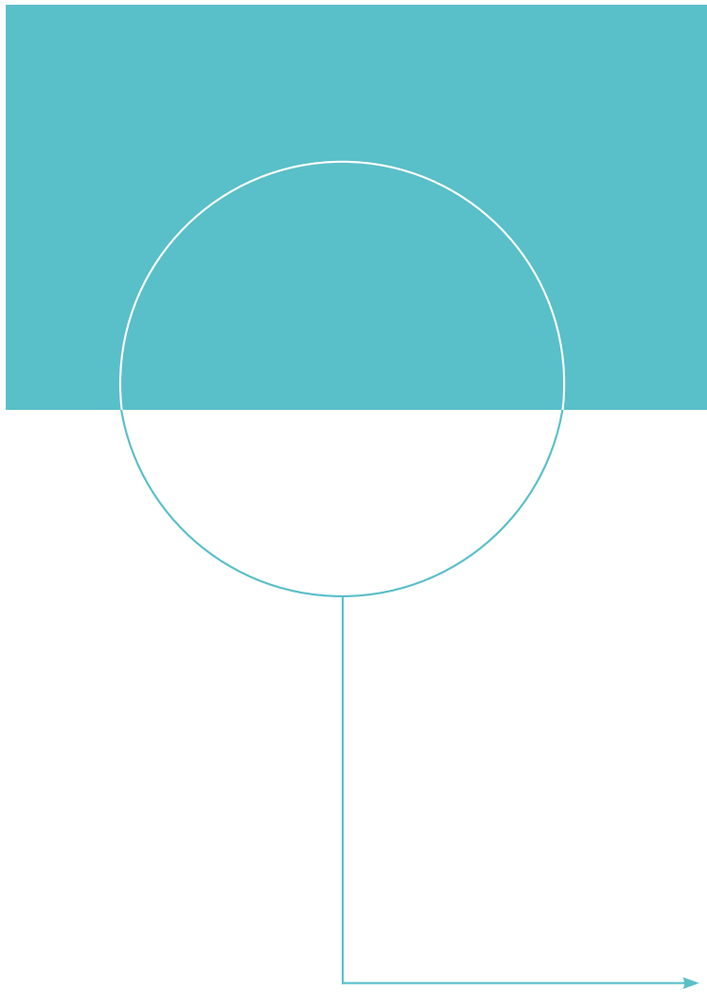


Master's thesis

2023

Nimesh Ranjan Dangol

NTNU
Norwegian University of
Science and Technology
Faculty of Architecture and Design
Department of Design

Nimesh Ranjan Dangol

Design of Interior Vertical Green Wall

May 2023

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of
Science and Technology

NTNU

Norwegian University of
Science and Technology

Design of Interior Vertical Green Wall

Nimesh Ranjan Dangol

Masters in Industrial Design
Submission date: May 2023
Supervisor: Prof. Andre Liem
Co-supervisor: Martin Hogh Olsen

Norwegian University of Science and Technology
Department of Design

Abstrakt

Innendørs vertikale plantevegger har blitt populære og er en voksende trend med estetisk appell som gir flere fysiske og psykiske helsemessige fordeler. Imidlertid er konvensjonelle vertikale plantevegger vanligvis i storskala og uegnet for personlig bruk eller boligbruk. Denne oppgaven tar sikte på å fange essensen av større vertikale plantevegger for å designe en personlig vertikal plantevegg i liten skala. I tillegg har dette prosjektet som mål å skape et rimelig og brukervennlig produkt som sømløst kan integreres med forskjellige interiører. Dataene for dette prosjektet ble samlet inn fra litteraturstudier, observasjoner og workshops. Prosjektet er i storgrad avhengig av en iterativ tilnærming, som involverer skisser, modellering og prototyping, hvor hver iterasjon påvirkes av prototypetesting og brukertilbakemeldinger. Sluttresultatet er en personlig vertikal plantevegg som er enkel å vedlikeholde og som tilbyr et visst nivå av interaksjon med brukerne, og fremmer et sterkt bruker-produkt-forhold

Søkeord: Vertikal grønn vegg, Piksler, innendørs planter, vanningssystem for planter, fordelene med innendørs planter

Abstract

Indoor vertical green walls have gained popularity as a growing trend, offering both aesthetic appeal and numerous physical and mental health benefits. However, conventional vertical green walls are typically large-scale and unsuitable for personal or residential use. This thesis aims to capture the essense of larger vertical greenwall to design a small scale personal vertical green wall. Additionally, this project aims to create an affordable and user-friendly product that seamlessly integrates with different interiors. The data for this project was collected through literature reviews, observations and workshops. The project heavily relies on an iterative approach, involving sketching, modeling, and prototyping, with each iteration being influenced by prototype testing and user feedback. The final result is a personal vertical green wall that is easy to maintain and offers a certain level of interaction with users, fostering a strong user-product relationship.

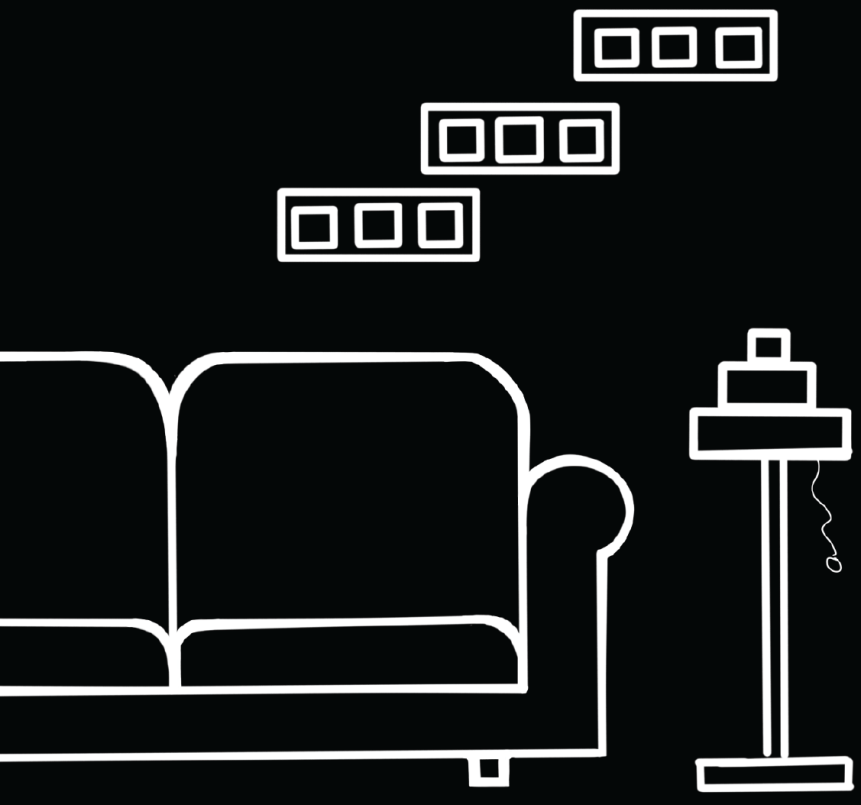
Keywords: Vertical green wall, Pixels, indoor plants, watering system for plants, benefits of indoor plants

Table of content

“A beautiful plant is like having
A friend around the house”

- Beth Ditto

1. Introduction



1.1 Student introduction

Nimesh Ranjan Dangol
B.Sc Civil Engineering
M.Sc Industrial Design Engineering

My name is Nimesh Ranjan Dangol, and I am a student from Nepal currently pursuing a 2-year Master's degree in Industrial Design. Despite having a Bachelor's degree in Civil Engineering from Pokhara University in Nepal, I have always been captivated by the world of design and creating products. Even during my engineering studies, I found building things to be the most interesting aspect of civil engineering. I loved creating things using available resources, which would have otherwise been expensive to purchase. Art, craft, and sketching were my passions, and they eventually led me to transition from engineering to design.

1.2 Acknowledgement

I would like to express my gratitude to Prof. Andre Liem, who had guide me throughout the whole process with constant mentoring and motivational support. His constant supervision of the thesis helped change aspects of the thesis, which would otherwise have been ordinary at best. I would also like to thank him for his patience since my approach to the thesis was not typical for a design student.

I am sincerely grateful greenfall for collaborating with me on this project especially Carlos and Francesco who were always ready to help throughout the design process providing me with valuable insights, facility to conduct meetings and workshop as well as reassurance on the direction the project was heading towards.

I would also like to thank my classmates who knowingly or unknowingly provided me with different ideas for the thesis.

Finally, I wish to acknowledge the Norwegian University of Science and Technology for providing me with a master's scholarship in design, without which this work could have never begun.

1.3 Master's Proposal

NTNU
Fakultet for arkitektur og design
Institutt for design

Master thesis for student Nimesh Ranjan Dangol

Design of Interior Vertical Green Wall

This project aims to explore how nature (plants) can be introduced as interior objects through the intervention of vertical structures within typical interior spaces

Background and Purpose of assignment

Typically, in a country with long winters and little sunshine, such as Norway, plants have proven to uplift people´s mood and cheer them up when suffering from anxiety and depression. For many years people have adopted small forms of greenery in their living spaces to brighten their environment. As maintaining gardens in apartments is impractical, confined "Vertical Green Walls" can provide people with the experience of having their own natural green intervention, which can nicely function as an interior object to be integrated in a working space, living room, kitchen or any other place within a home. "Vertical Green Walls" builds upon a shelving principle (small or large) that confines plants in small pods. The structure comprises of an irrigation system that circulates water through the plants. The purpose of "Green Walls" is to brighten up a space alongside with creating a healthy inner climate.

The main design challenge is to create a "Vertical Green Wall" that is easily to assemble, use and maintain, as well as aesthetically blend in well with the interior of typical spaces. The system should also look good as a decorative item with or without plants. Moreover, modularity is to be included as another key feature of the system. Making smaller modules which provides the option to increase or decrease the size of the vertical green wall is also a key part of the project, which distinguishes the system from those of other competitors. The system should have the option to be hung on a ceiling as well as be able to stand on itself.

Methods/Process:

This project will be conducted in a constructive and designerly way, which means that conjecture precedes analysis. Iterations of ideation, conceptualisation, prototyping and testing are the main activities. Moreover, the designer will adopt a reflective approach in assessing and selecting materials for the «Green Wall», focused on developing an optimal sustainable system. New knowledge and insights are expected to be gained through an explorative and iterative process of «Trail and Error» complemented with desk research.

A more structured design approach will be adopted in the detailing and materialisation stages. During these stages 3-D modelling and prototyping will be more precise to communicate and assess the market viability of the system.

Oppgaven utføres etter "Retningslinjer for masteroppgaver i Industriell design".

Hovedveileder: Andre Liem

Bi-veileder: Martin Høgh Olsen

Bedriftskontakt: Francesco Cantoro - *Greenfall: green walls made easy*

Tel no. +393206729516

Email: franceso@greenfallstore.com

Utleveringsdato: 9. januar 2023 Innleveringsfrist: 29. mai 2023

NTNU, Trondheim, (12 january, 2023)

(signatur)

Andre liem
Hovedveileder

(signatur)

Sara Brinch
Instituttleder

1.4 Project Brief

This project was a collaboration with Greenfall, a startup, aimed at creating a product that brings the idea of a vertical green wall to smaller spaces. The focus was on developing a picture frame with plants that can also be used in larger-scale vertical green walls. The product was targeted towards a specific audience who could use it in smaller spaces. Initially, the idea was to create a module that can hold plants and be hung like a picture frame. The project had since evolved into different ideas. The project started on January 10, 2023, with the first meet-ing with the company, and the deadline is May 31st, 2023.

Indoor vertical green walls are becoming a popular trend because they not only enhance the aesthetic appeal of the surroundings but also provide health benefits. However, indoor vertical green walls usually have larger dimensions that can cover a significant portion of the wall, making them blend in with the wall itself. The aim of this project to use the same principle but on a smaller scale, where the product will act as a live picture frame, with the focus on the plants reaching out of the frame.

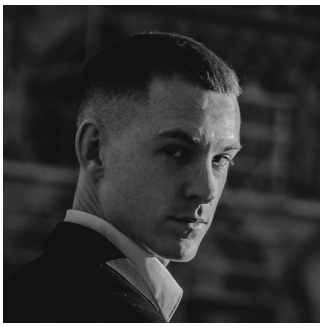
Design criterias

1. The product must be easy to use with minimum maintenance.
2. The users should have some degree of freedom in customizability.
3. The product should be capable of being used on a desk or hung on a wall.
4. Plants should be swappable and capable of being fitted in different orientation.
5. The product should be affordable.
6. The product should not contain pumps for watering system unless it is compatible with large scale vertical greenwalls
7. The product should have some degree of user interaction to form a bond between the user and the product.

1.5 Introduction to Greenfall

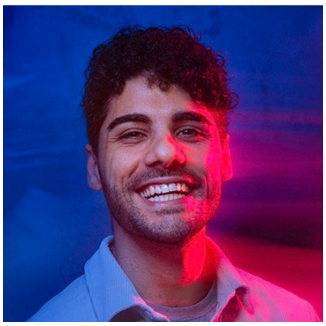
Greenfall is a startup company based in trondheim, Norway who are trying new innovative approaches to vertical green gardens. Greenfall is a team of design and nature enthusiasts who truely believe in the role nature plays in the mental and physical stability of people. They are focused on creating innovative design solutions that seamlessly integrate the beauty and benefits of the outdoors in to the indoor spaces for a healthier lifestyle. They are currenly in collaboration with NTNU and faktry to initiate their ideas into products.

Members



Carlos Quiles

CEO, Co-founder
Carlos@thegreenfall.com



Francesco Cantoro

Chairman of board, Co-founder
Francesco@thegreenfall.com

Edain Ramirez

Operation and chain supply manager

Presently, the company is located in a facility called “Faktry” where the dedicated team is actively engaged in prototyping the product. Additionally, the company has a greenhouse situated in the basement where various plants are cultivated. As part of their innovation process, the company is exploring the use of rockwool as an alternative to traditional plant soil. This substitution is aimed at addressing concerns regarding weight while capitalizing on the absorption capabilities of rockwool.

As a relatively small enterprise, the company is actively seeking investors and collaborators to facilitate the successful launch of their product. In order to expand their market presence, they are currently focused on developing pilot products that serve as a stepping stone towards achieving their objectives.

1.6 Stakeholder's map

A stakeholder map serves as a visual depiction of various individuals, groups, or organizations that hold a vested interest in a particular initiative, project, or business. These stakeholders can be directly or indirectly affected by the product and may have a direct or indirect influence on it. This step is particularly crucial for several reasons, including the identification of target users for the product. By creating a stakeholder map, designers can effectively capture the diverse needs of consumers that the product should address. In light of these considerations, two distinct stakeholder maps were developed.

The first stakeholder map encompasses the key organizations associated with Greenfall and the project. At the core of this map lies Greenfall, and surrounding it are internal and external stakeholders who impact both the product and its operations. The internal stakeholders consist of NTNU, faktry, and Rotolia, all of which share a direct connection with the company from the initial stages. On the other hand, external stakeholders encompass individuals and organizations whose actions have an impact on the project.

Rotolia is a plastic-based manufacturing company located in Valencia, Spain, specializing in the production of plastic-based products. The company initially collaborated with Rotolia for the manufacturing of the first prototypes, making Rotolia a key stakeholder in the project. As a startup, Greenfall does not have a fully functional working space yet and is currently utilizing the office space provided by Faktry, a shared working space for startups that helps them establish their operations in the early stages. The provision of a suitable work environment is crucial for starting a business as it can significantly impact the direction and success of the company.

Investors, although not directly involved in the design and manufacturing processes of the product, play a vital role in its success or failure. Startups require funding to initiate their operations, and investors provide the necessary capital. Furthermore, obtaining approval from the state or municipality is essential for any company to start its business legally. Without the authorization from the municipality, a company cannot commence its operations, which ultimately affects the availability of the product in the long run. Additionally, the municipality plays a role in disseminating information to the local population, which can also impact the company's prospects.

Manufacturers form the foundation of any product's manufacturing process. They are responsible for producing all the necessary components that are required to create the final product. Since the entire product revolves around plants, plant providers are also considered external stakeholders. Plant providers supply the market with suitable plants, which directly affects the company's operations and product availability.

Lastly, the users of the product ultimately determine the future of the company. Although they may not be directly involved in the initial phases of product development, their importance becomes undeniable in the end. The entire manufacturing chain relies heavily on the demand for the product, which is driven by the users. If users appreciate and enjoy the product, it gains popularity, resulting in increased sales and positively impacting the company.

In conclusion, for Greenfall and its product, the involvement of stakeholders such as Rotolia, Faktry, investors, the municipality, manufacturers, plant providers, and users all play significant roles in shaping the success and trajectory of the company. Each stakeholder's contribution and impact, whether direct or indirect, are crucial in determining the company's future

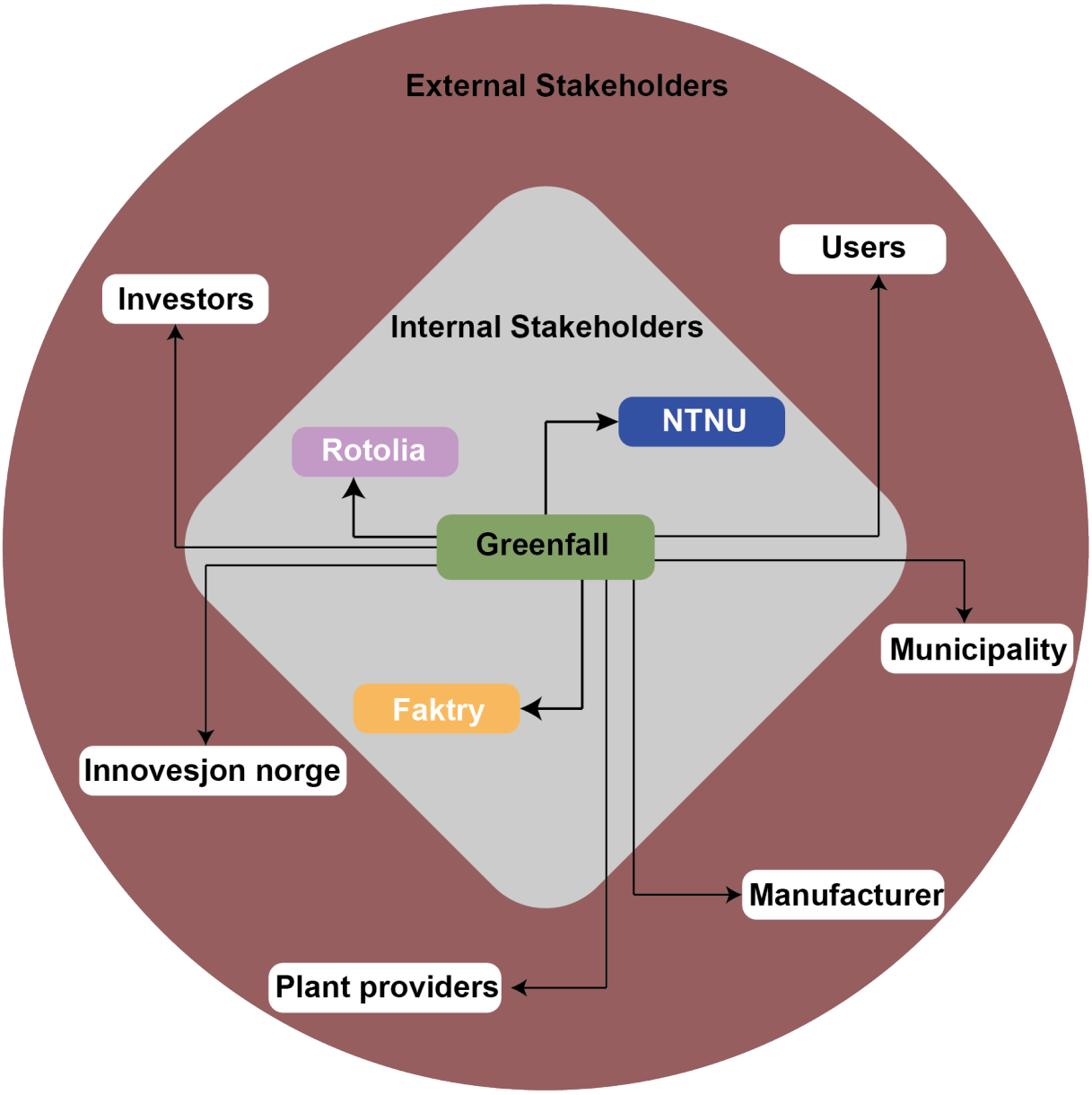


Figure 1. Stakeholder's map

The second stakeholder's map is primarily focused on the users of the product. It illustrates the various organizations that influence the user experience. This map played a significant role during the product development phase. Recognizing the importance of the target audience, it facilitated the exploration of features and requirements that would enhance the product. Moreover, it shed light on the realization that user experience is influenced by various factors beyond the product itself. For instance, aspects like maintenance, availability of spare parts, and ongoing support greatly impact the overall user experience.

The stakeholder's map also highlighted the significance of understanding the market and competitors in product development. It emphasized that consumer choices are ultimately the determining factor, as they have a wide range of options to choose from. By comprehending the strategies and attractions of competitors, the stakeholder map assisted in developing a more desirable product. This understanding enabled the company to align their offerings with consumer preferences and create a product that stands out in the market.

