be diluted at a set ratio to a volume of water to maintain enough of a balance for non-commercial vegetable production.

By implementing multiple open systems (non-reticulating), the capacity for a range of plants is improved, as each planter vessel can be mixed with a different hydroponic balance and concentration to suit the varying requirements of crops.

Growing Medium

Many common hydroponic systems consist of a growing medium suspended within a net cup, allowing the roots to be submersed or periodically watered by the nutrient solution. The wide range of growing mediums can have different implications for crops and is the most wasteful component of a hydroponic system, due to the need to replace the substrate for new crops. Fig. 3.7. shows the results of a study contrasting the seven most common hydroponic growing mediums using life cycle assessment to establish the substrate with the lowest environmental impacts (Vinci & Rapa, 2019). Alongside the environmental impacts of the substrates, a consideration of the crops to be grown is a key influencer in the selection of a growing medium, as an unsuitable medium for the plant types will result in poor crops. The most ideal medium property is to have a physical structure that maintains a balance of air and water storage for optimal root conditions, minimising the chances of asphyxia or drought stress, both of which can negatively impact the plant health and productivity (Mahale et al., 2020, p. 107).

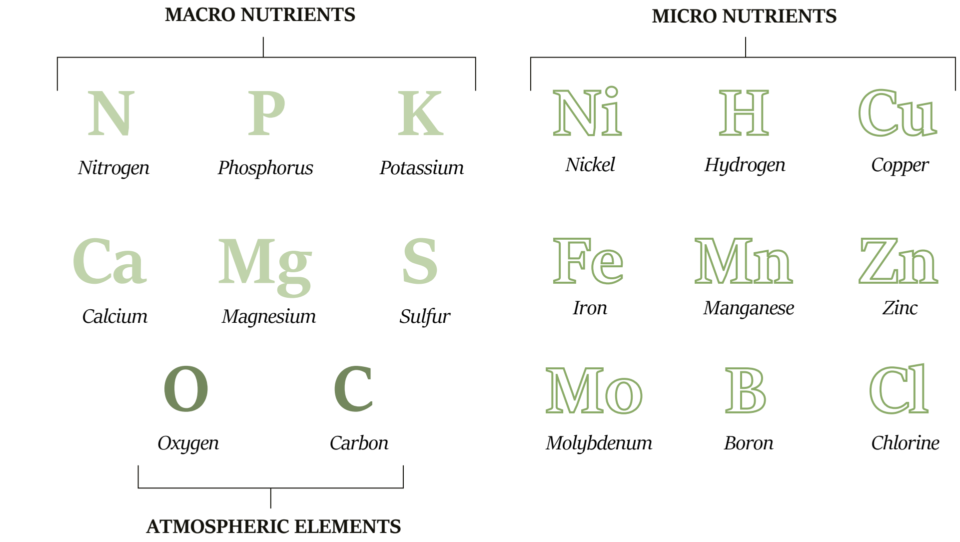

Figure 3.5. *Nutrient solution components*

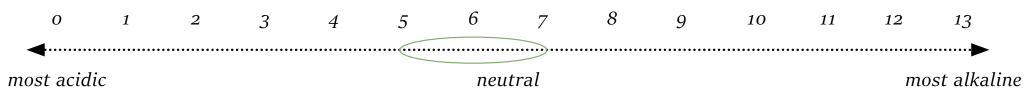

Figure 3.6. *Scale of pH range*

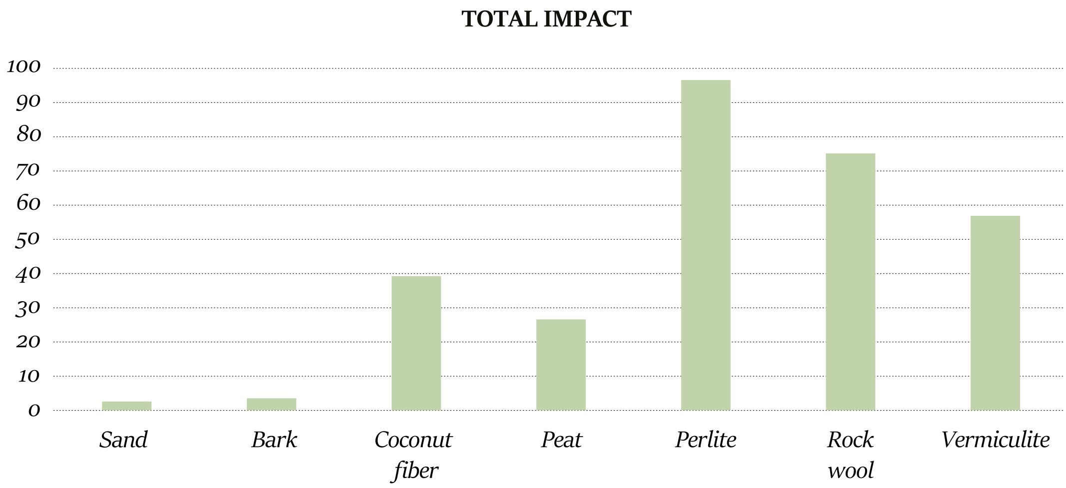

Figure 3.7. *Environmental impact of hydroponic growing substrates (adapted from Vinci & Rapa, 2019)*

3.2 Materials and Principles

The analysis of existing hydroponic systems in Section 3.1.1 highlighted that the primary materials are a metal or plastic framing, with polyvinyl chloride (PVC) piping or other plastic composites used as the growing medium vessels. The proximity of PVC to growing food raises concerns around the implications of food safety and health from possible chemical leaching into the water stream which sustains the plant roots (Petrović & Hamer, 2018, p. 8). Exploring the toxicity of materials in proximity to food is a field which falls outside of the research scope, however, it can be assumed that designing with materials that are already known to have no harmful implication is the most effective route forward. In existing systems, the materials consist of a high embodied energy and unsustainable methods of raw material extraction from the earth. The method of design and construction of existing solutions often prioritises functionality and has a resulting low level of aesthetic appeal and does not develop an architectural dialogue with the home or interior spaces. To address the issues with hydroponic systems, a full reconsideration of what constitutes a hydroponic system is proposed, with new material solutions aiming to lower the embodied energy of the intervention, reduce risk of toxic materials and provide a fresh aesthetic design for seamless apartment dwelling integration. To break down the requirements for design and integration of hydroponic systems, analysis of the existing system requirements is needed to understand the growing condition requirements.

Alternative material explorations pursued include timber, recycled metal and ceramics to lower the embodied energy of the system and reduce toxicity in the indoor environment. Fig. 3.8. shows a visual understanding of the contrast in embodied energy of materials, with air-dried softwood consisting of 0.1% of the embodied energy of virgin aluminium (Centre for Building Performance Research, n.d.). Designing for circularity and adaptive reuse is also a key criterion in design and assembly of the intervention to enable end-of-lifecycle reuse or sustainable repurposing. By ensuring that materials are kept separate and avoiding composite materials, disassembly is enabled at the end-of-lifecycle of the system.

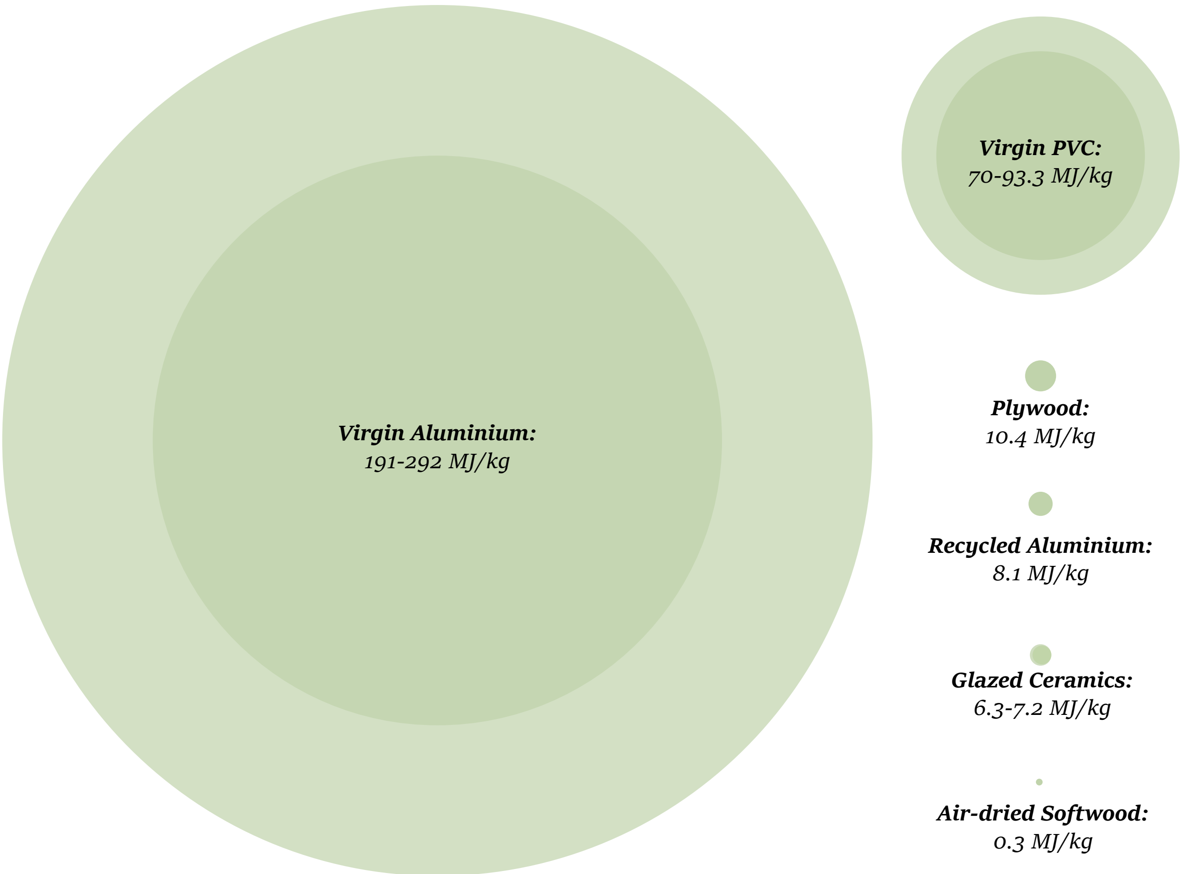

Figure 3.8. *Embodied energy material comparison (see Appendix 3)*

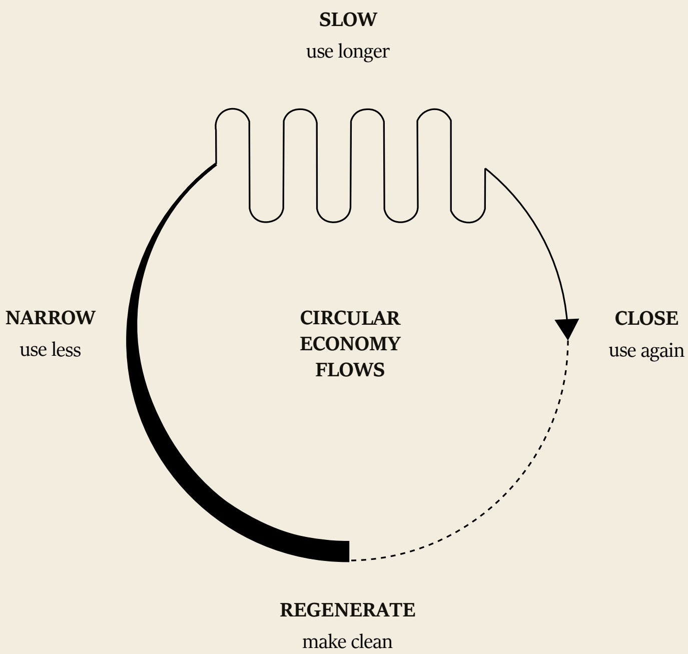

Figure 3.9. *Circular economy flow (adapted from Bocken et al., 2016)*

3.2.1 Circular Economy

The phases of a material in a linear manufacturing model consist of extraction, use, then disposal at the 'end-of-life'. The concept of circular economy incorporates purposeful material use and design principles that allow reuse at the end of an initial product life cycle (Bechthold et al., 2015, p. 58). Designing for circularity engages with using techniques for narrowing, slowing and closing resource loops (Bocken et al., 2016, p. 309). The series of circular techniques innovate towards the establishment of a circular economy flow, illustrated in Fig. 3.9. (Konietzko et al., 2020, p. 2).

Keeping different elements and materials separate reduces contamination and improves the potential for materials to remain in the circular economy. By using components that keep technological and biological material cycles separate and implementing the 'Design for Disassembly' strategy, the system can aim to fulfil circular design principles (Bocken et al., 2016, p. 311).

Ceramics

Clay is a traditional material that has been utilised effectively for a durable and easily waterproofed alternative to plastic containers or pipes and has been used efficiently for centuries. Previous work has explored the integration of architecture and ceramics in a range of innovative implementations, from architectural uses such as structure, daylighting façades and cooling systems to interior product applications in furniture and appliances (King et al., 2015, pp. 190–216). Building upon the existing body of knowledge, a series of possible methods of making were considered from the range of options for ceramic production. The most applicable possibilities were concluded to be slip casting, hand building/throwing, and 3D printing, due to the small scale of the intervention and available local technologies. Each presents a range of different benefits and limitations for form finding. Clay is a useful material for testing form finding due to its infinite reuse possibilities before the firing process.

Slip Cast Clay: Used for replicating the same item multiple times, typical method of ceramics for commercial products. Involves making a plaster mould and creating a watered-down clay called slip to pour into mould.

Hand Building/ Throwing: Can consist of making pieces by hand or with the use of a potter's wheel. Ideal for one-off pieces, or sets with some variance in shape/size.

3D Printed Clay: Allows for higher level of customisation and complexity. Runs from a digitally coded file with parametric inputs that that can be updated and redefined iteratively.

Timber

A natural material that can easily be sourced locally from sustainable forests or repurposed from existing uses, the interior application of timber means that it requires no toxic treatments. The implementation of traditional joinery techniques allows for an easily adaptable and de-constructable structure. To enable water-tightness when applied in a hydroponic system, treatment or lining would be required, which implies that timber should be utilised in a structural capacity rather than for planters.

Metal

As a highly recyclable material, most metals can be sourced from recycled rather than raw material, or repurposed from existing components. The strength and durability of metals are both key benefits to using this as a structural material. For use in hydroponic systems, galvanised metals are well suited to an environment with water that may leak, ensuring the long-term integrity of the system. At the end of the lifecycle, metal components can be either repurposed or entirely recycled into new products.

3.2.2 Timber Precedents

The range of timber structures in Fig. 3.10.-3.13. show an implementation of natural materials for growing plants vertically. With the exception of Fig. 3.13., all of these systems are soil based and not suitable for hydroponic growing. The waterproofing required does provide a challenge when using timber. Due to the capacity for bamboo to contain water, it is well suited to this system, although it does not fit into a wide range of architectural aesthetics or offer much formal diversity. The tectonic of how the urban agriculture intervention will fit into an architectural setting remains a key driver for encouraging uptake of interior agricultural systems, as form and aesthetic are important parameters for seamless integration.

The timber planters in the precedent studies create an illusion of sustainability, however, this is belied by the presence of concealed secondary materials to create watertightness. In principle, the integration of two materials should aim to be achieved in a way that adheres to circular economy principles, allowing for complete deconstruction and separation of materials at the end-of-lifecycle. The timber structures seen in Fig. 3.10.-3.12. are, therefore, applicable as case studies for structural systems that could support a secondary, but separable, watertight planter for the hydroponic nutrient solution.

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Figure 3.10. *'GrowMore'*

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Figure 3.11. *Para Eco House*

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Figure 3.12. *'Greenwall'*

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Figure 3.13. *Bamboo Urban Garden*

3.2.3 Form Precedents

Fig. 3.14.-3.17. show a range of innovative designs and systems for indoor vegetable growing. The use of different materials such as glass, concrete, terracotta and timber allow for natural forms to be emulated through sculptural expression. Biophilic design concepts filter through and play a key role is establishing the integration of nature indoors. The key issue with this set of precedents is the low volume of food able to be produced, as the main focus has been the form and aesthetic output.

The dialogue between form and function should achieve a balance to ensure the most effective outcome that integrates both aesthetic importance and functional productivity.

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Figure 3.14. *Hydroponic Herb Garden*

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Figure 3.15. *Amphorae*

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Figure 3.16. *The Brot*

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Figure 3.17. *Aeva Hydroponic System*

3.2.4 Biophilic Design Principles

The term biophilia refers to humans' inherent affiliation with nature (Söderlund, 2019, p. 1). Designing for wellbeing and an enhanced sense of biophilia in the urban environment indicates that the form and aesthetic of the intervention should aim to integrate biophilic design principles. There is a wide range of research highlighting connections between wellbeing and biophilic design, showing that the current modern apartment design typologies are lacking in their ability to connect occupants to a natural environment (Beatley, 2018; Gouveia et al., 2020; Kellert & Calabrese, 2015; Söderlund, 2019). The organic forms and close affiliation to nature seen in traditional architecture has been lost in the sterile modern forms of many urban dwellings, increasing the dissonance from the natural world (Söderlund, 2019, p. 14).

The biophilic design attributes engage with the human senses and are broken down into the three categories of direct experience, in-direct experience and experience of space and place illustrated in Table 3.3. (Kellert & Calabrese, 2015, pp. 12–20). By implementing elements from each of these categories into architectural practice, multisensory spaces are created that are evocative of biophilia on either a conscious or subconscious level. Vegetation and planting indoors as an element of biophilia can provide a range of measurable benefits that engage with the senses (Modi & Parmar, 2020, p. 5).

The use of natural materials such as ceramics, and the opportunity that 3D printing provides to develop biophilic forms and patterns allows for the urban agriculture intervention to be effective in evoking biophilia both through its form and function. The integration of biophilic design is, therefore, one of the key parameters for consideration.

DIRECT EXPERIENCE	IN-DIRECT EXPERIENCE	EXPERIENCE OF SPACE AND PLACE
light	*images of nature*	*prospect and refuge*
air	*natural materials*	*organised complexity*
water	*natural colours*	*integration of parts to wholes*
plants	*simulating natural light and air*	*transitional spaces*
animals	*naturalistic shapes/forms*	*mobility and wayfinding*
weather	*evoking nature*	*cultural and ecological attachment to place*
natural landscapes and ecosystems	*information richness*	
fire	*age, change and the patina of time*	
	natural geometries	
	biomimicry	

Table 3.3. *Biophlic design attributes (adapted from Kellert & Calabrese, 2015, p. 12)*

3.3 Situational Application

The urban environment is dominated by medium and high-density apartment dwellings (Fig. 3.18.). Ideally, an apartment will contain a balcony which provides access to nature, however, the potential for food production on a balcony space, while maintaining accessibility for outdoor relaxation and function are limited. The apartment, thereby, presents itself as the optimal site for an interior urban agriculture intervention, providing the opportunity for food production and improved climate resilience in a setting that is, otherwise, bereft of natural interventions.

Apartment Performance

Within a New Zealand context, the annual temperature and humidity fluctuations vary across the range of regions, however, do not typically reach extreme levels. Analysis of apartment thermal performance is operating under the assumption that the urban agriculture intervention will be integrated as part of the design process in a new build, meeting high thermal comfort and ventilation standards for minimal fluctuations in the indoor thermal environment.

There has been significant research on the impacts of plants indoors on VOC removal and lowering of excess CO_2 levels, which can have an overall impact on the energy demands for ventilation loads in apartments (Burchett, 2010, p. 35).

Hydroponic System

Plants ideally grow the best in a stable climate, without major fluctuations in temperature. Both air and water (nutrient solution) temperature are relevant factors in the rate of plant growth, with an ideal range for optimal enzyme activity (Brechner et al., 2013, p. 17). The ideal parameters for a controlled environment are outlined in Table 3.4., with a comparison to the ideal performance for an apartment indoor environment.

It is important to note that for optimised growth and the highest possible output, the hydroponic growing parameters are for commercial production. While the designed intervention may not achieve the same level of productivity without exact temperature and humidity controls, the benefits to the interior space will still be significant, even if total productivity is somewhat less efficient.

The initial start-up cost of beginning a hydroponic system provides a key barrier to entry for many people, however, the implementation of hydroponics as an architectural intervention means that the infrastructure is already set up so the feasibility for everyday people to use the system becomes a much more tangible goal. By having the intervention as a part of the system, it normalises it and, therefore, the growth of demand through the increase of use could potentially forecast the lowering of prices.

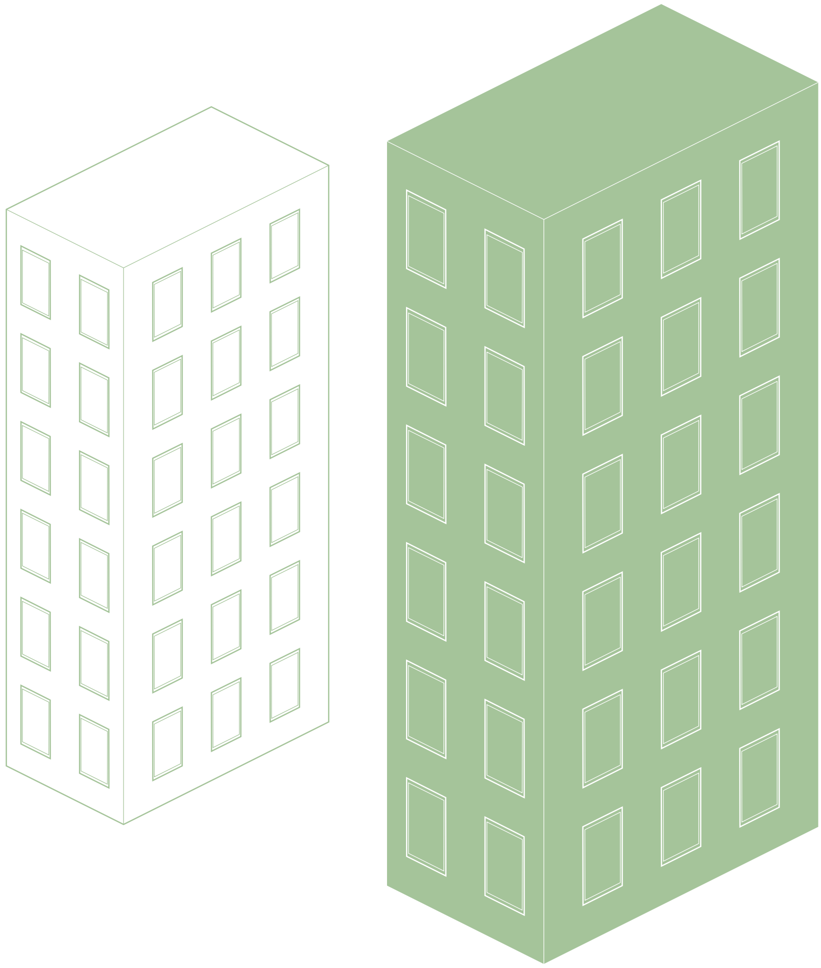


Figure 3.18. *Apartment blocks*

	Hydroponics	Indoor Environment
Air Temperature	19°C - 24°C	20°C - 26°C
Water Temperature	24°C ≤ 25°C ≥ 26°C	n/a
Relative Humidity	50% - 70%	30% - 60%
Carbon Dioxide	1,500 ppm	1,000 ppm

Table 3.4. *Ideal environmental set points comparison*

3.3.1 Kitchen

This section will comprise of a series of analyses of standard kitchens and the evolution of the kitchen to the modern format. The standardisation of an agricultural system into the modern kitchen should be done through new builds and a model of early adoption to absorb the system cost into the construction cost. The long-term project aim would be to create impactful change across the population, providing access to sustainable food solutions across the board.

The situational application of the urban agriculture intervention is the apartment kitchen, and the research investigates how agriculture can become an integral part of the system. The outcome of the explorations will stem from a fresh perspective on kitchen design and the notions of the space.

The narrowing of scope to specify apartment kitchens provides a range of unique parameters for design. Typically, kitchens are located on external walls of a house and include windows and multiple locations for connection to services. The use of apartment interiors is more restricted, with services ideally being contained to one inter-tenancy wall and the kitchen often located further away from the windows due to the limited amount of external wall and window spaces being allocated for living areas and bedrooms. This results in the kitchen being paired with the bathroom toward the center of the building. The potentials that arise from this for a hydroponic urban agriculture intervention include the benefits of using LED lighting in a darker space as a feature and productive tool for improved illuminance. The wellbeing benefits of having plants as an aesthetically visual element in a more internal space is also a key factor in the design.

Currently, the defined fixed elements of a kitchen, according to the Auckland Design Manual (n.d.), are fridge, oven, dishwasher, sink, benchtop stovetop, microwave (Fig. 3.19.). Key kitchen layout typologies are illustrated in Fig. 3.20. and are typically one or a combination of; galley, return, three-sided or island (Marriage, 2021, p. 141):

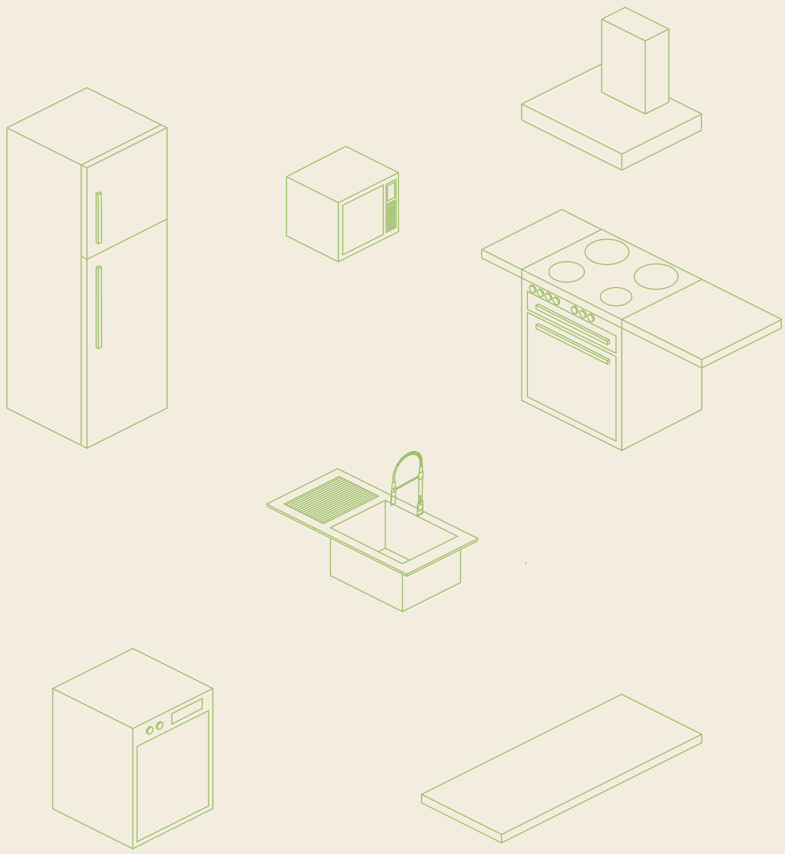


Figure 3.19. *Standard fixed kitchen elements*

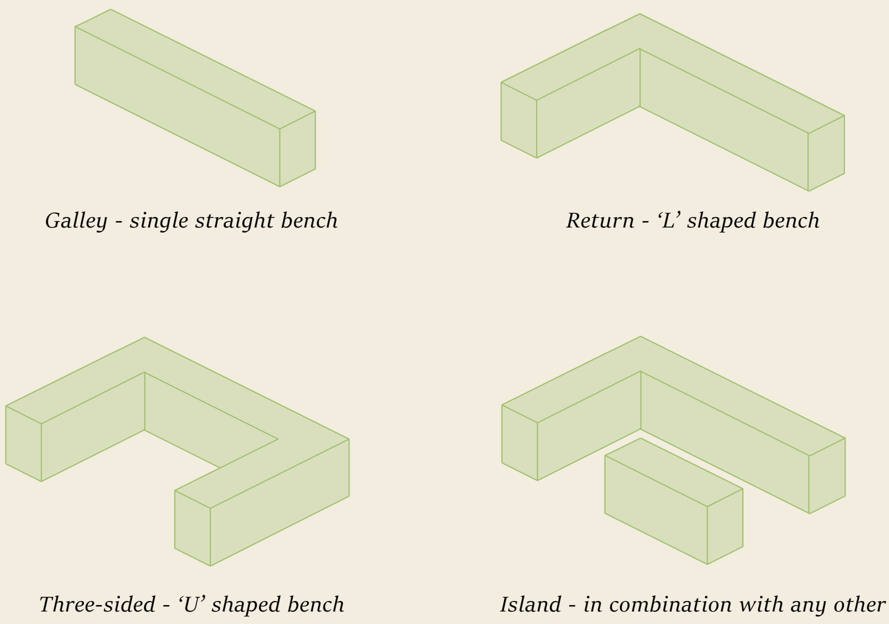


Figure 3.20. *Kitchen typologies*

Figure 3.21. *Testing hydroponic growing*

3.3.2 Lighting

Hydroponics

Within an apartment kitchen, where the urban agriculture intervention will be located, there is a base level of natural light, which is subject to seasonal and diurnal variability. Most hydroponic systems utilise artificial lighting in the most effective range to simulate solar radiation for photosynthesis; red wavelengths of 400-500nm and blue wavelengths 600-700nm are the most productive for plant growth, known as Photosynthetically Active Radiation (PAR) (Nederhoff & Marcelis, 2010, p. 46). To achieve optimal growing results, LED (light emitting diode) bulbs can be used as an energy efficient solution with a faster growth rate than natural light, illustrated in Fig. 3.22. (Promratrak, 2017, pp. 139–140). While the red and blue lighting is the most effective, the LEDs can be arrayed with white lighting to create full spectrum growth lights, which allows for a more neutral lighting aesthetic for a hydroponic system in a home.

