RE-IMAGINING INDOOR GARDENING SYSTEMS:

Ceramic Light Fixtures as Food Growing Typologies

by
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AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

STATEMENT OF CONTRIBUTIONS

Taylor Murray was the sole author of this thesis, which was written under the supervision of Professor David Correa. No portion of this document was written for publication.

All drawings and diagrams were authored by Taylor Murray. Exceptions to the sole authorship of this thesis is the production of ceramic artefacts. Ceramic artefacts were co-created by Taylor Murray and Yannik Sigouin, unless otherwise noted. Taylor Murray looked at the ceramic artefacts through the lens of urban food growing, and was responsible for the system and component design. Yannik Sigouin looked at the production of ceramic artefacts through a coding perspective that focused on optimising digital to physical workflows.

ABSTRACT

In recent years, many Canadians have shown interest in growing their own food at-home as a form of recreational hobby, to address concerns of self-sufficiency, and to encourage greater environmental sustainability. However, individuals living in small urban apartments are less likely to be able to start their own gardens due to distinct barriers such as a lack of time, space and gardening knowledge. This raises the question: How can design interventions enable apartment inhabitants to overcome these barriers and begin the practice of at-home food growing? While many systems for indoor gardening exist today, they face design challenges such as the construction of environmentally harmful materials, the lack of an architectural design language, and limitations on their ability to use aesthetics to create beauty. Innovation in the development of architectural ceramic assemblies provides an opportunity to use these systems to propose new typologies for indoor food growing that remedy the design flaws of existing indoor gardening systems. Therefore, this thesis will design and construct new typologies for indoor gardens using clay 3D printers to create multi-functional ceramic components for food growing. These new typologies are explored through a case study, which develops the indoor gardens as a light fixture. Additional applications for the food growing systems, such as in wall assemblies and cladding systems, are discussed in the research outlook. The key impact of this research is to develop a new aesthetic and architectural quality for indoor residential agriculture.

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CHAPTER 1 - INTRODUCTION

1.1 RE-IMAGINING INDOOR FOOD GROWING SYSTEMS

As Canadians continue to move into urban centres, the close connection that many once had to food growing practices is changing, and distance is created between urban inhabitants and their sources of food.[1] Those living in dense urban areas have few opportunities to interact with agricultural systems and therefore have little understanding of farming practices.[2] A lack of involvement in agricultural practices combined with increased distance from food sources has a potentially negative impact on the knowledge of food growing.

In the years since 2020, many Canadians have demonstrated interest in beginning at-home gardening practices.[3] During the COVID-19 pandemic, gardening became a popular past-time, as individuals searched for hobbies that could be performed at home during extended periods of lock-down.[4] In the years following, at-home gardening maintained its popularity as a means to increase self-sufficiency amidst high levels of inflation, and the rising cost of groceries.[5] No matter the reason cited for starting a garden, the increased attention to gardening practices presents a unique opportunity to re-centralize the importance of food growing in daily life.

Those who have not been able to start their own gardens at-home reported key barriers such as a lack of space, time, and gardening knowledge.[6] Architectural design solutions can contribute to reducing these barriers, and allow individuals to begin gardening practices. By coupling food growing infrastructures with architectural elements, urban inhabitants are enabled to regularly engage with gardening systems and re-build the knowledge of food growing. This promotes a greater sensitivity to environmental considerations and the importance of food and nutrition to health and wellbeing.[7] It also allows for numerous opportunities to emerge in the field of architectural design, such as in the creation of new atmospheres and aesthetics for interior space.

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1. Kortright and Wakefield, “Edible Backyards”
2. Kneen, “The People’s Food Policy Project: Introducing Food Sovereignty in Canada”
3. Mullins et al., “Home Food Gardening in Canada”
4. Music et al., “Seeds and the City”
5. Charlebois, “Canadians React to Food Inflation and Grow Their Own Gardens”
6. Charlebois and Music, “New Report”
7. Santos et al., “Contribution of Home Gardens to Sustainable Development”

This thesis explores these emergent opportunities through the design of a light fixture for residential food growing. Artificial light is often a requirement of indoor gardens, in order to provide the plants with a source of energy to grow from. It is also a requirement of residential space to create atmosphere, provide occupant comfort, and allow for daily tasks to be performed. Existing research in the development of architectural ceramic assemblies such as facade systems,[8] and light screens[9] will be explored in the design for the proposed light fixture. The system will be fabricated out of clay, due to its unique material properties that have long established its use in architectural design and in agricultural systems.[10]

The method used for developing the light fixture is an iterative process that tests system components through the creation of several models. Clay 3D printers are used to prototype each model, and rapidly test design variables such as massing and aesthetic details. The models are fabricated through a case study, which designs the light fixture as a complete system for indoor gardening by combining a light source with vessels for plant growing. The presented light fixture is evaluated on its ability to function as a practical system for food production, and its success as an aesthetic object in residential space. Future applications for this research, such as in the creation of walls and cladding systems for food growing, are discussed in the research outlook.

The resulting thesis hopes to have an impact on the way that Canadian cities adapt to the requirements of sustainable urban agriculture, while promoting indoor gardening as both a practical system and an aesthetic design opportunity. As cities continue to grow in size and in population, concerns about urban agriculture will remain a focus of architects, urban planners, and city dwellers alike. Integrating food growing systems with architectural design has the potential to encourage greater sustainability in cities by restoring the distanced relationship that many urban inhabitants have to independent food growing practices.

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8. ACAW, “Architectural Ceramic Assemblies Workshop”
9. Ochoa and Clarke-Hicks, “Grading Light”
10. The American Ceramic Society, “Brief History of Ceramics and Glass”

CHAPTER 2 - AIM

2.1 - INDUSTRIAL AGRICULTURE, URBANIZATION AND GROCERY STORES

In the last century, the relationship that many Canadians had to agricultural practices changed. At the beginning of the 20th century, food growing was a central part of daily life, with approximately one in three Canadians living on farms.[11] There were many small-scale farms that were family owned and operated, with high amounts of skilled labour, allowing for many types of crops to be grown together in complementary ways.[12] However, in the middle of the century, the Industrial Revolution began in North America and demanded greater efficiency and higher profits from the agricultural industry.[13] Human labour was supplemented with streamlined machines, diverse crop fields were turned into monolithic plots, and chemical pesticides were introduced to eradicate weeds and pests.[14] These new industrial farms quickly grew in size, and began to displace small-scale and family owned operations. As a result, farmers began to leave the industry in large numbers.[15] Today, less than one in forty-six Canadians live on a farm,[16] and less than one in one hundred are active farmers.[17]

Many of those who left agriculture as a result of industrialization moved from rural environments into urban areas.[18] Today, statistics from the Government of Canada show that almost 75% of Canadians are living in a large urban center.[19] This has had significant implications on the relationship that Canadians have to food growing systems, as essential knowledge of agricultural practices is being lost, and, "the vast majority of the population are urban dwellers with little connection to, or understanding of the realities of farming or fishing."[20] As a result, many of those living in urban environments depend on grocery stores to provide for their food and nutritional requirements.

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11. Government of Canada, "Agriculture-Population Linkage Data for the 2006 Census"
12. John Hopkins University, "Industrialization of Agriculture"
13. Throughton, "Industrialization of US and Canadian Agriculture"
14. John Hopkins University, "Industrialization of Agriculture"
15. Kneen, "The People's Food Policy Project: Introducing Food Sovereignty in Canada"
16. Government of Canada, "Agriculture-Population Linkage Data for the 2006 Census"
17. Kneen, "The People's Food Policy Project: Introducing Food Sovereignty in Canada"
18. Samson, "Rural Canada in an Urban Century"
19. Government of Canada, "Canada's Large Urban Centers Continue to Grow and Spread"
20. Kneen, "The People's Food Policy Project: Introducing Food Sovereignty in Canada"

However, grocery stores have also undergone significant changes through the 20th century. Firstly, local public markets were displaced by ‘combination stores’, which supplied many types of groceries and household items in one place, and were preferred by customers for their convenience.[21] Secondly, consumers began to favour pre-made foods, leading to the emergence of a food processing industry.[22] The food processing industry designed countless new ultra-processed food options, which are, “not modified foods but formulations of industrial ingredients and other substances derived from foods, plus additives.”[23] Ultra-processed foods often have high concentrations of sugar, and salt, and are less nutritious than home-cooked meals using whole ingredients.[24]

Today, many negative effects as a result of these two changes can be seen. Firstly, some of these initial ‘combination stores’, like Loblaws,[25] have become huge chains, with the three largest grocers - Loblaws, Sobeys, and Metro - controlling almost 60% of Canada’s grocery market.[26] The absence of competition contributes to a lack of agency amongst consumers, who are dependent on them for their food supply and are therefore subject to the decisions made by these leading chains.[27]

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21. Boothman, “A More Definite System”
22. Huebbe and Rimbach, “Historical Reflection of Food Processing”
23. Moubarac, “Ultra-Processed Foods in Canada”
24. Huebbe and Rimbach, “Historical Reflection of Food Processing”
25. Boothman, “A More Definite System”
26. Statista, “Grocery Retailers Market Distribution in Canada”
27. York University, “Corporate Concentration”

This was evidenced in March of 2020, when the COVID-19 pandemic took hold in Canada. The global uncertainty caused by the onset of the event saw many rush to the grocery store to stock up on household products. Quickly, grocery stores saw long lines outside the building, and empty shelves inside. Individuals resorted to food hoarding and panic buying as concerns grew about the, "prospect of supply disruptions, restrictions on movement, or fear of demand-driven shortages."[28] The pandemic set into motion a series of events that triggered high rates of inflation in the years following.[29] In September of 2022, the price of food purchased from grocery stores was inflated by 11.4% - the highest it has been since August of 1981.[30] Despite the high costs of groceries faced by consumers, Canada's concentration of grocery store chains appeared to profit off the price increases, and were accused of price profiteering.[31] As a result, many are calling for an increase in competition in the grocery sector, to provide more options to consumers[32] (Figure 2.1.1).

The Current

'Herd effect': Social media images of empty shelves fuelling panic buying over coronavirus, says prof

TORONTO STAR

Home / Business

BUSINESS

Global pandemic leads to surge in Canadian grocery store profit — and cost

CANADA

'Harder and harder:' Food inflation and how it's impacting the groceries people buy

Loblaw and Metro report higher sales, quarterly profit as they face scrutiny over food price inflation

Canada Needs More Grocery Competition

Competition Bureau Retail Grocery Market Study Report

June 27, 2023

BUSINESS OPINION

There is a solution to skyrocketing grocery prices — and it's not introducing a fourth grocery chain

CANADA | News

Nearly half of Canadians choosing cost over nutrition when buying food due to high prices: survey

Figure 2.1.1 - Collage of Canadian news headlines from 2020 - 2023.

28. O'Connell et al., "Preparing for a Pandemic"
29. Macklem, "What's Happening to Inflation and why it Matters"
30. Government of Canada, "The Daily - Consumer Price Index, September 2022"
31. CBC Radio, "Soaring Food Prices, Record Profits Prompt Questions"
32. Government of Canada, "Canada Needs More Grocery Competition"

Further, industrially processed foods began to comprise a significant part of diets, with studies done by the Heart and Stroke Foundation revealing that in 2015, 48.3% of Canadians were receiving their total calories from ultra-processed foods.[33] The continued consumption of industrially processed foods offered in grocery stores has been linked to higher incidence of obesity, and diabetes.[34] In addition to these health concerns, there are also intellectual and social harms caused by the prevalence of processed and ready-made foods, as they diminish the requirement for home cooking,[35] which passes down knowledge on how to prepare certain foods and nutritious meals.[36] It also prevents individuals from gaining the social benefits that occur when families and friends come together to share foods.[37]

As a result of these events, the personal connection and deep knowledge that many Canadians once had to food growing processes and preparation has been significantly altered by the arrival of industrial agriculture, urbanisation, corporate grocery chains, and the food processing industry. In recent years, scholars and policy makers have called attention to these issues. Consumers have reacted to the findings by becoming, "increasingly disenchanted with the ways in which the Canadian food supply is being managed,"[38] and are looking for alternative ways to produce their own food.

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33. Moubarac, "Ultra-Processed Foods in Canada"
34. Kneen, "The People's Food Policy Project: Introducing Food Sovereignty in Canada"
35. Moubarac, "Ultra-Processed Foods in Canada"
36. Government of Canada, "Importance of Food Skills"
37. Moubarac, "Ultra-Processed Foods in Canada"
38. MacRae et al., "Health and Sustainability in the Canadian Food System"

2.2 - THE RISE OF AT-HOME GARDENING PRACTICES

One practice that has gained popularity as a method of food production in recent years is at-home gardening. At-home gardening has long been used to increase self-sufficiency and food supply in times of crisis, such as the ‘Relief Gardens’ of the Great Depression, the ‘Victory Gardens' of the World Wars, and the ‘Crisis Gardens’ of the 2008 recession.[39] Perhaps unsurprisingly, it again became a hugely popular solution for many Canadians during the COVID-19 pandemic and the high levels of inflation that followed. The demand to start a garden rose so quickly that in some instances, gardening stores completely sold out of supplies.[40] This sparked the interests of many Canadian scholars, who began to research the behaviours and motivations of those who were engaging with gardening practices. Initial surveys done by researchers at Dalhousie University showed that in 2021, 51% of participants reported that they grow a fruit or vegetable at home.[41] Of this 51%, 17.4% stated that they began the practice during the pandemic.[42]

The findings of these research studies show that the reasons cited for starting a garden varied. For some, gardening became a hobby in response to the time spent at home during the COVID-19 pandemic.[43] For others, the decision to start a garden was motivated by the rising cost of grocery store items.[44] A result that was consistent through the findings is that the majority of respondents state that they depended on their gardens for their ability to build skills and increase their knowledge of food growing. 54% of long-time gardeners, and 69.3% of new gardeners agreed that they grow food at home to acquire new skills for themselves.[45]

No matter the reason for starting a garden, the increase in gardening practices presents the opportunity to leverage this interest and encourage more people to grow their own food. The aim of this research is to explore the ways that this can be achieved through design solutions.

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39. Mullins et al., “Home Food Gardening in Canada”
40. Music et al., “Seeds and the City”
41. Mullins et al., “Home Food Gardening in Canada”
42. Ibid.
43. Music et al., “Seeds and the City”
44. Charlebois, “Canadians React to Food Inflation and Grow Their Own Gardens”
45. Mullins et al., “Home Food Gardening in Canada”

CHAPTER 3 - RELEVANCE

3.1 - THE BENEFITS OF INDOOR GARDENING

Enabling more people to begin their own gardens presents many benefits that impact environmental sustainability, and individual health and wellness.

Environmental Sustainability

Unlike current systems of industrial agriculture, at-home gardening is a very sustainable method of food production. On industrial farms, the process of getting food from farm to table is energy intensive, requiring carbon outputs from large refrigerators used to store the crops, and the trucks that transport them.[46] However, at-home food growing is unique in the sense that food is grown at the site of consumption, which eliminates these carbon emissions and allows for food to be consumed directly after harvesting. Additionally, engaging with the process of gardening allows individuals to become more aware of environmental considerations and therefore contributes to encouraging sustainable practices. For example, at-home gardeners have growing plots that are diverse, often growing many types of crops together, including non-commercial and local produce varieties.[47] They are also far more likely to grow organically, and not use synthetic fertilisers or chemical pesticides.[48,49] All of these examples counter the negative trends observed in industrial farming and provide a safe and sustainable alternative for acquiring fresh produce.

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46. Santos et al., “Contribution of Home Gardens to Sustainable Development”
47. Ibid.
48. Kortright and Wakefield, “Edible Backyards”
49. Santos et al., “Contribution of Home Gardens to Sustainable Development”

Individual Health and Wellness

At-home gardening contributes to individual health and wellness, with participants in a study done by Dalhousie University unanimously agreeing that they obtain mental and physical health benefits from their gardens.[50] For example, engaging with gardening practices improves mental health by reducing anxiety and stress, and increasing cognitive ability.[51] Further, improvements to physical health are gained through greater diet diversity, the consumption of fresh fruits and vegetables, and consistent exercise attained through garden maintenance.[52] Lastly, many people enjoy greater social opportunities through the practice of at-home gardening. It may encourage family members to come together, as gardening knowledge is often shared intergenerationally.[53] Additionally, many of the gardeners interviewed in a study of food growers in Toronto state that they have made close friends in their community as a result of routinely sharing knowledge, supplies, or produce.[54]

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[50] Mullins et al., "Home Food Gardening in Canada"
[51] Santos et al., "Contribution of Home Gardens to Sustainable Development"
[52] Ibid.
[53] Ibid.
[54] Kortright and Wakefield, "Edible Backyards"

3.2 - EXISTING BARRIERS TO INDEPENDENT FOOD GROWING

Despite the benefits of at-home gardening, existing barriers have prevented many from being able to implement the practice. A 2022 study by Dalhousie University sought to analyse these barriers and revealed that 55% of Canadians cited not having enough space to start a garden, followed by 39% without enough time, and 27% who believed that they did not have enough knowledge of gardening.[55] Further, statistics from the government of Canada that surveyed the methods of at-home gardeners shows that 75% of gardeners grow food in their yards, 31% on their balconies, 24% indoors, and 1% in community gardens.[56] The significant percentage difference in these figures suggests that some methods of at-home gardening may be more accessible than others.

For example, community gardens have been the focus of academic interest in previous years, despite the fact that the overwhelming majority of Canadians who grow their own food do so at home.[57] Some scholars have speculated that people may be unaware of the community garden opportunities offered in their cities due to a lack of promotion.[58] It can also be inferred that individuals simply prefer the access and convenience of being able to grow their food at home.

For those who would like to practise food growing at home, the availability of space is a significant determinant as to whether or not individuals are able to start their own gardens.[59,60,61] Those who live in detached houses are more likely to have a garden due to the availability of space in a front or back yard, while individuals living in apartments were less likely to practise gardening.[62]

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55. Charlebois and Music, “New Report”
56. Government of Canada, “Homegrown Fruit, Vegetables and Flowers”
57. Mullins et al., “Home Food Gardening in Canada”
58. Ibid.
59. Ibid.
60. Goodfellow and Prahalad, “Barriers and Enablers”
61. Charlebois and Music, “New Report”
62. Goodfellow and Prahalad, “Barriers and Enablers”

Another barrier reported to starting at-home gardens is a lack of time.[63,64] In some studies, survey participants rated not having appropriate amounts of time to start and maintain a garden as being their most significant barrier to entry.[65] However, the authors of this study speculate that time may be more of a perceived, rather than an actual barrier. That is to say, the idea that gardening is time consuming may be as much of a deterrent as the actual amount of time required to garden.[66]

Lastly, experts on the subject regard a lack of gardening knowledge and experience as being one of the most important barriers to successfully growing food.[67,68,69] A lack of familiarity with concepts such as how to begin a garden, as well as fundamental gardening practices, habits, and instincts, makes independent food growing much more difficult. According to an expert in the study, this largely has to do with today's culture, as they assert:

"Once upon a time it was part of our culture, because it had to be, everyone had a relationship to some type of food growing system … I think it was part of our foundation culture, and that's not there anymore."[70]

Therefore, the importance of building and exchanging knowledge of food growing cannot be underestimated in establishing successful gardening practices. Significant sources of food growing information come from intergenerational knowledge that is passed down between family members, as well as information that is exchanged between friends in gardening communities.[71] Multiple studies state that early interactions with food growing are influential in the choice to grow food later in life,[72,73] and those who were not exposed to the knowledge of food growing, will need to be 'enthusiastic and motivated' in order to start their own gardens.[74]

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[63] Charlebois and Music, "New Report"
[64] Goodfellow and Prahalad, "Barriers and Enablers"
[65] Ibid.
[66] Ibid.
[67] Ibid.
[68] Kortright and Wakefield, "Edible Backyards"
[69] Charlebois and Music, "New Report"
[70] Goodfellow and Prahalad, "Barriers and Enablers"
[71] Kortright and Wakefield, "Edible Backyards"
[72] Ibid.
[73] Goodfellow and Prahalad, "Barriers and Enablers"
[74] Ibid.

The last barrier that was not mentioned in the studies, but is considered in this research is the Canadian climate. Much of Canada's crop land is located in the temperate climate zone with four distinct seasons, meaning that food cannot be grown through the harsh winters and is limited to the warmer temperatures that begin in spring and end in fall. In this sense, indoor food growing systems are advantageous as they are able to make use of already conditioned indoor space and allow for year-round food growing independent of the weather. This is preferable both as a means to ensure a continuous source for knowledge building, and as a method of enabling produce to be grown in all months.

It can then be concluded that there is a need to make indoor gardening solutions more accessible to those who have not been able to start their own gardens due to a lack of space, time and gardening knowledge. Individuals who live in urban residences are more likely to face these barriers, as they may live in small spaces that have a greater degree of separation from natural ecologies and the knowledge of food growing. Therefore, this thesis will explore design solutions to enable those living in small urban apartments to start a garden at-home.

CHAPTER 4 - SCOPE

4.1 - DESIGNING NEW TYPOLOGIES FOR INDOOR GARDENING

Integrating new typologies for indoor food growing with architectural design can reduce the barriers of space, time, and knowledge that many people face when trying to start their own gardens at home. It also creates great potential for beauty and creativity in interior space.

For example, the barrier of space can be reduced by designing indoor gardening systems to be integrated with existing architectural elements. Coupling indoor gardening infrastructures with the design of residential systems prevents the addition of stand-alone gardens that take away from the space available for other residential programs.

Additionally, the barrier of time is both a perceived and actual barrier, meaning that the perception that at-home gardening is time consuming is as much of a deterrent as the amount of time that gardening truly requires.[75] By providing the infrastructure to start a garden as part of the design of residential space, it is less likely that time will be perceived as a barrier, as the time required to start a garden is reduced. Further, if these gardening systems are designed to be efficient, time spent interacting with the systems can be maximised and condensed.

Lastly, studies show that those who do not have the knowledge of food growing will need to be sufficiently 'enthusiastic and motivated' in order to start their own gardens.[76] In this sense, it is beneficial to provide the infrastructure required to start a garden as a motivating factor. By designing the infrastructure to be aesthetically beautiful, there is greater incentive to interact with the systems as individuals are likely to enjoy their presence in their home. Therefore, by providing infrastructure for indoor gardening that is visually pleasing, the consistent use of these systems can be promoted and used as a tool for building knowledge of food growing processes.

In summary, re-centralizing at-home gardening practices with the design of interior space presents the opportunity to reduce the barriers that individuals face when starting a garden, and allows for great creativity in architectural design. There is currently a disconnect between many Canadians living in urban environments and the agricultural practices that were once a focal point of daily life. By integrating food growing systems with residential space, the knowledge of food growing can be re-focused instead of being lost.