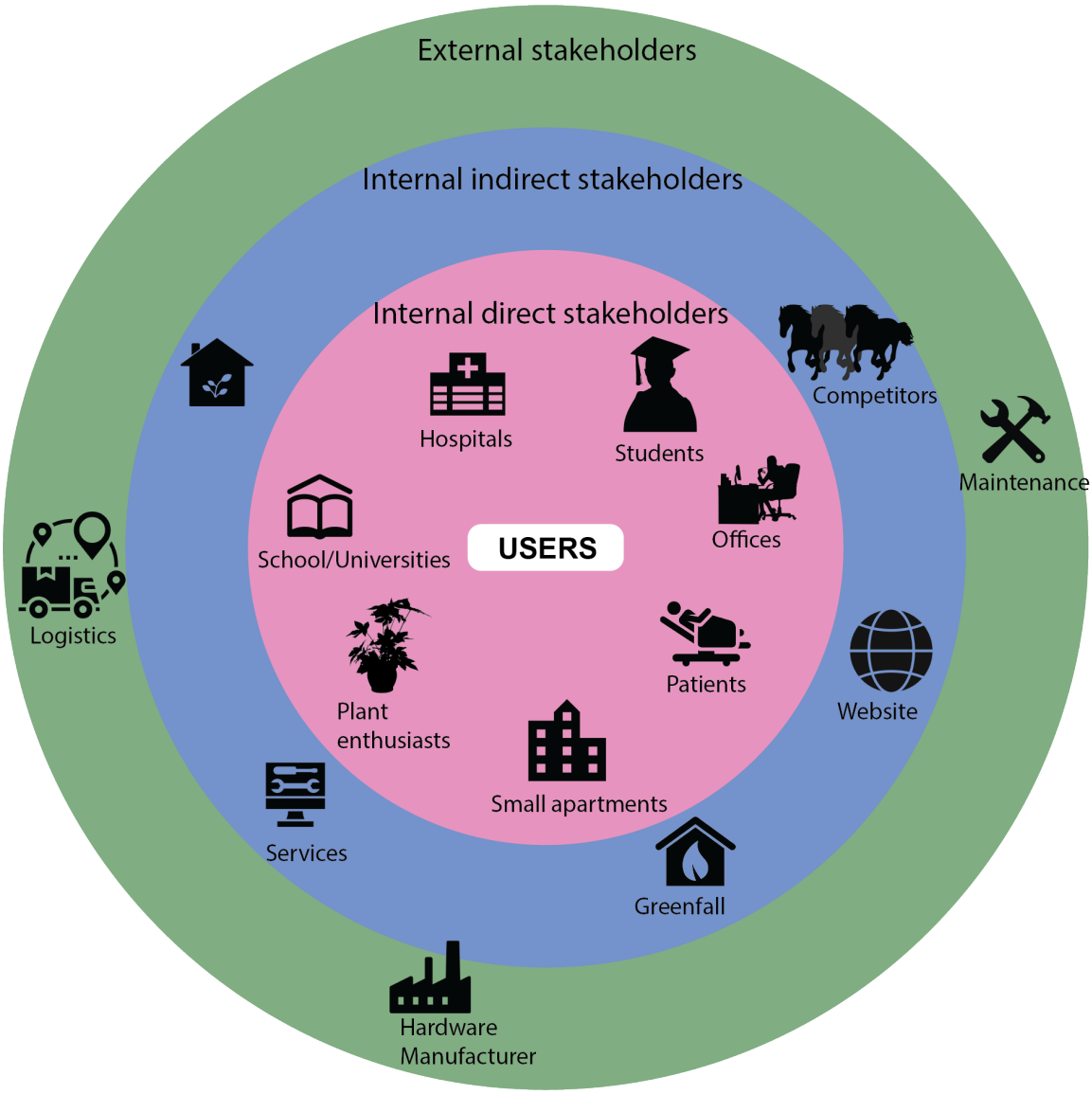
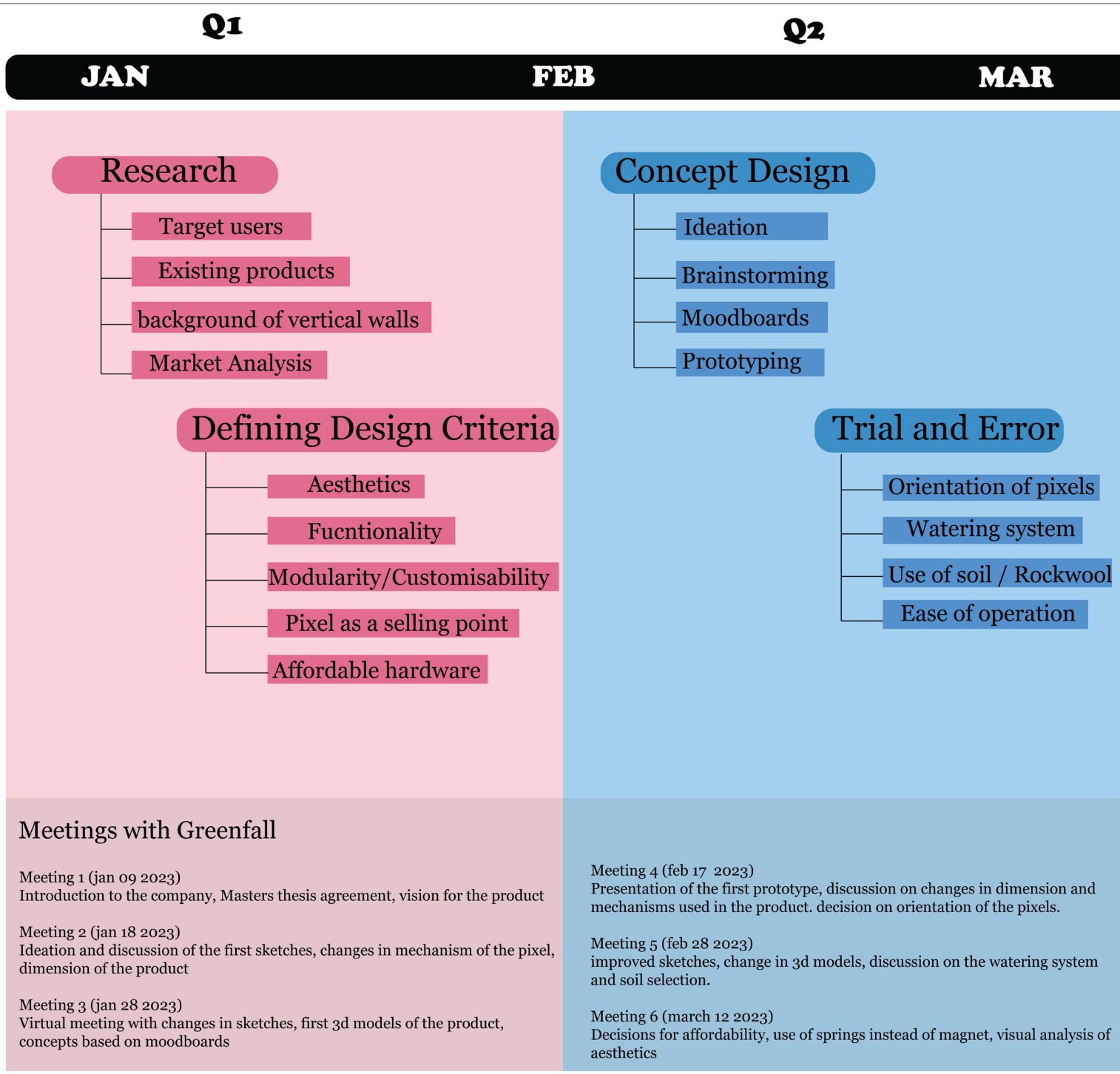


Figure 2. User centric Stakeholder's map

1.7 Tracking of progression



Research/ Concept and Design

Q3 APR

Q4 MAY

Material protyping and testing

- 3D rendering and prototyping
- Prototyping with different materials
- Testing mechanisms
- Testing watering system

Compilation of Results

- Analysis of gathered data
- Final prototype
- Preperation of report
- Preperation of the presentation

Meeting 7 (Apr 22 2023)
Discussion about sustainibility and possible collaboration with Rotolia

Meeting 8 (May 3 2023)
Discussion about the results of the testing and final prototype presentation

Validation and testing

Compilation

1.8 Target users

The viability of any product relies on its ability to cater to a specific group of individuals who find the product most appealing. The stakeholder map plays a crucial role in identifying the target users for the product. In the case of the pixel, which serves the purpose of interior decoration, the target users encompass anyone seeking to enhance the environment in their homes or workplaces. The concept of an interior vertical garden or wall has gained significant popularity due to its ability to seamlessly combine aesthetics and functionality within its design.
Within this project, the primary target users were individuals who owned small apartments with limited space or office spaces where the product couldn't easily blend in with the surroundings. Each target group was represented by a persona that effectively captured their unique needs and challenges. By developing personas, I gained a deeper understanding of the target users' requirements and problems, enabling them to design a product that specifically addresses those needs.

Small apartment owners

Many plant enthusiasts desire to incorporate plants into their interior design in a subtle yet noticeable manner. However, large plants that take up a significant amount of space can dissuade homeowners from the idea. Pixels, on the other hand, are small and take up unused wall space, freeing up floor space for essential items. They can be discreetly hung on the wall, giving the room the feeling of having plants without taking up precious space. Additionally, the product requires minimal maintenance, making it an ideal choice for individuals who are hesitant about owning plants but are open to experimenting with greenery as part of their decor. This could potentially spark the user's interest in growing more plants, which is always beneficial for the environment.

Office spaces

Many workplaces have a corporate aesthetic that can make employees feel disconnected from nature. Introducing plants into the workspace can boost morale and increase productivity. Additionally, incorporating plants into the decor can add a touch of elegance and help alleviate stress, which is particularly important in a work environment. Pixels offer the added convenience of a stand, allowing them to be placed on a desk for added diversity. A single system can be easily set up on a desk and requires minimal maintenance, with watering every other week being sufficient to keep the plants alive while still allowing workers to focus on their tasks.

Hospitals/Schools

Plants have been proven to have a positive impact on both physical and mental health. Research has shown that including plants in your environment can increase productivity and improve mental well-being. Hospitals often use plants to create a more positive atmosphere, which can be particularly beneficial for patients who are in the recovery phase. There have even been experiments with plants and paintings in patient rooms, which have resulted in shorter recovery times and a more calming environment. Similarly, having plants in the classroom can help reduce stress levels among students. As children are in the midst of their developmental phase, a positive environment can boost their academic performance.

PERSONA 1

Name: Tyler Lin

Tyler is an industrial design gardaute who works at a consultancy. He spends most of his time in the office including overtimes.

User: Office worker

Tyler is stuck at his work most of the time looking at his computer screen all day. He likes having plants on his work desk to take his mind off of work and create an illusion of the outdoors that he misses. The plants in his office die when he is on vacation since there is no one to take care of it when he is not there. He wants an easier solution to maintaining the plants while he is away.

PERSONA 2

Name: Helene Giske

Helene is a full time student at NTNU persuing a masters in electrical engineering. She like going on hikes when the weather is nice but mostly stuck at the university studying and completing her assignments

User: student

Helene spends most of her time in the university which she feels can be depressing and demoralising at times. She likes watching trees and plants from the window to get a boost in her productivity. Her classroom doesnt have any plants and she wishes there were some since she likes the outdoors so much. She feels that her classroom has a dull vibe which affects her motivation often resulting in her staring into space.

PERSONA 3

Name: Bryan Colby

Bryan is a student who rents an apartment in trondheim. He has a relatively small aparment which is barely enough for his furnitures. He works part time and spends most of his time either working or studying in his room.

User: Small apartment owner

Norway is a cold country with winters spent in darkness. Since bryan doesnt have a lot of spare time to go about in nature, he likes having small plants around in his apatment. He says that having plants around makes him more productive and gives character to his small apartment. He would like to have more plants but most plants take up space in his tiny apartment ehich could be used for other household items.

PERSONA 4

Name: Gisela Hansen

Gisela is a nurse at St. Olav Hospital in Trondhiem. Her shifts alternates between day and night shifts. She likes spending time indoors reading and painting but likes having plants around in her surrounding.

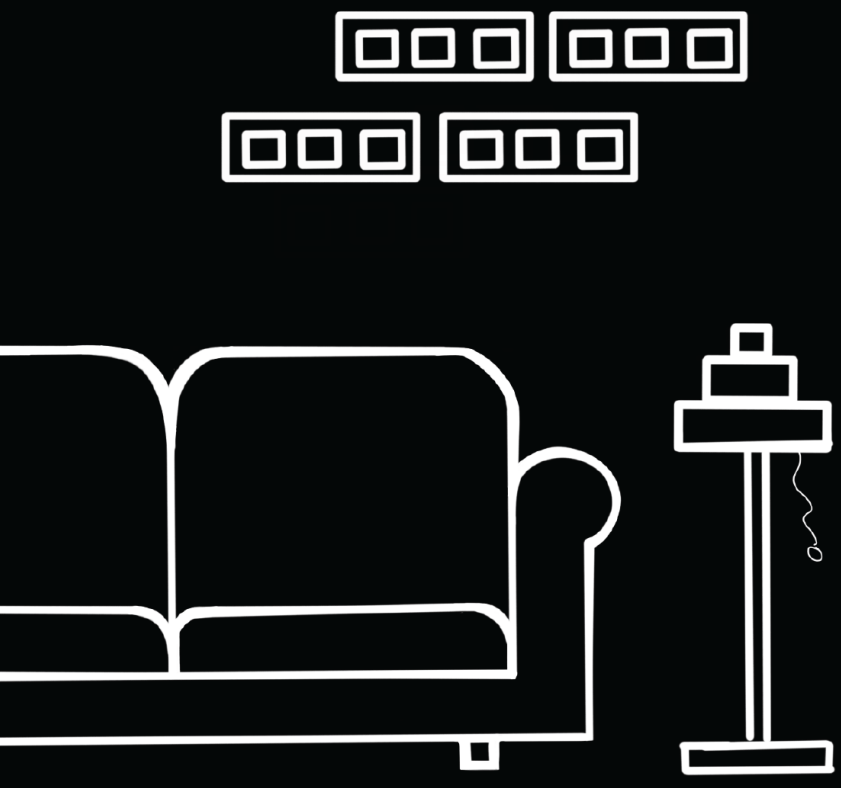
User: Nurse (hospital)

Gisela is constantly surounded by people who are either sick or injured. She says that the environment in the hospital is gloomy and depressing most of the times. She finds the additioin of plants in hallways and some patients room can lift he mood and help create a lighter vibe. She also mentions that patients who are recovering from illness or surgeries react positively to the plants present in the room making the process of recovery faster.

1.9 Problem statement

The existing vertical garden available in the market are designed for large scale applications and are often unsuitable and economically unviable for small spaces or residential use.

2. Methodology



2.1 Literature review

2.1.1 Research on plants and soil types

Each plant has its own set of unique requirements for optimal growth. Factors such as sunlight, water, humidity, ventilation, nutrition, and soil pH all play crucial roles in determining the overall health of a plant. This was demonstrated through an experiment conducted by Boddie V. Pennisi (2009), where these factors were manipulated as variables to observe the growth patterns of various plants. The research findings indicated that most indoor plants originate from tropical and subtropical regions, making temperatures between 58°F and 86°F (14°C to 30°C) ideal for their growth. Additionally, it was stated that indoor plants thrive best in humidity levels ranging from 40% to 50%, while levels below 20% are considered too low.

While most scientific studies on soil types and plant health focus on agricultural plants with distinct requirements, there have been numerous articles published by specialists that contribute to our understanding of the diverse soils used for indoor potted plants. Mohd Mahathir Suhaimi (2017) categorized indoor plants into various groups, including foliage plants, flowering plants, cacti, orchids, and ferns, each with their specific soil requirements. Soils play a vital role in the growth of plants, whether they are cultivated indoors or outdoors, as they provide essential aeration and proper nutrient absorption. H. F. Bergmen conducted an experiment to highlight the importance of adequate air circulation within the soil. The effects of proper air circulation were observed through the leaves, where plants deprived of oxygen exhibited wilting leaves, stunted growth, and changes in the color of newly developing leaves. Similar tests conducted by Yuan Li (2019) focused on soil aeration but with crops instead of indoor plants, yielding comparable results.

According to Boddie V. Pennisi (2009), the best soil mixture for indoor flowering plants comprises a blend of garden loam (potting soil), sand or vermiculite, and peat moss, in equal ratios of 1:1:1. Another common issue observed in indoor plant soil, as well as soils in general, is the development of diseases and molds. R.C. Lambe (1980), suggested that sterilizing the soil through stem pasteurization or chemical fumigation can help prevent such problems.

In 1978, McConnell D.B listed several common indoor plants used in households, along with their specific cultural requirements. The following examples from the list illustrate how different plants have varying needs for proper growth

L = Light
1. Sunny light areas: At least 4 hours of direct sun
2. High-light areas: Over 200 ft-c, but not direct sun
3. Medium-light areas: 75 ft-c to 200 ft-c
4. Low-light areas: 25 ft-c to 75 ft-c

T = Temperature
1. Cool: 50°F night, 65°F day temperatures
2. Average: 65°F night, 75°F day temperatures
3. Warm: 70°F night, 85°F day temperatures

H = Relative Humidity
1. High: 50% or higher
2. Average: 25% to 49%
3. Low: 5% to 24%

W = Watering
1. Keep soil mix moist
2. Surface of soil mix should dry before re-watering
3. Soil mix can become moderately dry before re-watering

S = Suggested Soil Mix
For specific ingredients, refer to the various growing mixes in "Soil/Growing Medium." The soil mixes are keyed as follows:
1. Flowering house plants
2. Foliage plants
3. Bromeliads
4. Orchids
5. Succulents and cacti
6. Ferns
7. African violets and other Gesneriads

Botanical Name	Common Name	Cultural Care				
		L	T	H	W	S
Abutilon hybridum	Flowering Maple	1	1	2	2	1
Acalypha hispida	Chenile Plant	1	2	2	2	1
Achimenes hybrids	Magic Flower	2	2	2	1	7
Acorus calamus	Sweet Flag	2-3	2	2	1	2
Acorus gramineus	Miniature Sweet Flag	2-3	2	2	1	2
Adiantum raddianum	Maidenhair Fern	2-3	2	1	1	6
Adromischus cristatus	Crinkle-Leaf Plant	2-3	2	2	2	5
Adromischus festivus	Plover Eggs	2-3	2	2	2	5
Aechmea fasciata	Silver Vase	2-3	2	2	2	3
Aechmea miniata 'Discolor'	Purplish Coral Berry	2-3	2	2	2	3
Aechmea 'Royal Wine'	Royal Wine Bromeliad	2-3	2	2	1	3
Aeschynanthus marmoratus	Zebra Basket Vine	2	2	2	1	7
Aeschynanthus pulcher	Lipstick Vine	2	2	2	1	7
Agave Americana 'Marginata'	Variegated Century Plant	1	2	3	3	5

Table 1. Indoor plants and their cultural requirements
(adopted from McConnell D.B, 1978)

2.1.2 Positive impact of indoor plants

Plants offer numerous benefits, one of which is their ability to improve the air quality in their surroundings. By reducing the CO2 content in the air, plants contribute to cleaning the air, ultimately benefiting human health. Many countries have recognized the importance of indoor plants for enhancing human well-being and productivity (Mohd Mahathir Suhaimi, 2017). Including plants in indoor spaces not only has physical advantages but also boosts people's mental morale. Studies have shown that plants can aid in the recovery time of post-surgery patients. Medical procedures can cause physical pain, discomfort, and fear, which in turn prolongs the recovery process (S.H. Park,2008). Some post-operation symptoms and pain can be severe, leading to increased dependence on drugs for relief. However, plants have shown to provide slow yet helpful results without any side effects. A study conducted by (Chang and Chen ,2005) and (Coleman and Mattson,1995) demonstrated that plants in recovery rooms can serve as positive distractions, blocking worrisome thoughts and aiding in the recovery process. The presence of plants induces a quick feeling of relaxation in people (Ulrich and Simons, 1986). An experiment involving patients with the same illness showed that those with plants in their rooms had significantly lower intake of analgesics. This idea was supported by K. Dijkstra's study on the effects of plants in reducing stress. People in natural environments not only showed faster recovery from physical stress but also improvement in psychological health (Kaplan, 2001).

Similarly, plants have a positive impact in the work environment as well. This impact includes reducing psychological stress responses, enhancing task performance, improving emotional state, and positively influencing room assessment (Adachi et al., 2000; Larsen et al., 1998; Shibata and Suzuki, 2001). A study by Tina Bringslimark demonstrated how plants are psychologically beneficial for promoting restoration in offices, based on factors such as sick leave taken and productivity in the workspace. Previous experimental studies suggest that the effects of plants seem to be more pronounced in people experiencing high levels of stress (Kim and Mattson, 2002). This was supported by (Shoemaker et al., 1992), which suggests that the impact of plants on office workers is directly proportional to their need for restoration. A survey conducted in Japan by (Masahiro Toyoda,2020), measuring participants' pulse rates, showed a decrease in the pulse rate of those who had plants on their work desks, indicating a calm state of mind compared to workers without plants. Studies have also investigated the influence of different sizes and volumes of greenery (Nishina, 2008) and the number of plants present (Imanishi et al., 2002). Indoor plants have also been shown to increase people's attention capacity. According to Attention Restoration Theory, being in contact with vegetation, having views of natural elements through windows, and having indoor plants may contribute to attention restoration (Kaplan, 1993). Similarly, the psychological benefits of indoor plants have been studied in the context of classrooms also showing indoor plants can be used as replacement for architechtural elements in the room such as windoes ww(Doxey, Waliczek, & Zajicek, 2009; Han, 2009).

2.1.3 Background on vertical green wall

A vertical garden is a structure consisting of panels of plants that are either hung on a wall or stood upright with the help of a support system. Hydroponics is a commonly used technique for growing plants in vertical gardens, as it involves using mineral-based nutri-ent solutions instead of soil. The popularity of vertical green gardens has grown in recent years due to their health benefits and aesthetic appeal.The concept of indoor vertical gar-dens originally arose due to the increase in urbanization, which resulted in a loss of agricultural land. In response, indoor vertical gardens were developed as an alternative way to grow crops within closed spaces. However, they have since evolved into an aesthetic element of home décor, with various methods of incorporating plants into interior design, such as live pictures, living walls, preserved moss walls, green roofs, and green screening. These methods have become so popular that people have even begun to use artificial plants to maintain the aesthetic of their rooms.

Indoor vertical walls have more than just aesthetic benefits. Large-scale vertical green walls can be used as temporary partitions in modern houses, as they provide separation between spaces and offer thermal and acoustic advantages. In some metropolitan areas with sub-tropical climates, green walls are used for thermal insulation in high-rise buildings, as they help to reduce the heat transfer from the interior of the building.

2.2 Workshop with Greenfall

A workshop was organized with the team members of Greenfall to gain a deeper understanding of the design requirements for the personal vertical wall. While I had a specific idea in mind as a designer, I recognized the significance of incorporating outside perspectives, particularly from the users, to ensure the product's success. Given that some Greenfall members had experience with traditional vertical walls and shared a similar vision for the product's functionality, they were involved as participants in the workshop.

The workshop was designed to foster an open and unrestricted environment, encouraging participants to think creatively and generate innovative ideas. Four participants took part in the workshop, each provided with the same set of questions to address. Their answers were collected and analyzed to identify the most common ideas and subsequently build upon them.

The workshop consisted of four distinct categories, and participants were individually engaged to minimize the possibility of ideas being influenced or shared among them. This approach aimed to capture diverse perspectives and ensure a comprehensive exploration of the design aspects

question "What comes to mind when you hear the term personal vertical wall"?

Question "What problems do you have with regular form of potted plants? "

question " What are the features that you would like to have in your own personal vertical wall"?

Question "Where would you like to have your personal vertical wall?"

Step 1: consisted of the participants answering these 4 questions and jotting them down on post it notes. All answers were acceptable regardless of how far-fetched they seemed.

Step 2: After the answers were written down, they were collected and then scanned through to see if there were any overlapping ideas. The answers which were repeated were kept together and individual unique ideas were kept separate.

Step 3: The ideas were separated into categories. For e.g. If the participants answered needed to water the plant constantly, or not being able to water the plants if they are out for a week, the second question, this would be under the category of watering system.

Step 4: After all the ideas were categorized, the ideas were revealed to the participants to then discuss amongst themselves and find the top 3 most desirable features for the product.

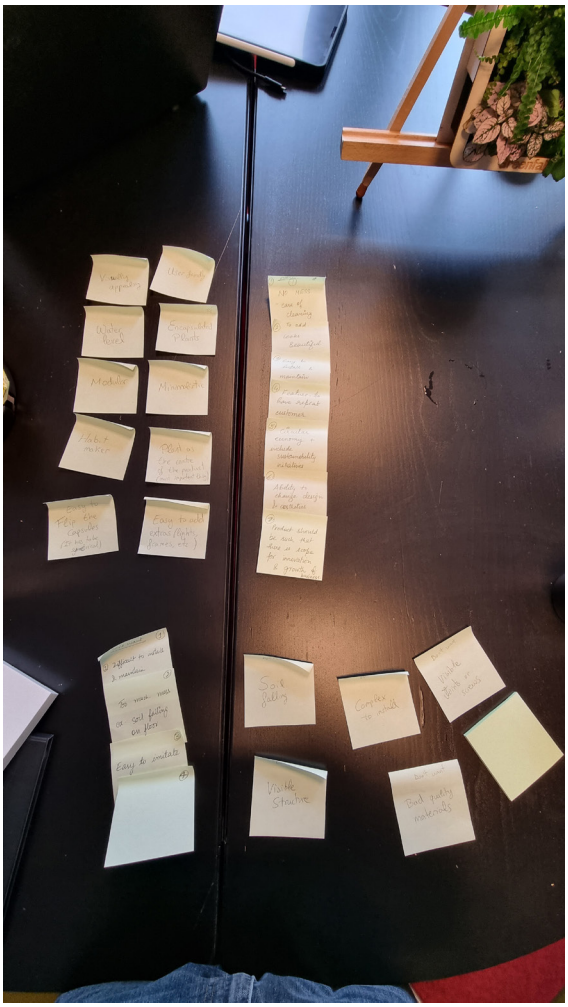


Figure 3

Figure 4

Figure 5

Figure 3, 4 & 5. Workshop with members of Greenfall

Answers to the Questions

"What comes to mind when you hear the term personal vertical wall"?