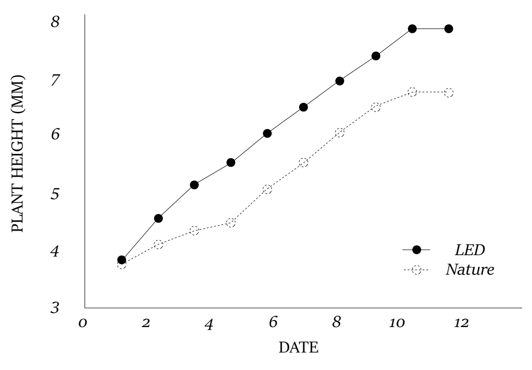


Figure 3.22. *Growth comparison of lettuce oak*

Kitchen

A range of variables are key contributing factors to the lux levels (lx) and illuminance in a kitchen space. Using the reflectance of the kitchen surfaces and the illuminance of the lights, to calculate the lux level at the working plane (the kitchen bench, 900mm above floor) the impact of the hydroponic lighting system on the kitchen illuminance can be calculated (McGuiness et al., 1982, p. 10). The optimal illuminance for visual comfort in a kitchen is 200 lx – 300 lx for general illuminance, with a higher lux level required for task areas such as bench tops, between 350 lx – 800 lx(Norgate, 2015, p. 67).

The lighting conditions for hydroponic systems are able to be automated to a timer. To simulate daylight cycles and natural growing environments, the lighting is automated to run for 16 hours per day and turn off for an 8-hour period overnight, which coincides with typical kitchen usage hours, allowing ambient lighting to be provided to the kitchen during the working hours. Supplementary lighting will be required for sufficient illuminance in the kitchen in evenings and mornings when there is no natural daylighting to supplement the hydroponic lights.

3.4 Spatial Integration

An analysis has been undertaken in order to better understand how standard kitchens can be integrated with an agricultural hydroponic system, using the four basic kitchens typologies identified; galley/I-shape, return/L-shape, three-sided/U-shape and island.

The kitchen work triangle is a method commonly used to define an aesthetic and efficient kitchen layout. The three points of the triangle are the fridge, stove and sink, which equate to food storage, cooking and cleaning. In-between each of the points of the working triangle, a work surface is beneficial to separate the zones. The distance between each of the work stations should be between 1.2m-2.7m with a total sum of 4m-7.9m combined (Pejic et al., 2020, p. 200).

The relationships between the three points of the triangle and other parameters of importance within the kitchen are established by Pejic et al. (2020) through a study of automatic rule-based kitchen layout design (Fig. 3.24.). By establishing the urban agriculture intervention as a replacement for a window in an apartment kitchen and also defining the other key parameters that need to be located close by (water for the plants and cleaning to rinse or prepare harvested food) the relationship to the other aspects of the kitchen can be defined.

Fig. 3.23. illustrates the ideal arrangement of the relationships between the kitchen working triangle components, showing the primary links made between each point within the kitchen. The urban agriculture intervention component is integrated as the quaternary element for consideration. Based on the workflow from growth to cooking/storage, the intervention should be located in conjunction with the 'cleaning' section of the working triangle and near to the 'storage' section, which removes the intervention from excess heat produced by the oven and facilitates an effective and intuitive kitchen design.

Fig. 3.25. locates the intervention in relation to the working kitchen triangle and arranges the other elements in a hierarchy of importance and locality of distance to the intervention.

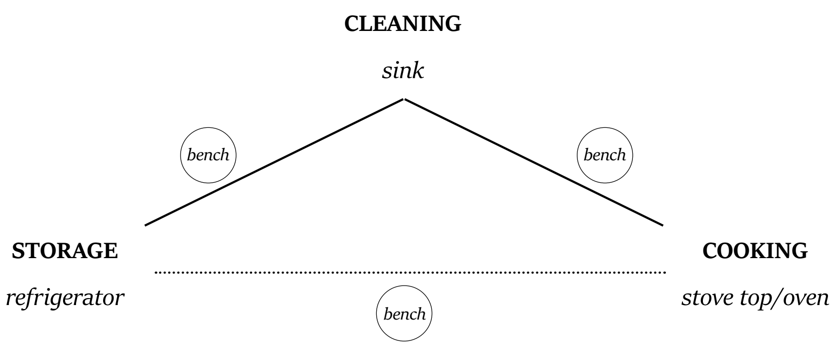


Figure 3.23. *Kitchen working triangle*

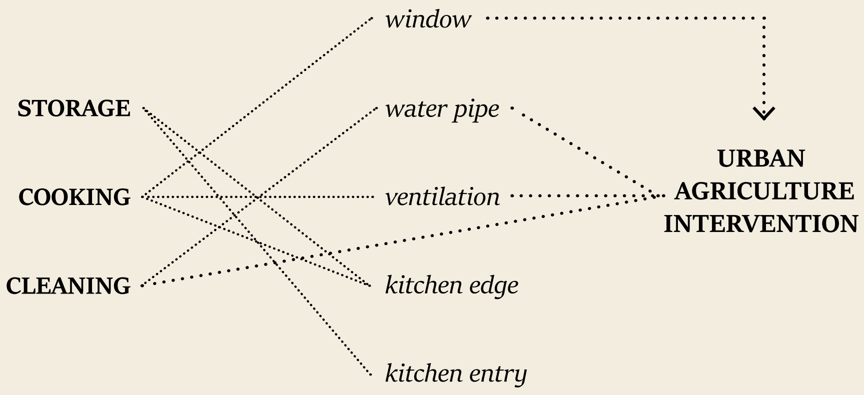


Figure 3.24. *Working kitchen relationships*

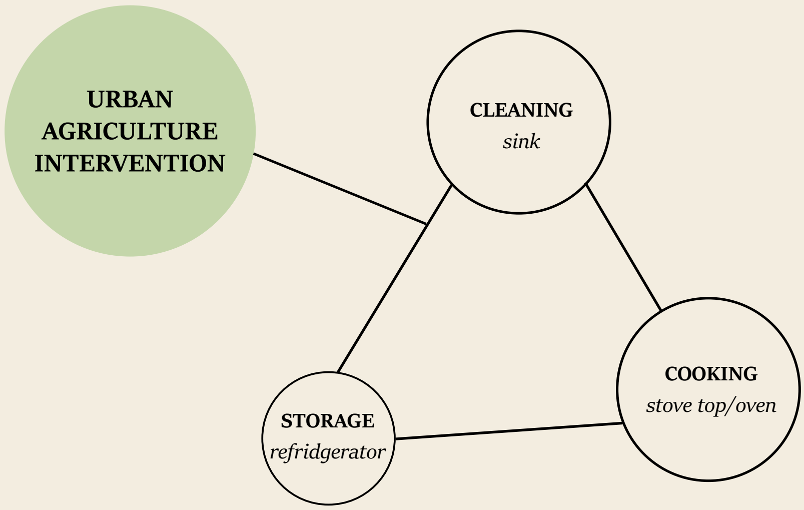


Figure 3.25. *Interjection of urban agriculture intervention with proposed kitchen hierarchy*

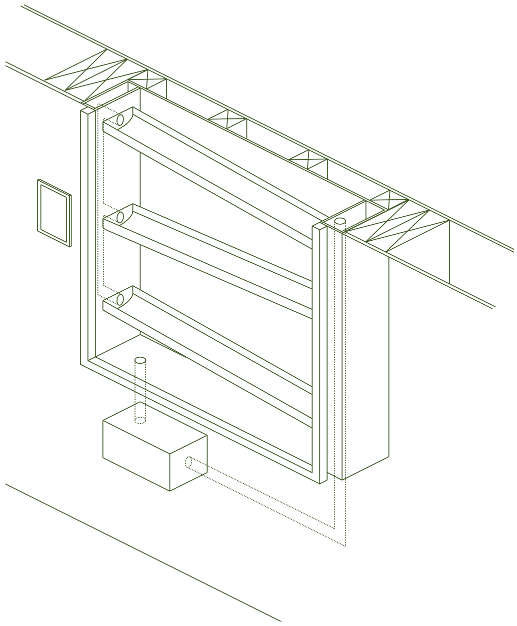


Figure 3.26. *Diagram of built-in hydroponic system*

Figure 3.27. *Indicative render of built-in system*

3.4.1 Massing

Initial modelling of an above bench intervention based on existing hydroponic systems in Fig. 3.26. and 3.27. show that the light and visual access to plants is restricted to a small area within the kitchen. Alternatively, redesigning an open plan space with a hydroponic partition wall means the visual access to plants is improved throughout the apartment and the volume of productive food area to floor area ratio is maximised by the use of a vertical intervention with a greater height ratio, as established in Section 2.3.

To undertake an initial study of how the implementation of these changes would transform the kitchen work space, a series of programmatic kitchen massing studies have been implemented (Fig. 3.28.). In the programmatic studies, the intervention massing has been placed into each of the four key kitchen typologies set out in Section 3.3.1. The three elements of the working kitchen triangle have been placed strategically in relation to the intervention according to the parameters set out in Section 3.4 to employ optimised kitchen workflows and ensure connections are maintained.

The design process will focus on finding solutions that enable a large-scale hydroponic system and integrate it into a partition wall to function as an operational component of the kitchen. The aim is to change perceptions of food production and to normalise it as a key kitchen element in the same way that a dishwasher or microwave has slowly trended to become a standard fixture of the modern kitchen. The target solution will promote self-sufficiency, food resiliency and aim to localise food production to minimise carbon emissions and packaging from food transport to mitigate food shortages caused by climate change or supply issues.

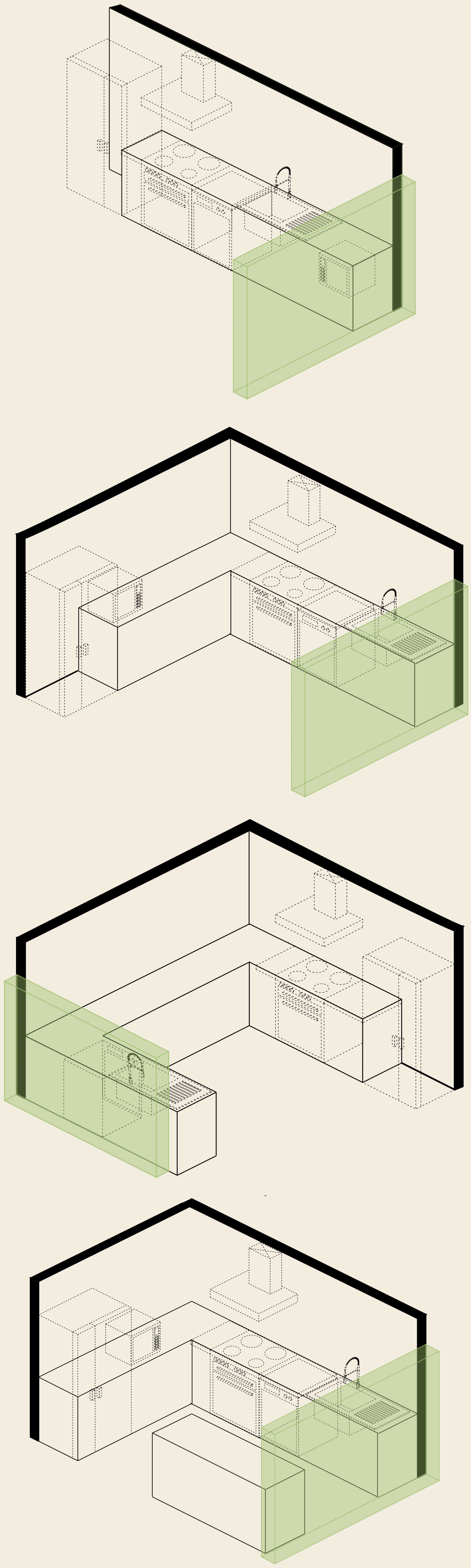


Figure 3.28. *Kitchen massing diagrams with green wall intervention*

3.5 Technical Parameters

LIGHTING	
distance above plants	300-500mm above plants for bulbs of <200 watts
adjustability	ideal but not essential
bulb type	full spectrum LED bulbs
NUTRIENT SOLUTION	
transferral	manual refill or automated pump circuit
ratio of nutrient to water	5ml nutrient solution : 1 litre water
nutrient make-up	N, K, P, Ca, Mg, S, Mn, B, Fe, Cu, Zn, Mo
PLANTING AREA	
distance between plants	100-200mm for leafy greens; 300-350mm for larger plants
diameter of planting cup	approx 30-50mm - variable depending on brand
minimum no. of plants required	variable depending on planter volume
height of growth space above planter	300mm minimum
FRAME/STRUCTURE	
material	timber or recycled metal
approx weight to be supported	planter weight approx 3-5 kg (without water)
circular design connections	potential for disassembly required
PLANTER	
material	NZ classic white clay - bisque fire 1000°C and glaze fire 1150-1280°C
kiln diameter	400mm diameter
no. of kiln shelves	6 shelves
capacity for 3D printing	required
planter depth	80-100mm high
GROWING MEDIUM	
medium type	peat/coconut jiffy pellets or rockwool cubes
support for medium	net cup grow pot
MISC. REQUIREMENTS	
lightproof	ceramic planter requires lid to maintain dark space for roots
water oxygenation	airpumps in planters or reticulating oxygenated reservoir (for active)
hydroponic system type	passive or active reticulating system

Table 3.5. *Technical design parameters*

3.6 Conclusions

The benefits of vertical green interventions for indoor application compared against the baseline/ traditional method of indoor greenery have been highlighted to be ideal for high-density urban interior spaces. Research into residential hydroponic systems should concentrate on developing accessible and productive hydroponics for widespread integration into urban environments for improved food security and resilience in cities moving into the future. The volume of food required to be produced for an average household to promote resilience and create significant impact on the carbon footprint of food sourcing in cities means that a larger intervention with a much higher output of produce is required for further implementation of urban agriculture solutions (comparison shown in Section 3.1.1).

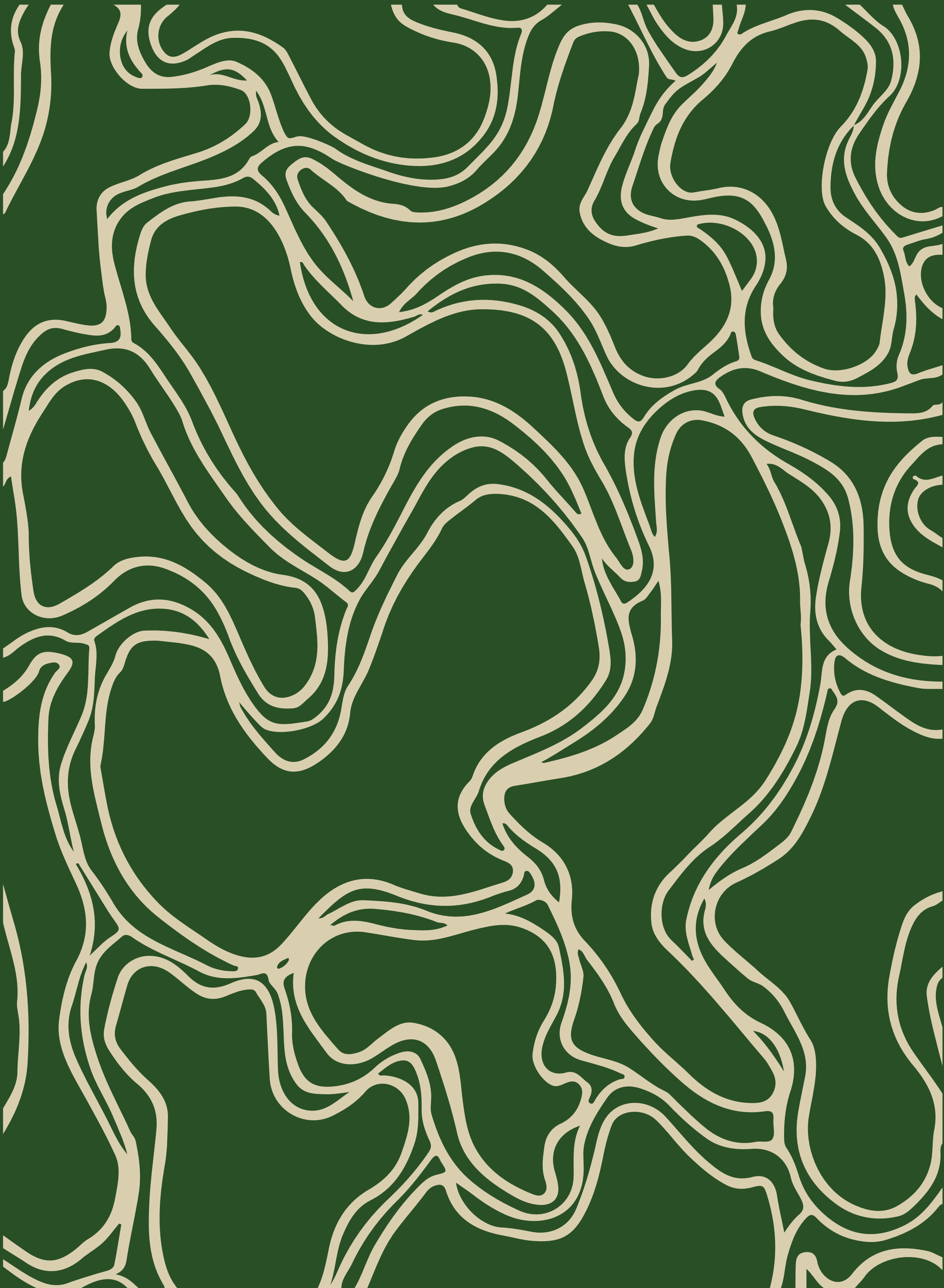
However, this research has found that while there are very tangible challenges when designing a system to be retrofitted into existing architectural framework, it seems possible that none of these aspects would present as issues if the systems were installed at the time of construction of new buildings. The barriers to implementation, such as upfront cost of system, floor or bench space in apartments, and risks to buildings associated with any form of retrofitted designs that require plumbing or power. Therefore, further research and design is recommended to focus on the inclusion and promotion of purpose-built hydroponic partitions in the design phase of new construction for integrated architectural urban agriculture solutions indoors.

Based on the findings from examining existing solutions, the current standard of using primarily plastic and aluminium materials should be challenged through alternative material explorations that can maintain effective and functional hydroponic systems with a lower embodied energy. The precedents in Section 3.2.2 and 3.2.3 exemplified possible different uses of material on a small-scale product level. The research should aim to integrate the intervention into an architectural space and on a larger-scale to improve productivity and impact.

The primary outcomes from analysis of case studies inform the design parameters for the next stages of research:

a) Exploring alternative materials for a hydroponic system.
b) Integration of food storage and food production into domestic kitchens to transform architectural dialogue within the kitchen space.

A set of parameters for design have been established in Section 3.5 (Table 3.5.) based on the literature and systems analysis undertaken throughout this chapter. These parameters can be implemented in the design stage when technical and systems integration is required, to ensure optimal design outcomes.



Chapter Four

~Design Exploration

4.1 Introduction

This chapter uses methods of drawing, digital modelling and physical making to explore the possibilities for a hydroponic partition wall. Fig. 4.1. shows the parameters that have been established through literature review and initial findings. These parameters encompass a wide range of fields and the convergence of these is a key requirement for a successful design output (Fig. 4.2.).

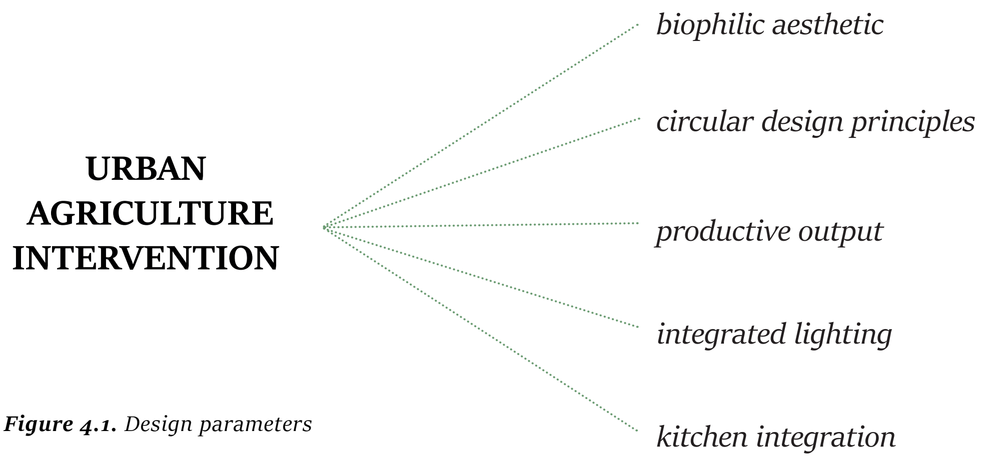


Figure 4.1. *Design parameters*

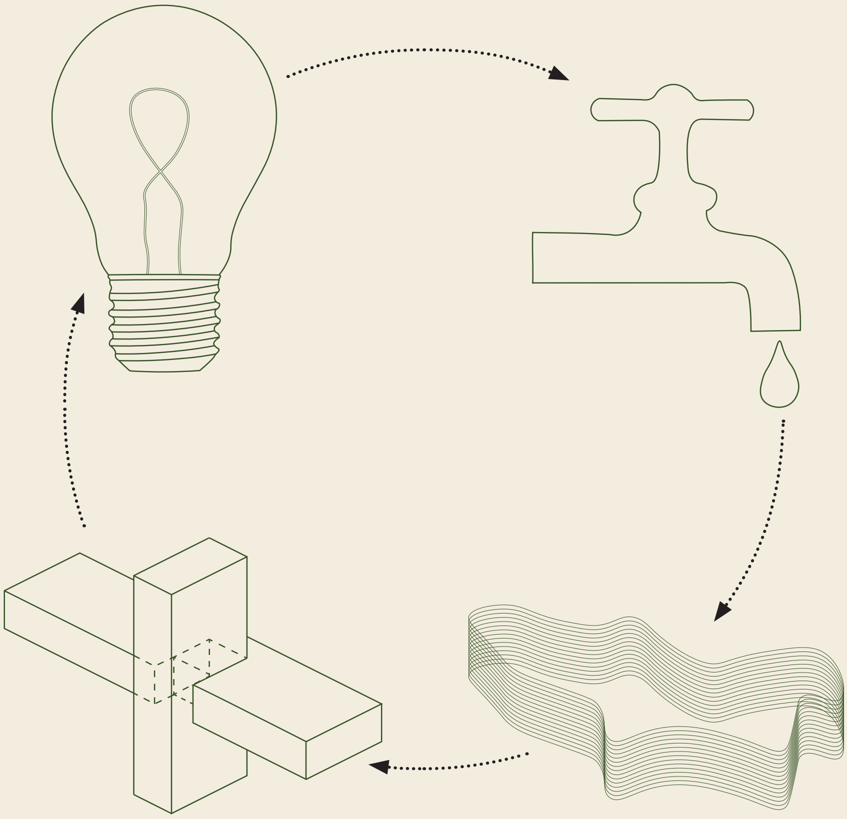
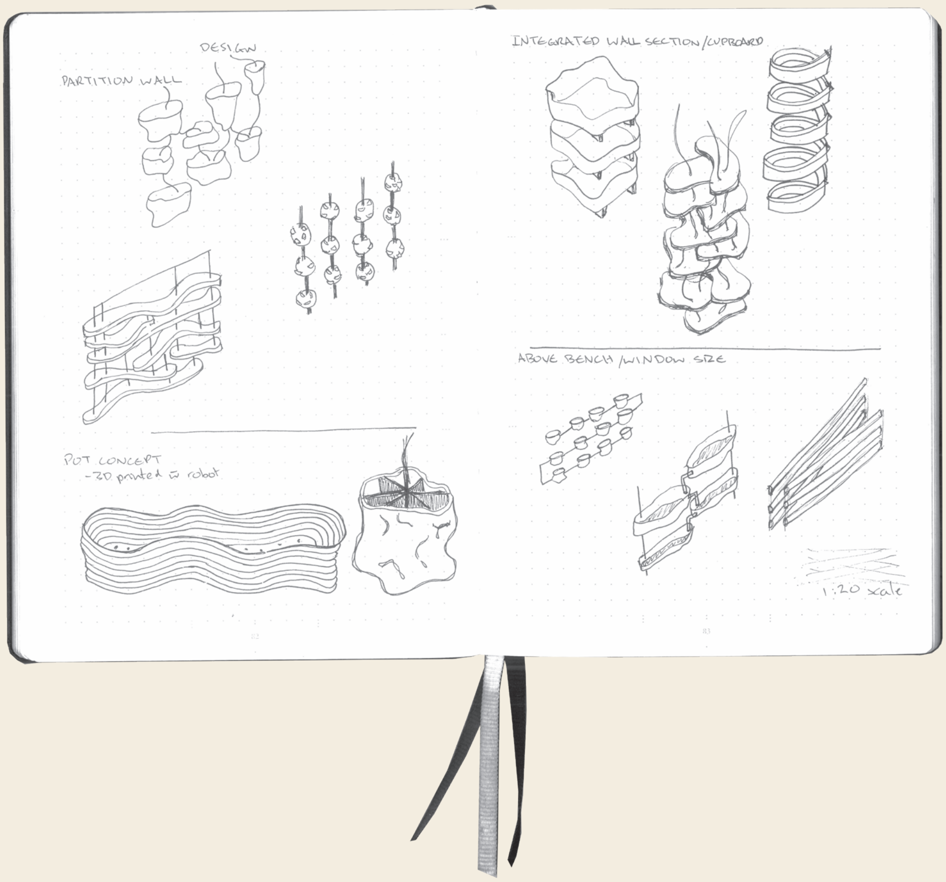


Figure 4.2. *Integration of parameters*

4.2 Design Concepts

Initial design sketches (Fig. 4.3.-4.4.) looked at methods of incorporating biophilic properties into a hydroponic system based on the research findings. Investigation of new methods of making explored timber and ceramic as material alternatives to replace the plastic and metal of typical systems.