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75. Goodfellow and Prahalad, "Barriers and Enablers"
76. Ibid.

4.2 - LIGHT FIXTURES AND WALL SCREENS AS FOOD GROWING SYSTEMS

The design of light fixtures provides a place to start when considering architectural elements that can be harmoniously integrated with food growing infrastructures. Artificial lighting is often a requirement for indoor gardening systems as it provides plants with a source of energy to grow. It is also a fundamental consideration in the design of successful interior space to create atmosphere, occupant comfort, and allow for daily tasks to be performed. Therefore, an opportunity exists to design light fixtures as new food growing typologies, by combining the light that provides energy to plant life, with the light that is necessary to illuminate interior space.

CHAPTER 5 - STATE OF THE ART

5.1 - FOOD GROWING: EXISTING INDOOR GARDENING SYSTEMS

There are many existing methods for indoor gardening that can be used as precedents in the design of the proposed light fixtures. One such example that has gained in popularity as an indoor gardening solution are hydroponic systems, which use water and nutrient solution to grow plants instead of soil.[77] Hydroponic systems have become a preferred method for indoor gardening because they have many advantages over soil based growing that are especially relevant for those living in urban residences. Firstly, they are more convenient to use than systems that grow in soil, as they produce little mess and the water supply can be quickly replenished at the kitchen sink. They are also highly efficient and can be designed to grow crops on very small footprints. Lastly, they use up to ten times less water than soil-based growing, produce higher crop yields,[78] and can expedite the time required for plant growth.[79] For many of these reasons, studies done by Dalhousie University reported that in 2022, 6.2% of Ontarians were already using hydroponic systems to grow food at home.[80]

There are many types of hydroponic systems including Ebb-Flow, Deep Water Culture (DWC), Nutrient Film Technique (NFT), and Aeroponics.[81] The main operational difference between different types of hydroponic systems are whether they are 'active' and require mechanics such as a water pump to circulate water through the system, or 'passive' and use stagnant water. Both active and passive hydroponic systems are easily accessible, and are often constructed as DIY projects using PVC pipes, plastic buckets and chemical adhesives. Alternatively, they can be purchased as a prefabricated unit.

In order to test the suitability of hydroponic systems for indoor residential food growing, two systems were constructed and operated for three weeks. The first system chosen was the Nutrient Film Technique, which is an active system that uses a water pump to continuously circulate oxygenated water over the plant roots (Figure 5.1.1). The second system chosen was the Kratky method, which is a passive system that partially submerges plant roots in a reservoir containing stagnant water and the nutrient solution (Figure 5.1.2).[82] These two methods were chosen to test the differences in passive and active systems, and determine which is most suitable for use in the construction of new food growing typologies.

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77. Maurya et al., "Study of Hydroponic Systems and Their Variations"
78. U.S. National Park Service, "Hydroponics: A Better Way to Grow Food"
79. Maurya et al., "Study of Hydroponic Systems and Their Variations"
80. Charlebois, "Canadians React to Food Inflation and Grow Their Own Gardens"
81. Maurya et al., "Study of Hydroponic Systems and Their Variations"
82. Ibid.

The Nutrient Film Technique (NFT)

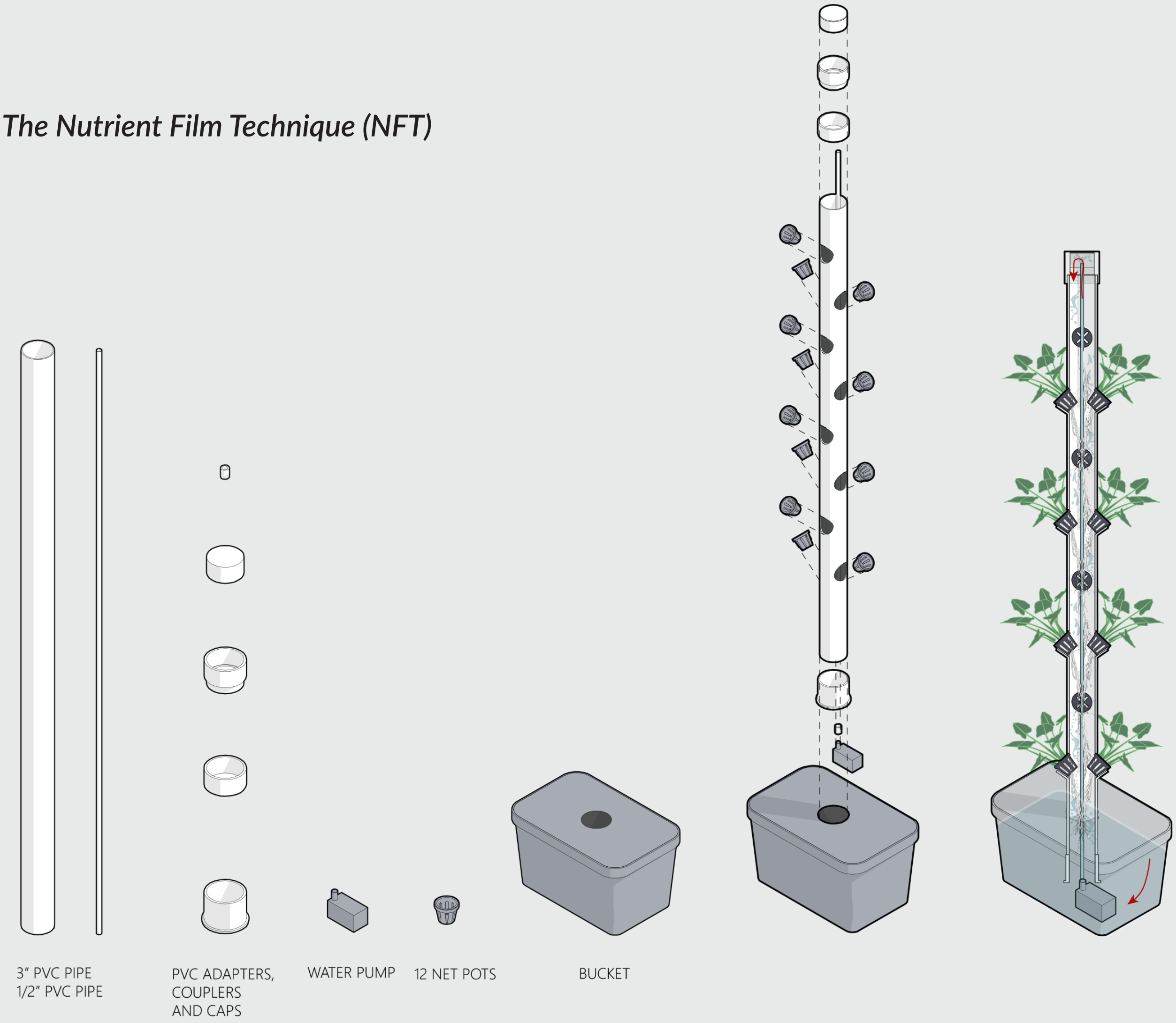

Figure 5.1.1 Materials and assembly for the NFT system.

The NFT system was constructed using PVC pipes, adapters, a water pump, and a plastic bucket. To construct the system, a ½" PVC pipe was nested inside a 3" PVC pipe. The 3" PVC pipe was cut to have 12 circular openings for the plant pots to fit into. The water pump was submerged in the nutrient solution contained in the plastic bucket, and fit to the end of the ½" PVC pipe. The nutrient solution is pumped to the top of the system, where it deflects off a pipe cap and falls through the interior of the 3" pipe, providing nutrients to the plant roots before returning to the water reservoir. The water is recycled and the process repeats.

The system used approximately 12L of water in the three week period. Water was continually lost due to leaking and evaporation. Further, the system produced a significant amount of noise, as a result of the mechanical water pump and the constant rushing of water through the system. Lastly, the plants did not demonstrate significant growth in the three week period.

The Kratky Method

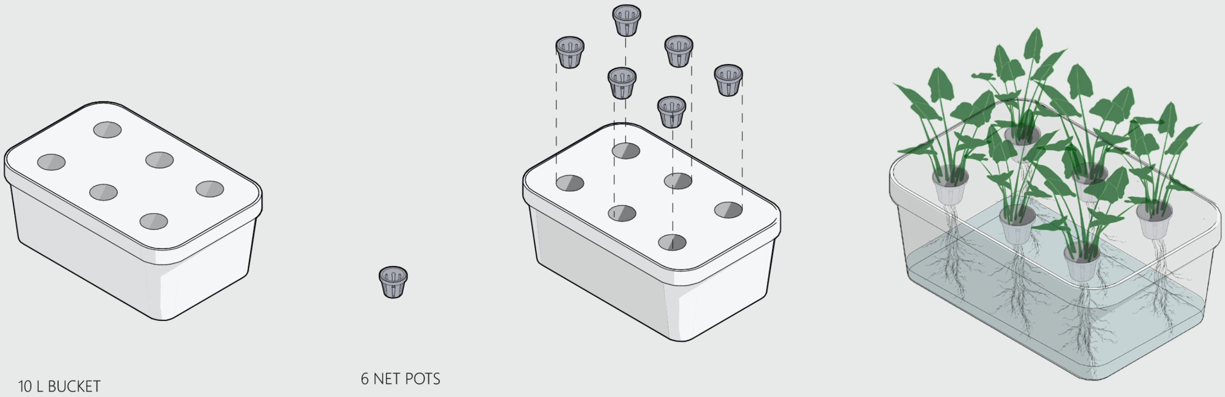

Figure 5.1.2 Materials and assembly for the Kratky Method.

The Kratky Method system was constructed using only one plastic bucket with 6 circular openings removed from the bucket lid for the plant pots to fit into. The plant roots are partially submerged in the water reservoir, to allow the roots to access the nutrient solution as well as oxygen. As the plants grow in the system, their roots expand into the water reservoir and take-up the nutrient solution. The nutrient solution can be continually replenished as long as the oxygenated area of the roots are not submerged in the solution.

This system is extremely efficient with water use. The water reservoir was supplied with an initial 8 L of water, and it is estimated that only a ¼ L of water was used in the first three weeks. There is no mechanical noise and no threat of crop loss in the absence of electricity as this system does not depend on a water pump. Lastly, the plants grew significantly.

Each system was evaluated using criteria such as simplicity, affordability, size, water use, and plant growth. This assessment of each system demonstrated that the Kratky method had many advantages over the NFT system, as it is simple to construct, inexpensive, efficient with water use, and grew the plants to be much larger and healthier in the three week time frame.

However, despite all the apparent successes of the Kratky Method, hydroponic systems as a whole face several design challenges. The first design challenge is the prevailing use of plastics in their construction, as the manufacturing of plastics has been demonstrated to have negative effects on the environment. Plastic is also not a material that is often used in the design of interior space, making the systems look out of place in residential environments (Figure 5.1.3). Secondly, their design lacks an architectural language, as they are often conceived of as stand-alone units that are not integrated with residential space (Figure 5.1.4). Lastly, large scale implementations of these systems seek to conceal the plant growth within cabinets or furniture, which limits aesthetic opportunities and the ability to create biophilia. (Figure 5.1.5). Therefore, there is a need to re-imagine the formal and material considerations of these hydroponic systems, in order to ensure that they are sustainable, harmoniously integrated with residential architecture, aesthetically beautiful, and capable of restoring the knowledge of food growing practices.

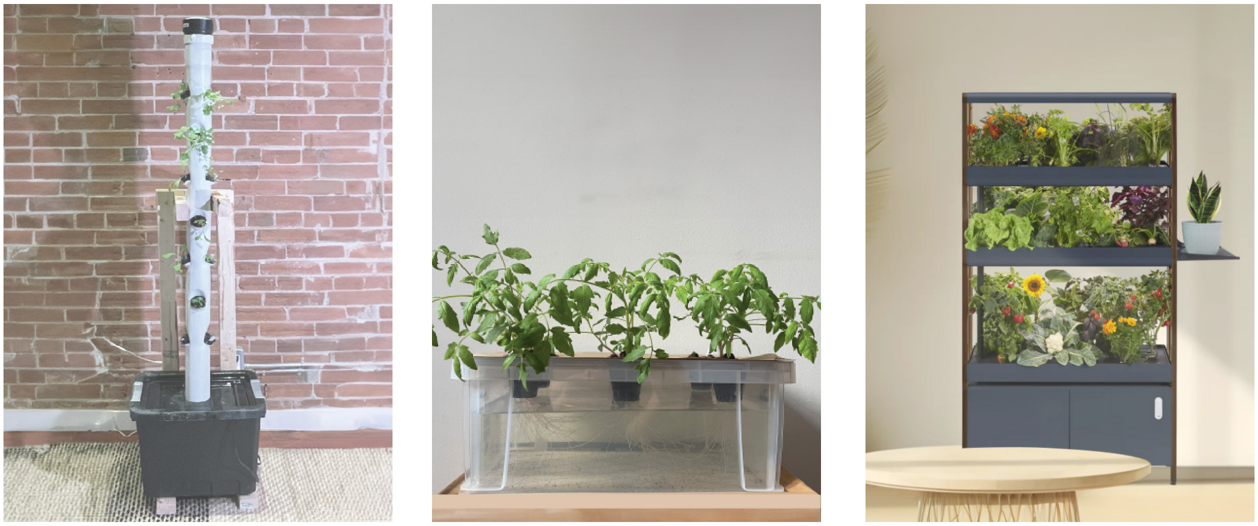

Figure 5.1.3 - 5.1.5 - NFT hydroponic system built using PVC pipes (left). The Kratky Method hydroponic system built using a plastic bucket (middle). Large-scale implementations of hydroponic systems seek to conceal the plant life in cabinetry or millwork (right).

5.2 - ARCHITECTURAL CERAMIC ASSEMBLIES

The design of architectural ceramic assemblies presents opportunities to better the design of existing hydroponic systems. Firstly, ceramics offer a sustainable alternative to the use of plastics in the construction of these indoor gardens, as clay is a naturally occurring raw material that is available in abundant quantities across Canada.[83] Further, ceramic products have a long historical precedent of use in plant growing, food storage and in architecture. Since ancient times, humans have used clay to craft ceramic vessels for artistic and functional purposes in agriculture and food production[84] (Figure 5.2.1). Clay pots have traditionally been used to grow plants domestically, a practice that has been used by many cultures and may first trace back to use by the Ancient Egyptians.[85] Today, this practice continues, as ceramic pots are often used as vessels to contain houseplants, and to decorate interior space.

Architecture has also consistently used ceramic products in construction, such as using brick to build structural systems, terracotta roof tiles to control the movement of water, and decorative ceramic tiles to ornament walls and floors (Figure 5.2.2 - 5.2.4). Today, ongoing research on the unique properties of ceramics has allowed for new applications of this material in architectural practice. The continued innovation occurring in the development of ceramic assemblies makes it possible to design new typologies for indoor food growing that have an established architectural language.

Figure 5.2.1 - **Figure 5.2.3** Terracotta pot used for wine storage preserved from Pompeii, Italy (left), use of brick in Hadrian's Villa, Tivoli, Italy (middle), Terracotta roofs in Venice, Italy (right).

83. Dumont and Natural Resources Canada, "Clays"
84. The American Ceramic Society, "Brief History of Ceramics and Glass"
85. Mandell and Burke, "Egyptian 'Flowerpots'"

Figure 5.2.4 - Decorative ceramic tiles in Casa Batllo by Antoni Gaudi in Barcelona, Spain.

For example, the Architectural Ceramics Assemblies Workshop (ACAW), based in Buffalo, New York, annually brings together teams of architects, academics, terracotta manufacturers and industry professionals to design and construct terracotta facade systems. The intention of the workshop is to demonstrate how terracotta can be used innovatively in the fabrication of large-scale architectural assemblies.[86] Through the workshop's eight year history, many systems have been constructed that consider plant life in their design. These examples offer precedents for how plant growing can be not only integrated with, but celebrated in the design of large scale ceramic assemblies (Figure 5.2.5 - 6).

Isabel Ochoa and James Clarke-Hicks have conducted research on architectural ceramics by developing an innovative approach to creating functionally-graded ceramic light screens using clay 3D printers (Figure 5.2.7 - 8). Their research produces a series of ceramic screens that, "vary in brightness and illumination based on how light may be obstructed, reflected, or transmitted across their surfaces."[87] Their work sets precedent for how clay 3D printers can be used in the fabrication of ceramic artefacts that incorporate lighting systems and control the character of the light produced.

Lastly, various artists and ceramicists have developed methods for using clay 3D printers or conventional means of ceramic production to fabricate vessels used as household objects or containers for plant growing. For example, TRYK lab uses clay 3D printers to fabricate interior products that experiment with form by using additive manufacturing techniques as well as traditional ceramic fabrication methods (Figure 5.1.9).[88] Additionally, Studio Biskt researches extruded ceramics, using hollow dies to produce furniture, household objects and plant pots (Figure 5.1.10).[89] In both of these examples, the vases and pots produced seamlessly blend into the plant life, offering examples of how natural qualities can be considered aesthetically in the design of beautiful food growing vessels.

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86. ACAW, "Architectural Ceramic Assemblies Workshop"
87. Ochoa and Clarke-Hicks, "Grading Light"
88. TRYK.Lab, "Studio"
89. Studio Biskt, "About"

Figure 5.2.5 - 5.2.6 - Ceramic assembly designed by Cookfox and Buro Happold, ACAW 2021 (left), and Eric Parry Architects, ACAW 2023 (right).

Figure 5.2.7 - 5.2.8 - Ceramic light fixtures designed by Isabel Ochoa and James Clarke-Hicks.

The aforementioned works demonstrate how architectural ceramic assemblies can be used to design and construct new typologies for indoor food growing that incorporate light and plant life, and create aesthetic beauty by using natural themes. By designing the proposed systems as ceramic assemblies, there is an opportunity to correct the challenges faced by existing hydroponic systems, as ceramic assemblies are constructed from naturally occurring materials, have an established architectural language, and are capable of using aesthetic beauty to promote food growing practices. This thesis will use clay 3D printers in the design and construction of the proposed systems for indoor food growing. The use of 3D printers allows for the fabrication of complete parts of the systems, such as the components for lighting and food growing vessels. It also allows for greater control and customization over the aesthetic qualities established.

Figure 5.2.9 - 5.2.10 - Ceramic flower vase designed by TYRK lab (left), extruded terracotta pot designed by Studio Biskt (right).

CHAPTER 6 - METHODOLOGY

6.1 - OVERVIEW

The food growing systems will be developed through an iterative printing process that tests component designs through the creation of several models. An iterative process is preferable for this research due to the unique material properties of clay. Clay is printed when it is in a wet, fluid state and therefore initial design concepts and computer modelling projections often differ from the 3D printed artefact. The process of continually printing, evaluating, and adjusting the designs, allows for the characteristics of clay to be leveraged in the design, in a way that would not otherwise be possible.

Before the iterative printing process begins, the schematic design phase determines the required components of the system, and their relationship to one another (Figure 6.1.1). Then, the design development phase 3D prints the components through two key iterations.

The first iteration uses the Scara V4 printer to fabricate a series of test prints at approximately 0.75:1 scale. The Scara printer is ideal for rapid prototyping, as it uses a large 3600 cc extruder tube, which can create many prints in succession. The intention of this stage is to develop the massing, proportional relationships, and structural connections of each component.

The second iteration uses both the Scara V4 printer, and the Lutum 4.6 printer to develop components at 1:1 scale. The Lutum 4.6 printer uses a 1400 cc extruder tube, and is capable of producing high detail quality prints. The Lutum was used to create all printed artefacts in this stage, except for components that required more than 1400 cc of clay, which were produced using the Scara. The second iteration intends to develop the detail quality of each component, and create precise structural connections throughout the system.

All prints were created using a white, mid-fire stoneware (PSH 516). Each print uses a 3mm nozzle, and a 2mm layer height.

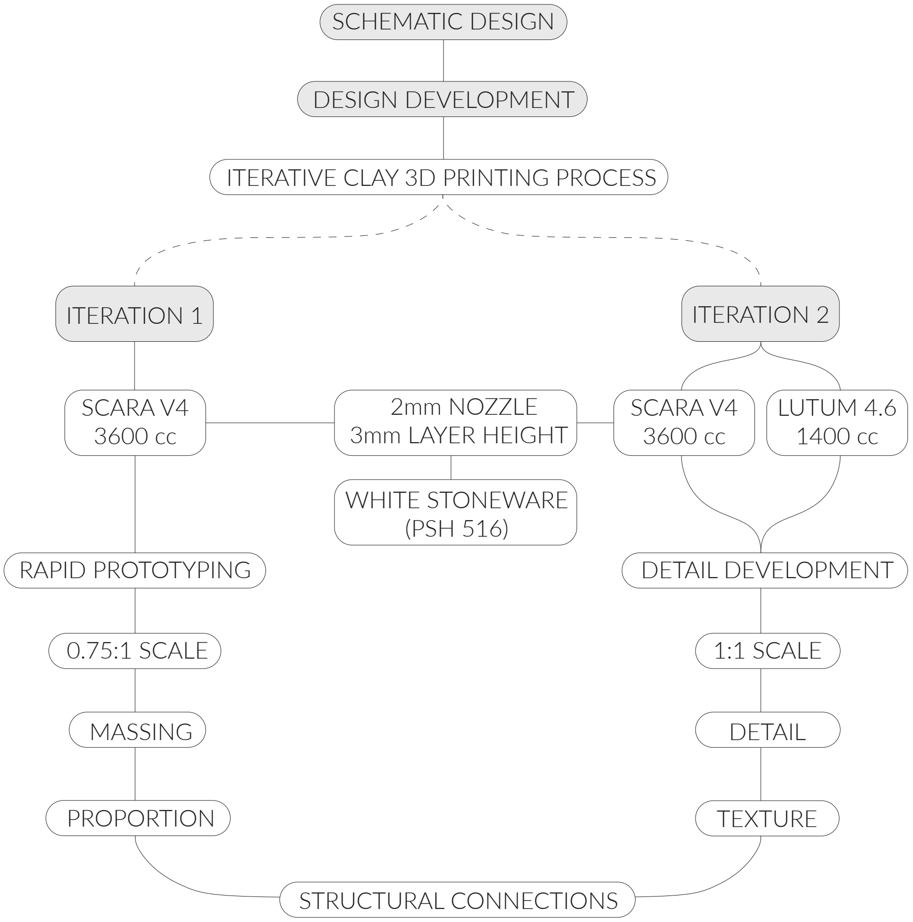


Figure 6.1.1- Overview of methods used to develop the light fixture case study.