- plants that hang on the wall
- Wall mounted
- Wall full of plants
- Customizable canvas for plants
- Partition wall with plants
- Different plants together to form a pattern
- Dirt inside the room on the floor
- plants that hang on the wall
- Form of home decor
- Picture frame with plants

What problems do you have with regular form of potted plants? "

- Take up space
- Dirt everywhere and leakage of water
- Cant manage to keep them alive
- Need to be watered constantly
- Too big for my room
- Overgrown plants
- Die too fast
- More plants require more time for the plants
- no space to keep them
- Pots get messy when watered and there is formation of sludge
- Repotting creates a lot of mess
- More space for more plants

" What are the features that you would like to have in your own personal vertical wall"?

- Way of self watering
- Make patterns with plants
- plants that hang on the wall
- plants that hang on the wall
- plants that hang on the wall
- plants that hang on the wall
- plants that hang on the wall
- swappable plants without mess
- Dont have to worry about the plants everyday
- Indication that plants need water

Dont need to add additional nutrition

Have different plants together

Show water level

Different plants for different season

cheap and affordable

have plants that dont overgrow

Visually appealing

Modular and help in building habit

Be modular with other system

Water lasts longer

plants that hang on the wall

Easy to maintain and repair if needed

"Where would you like to have your personal vertical wall?"

desk

wall

living room wall

kitchen wall

by the lobby

These answers showed a similar pattern to the observation that was conducted. Through this categories were made which were then targeted as key points to approach the deadign. The response from the participants lined up close to the design criterias which were originally set before conducting the workshop. Although some ideas were added, the gist of the answers aligned with the findings from the observation and informal interviews.

From the workshop 5 main categories were formed

1. Aesthetics
2. Watering system
3. Cost efficient
4. User interaction
5. Interchanging facade

2.3 Observations

The process of analyzing how people incorporate plants into their daily lives began with observation. This approach provided valuable insights into why people desire plants in their surroundings and where they choose to place them. The initial observations focused mainly on small apartments to determine if the lack of space posed a challenge for incorporating plants. Subsequently, the observation locations expanded to include libraries, offices, classrooms, and St. Olav Hospital. Although the hospital visit was primarily intended to explore the incorporation of plants for patient recovery, greenery was observed in the waiting areas and reception. Informal interviews in the form of casual chats accompanied the observations. These conversations helped uncover the reasons why people enjoy having plants indoors and the challenges they encounter. It is important to note that all the observations were conducted in Trondheim, Norway, which may influence the findings due to cultural and climatic factors. The observations were conducted during daytime, except for the observations in student housing, which spanned multiple weeks.

The majority of the apartments visited were located in Steinan Student Housing, with some in Moholt Student Housing as well. This setting provided an excellent opportunity to observe how people incorporated plants into their small rooms. Surprisingly, many residents had a diverse range of plants in their rooms, including tall plants positioned in room corners. Most of these individuals were willing to sacrifice space, and in some cases, furniture, to accommodate plants. While they acknowledged the impracticality of such arrangements, their passion for having plants outweighed the inconvenience. Notably, small plants were commonly placed on study desks or near windows, with some students mentioning that having plants in their peripheral vision aided their concentration while studying or working. However, there were also instances where plants were inconveniently placed on the floor by the window. Interestingly, some students did not prioritize visibility and were content as long as the plants were present in the room. Artificial plants were also observed in some rooms, primarily used for decorative purposes. When asked about the absence of real plants, the students cited the perceived burden of plant care as the reason for their choice. This trend of desiring plants but struggling to maintain them was prevalent among many students.

Observations were also conducted in the NTNU library, a popular study location for students. When asked about the role of plants in their decision to study there, some students mentioned that plants create a soothing environment conducive to peaceful studying. However, when asked about having plants in their own homes, many students cited difficulties in caring for plants or limited space as barriers to incorporation. One student remarked that while they had a cactus in their room, larger plants or a greater number of plants would have a more significant effect on the overall ambiance.

Several offices, primarily within NTNU, were also visited during the initial stages of the project. In these office spaces, plants were used as part of the decor. Small plants placed on work desks were a common sight, and plants were frequently used in reception areas as well. The size and number of plants in offices were relatively smaller, as employees did not devote significant time to their care. One shared concern in office settings was the risk of plants dying during vacation periods. Workers also expressed that having a window with a view of nature contributed to a more relaxing and productive environment amidst the noise present in the workplace.


Eloise


MIX AND MATCH


FOREST BATH
NO.01

2.4 Competitor's overview

Several competitors were examined to identify similarities in the product and observe the approaches they used to overcome various challenges. Due to the fact that vertical green walls are predominantly utilized in larger spaces, only a few products with similar characteristics were discovered. The following list showcases some of the competitors along with their respective advantages and disadvantages. Analyzing the existing market offerings aided in comprehending the prevailing trends and simultaneously generated ideas for making the product distinctive

Company : NAAVA
Product : Naava one
Dimensions : height = 210 cm
width = 60 cm
depth = 30 cm
Plant capacity : 35 pcs

PROS

- Inbuit automated watering system
- App controlled system
- Addition of light for growth of plant
- A variety of plants can be used at once

CONS

- Expensive
- Requires large space
- Impractical to be used in residential houses

Figure 6. Naava one (n.d.)

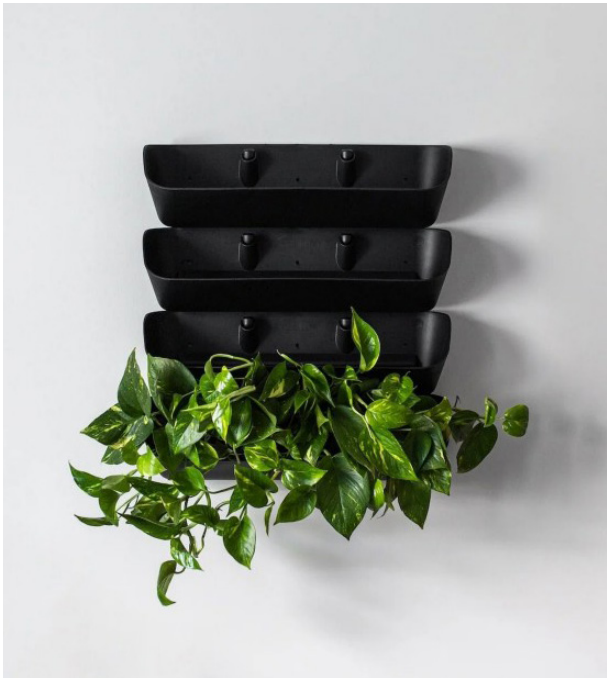


Figure 7 . Skogluft living wall kit (n.d.)

Company : Skogluft
Product : Skogluft living wall
Dimensions : height = 61.8 cm
width = 54.7 cm

Plant capacity : 16 pcs

PROS

- Simple design and assembly
- Modular plant shelves for arrangement
- compact and light weight

CONS

- Lack of a watering system
- Lacking aesthetic appeal
- Requires the plants to be planted manually

Figure 8. Live picture 2 (n.d.)

Company : Arti Garden and home
Product : Live picture 2
Dimensions : height = 112 cm
width = 72 cm
depth = 7 cm

Plant capacity : 18 pcs

PROS

- in built watering system
- indicator for water level
- Good build quality with zinc power coated steel frame
- quick and easy installation

CONS

- steel increases the weight of the product which is not ideal for hanging on the wall
- No option for modularity

Figure 9. Plantbox green wall (n.d.)

Company : Greentech
Product : Plantbox green wall
Dimensions : height = 60 cm
width = 20 cm
depth = 14.5 cm

Plant capacity : 6 pcs

PROS

- in built watering system with large reservoir
- indicator for water level
- different troughs that can be stacked to increase the size of the vertical wall

CONS

- requires more quantity of compost to fill the pallets
- can not be hun on the wall, takes up floor space
- requires a drip tray

2.5 Moodboards

Mood boards played a vital role as a visual aid during the sketching phase, offering inspiration and ideas. Three distinct mood boards were created, each showcasing distinctive standout features. The primary objective of these mood boards was to facilitate the aesthetic development of the product. They served as a reference point for exploring various design elements and refining the overall visual appeal.

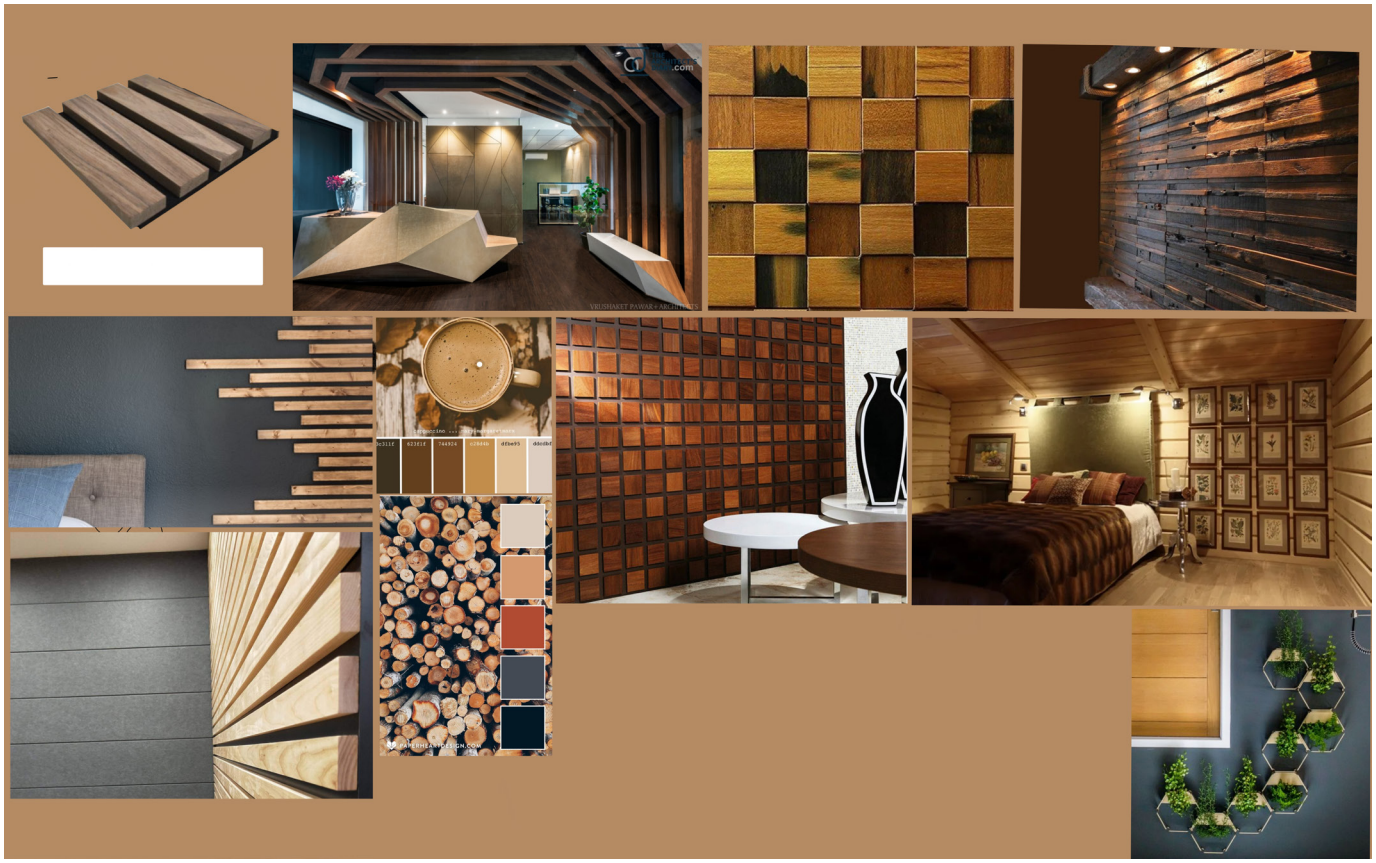


Figure 10. Moodboard 1

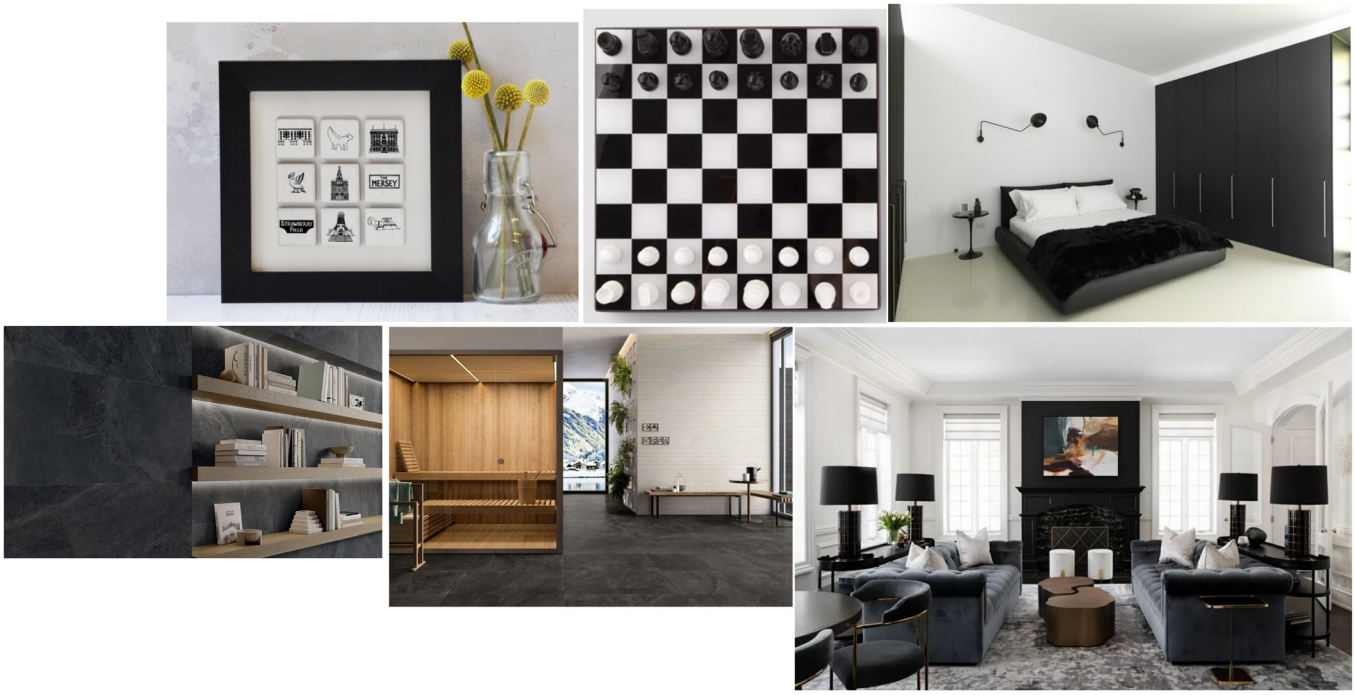


Figure 11. Moodboard 2

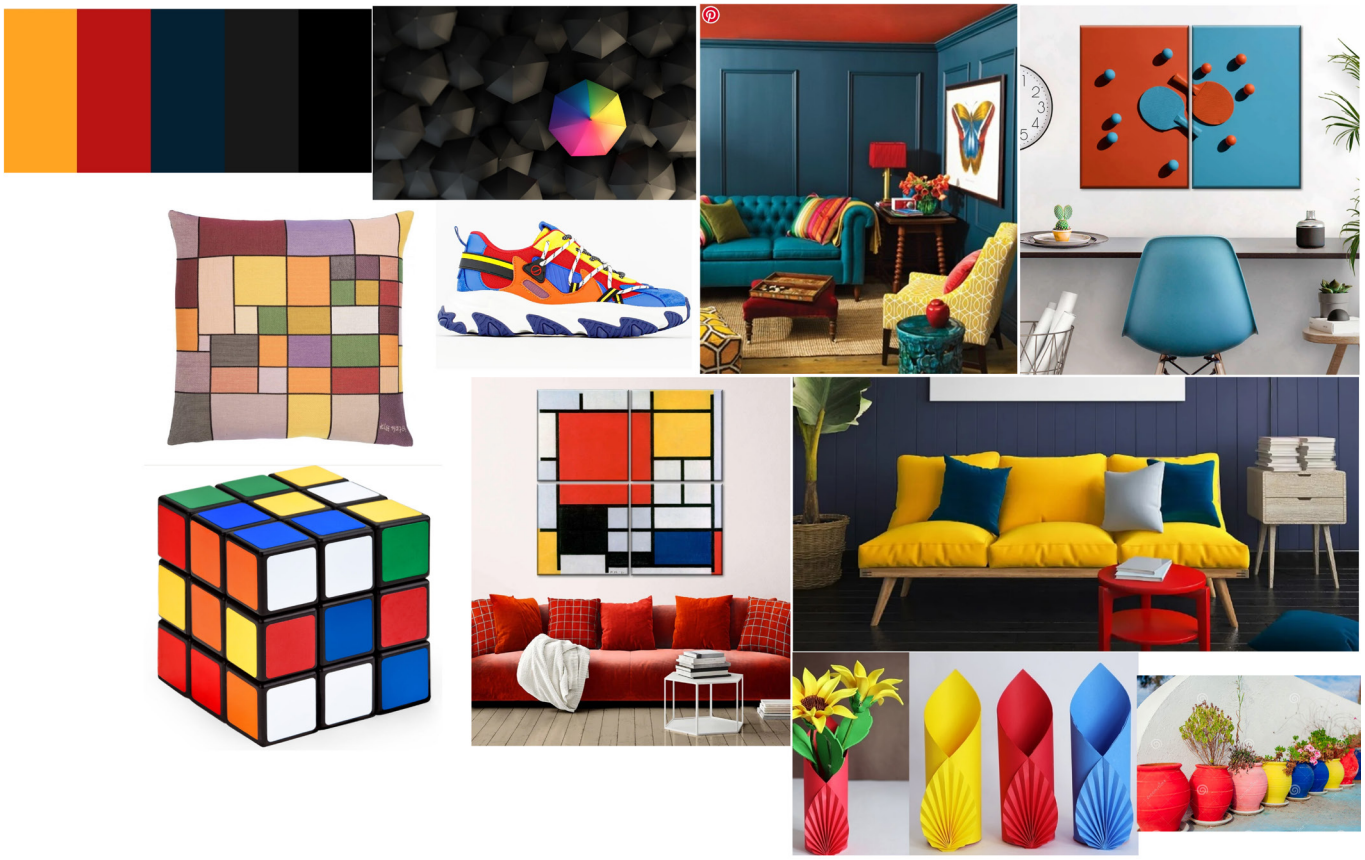
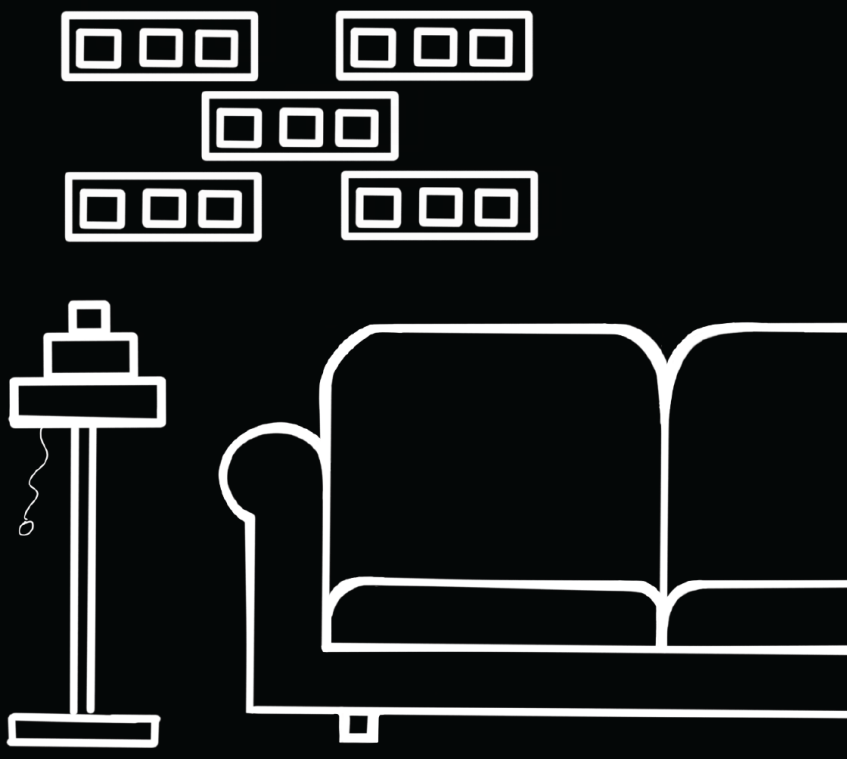


Figure 12. Moodboard 3

The first mood board aimed to capture a cozy cabin vibe, inspired by the prominent use of wooden structures in Norwegian culture. It featured warm color tones, conveying a soothing and inviting atmosphere. The wood paneling on the structure significantly influenced the final design decision.

The second and third mood boards were more experimental, exploring different color combinations and the unique character they brought to the product. The second mood board showcased a monochrome approach, with shades of black and white dominating the palette. This clean aesthetic allowed the product to seamlessly integrate into various household decors.The third mood board ventured into a retro perspective, incorporating creative and playful colors. This exploration helped identify different color schemes suitable for diverse decoration scenarios.

3. Conceptualization with sketches



3.1 Ideation and sketching

Ideation and sketching are crucial parts of any design methodology. After the initial research phase, a meeting was set up with Greenfall to discuss the possible directions that can be taken to achieve the goal of the project. This was the brainstorming phase where everyone in the team presented different ideas that they had for the product. The first step in this process was figuring out what characteristics were crucial for the product to be unique and functional and at the same time affordable for the customers. Once all the ideas were put together, I then proceeded to further refine all the ideas and come up with concepts. The brainstorming session was tricky since there are a lot of comparable products that exist in the market already and I wanted to design something that was different, functional, and aesthetically pleasing at the same time. It was noticeably clear that the project would be predominantly based on the practical aspects which included a lot of sketching and prototyping and testing.
The ideation phase of the project was conducted throughout the entire project. There were always some details that were missing and changes that could be made to better optimize the product. Several sessions were held that were dedicated to the addition of new ideas which was carried out till the first week of May. Even at the end stages of the project, there were discussions about some features that would be better if left out and some that needed to be added.

Initial sketches

The first 4 weeks of the thesis was mostly coming up with ideas for the product. This meant a lot of sketches with different ideas displayed in each sketch. All the sketches were discussed weekly with the Greenfall team and my supervisor prof. Andre Liem. There were different sketches varying in dimension, functionality, and orientation, each improving with the number of iterations. The first sketches were purely based on the aesthetic look of the product. I wanted to design a live green picture that would be good for rooms with small spaces but at the same time have the modularity to be used in larger scale vertical green walls. A lot of competitors that were in the same market had the plants in an upright positioning, but I wanted to create an illusion where the plant was seemingly breaking out of the frame hence a live picture. This led to sketches where the plants were horizontally oriented instead of vertically to have a more dramatic effect. The sketches were mostly divided into 4 different sections which were the structure, the pods that held the plant (Pixel) and the mechanism for holding it to the structure, the watering system, and the stand. The stand was given the least priority at the beginning since it was an extension of the actual product but was still one of the designs criteria.