The preliminary stage of design focuses on form-finding and research through design to push the boundaries of what a hydroponic system is typically perceived to be. There is a focus on forms that can be developed into partitions as the selected application established in Section 3.6, and explorations that consider interesting materiality.



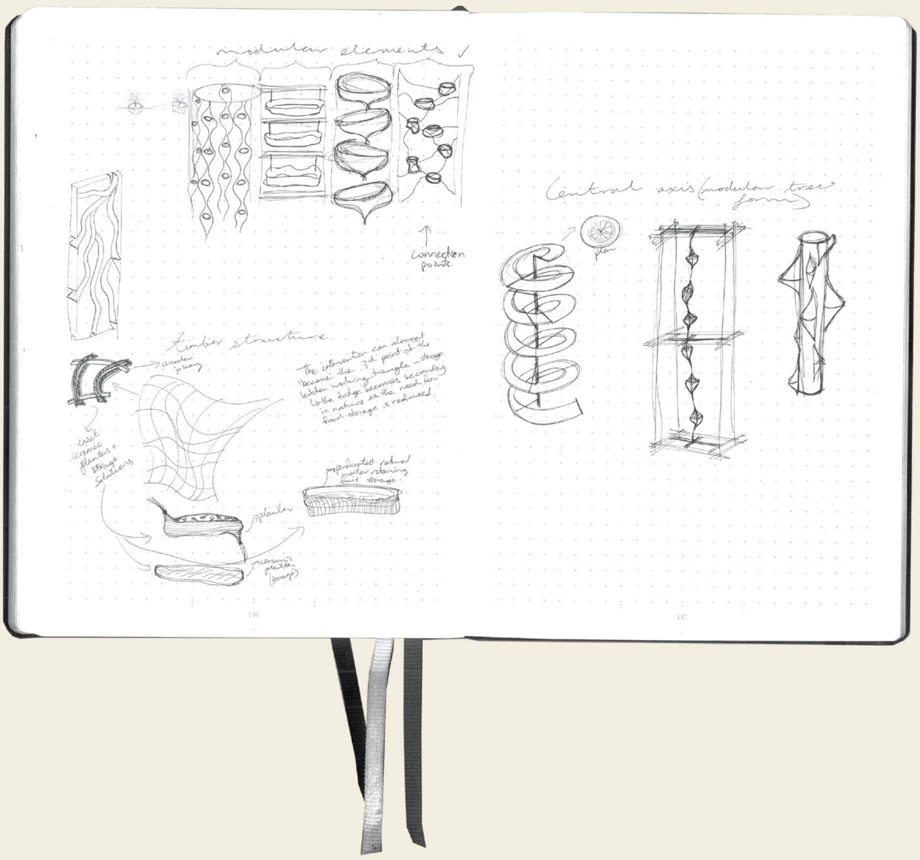


Figure 4.3. - 4.4. *Design sketches*

4.2.1 Physical Modelling

Figure 4.5. *Clay net cup*

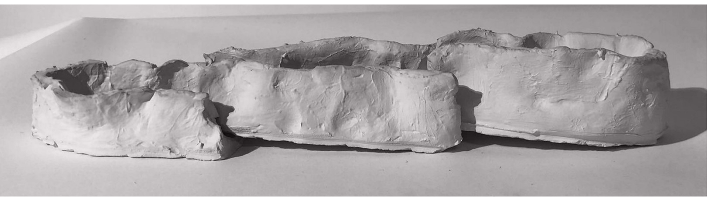


Figure 4.6. *Connecting clay section6*

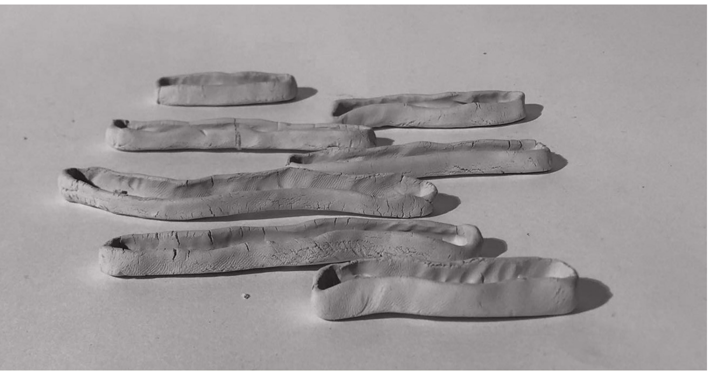


Figure 4.7. *Clay half-pipe planters*

Initial physical modelling with air dry clay used basic hand building techniques and was used to explore the application of the aesthetic qualities of clay to the initial design sketches.

The test net cup (Fig. 4.5.) was successful as a 1:1 scale trial of replacing the plastic net cups (required for holding a hydroponic growing medium) with a ceramic option, however, it was concluded that the time taken to make one cup with enough strength to hold together was not a viable route due to the time taken and volume of net cups required for a fully functioning hydroponic system. Further exploration was then required into other material alternatives to plastic.

The results of the initial testing of planter forms (Fig. 4.6.-4.7.) revealed the difficulty of working with clay on such a small scale (1:20) as the thickness required does not translate well into small pieces. The testing also showed the difficulty of hand building pieces to interlock together, due to drying shrinkage and inaccuracy. This could be mitigated through the use of the ceramic 3D printing with the robot, as shrinkage will occur at an even rate, so parameters can be controlled for a closer margin of accuracy.

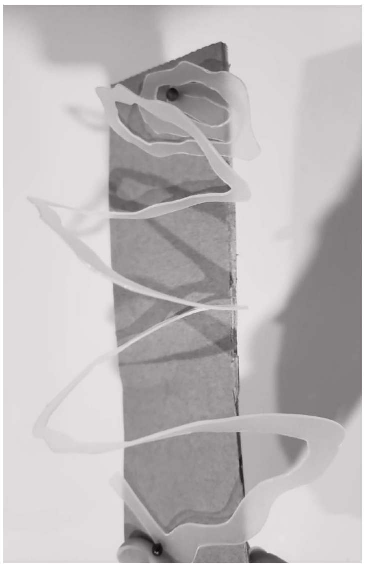
 

Figure 4.8. - 4.9. *Physical testing of abstract partition*

Further physical explorations of form finding based on initial iterations explored ways of extending the design ideas through abstract curves inspired by biophilic design. Transitioning some of the initial sketched forms into physical partition modelling (Fig. 4.8.-4.9.) highlighted a need for further refinement of forms, which led to a shift to digital modelling.

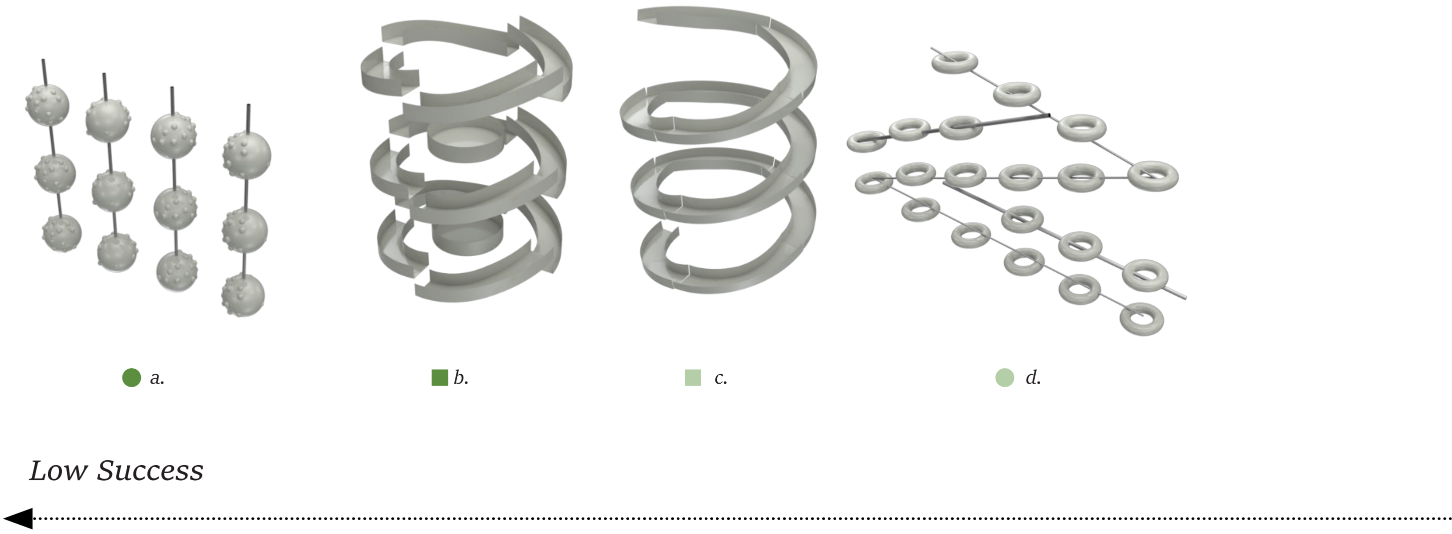
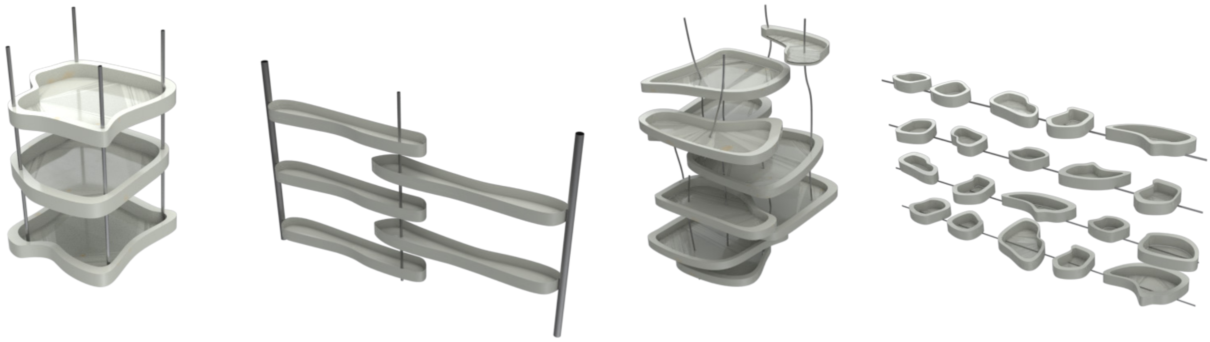


Figure 4.10. *Digital models: iterations a-h*

4.2.2 Digital Iterations

Initial explorations translated sketching and visualisation of the biophilic design principles and design considerations into forms that would be applicable as hydroponic systems, and could be developed into modular components or partitions (Fig. 4.10.). By assessing these from low to high success, design parameters have been considered in the design matrix (Table 4.1.) to ascertain the highest integration.



e. f. g. h.

High Success

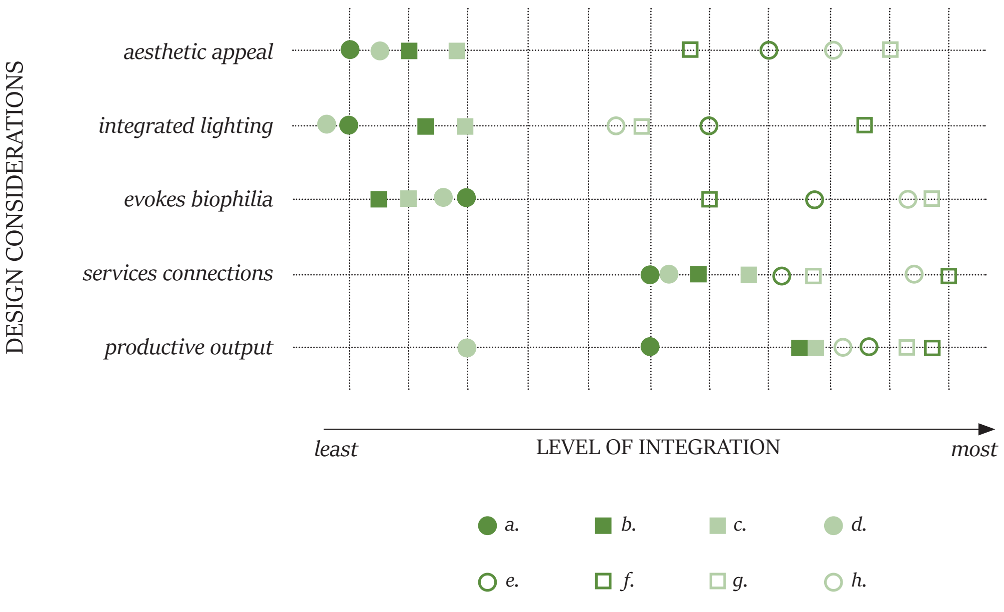


Table 4.1. *Design matrix*

4.3 Biophilic Form Abstraction

Form finding through biophilic design inspiration provided an opportunity to push the partition design further and achieve a more natural integration of biophilic forms (Fig. 4.11.). By exploring form without programme, the biophilic design principles explored in Section 3.2.4 are able to be explored freely, without the restraints of technical system application.

By sketching biophilic-inspired images and drawing inspiration from a range of natural phenomena, both two-dimensional and three-dimensional explorations have been achieved to broaden the scope of design. Two avenues have been explored from the initial sketches:

a) digital layering and distortion of the scanned drawings (Fig. 4.12.-4.13.).

b) physical manipulation of drawings by cutting out sections and pinning/ stitching to a backboard (Fig. 4.14.-4.17.).

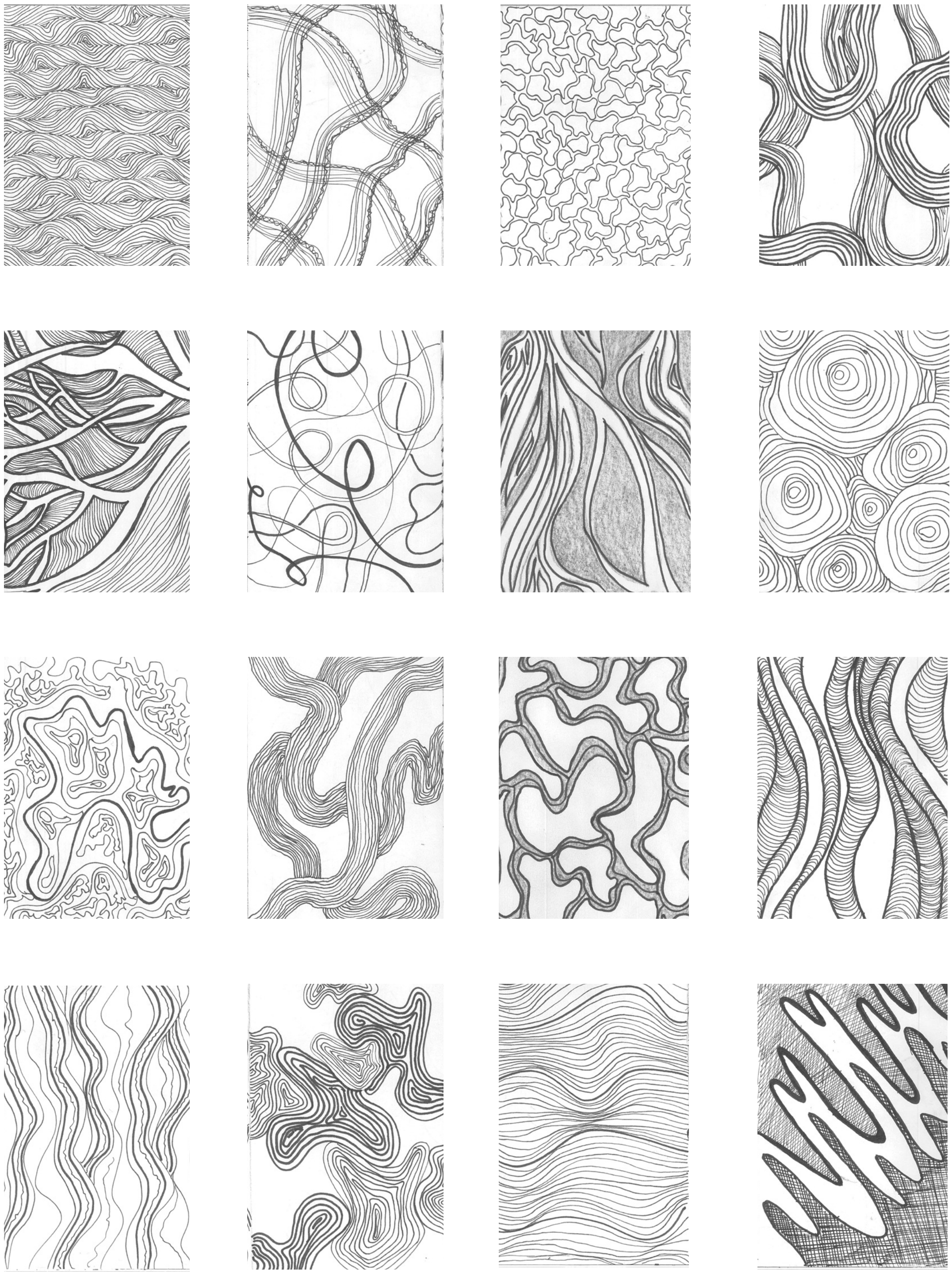


Figure 4.11. *Biophilia inspired drawings*

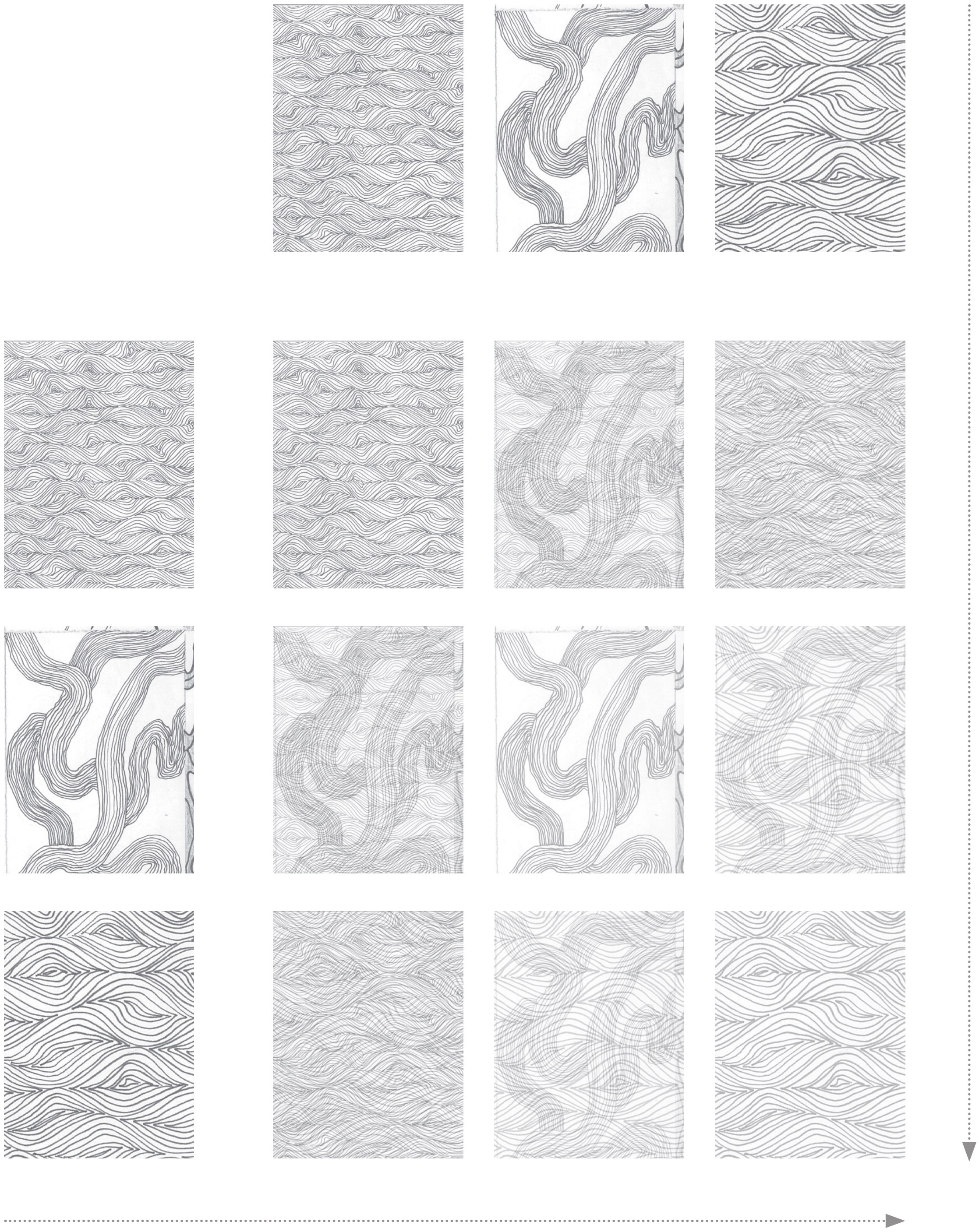


Figure 4.12. *Distortion matrix using digital layering and collage*

Figure 4.13. *Result of collage series - integrating all layers*

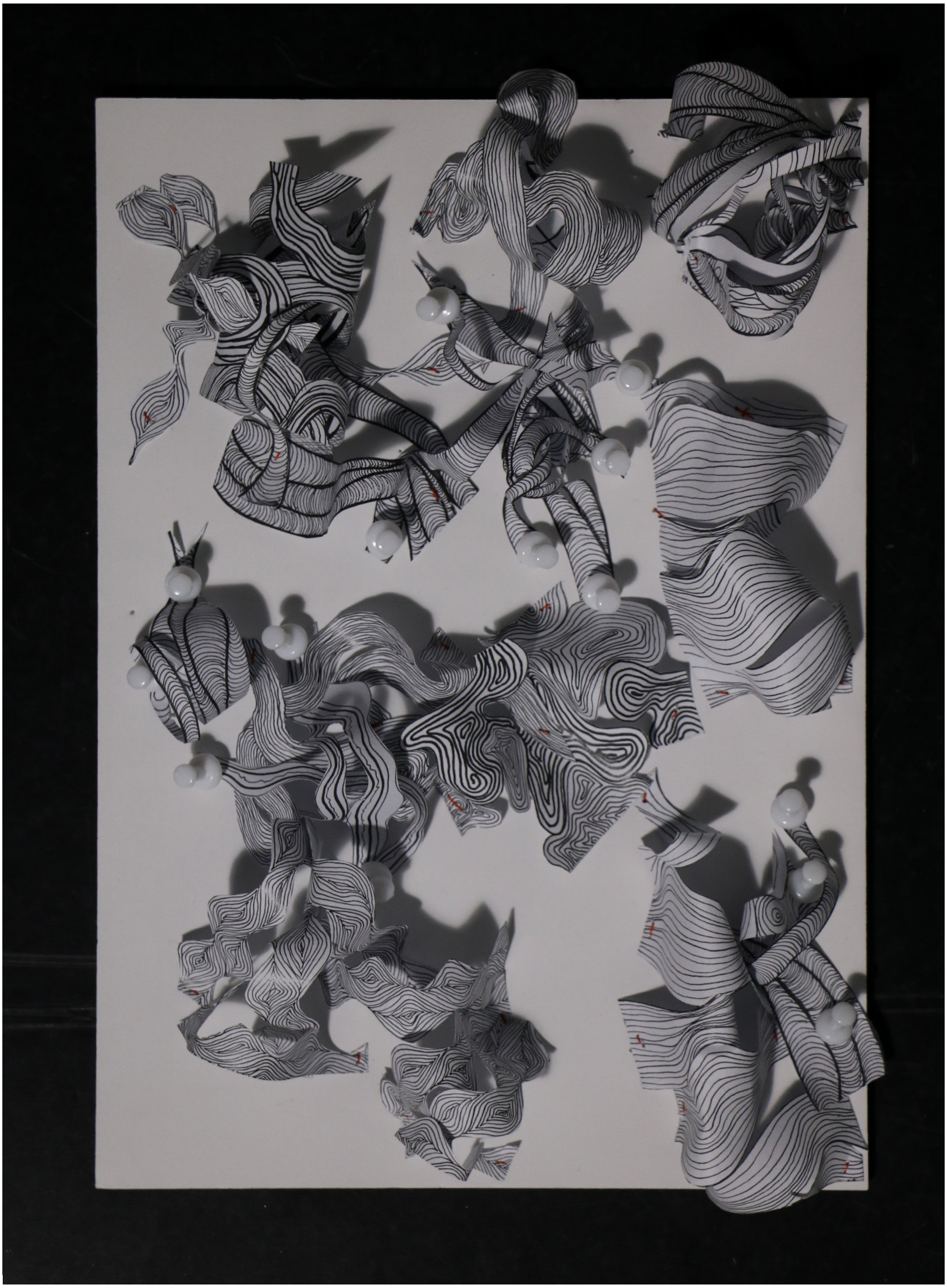


Figure 4.14. *Physical manipulation of deconstructed sketches*

Figure 4.15. *Physical manipulation of deconstructed sketches and digital collage*

Figure 4.16. *Physical manipulation of deconstructed sketches*

Figure 4.17. *Physical manipulation of deconstructed sketches*

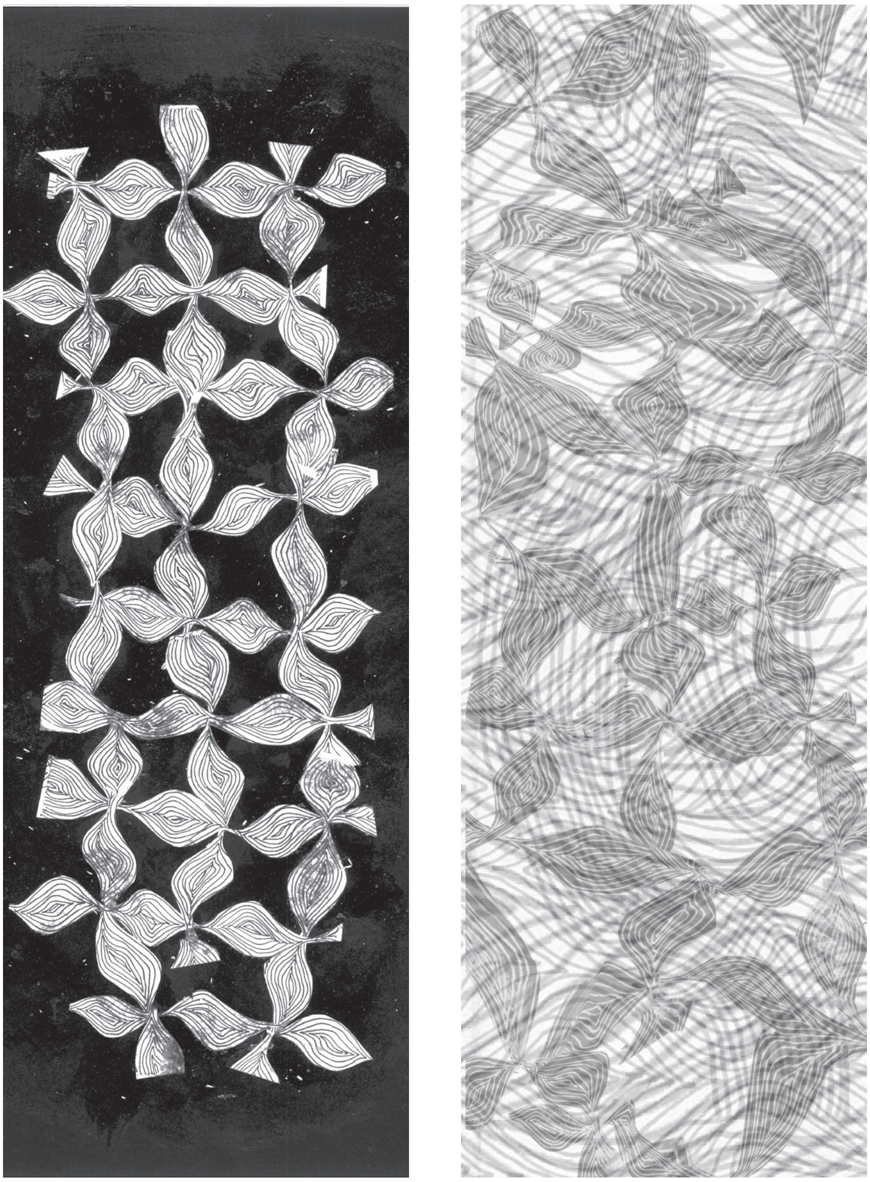


Figure 4.18. - 4.19. *Physical collage of deconstructed sketches and digitisation of physical exploration*