6.2 - DIGITAL WORKFLOW

The schematic design phase used hand sketching to test options for the formal and organisational compositions of the light fixture (Figure 6.2.1). Following this, the 3D modelling software Rhino was used to model each component (Figure 6.2.2). Once this was complete, the visual scripting software Grasshopper was used to generate a series of contour lines that correspond to the surface of each of the models. The contour lines are the toolpath that the printer follows, while the distance between the lines is the layer height (Figure 6.2.3). The tool path lines were further adjusted in Grasshopper to develop the aesthetic details of the system, by using additional scripts to experiment with geometric rotations, surface gradients, textures, and patterns (Figure 6.2.4). Once the aesthetic details of the system were complete, the model was prepared for 3D printing. A final script was used in Grasshopper to produce custom G-Code. The G-Code is a series of spatial coordinates describing the massing of the 3D model that acts as a set of instructions for the 3D printer. The G-Code was checked in the slicer software Cura, to ensure that the massing and the code had been produced correctly. Following this, the model could be uploaded to the 3D printer.

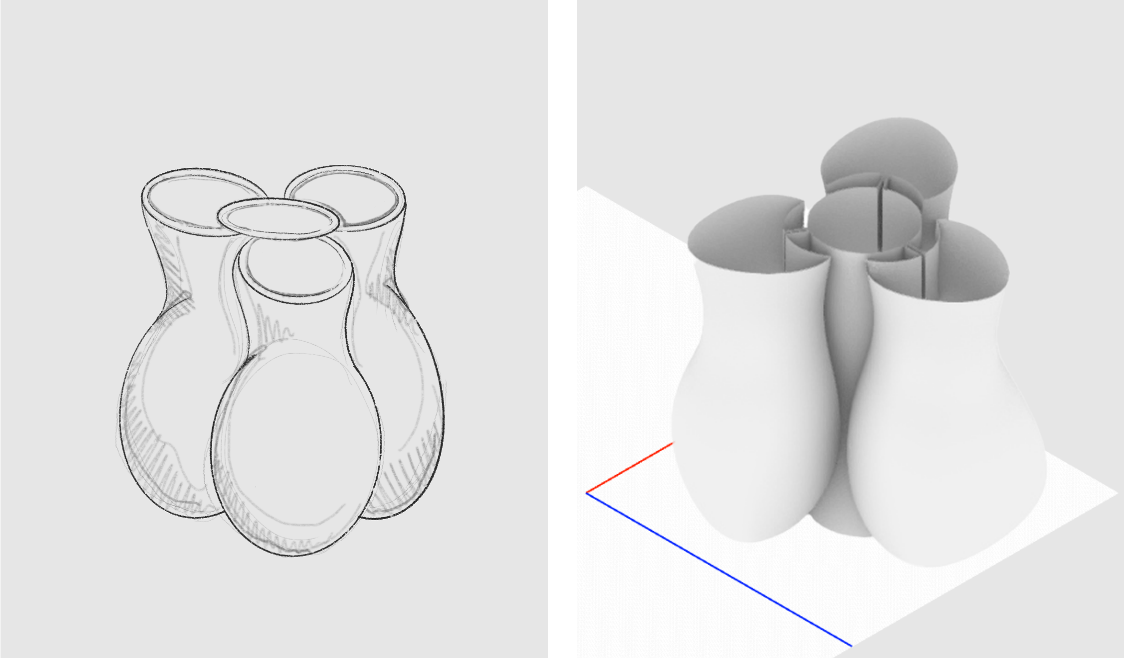


Figure 6.2.1 - 6.2.2 - Hand sketching was used to test massing options for the food growing components (left). After a desirable massing was sketched, it was 3D modeled in Rhino (right).

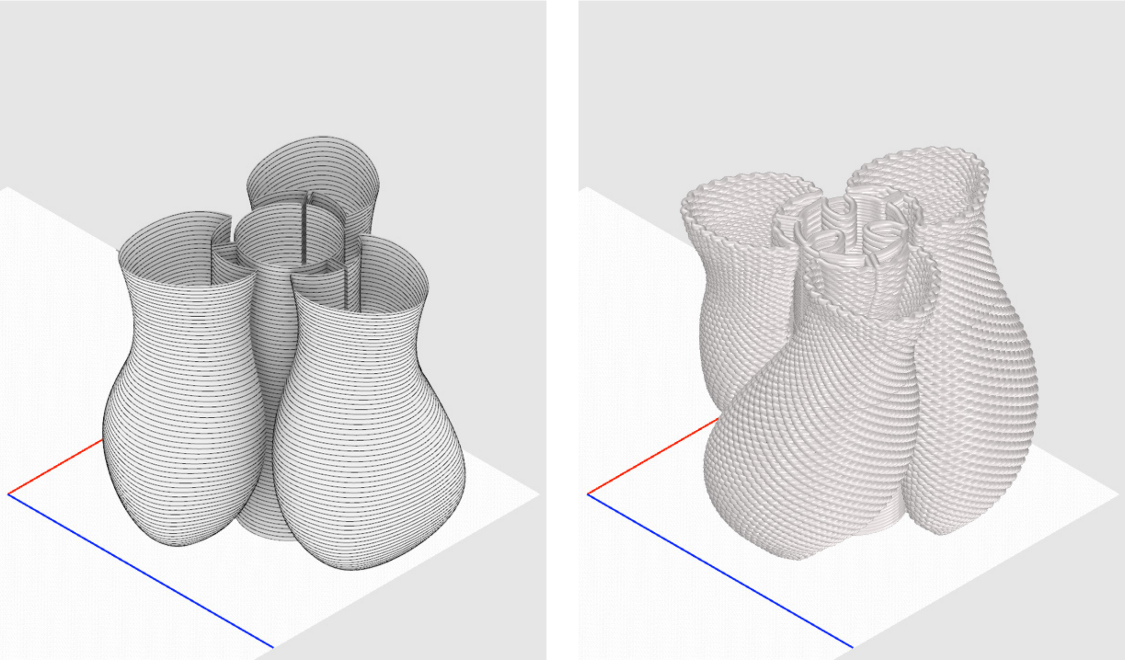


Figure 6.2.3 - 6.2.4 - After the massing was created, grasshopper was used to create the tool path for 3D printing (left). The tool path could be altered in grasshopper to adjust geometric and aesthetic properties (right).

6.3 - PHYSICAL WORKFLOW

After the creation of the digital files, the 3D printer and the clay also need to be prepared for printing. In order to prepare the clay for use, it needed to have its water content increased to improve plasticity. The blocks of clay were cut into 1” cubes, and stored in a bucket with water (Figure 6.3.1). The ratio was 1 cup of water to 10 kg of clay. The clay was then left to saturate for at least 24 hours before being removed and recombined into a solid mass by wedging. Wedging the clay is a critical step of the process to ensure that the added water has been evenly distributed, and to remove any air pockets in the clay (Figure 6.3.2). The presence of air pockets can severely damage print quality, as they become highly pressurised and tear through the print when they are pushed through the nozzle.

After wedging, the clay was shaped into a cylinder and fit into a metal extruder that pushes the clay into the acrylic tube used for printing (Figure 6.3.3). Once the tube was full of clay, a 3 mm nozzle and the printer motor were fastened (Figure 6.3.4). The clay and 3D printer are now prepared for printing (Figure 6.3.5).

During printing, each file is produced on an MDF batt, which was used to transport the print to a drying tent once it was complete (Figure 6.3.6). Occasionally, a heat gun was used to dry pieces during printing, and provide rigidity to the clay that helped to create steep overhangs (Figure 6.3.7). Any prints that were not successful, due to imperfections or print collapse, could be entirely reclaimed making this process zero waste (Figure 6.3.8). Prints that were successful needed to be dried for approximately one week before they were able to be loaded into the kiln for bisque firing. The size of the prints were limited by the interior dimensions of the kiln, which are 22” long by 22” wide, and 27” high. The clay is bisque fired in the kiln at cone 06, which is approximately 1000 °C. The observed shrinkage rate after bisque firing was approximately 12-15%.

Figure 6.3.1 - 6.3.2 - Clay is stored in a bucket with excess water (left). After the clay has been left to saturate in the water, it is wedged by hand to remove air pockets (right).

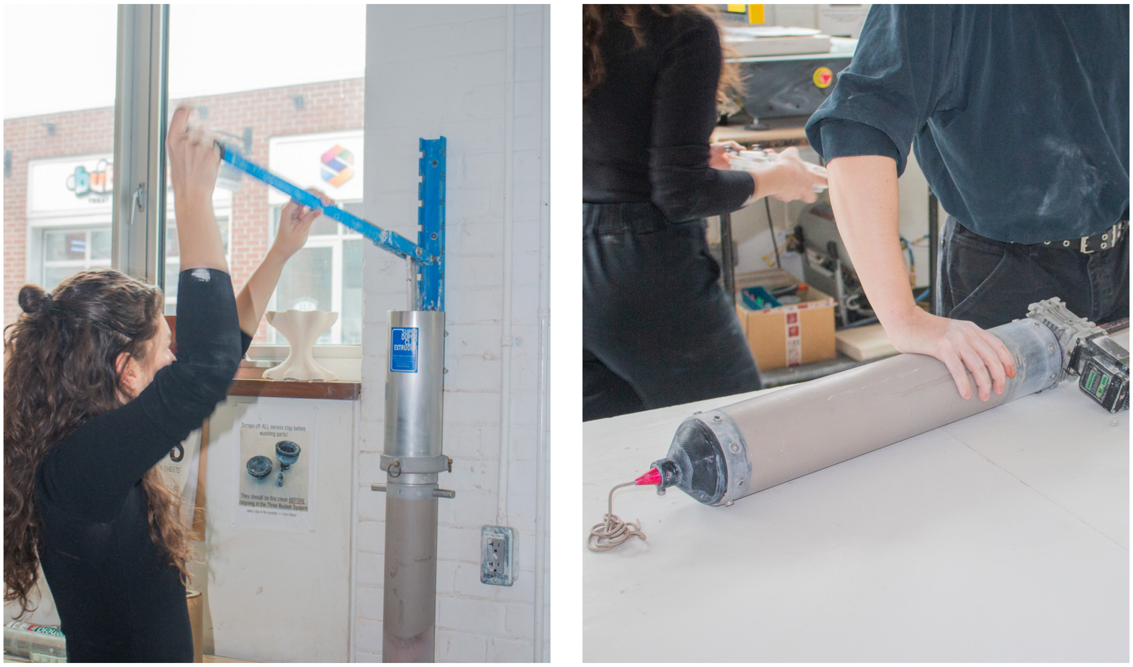


Figure 6.3.3 - 6.3.4 - The clay is shaped into cylinders and pushed through an extruder into the acrylic tube used for printing (left). The nozzle and motor are attached to the clay tube (right).

Following the bisque firing, the pieces were removed from the kiln and are solid, brittle, and slightly porous. The pieces were then dipped in a bucket of glaze, which makes the vessels impermeable to water and adds colour to the surfaces. They were again loaded into the kiln and fired at cone 6, which is approximately 1200 °C. The pieces shrink again, by approximately 10 - 15%. Following this, the ceramics pieces were complete. This process is the standard method used in this research for the production of all ceramic artefacts.

In summary, the physical design process includes constraints that affect the design capabilities of the printed ceramic components. These limitations include:

- The size of the printer's extruder tube, which is 3600 cc on the Scara printer, and 1400 cc on the Lutum printer. A continuous print that requires more clay than can be contained in the printer's extruder tube is not possible.
- The size of the prints cannot exceed the interior dimensions of the kiln shelves, which are 22" long by 22" wide, and 27" high.
- The shrinkage rates of the clay reduce the size of the final printed artefact. The observed shrinkage rate for the white stoneware is approximately 12-15% after bisque firing, and 10 - 15% after glaze firing.

Figure 6.3.5 - 6.3.6 - The tube is then connected to the 3D printer (left). The printer is ready to print files (right).

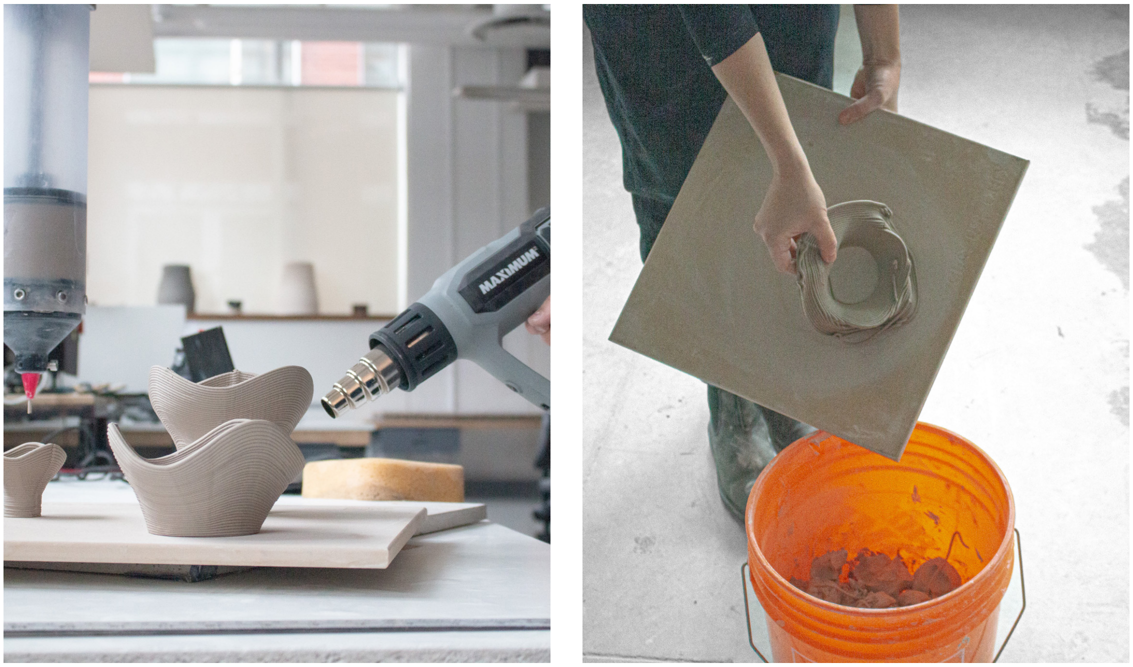


Figure 6.3.7 - 6.3.8 - A heat gun may be used to dry the clay more rapidly and allow for steep print angles to be achieved (left). Any prints that are unsuccessful are able to be reclaimed (right).

CHAPTER 7 - LIGHT FIXTURE CASE STUDY

7.1 - SCHEMATIC DESIGN

The fundamental requirements of the light fixture food growing systems are grow lights to provide energy to the plants, compartments for the plants to grow within, and support and suspension elements to provide structure to the system.

Plant Vessels

The initial experiment in constructing the Kratky Method allowed for changes to be identified that would make further iterations more convenient for use. The first change identified was the need to compartmentalise the system, so that each plant has its own vessel to grow within. This prevents slower growing plants from having their roots eventually suspended above the water level, as the faster growing plants take up the nutrient solution (Figure 7.1.1). Secondly, the interior volume of the vessels should be able to contain between 0.5 - 1L of water, to allow small to medium sized plants enough root space to develop into full maturity.

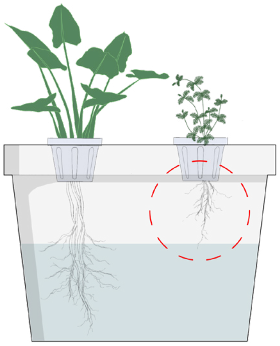


Figure 7.1.1 - The plant growing vessles should be compartmentalized.

Lighting System

The grow lights used in the proposed food growing systems must serve two purposes. They must provide sufficient energy to the plants to grow, and offer a pleasant ambient light to the interior space. It is therefore necessary to select lights that are suitable for plant growth and safe for daily residential use. The Sunblaster CFL bulb, and the Necgemlex Smart LED are two bulbs that are appropriate for residential and agricultural use. Each of these bulbs were purchased to conduct lighting tests and assess which light was most suitable for use in the indoor food growing systems.

The Sunblaster CFL bulb is in the colour temperature 6400K, which is akin to cool, natural daylight and is the ideal colour range for vegetative plant growth. It was purchased in two sizes, 26 Watt and 13 Watt. Preliminary lighting tests revealed that this bulb is very bright to the eye and becomes hot when used for long periods of time (Figure 7.1.2).

The Necgemlex Smart LED grow light has a warmer colour temperature of 4500K which is suitable for all stages of plant growth, from flowering to vegetative. This is a 9 Watt bulb that features three modes of brightness. This light is more comfortable to the eye than the Sunblaster CFL bulb, and when used for long periods of time, this light becomes warm but not hot to the touch (Figure 7.1.3).

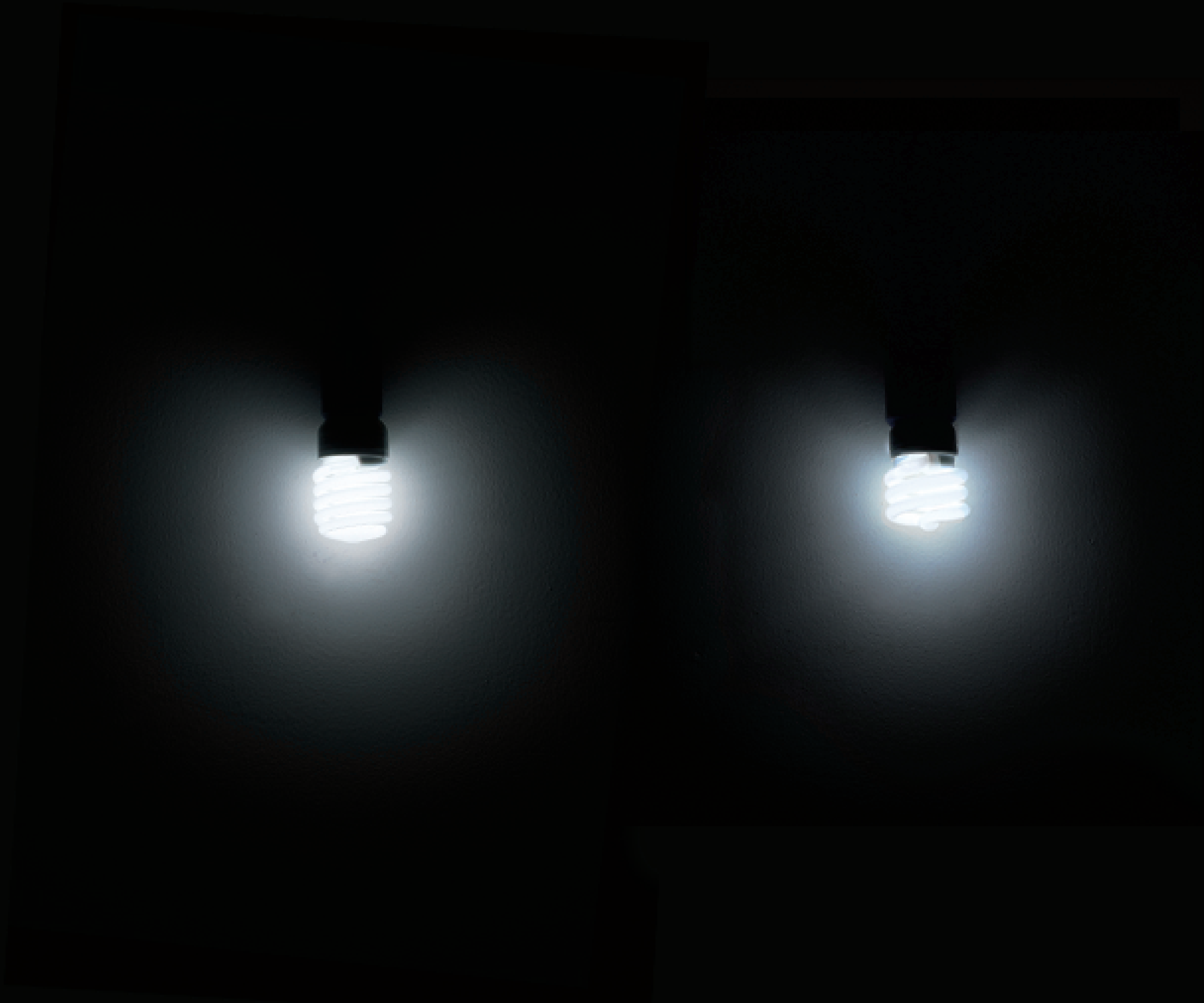


Figure 7.1.2 - 26 Watt Sunblaster CFL bulb (left), 13 Watt Sunblaster CFL bulb (right).

Figure 7.1.3 - 9 Watt Necgemlex Smart LED on the highest brightness setting (left), and on the lowest brightness setting (right).

Following the preliminary lighting tests, it was determined that the Necgemlex Smart LED grow light was the preferred lighting option. The colour temperature is warmer, and more conducive for use in residential space. The brightness is also more comfortable to the eye, and can be adjusted as required. Lastly, this bulb does not get hot to the touch, which is necessary as it will be in close proximity to the system's suspension elements, and plant foliage.

In the design of the proposed food growing systems, one light bulb will be positioned above the plants to provide them with a direct source of energy to grow. Placing another light bulb underneath the plants may encourage them to grow around the fixture to reach this additional light source, creating a full appearance of growth across the system. Light shades will be used to direct the light toward the plants, and prevent harsh, unfiltered light from reaching the residential space. Lastly, the distance between the plant and the grow light is an important consideration for healthy plant growth (Figure 7.1.4). The Necgemlex Smart LED bulb recommends a distance of 12" - 16" between the plant and the light bulb. If the plant is too close to the bulb, its leaves may burn. If it is too far from the bulb, it will stretch to grow in the direction of the light and develop long stems and few leaves. The plant will be continually growing and changing in the system. It is therefore necessary that the position of the plant growing vessels is adjustable relative to the position of the light, to allow for the ideal distance of 12" - 16" to be maintained.