3.2 concept sketches

3.2.1 Concept 1

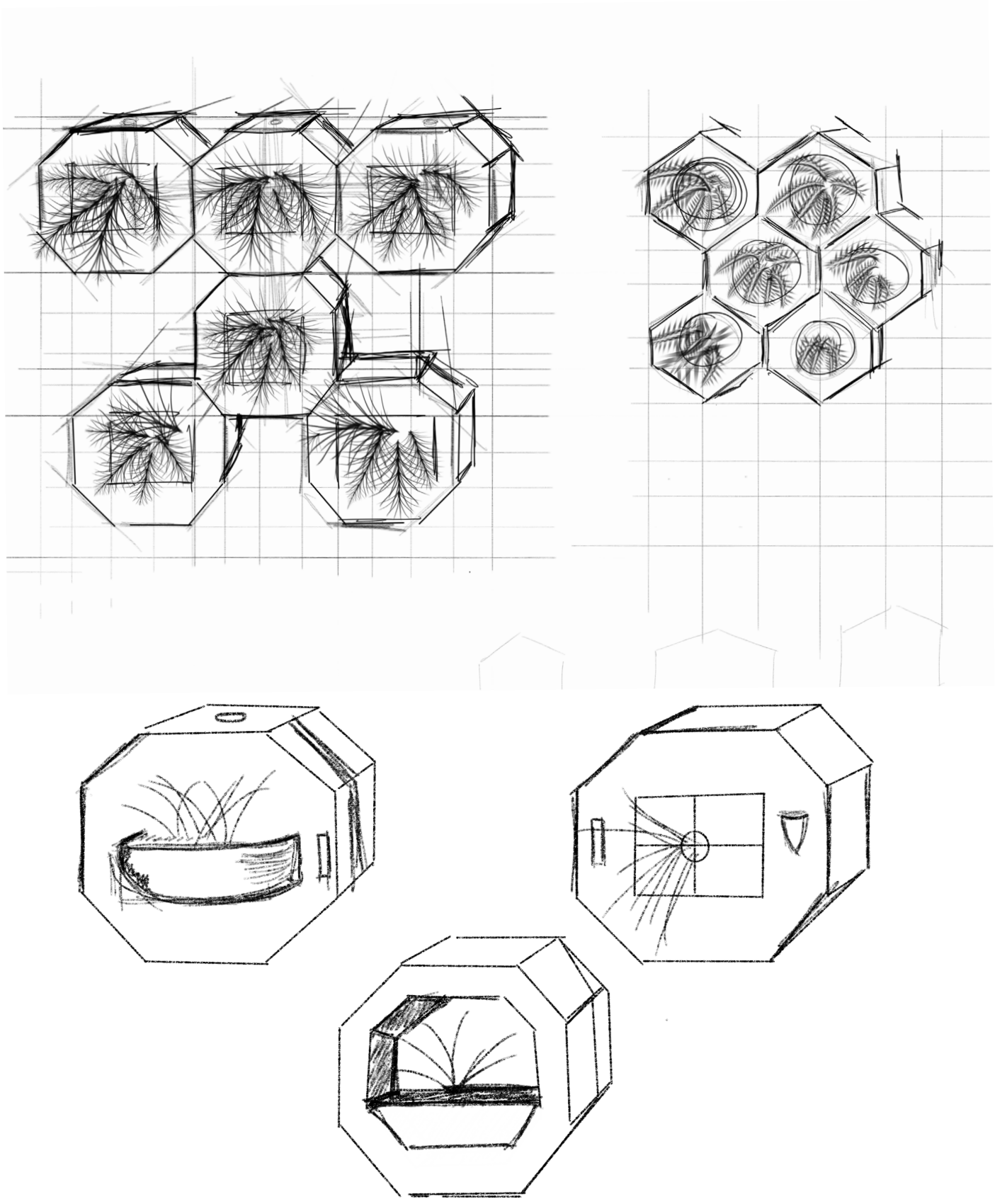


Figure 13. Exploratory concept sketches of different shapes

3.2.2 Concept 2

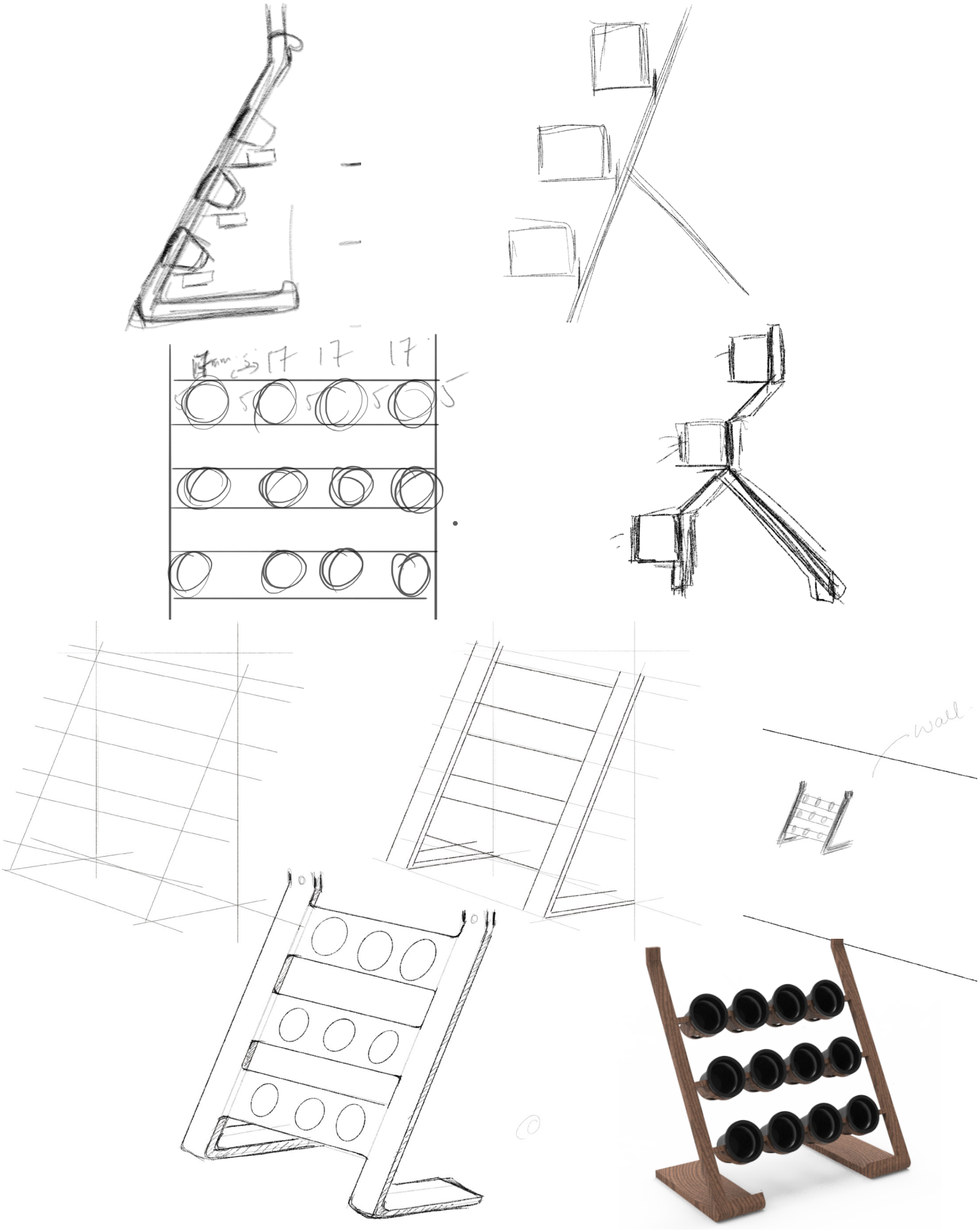


Figure 14. Concept sketches with plant pods available in the market

3.2.3 Concept 3

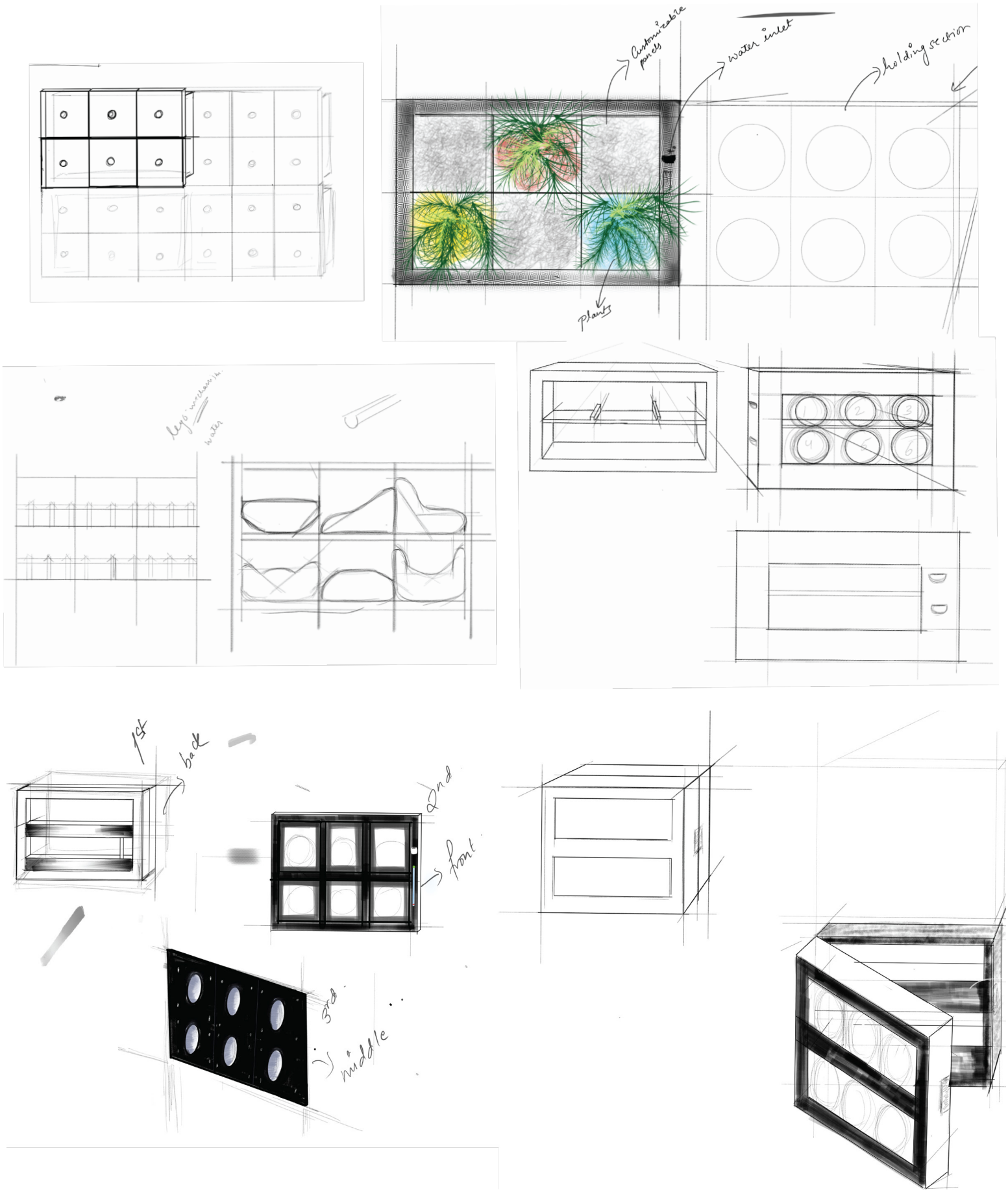


Figure 15. Concept sketches with 6 slots for the pixels

3.2.4 Concept 4

Figure 16. Concept sketches with 3 slots for the pixels

3.3 concept sketches for stands

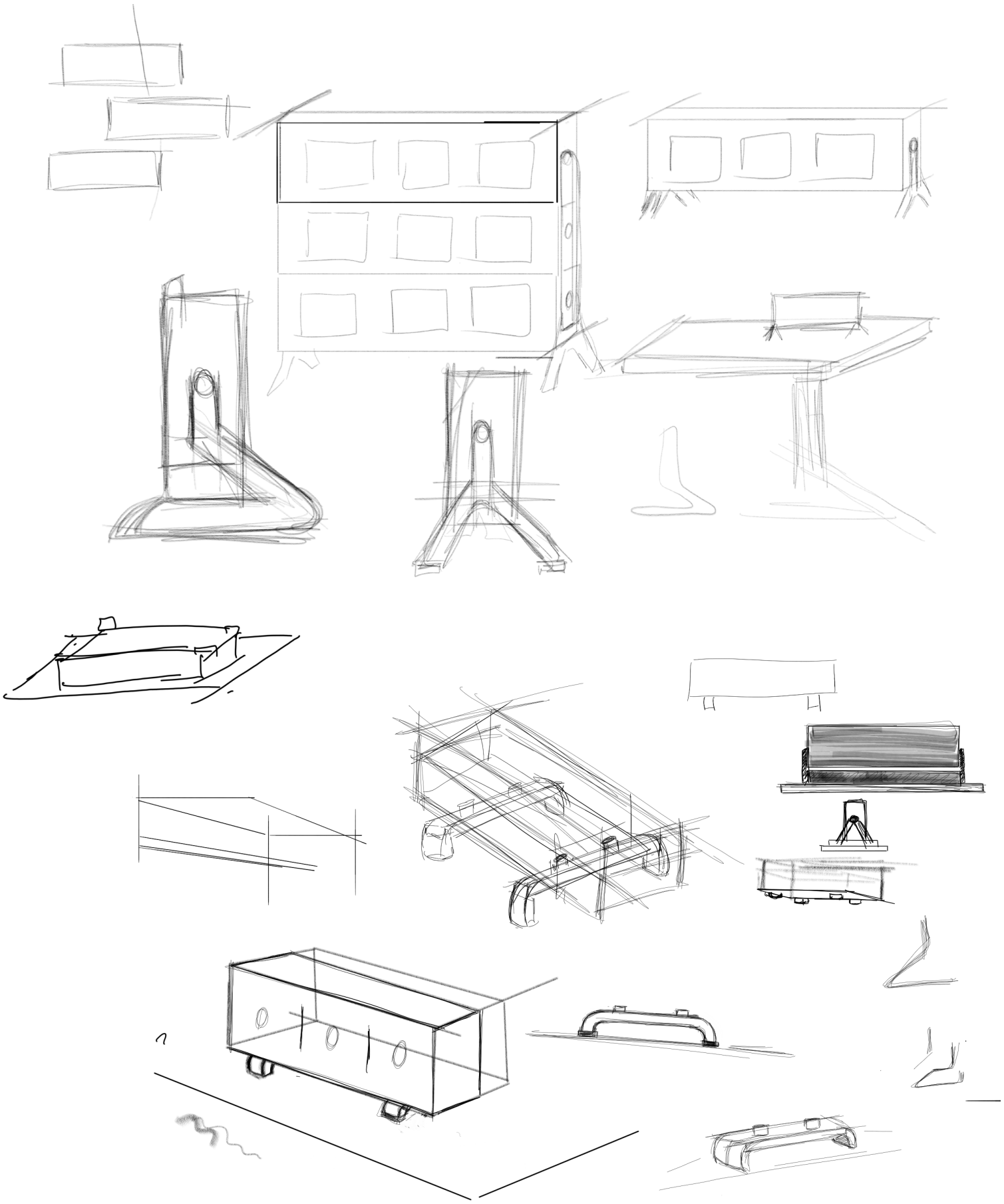


Figure 17. Concept sketches with stands for desks

3.4 concept sketches for watering system

3.4.1 concept A

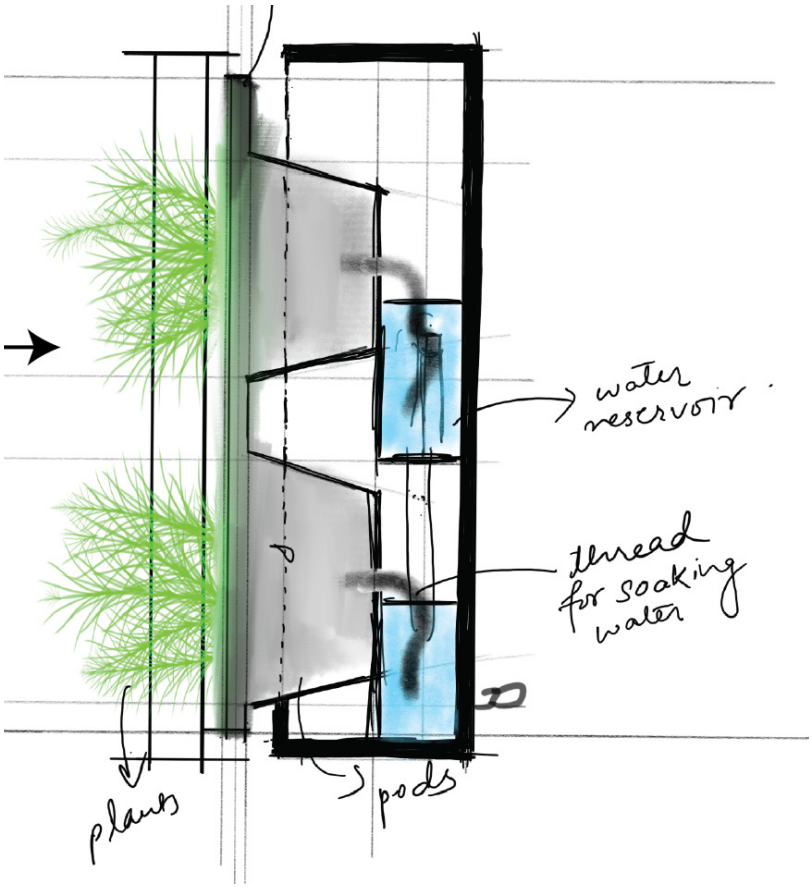


Figure 18. Concept sketch with water source below the plant

3.4.2 concept B

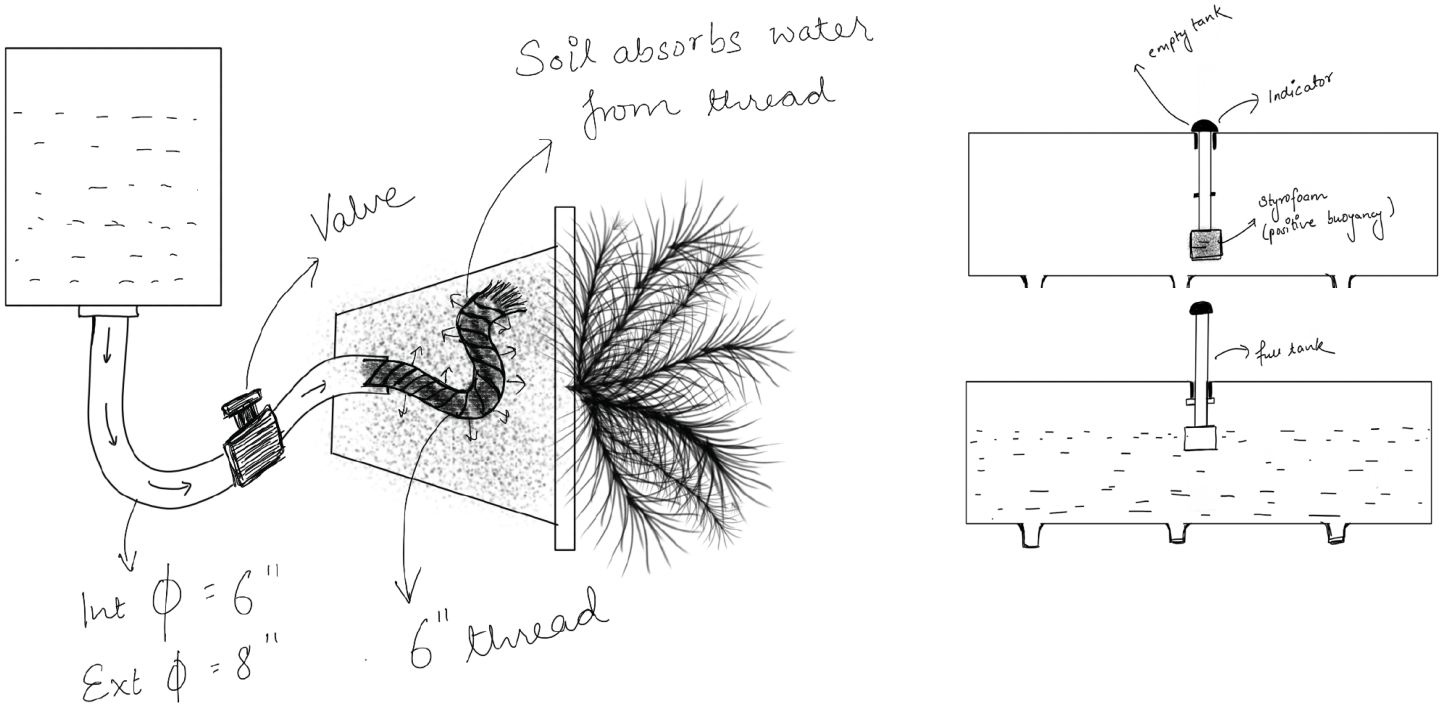
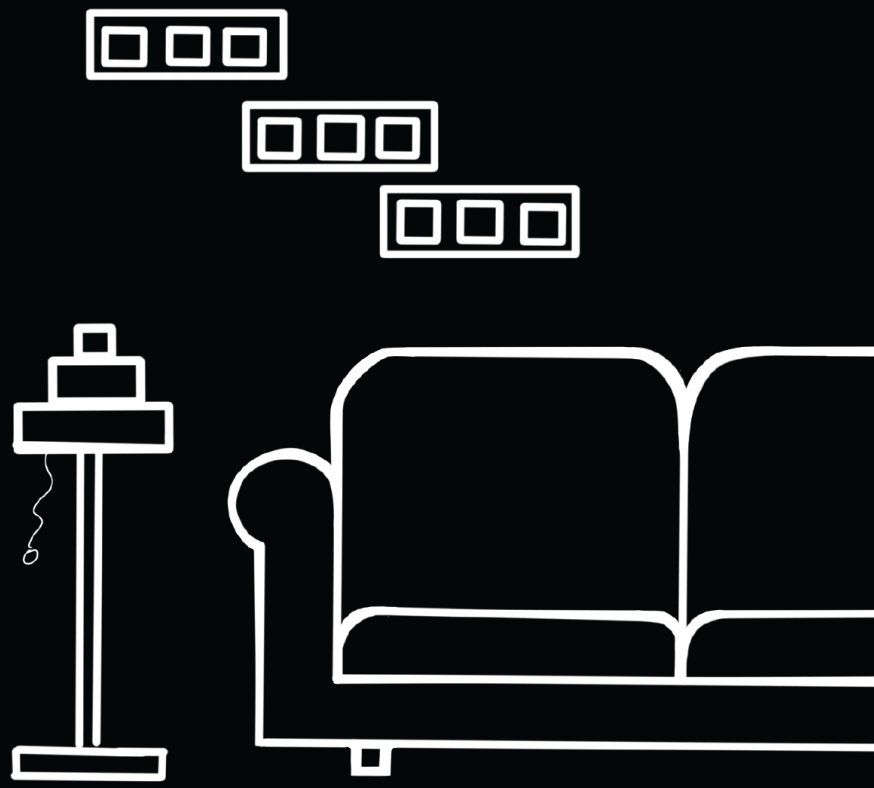


Figure 19. Concept sketch with water source above the plant and indicators for water levels

4. Rapid prototyping of the concept



To assess the practicality of each 3D model, prototypes were created to simulate real-life scenarios. A variety of materials were employed for prototyping, including cardboard, laser-cut components, and 3D-printed parts. Towards the end of the prototyping phase, 3D printing was primarily utilized to examine functionality and conduct thorough testing.