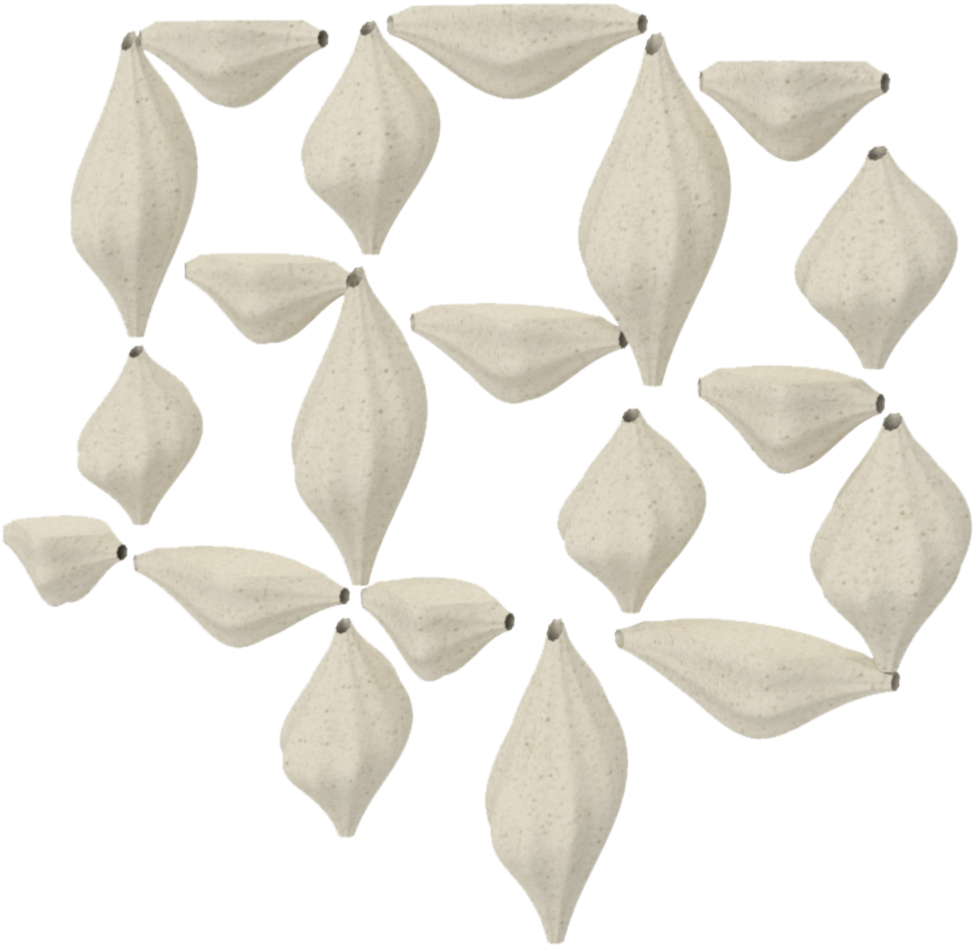


Figure 4.20 *Digital interpretation of forms*

4.3.1 Abstraction Outcomes

The outcome of the form abstraction has been a series of new conceptual shapes and patterns to be translated into the design process through further sketching and digital 3D modelling. The mixed media approach and continuous flow between analogue and digital has allowed for heightened engagement between methods of working to lead to more developed design iterations.

Grasshopper and rhino have been used to develop digital interpretations of the abstract patterns seen in Fig. 4.18.- 4.19., with varying shapes and sizes to emulate a natural series of biophilic designs. Fig. 4.20. shows an interpretive render with a ceramic materiality applied to the surfaces.

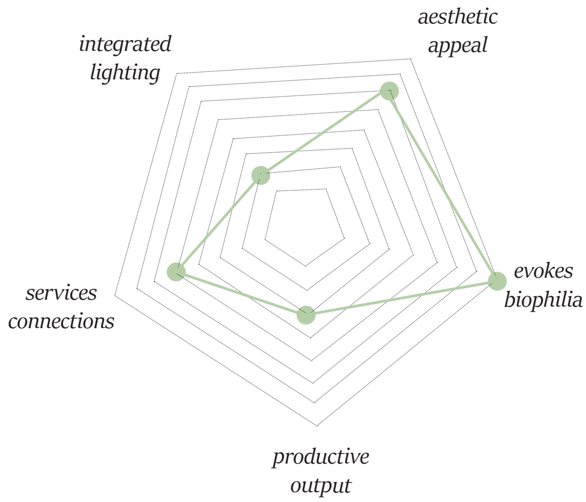
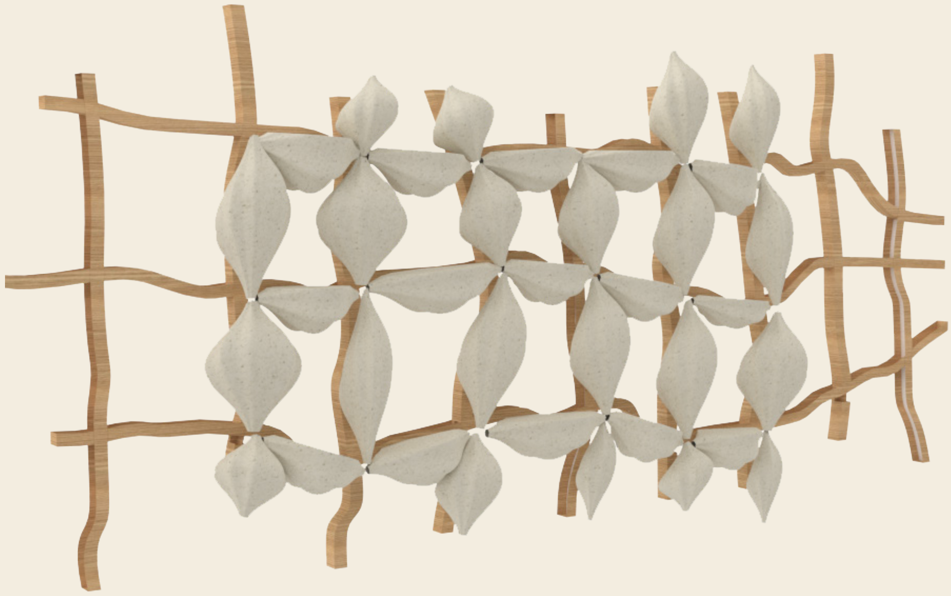


Table 4.2. *Design matrix*

Fig. 4.21.-4.22. shows the re-integration of the abstract forms into an architectural context as a partition screen, with further development of the ceramic forms into a potential partition wall with timber structure. The speculative nature of the design at this stage of the process is reflected in the design matrix (Table 4.2.), showing the low level of integration with functional aspects of the hydroponic systems. However, the biophilic influence and natural materials create appealing aesthetic qualities to test through prototyping.



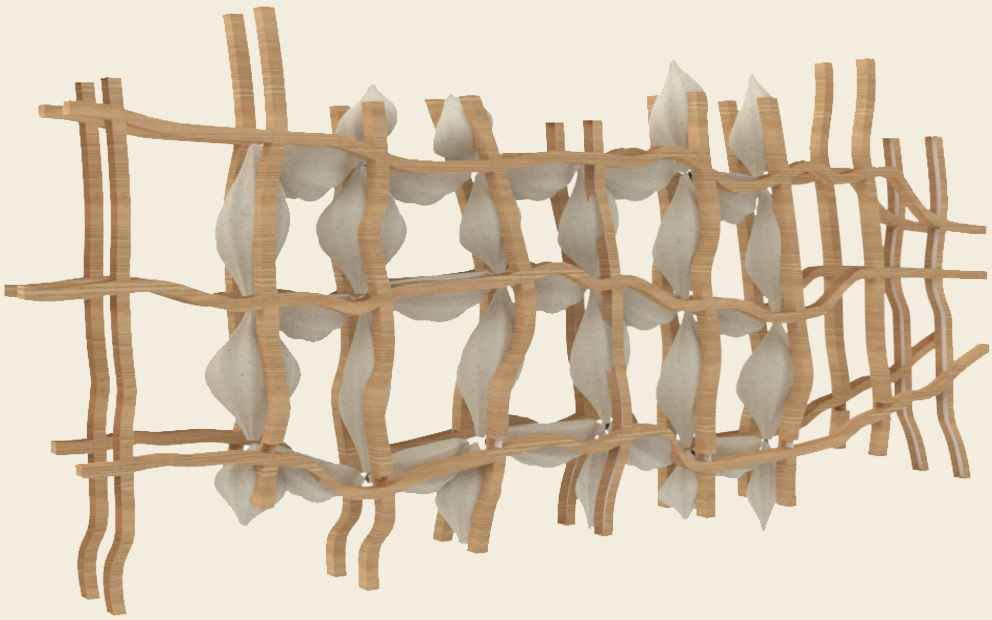


Figure 4.21. - 4.22. *Digital manipulation of physical collage*

4.4 Robotics

Due to the necessity to use iterative testing and develop a range of slightly adjusting forms, 3D printing clay has been selected to be the most suitable method of making.

Using an ABB robotic arm (IRB 6700-200/ 2.6m), experimentation with a 3D printing extrusion head can be used to develop forms and explore further potentials for clay during the fabrication process. Digital optimisation can be translated into the physical prototypes through the printing process, achieving a high level of accuracy for modular components that are required to fit together, however, precision to detail allocated by the robotic process is still susceptible to some risk of change due to the 10-15% clay shrinkage during the drying process, which can be influenced by temperature and humidity of the environment (Urbano Gutiérrez & Wanner, 2016, p. 7).

The visual markers that are a by-product of 3D printed clay also lends itself to the development of an aesthetic that is defined by the tool chosen. The tool path, layer height, extrusion nozzle size and viscosity of clay are all key parameters that will influence the final visual appearance of the extruded clay forms (Gürsoy, n.d., p. 22). Table 4.3. shows the framework developed by Gürsoy for establishing systematic explorations in clay 3D printing (n.d., p. 24).

DIGITAL INPUT	PRINTING	POST-PROCESSING
Geometry solids surfaces curves ***Gcode*** gcode generator software custom gcode generation	***Material(s)*** single/multiple material different types of clay different colours ***Tools*** different nozzles ***Print Settings*** print speed extrusion speed layer height nozzle height ***Print Base*** static vs. dynamic base flat vs. non-flat base ***Exterior Stimuli*** change in temperature interruptions etc.	***Geometry*** reshaping the layers ***Firing*** kiln type temperature ***Material(s)*** with glaze / without glaze glaze types

Table 4.3. *Framework for systematic explorations in 3D printing*

4.4.1 Clay extrusion

The clay extruder is attached to the ABB robotic arm (Fig. 4.24.) and can be operated with a handheld manual controller or follow scripted paths to extrude/print the ceramic forms. Forcefully packing the clay by hand into the extrusion tube minimises the risk of air bubbles in the clay for integrity of the printed forms. The planter forms have been developed in Grasshopper and Rhino and follow a continuous path. The layer height, nozzle size, type of clay and speed of movement along the extrusion path can all be contributing factors in the final outcome. The nature of the scripting to follow a continuous path means that each layer must be at least partially extruding onto the path below to achieve solid walls, with angles of more than 45° presenting a low level of structural integrity (Fig. 4.23.).

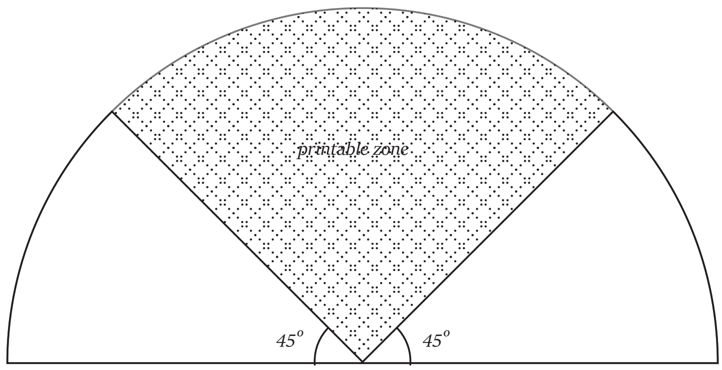


Figure 4.23. *Printable angles on robot*

Figure 4.24. *ABB robotic arm with clay extruder*

Figure 4.25. *Digital form of iteration 1.1*

4.4.2 Test Print #1

The initial test clay print was unsuccessful due to the attempt to print the digital model (Fig. 4.25.) upside down with the opening on the print tray and a curved base. The area of the curve and the angle proved unsuccessful due to the limitations of the robot to print continuous angles of more than 45°. Each extruded path of clay needs to be able to layer at least partially onto the previous extrusion or the resulting squiggly lines seen in iteration 1.1 appear as the system tries to connect both paths (Fig. 4.26.-4.28.). This was a key learning from the initial exploration, as it has shown that the planters will likely require a flat base, with some angling and curvature able to the explored in either the plan shape or the walls.

layer height	*2.5mm*
nozzle size	*7.0mm*
clay type	*terracotta (not soaked)*
extrusion speed	*30%-45%*

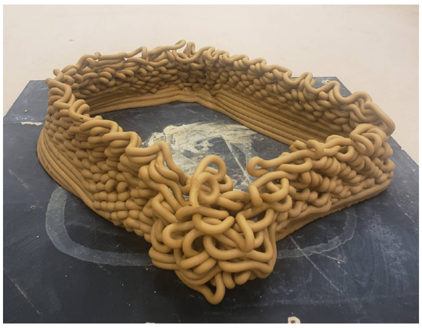


Figure 4.26. - 4.28. *3D printing iteration 1.1*

4.4.3 Test Print #2

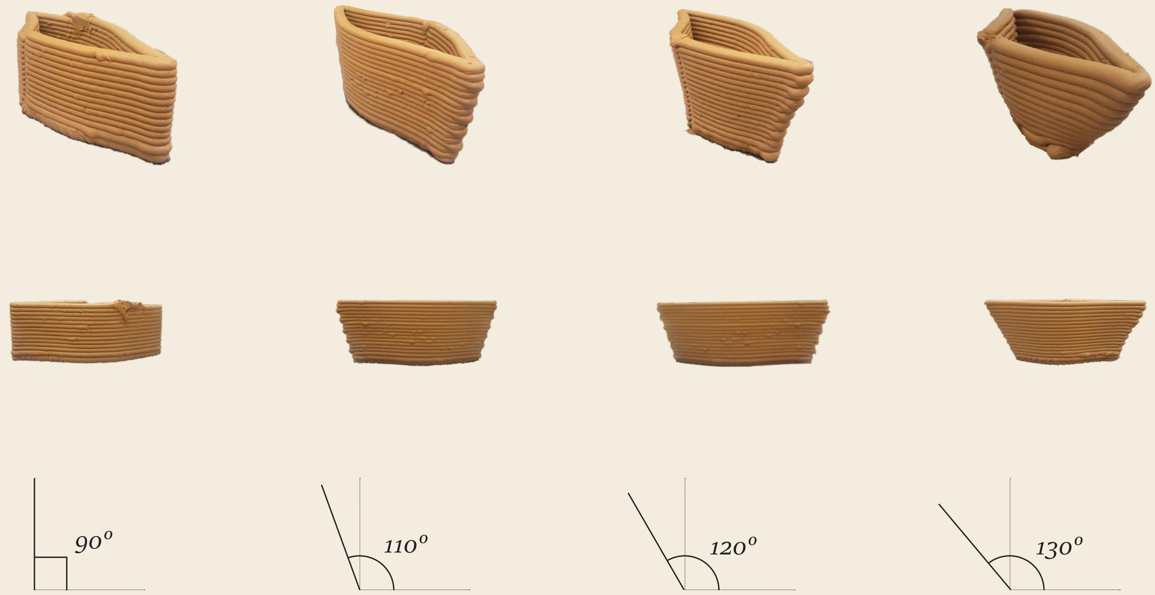
The second experimentation with the robot showed more success, with the form of iteration 1.1 retained and translated into a simplified version. An iterative process was undertaken to explore the angles of the walls that would be feasible to print, built up from a flat base level.

Iteration 2.1 (Fig. 4.29.) was printed with walls perpendicular to the base, with each following iteration at an increasing obtuse angle to perpendicular (Fig. 4.29. iteration 2.2-2.4). These trial prints were at a 1:25 scale of the approximate size expected of the final pieces, which enabled a much faster print time to work through an iterative process.

After printing, experimentation using hand manipulation of the walls was engaged with to gauge the aesthetic qualities of implementing curved or asymmetric forms in future iterations to adopt biophilic design principles (Fig. 4.29. iteration 2.5-2.8).

layer height	*2.5mm*
nozzle size	*7.0mm*
clay type	*terracotta - soaked with 500ml water:10kg clay*
extrusion speed	*40%-70%*

Angle Testing



iteration 2.1 *iteration 2.2* *iteration 2.3* *iteration 2.4*

Manipulation of Forms

iteration 2.5 *iteration 2.6* *iteration 2.7* *iteration 2.8*

Figure 4.29. *Series of 3D printed ceramics: iterations 2.1-2.4*

4.5 Early Technical Integration

Robotics test prints #1 and #2 informed the design parameters based on what was possible to be 3D printed with the ceramic material. This led to a re-evaluation of the design scope and a further simplification of the design to address the technical parameters and the required systems needed for the functionality of a hydroponic system (Fig. 4.30.-4.31.). The design matrix (Table 4.4.) shows that this iteration has a high level of technical integration, with a lower biophilic and aesthetic level of consideration.

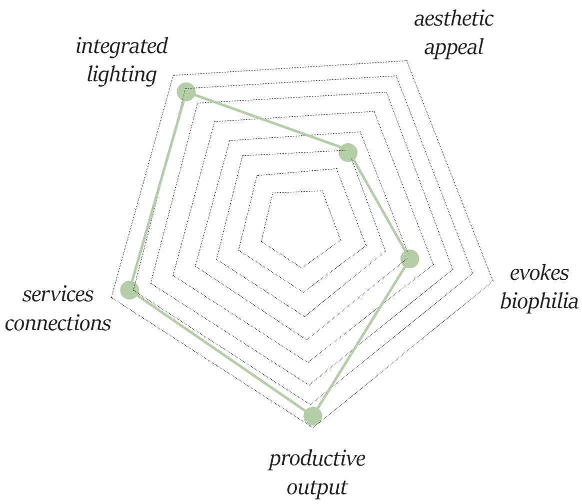
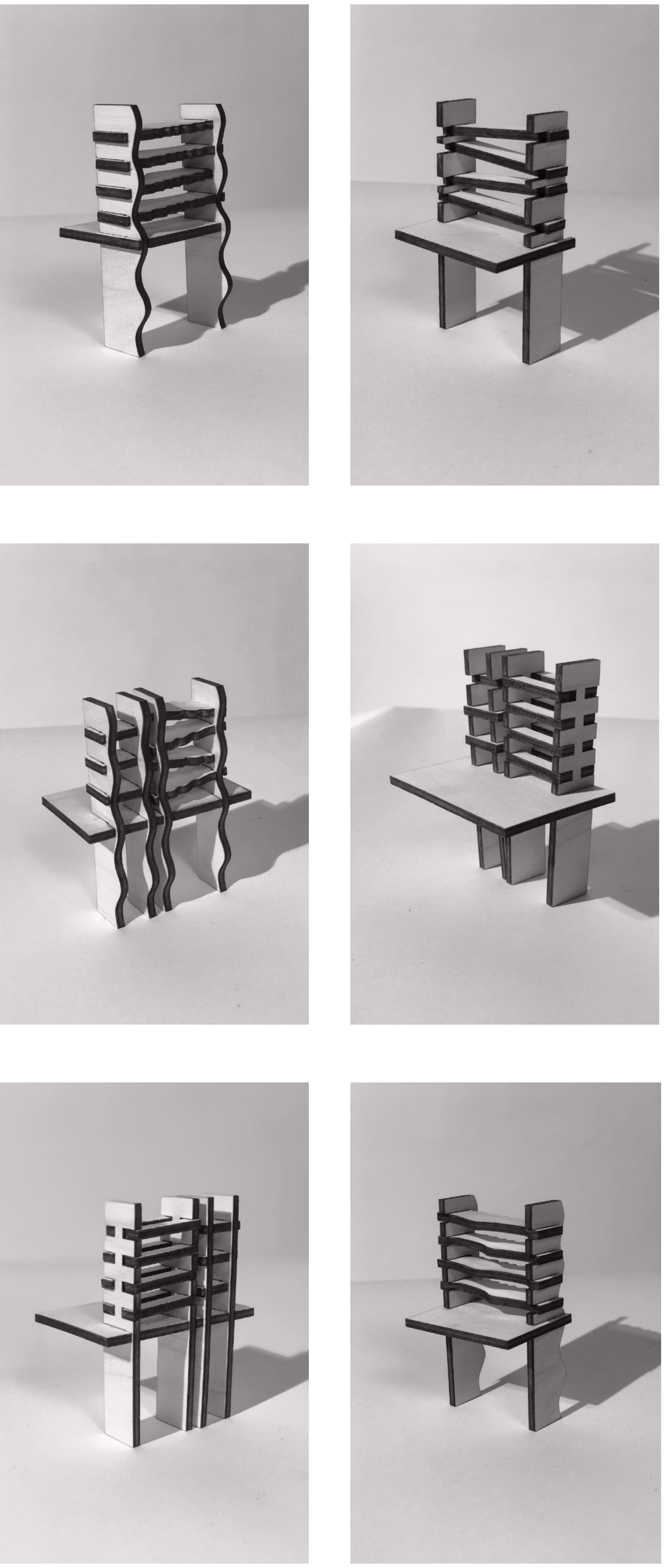


Table 4.4. *Design matrix*

Figure 4.30. *Flat shelving with ceramics planters for deep water culture hydroponics*

Figure 4.31. *Angled shelving with ceramics planters for nutrient film technique hydroponics*



Further explorations of physical modelling (Fig. 4.32.) and sketching (Fig. 4.33.) have been used to investigate ways in which the concept of a shelving unit could become a modular architectural component that integrates both hydroponics and food storage into an adaptive design. This aims to incorporate both circular design principles and modular sizing to be adaptable to a range of applications.

Figure 4.32. *Series of physical iterations*

Figure 4.33. *Sketch of partition with integrated hydroponics and food storage*

Figure 4.34. *Render of iterative design process*

This iteration aims to seamlessly integrate the concept of food storage and hydroponic growing based on the physical modelling explorations (Fig. 4.34.-4.35.). The kitchen bench as the centre level of the shelf aims to transform the partition from a passive divider of space into an active kitchen element and structural component of the bench. The concept of modular sections would allow this to be applicable in a range of contexts.

The feasibility as assessed in the design matrix (Table 4.5.) is low, due to the impractical shape of the planters which would create an uneven distribution of nutrient solution to the plants and the lack of integrated lighting.

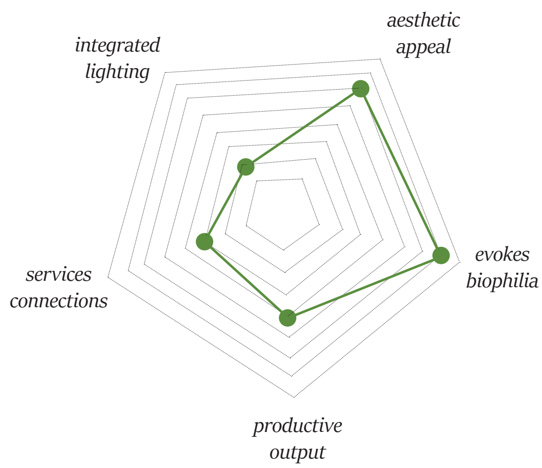


Table 4.5. *Design matrix*

Figure 4.35. *Rendered visulisation of integrated ceramic hydroponics and food storage shelving with kitchen bench*

Figure 4.36.

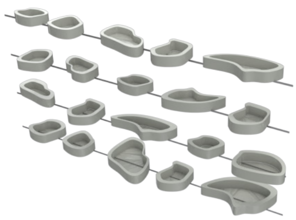


Figure 4.37.

Figure 4.38.

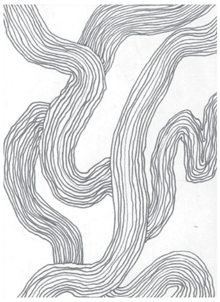


Figure 4.39.

Refinement

After assessing the previous iterations of design against the design matrix, the above iterations (Fig. 4.36.-4.39.) have been brought together due to the difference of successful properties from each series. The renders shown in Fig. 4.40.-4.41. show a set of iterations that aim to integrate both the technical and aesthetic considerations and implement timber joinery methods to enable circular design principles as assessed in Table 4.6.