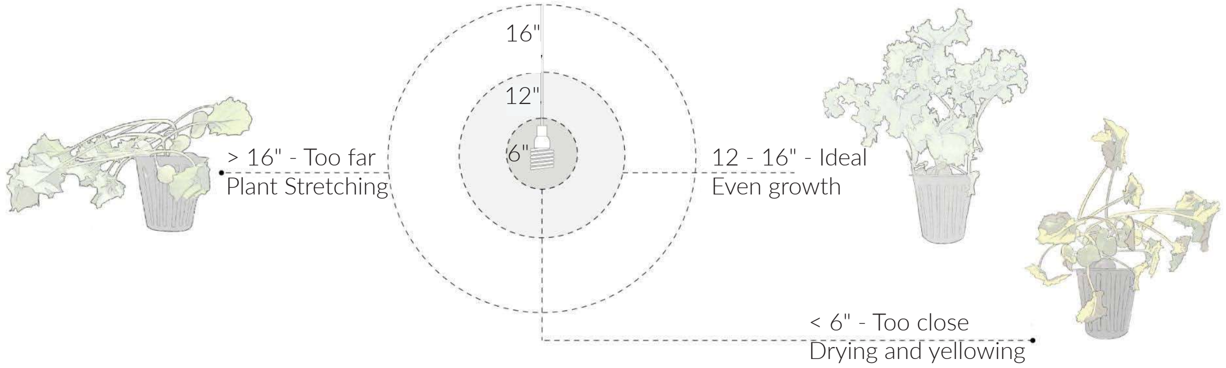
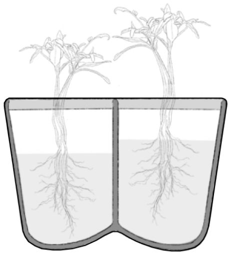


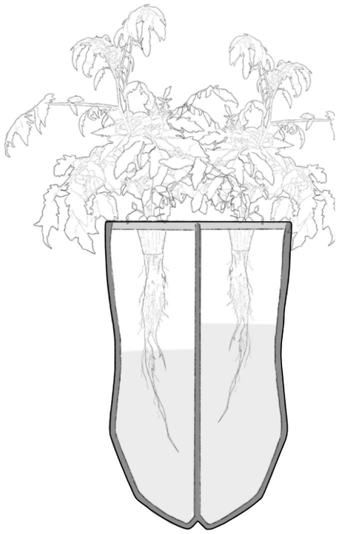
Figure 7.1.4 - Diagram showing plant growth in relation to the position of the grow light.

Support and Suspension System

Structural support components are required to connect elements of the light fixture to one another, and to the existing residential structure. The structural design will need to allow for the plant growing vessels to move and maintain the recommended distance between the plants and the grow lights. The plant growing vessels should also be able to detach from the structural system for cleaning and maintenance.

Summary of Schematic Design Requirements





①

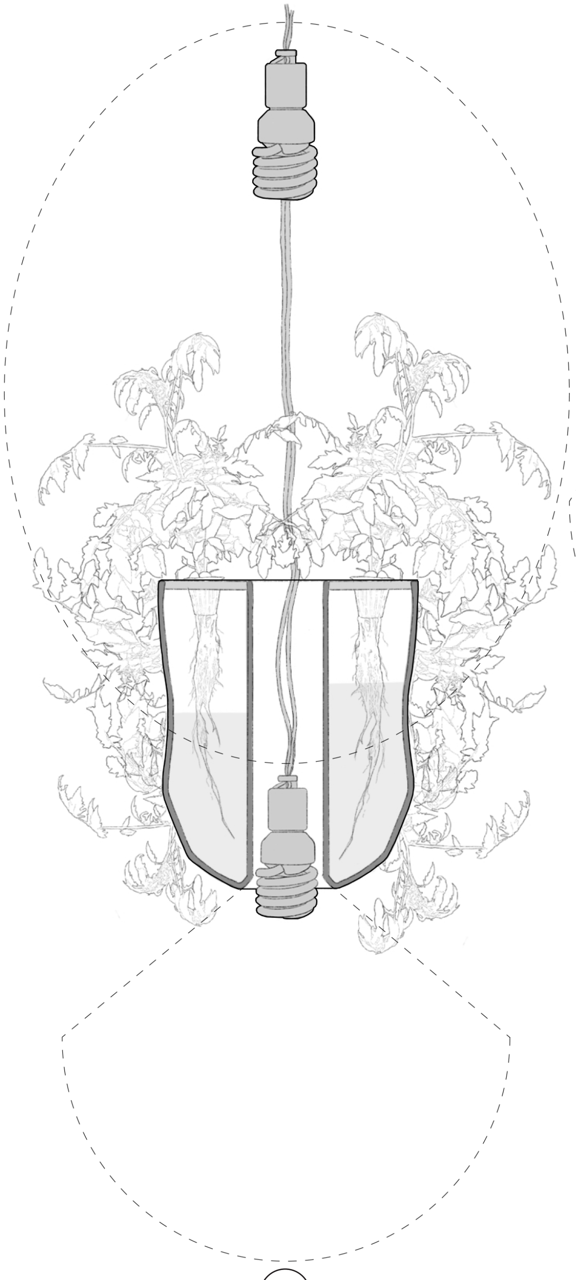
The plant growing vessels will be compartmentalised.

②

The interior volume of plant vessels will be able to contain between 0.5 - 1L of water to allow plants to grow to full maturity.

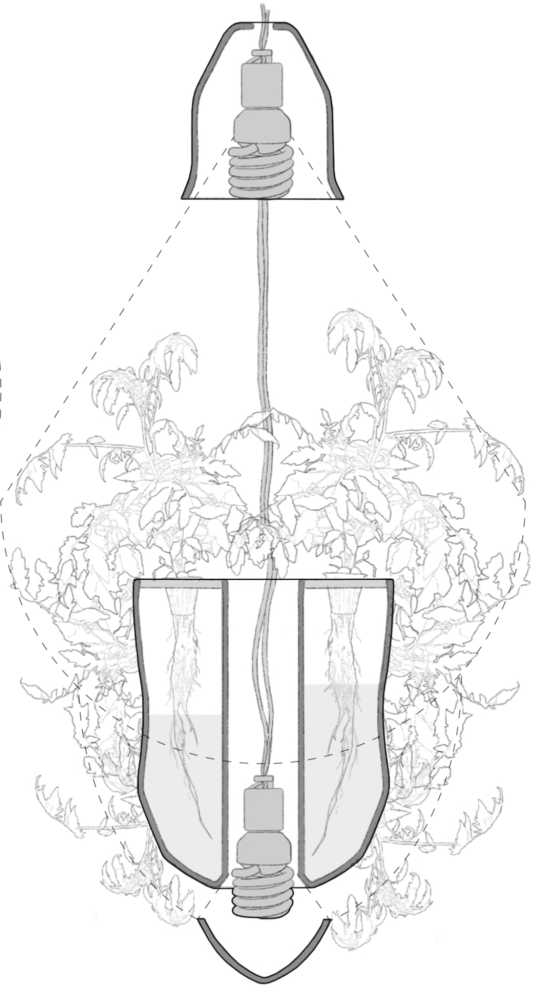
③

A light bulb will be positioned above the plants to directly provide them with energy.



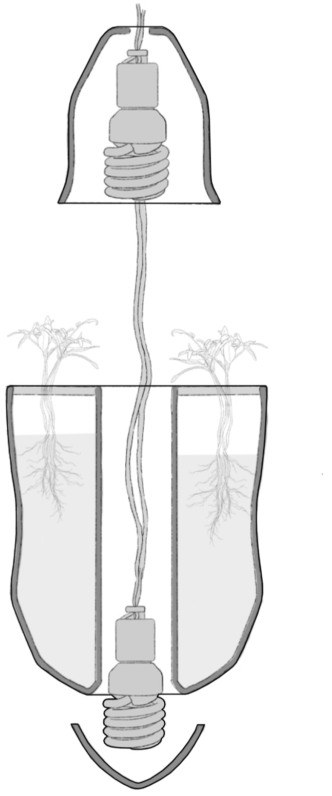
④

A light bulb may be positioned below the plants to encourage them to grow fully around the system.



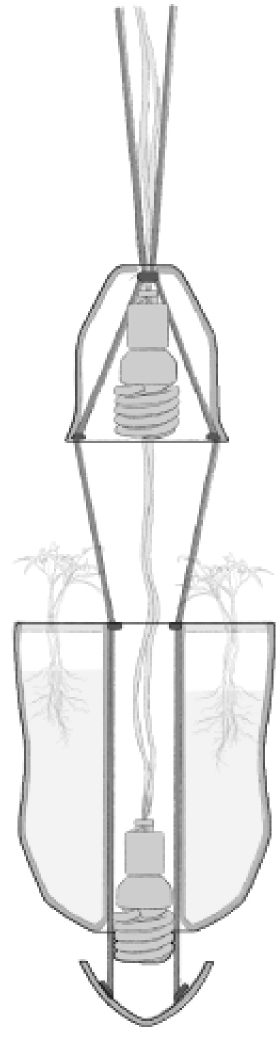
⑤

Light shades will be used to control the direction and intensity of the light emitted from the bulb. The shade above will direct light down to the plants. The shade below will reflect light up at the plants.



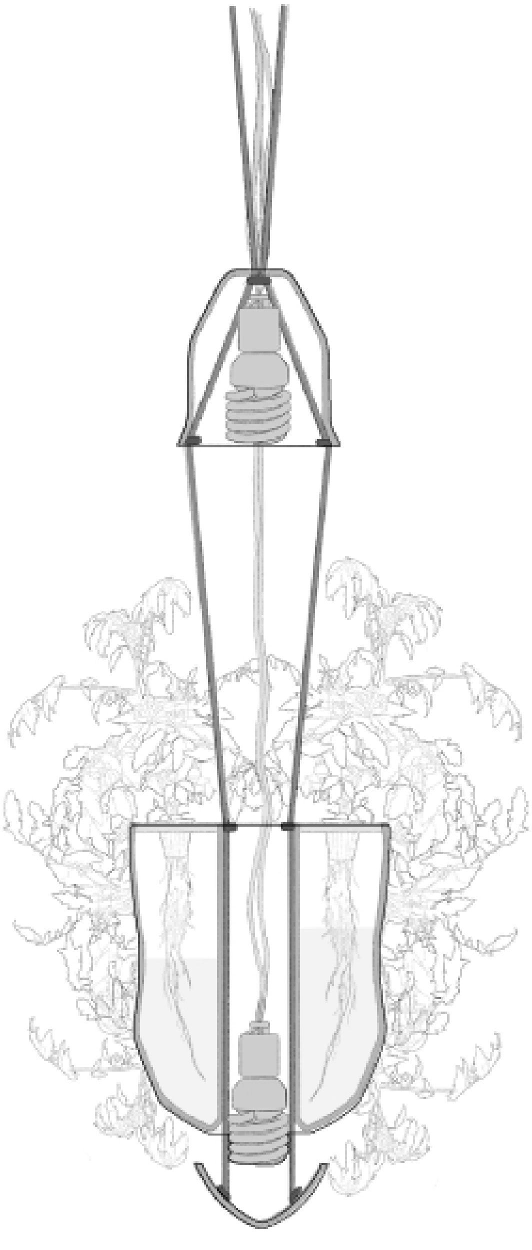
⑥

The distance between the light bulb and the plants will be adjustable, to accommodate different stages of plant growth.



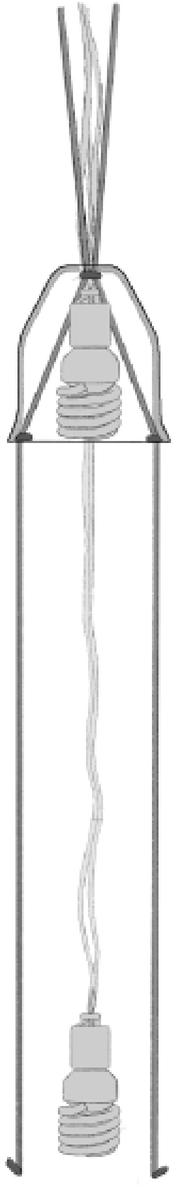
⑦

Components of the system will be connected to one another.



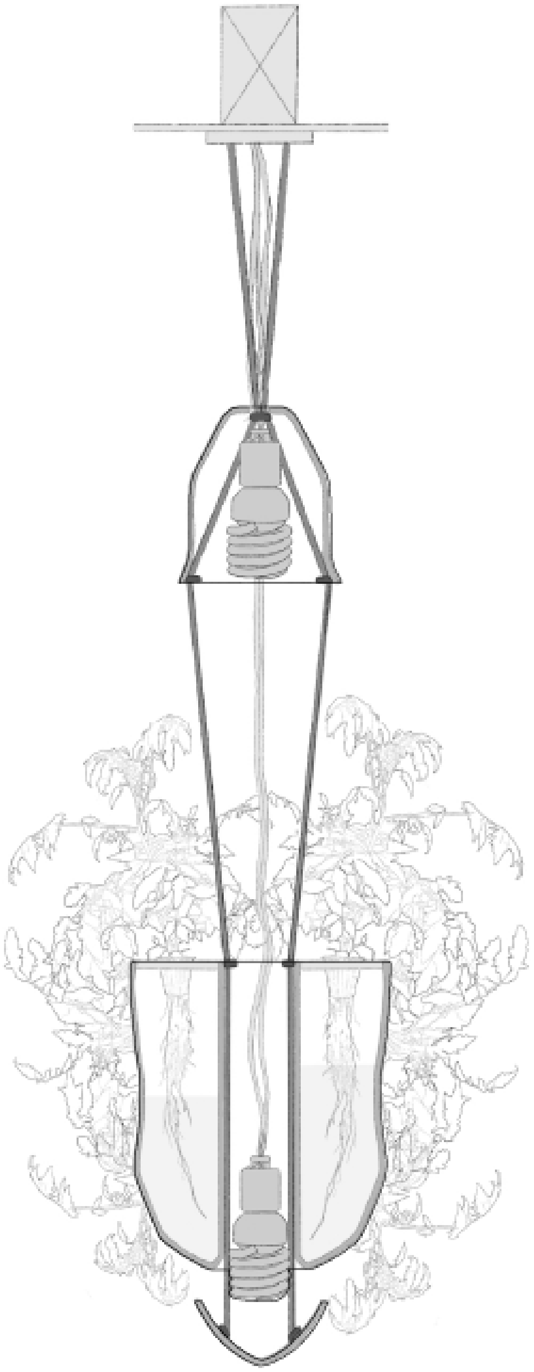
⑧

The support structure will allow for the position of the plant growing vessels to be adjusted.



⑨

The plant growing vessels will be able to detach from the system to allow for cleaning and maintenance.



⑩

The system will connect to existing residential structures.

7.2 - DESIGN DEVELOPMENT

In the design development phase the massing, aesthetic, and structural considerations for the food growing systems were investigated. The process was broken down into multiple iterations to allow for the ceramic artefacts to be developed in detail (Appendix A). All components were fabricated using a 3mm nozzle and a 2mm layer height. In the first iteration, test prints were created using the Scara 3D printer. Though the Scara produces less precise prints than the Lutum, it was used for its ability to create rapid prototypes at 0.75:1 scale that allowed for print variables such as tool path, print orientation, g-code production, massing and proportion to be assessed. In the second iteration, test prints were created at 1:1 size using both the Scara and Lutum printers. The precision of the Lutum was used to explore aesthetic details such as surface texture and lighting quality. It also allowed for the structural system to be accurately integrated with the ceramic components.

7.2.1 - Iteration 1

7.2.1.1 - Concept Overview

The first iteration was intended to develop the massing and proportional relationships for each component, including the light shade for above the system (1), food growing vessels (2), and the light shade for below the system (3) (Figure 7.2.1.1.1). There are two grow lights, one in the upper light shade to project lights down to the plants (4a), and one in an open channel in the plant growing vessles (4b). This light reflects off the lower light shade to project light up at the plants. An iterative printing process was used to determine how each of the proposed component massings were best achieved using the capabilities of the clay 3D printer. Structural connections were integrated with each component to allow them to be connected to one another and suspended from an existing structure (5). Lastly, aesthetic considerations were established in this stage, first by creating an attractive quality to the underside of each component, as the suspended system will be primarily viewed from below. Then, each component was designed to have a dynamic appearance, to reflect the continually growing and changing plant life that is housed within the system. The design development for each component can be assessed using the following categories: *massing*, *print orientation and base condition*, *structural connections*, *dynamic quality*.

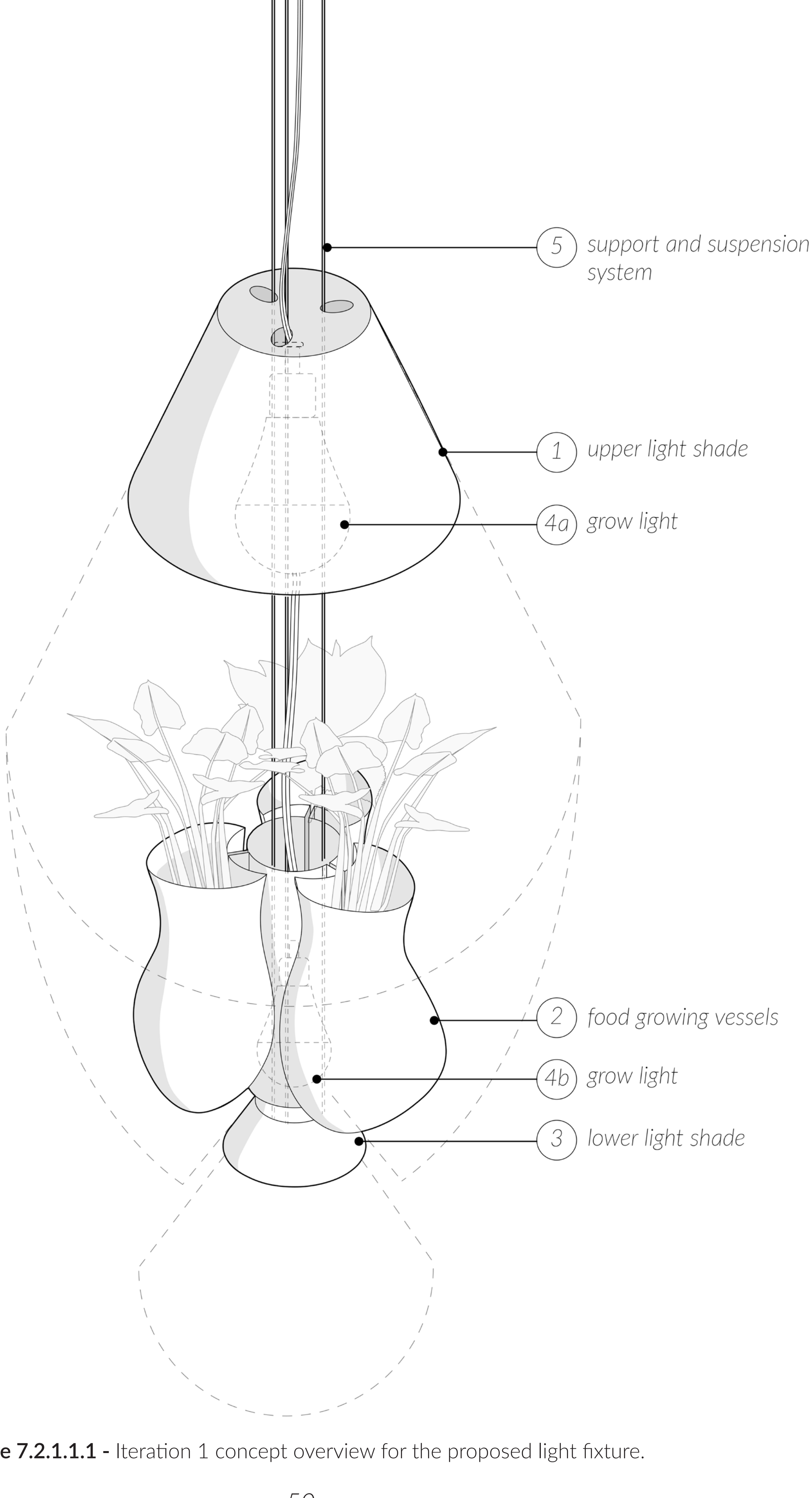


Figure 7.2.1.1.1 - Iteration 1 concept overview for the proposed light fixture.

7.2.1.2 - Component Design

Plant Growing Vessles

Massing
The massing for the plant growing element consists of three vessels arranged around a circular channel. The circular channel is required to house the grow light that will be positioned underneath the vessels, as well as to allow structural and electrical cables to run through the system. This component was initially printed from bottom-to-top, with a flat base (Figure 7.2.1.2.1)

Print Orientation and Base Condition
To create visual interest on the underside of the plant growing vessels, this component was revised to be printed up-side-down, to allow the base to end in a non-planar geometry (Figure 7.2.1.2.2). Print path layers offset at a 45° angle to gradually close in the base. The 45° angle was chosen as it is the lowest allowable angle that prevents the tool path from delaminating from itself or buckling in the centre while using a 3 mm nozzle and 2 mm layer height. It is necessary for the tool path to fully close as the plant vessels are required to be water-tight (Figure 7.2.1.2.4).

Structural Connections
Three structural loops were positioned between the food growing vessels to create a point of attachment for cables (Figure 7.2.1.2.5). Three cables were used to provide an appropriate level of support to the system, and allow the fixture to be levelled when it is suspended.

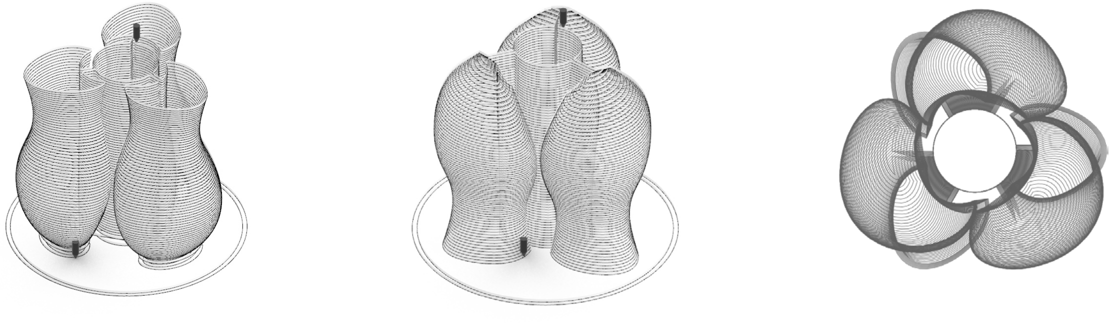
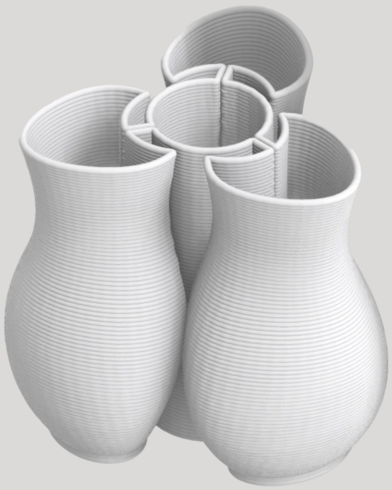


Figure 7.2.1.2.1 - 7.2.1.2.3 - Plant vessels were printed from bottom-to-top with a flat base (left), then from top-to-bottom to create a curved base (middle). Plant vessels were rotated 60° around the circular channel. (right).