Initially, the models were prototyped using cardboard pieces, which were not created on a 1:1 scale. These early prototypes served as preliminary representations to evaluate concepts and make initial adjustments. To expedite the prototyping process and allow for more extensive testing, most of the test prototypes were intentionally small in size.

By employing different materials and techniques for prototyping, the design team aimed to refine the models and verify their viability in real-world scenarios. Ultimately, 3D printing played a crucial role in producing functional prototypes that closely resembled the intended final product.

Figure 20. First cardboard prototype of concept 3

The cardboard prototypes, although relatively rough in appearance, served a specific purpose in the design process. They were primarily used for visual assessment, allowing the designers to identify any obvious flaws before investing more time in creating 3D-printed prototypes, which require a longer production time. Cardboard proved to be a suitable starting point for prototyping due to its easy availability and its ability to provide a tangible representation of the product's visual aspects.

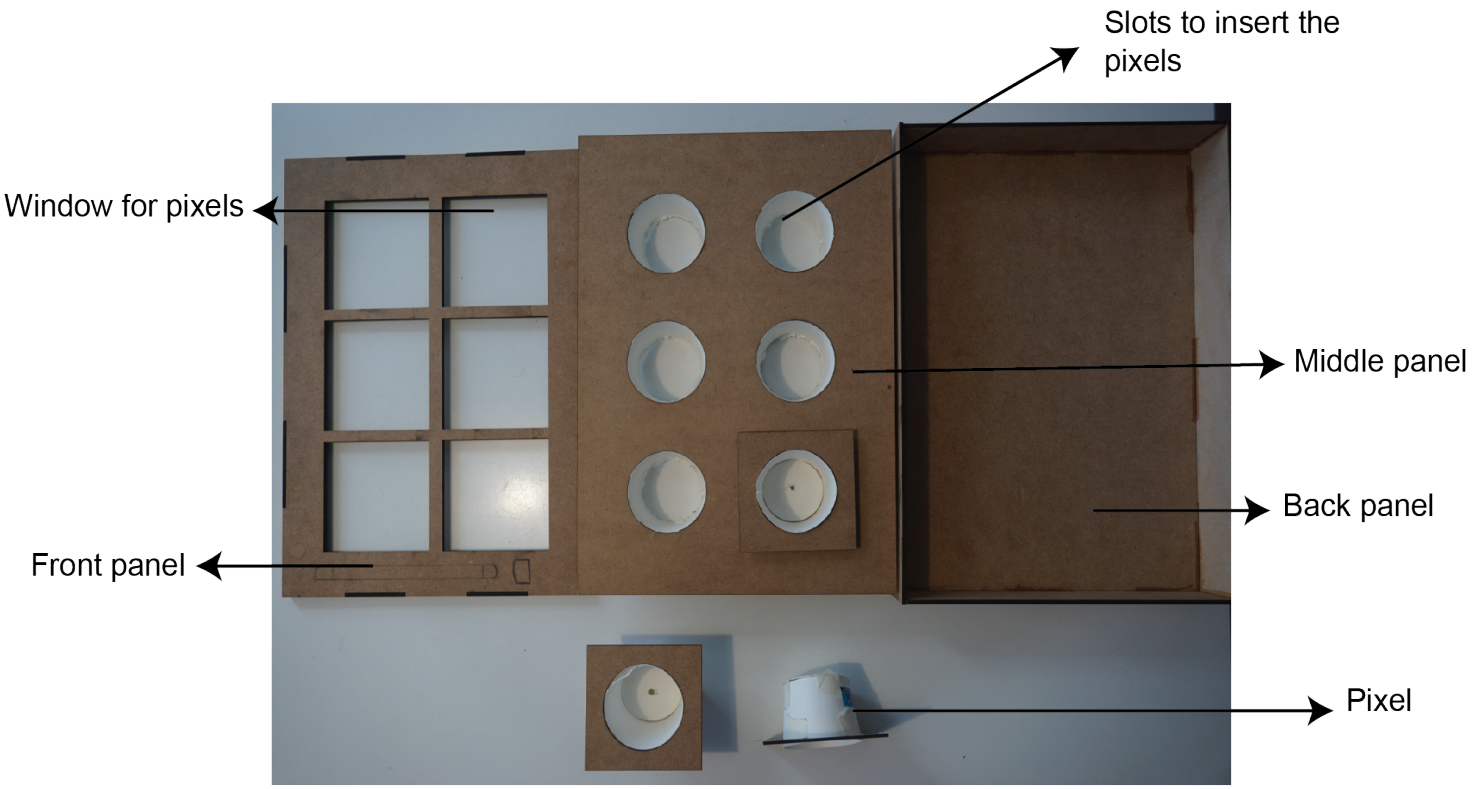


Figure 21. Laser cut prototype with first iteration of the pixels

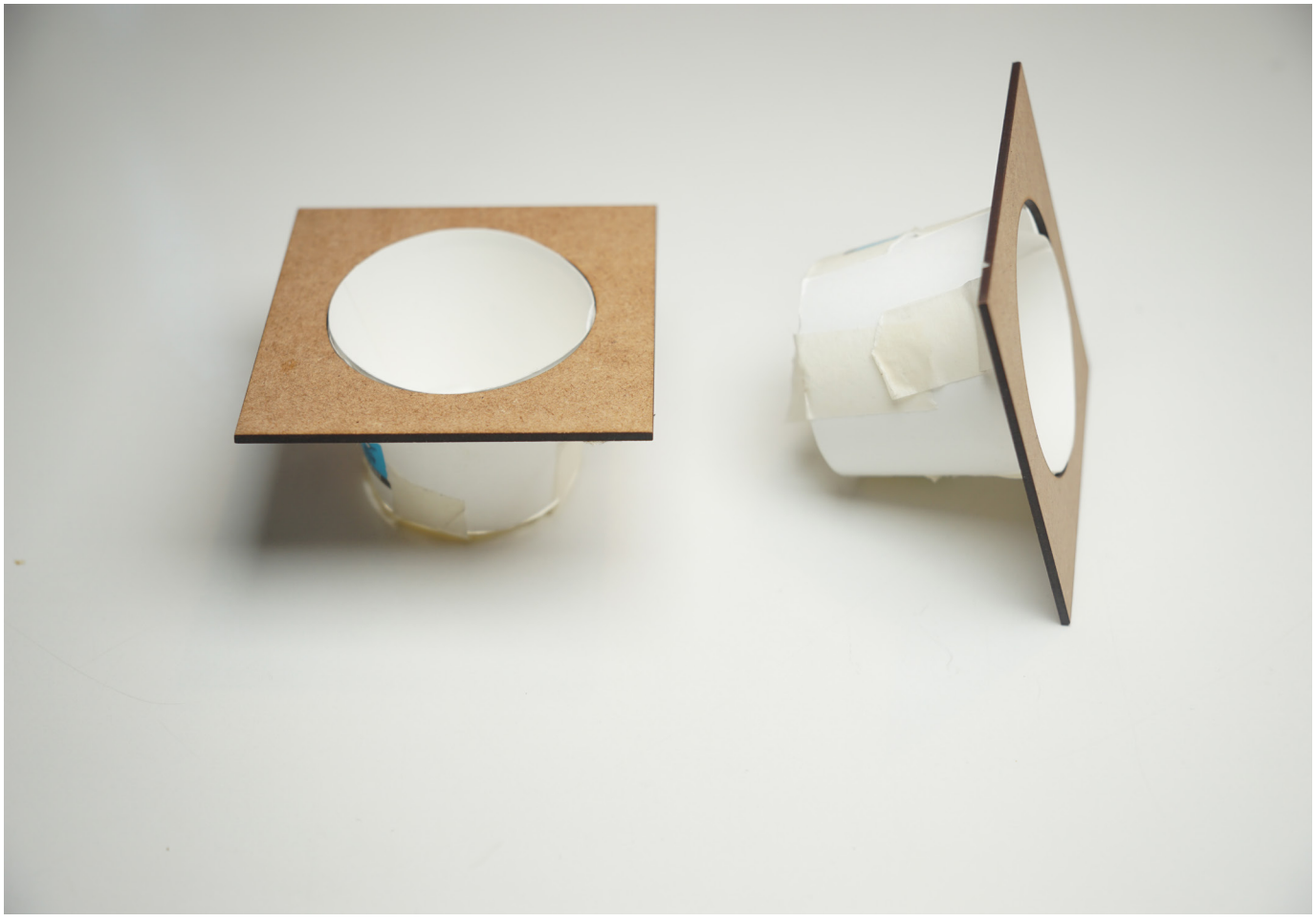


Figure 22. Pixel protoype made out of laser cut cardboard and paper cups

To identify design flaws, a 1:1 scale prototype was developed using laser-cut cardboard pieces and paper cups. Typically, creating prototypes in actual scale occurs towards the later stages of a project. However, in this case, it was done earlier to gain insights into the design's shortcomings.

During the evaluation of the full-scale prototype, several issues were identified. The ov ıll thickness of the product was found to be insufficient, resulting in limited space for a reservoir. Additionally, when mounted on the wall, the prototype appeared excessively large and boxy, which was not desirable.The prototype played a crucial role in the decision-making process, leading to the exclusion of the middle panel. It was determined that the middle section added unnecessary weight and material to the design. Consequently, the functionality initially attributed to the middle panel was transferred to the front panel, streamlining the overall structure.

While the precision laser cuts contributed to the creation of a well-crafted prototype, it still exhibited several design flaws. In hindsight, utilizing scrap cardboard to construct a 1:1 scale model would have been a more resource-efficient and time-saving approach.

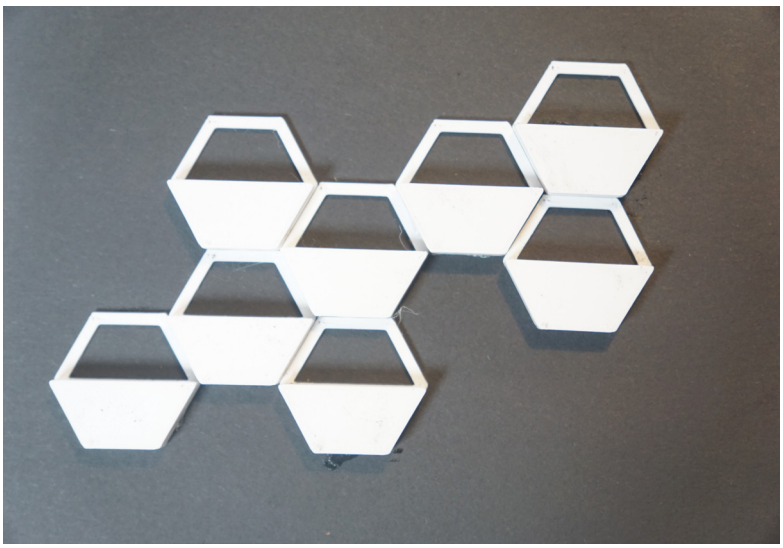


Figure 23. 3D printed prototype of hexagonal plant pods (concept 1)

The prototype featuring a hexagonal pattern explored the possibility of using plant pots in different shapes. The intention was to move away from the conventional cuboid design and embrace a more fluid and organic pattern. However, this particular concept was ultimately not pursued due to its limitations in terms of practicality and versatility. While aesthetically pleasing, it did not offer the flexibility to accommodate various pixel designs, nor did it showcase enough versatility in functionality.

The design of this prototype drew inspiration from nano leaf lights, which influenced the exploration of unconventional shapes and patterns. Although this particular idea did not progress further, it served as an experimental endeavor in the pursuit of innovative and distinctive designs

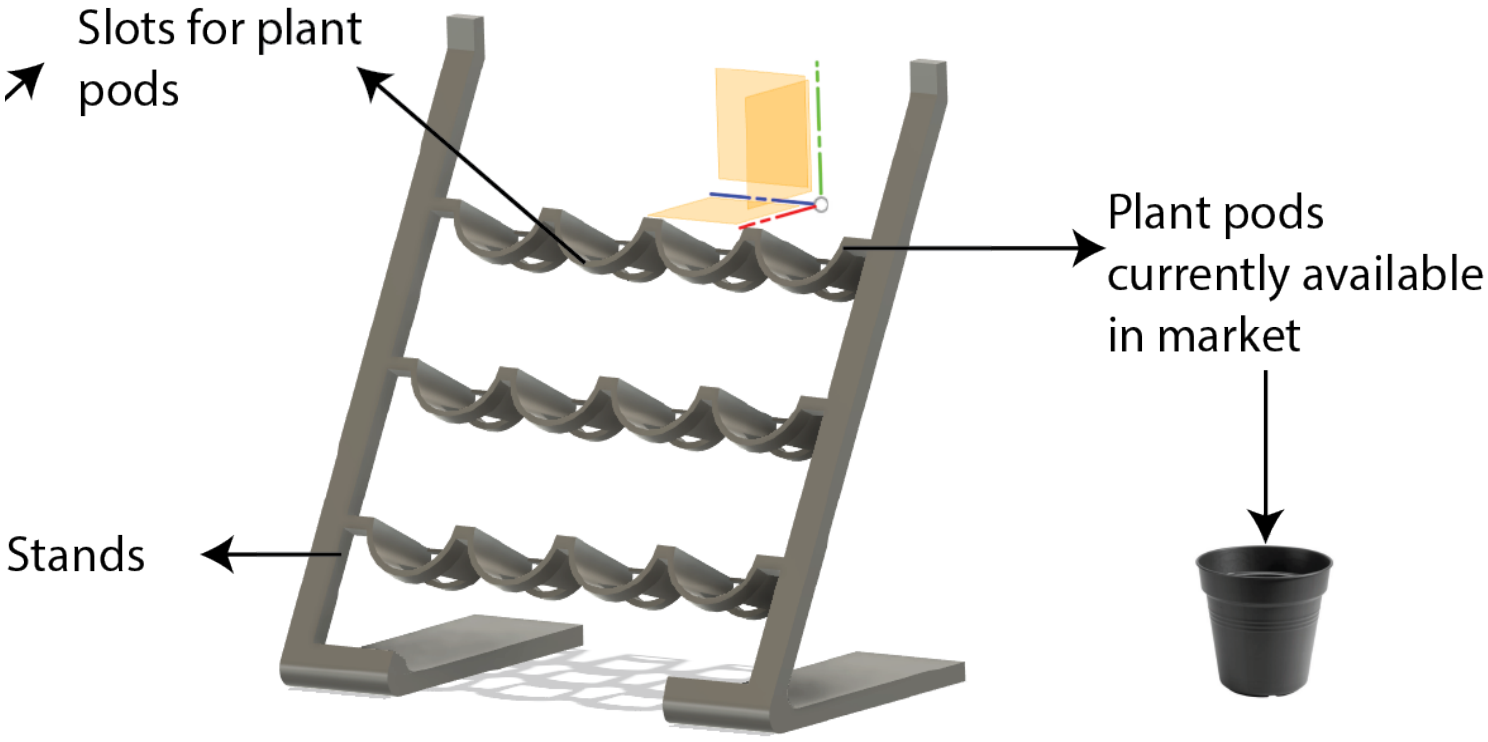


Figure 24. 3D model of concept 2

The above illustration only portrayed a 3D model of the concept, without undergoing any prototyping. The main focus of this concept was simplicity, primarily serving as a shelf for plant pots and nothing more. The objective was to utilize existing plant pods readily available in the market, incorporating a lightweight and hollow design. However, in this particular scenario, the notion of “less is more” did not prove effective due to the absence of a suitable method for watering the plants within this assembly, as well as a lack of indicators for monitoring water levels. Numerous perceived issues arose with this design, leading to the decision of not proceeding with prototyping, as the flaws were apparent.

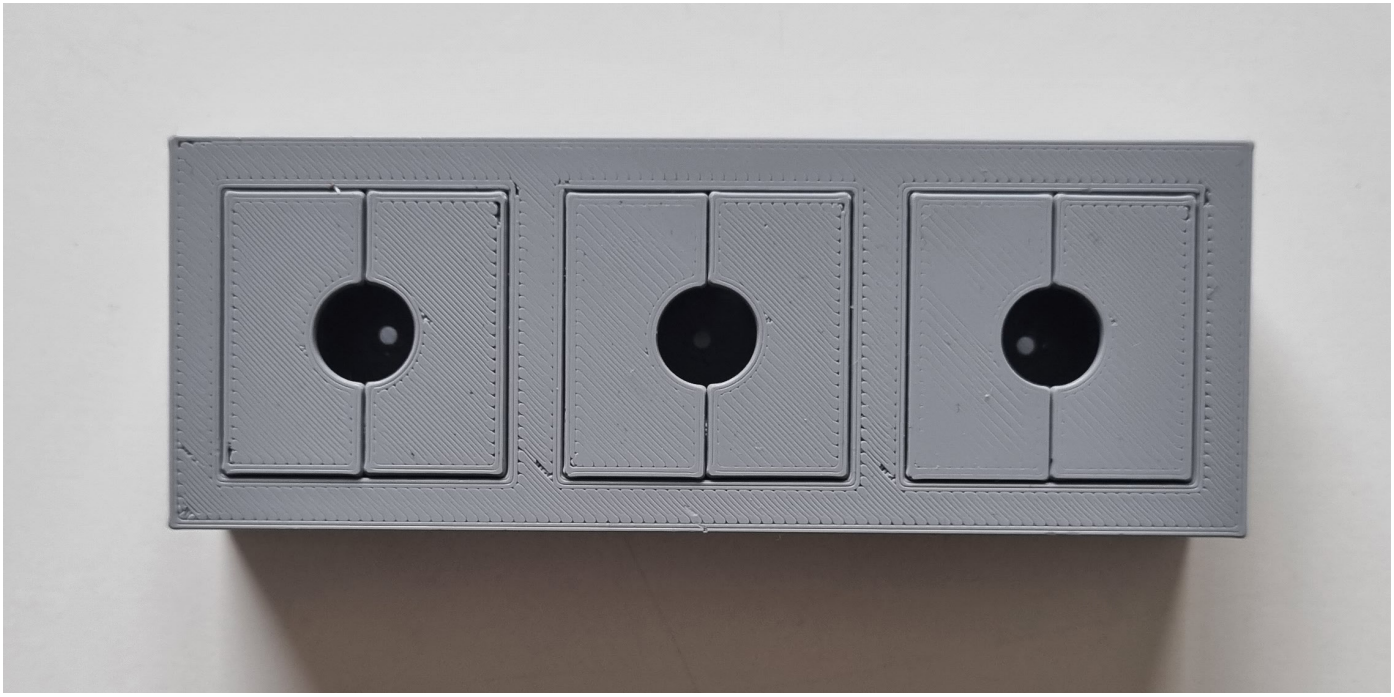


Figure 25. 3D printed prototype of concept 4 (30% of the original size)

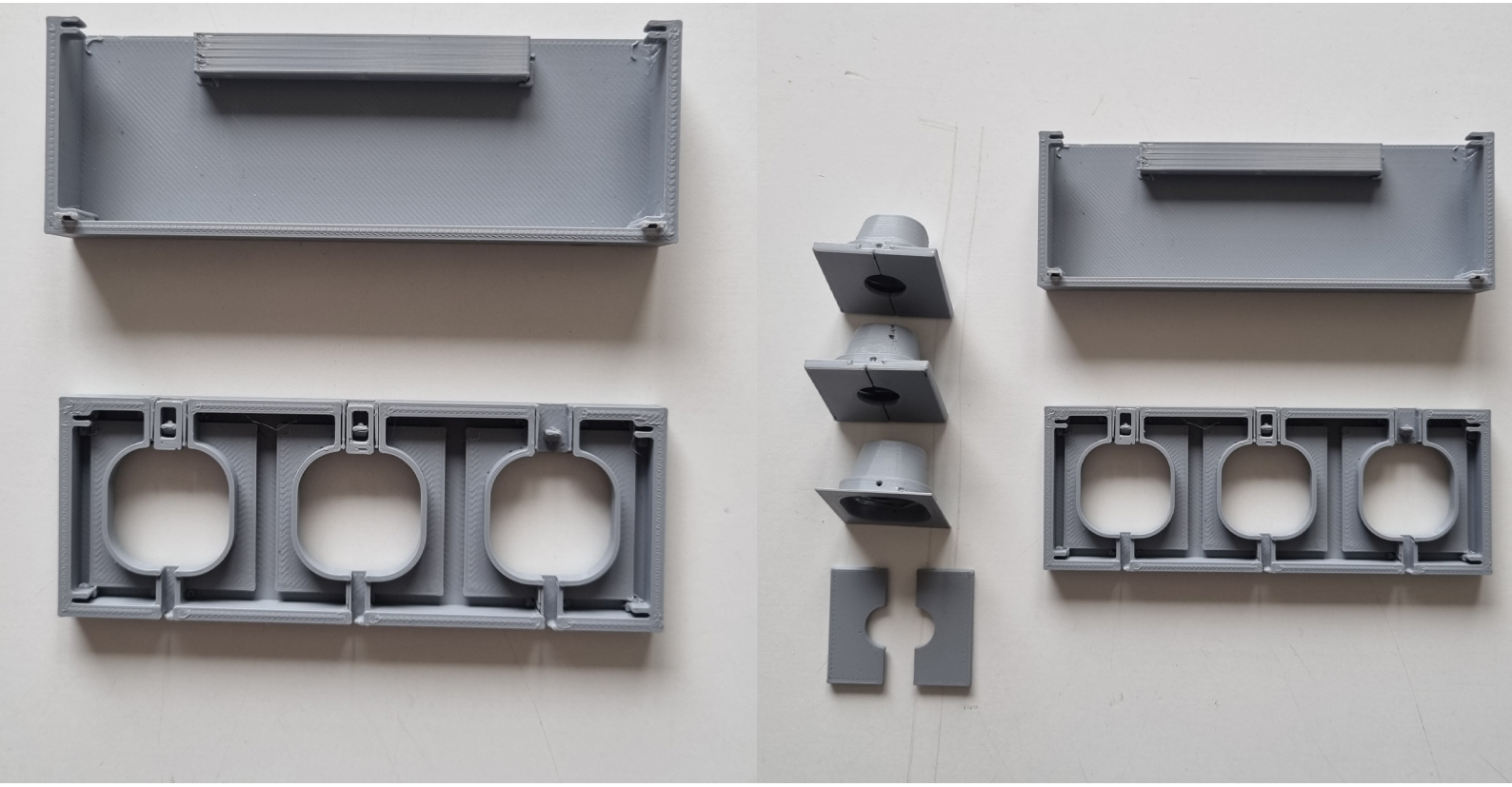
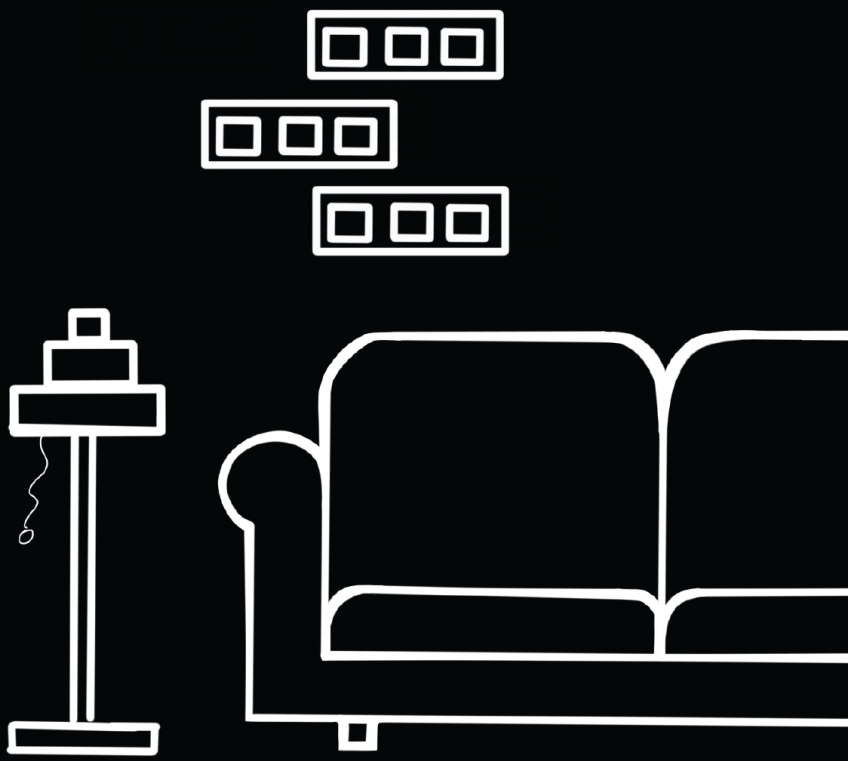


Figure 26. 3D printed prototype of concept 4 with all the components

This test prototype served as the final iteration before the decision was made to proceed with one of the concepts developed throughout the process. It was 3D printed at 30% of the original size to assess both its visual appeal and functionality. Compared to the previous prototypes, this one was more intricate, offering greater promise in real-world scenarios. Although the small pixels lacked intricate details, they effectively demonstrated the system's functionality. As a test prototype, many details were modified and refined along the way to enhance the system's performance and coherence.