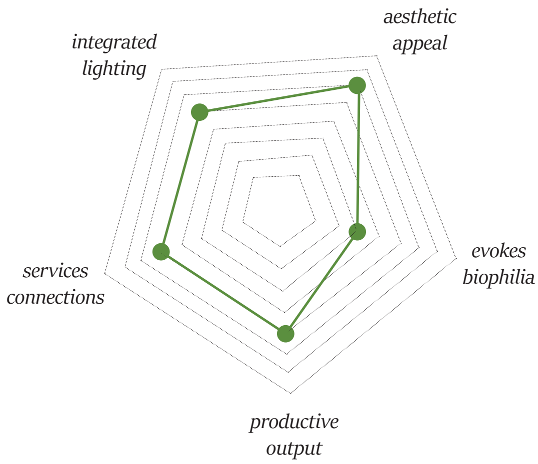


Table 4.6. *Design matrix*

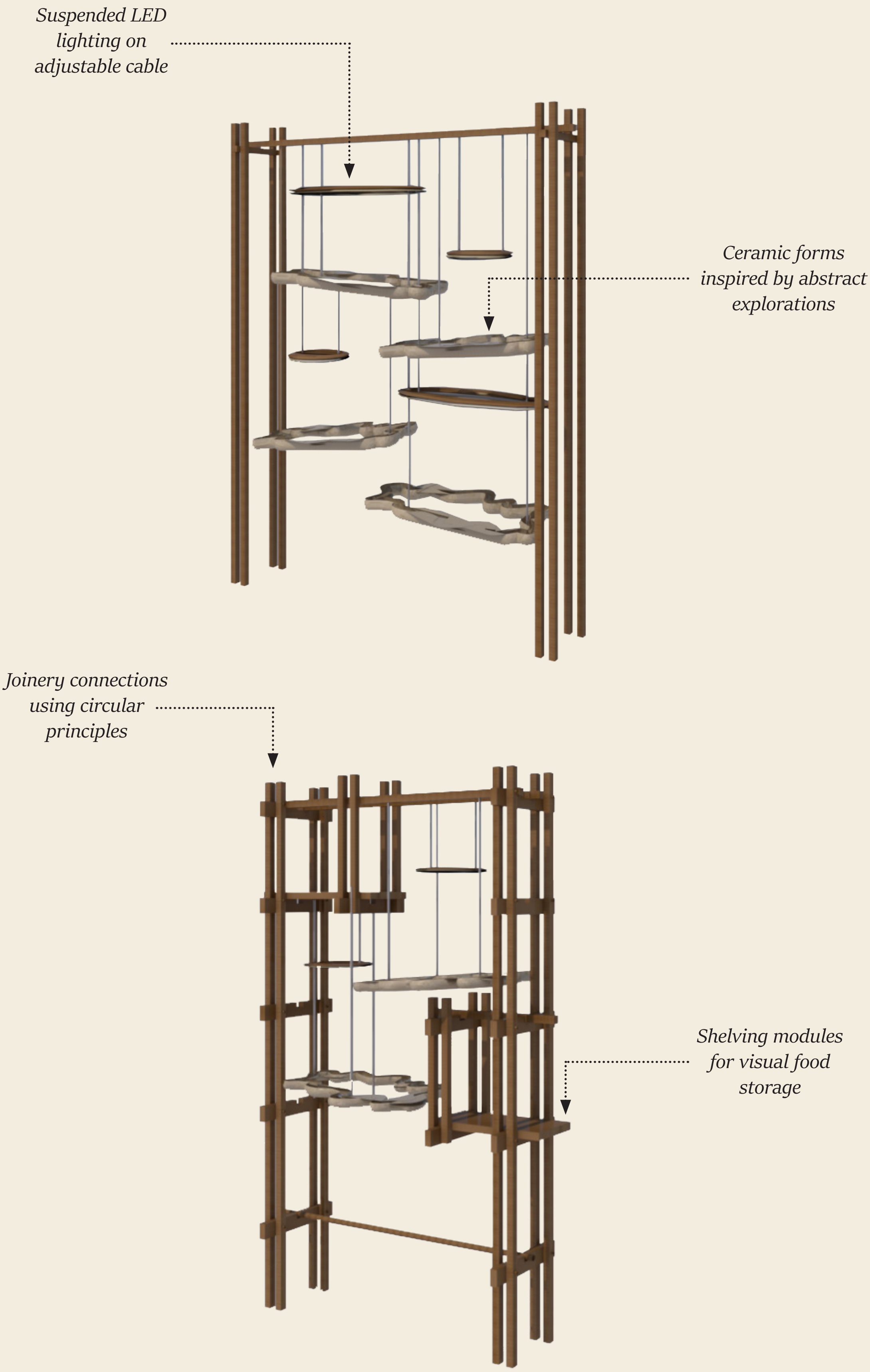


Figure 4.40. - 4.41. *Rendered visulisations of integrated ceramic hydroponics and food storage shelving*

Figure 4.42. *Rendered elevation of integrated design*

Further development of the design to refocus on the ceramics as a key element and enable a higher level of adaptability had led to an investigation of timber joinery techniques as a method of support for the hydroponic planters (Fig. 4.42.). By exploring the use of a French cleat as a rearrangeable and modular shelf support, the system is able to implement both shelving and hydroponics in a highly adaptive manner (Fig. 4.43.).

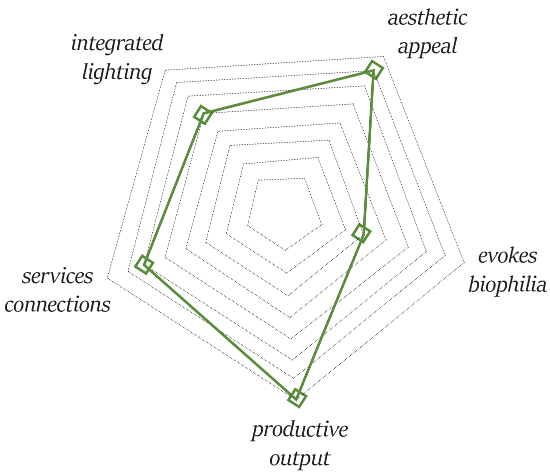


Table 4.7. *Design matrix*

Figure 4.43. *Rendered visulisations of integrated ceramic hydroponics and food storage shelving*

4.6 Prototyping

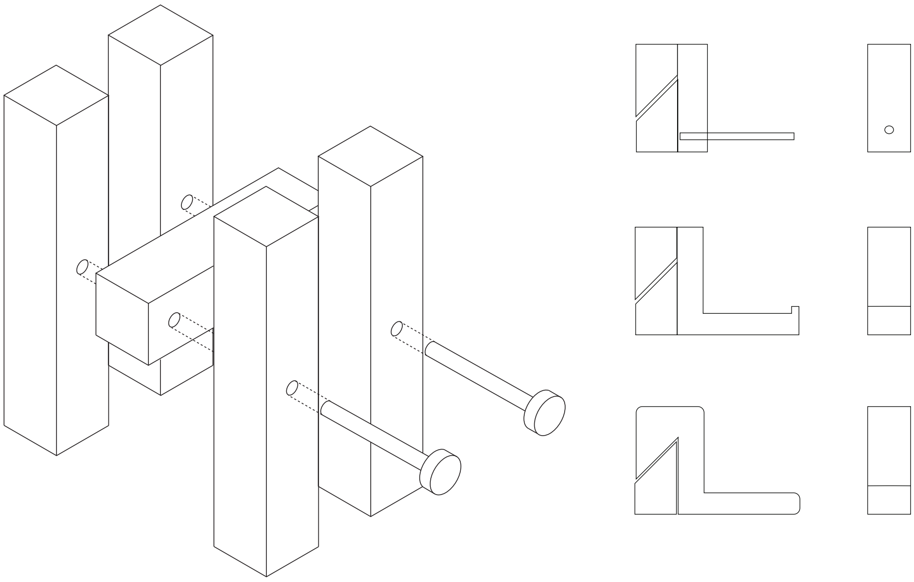


Figure 4.44. - 4.45. *Isometric diagram of corner joinery with dowel pin connections and iterative designs for french cleat shelf connection*

Joinery Modelling

Exploring the use of the French cleat and circular design with a dowel pin joint (Fig. 4.44-4.45.). The making process is a key practice for the design development, with resolution occurring during the building. The materials have been sourced from timber scraps to minimise the use of new material in the testing phase.

Functionality of the French cleat shelf support system was successful and was able to support a cantilevered shelf using only gravity loads to resist (Fig. 4.46.-4.48.). The resulting prototype should be modified to use less timber and be developed into a more streamlined aesthetic design.

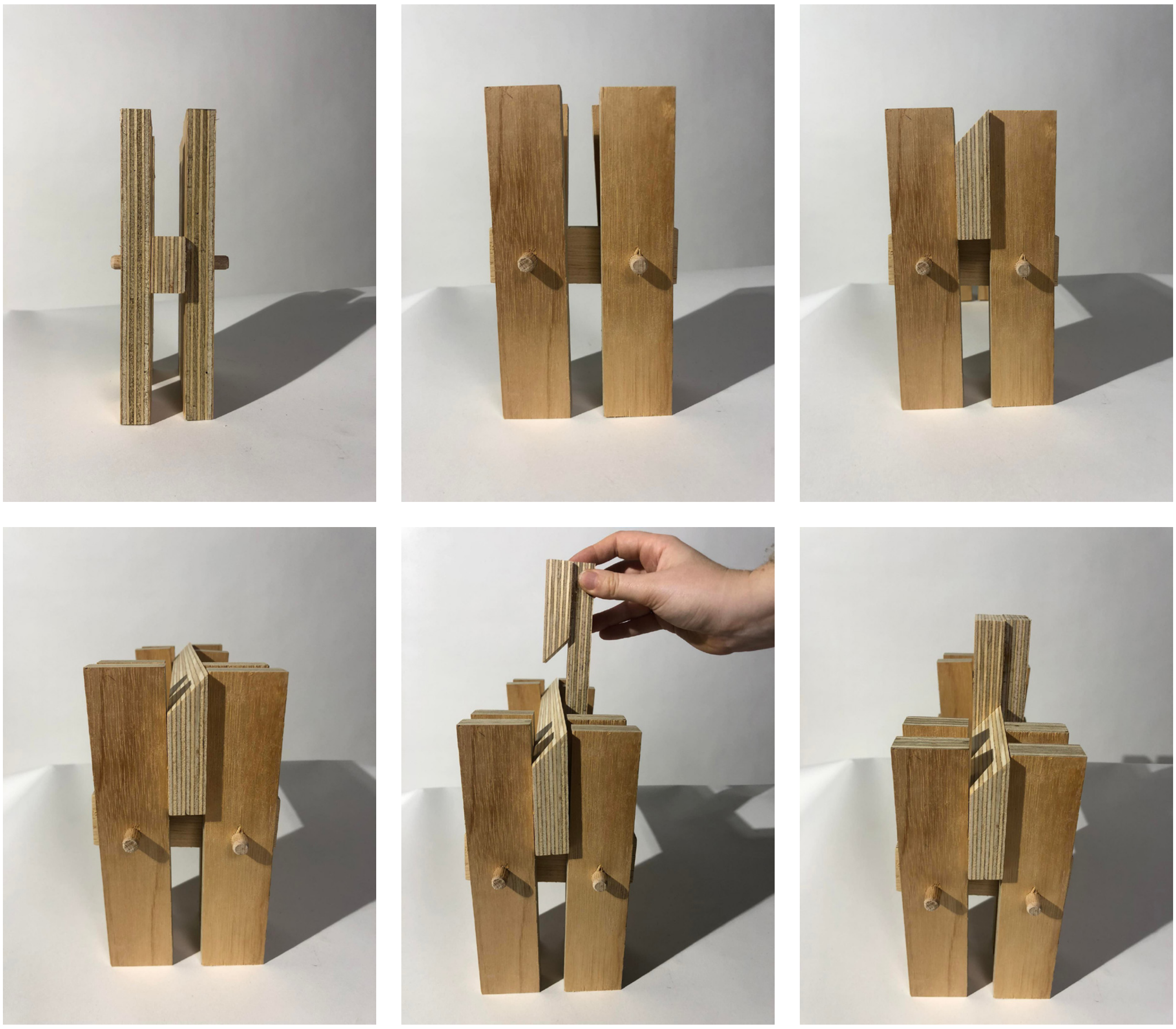


Figure 4.46. *Series of images of physical prototype of french cleat shelf*

Figure 4.47. *Physical prototype of french cleat shelf and corner joinery*

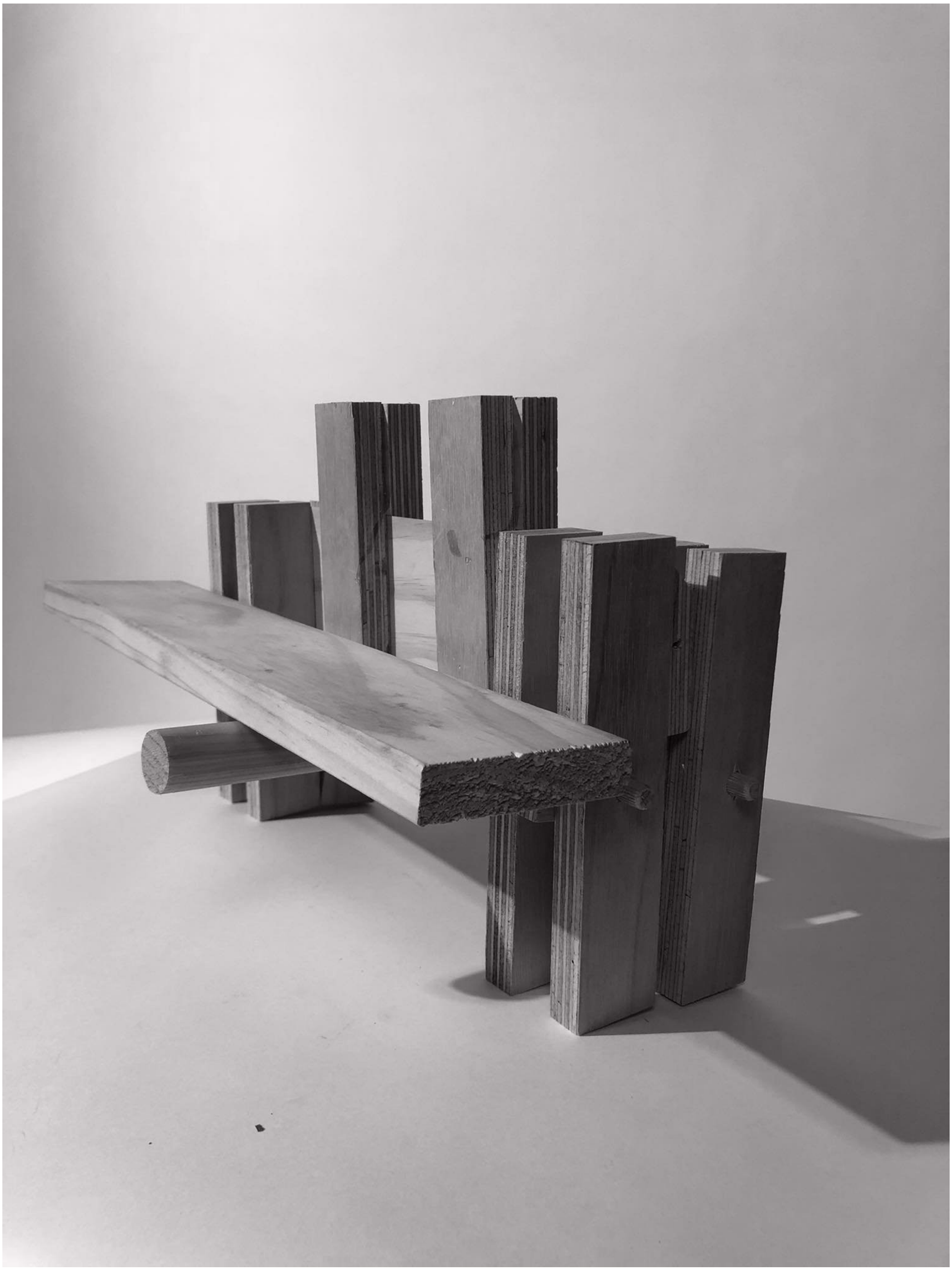


Figure 4.48. *Physical prototype of french cleat shelf and corner joinery*

Figure 4.49. - 4.50. *Before and after visualisations of design incorporated into kitchen space*

4.7 Initial Outcomes

The key outcomes from the initial design phase are:

a) the establishment of 3D printing robotics extrusion parameters for ceramic planters

b) biophilic design outcomes for the ceramic forms through the process of abstraction

c) a developed understanding of timber joinery and structure through physical prototyping

The resulting prototype functioned successfully, however, the physical realization led to further questioning of the aesthetic qualities (Fig. 4.49.-4.50.). While the modularity and circular construction methods of the design are ideal, the aesthetics and integration of the ceramic planters into the form could be significantly improved. To create an architectural intervention that supports long term urban agriculture productivity and incorporates biophilic design, there a higher level of integration is required between the design considerations in the design matrix.

Redefining Scope

Aiming to develop the ceramic forms further to move away from the aesthetic appearance of a shelf and further integrate the intervention architecturally is a key requirement for outcomes and applications. Key methods for developed design include more prototyping and testing of forms, with analytical review of findings at each stage.

4.7.1 Design Process

Development of a system that implements the clay structurally was iterated through sketch designs of possible iterations. Fig. 4.51 shows a series of concepts for a modular ‘brick’ system which could interlock. While this idea showed promise, the forms would be better suited to slip-casting or another method of making due to the regularity of shapes. To continue developing the biophilic forms and experimentation with the robotic 3D printing, Fig. 4.52. was selected to test through physical prototyping, based on the interesting aesthetic that could be developed by a system that could be moved around vertically.

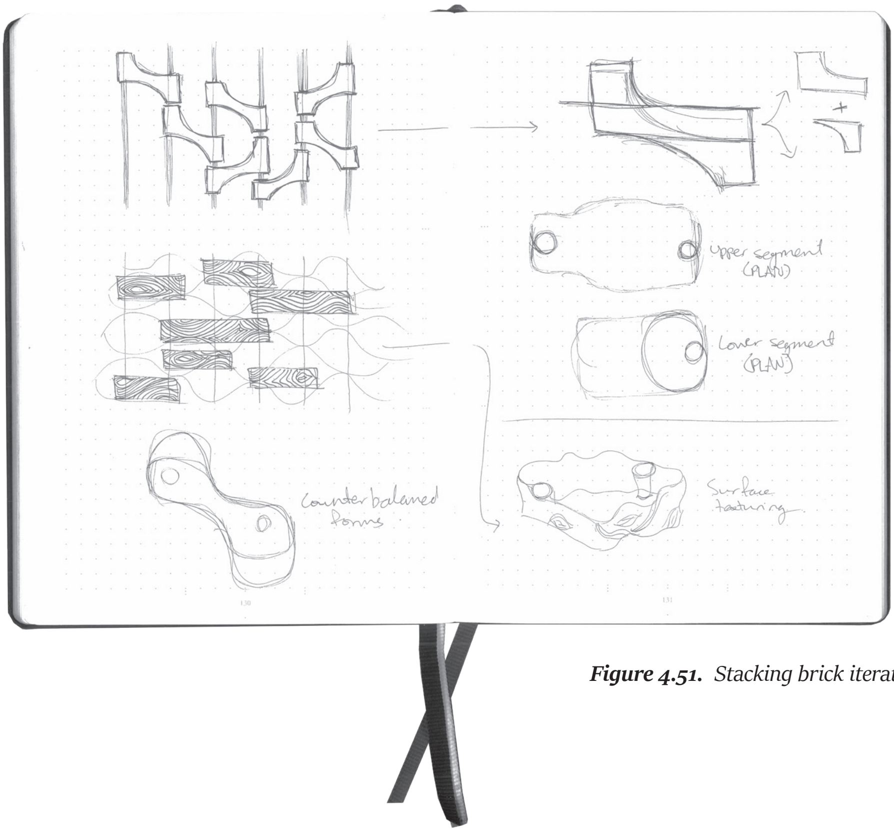


Figure 4.51. *Stacking brick iterations*

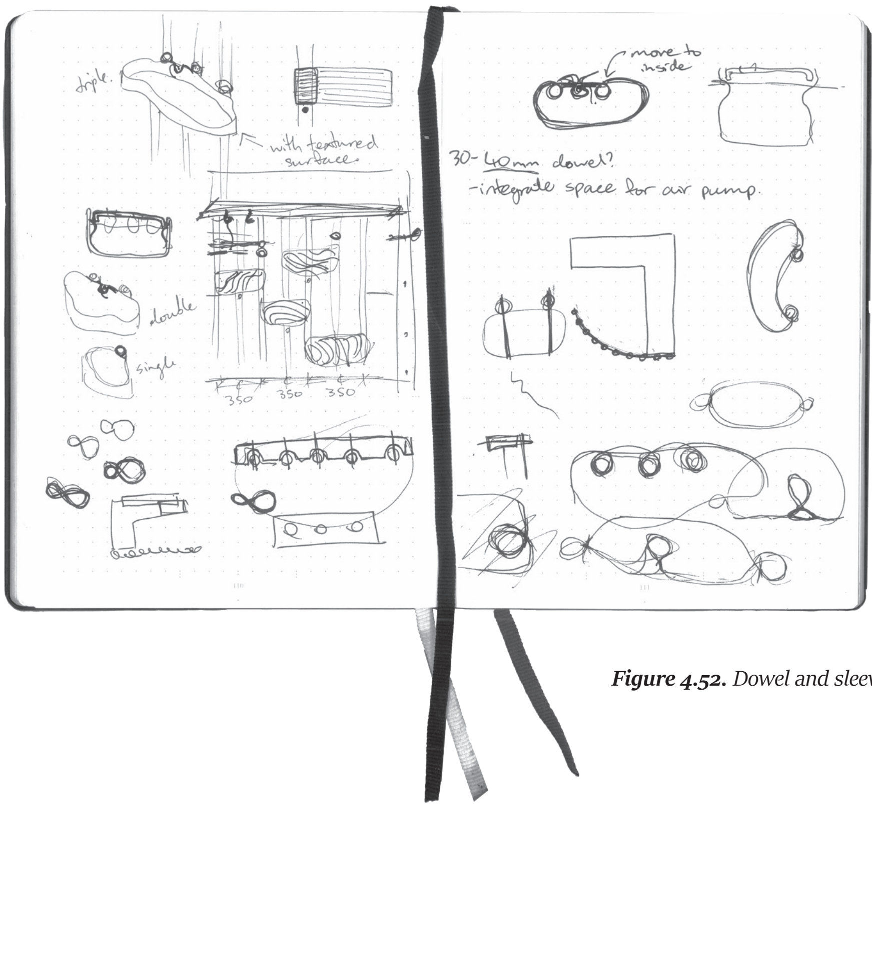


Figure 4.52. *Dowel and sleeve iterations*

4.8 Design Refinement

By creating a partition from timber slats or dowels, as shown in Fig. 4.55., the hydroponic system begins to define social spaces and becomes a key architectural move in the design of the kitchen. Utilising the ceramic planters as an integrated structural element to connect seamlessly to the timber structure elevates the simplicity of the design, incorporates circular design principles and reduces the required amount of material.

This design for the ceramic planter employs a non-circulating method of hydroponics, known as root-dipping (Fig. 4.53.). The plants are grown in a substrate within the net cups and the lower section of the cups are submerged in the nutrient solution. This system does not require an air stone, as some of the roots are air absorbing and some are nutrient absorbing.

It can also function with the Kratky method (Fig. 4.54.) if the planters are deeper, in which the nutrient solution level slowly drops and the plant roots extend with it to continuously absorb both nutrients and oxygen. This method works better with rapidly growing crops such as leafy greens and herbs.

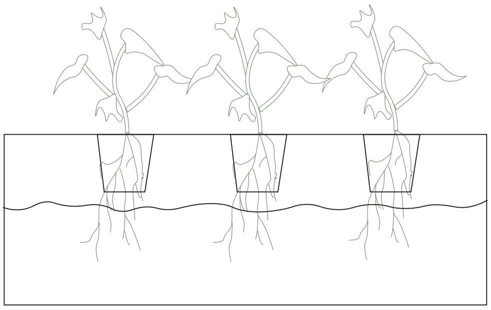


Figure 4.53. *Root dipping hydroponic technique*

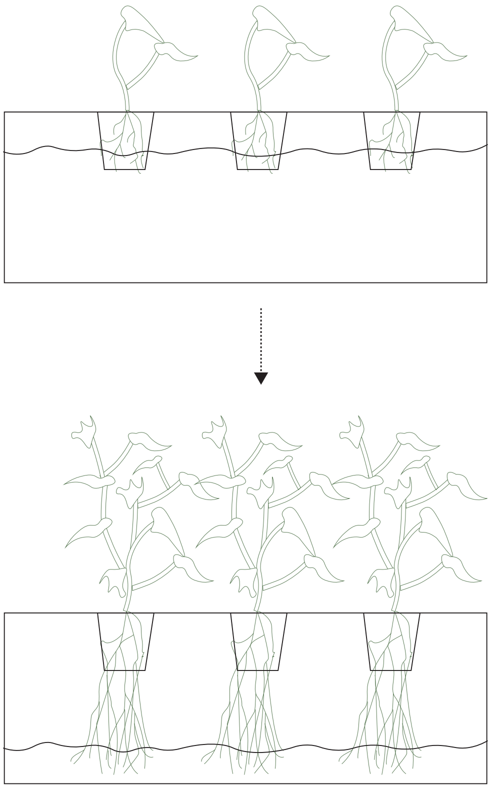


Figure 4.54. *Kratky method hydroponic technique*

Figure 4.55. *Rendered visualisation of design in-situ*

4.9 Making and Testing

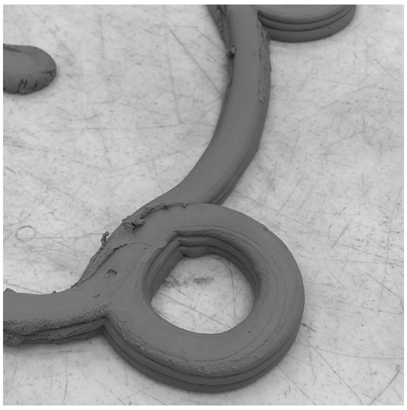


Figure 4.56. *Iteration 3.1*

Test Print #3

The series experimented with testing new techniques with the robot such as incorporating a base and using overlapping print paths for strong joints to connect to the dowels (Fig. 4.57.).

This test used Macs Mud Classic White Clay, soaked in a bucket for four days with a ratio of 500ml water ~ 20kg clay.

Assuming a 40mm dowel would be implemented for the partition structure, holes were printed at a 44.8mm diameter to allow for 10% shrinkage and an additional 2% tolerance.

Iteration 3.1 (Fig. 4.56.) used a 2.5mm layer height and shows the extruder tip dragging clay where it overlaps, causing irregular printing and rough edges.

layer height	*2.5mm - 4.0mm*
nozzle size	*7.0mm*
clay type	*classic white - soaked with 500ml water:20kg clay*
extrusion speed	*100%*

Figure 4.57. *Ceramic planters from robotics test print #3*

Strength Testing

For iteration 3.2 (Fig. 4.58.), the layer height was increased to 4mm which created a smooth path for extrusion, showing good success for overlap sections. This print was not printed with a base.

Iteration 3.3 (Fig. 4.59.) was the first print with a rolled slab base of 4mm thick. The clay extrusion appeared to adhere to the base when printing, however, after 48 hours of drying the base cracked away from the walls.

Iteration 3.4 (Fig. 4.60.) and 3.6 (Fig. 4.62.) adhered to the bases initially, but ended up with large cracks running through the bases in the final drying stage.

Iteration 3.5 (Fig. 4.61) was the most successful, as the dowel supports were located internally, providing more support for the base and drying the most effectively.

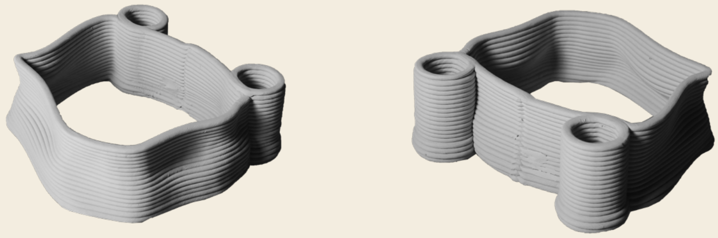


Figure 4.58. *Iteration 3.2*

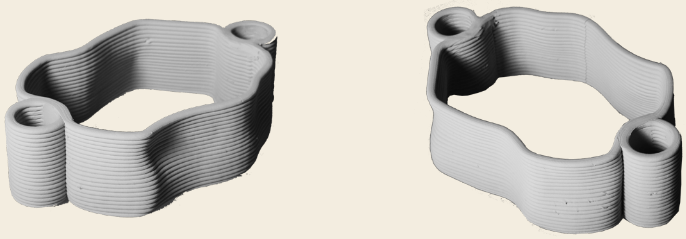


Figure 4.59. *Iteration 3.3*

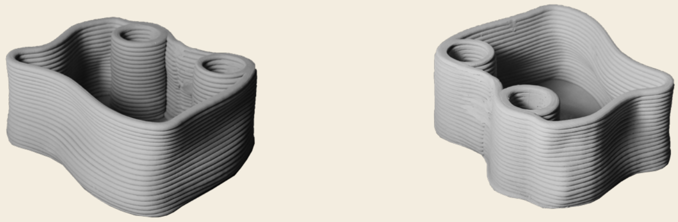


Figure 4.60. *Iteration 3.4*

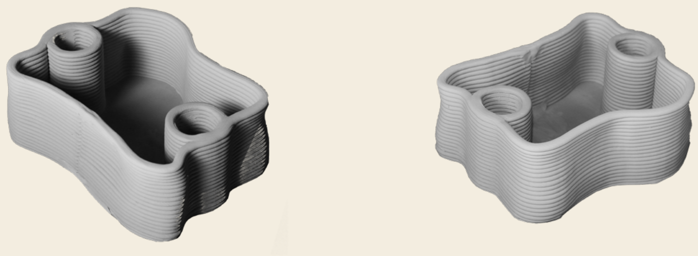


Figure 4.61. *Iteration 3.5*

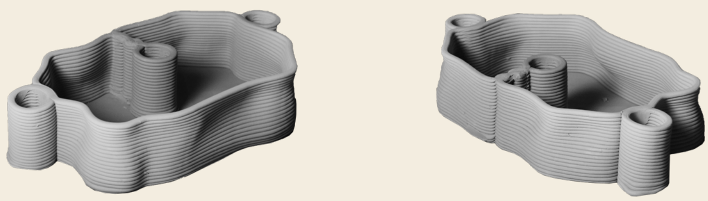


Figure 4.62. *Iteration 3.6*

Test Print #4

For iteration 4.1 and 4.2, a different process was undertaken to achieve a stronger adhesion from the walls to the base to ensure waterproofing and structural integrity (Fig. 4.63.). These two prints were printed at a smaller scale to emulate the final shape, but with minimal wastage.