Dynamic Quality
To create the appearance of movement, the vessels were rotated around the circular channel. The angle at which the vessels rotate around the channel were tested iteratively, using 30°, 45° and 60° increments. Ultimately, the 60° rotation was chosen, as it allowed for the top of each vessel to rotate enough to overlap with the adjacent vessel when viewed in plan (Figure 7.2.1.2.3, 6). This creates a full appearance and provides depth when viewing the component from below. Initial experiments in creating texture were achieved by offsetting points of the toolpath to enhance the surface quality.

Figure 7.2.1.2.4 - 7.2.1.2.6 - Comparison between the appearance of a flat base, a delaminated base, and a laminated, curved base (left). Three structural connections are seen at the top of the vessels (middle). Front view of the plant growing component (right).

Summary of Design Progression



Three vessels are arranged around a circular channel. The vessels are printed from bottom-to-top against the print bed and have a flat base.

The print orientation is flipped and is created from top-to-bottom, allowing the base of the vessels to end in a curved geometry.

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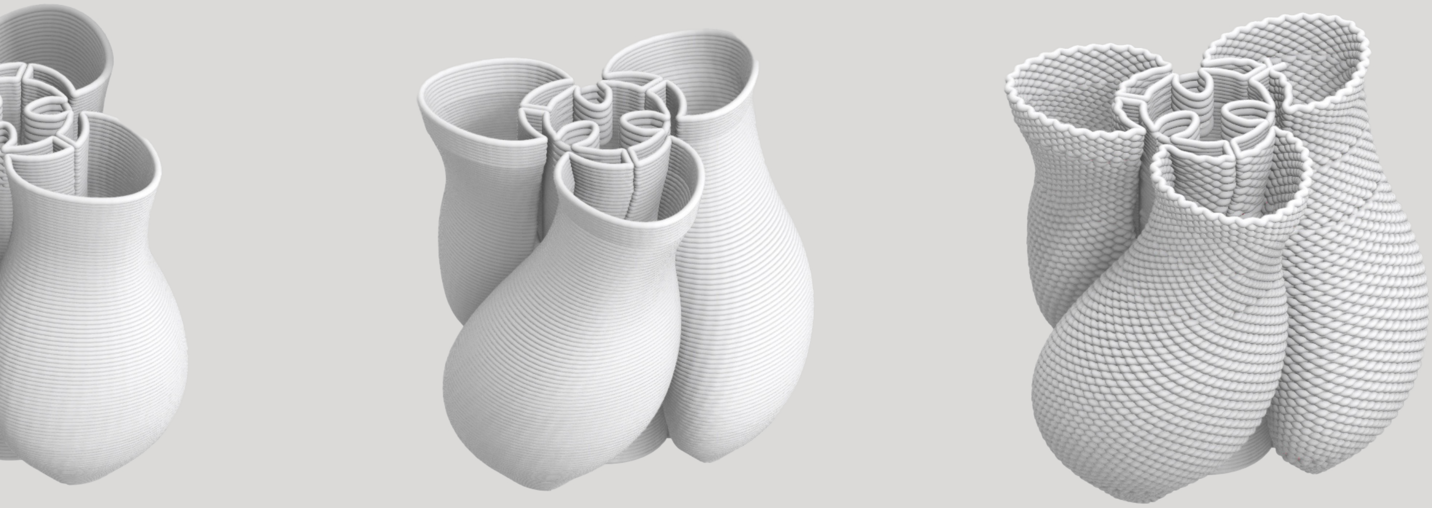


loops are created
of attachment for
les.

The vessels are rotated 60° around the circular channel to create the appearance of movement.

Surface quality and texture are experimented with.

Figure 7.2.1.2.7 - Design progression for the plant growing component.

Upper Light Shade

Massing
The massing began with a cone shape that is narrow at the base to align with the top of the grow light, and wide at the top to direct the light down toward the plants.

Print Orientation and Base Condition
The narrow end of the upper shade required a closed base, to hold the grow light in place. This was created by printing two layers flat against the print bed (Figure 7.2.1.2.8).

Structural Connections
Three structural openings were created in the base plate that align with the structural loops in the food growing vessels below. These provide a point of attachment for cables (Figure 7.2.1.2.11).

Dynamic Quality
To create the appearance of movement, the edge condition of the light shade ends in a waving curve that is created using isocurves. Isocurves move non-uniformly in the z-axis to create an undulating line. In this instance, it was used to create three undulations that are aligned to the placement of the three plant growing vessels below (Figure 7.2.1.2.9).

In order to create the waving curve, the printer would quickly step-up in z-axis at the high points, and then strongly compress down at the low points. This dramatic difference in movement created structural instability across the print, which would lead to immediate collapse or eventual cracking (Figure 7.2.1.2.12). To accommodate for this, structural ribs were added at the high and low points of each curve to provide rigidity. This was a successful strategy to prevent distortion and print failure.

Figure 7.2.1.2.8 - 7.2.1.2.10 - A cone shape with a closed base is created (left). A waving curve is used at the opposite end of the cone to create the appearance of movement (middle). An additional light shade is designed to nest inside the outermost shade (right).

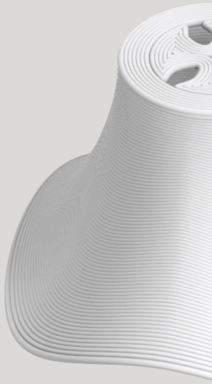
Lastly, to further create the appearance of movement, an additional light shade was designed to be nested inside the outermost shade. The smaller, nested shade has the same proportions as the larger shade, but is rotated 30° so that the high points on the edge of the small shade are aligned to the low points on the edge of the large shade (Figure 7.2.1.2.10). The same three structural loops are created at the base on the nested shade, and are aligned to the three openings on the large shade. The effect of the two nested shades together creates depth (Figure 7.2.1.2.13).

Figure 7.2.1.2.11 - 7.2.1.2.13 - The base is printed flat against the print bed with three structural openings (left). A print that experienced collapse due to changes in z-height remains intact on the right side where the structural seam is located (middle). A small shade nests inside the exterior shade and houses the light (right).

Summary of Design Progression

The massing begins with a cone shape that is narrow at the top to align with the base of the grow light, and wide at the base to direct light towards the plants.

The narrow end of the cone is printed flat against the print bed to create a base with three structural openings that provide a point of attachment for cables.



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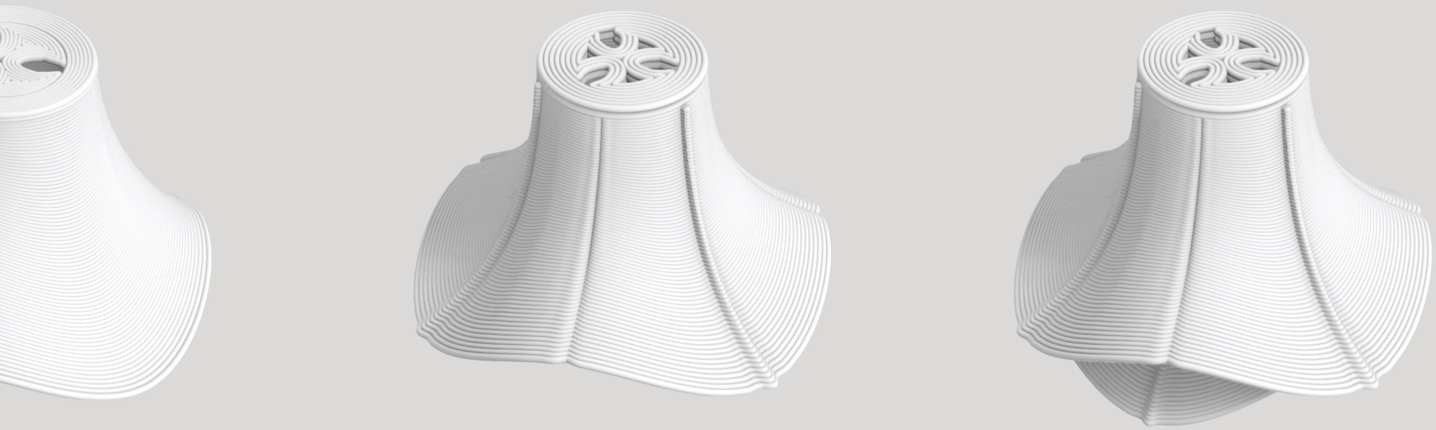


ed on the edge of
ocurves to create
movement.

Structural ribs are added to the high and low points of each curve to provide rigidity and prevent print collapse.

An additional light shade is created to nest inside this shade to create depth.

7.2.1.2.14 - Design progression for the upper light shade.

Lower Light Shade

Massing
The massing began with a cone shape, with a narrow base to allow it to fit within the circular channel of the food growing vessels above (Figure 7.2.1.2.20). The opposite end of the cone widens to create a surface for the light below the system to reflect off of, and direct it up toward the plants (Figure 7.2.1.2.15).

Print Orientation and Base Condition
The narrow end of the curve was printed against the print bed to provide a flat surface to interface with the circular channel in the plant growing component (Figure 7.2.1.2.16).

Structural Connections
Three structural loops are created to align with the loops in the plant growing vessels and the upper light shades (Figure 7.2.1.2.18).

Dynamic Quality
Waving curves are used to provide a sense of movement across the top edge of the shade, and to visually unite the appearance of the lower light shade with the two upper light shades (Figure 7.2.1.2.17, 19).

Figure 7.2.1.2.15 - 7.2.1.2.17 - A cone shape is created with a narrow base to fit within the channel of the plant growing component (left). Three structural connections are created at the base (middle). A waving curve is created at the opposite end of the cone to create the appearance of movement (right).

Figure 7.2.1.2.18 - 7.2.1.2.20 - Three structural openings are created at the base (left). The three light shades used in the system have similar forms but different scales (middle). The components are designed to nest within each other (right).

7.2.1.3 - Assembly

To assemble the system, three pieces of aircraft cable were cut into 4’ lengths. A vinyl washer and crimping sleeve were thread onto each piece of aircraft cable, and they were aligned to the structural loops on each ceramic component. Once in the correct position, the sleeve was crimped, and the aircraft cable was thread through the ceramic loops. The vinyl washers held the crimping sleeves in place under the structural loop, and prevented the edges of the aluminium sleeves from scraping against the ceramic structure. This process was repeated for each of the pieces in the system, starting with the food growing vessels (1), followed by the interior light shade (2), exterior light shade (3), and the lower light shade (4) (Figure 7.2.1.3.1). Care was taken to ensure that each component was level before moving onto the next piece. At the bottom end of the aircraft cable, any length that was left underneath the lower light shade was clipped off. At the top end of the cable, the extra length was finished in a loop using a wire rope cable clip (5). This loop was suspended from an L bracket for installation at the Canadian Clay and Glass Gallery (Figure 7.2.1.3.2 - 3, Material Syntax exhibition, February 6 to April 7, 2024).

This method of structural assembly posed issues for the installation of the electrical system. The distance between the three aircraft cables was not great enough to be able to accommodate the grow light, which prevented the light from being installed in the system. Further, the absence of a central opening through the base of the exterior light shade required that the electrical cables run through the structural openings at the side of the base, which prevented the grow light from being level.

Lastly, the use of crimping sleeves caused all connections in the system to be fixed. This prevented the distance of the plant growing vessels from being adjusted relative to the grow light, as the plants grew in the system. It also prevented this component from being able to be removed for cleaning and maintenance. Therefore, future iterations of this system will need to reconsider the structural materials and design to allow for the proper installation of the grow light, and to create non-fixed and adjustable connections.

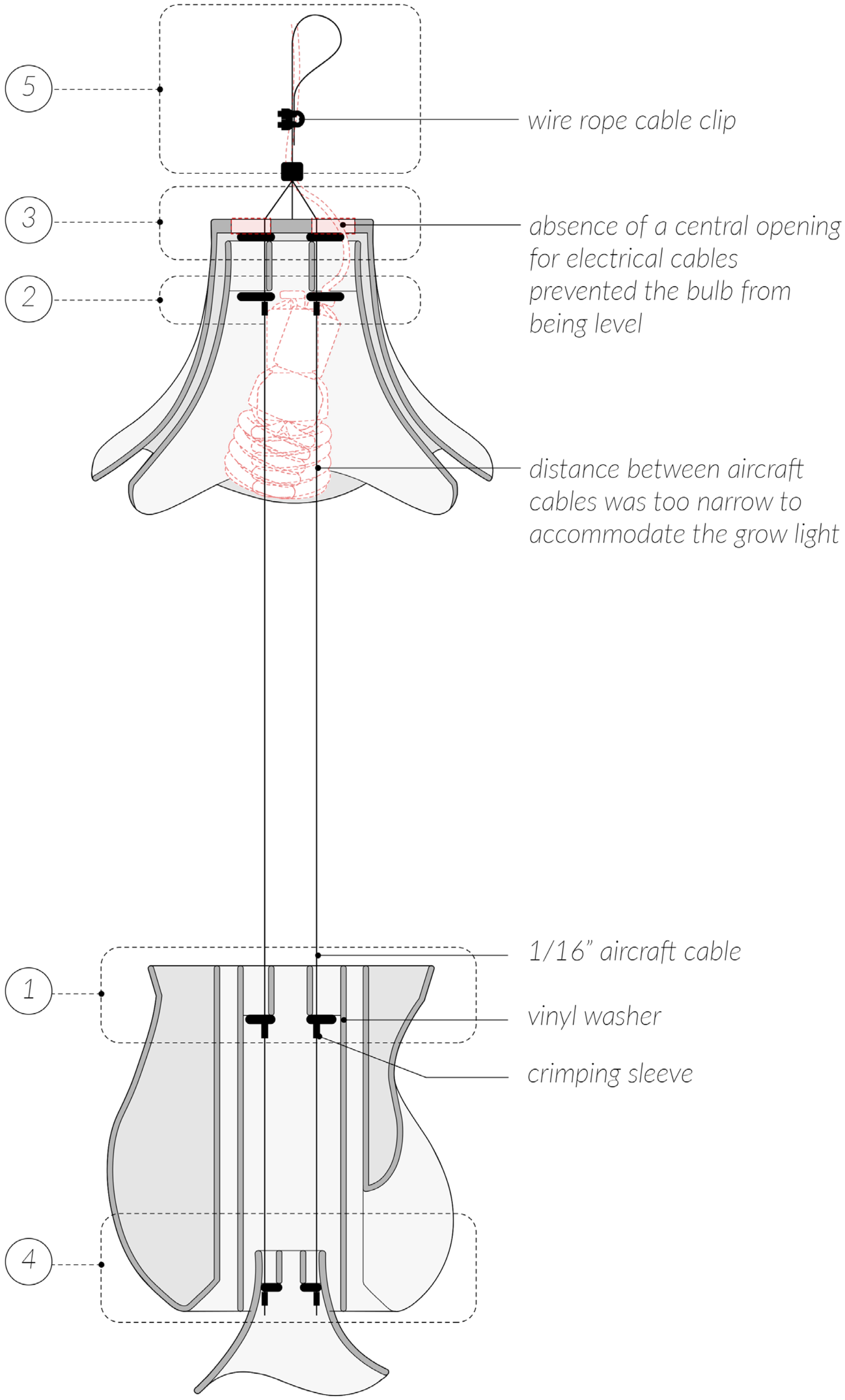


Figure 7.2.1.3.1 - Diagram showing the structural system for the finished installation at the Canadian Clay and Glass Gallery.

Figure 7.2.1.3.2 - Finished installation at the Canadian Clay and Glass Gallery (above).

Figure 7.2.1.3.3 - Texture on plant growing component (right).

7.2.1.4 - Reflections

The first iteration was successful in creating all of the required components for the system that had an appropriate massing and proportional relationships. However, each component requires further revisions in order to meet the design requirements determined by the schematic design phase.

Firstly, as the components were not developed at full scale, the plant growing vessels were able to contain only 0.4 L of water, which is less than the specified 0.5 - 1L.

Light tests were able to be conducted for this prototype by removing the structural cables that connected the plant growing vessels to the interior light shade (Figure 7.2.1.4.1). These tests revealed that due to the brightness of the grow lights, the upper light shades need to cover more of the light bulb to prevent harsh, direct light from reaching the residential space. Further iterations of these components will focus on designing ways to control the quality and intensity of the light emitted from the fixture. In addition to this, the upper light shades will require a central opening to allow for the grow light to be properly installed and levelled in the system.

Lastly, the support and suspension elements will need to be revised to not interfere with the grow light that runs through the centre of the system. Consideration will be given as to how to design connections between structural elements that are adaptable and allow for components of the system to be adjusted or removed as required.

Therefore, the goals for the second iteration of the light fixture are as follows:

- Print all components at 1:1 scale.
- Revise the design of the upper light shades to control the intensity of the light emitted from the grow light.
- Reconsider the materials and design of the structural system to allow for the proper installation of the grow light.
- Design structural connections to be adaptable, and allow for components to be adjusted or removed from the system.

Figure 7.2.1.4.1 - Light study using completed Iteration 1 components.

7.2.2 - ITERATION 2

7.2.2.1 - Concept Overview

The second iteration uses both the Scara and Lutum printers to develop ceramic components at 1:1 scale. The amount of clay that can fit in the extruder tube for the Scara is 3600 cc, and for the Lutum is 1400 cc. This was a limiting factor in scaling-up the size of the pieces. All components printed in the second iteration were scaled-up to be 25% larger than the geometries created in the first iteration. This change in size allowed for the water contained in the plant growing vessels to increase from 0.4 L to 0.5 L. It was not possible to increase the size of the plant growing vessels by more than 25%, as it would require more than 3600 cc of clay to produce the component at this scale. The light shades were created using the Lutum printer, as they required less than 1400 cc of clay, and benefited from high detail resolution.

This iteration began by reconsidering the design and material choice for the structural system. This was required to allow for the proper installation of the grow light, and to create non-fixed connections between components. Instead of continuing to use aircraft cable for the suspension system, ¼" braided rope was substituted. The intention is to use the flexibility of the braided rope to weave the structural system into the ceramic components, while creating points of connection that are not permanently fixed. This will allow for pieces of the system to be adjusted or removed as required. It will also allow for the structural system to be tied into the outer edges of the ceramic pieces, preventing the structure from running directly through the centre of the system where clear space for the grow light is required.

The revised concept for the structural system is separated into two parts (Figure 7.2.2.1.1). The first part is the upper light shades and the grow light. The exterior light shade will be solid and able to move up and down relative to the interior light shade (1a), whereas the interior shade will be perforated and have a fixed position in the system (1b). This allows for the amount of light emitted from the grow light to be controlled and adjusted (2). The second part of the system is the plant growing vessels (3a) and lower light shade (3b). The position of the plant vessels can be adjusted by moving the location of the knotted connection under the lower light shade (4). By undoing the knot, the plant growing component can be removed from the system for cleaning and maintenance. The second grow light that was initially intended to be placed in the interior channel of the plant growing component has been removed from the design, and this compartment will instead provide a place for the braided rope to run through (5).

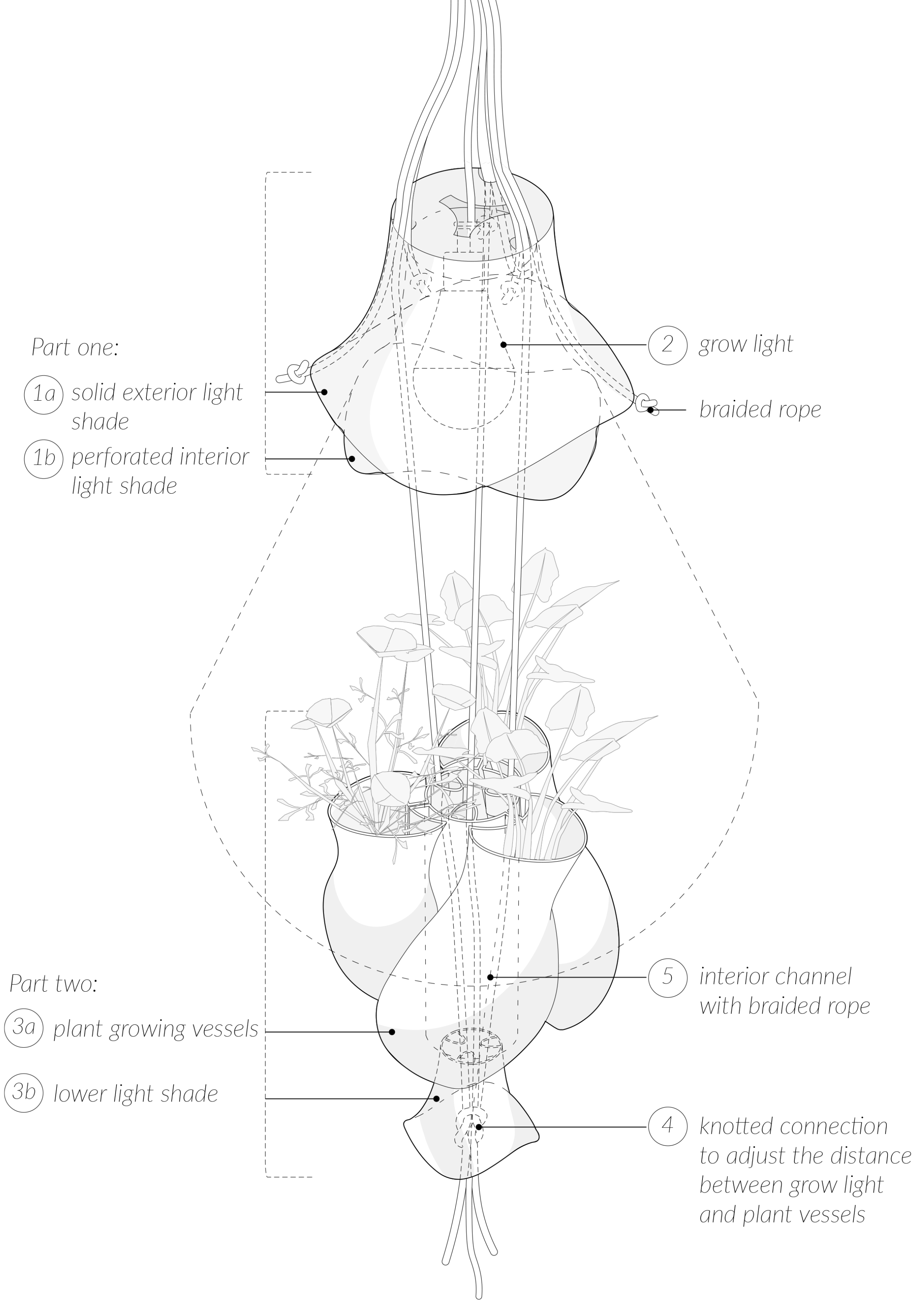
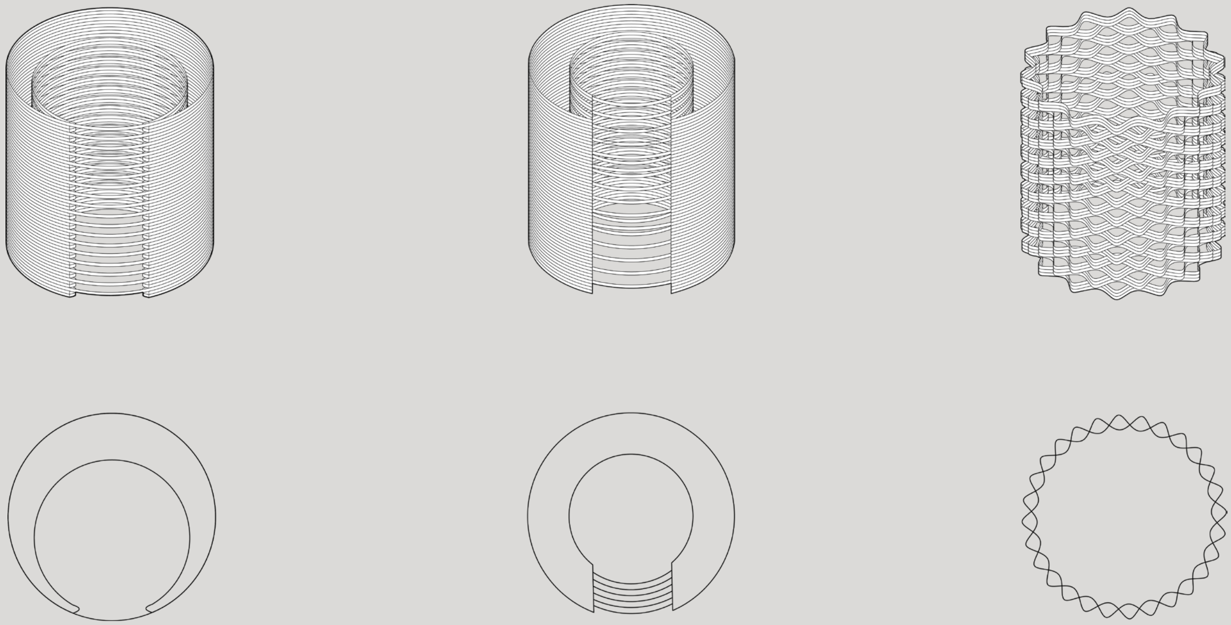


Figure 7.2.2.1.1 - Revised structural concept for the proposed food growing light fixtures.