5. Concept selection and testing



5.1 Selection of final concept

Multiple factors were considered in the evaluation, including market demand, technical constraints, cost implications, and user preferences. Each concept underwent prototyping, testing, and iterative feedback loops to gather valuable insights and validate its viability.

Throughout this stage, concepts were scrutinized and analyzed to determine their strengths and weaknesses. They were refined, modified, and optimized to align with the project's goals and objectives. The ultimate aim was to select a concept that demonstrated the highest potential for success and customer satisfaction.

The final decision was however made based on the feedbacks from users and the initial design criterias mentioned before which were,

swappable plant modules: The plants should be interchangable without having to repot it everytime.

Degree of interaction: The product should have a form of interaction with the user other than just watering to form a bond with the user. This should not be time intensive task but a unique and fun addition to the experience of the product.

watering system: The product shoul have a watering system where it can hold water for certain period of time without having to be watered every other day.

Cost effective: The product should be reasonably priced and should not be very expensive.

Low maintainance: The product should have a self sufficient system which doesnt not require constant attention from the user.

Good aesthetics: The product should aesthetically pleasing at the same time serving a funstional purpose.

Concepts	Swappable plant modules	degree of user interaction	watering system	cost effective	low maintainance	good aesthetics
Concept 1	✗	✗	✗	✓	✓	✓
Concept 2	✓	✗	✗	✓	✓	✓
Concept 3	✓	✗	✓	✓	✓	✗
Concept 4	✓	✓	✓	✓	✓	✓

Table 2. 3D Criteria for selection of the concepts

5.2 Developement of final sketches

5.2.1 Sketches and ideation behind the orientation of the plant pods

The orientation of the plant pods played a crucial role in this project, as it set the product apart from existing alternatives. The concept of creating a live picture hinged on the plants directing their growth towards the viewer. Since plants naturally grow towards the most favorable environment, including sunlight, it was essential to design the pixels in a way that allowed for rotation. This rotation capability would enable users to adjust the pixels, ensuring a steady and optimal growth of the plants. By incorporating this feature, the product aimed to provide users with greater control and customization over their vertical green wall

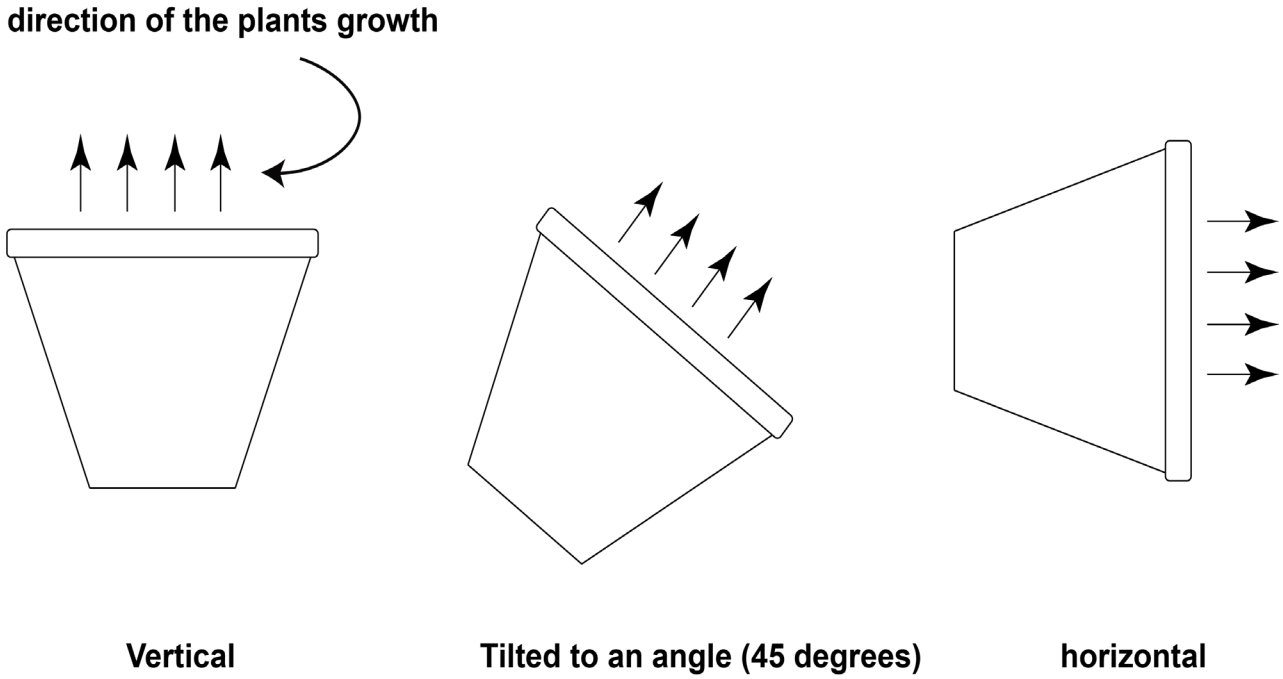


Figure 27. Orientation of the plant pods

The decision to have the plants grow horizontally presented certain challenges. Unlike traditional vertical growth patterns commonly found in flower pots and green walls, horizontal growth required addressing specific considerations. While angling the pods at under 45 degrees could still accommodate the plants and facilitate watering, the main challenge arose with ensuring proper ventilation for plant growth. Without adequate ventilation, damp soil could lead to bacterial growth and potential mold issues over time. Additionally, the presence of ventilation holes at the bottom of the pods posed a challenge of water leakage since water would travel straight downwards.

Furthermore, the horizontal orientation introduced additional difficulties. Securing the soil in place became a concern, as traditional top watering methods were not suitable for these pods. A specialized watering system needed to be developed to cater to the specific needs of the horizontally oriented plants. Another issue to address was stabilizing the pods due to their forward weight distribution. This required the implementation of a mechanism or method to securely hold the pods in place.

Overall, the decision to have horizontal plant growth necessitated overcoming challenges related to soil retention, watering systems, ventilation, and stability, in order to ensure optimal plant growth and functionality of the product

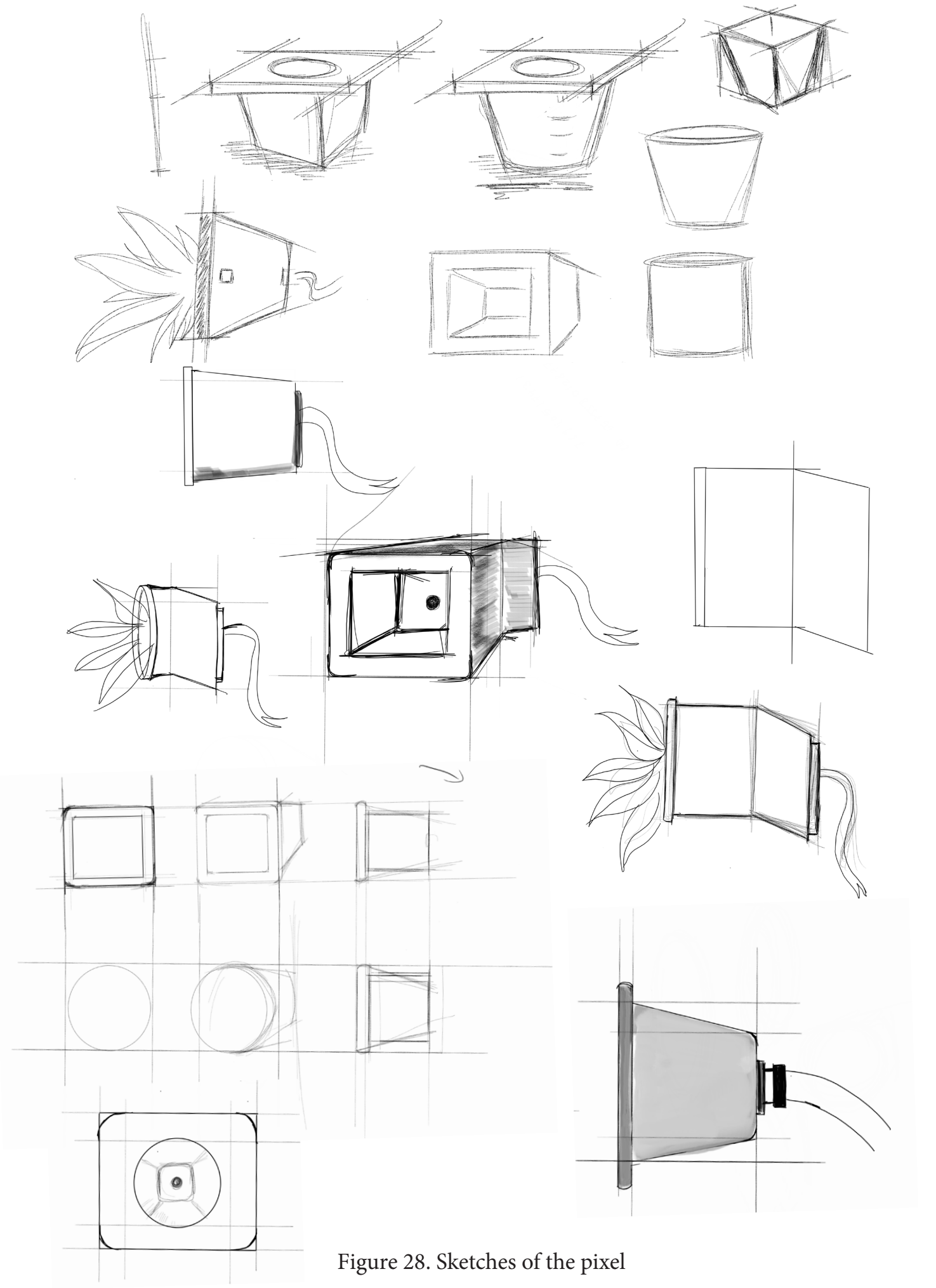


Figure 28. Sketches of the pixel

During the initial sketching phase, the focus was on refining the shape and orientation of the pod. I aimed to design a pod that could accommodate sufficient soil for plant growth without being overly bulky. While the mini plant pods available in the market provided a good size reference, I made slight modifications to increase the soil capacity. Opting for a tapered shape followed the trend of flowerpots and leveraged users' familiarity with similar products. Additionally, choosing a symmetrical shape was important to allow for rotation if needed.

Considering the horizontal orientation of the plants, it was crucial to address the issue of soil spillage. Introducing a cover for the front side of the pod seemed like a logical solution. However, I had to ensure that the cover did not hinder plant growth due to restricted openings. The attachment mechanism for the cover was also a significant consideration. I wanted it to be easy to open or remove, allowing users to replant if desired. Avoiding a permanent cover was essential to facilitate the initial planting process and prevent potential challenges.

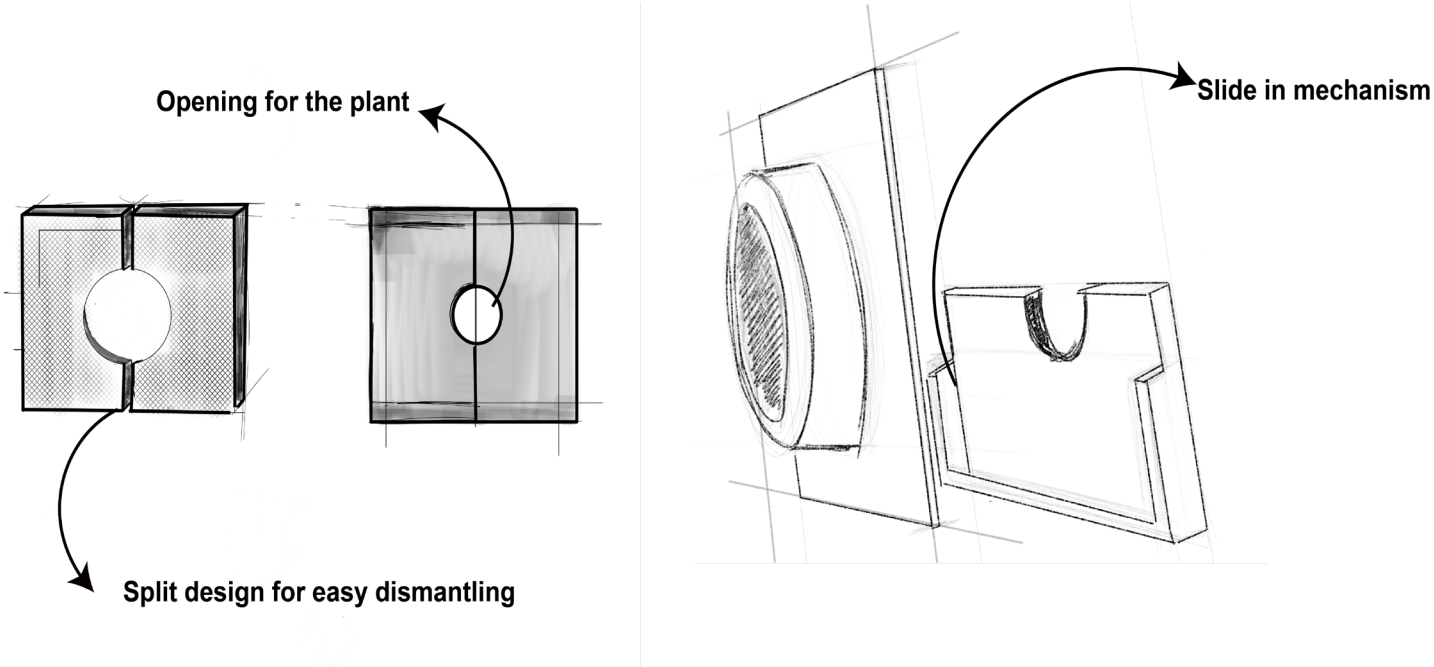


Figure 29. Pixel covers

The initial design of the pixel (plant pod along with the cover) aimed for a plain and discreet appearance to ensure it blended seamlessly without drawing attention. However, it became evident during testing that the pods lacked sufficient airflow, despite not showing signs of molds or moss after a month. Recognizing the importance of airflow for optimal plant growth, I decided to revise the design.

The new design iteration focused on incorporating ventilation to facilitate proper airflow within the pods. The challenge was to create openings that were small enough to prevent soil from escaping while still allowing adequate airflow. This balance was crucial to maintain a clean and tidy appearance while promoting a healthy environment for the plants.

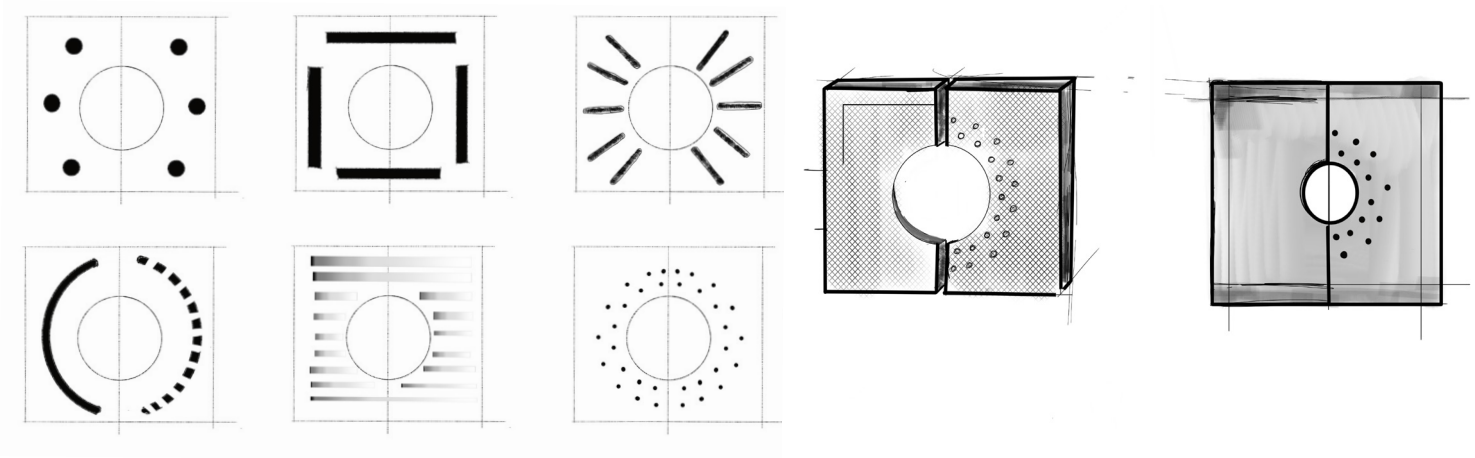


Figure 30. Different ventilations on the pixel cover

5.2.2 Mechanism to hold the pixel in place.

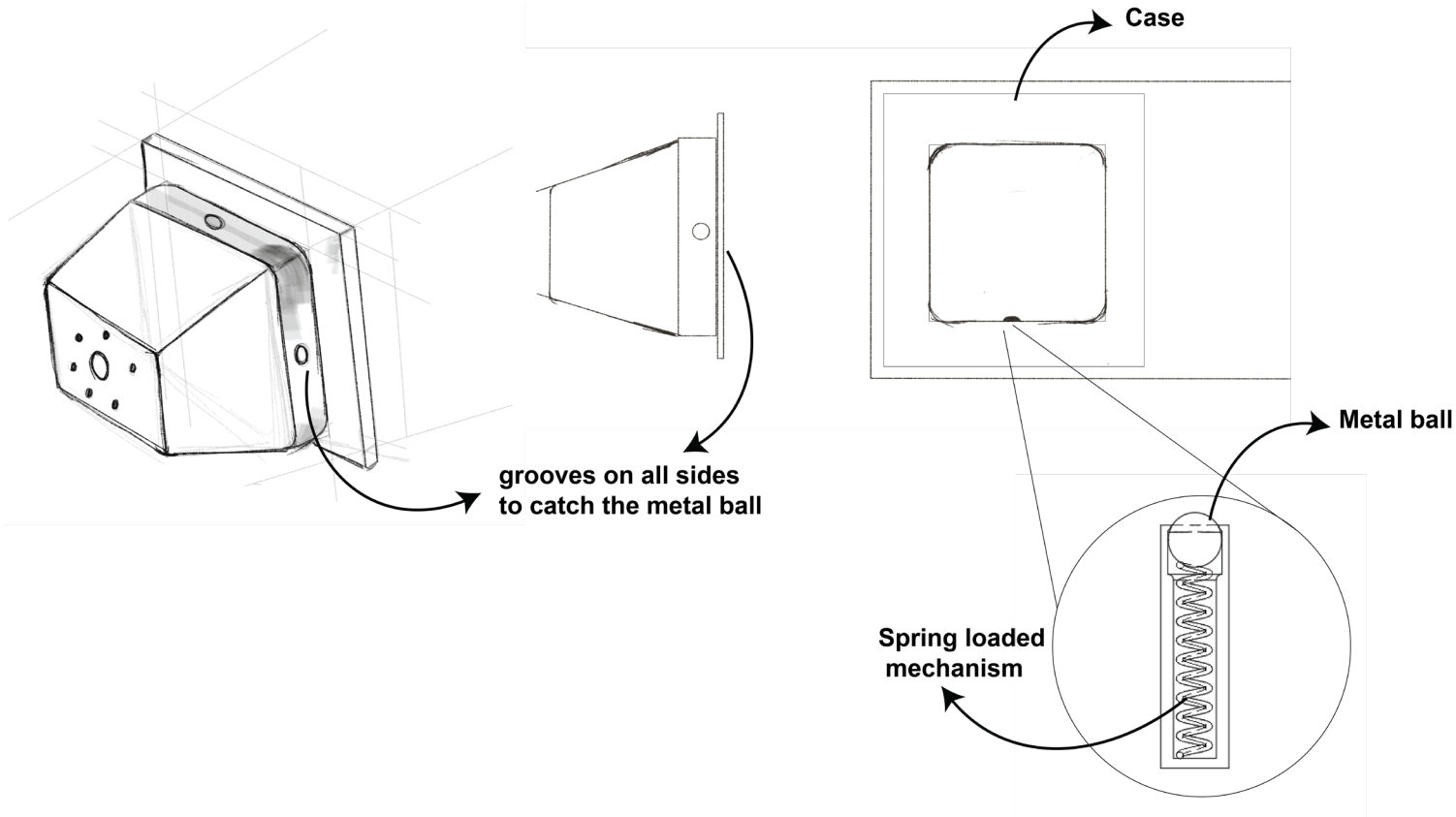


Figure 31. Ball spring plunger mechanism

The mechanism chosen for holding the pixel in place is a simple and cost-efficient solution. While magnets would have been a simpler option, they proved to be more expensive compared to using a spring and a 6mm diameter metal ball. The functionality of the mechanism is as follows:

When the pixel is pushed into the slot, it is held in place by the spring-loaded metal ball. The pixel features spherical grooves on all sides, enabling it to be rotated both clockwise and anticlockwise. The spring's strength is carefully calibrated to securely hold the pod in place while allowing for easy removal when needed. This design allows users to manipulate the direction of plant growth.

During the design process, alternatives such as magnets and snaps were explored. However, magnets proved to be expensive for bulk production, and snaps were found to be unreliable. Additionally, snaps made it difficult to remove the pixel from the case. Therefore, the spring-loaded mechanism with the metal ball was chosen as the optimal solution for securing and adjusting the pixel in place. For example, if the plant starts growing towards the right side, the user can rotate the pixel by 180 degrees, repositioning the plant's growth towards the left. Over time, the plant will continue growing towards the right, gradually adjusting its position towards the center. As the pixel is inserted into the slot, the ball is pushed down as the spring compresses. Once the pixel is fully inserted, the spring decompresses, releasing the metal ball into the groove.