The slab bases were rolled to 4mm between damp cloths, using rods as a guide to ensure even thickness. The base was then scored before printing the form to create stronger bonds between the two clay bodies. After printing the walls, a mixture of clay and water known as 'slip' was applied with a brush to the interior base connections to seal the edges. The exterior of the base was trimmed and the ceramic piece was dried under a piece of scrap plastic for two weeks. The slower drying process allows the moisture to evaporate from the clay more evenly and minimises the risk of cracking and breaking.

As an aesthetic experiment, iteration 4.2 (Fig. 4.65.) was smoothed out on one side to explore a more traditional look to the clay walls. While this successfully dried smooth, the appearance of the 3D printed layers provides more of a unique texture and is able to be implemented to emulate biophilic forms.

layer height	*4.0mm*
nozzle size	*7.0mm*
clay type	*classic white - soaked with 500ml water:20kg clay*
extrusion speed	*100%*

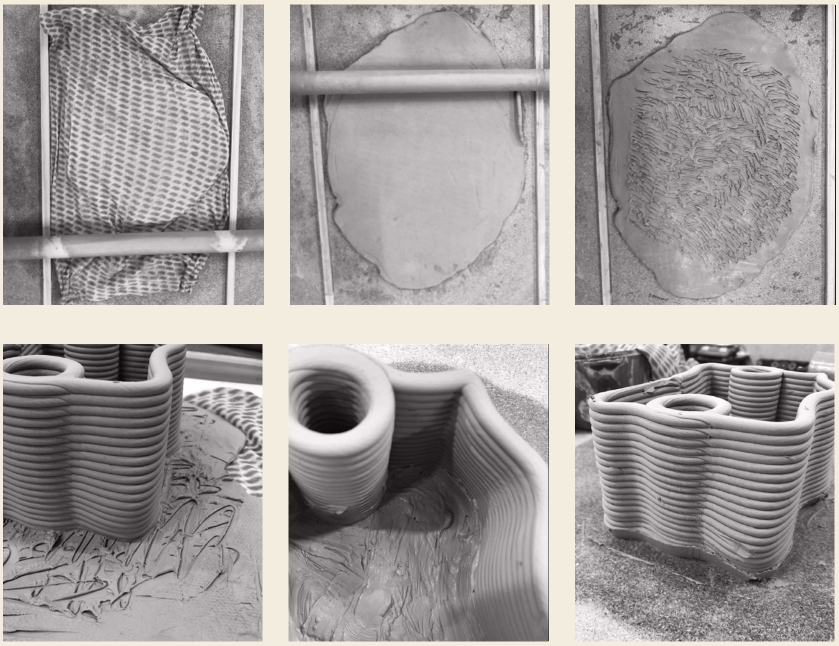


Figure 4.63. *Process of adhesion testing*

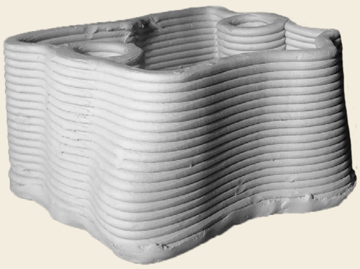


Figure 4.64. *Iteration 4.1*

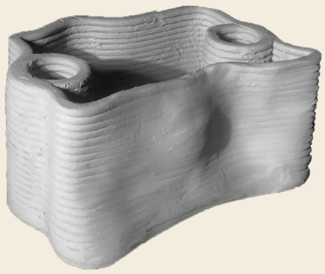
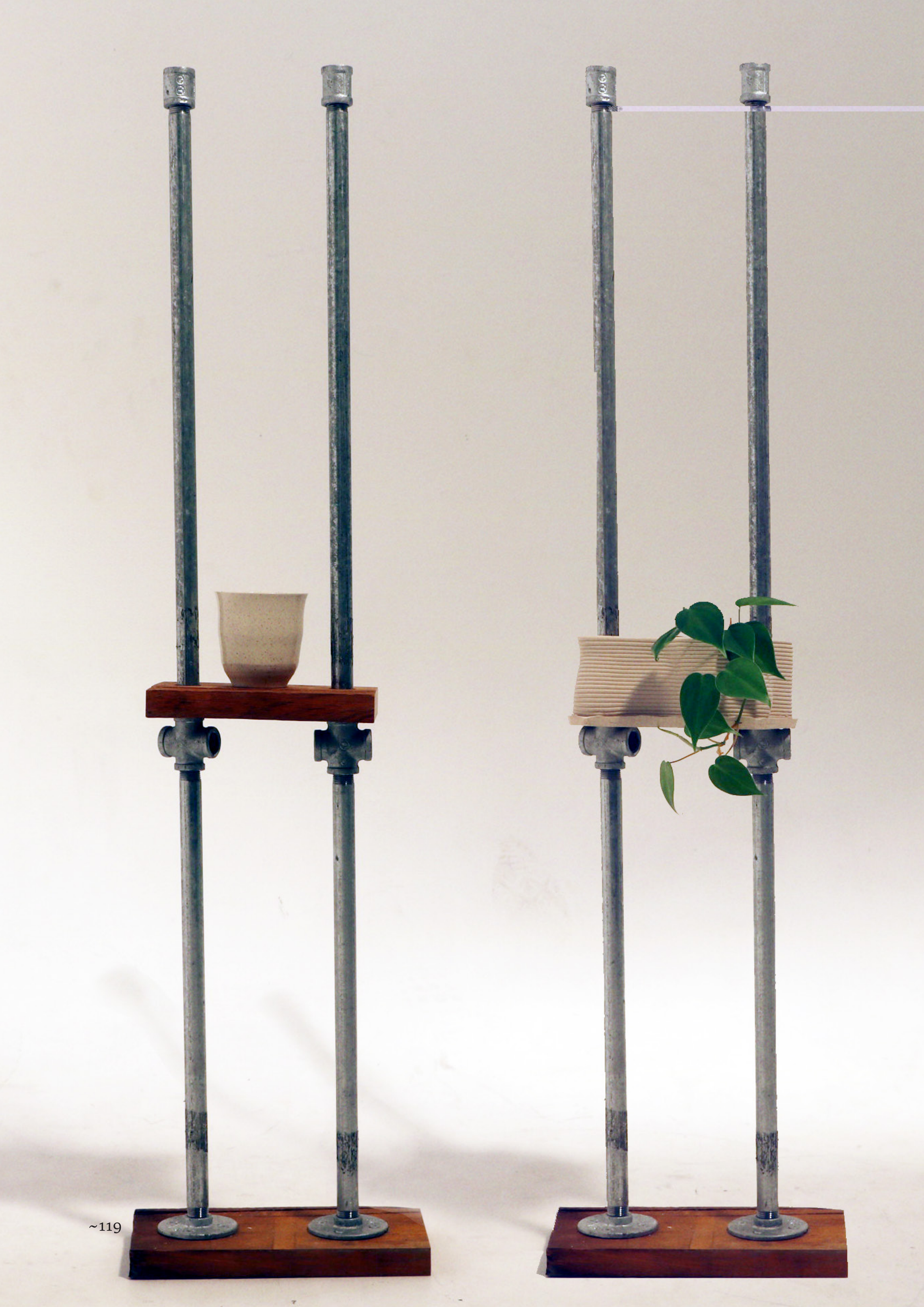


Figure 4.65. *Iteration 4.2*



4.10 Conclusions

The outcomes from this series of prototype testing were:

a) the fiberboard drying surface drew too much moisture from the print, causing the bases to dry at a faster rate than the walls, causing cracks and breakage

b) a more humid environment helps to avoid cracks so prints should be covered with a bag, container or damp cloth for a slower drying process

c) the circular overlapping joint connections appear to be well connected and providing a strong pivot point to support the system

The most successful iteration for strength was iteration 3.5 (Fig. 4.66) and this model was able to be used to build a small-scale prototype of the system. This placement of the joint connections on the interior of the wall will be used to inform the design outcomes.

Figure 4.66. *Physical model testing of iteration 3.5 on galvanised pipes with reclaimed timber shelf*

Chapter Five

~Initial Application

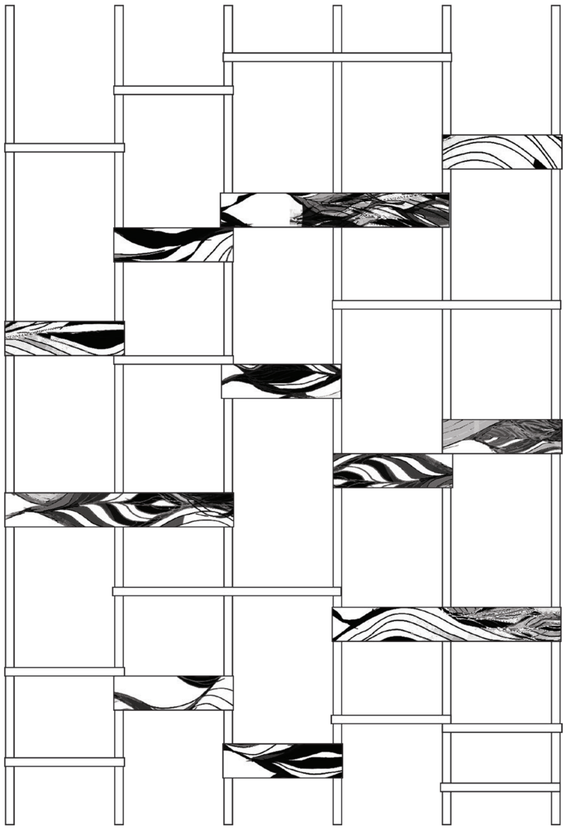


Figure 5.1. *Overlay onto ceramic planter layout*

5.1 Application

This chapter summarises the findings from the design parameters established in Section 3.8 and the iterative design exploration outcomes in Section 4.10. In order to explore inhabitation and draw conclusions about the implementation within kitchens a series of design applications were undertaken. This chapter reports on these explorations.

The selected design for a full-scale prototype has been ascertained through the most successful 3D printing experimentations. While further exploration would be needed to arrive to a fully resolved 3D printing solution, the ceramic prints shown in this chapter are useful to visually and physically explore possible applications at a full-scale volume. To encapsulate the biophilic design principles, hand sketching and digital overlay (Fig. 5.2.) has been used to create a speculative map of application to a proposed layout of the ceramic planter forms (Fig. 5.1.). These images are used to inform the digital Rhino and Grasshopper modelling of full-scale prototype ceramic prints (Fig. 5.3.).

Figure 5.2. *Digitally manipulated hand sketch*

Figure 5.3. *Digital models of final ceramic planters*

Figure 5.4. *Contextualised render of design*

5.1.1 Design Details

A set of indicative technical illustrations show the functional tectonics of the partition (Fig. 5.5.-5.7.). A galvanised steel quick clamp system has been used to allow maximum modularity and circularity of the design. The shift from timber dowels as the partition supports to a steel pipe system was made due to several factors:

a) The weight of the ceramic planters when filled with water is significant and timber dowels were likely to buckle under the loads applied in direct fixed locations.
b) To move the planters and shelf units around on the dowels a series of holes and pins would need to be drilled through, further weakening the timber or requiring a significantly thicker dowel.
c) Steel pipes have hollow centers, allowing electrical wiring to be run through the pipes to the intermediary lights and also creating future potentials for air pump implementation or plumbed piping if a higher level of autonomy was required for the system instead of the current passive Kratky method of hydroponics.
d) The steel quick clamp system implements grub screws, which can be loosened and fastened within a steel sleeve that supports the ceramic planter and can be fully disassembled. This is a common system that could be repurposed into a range of uses at the end-of-lifecycle, including; shelving, scaffolding, wardrobes and furniture building.

The planters require lids to support the net cups which hold the growing substrate and suspend the plant roots in nutrient solution. Clay lids are difficult to produce with consistent holes, due to the shrinkage variables, meaning that a reclaimed timber lid has been selected. The timber does not have direct contact with the nutrient solution and can be oiled to imbue and non-toxic water protection.

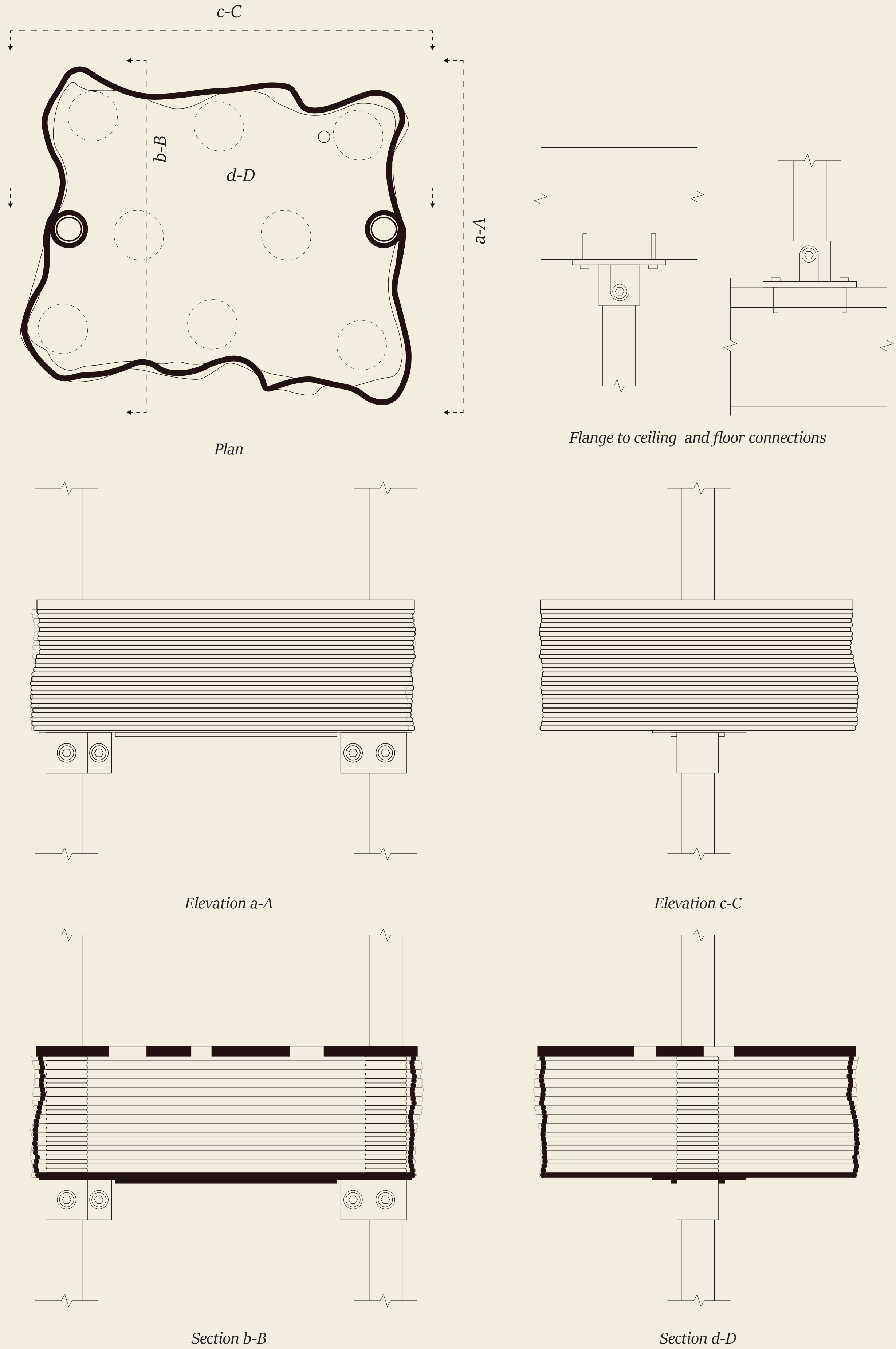


Figure 5.5. *Details 1:5 @ A4*

5.1.2 Exploded Isometrics

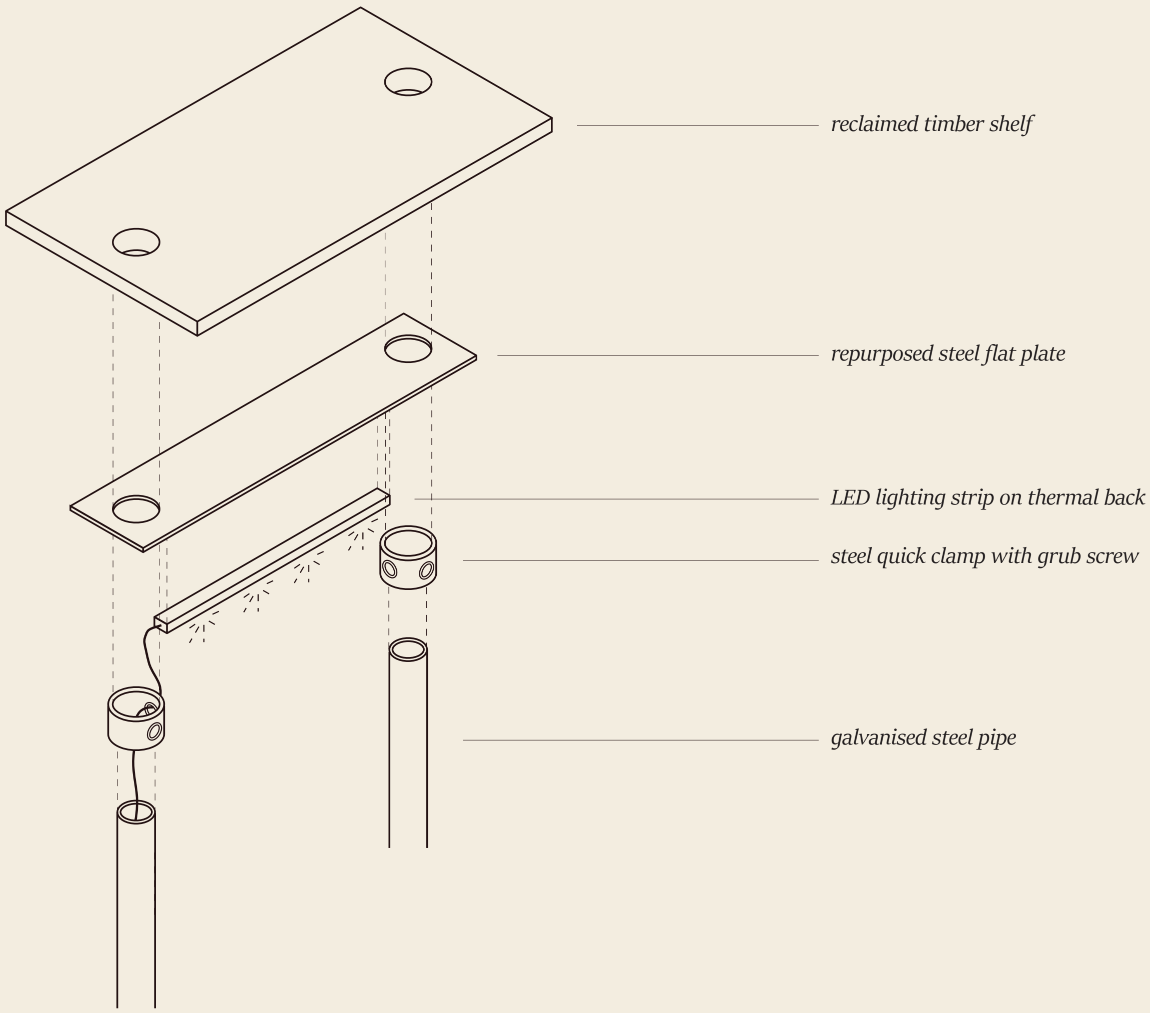


Figure 5.6. *Exploded isometric of timber shelf and LED lighting strip*

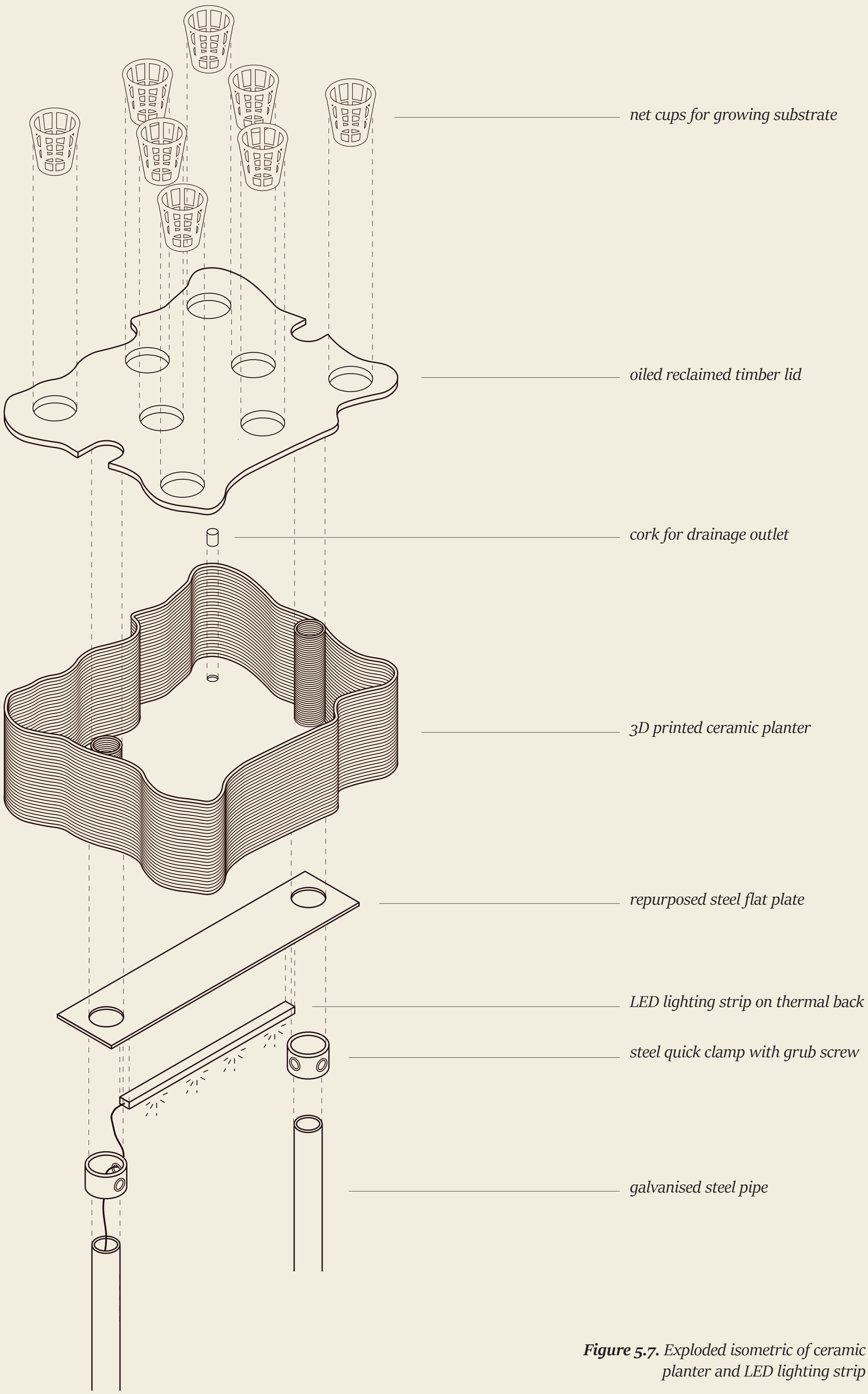


Figure 5.7. *Exploded isometric of ceramic planter and LED lighting strip*

Figure 5.8. *Full-scale ceramic planters*

5.2 Full-Scale Prototype

To test the prototype physically, a series of planters were printed at full-scale to establish a range of textured surface patterns (Fig. 5.8.-5.17.). The digital models of the planters in Section 5.1, derived from biophilic sketches developed through Chapter 4, were printed. One model collapsed from a lack of wall stability and the six resulting planters dried in varying states of success. These followed a combination of the printing methods established in test print #3 and #4 in Section 4.9. Slab bases were rolled slightly thicker to 5mm to provide stability over an increased base surface area and slip was used to increase adhesion between walls and base. A slow drying method under covers was used to try and minimise breakage and uneven shrinking. The wide span of the base surface meant that the planters could not be turned over until nearly dry, which meant that the airflow around the walls was not consistent with the base, leading to significant cracking in three of the bases. A method of sealing the cracks by scoring the base, applying slip, then adhering another smaller rolled piece of clay slab was used to rectify the issue before the pieces fully dried.

layer height	*4.0mm*
nozzle size	*7.0mm*
clay type	*classic white - soaked with 500ml water:20kg clay*
extrusion speed	*100%*

Figure 5.9. *Perspective of ceramic planter*

Figure 5.10.-5.12. *Elevations of ceramic planters*

Figure 5.13. - 5.16. *Details of ceramic planters*

Figure 5.17. *Overview of ceramic planters*

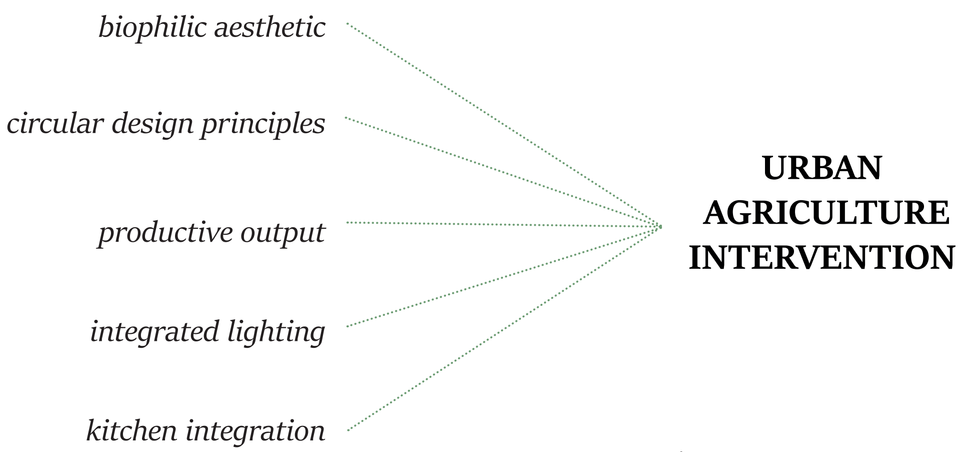


Figure 5.18. *Design parameters*

5.3 Review of Making

This section is a review and analysis of the selected key parameters and how they converge into a design outcome (Fig. 5.18.).

The technical parameters for design that were established in Section 3.5 have been reviewed against the selections made for the full-scale prototype in Table 5.1. This was used as a guideline for the design development and to ensure technical functionality of the full-scale prototype.