7.2.2.2 - Component Design

Evaluation of Methods to Create Openings and Aperatures

It is necessary to create openings in the upper light shades to provide points of connection for the braided rope to weave into, and apertures for the light to emit from in the interior light shade. To understand methods for creating openings in 3D printed ceramic artefacts, the thesis ‘Grading Light’ by Isabel Ochoa and James Clarke-Hicks was reviewed. This thesis demonstrates how material deformation can be used to alter lighting effects in 3D printed ceramics, and identifies methods for creating apertures such as overhangs, light shelves, and light scoops (Figure 7.2.2.2.1).[90] Each of these methods were iteratively tested to determine which interventions were most successful in producing the openings required for incorporating structure and creating the desired lighting effects.



Overhangs *Light Shelves* *Light Scoops*

Figure 7.2.2.2.1 - Toolpathing required for methods of creating apertures including overhangs (left), light shelves (middle), and light scoops (right).

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[90] Ochoa and Clarke-Hicks, “Grading Light”

Overhangs

The overhang method uses alternating print layers to create unsupported areas of the tool path that produce small gaps in the printed artefact (Figure 7.2.2.2.2 - 3). Braided rope can be thread through each of the overhangs created, however this is a tedious and difficult process. Also, because the overhangs are formed from a single print layer, putting weight on these areas by integrating them with the structural system leaves them prone to breaking and cracking. These overhangs also do little to diffuse the internal light source and highlight print inconsistencies such as changes in extrusion or speed.

Figure 7.2.2.2.2 - 1" overhang.

Figure 7.2.2.2.3 - 2" overhang.

Light Shelves

Light shelves build on the overhang method by stacking and offsetting multiple layers of unsupported overhangs to create an angled shelf (Figure 7.2.2.2.4 - 5). The angle of the shelf diffuses the internal light source, creating an attractive light gradient that is more forgiving of print inconsistencies. However, this angle also makes it difficult to weave the braided rope through each of the shelves to create structural connections.

Figure 7.2.2.2.4 - 1" light shelf.

Figure 7.2.2.2.5 - 2" light shelf.

Light Scoops

Light scoops use undulating tool paths that are offset from one another to create vertical channels through the printed artefact (Figure 7.2.2.2.6 - 7). Many layers can be stacked on one another and provide a more structurally sound connection when integrated with the braided rope. The creation of a clear, vertical channel makes it easy to thread the braided rope straight through the opening. Lastly, the light scoops create interesting patterns of light diffusion that can be altered to create many designs. For these reasons, light scoops were the method chosen for creating openings for structural integration, and apertures for altering the lighting quality of the food growing light fixtures.

Figure 7.2.2.2.6 - 0.75" light scoop.

Figure 7.2.2.2.7 - 1.5" light scoop.

Upper Light Shades

The method for creating light scoops was applied to the exterior light shade at the three high points of the waving edge (Figure 7.2.2.2.8). This created a vertical channel that allowed for the braided rope to be woven into the component (Figure 7.2.2.2.11). In order to continue the pattern established by the integration of the light scoops at the seams, a woven texture was carried across the surface of the light shade.

The method for creating light scoops was also applied on the interior light shade to create light apertures (Figure 7.2.2.2.9). Different sizes of scoops were iteratively tested to determine which produced the most desirable lighting quality, including 2mm and 4mm apertures. This shade is designed to be nested in the exterior shade (Figure 7.2.2.2.10, 12).

The suspension system for the exterior and interior light shades needed to remain separate in order to test methods for adjusting the position of the exterior shade relative to the interior shade. The interior shade features the same three structural loops at the base as the previous iteration, which provide an opening for the braided rope to connect to. The exterior light shade has a closed base with three openings that are aligned to the channels for the braided rope (Figure 7.2.2.2.13). At the top of the channel, the rope can be thread through these openings to the interior of the shade. The ropes can then exit the shade through a central opening in the base. This allows for all the suspension ropes from the two light shades and the electrical wires to form one central cable that reaches the ceiling.

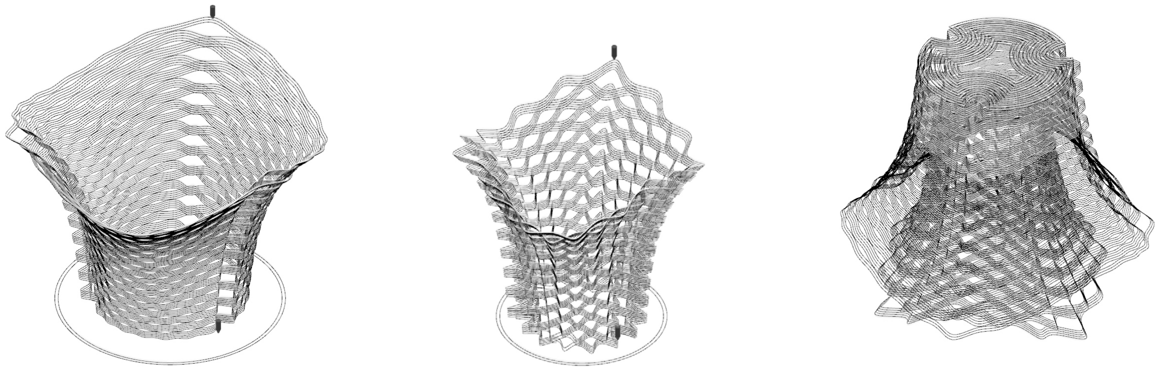


Figure 7.2.2.2.8 - 7.2.2.2.10 - Openings for the braided rope were created in the structural ribs at the high points of the exterior light shade (left). Openings were also created in the interior light shade to create light aperatures (middle). These two shades are nested (right).

Figure 7.2.2.2.11 - 7.2.2.2.13 - Braided rope runs through the channel created in the exterior light shade (left). The two shades are nested (middle). Openings in the base of the exterior shade provide points of connection for the braided rope (right).

Test Assembly and Light Studies

The suspension system was woven into the two light shades and they were nested into one another. The feasibility of being able to adjust the position of the exterior light shade was tested by pulling the length of rope through the seam to move the light shade up. Friction between the braided rope and the ceramic seam made it difficult to pull the rope through the shade. Individually adjusting the lengths of the three braided ropes causes the exterior shade to become off-level, occasionally causing it to hit the interior shade. Lastly, separating the suspension elements of each of the two light shades complicates the structural strategy, and results in six separate lengths of rope that need to be gathered at the top of the light shades. This creates a very thick cable at the top of the system, which is not in good proportion to the other components of the light fixture.

Lighting tests were performed to test the quality of light created by the 2mm and 4mm apertures. The tests demonstrated that the 2mm apertures were not large enough to produce the desired lighting effects (Figure 7.2.2.2.15 - 17). The 4mm apertures produced a subtle and attractive lighting quality across the light shade (Figure 7.2.2.2.18 - 20). The lighting tests also demonstrated that nesting the two shades prevented light from being visible on the exterior shade, and did not create the desired lighting quality.

Due to the fact that nesting the two light shades complicates the structural strategy, and prevents the desired light qualities from being produced, it was decided to move forward using only one light shade. The 4mm exterior shade was the preferred option (Figure 7.2.2.2.19. However, the size of the exterior light shade, and the thickness of the braided rope were both slightly too large in proportion to the rest of the light fixture. Moving forward, the size of the exterior light shade was reduced by 10%, and the ¼” rope was substituted for ⅛” rope.

Figure 7.2.2.2.14 - Assembly of nested light shades.

Figure 7.2.2.2.15 - 16 - 2mm aperture interior shade (left), 2mm aperature exterior shade (middle).

Figure 7.2.2.2.17 - 2mm aperture shades nested (right).

Figure 7.2.2.2.18 - 19 - 4mm aperture interior shade (left), 4mm aperature exterior shade (middle).

Figure 7.2.2.2.20 - 4mm aperture shades nested (right).

Plant Growing Vessles and Lower Light Shades

The massing and methods of creating structural connections for the plant growing vessels and lower light shade largely remained the same. Separation between print layers at the base of the plant growing vessels was observed in prints that used a smooth tool path (Figure 7.2.2.2.25). Dispatching points on the tool path to create texture prevented print layers from separating through drying. New patterns were experimented with as a means to minimise print layer separation and to visually connect the appearance of the plant growing components with the textures created in the upper light shades (Figure 7.2.2.2.24). These patterns incorporated fluted and woven effects, and were also applied to the lower light shade (Figure 7.2.2.2.21-23). A vertical seam was added through the centre of each of the plant growing vessels, to continue the linear movement created by the dispatched seam in the upper light shades (Figure 7.2.2.2.26).

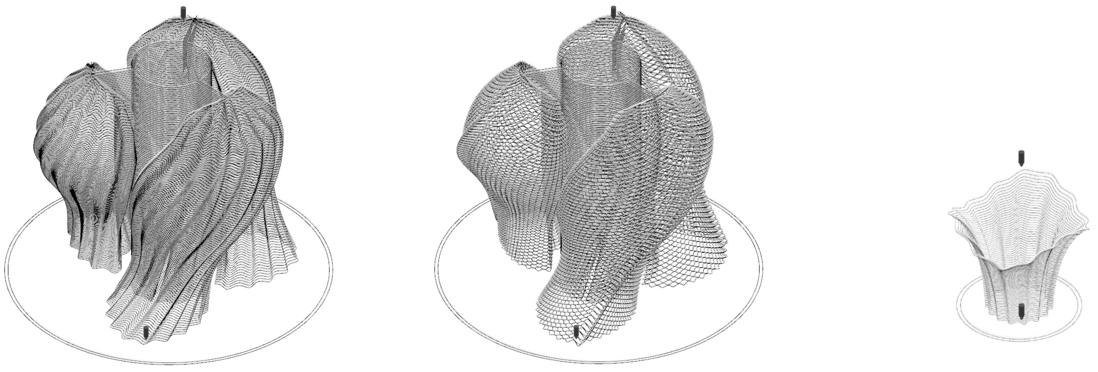


Figure 7.2.2.2.21 - 7.2.2.2.23 - New textures experimented with fluted patterns (left) and seams through the center of the plant growing vessles (middle). A fluted pattern was also applied to the lower light shade (right).

Figure 7.2.2.2.24 - 7.2.2.2.26 - Different textures and patterns were created for the plant growing components (left). A smooth tool path is prone to print layers separating during drying (middle). Dispatching the tool path to create texture minimizes print layer separation during drying (right).

7.2.2.3 - Assembly

The assembly of the system is divided into two parts. The first part is the upper light shade, and the second part is the plant growing vessels and the lower shade.

To assemble the upper light shade, ⅛” braided rope is thread through the vertical seam. The rope is woven around the layers at the top of the light shade, and is knotted to hold the rope in place (Figure 7.2.2.3.1). The knot is then tucked back into the structural seam, to conceal the extra length of rope. The opposite end of the rope is woven into the base of the light shade (Figure 7.2.2.3.2). These steps are repeated for each of the three structural seams.

The grow light connects to the system at the base of the light shade (Figure 7.2.2.3.3). The central opening in the base is large enough for the metal clip of the light socket to be pulled through (Figure 7.2.2.3.4). This causes the top face of the light socket to be flush against the interior of the base, allowing the grow light to be levelled.

To assemble the second half of the system, three lengths of rope are thread through the structural loops in the lower shade, then through the loops in the plant growing vessels (Figure 7.2.2.3.5), and lastly through three openings at the perimeter of the base in the upper light shade (Figure 7.2.2.3.6).

The distance between the top of the plant growing vessels and the light bulb is then adjusted to be between 12” - 16”. The three lengths of rope are tied into a knot beneath the lower light shade, to hold the plant growing vessels in this position. The system can then be suspended (Figure 7.2.2.3.7). Plants may be placed in each of the vessels (Figure 7.2.2.3.8).

In order to remove the plant growing vessels from the system, or alter the amount of distance between the plants and the grow light, the plant growing vessels and lower shade are held up and the knot is undone (Figure 7.2.2.3.9). The plant growing vessels can then be detached from the system for cleaning and maintenance. Alternatively, the knot can be repositioned lower in the system to create greater distance between the plants and the grow light (Figure 7.2.2.3.10).

Figure 7.2.2.3.1 - 7.2.2.3.2 - The braided rope is thread through the vertical seam and knotted (left). The opposite end of the braided rope is woven into the base of the light shade (right).

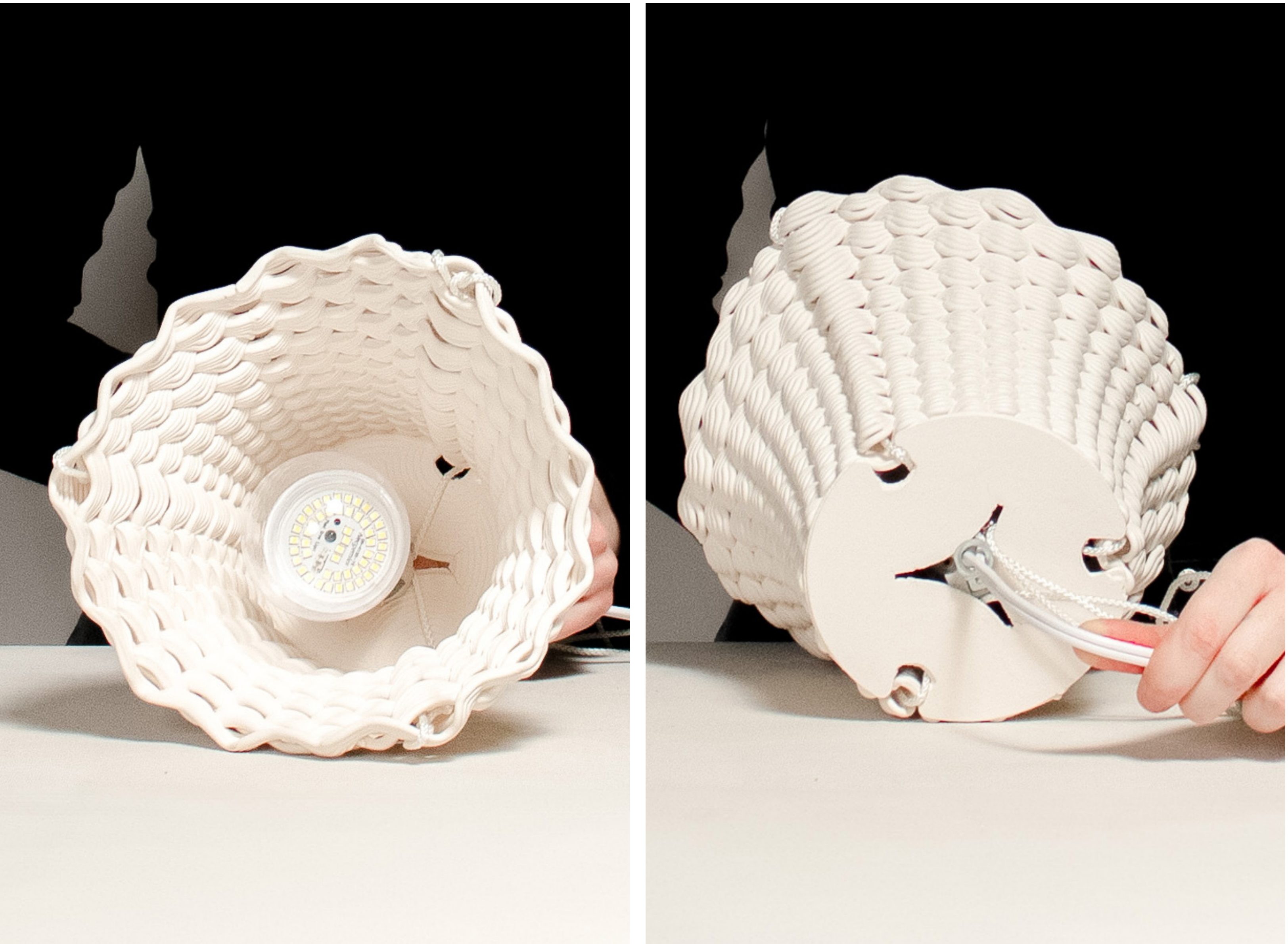


Figure 7.2.2.3.3 - 7.2.2.3.4 - The grow light connects to the system at the base of the light shade (left). The metal clip of the bulb, along with the electrical wires are pulled through the opening in the base (right).

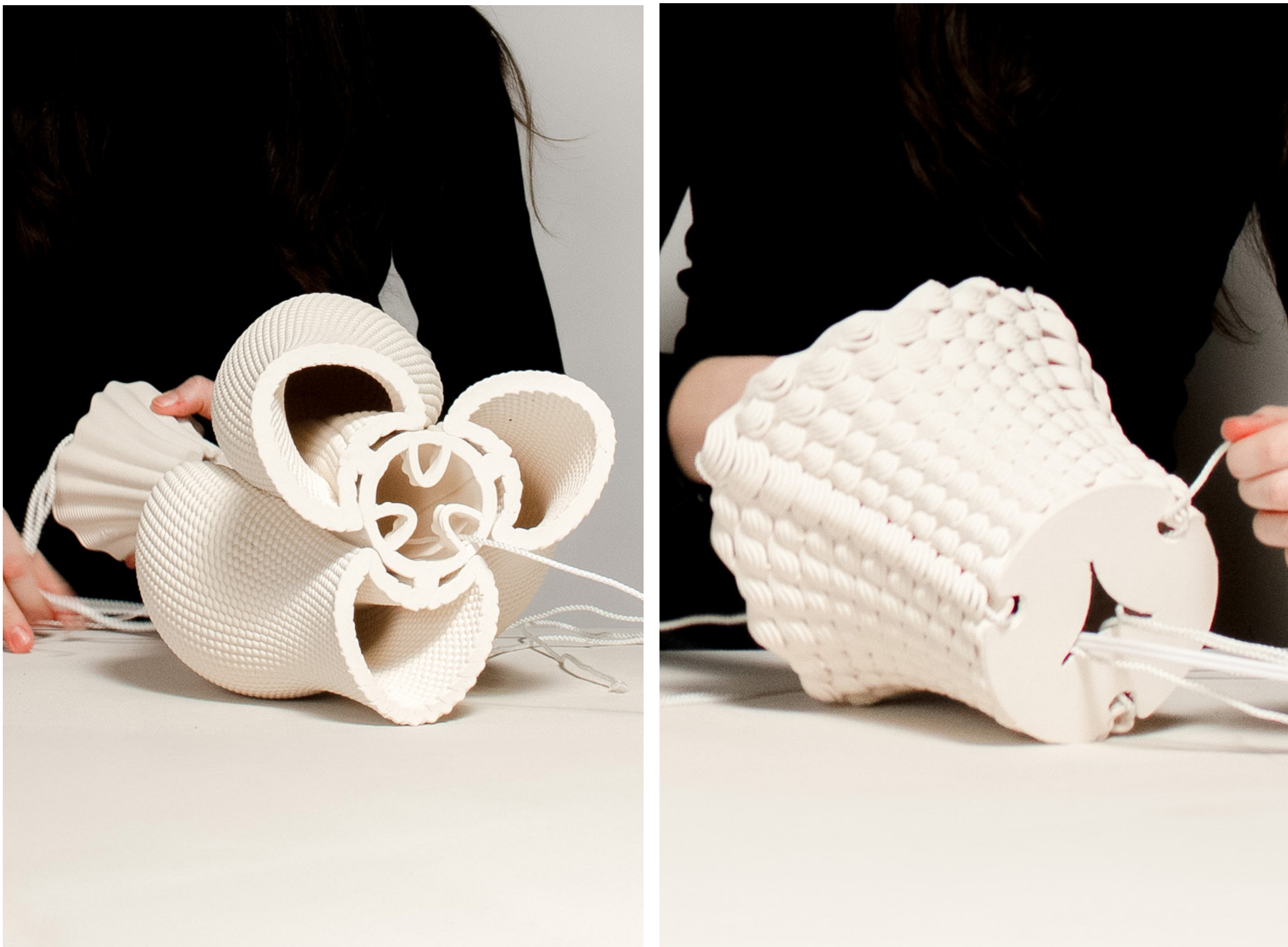


Figure 7.2.2.3.5 - 7.2.2.3.6- Three lengths of braided rope are thread through the lower light shade and the plant growing vessles (left). The same lengths of rope are then thread through the upper light shade (right).