5.2.3 Alternate mechanism to hold the pixel

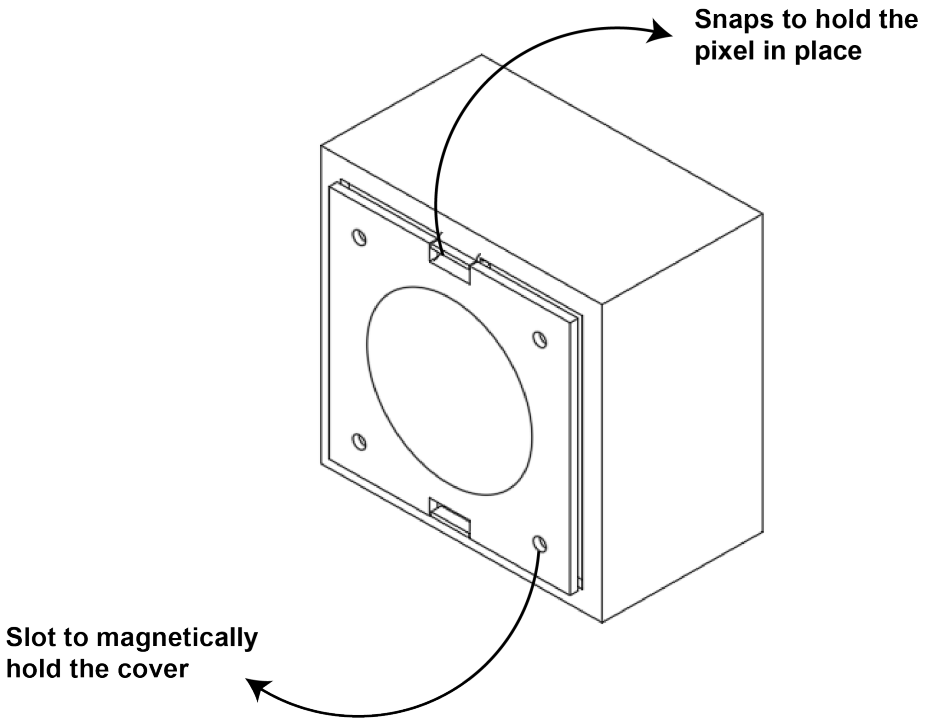


Figure 32. Use of snaps and magnets in the pixel

The utilization of snaps combined with magnets resulted in excessive material usage, leading to higher production costs. When testing the mechanism with a plant, users faced challenges in consistently achieving optimal snap functionality. Moreover, the snaps proved to be fragile and prone to breaking, primarily due to the choice of materials during the prototyping phase. Consequently, they lacked reliability. Another factor discouraging the use of snaps was the necessity for receivers on all sides of the pixel to facilitate rotation, resulting in an untidy and cheap appearance of the design.

5.2.4 Release mechanism for the pixel

The surface of the pixel covers had a relatively smooth texture, making it challenging to remove them from the slot. Due to the absence of a clear grip for users to pull the pixel out, a press-to-release mechanism was incorporated. This mechanism involved a spring mechanism that, when pressed, released the pixel from its position. Two different spring mechanisms were evaluated: one utilizing a dual spring and the other utilizing a single spring. However, the setup with two springs proved to be rigid and uncomfortable to use. Moreover, the addition of a grip to facilitate pixel removal resulted in users frequently coming into contact with the delicate plants, which sometimes led to the unintentional breaking of leaves and small stems.

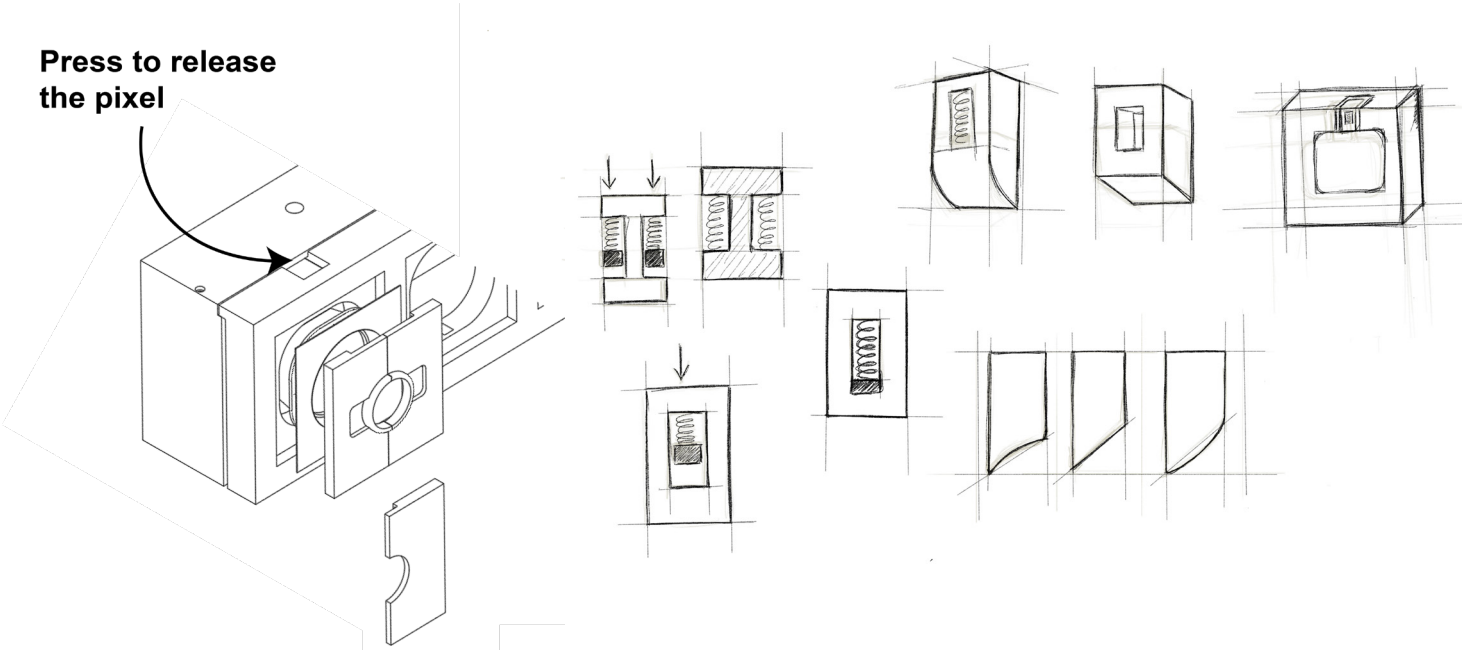
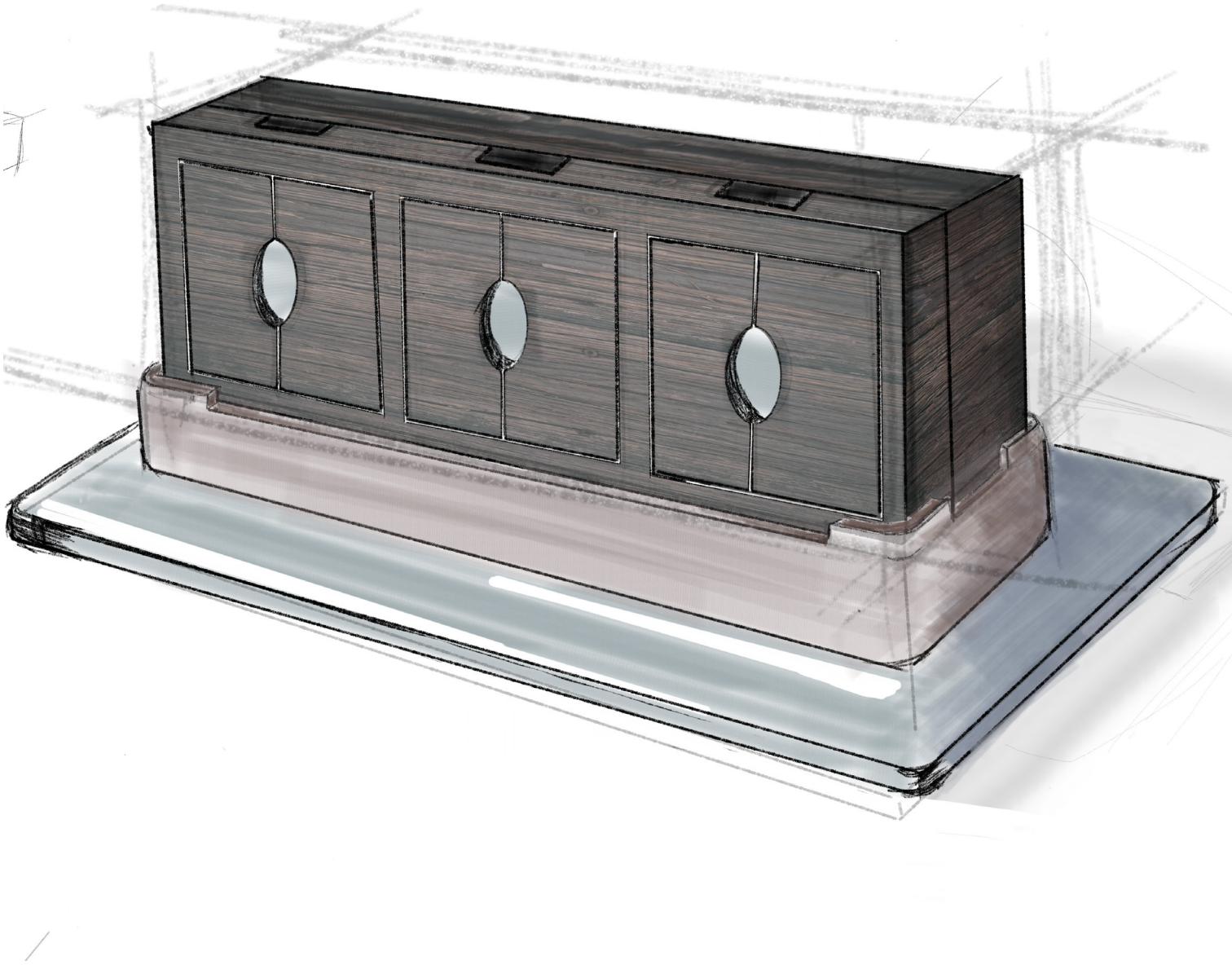


Figure 33. Release mechanism for the pixel

5.2.5 Developement of the shape of the product

The product aimed to be inconspicuous in small spaces while still making its presence felt in the room. Various ideas were explored to determine the desired appearance of the product. Experimenting with different shapes and sizes proved helpful in refining its overall look. The process of visualizing the product began with initial rough sketches, followed by prototyping. These iterative sketches depict the gradual evolution of the product's shape.

The sketches presented here represent the first draft of rough sketches, created in a random manner. During this stage, the concept of how the product should look was clear. The design of the pixels preceded the development of the actual compartment holding them, which necessitated revisiting many aspects to align them with the overall product design. The original concept involved six pixels arranged in two rows of three, which is why the initial sketches lean more towards a boxy design. The final sketches, although still rectangular in shape, aims to serve the purpose of a clean look inspired by a block of wood with plants growing between them.



5.3 3d modeling

The essence of any product design project lies in 3D modeling, serving as its core. This process enables designers to analyze the design from multiple perspectives beyond the limitations of two-dimensional planes. Often, modeling uncovers ideas that may have been overlooked during the initial stages of ideation and sketching. Consequently, the modeling phase of the project revealed numerous flaws in initially promising concepts. The sketches, which started as rudimentary notes, began to take shape as they were transformed into detailed models and rendered images. In this regard, the sketches acted as guidelines for the experimentation and testing of the product.

Each component of the product underwent iterative modeling, constantly refining and improving until all the pieces harmonized seamlessly. Working on a 1:1 scale from the outset facilitated the visualization of the product and allowed for easy adjustments as necessary. Given the iterative nature of the development process, sketching and modeling occurred simultaneously. Small yet significant details, such as chamfers and fillets, were incorporated during the modeling phase to enhance both the aesthetics and functional fit of different parts.

Fusion 360 was the chosen software for the 3D modeling process. This phase remained in a state of constant evolution, with valuable details being added or omitted along the way. The ability to visualize the product before prototyping was a major advantage provided by 3D modeling, significantly reducing the chances of errors. Moreover, 3D modeling played a crucial role in obtaining printable prototypes, as most of the testing was conducted using 3D-printed parts. While alternative methods exist for prototyping without 3D models, they often lack accuracy and functional capabilities.

Below are some examples showcasing ideas that materialized through the process of 3D modeling.