5.3.1 Technical Parameter Review

LIGHTING	
distance above plants	300-500mm above plants for bulbs of <200 watts
adjustability	full adjustability in vertical direction; structure fixed
bulb type	full spectrum LED bulbs
NUTRIENT SOLUTION	
transferral	manual refill
ratio of nutrient to water	5ml nutrient solution : 1 litre water
nutrient make-up	N, K, P, Ca, Mg, S, Mn, B, Fe, Cu, Zn, Mo
PLANTING AREA	
distance between plants	100-200mm for leafy greens; 300-350mm for larger plants
diameter of planting cup	50mm top diameter
minimum no. of plants required	7-10 depending on planter iteration
height of growth space above planter	300mm minimum
FRAME/STRUCTURE	
material	galvanised steel and reclaimed timber shelves
approx weight to be supported	planter weight approx 3-5 kg (without water)
circular design connections	steel quick clamps and pipes - fully deconstructable
PLANTER	
material	NZ classic white clay - bisque fire 1000°C and glaze fire 1150-1280°C
kiln diameter	planter dimensions of 350 x 280 x 110
no. of kiln shelves	6 shelves
capacity for 3D printing	successfully printed
planter depth	110mm high
GROWING MEDIUM	
medium type	peat/coconut jiffy pellets and rockwool cubes
support for medium	net cup grow pot - diameter at top 50mm and depth of 60mm
MISC. REQUIREMENTS	
lightproof	lid to fit planter
water oxygenation	not required for selected method
hydroponic system type	hydroponic Kratky method

Table 5.1. *Technical parameters*

Figure 5.19. *Series of materiality studies*

5.3.2 Biophilic Aesthetic

The design of the prototype meets a range of the biophilic principles outlined in Section 3.2.4. By reviewing against the design attributes in Table 5.2. it can be established that the design has implemented elements from each of the three categories of experience to evoke biophilia on conscious and subconscious sensory levels.

Direct Experience: The presence of vegetation brings direct wellbeing benefits and connections to nature, and can have positive implications for the removal of VOC's and oxygen renewal.

In-Direct Experience: The use of natural materials such as timber and clay has achieved a natural tones colour palette for the intervention. The texture of the ceramic planters uses naturalistic shapes and forms to evoke natural movement and the irregularity of organic forms (Fig. 5.19.). The simulation of natural light through the use of full spectrum LED lights provides a low level of constant light in spaces that are removed from windows.

Experience of Space and Place: By creating an open plan space with a permeable partition, the design contributes to visual connections between interior spaces to promote prospect and refuge, and offers a transition from one space to another.

DIRECT EXPERIENCE	IN-DIRECT EXPERIENCE	EXPERIENCE OF SPACE AND PLACE
light	*images of nature*	*prospect and refuge*
air	*natural materials*	*organised complexity*
water	*natural colours*	*integration of parts to wholes*
plants	*simulating natural light and air*	*transitional spaces*
animals	*naturalistic shapes/forms*	*mobility and wayfinding*
weather	*evoking nature*	*cultural and ecological attachment to place*
natural landscapes and ecosystems	*information richness*	
fire	*age, change and the patina of time*	
	natural geometries	
	biomimicry	

Table 5.2. *Biophilic design attributes*

5.3.3 *Circular Design Principles*

Adjustable shelving remains an element of the design to ensure occupant autonomy as a primary factor in the development of moveable modules, which promote adaptability and demountability. By incorporating both the modular hydroponic planters, and the shelf modules, the design enables the occupant or designer to establish how much permeability is required in the partition from the beginning. Aligning with circular design principles means that only required materials should be used, so in a setting with lower occupancy, less ceramic planters may be required, allowing for more reclaimed timber shelves. This ensures a minimisation of material use from the initiation and adheres to the principles of only using what is needed.

The modular nature of the design integrates shelving with ceramic hydroponic planters for an adaptable and unique system that employs circular economy principles. By enabling a simple system, the intervention aims to be 'anti-fashion' to minimise the risk of dating rapidly as trends move on. Integrating biophilic aesthetic principles with circular design for disassembly strategies enables the outcome to truly embody sustainable principles within the construction, usage and end-of-lifecycle phases (Table 5.3.).

CONSTRUCTION	USAGE	END-OF-LIFECYCLE
circular design principles *natural or recycled materials (no composite materials)* *eliminating toxic materials*	*hydroponics use 80%-90% less water to grow* *localised food production eliminates packaging and lowers food carbon miles* *LED lighting provides simulation of daylighting with high energy efficiency* *needing a smaller fridge results in lesser manufacturing, power use and chemicals* *food storage shelves create visual connections to food and reduce food waste*	*fully deconstructable* *un-treated timber is able to be reused or disposed of safely* *steel pipe and quick clamps are common system with many reuse potentials or steel is fully recyclable* *ceramics are a natural material*

Table 5.3. *Application of circular principles to the design outcome*

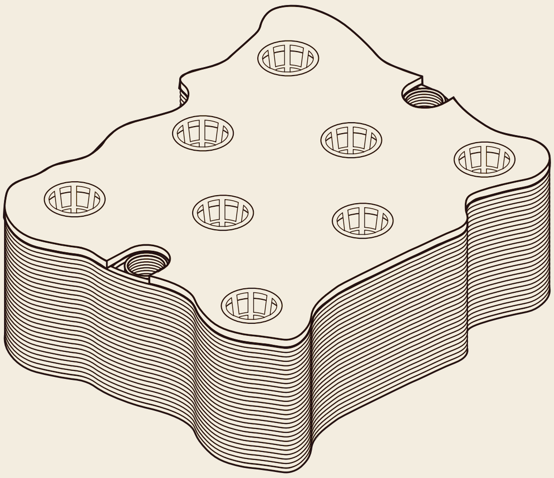


Figure 5.20. *Isometric view of assembled ceramic planter*

5.3.4 Productive Output

The potential output has been calculated using the same method from Section 3.2, based on existing system analysis and research. the change in hydroponic system to the Kratky technique could provide variance in productivity, meaning all calculations are approximate outputs.

The potential productive output for the intervention is variable, based on the selected permeability and application which would influence the number of ceramic planters. Each planter has capacity for 8 plants (Fig. 5.20.), with an estimated annual produce of 41.6kg. The modularity of the system means that the volume of produce can be scaled up effectively by adding more planters, to suit the requirements of the occupants.

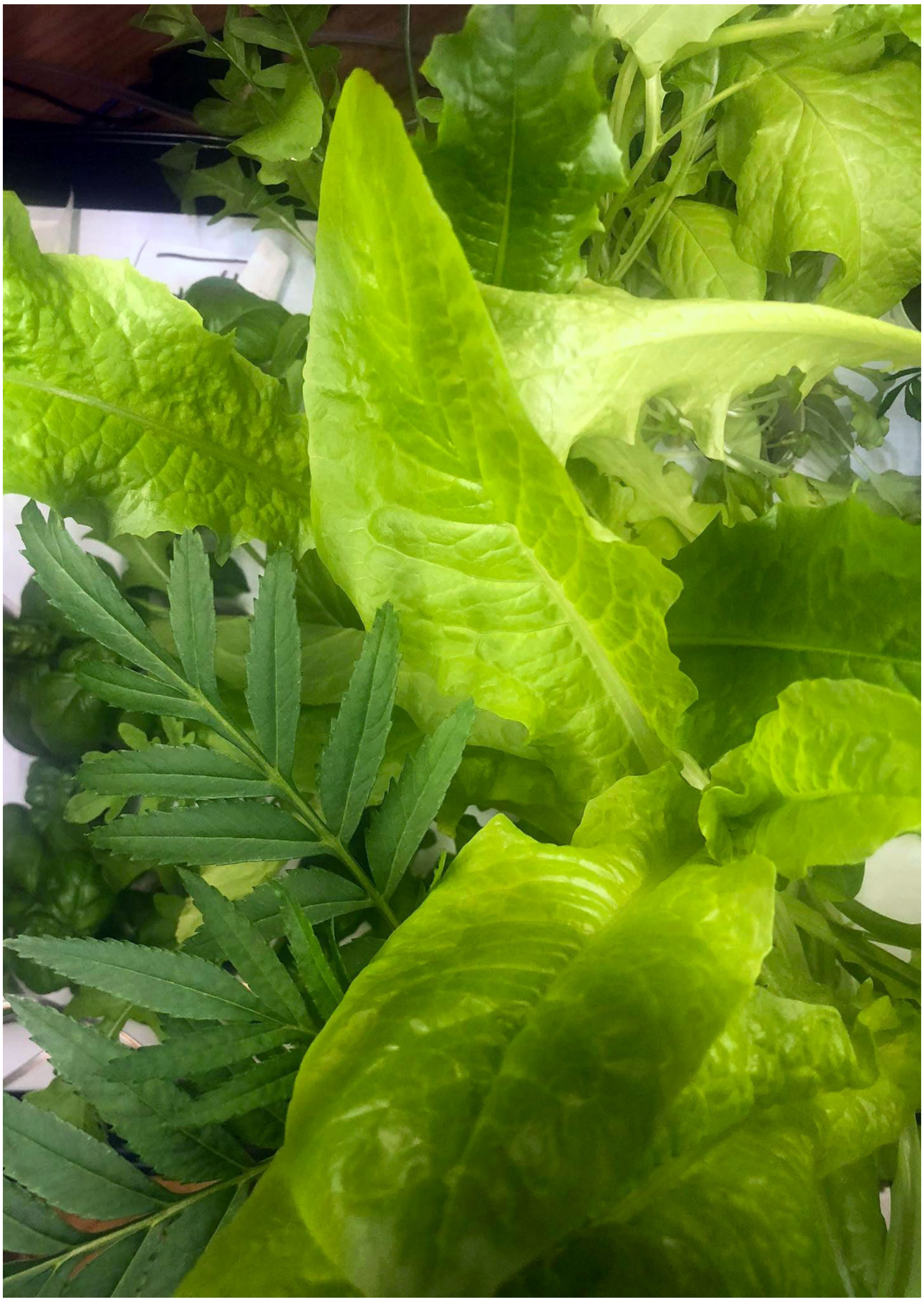


Figure 5.21. *Hydroponic lettuce, basil and marigold*

5.3.5 Integrated Lighting

The modular nature of the lights mean that they can be adjusted vertically to suit the needs of the planter directly below, with all wiring run through the steel pipes (Fig. 5.22.). The LED lighting strips are mounted on recycled steel flat plate with thermal electrical tape to reduce the effects of any excess heat on the planters or timber shelves.

The lighting requirements for the plants growing in the intervention have been weighed up against the ideal requirements for the human environmental comfort in the kitchen. Fig. 5.23. illustrates the dispersion of the lights from different heights and the corresponding lux levels at the kitchen bench working plane and on the floor. The calculations of lux are based on an ambient LED light with a beam angle of 115° and a luminous flux of 1000lm (Samsung Electronics, 2020, p. 92).

The widest illuminated area has a 3.1m diameter at floor level, creating a background level of ambient lighting for the kitchen and surrounding areas (Fig. 5.23.). The higher intensity lux levels, which are additive from several lights, localise the most intensive light to the base of the intervention. The benchtop working plane has an excessive lux level of 989 lx for 0.096 sqm of bench area near the edge. Fig. 5.23. operates as an illustrative diagram of the potential lux levels and indicates that when applied in-situ the proximity of the bench edge should be located more than 0.3m from the partition center.

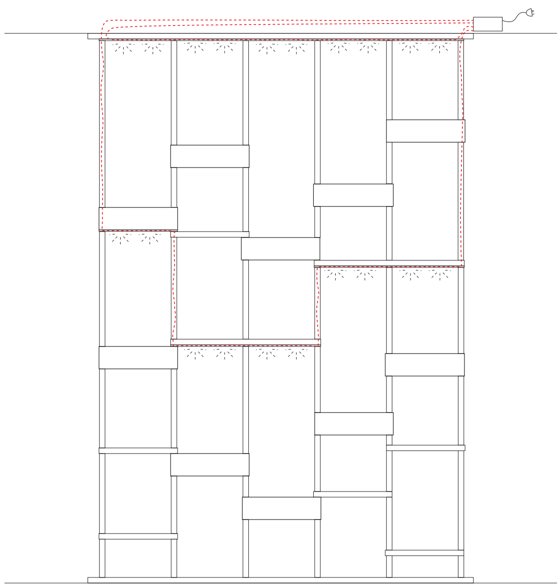


Figure 5.22. *Electrical diagram*

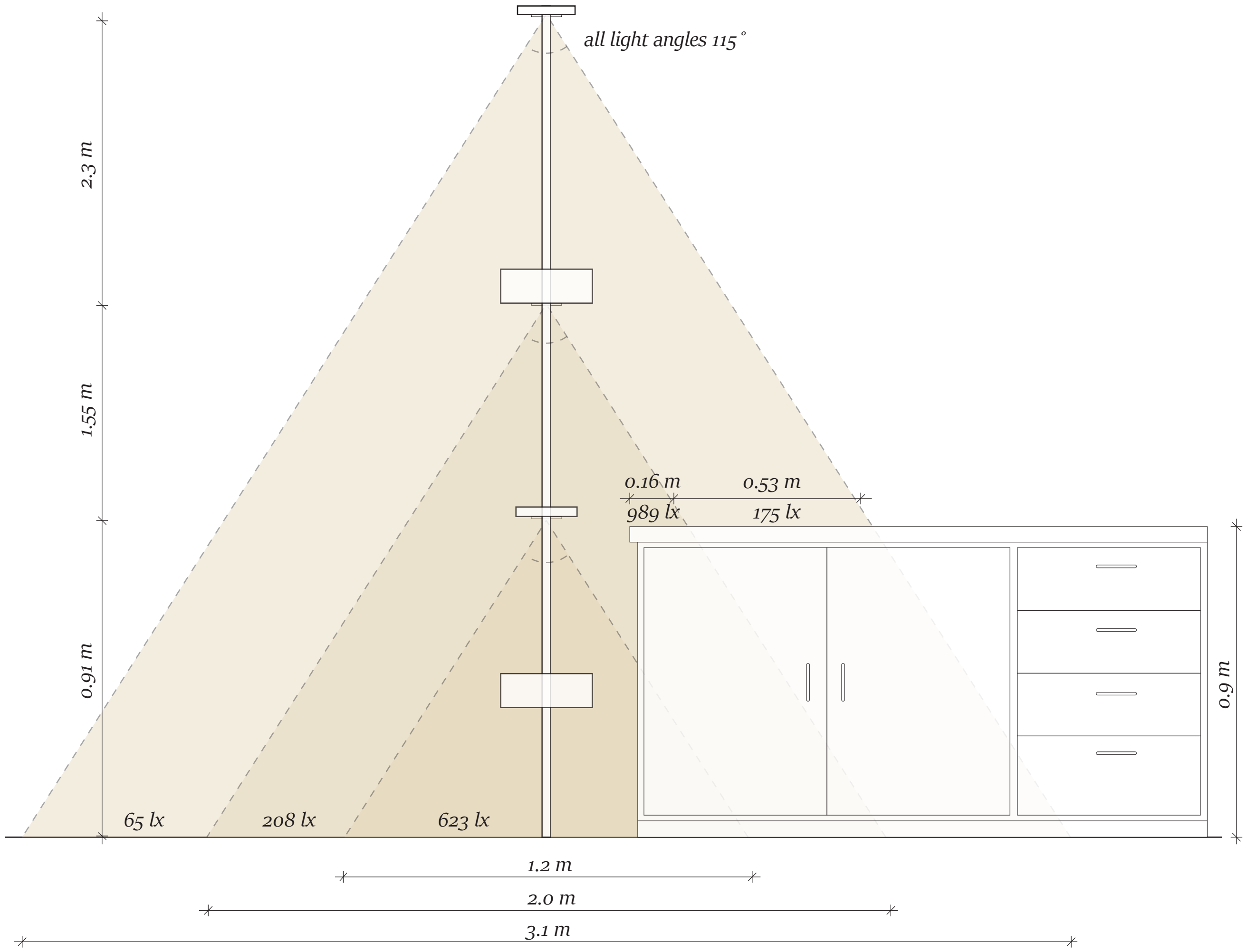


Figure 5.23. *Lux level illustration*

5.4 Architectural Application

This section explores the application of the designed hydroponic partition wall into a series of selected sites to analyse the potential performance if urban agriculture were integrated from the outset of apartment design.

The use of a partition wall (Fig. 5.24.), as established in Section 3.4.1, as a hydroponic urban agriculture intervention explores a new application for a partition and explores different levels of permeability within an open plan space. The intervention effectively functions as a 'window' for the internally based kitchens. By providing ambient background light and visuals of vegetation, the partition allows internal kitchen spaces to feel less enclosed.

Through integration of the elements of visual food storage with the hydroponic growing system, the visual and physical connection to food can be used to transform the way the kitchen working triangle operates and redefine the way that architecture is used to inform occupation and usage. The application to the selected sites follows placement locality into the kitchen working triangle established in Section 3.4. Rather than extending the triangle, the agriculture intervention operates in close proximity as an additional facet, rather than a direct replacement (Fig. 5.25.). The importance hierarchy of elements in Fig. 5.25. denotes the 'storage' element as the least important when considered in conjunction with the partition, as the hydroponics provide fresh vegetables and the shelving provides space to display other consumables to create a visual connection to food. In consideration of the lesser refrigeration requirements, all of the following redesigned kitchens assume a small below-bench fridge, prioritising open bench space and reinforcing the need for occupants to regard food purchasing and storage in a more considered manner.

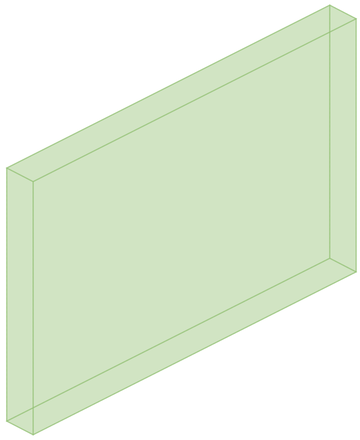


Figure 5.24. *Partition wall massing dia-*

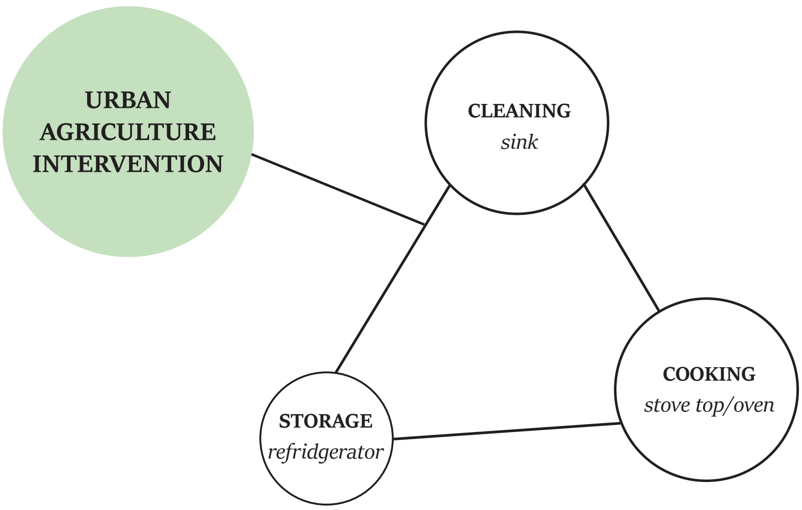


Figure 5.25. *Interjection of urban agriculture intervention into standard kitchen layout*

5.4.1 Selected Sites

The kitchen as a site cannot be seen as a standalone component of the apartment. Apartment floorplans are often open-plan and, therefore, the threshold between the kitchen and the living spaces is a blurry one. By looking at standard building conventions and sizing, the kitchen can be redesigned to focus on new methods of food sourcing. The remainder of the floorplan must be considered in relation to the agricultural intervention and to maintain circulation, accessibility and maximise aesthetic potential for the interior space.

The 'site' is then further defined into a series of case study kitchen designs which provide potential for redesign to integrate a hydroponic intervention.

The sites in Fig. 5.26.-5.28. show a range of selected apartment designs located in New Zealand. These showcase three different kitchen typologies as designed, and are a good approximation of standard apartments available on the market. The following sections (5.4.2-5.4.4) focus on the application of the earlier assessment of kitchen typology integration (Section 3.4.1), demonstrating how the urban agriculture partition can be applied. The redesign is aiming to maintain or improve the efficiency of the kitchen working triangle while considering the most suitable arrangement of kitchen elements in relation to the partition.

The limitations created by the existing footprint of the apartments means that the redesign and integration of an urban agriculture element using different parameters must consider existing accessibility, window placement, and dialogue with the other social spaces.

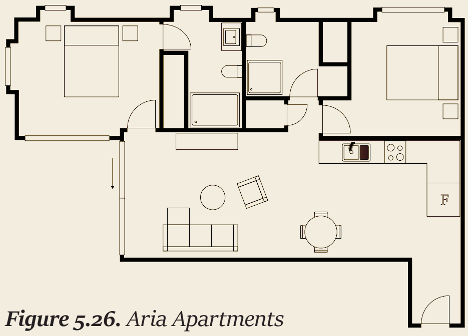


Figure 5.26. *Aria Apartments*
~L-shape kitchen

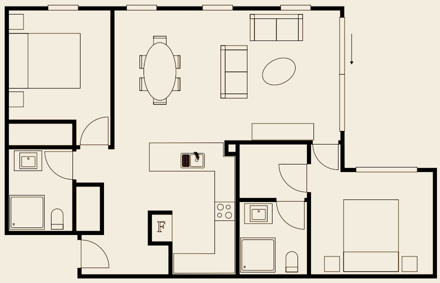


Figure 5.27. *FABRIC Onehunga Apartments*
~U-shape kitchen

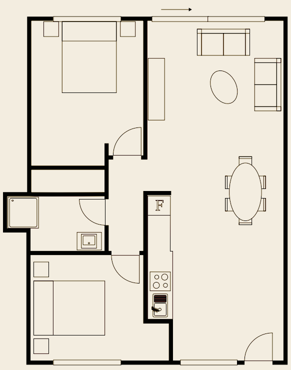


Figure 5.28. *Ilico Apartments*
~galley kitchen

3.4.2 Aria Apartments

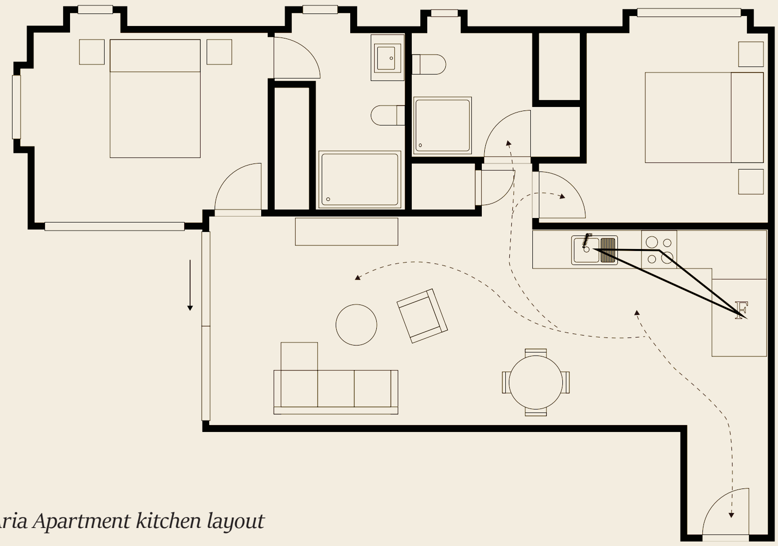


Figure 5.29. *Original Aria Apartment kitchen layout*

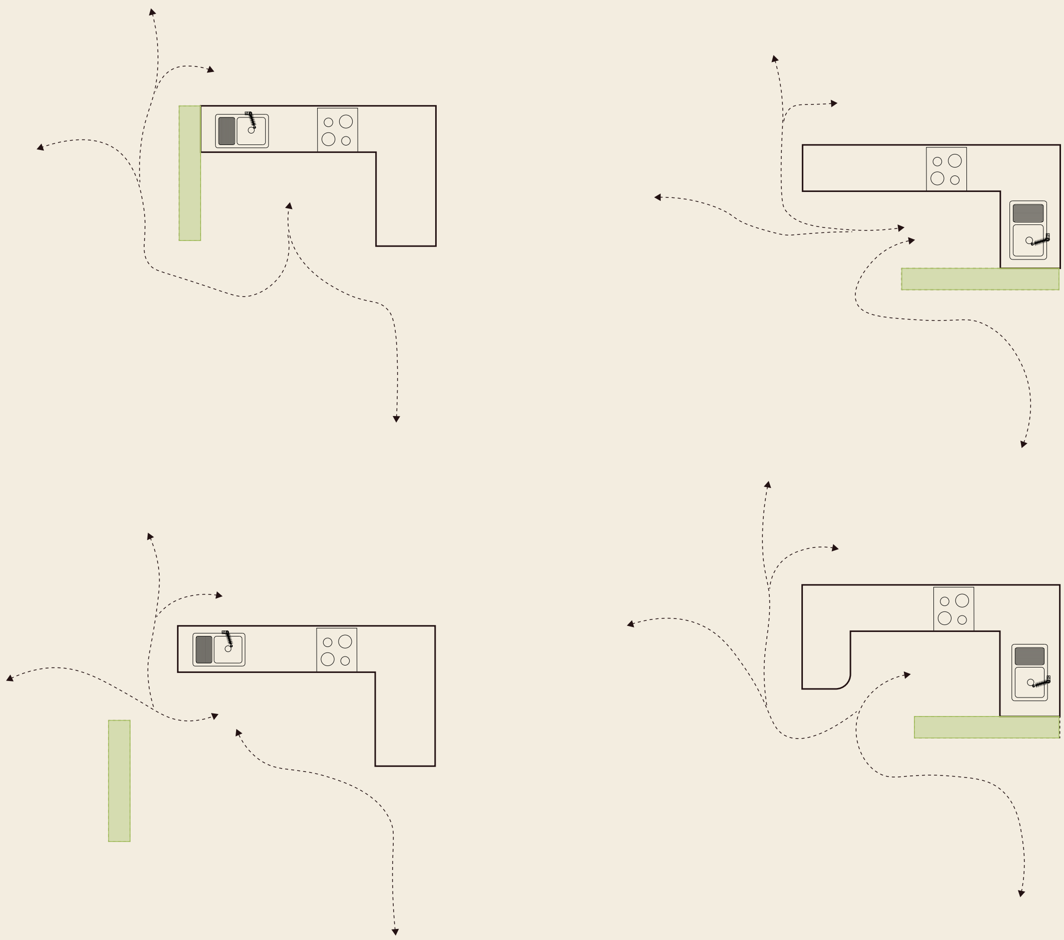


Figure 5.30. *Iterative floorplan designs with intervention partition shown*

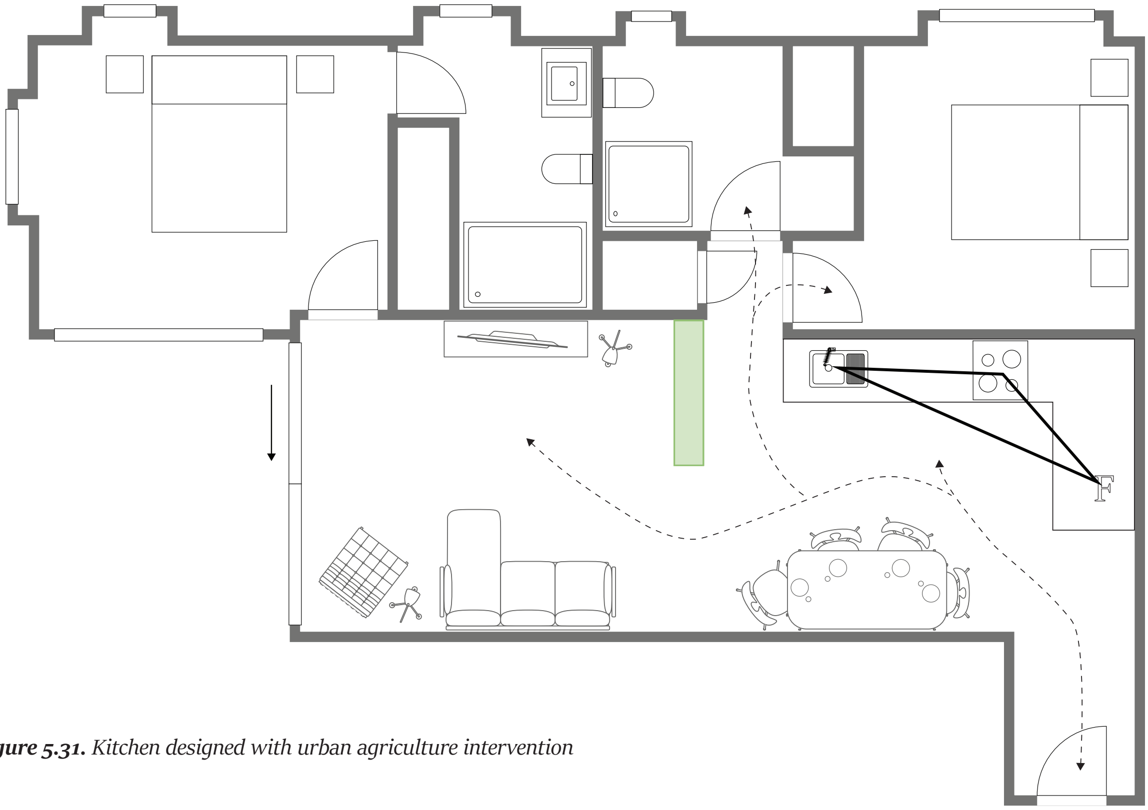


Figure 5.31. *Kitchen designed with urban agriculture intervention*

To maintain accessible walkways of 1.2m through the kitchen, the L-shape layout has been retained, due to the narrow nature of the apartment (Fig. 5.29. and Fig. 5.31.). The partition is located 4.7m from the only window in the living space to provide illuminance into the internally located kitchen. The placement is used to define the social spaces of the dwelling, by denoting the shift between bedrooms/bathrooms, living room and kitchen/dining. The changes to the working kitchen triangle in Fig. 5.32. include a shift in the placement of the sink and stove, moving each to the left and right respectively. This creates more working space between them and reduces the distance from the sink to the partition according to the established hierarchy of placement.