Figure 7.2.2.3.7 - 7.2.2.3.8 - The system can then be suspended (left). Plants can be placed in each of the three growing vessles (right).

Figure 7.2.2.3.9 - 7.2.2.3.10- To adjust the position of the system, the components are held up, and the knot underneath the lower light shade is undone (left). The knot can be repositioned to alter the distance between the plant vessles and the grow light (right).

Figure 7.2.2.3.11- Complete Iteration 2 assembly.

7.2.2.4 - Glaze

Glaze was applied to the ceramic components to add colour, enhance the quality of the surface texture, and to make the plant vessels impermeable to water. Several types of glaze were applied to test tiles in a variety of colours, and were often layered together to produce new shades (Appendix B). Through these glaze tests, it was determined that the most effective combinations included a neutral or white base with hints of colour. Large amounts of colour were overpowering when applied to the entire tile, however, hints of colour provided an element of customization, created visual interest, and complimented the colours in the plant life.

The finish and thickness of the glaze applied to the ceramic components were also important considerations. Matte finish glazes prevented light reflection and scattering, and often concealed the appearance of the tool path (Figure 7.2.2.4.1). Glossy finishes were preferred as they enhanced lighting effects, and highlighted surface qualities (Figure 7.2.2.4.2). The thickness of the glaze applied also determined the surface character.
If the glaze was too thick, it would hide the texture created by the tool path, and add thickness to the component that prevented them from being able to nest together (Figure 7.2.2.4.3). Glazes with an appropriate amount of water highlighted the tool path, allowed for pieces to connect to one another, and coated the components thoroughly enough to make them impermeable to water. In order to achieve the desired glaze thickness, glazes were purchased in powdered form and mixed with a custom ratio of distilled water. The preferred ratio discovered through these tests was 10 lbs of dry glaze to 6 L of distilled water.

The final glazes chosen were 'White Opal' as the base shade, and 'Dark Flux' as the contrast shade. Dark flux is a glaze enhancer that is formulated to be layered over other glazes, as it reacts with each glaze to pull out new colours and create movement. When applied over White Opal, it creates bright blue to black colours (Figure 7.2.2.4.4). It was applied to specific parts of the component to highlight their features, such as the vertical channel of the upper light shade, the seam of the plant growing component, and the waving edge of the lower light shade.

Figure 7.2.2.4.1 - 7.2.2.4.4- Matte glazes in shade wintergreen (left). Glossy glazes in shade white opal (middle left). Glaze application that was too thick (middle right). White opal and dark flux layered together (right).

These glazes were applied to the three ceramic components of each fixture, and were fired in the kiln at cone 6. Unfortunately, the gaze firing of the actual components revealed several issues that were not present during the glaze tests. First, the glaze colours became muddy and patchy when applied to the components of the system (Figure 7.2.2.4.5). It is not clear what caused this to occur, but variations in kiln firing temperatures is a possible explanation. Second, the glaze applied to the interior of the plant vessels dripped out the component and caused it to fuse to the glaze tray (Figure 7.2.2.4.6). This occurred as a result of the method for applying glaze to the inside of the component. To apply glaze to the plant vessels, wax resist was first brushed onto the top 1 cm of the lip of the vessels, to provide an area where glaze could not adhere, and prevent the component from fusing to the glaze tray during firing. The inside of the plant vessels were then filled with glaze, and tipped upside down to allow the extra glaze to drain out of the vessels. However, this method likely created a glaze application on the inside of the vessels that was too thick, causing the glaze to flow past the wax resist area during firing, and completely fuse the component to the glaze tray. Lastly, the light shades experienced excessive warping and collapse during firing as a result of the curved shape of the shade (Figure 7.2.2.4.7).

There are several ways to move forward and refine the issues caused by this glaze firing. However, due to the amount of time required to troubleshoot these problems, glaze applications were not considered further in this research, and are instead discussed as an avenue for future development.

Figure 7.2.2.4.5 - 7.2.2.4.7 - The glazes on the component became patchy after firing, and produced a different result from the glaze test (left). Excess glaze in the plant vessles caused the component to fuse to the glaze tray (middle). The glaze firing caused the upper light shades to warp and collapse (right).

7.2.2.5 - Reflections

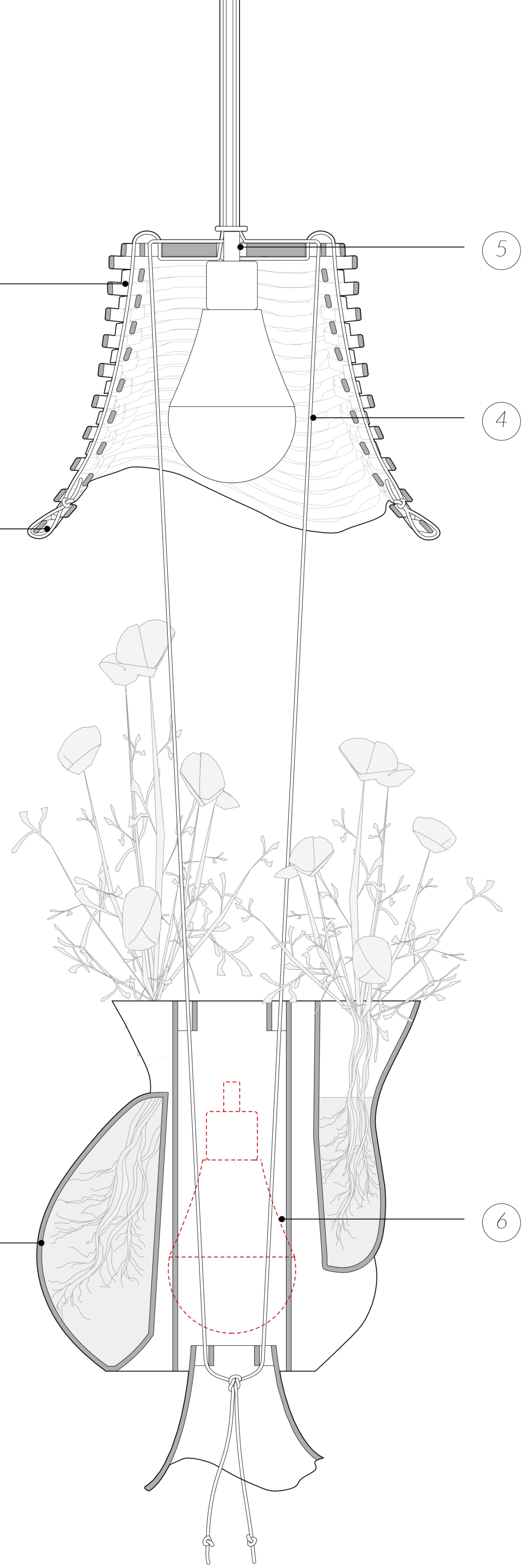
The primary goals for the second iteration were to print the components at 1:1 scale, revise the design of the light shades to control the intensity of light emitted, and to reconsider the structural materials and methods of assembly. Attention was given to developing the aesthetic details and textural qualities of the system. While there was success in accomplishing the above goals, there are many elements of the design that could be explored further in future iterations.

For instance, the components from the previous iteration were increased in size by 25% to be fabricated at 1:1 scale, and to achieve an interior volume of 0.5 L for the plant growing vessels (1) (Figure 7.2.2.5.1). This was the largest size that the plant growing component could be scaled to, as it used all the clay that could be contained in the 3600 cc extruder tube. Further iterations of this system could consider modifying the design of this component, to allow the plant vessels to contain more than 0.5 L of water, and enable plants of larger varieties to be grown in the system.

The design of the upper light shade was refined to prevent bright, direct light from reaching the residential space. Increasing the size of this component by 25% allowed for the shade to conceal the profile of the grow light, which reduced the amount of light entering the residential space (2). To further control the quality and character of light across this component, small openings were created in the surface of the shade to produce light apertures. Diffuse, ambient light seeps through these perforations and into the residential space (Figure 7.2.2.5.2).

Additional openings were created in the upper light shade, to produce vertical channels for the braided rope to be woven into (3). This directed the structure away from the centre of the system, where clear space for the installation of the grow light was required (4). A central opening in the base of the light shade allows the grow light to be levelled in the system (5). As a result, the grow light could be properly installed in this iteration.

The schematic design phase proposed that more than one light could be incorporated in this system, to allow for the plants to grow in many directions and create a full appearance. A second light could not be incorporated in the interior channel of the plant growing vessels, due to limitations on increasing the size of this component (6). However, future iterations could revise the design to include more than one light source, and experiment with how this can influence the direction of plant growth, and create additional lighting effects.



③ the braided rope is woven into the surface of the shade to prevent it from interfering with the placement of the grow light

⑤ a central opening in the base of the light shade allows for the grow light to be leveled

④ clear space is required in the center of the shade for the grow light

② the light shade conceals the profile of the grow light

① the interior volume is 0.5 L and is capable of growing small plants

⑥ a second grow light was not included due to limitations on the ability to increase the size of this component

Figure 7.2.2.5.1 - Diagram showing the revised Iteration 2 system for assembly.

The design of the plant growing vessels and lower light shade were developed to create a tactile and engaging quality. Surface textures were experimented with, by offsetting points of the toolpath to create stippled, fluted, and woven effects. The appearance of the surface texture is enhanced by the position of the grow light above. Light is washed across the stippled surface of the plant growing vessels, and the fluted pattern on the lower light shade (Figure 7.2.2.5.3). In addition to this, the light that shines through the interior channel of the plant growing vessel casts a single projection onto the floor below that resembles a flower (Figure 7.2.2.5.4). This outcome was not anticipated in the design process, but is enjoyed as a feature of the system.

The structural design was revised to create flexible and non-fixed connections. By moving or untying the knot underneath the lower light shade, the plant growing vessels can be repositioned or removed from the system. However, this process requires two people - one to hold the plant vessels and lower light shade up, while the other person unties and repositions the knot. While this strategy is effective, future developments to the structural system could make this process more feasible for a single user.

Lastly, the most significant avenue for future development is in the application of glaze to the plant growing component. Continuing this research is necessary, as it makes the plant vessels impermeable to water. Suggestions for correcting the issues that occurred as a result of the glaze firing include revising the shape of the upper light shade to prevent collapse, and developing a method for applying the glaze to the interior of the water vessels that prevents a thick coating. Alternatively, the mid-fire clay that was used to fabricate all components in this research could be substituted with a low-fire clay. Switching to a low-fire clay body, such as a white terracotta, would allow the pieces to be fired at lower temperatures, possibly preventing collapse and excessive warping during firing.

Figure 7.2.2.5.2 - Detail on the upper light shade.

Figure 7.2.2.5.3 - Detail on the plant growing component and lower light shade.

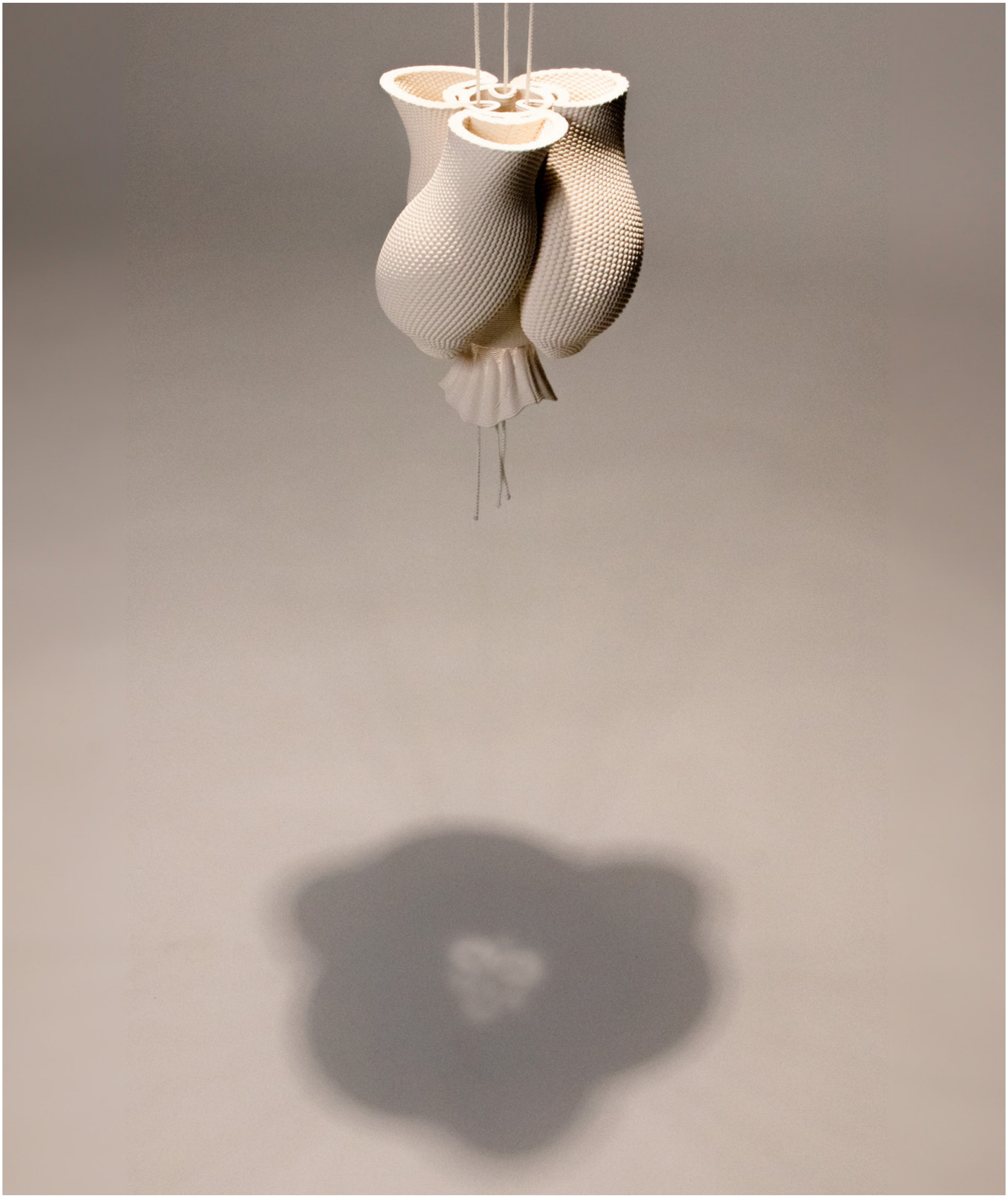


Figure 7.2.2.5.4 - A projection of light is created below the system that resembles a flower.

7.3 - DOCUMENTED PLANT GROWTH

The interior volume of each of the plant growing vessels is 0.5 L, and as such, this system is best suited to growing small plants such as leafy greens and herbs. Chives, oregano, and mint were planted in the vessels and grown using the Kratky method. The grow light was programmed to run for 16 hours each day on the highest brightness setting. The plants demonstrated noticable growth in a two week period.

Figure 7.3.1 - Plants immediately after they were placed in the system.

Figure 7.3.2 - Plants after two weeks.

7.4 - INTEGRATION WITH RESIDENTIAL SPACE

The compact size of the light fixture, as well as its ability to be suspended allows for it to be installed in many places. The light fixture may be installed in a living room over a side table or next to an armchair (Figure 7.4.1). It can be placed in a bedroom, over a dresser or a night table. Alternatively, many of the light fixtures can be installed together, to form a system of greater food growing capacities. In this instance, the fixtures may be installed over a kitchen island, or a dining room table (Figure 7.4.2).

Figure 7.4.1 - Single system suspended in a living room.

Figure 7.4.2 - Multiple systems suspended together over a kitchen island.

CHAPTER 8 - DISCUSSION

8.1 - DISCUSSION

The first ambition of the project was to design a light fixture for residential food growing, that allows individuals living in small urban apartments to overcome key barriers such as a lack of space, time, and gardening knowledge.

The proposed light fixture addresses the barrier of space through its compact design, and suspended structure. The system can be installed almost anywhere in residential space, even where access where natural light is not available, as the integrated grow light supplies the plants with enough energy to grow effectively. Additionally, the design of the indoor garden is coupled with the design of a light fixture, to prevent the addition of a stand-alone garden that takes away from the space available for other residential programs.

The design considers the dimension of time. Beginning indoor food growing practices first requires time to be invested in organising and preparing a space to garden in. The proposed light fixture does not require this initial time investment, as it provides users with all the infrastructure to start a garden. Additionally, the use of hydroponics allows for the amount of time spent interacting with this system to be condensed. Hydroponic systems are a convenient and efficient method for indoor food growing - they produce little mess, their water supply can be replenished at the kitchen sink, and they can even expedite the time required for plants to grow.[91]

Lastly, engagement with the light fixture was intended to allow users to overcome a lack of gardening knowledge. The presented system responds through its small scale, simplicity of operation, and minimal user maintenance. The main requirement is that the user replenish the water supply. As such, it makes it possible for individuals without previous experience to have a higher chance for success in growing food, and building the knowledge of food growing. Aesthetic details of the light fixture were carefully developed, to create a tactile object that encourages appreciation and interaction with the system. Through consistent engagement with the light fixture, it is hoped that fundamental gardening skills, habits, and instincts can be acquired.

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[91] Maurya et al., "Study of Hydroponic Systems and Their Variations"

The second ambition of the project was to use the light fixture to correct some of the design challenges faced by existing hydroponic systems for residential food growing. The initial experiment in constructing two hydroponic structures allowed for issues to be identified, such as the use of plastics as a construction material, the lack of an architectural design language, and limitations on the use of aesthetics to create beauty. To counter this, the components are constructed from clay, which is a naturally occurring material with a long history of use in agricultural practice and architectural construction. Additionally, the proposed food growing systems are coupled with the design of an existing architectural element, a light fixture, to allow the gardening systems to develop an architectural language that is consistent with residential design. Lastly, the system was carefully designed to be an aesthetically pleasing object in residential space. The ability to develop the system as an aesthetic object largely had to do with the iterative printing process that was used in this research. This method of making and continually refining the design in response to print observations allowed for the discovery of new material qualities and capabilities that were previously unknown. Through this material research, the system developed engaging textural qualities that promote user engagement and appreciation.

Due to the restricted size of the light fixture, it is only capable of growing three small plants such as lettuces and herbs. At this scale, the light fixture could provide a household with limited savings on a weekly grocery bill. At the time of writing this thesis, the cost of a bunch of herbs is approximately $3.00, and the cost of a head of lettuce is approximately $5.00. It is estimated that each vessel the fixture could grow half a bunch of herbs, and a quarter of a head of lettuce on a weekly basis. As such, depending on the plants chosen to be grown in the system, the fixture could save a household between $3.75 - $4.50 per week on groceries. At this scale, the benefits of this system are most impactful in helping individuals build their knowledge of food growing, and create a relationship to sustainable agricultural practices. In order for the system to meaningfully contribute to reducing a weekly grocery bill, the design would need to be adapted and scaled-up to create a system of greater food growing capacities.

CHAPTER 9 - CONCLUSION

9.1 - RESEARCH OUTLOOK

The proposed light fixtures for food growing can be modified and adapted to suit many applications. For example, in cases where suspending the light fixture from an existing structure is not possible, the design of the system could be adapted to suit wall-mounted or floor-mounted typologies.

Further, the development of the light fixture case study highlights key considerations for designing architecturally-integrated food growing systems. These considerations can be coupled with the design of other architectural elements, like walls or cladding systems, to propose additional typologies for food growing.

The key considerations reflected through the development of the light fixture case study include:

① Compartmentalising plant growing vessels to allow each plant a water supply that is proportionate to their rate of growth.

② Relating the interior volume of the plant vessels to the size of the plant grown in this component. Through previous experiments using the Kratky Method, it is estimated that a volume of 0.5 L is suitable for small plants, 1 L for medium sized plants, and 2 L or more for large plants.

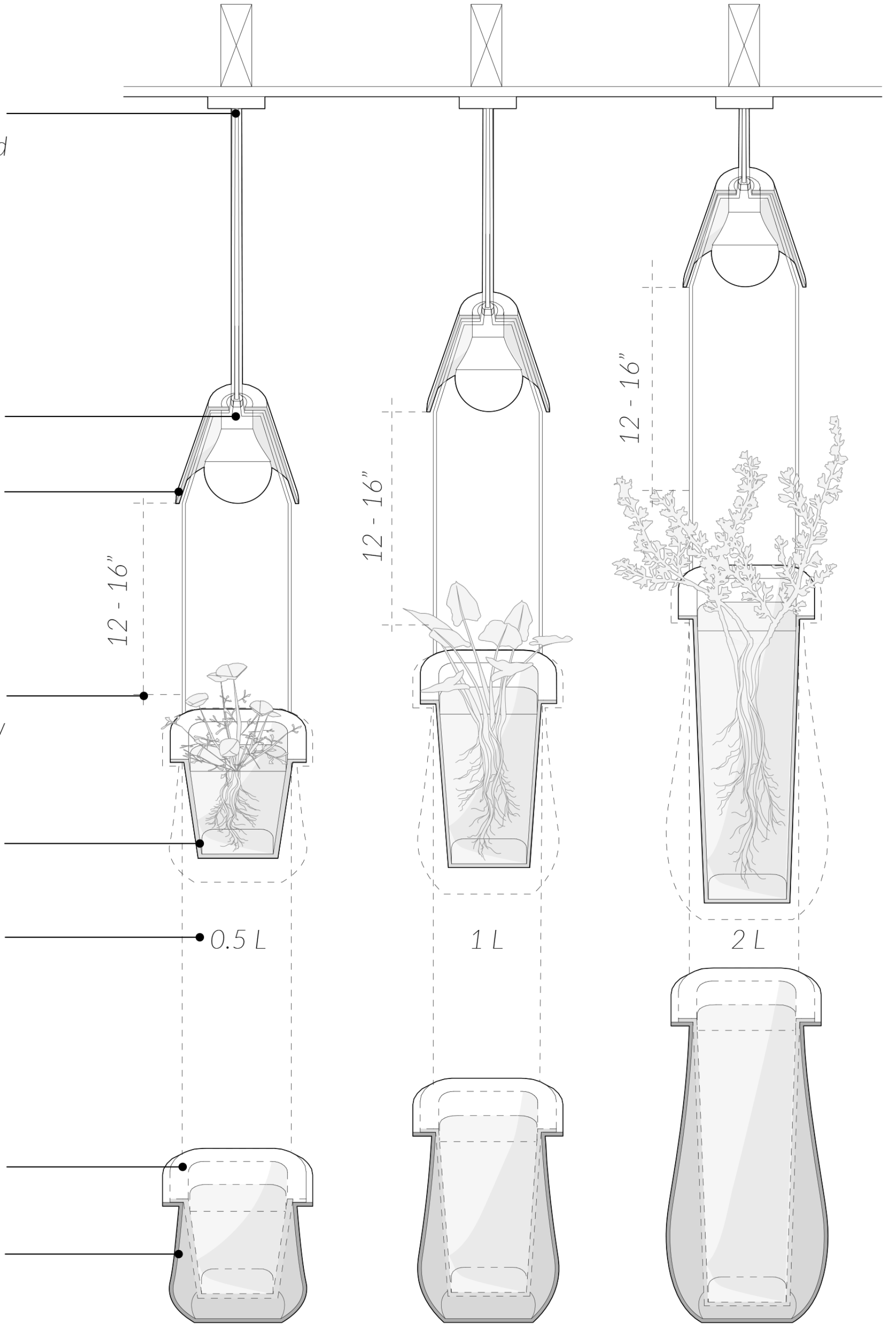
③ A grow light positioned above the plants to directly supply them with energy.

④ Light shades to control the direction and intensity of the grow light.

⑤ A set distance maintained between the plant and the grow light.

⑥ The ability to adjust the position of the plant growing vessels relative to the grow light, or remove them from the system for cleaning and maintenance.

⑦ Structural elements to connect components of the system to one another and to the existing structure.



7 Structual elements connect components to one another and to the existing structure

3 A grow light is positioned above the plants

4 Light shades control the intensity of the light

5 A set distance is maintained between the plant and the grow light

1 The plant growing vessels are compartmentalized

2 The volume of each vessel is related to the size of the plant grown in the component

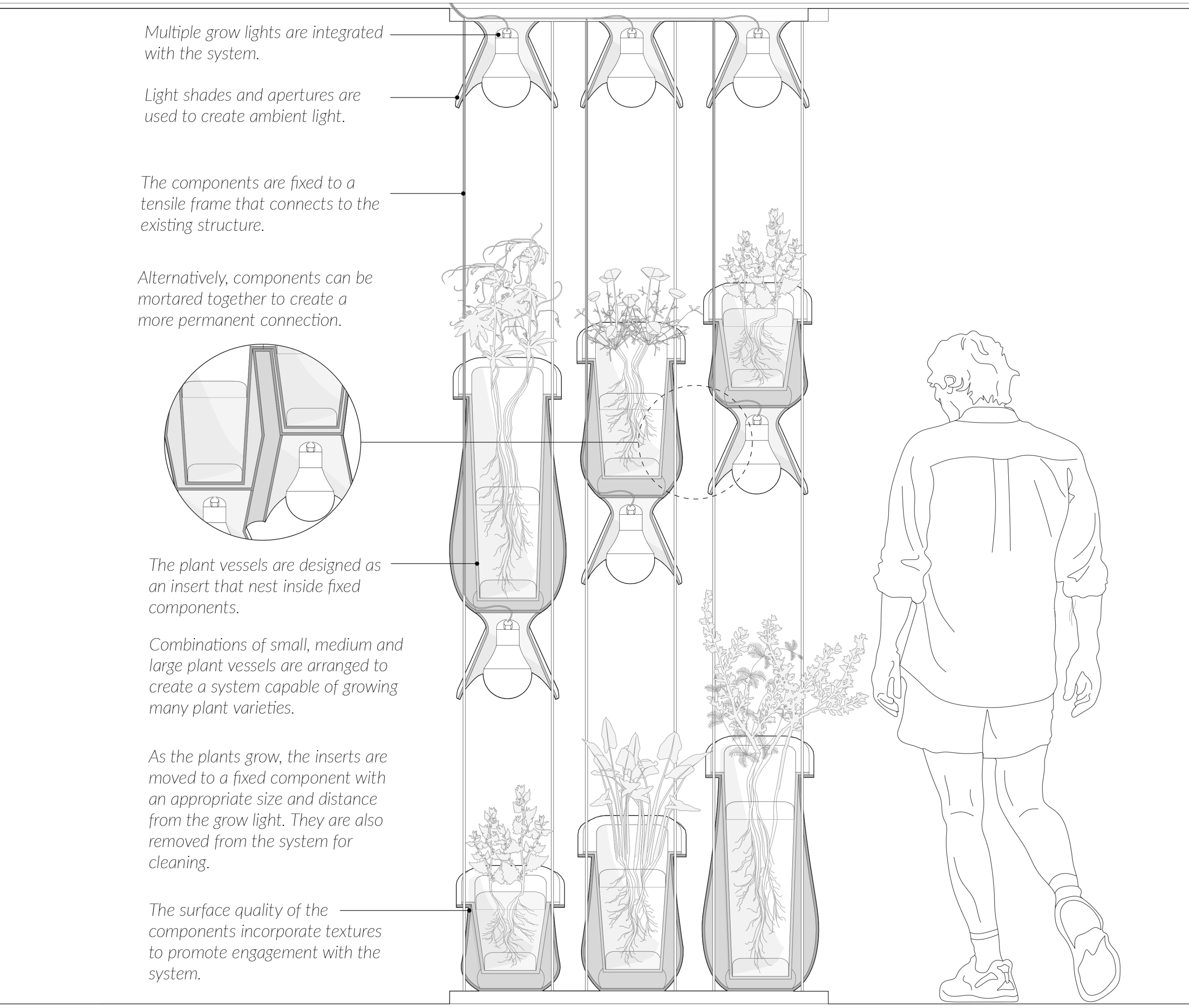
6 The plant growing vessels can be removed or adjusted

This can be achieved by designing the plant vessels as a removable insert that nests inside other components that have a fixed position

Figure 9.1.1- Diagram of key considerations developed through the light fixture case study.

Interior Wall Assemblies

The following examples illustrate how these requirements can be applied to the development of an interior wall and exterior cladding assembly for gardening.



Multiple grow lights are integrated with the system.

Light shades and apertures are used to create ambient light.

The components are fixed to a tensile frame that connects to the existing structure.

Alternatively, components can be mortared together to create a more permanent connection.

The plant vessels are designed as an insert that nest inside fixed components.

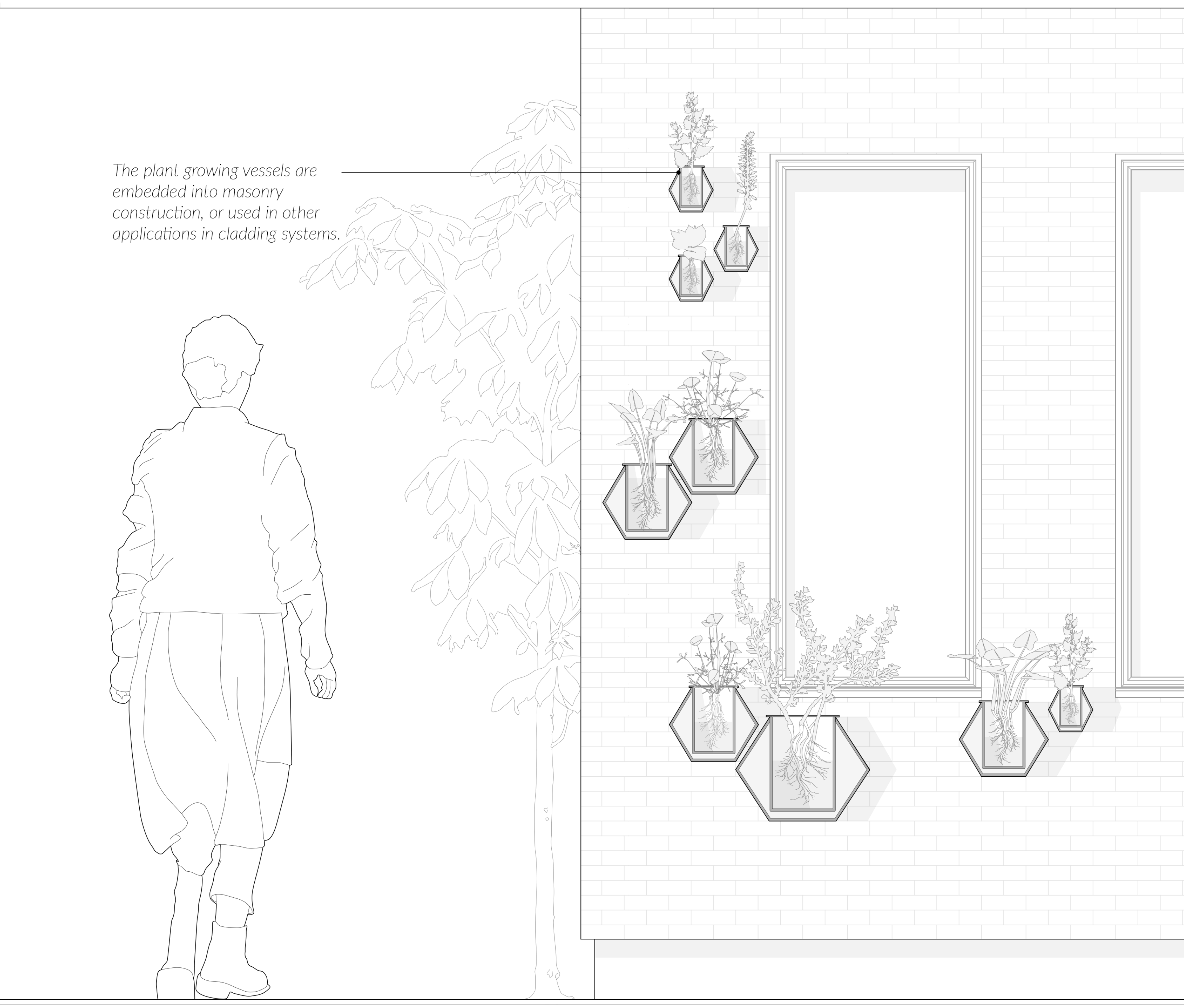
Combinations of small, medium and large plant vessels are arranged to create a system capable of growing many plant varieties.

As the plants grow, the inserts are moved to a fixed component with an appropriate size and distance from the grow light. They are also removed from the system for cleaning.

The surface quality of the components incorporate textures to promote engagement with the system.

Figure 9.1.2- The key components can be used to develop an interior wall system for food growing.

Outdoor Cladding Systems



The plant growing vessels are embedded into masonry construction, or used in other applications in cladding systems.

Figure 9.1.3- The key components can also be used in cladding systems.

In the two examples illustrated above, the systems are not specific to residential architecture, and can be integrated with many building uses. The wall screen system may be used in a school, to teach students about food growing and the requirements for sustainable urban agriculture. The cladding system can be installed at the ground level of a community centre, as a form of vertical community garden, and to engage the public with the building at the street level. The above examples hope to demonstrate that the presented research offers valuable insights that can be extended into many future research trajectories addressing architecturally-integrated food growing systems.

9.2 - CONCLUSION

This thesis explored the ways in which indoor gardening systems can be integrated with architectural design to create new typologies for residential food growing. The systems designed are intended to carve a niche in urban agriculture that is functional, aesthetically beautiful, and capable of re-building the knowledge of food growing practices.

The case study proposes a light fixture that acts as a functional garden, to demonstrate how indoor food growing systems can be designed to suit a variety of architectural applications. This case study was developed through an iterative clay 3D printing process that involved the creation of several models. Two clay 3D printers were used in this research, the Scara V4, and the Lutum V4.6. The technical capabilities of these clay printers were explored in depth, while progressing the massing and aesthetic details for the food growing systems. Following the creation of each of the case studies, they were evaluated for their ability to function as practical systems for food growing, and their success as an aesthetic object in residential space.

The light fixture case study is a small-scale, suspended system that developed the fundamental requirements for the indoor food growing infrastructures. The schematic design phase identified several constraints including parameters for the size of the food growing vessels, the position of the grow light, and the distance required between the plants and the light source. Beyond these functional considerations, aesthetic details were developed using the capabilities of the clay 3D printers, such as creating weaving curves that use variable z-values, light apertures created by small offsets in the printer's tool path, and surface qualities that experimented with pattern and texture (Figure 9.2.1). From a functional perspective, the proposed light fixture for food growing is limited in scale, and is capable of growing three small plants such as lettuces and herbs. However, it is capable of teaching users about the fundamental requirements of food growing practices, and can contribute to building gardening habits and instincts. This, in addition to its small, suspended size, and efficient hydroponic system, allow for the barriers of time, space and knowledge to be reduced for those living in small urban apartment units.

The discussion section highlights how the framework developed in the light fixture typology can be adjusted and integrated with other architectural elements. Conceptual drawings for a wall and cladding system show how these components can be scaled-up, to create gardens of greater food growing capacities, that can accommodate larger plant varieties.

Each of the above examples demonstrates the range of aesthetic opportunities and possibilities that are afforded when food growing systems are coupled with architectural design. As Canadian cities grow and densify, concerns about sustainable urban agriculture will continue to be a focus in the field of architectural design. Providing urban inhabitants with the infrastructure to start their own indoor gardens ensures a sustainable method of food production that is capable of restoring relationships to food growing practices.

Figure 9.2.1 - Details of the light fixture.

Letters of Copyright Permission

Figure 5.1.5

Image of Rise Gardens Hydroponic System.

"Taylor,
You can use this image.
Good luck with your thesis.
Regards,
Hank Adams
CEO, Rise Gardens"

Figure 5.2.7 - 5.2.8

Images of ceramic light fixtures in the thesis 'Grading Light' by Isabel Ochoa and James Clarke-Hicks.

"Hi Taylor,

Thanks so much for checking. Yes, you can absolutely use the images.

Best,

Isabel"

Figure 5.2.9

Image of ceramic vase by TRKY Lab.

"Hey Taylor, we're really sorry! I forgot to answer you of cause you can use the photo! Good luck with your thesis."

Figure 5.2.10

Image of extruded clay plant pot by Studio Biskt.

"Hello,

No worries, you just need the photo credits
Studio Biskt
©Avenueduroi-AlexandraColmenares
Studio Biskt
thank you for asking."

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APPENDIX

Appendix A - Progress Clay 3D Prints


Intersecting toolpath test 1.


Intersecting toolpath test 2.


Intersecting toolpath test 3.


Light reveal test.


Overhang tool path test 1.


Overhang tool path test 2.


Overhang tool path test 3.


Overhang tool path test 4.


Overhang tool path test 5.


Light shelf test 6.


Light shelf test 7.


Light shelf test 8.


Light shelf test 9.


Light shelf test 10.

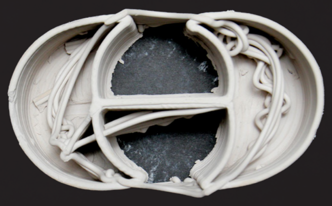

Light scoop test 1.


Light scoop test 2.


Light scoop test 3.

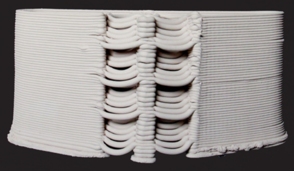

Light scoop test 4.

Tests for combining vessles and light apertures.

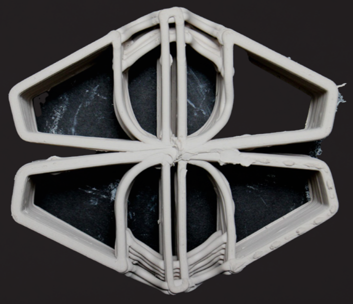


Vessels and light test 1.

Vessels and light test 2 (plan).



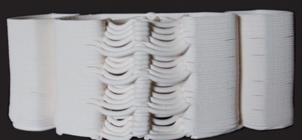
Vessels and light test 2 (elevation).



Vessels and light test 3 (plan).

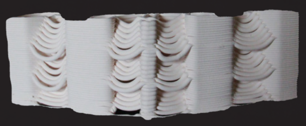
Vessels and light test 3 (elevation).

Vessels and light test 4 (plan).



Vessels and light test 4 (elevation).

Vessels and light test 5 (plan).



Vessels and light test 5 (elevation).

Lofting multiple vessels test (plan).

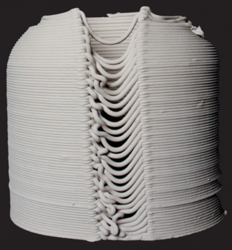
Lofting multiple vessels test (elevation).

Closing unsupported toolpath test 1.

Closing unsupported toolpath test 2.

Closing unsupported toolpath test 3.

Closing unsupported toolpath test 4 (plan).



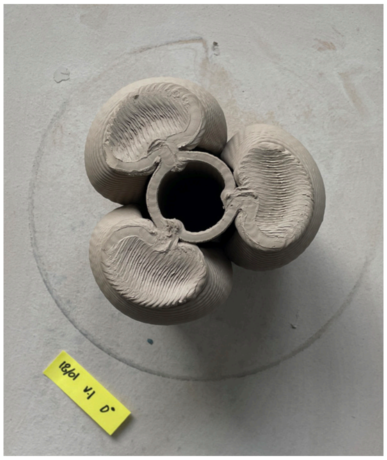
Closing unsupported toolpath test 4 (elevation).

Arraying vessels around circular channel test 1 (plan).

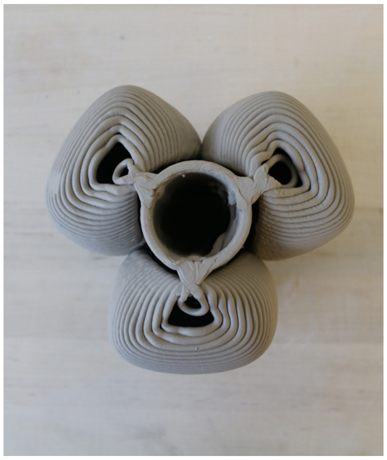
Arraying vessels around circular channel test 1 (elevation).

Plant growing component tests.


Printing vessels with flat base test 1.


Printing vessels with flat base test 2 (plan).


Printing vessels with flat base test 2 (elevation).


Printing vessels with curved base test 3 (plan).


Printing vessels with curved base test 3 (elevation).


Printing vessels with curved base test 3 (elevation).


Printing vessels with curved base test 4 (plan).


Printing vessels with curved base test 4 (plan).

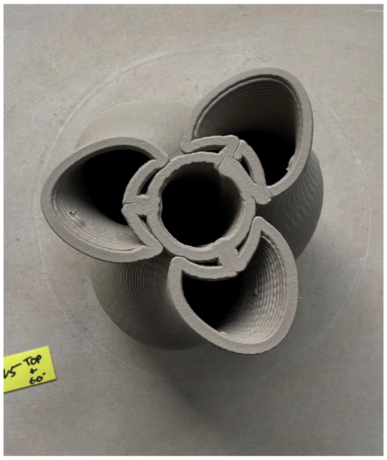

Printing vessels with curved base test 4 (elevation).


Printing vessels with curved base test 5 (plan).


Printing vessels with curved base test 5 (elevation).

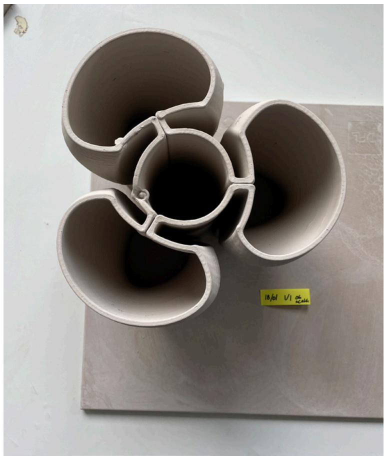

Printing vessels with curved base test 5 (elevation).


Printing vessels with curved base test 6 (plan).

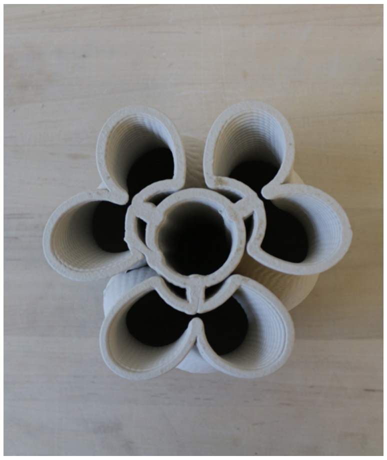

Printing vessels with curved base test 6 (plan).


Printing vessels with curved base test 6 (elevation).


Printing vessels with curved base at 1:1 (plan).


Printing vessels with curved base at 1:1 (plan).


Printing vessels with curved base at 1:1 (elevation).



Six vessels around circular channel test.

Final form (test 6) with structural loops (plan).

Final form (test 6) with structural loops (elevation).

Stippled texture test 1 (plan).

Stippled texture test 1 (elevation).

Stippled texture test 2 (plan).

Stippled texture test 2 (elevation).

Fluted texture test 3 (plan).

Stippled texture test 3 (elevation).

Light shade tests.

Angle test for cone shape.

Isocurve test 1 (plan).

Isocurve test 1 (elevation).

Isocurve test 2 (plan).

Isocurve test 2 (elevation).

Isocurve test 2 (perspective).

Isocurve test 3 (plan).

Isocurve test 2 (elevation).

Isocurve test 4 (plan).

Isocurve test 4 (elevation).

Isocurve test 5 (exterior shade, plan).

Isocurve test 5 (exterior shade, elevation).

Isocurve test 6 (interior shade, plan).

Isocurve test 6 (interior shade, elevation).

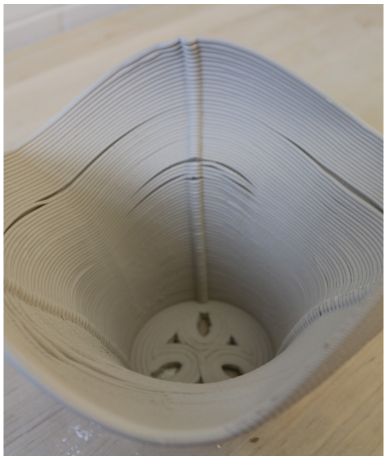
Nesting shades test.

Isocurve test 7 at 1:1 experiencing distortion.

Isocurve test 7 at 1:1 experiencing collapse.

Isocurve test 8 at 1:1 experiencing collapse.


Isocurve test 8 with three ribs experiencing cracking (plan).


Isocurve test 8 with three ribs experiencing cracking (perspective).


Isocurve test 9 with six ribs remains intact (plan).


Woven texture test 1 (plan).


Woven texture test 1 (elevation).


Woven texture test 2 (elevation).


Woven texture test 3 seperating at seam condition (elevation).


Woven texture test 4 experiencing collapse (plan).


Cracking at structural base of the light shade (plan).

Appendix B - Glaze Tests

White Opal.

Wingergreen.

SW 194.

SW 197.

SW 196.

Oyster.

SW 198 over SW 195.

SW 190 over SW 195.

Cobaltic Sea.


SW 195.


SW 193.


SW 191 over SW 193.


SW 511.


SW 192.


SW 198.


SW 190.


SW 191.


SW 512 over SW 193.