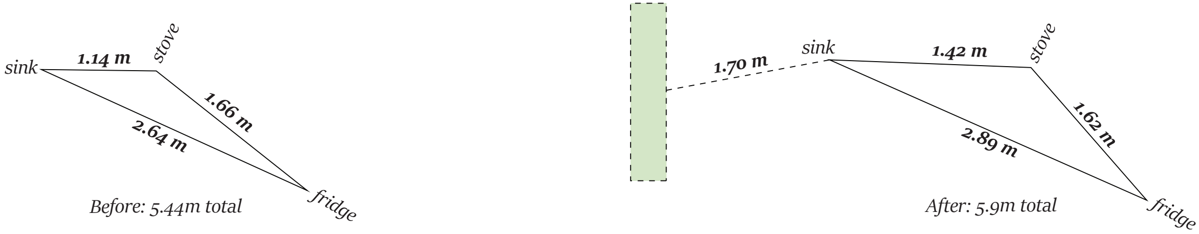


Figure 5.32. *Kitchen working triangle comparison*

Figure 5.33. *Render of proposed redesign of Aria Apartment*

Figure 5.34. *Render of proposed redesign of Aria Apartment*

3.4.3 FABRIC Onehunga Apartments

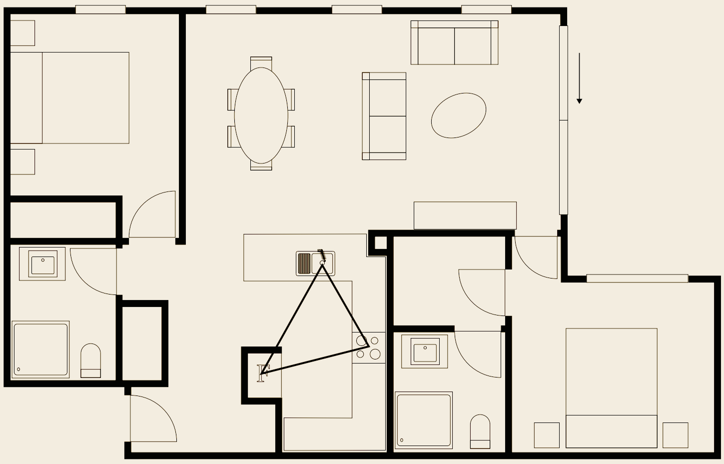


Figure 5.35. *Original FABRIC Onehunga Apartments kitchen layout*

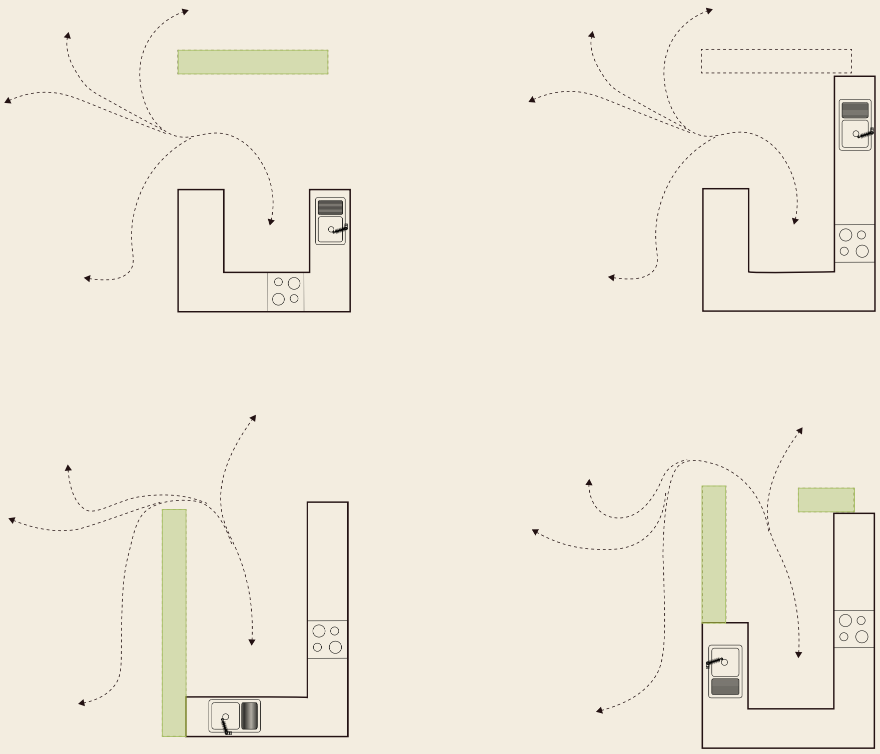


Figure 5.36. *Iterative floorplan designs with intervention partition shown*

Figure 5.37. *Kitchen working triangle comparison*

To facilitate a higher level of permeability throughout the space, this apartment has been redesigned to an L-shaped island kitchen typology (Fig. 5.38.). This ensures that accessible routes are in place and bench space is maximised. This apartment has several windows into the dining/living, however, the kitchen is internally located, allowing the partition to function in the most useful capacity as a simulation of a window. This design results in a smaller working triangle (Fig. 5.37.) and the partition is located 0.9m from the sink, 2.6m from the oven and 2.4m from the fridge.

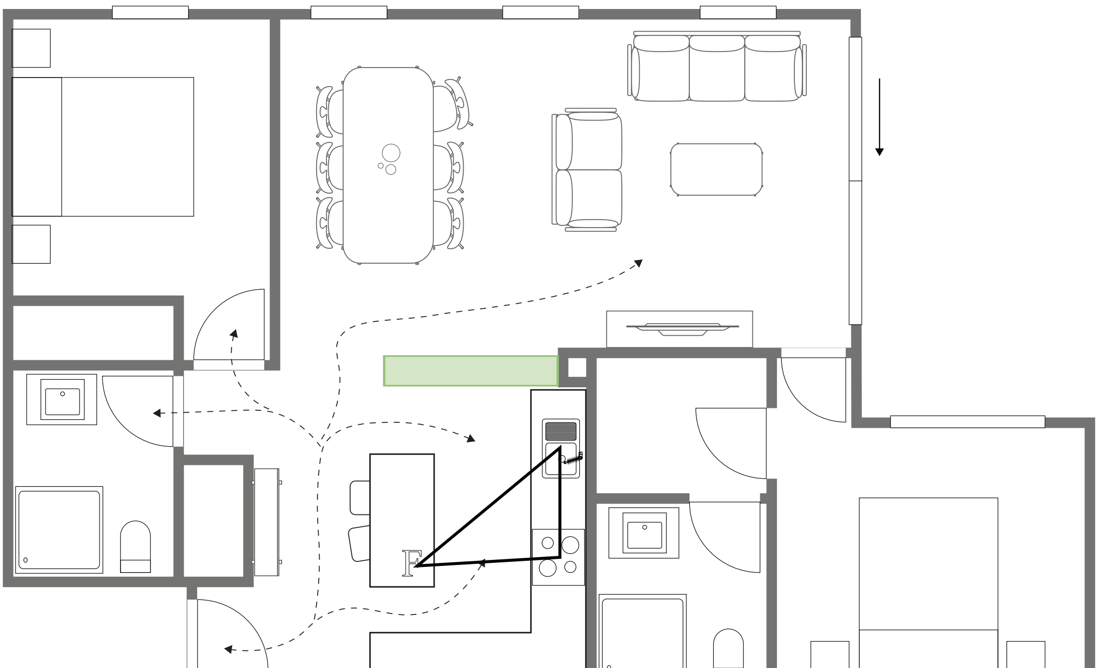


Figure 5.38. *Kitchen designed with urban agriculture intervention*

Figure 5.39. *Render of proposed redesign of FABRIC Onehunga Apartment*

Figure 5.40. *Render of proposed redesign of FABRIC Onehunga Apartment*

3.4.4 Ilico Apartments

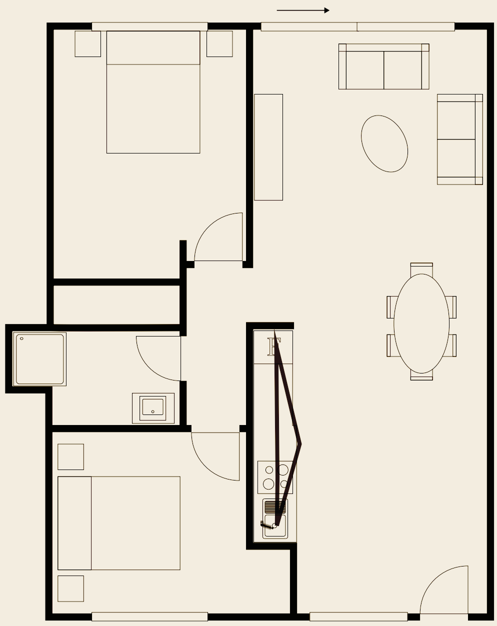


Figure 5.41. *Original Ilico Apartments kitchen layout*

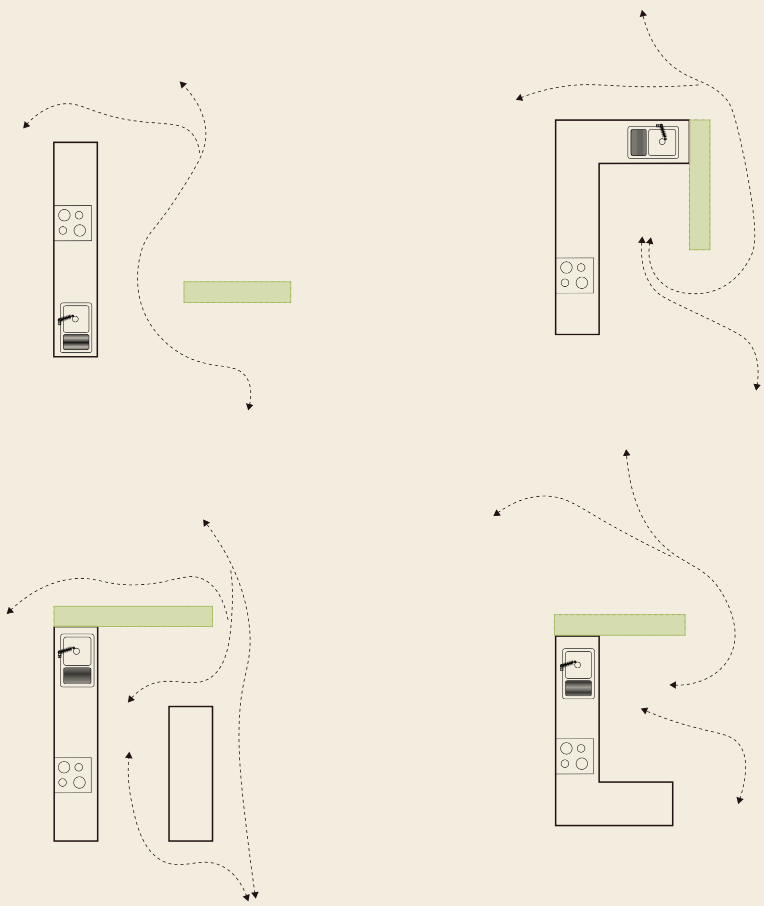


Figure 5.42. *Iterative floorplan designs with intervention partition shown*

The galley kitchen of this apartment (Fig. 5.41.) presented the most challenging to redesign, as the working kitchen triangle is difficult to apply in this setting. The redesigned galley with island combination of typologies has created clear social space, dividing the hallway into a clear path, with the partition separating the living and kitchen zones (Fig. 5.44). The windows on each end of this site, meant that the partition should be located in the central zone to provide maximum benefits from the lighting to the areas with lowest illuminance. The kitchen working triangle is significantly improved by the new kitchen typology (Fig. 5.43.) and the useful bench space is almost doubled. The sink is located on the island bench, near the services wall, to enable access from both the kitchen side and directly from the partition.

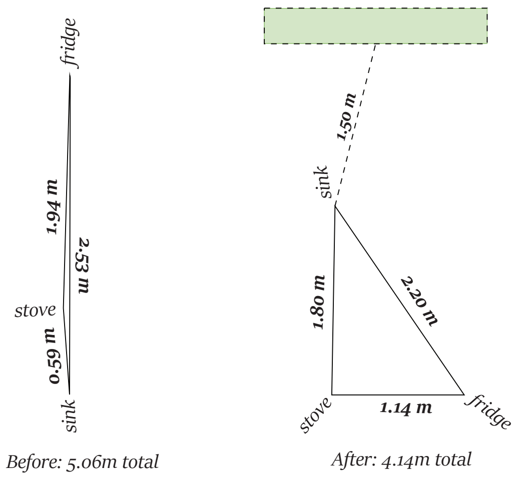


Figure 5.43. *Kitchen working triangle comparison*

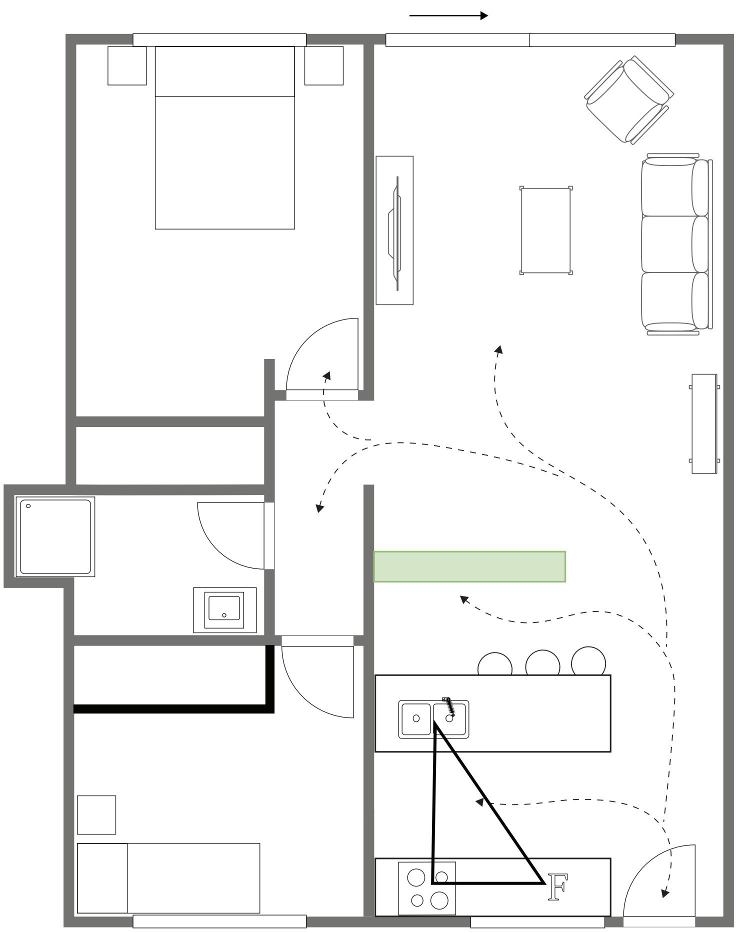


Figure 5.44. *Kitchen designed with urban agriculture intervention*

Figure 5.45. *Render of proposed redesign of Ilico Apartment*

Figure 5.46. *Render of proposed redesign of Ilico Apartment*

3.4.5 Application Outcomes

Minimal changes to the working triangle distance in each of the redesigns implies that an effective kitchen layout can still be maintained with the implementation of the partition intervention. By creating sources of ambient lighting in the areas of lowest illuminance within the apartments, the partition enables improved occupation through visibility. The set of design parameters established in Section 4.1 have been successfully converged to develop an architecturally integrated urban agriculture intervention that evokes biophilia and promotes sustainability as a tangible outcome. However, further development would be needed to review whether the apartment floor plans as a whole should be adjusted to further accommodate and integrate the hydroponics growing in the kitchen.

Figure 5.47. *Ceramic planter*

Chapter Six

~Conclusion

6.1 Conclusion

This thesis employed research for design and research through design to investigate how urban agriculture interventions could be integrated into architecture to facilitate food production within domestic kitchens. A number of gaps in knowledge were discovered through a literature review of the existing solutions, identifying areas in which to further explore and engage with the selected context of hydroponic partitions.

Analysis of technical system requirements for hydroponics identified a series of passive and active systems that could be incorporated into the subsequent design work. From a review of both the aesthetic qualities and materiality of existing hydroponic solutions, the implementation of robotic 3D clay printing arose as a method of making. The exploration of 3D printing clay for the purposes of architecturally integrating a hydroponic system aesthetically and technically was a specific application and a foray into research that has previously been a gap.

The wide breadth of technical research and knowledge required to develop a thorough understanding of both hydroponic systems and robotics as a method of making meant that the scope was significantly widened.

The aim of the work defined the research as contributions to a developing body of knowledge of how to more effectively integrate growing edible plants in the indoor environment. The methods facilitated within the research focused on solutions for materiality through making and experimentation. At an architectural level, the wider implications that could be achieved from a small-scale intervention in the kitchen and the inhabitation shift of interior spaces through the integration of urban agriculture were measured through a series of set parameters.

The research contained a series of inter-relating elements that had to each be resolved in relation to each of the other key elements. The main output of the research is the furthering of knowledge of many aspects of these elements, and establishing a space within architecture for sustainable food-based interventions to be developed. The work makes a contribution to the field as far as possible within the limitations of what was achievable within a Master's thesis and articulates elements which others could develop further in subsequent studies.

6.2 Research Limitations and Future Opportunities

The focus of the thesis was to explore how to bring food production into urban residential architecture. The core objective was to proactively challenge and rethink food production and create opportunities to include agriculture in urban apartments. The results show that a highly comprehensive rethinking was required, and the integration of a range of complex systems of technical information was necessary. As a consequence, a range of different areas of knowledge were drawn upon, which required a reasonable level of skill in a range of areas that were not initially anticipated as relevant. This appears to be one of the core characteristics of transdisciplinary integrations which are needed for truly more sustainable approaches. However, this also means that a range of area which were not the primary focus of the work, had to be engaged with to a high level of skill. Perhaps the only way to truly progress pro-sustainable transitions is to create space for deep transdisciplinary engagement.

The key limitation of using complex systems as supporting tools was the time consumed by learning how to run these systems, for example, robotic systems and the making of ceramics. These were both technical barriers that required significant research and learning to operate and could each constitute the entirety of a thesis individually. However, the research outcomes have created foundations for future research avenues implementing ways of making with clay and robotic 3D printing. On this level, the project opens significant opportunities for further research.

The extensive analytical comparisons undertaken as to which growing system is the best suited method of application took a significant length of time, meaning that the capacity for refinement and experimentation through making processes was limited. Subsequent work would be able to develop from findings made here, and start with the knowledge that hydroponic systems are the most effective for this application. Such subsequent studies would be able to explore the making earlier, potentially enabling further progression in terms of making. Unfortunately, such information and prior analysis was not available for this project, therefore, the making was progressed as much as possible within the constraints.

Additional issues emerged from using clay as the primary medium – due to the naturally slow-drying nature of clay – delays caused by the drying has to be factored in. This was impossible to foresee when starting the study, as the nature of system and suitable materials were only identified through the work undertaken in the early stages of the project. This limited the level of possible feasibility testing, which caused significant limitation in terms of developing the ceramics.

One of the early conclusions of the work was that purpose designed solutions might be better than retrofitting into existing homes. Yet, this research only had the time to conceptualise some retrofitted placements within existing apartment plans by redesigning the kitchens (Chapter 5). Further research is needed to explore more fully how the introduction of hydroponics to kitchens as a norm might change the overall design of apartment floorplans.

Despite these limitations, this work sets the scene and brings together many of the relevant reviews, technical insights and evaluations which are essential for further development in this area. Therefore, the main contribution to knowledge is in establishing a base for future development in this space, and undertaking some of the critical preliminary testing of the articulated approaches. By doing this, the work furthers the field to allow for others to continue researching and developing in this area. Future research is still required to resolve the implementation and more could be done to review the solution and refine the design of it from the perspective of visual and biophilic qualities. With more developed robotic scripts and 3D printing the design could improve in terms of efficiency of planting density and potential food production, with a greater level of detail. The current stage of work has shown a proof-of-concept ceramic form and established the parameters for the integration into residential kitchens.

However, one indisputable conclusion of this work is that a significant rethinking of the existing practices requires an interdisciplinary approach, attention to detail and research into a range of complex parameters. Nevertheless, this is possible work with tangible benefits and is a necessary step if we are to move to a carbon neutral future.

6.3 List of Figures

All figures in the document are author's own, unless otherwise stated below.

Figure 3.2. Hydroponic Kits NZ. (2022). *Benchtop Hydroponics System with 8 pots* [Photograph]. https://hydroponickits.co.nz/product/benchtop-hydroponics-system-with-8-pots/?utm_source=Google%20Shopping&utm_campaign=gshop%20new%20feed%20september%20&utm_medium=cpc&utm_term=997&gclid=Cj0KCQiAyMKbBhD1ARIsANs7rEH9CuC_uKcHlaJj0EUsQ-uQPd7T6Td4NCKJuiMKWdcRE0WLk_ogs6EaApdqEALw_wcB

Figure 3.3. Urban Plant Growers. (2022). *The Family Farm* [Photograph]. Urban Plant Growers. https://www.urbanplantgrowers.com/products/familyfarm

Figure 3.10. Lindholm, S., & Husum, M. (2019) *GrowMore* [Photograph]. Yanko Design. https://www.yankodesign.com/2019/10/29/live-green-eat-green-with-this-diy-modular-garden-that-expands-with-you/

Figure 3.11. Dongfang, J. (2012). *Para Eco House* [Photograph]. ArchDaily. https://www.archdaily.com/289503/para-eco-house-tongji-university-team

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Figure 3.13. Jardins de Babylone. (2011). *Bamboo Urban Garden* [Photograph]. Jardins de Babylone. https://www.jardinsdebabylone.fr/realisations/design-vegetal/agriculture-urbaine/

Figure 3.14. Rinaldo, Ken., & Pilchuck, Amy. (2006). *Hydroponic Herb Garden* [Photograph]. Ken Rinaldo. http://www.kenrinaldo.com/portfolio/hydroponic-herb-garden-2006/

Figure 3.15. Bearak, M., Kelle, D., & Mercier, A. (2011) *Amphorae* [Photograph]. Morpholio. https://www.mymorpholio.com/site.php/collection/index/id/cGoI2ezMPNgJKZTR

Figure 3.16. Benditas Studio. (2019). *The Brot* [Photograph]. Yanko Design. https://www.yankodesign.com/2019/06/10/freshen-up-your-plants-and-garden-with-these-designs/amp/

Figure 3.17. Tidd, C., & Jakiela, K. (2019). *Aeva Hydroponic System* [Photograph]. Yanko Design. https://www.yankodesign.com/2019/06/10/freshen-up-your-plants-and-garden-with-these-designs/amp/

Figure 5.26. Author's image, adapted from: TOA Architects. (n.d), *Aria Apartments floorplan* [Digital diagram]. Ray White.

Figure 5.27. Author's image, adapted from: Ashton Mitchell Architects. (n.d), *FABRIC Onehunga Apartments floorplan* [Digital diagram]. BP&O Plus. https://bpando.org/2017/02/21/branding-fabric-onehunga/

Figure 5.28. Author's image, adapted from: Warren and Mahoney Architects. (n.d), *Ilico Apartments floorplan* [Digital diagram]. Sensopia.

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6.5 Appendix

Appendix 1

Spread of available products in New Zealand

System Type	*Potted Plants*	*Planter Box Wall*	*Pockets*	*Felt System*	*Nutrient Film Technique*	*Deep Flow Technique*	*Aeroponics*	*Capillary Action*	*Root Dipping Technique*
CUSTOM DESIGN	--	≥4	≥0	≥4	≥1	≥0	≥0	≥0	≥0
FIXED PRODUCT	--	≥3	≥5	≥1	≥4	≥8	≥2	≥4	≥2

Appendix 2

Comparison of two hydroponic systems; Benchtop System and Family Farm System

	Dimensions (mm)	*No. of growing spaces*	*Volume (m3)*	*Weight (kg)*	*Estimated annual produce (kg)*
BENCHTOP SYSTEM	*280 x 170 x 160-520*	*8*	*0.01*	*1.4*	*41.6*
FAMILY FARM	*384 x 648 x 1225*	*72*	*0.305*	*37*	*374.8*

Appendix 3

Comparison of material characteristics

COMPARISON OF MATERIAL CHARACTERISTICS

	Baseline/Existing Solutions				**Proposed Solutions**				
	Aluminium		**PVC (Polyvinyl Chloride)**		**Pottery/Ceramics**		**Timber**		
	Virgin	***Recycled***	***Virgin***	***Recycled***	***Glazed***	***Recycled***	***Plywood***	***Air Dried Softwood***	***Recycled***
Embodied Energy (MJ/kg)*	191-292	8.1	70-93.3	-	6.3-7.2	-	10.4	0.3	-
Local Sourcing**	no	yes	no	no	yes	yes		yes	yes
Waterproof	yes	yes	yes	yes	yes	yes	yes	no	no
Framing/Structure	yes	yes	no	no	no	no	yes	yes	yes
Misc. requirements or barriers			*possible toxic leaching*	*possible toxic leaching*	*limitations of size due to kiln volume*	*sizing and specified requirements uncontrollable parameters*	*would require waterproof lining*	*would require waterproof lining*	*would require waterproof lining*

**embodied energy figures sourced from x y z*

***local sourcing defined as able to be sourced from materials within New Zealand for the purposes of this research*

Appendix 4

Hydroponic growing to test researched data