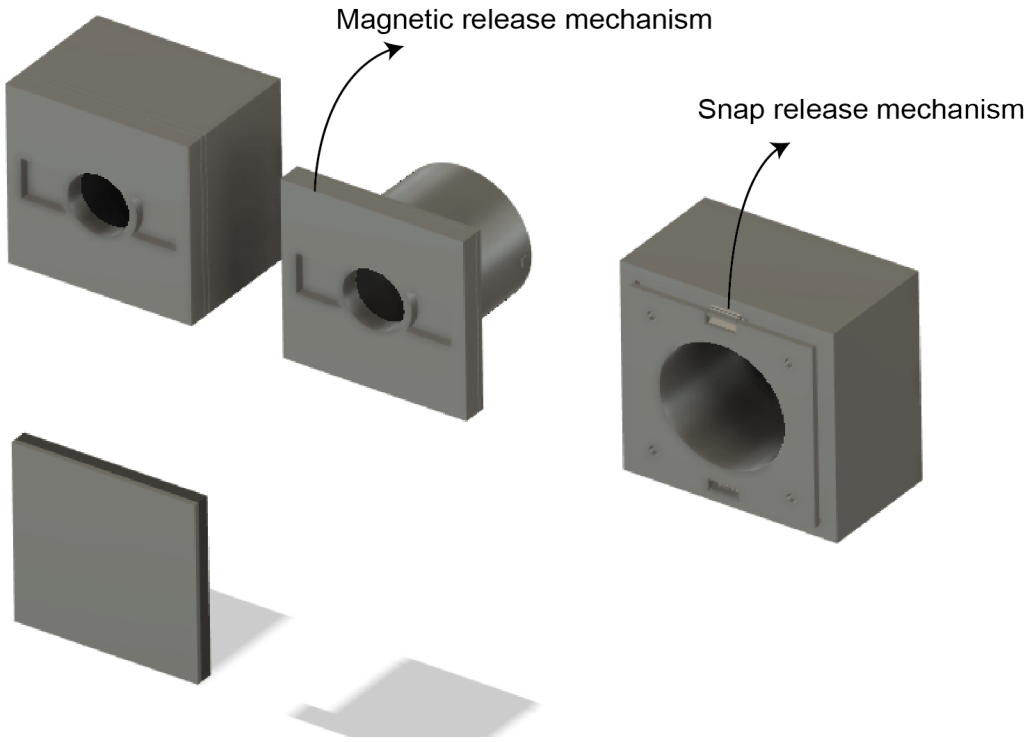


Figure 34. 3D model of different release mechanism tested

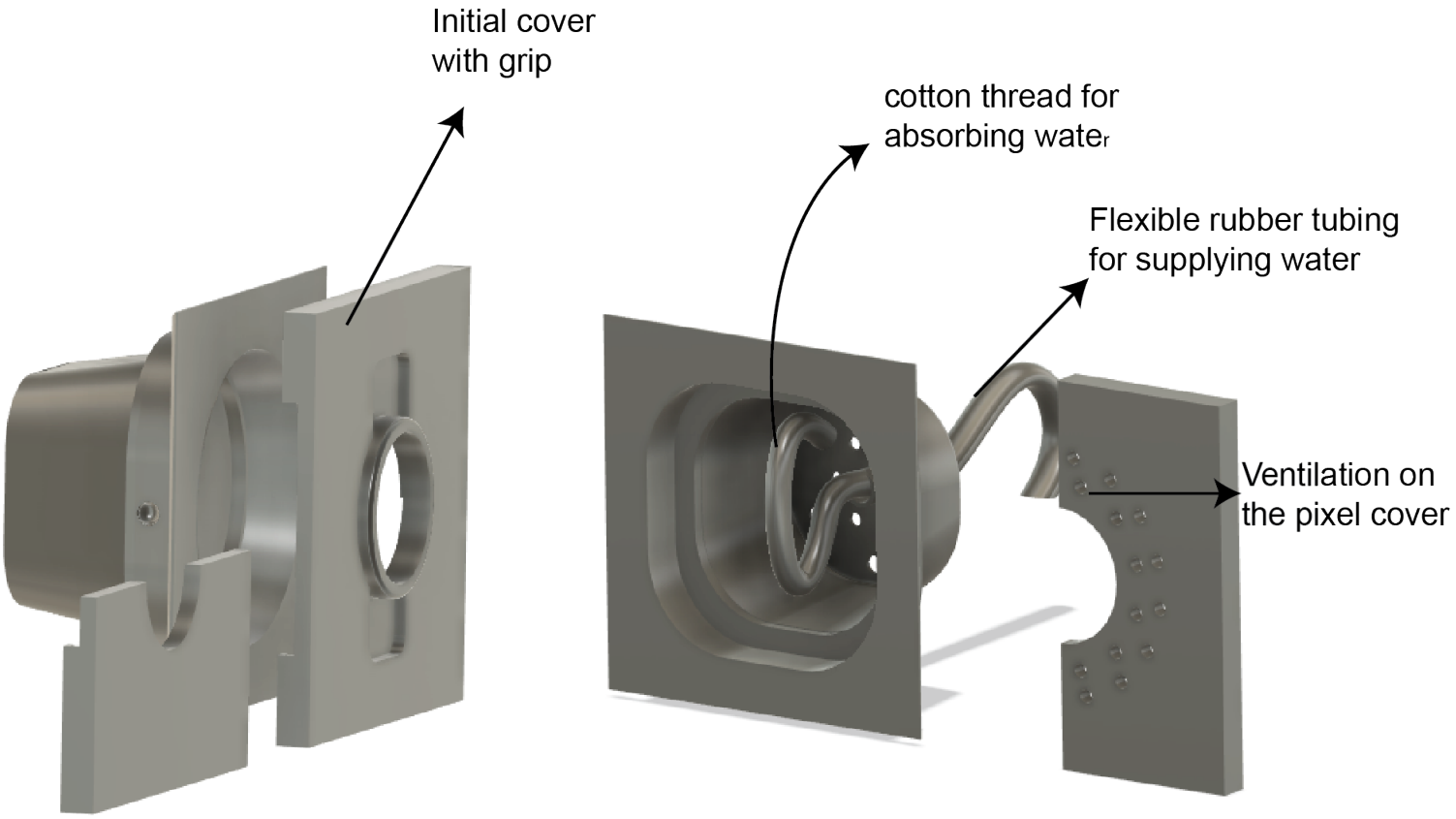


Figure 35. 3D model of the pixel and pixel cover

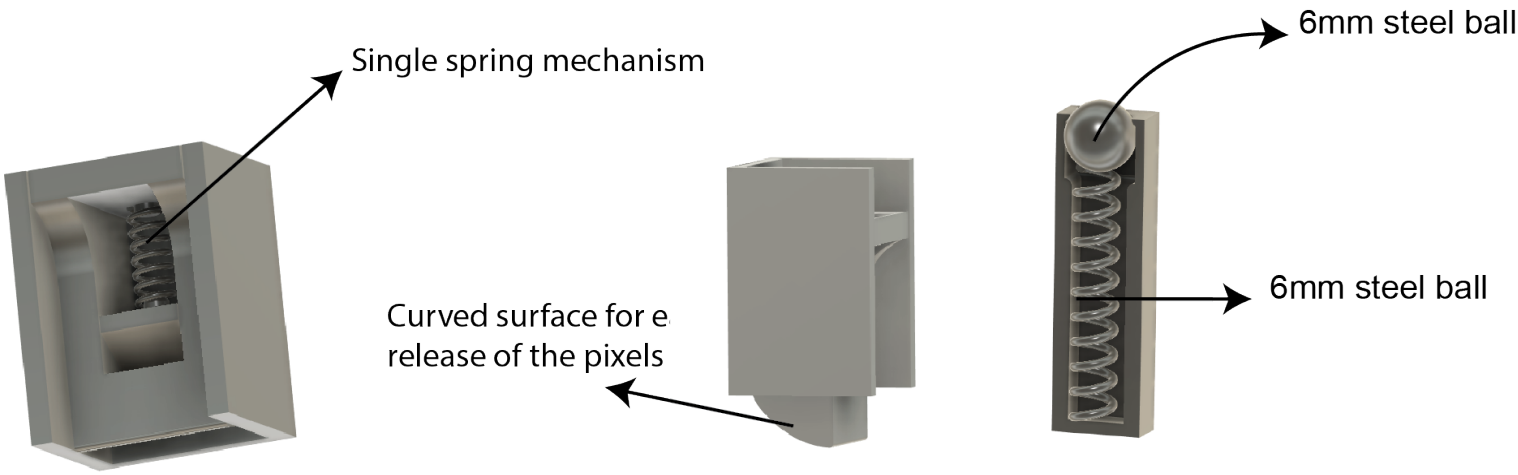


Figure 36. 3D model of the release mechanism and the ball spring plunger

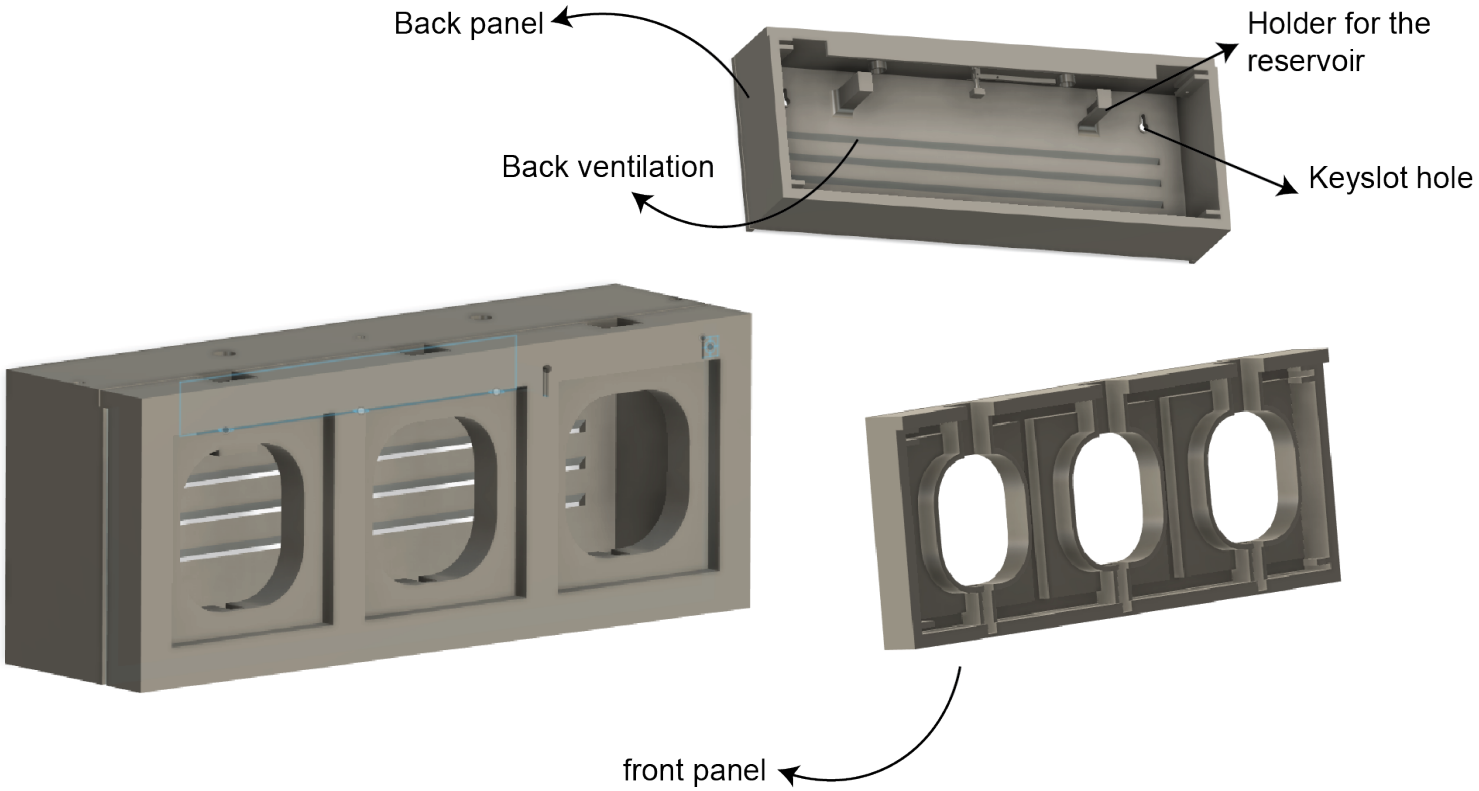


Figure 37. 3D model of the front and back panel

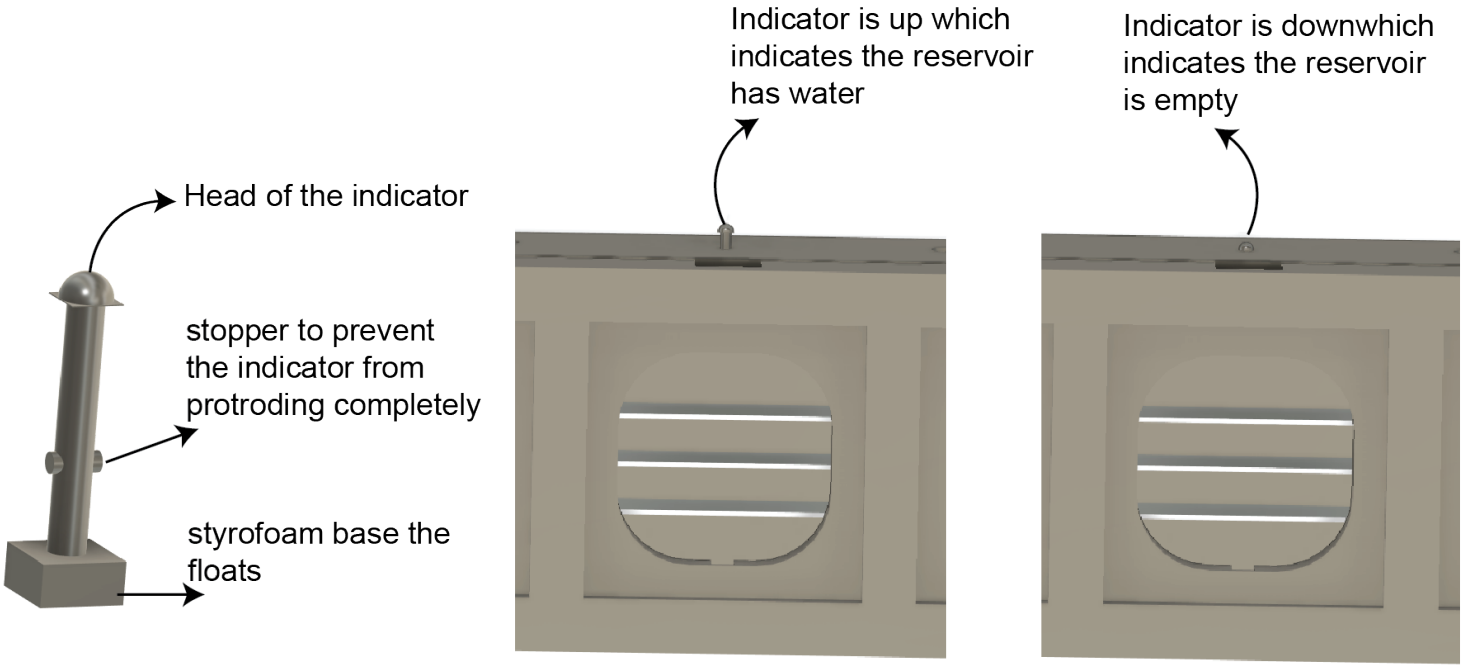


Figure 38. 3D model of the indicator

5.4 Prototyping of the final concept

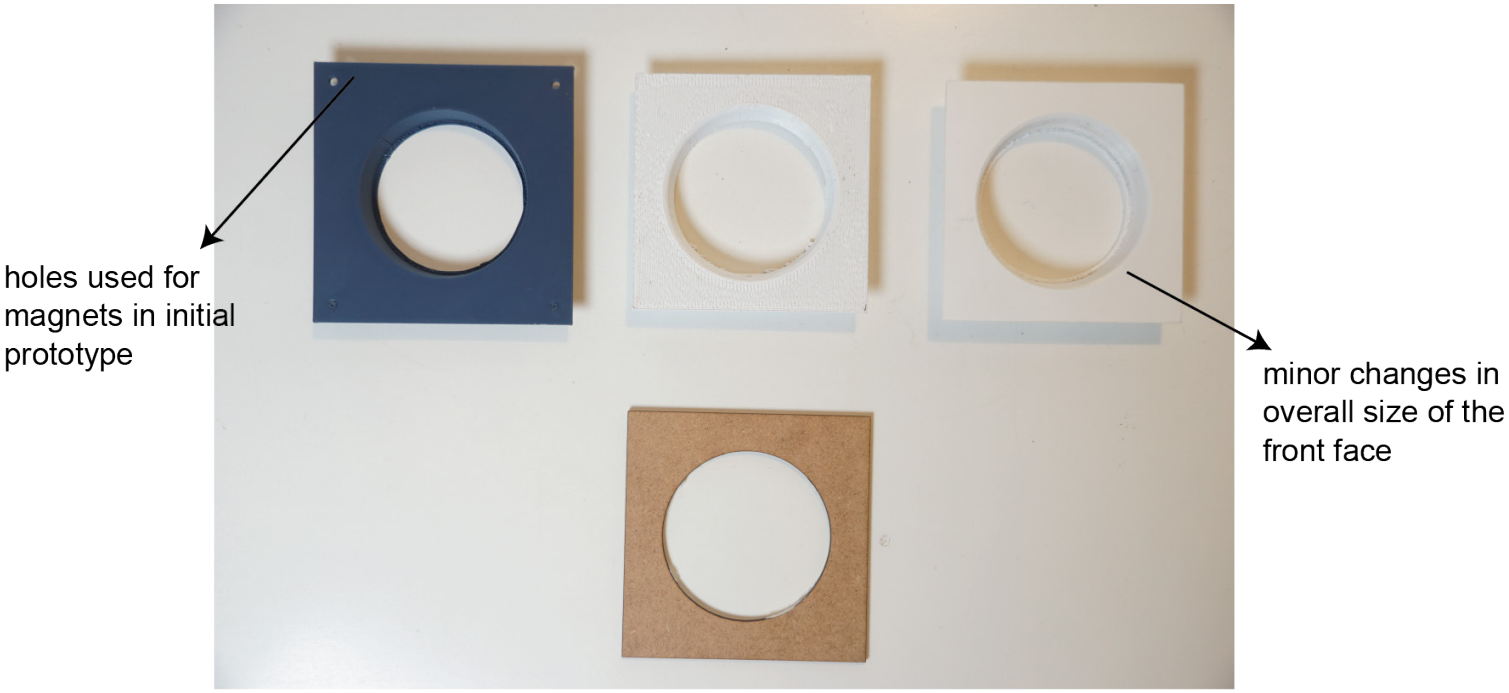


Figure 39. Iterations of the pixel facade

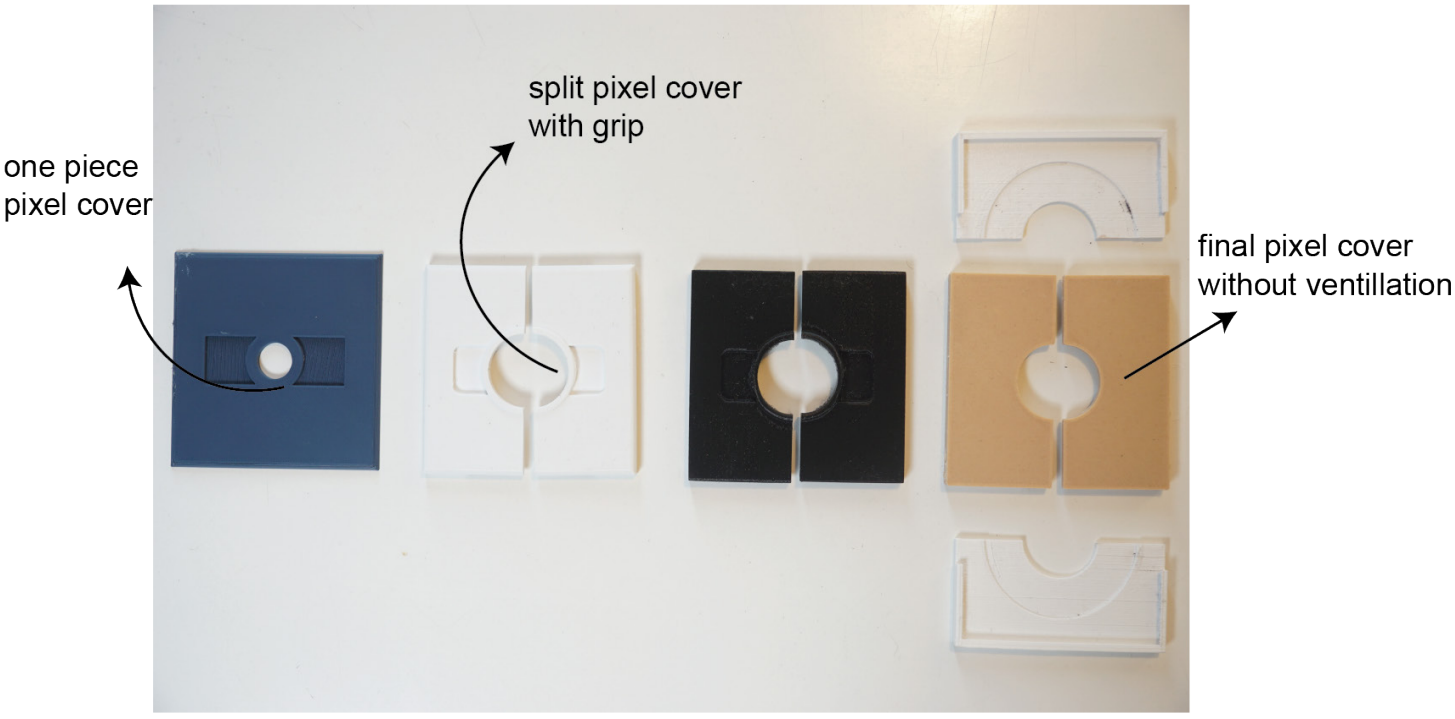


Figure 40. Iterations of the pixel covers

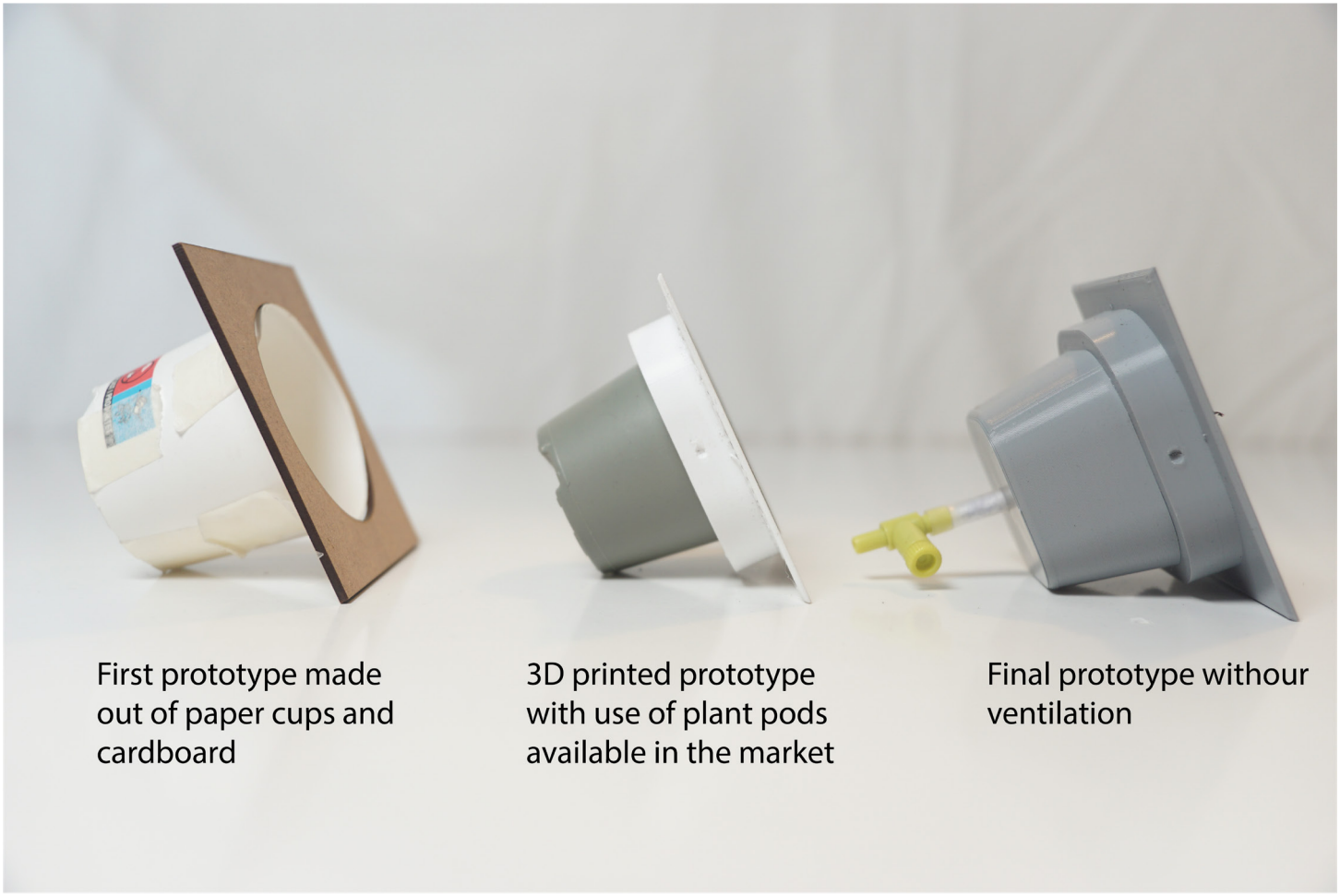


Figure 41. Iterations of the pixel

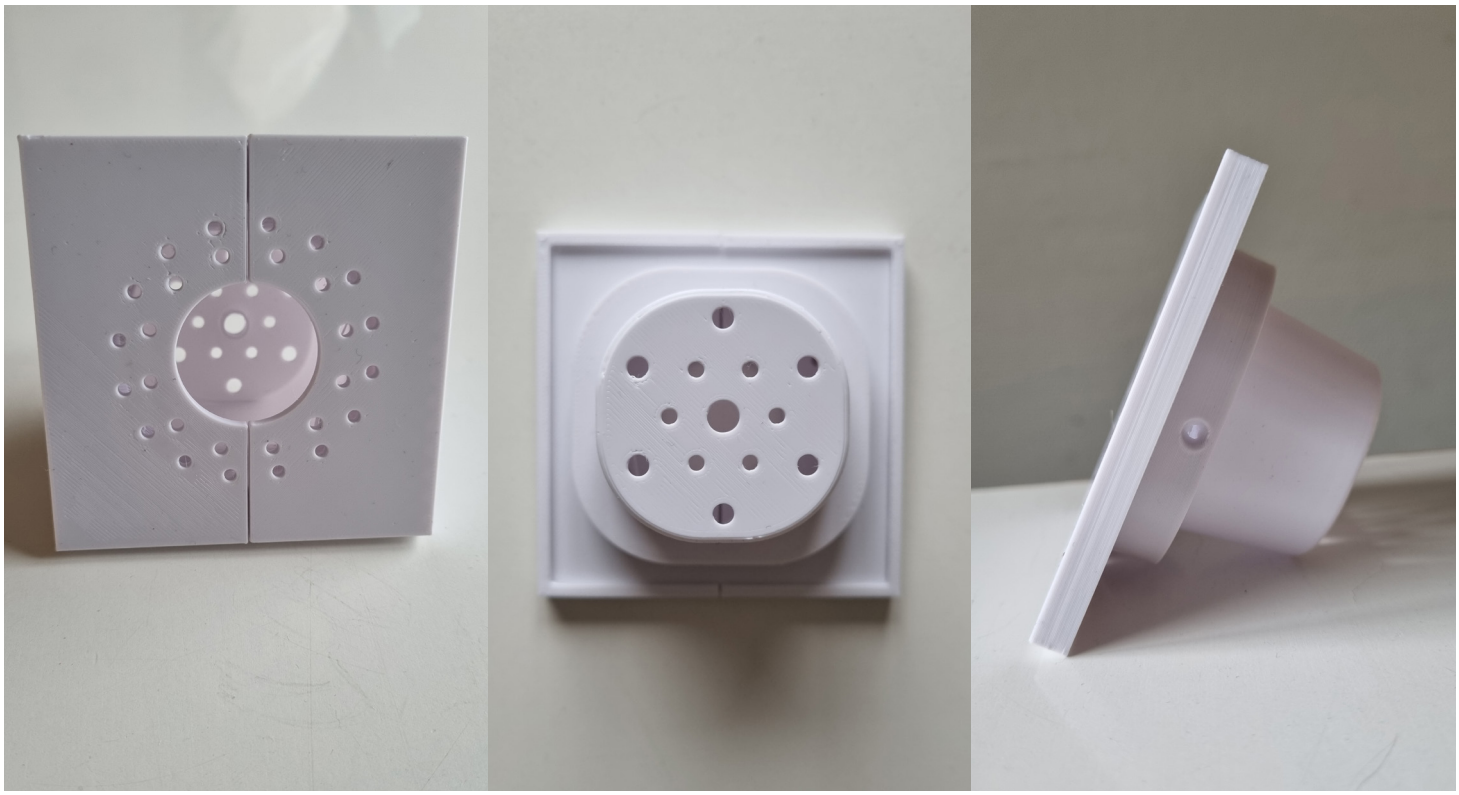


Figure 42. final prototype of the pixel with ventilation

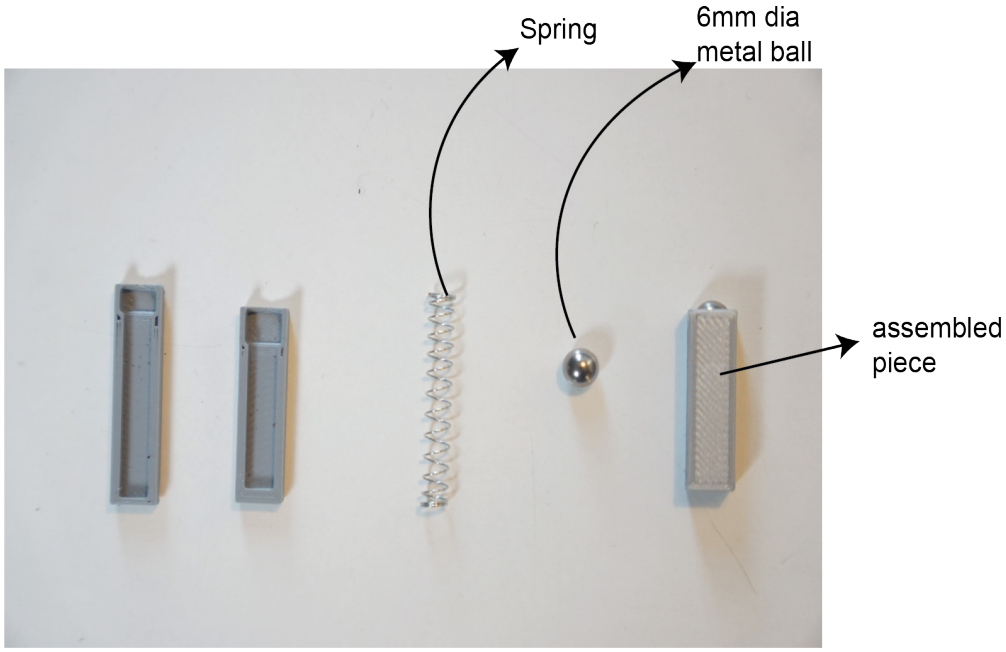


Figure 43. Protoype of the ball spring plunger mechanism

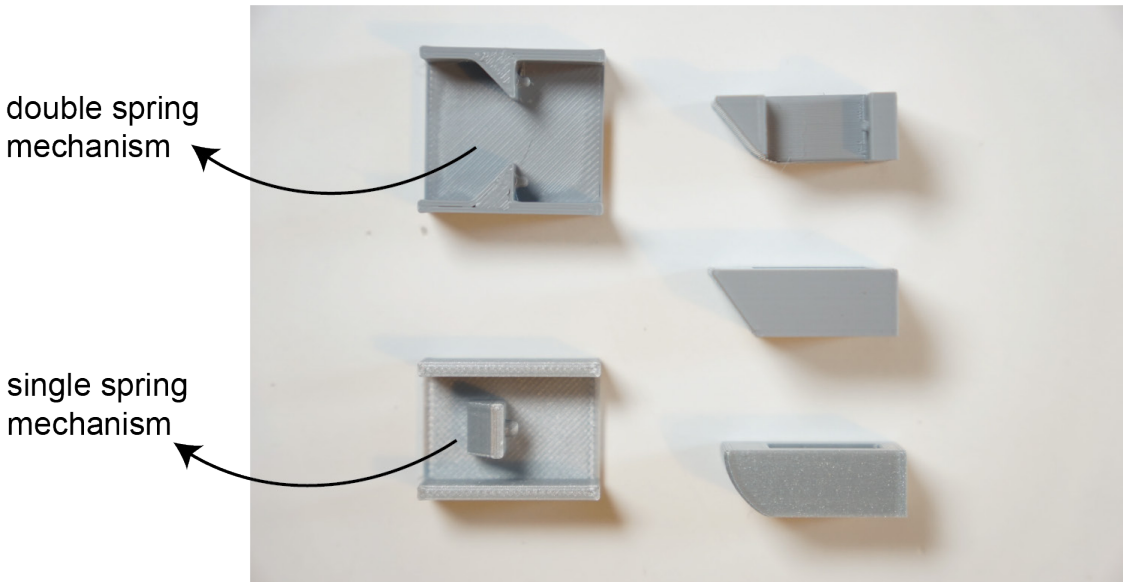


Figure 44. Protoype of the single spring release mechanism

The ball spring plunger was devised as a substitute for snaps and magnets in the product design, mainly due to the vulnerability of snaps to breakage and the cost implications of using magnets, which would significantly increase the overall price. In this mechanism, a 30 mm tall spring with a 4 mm diameter was utilized. To ensure effective operation, a 6 mm diameter metal ball was chosen, surpassing the spring's diameter.

The compression of the spring was carefully calibrated to secure the pixel in place, even when subjected to the weight of the soil and plant. This was essential to prevent the pixel from dislodging easily.

In the release mechanism, springs were also integrated. Two tests were conducted, exploring the use of either a single spring or a double spring approach. The double spring setup was examined to assess whether it would enhance the stability of the mechanism. However, it was found that employing two springs made the mechanism stiffer and harder to activate for pixel release. On the other hand, the single spring proved to strike the optimal balance, providing both the necessary stability and ease of use for the release mechanism.

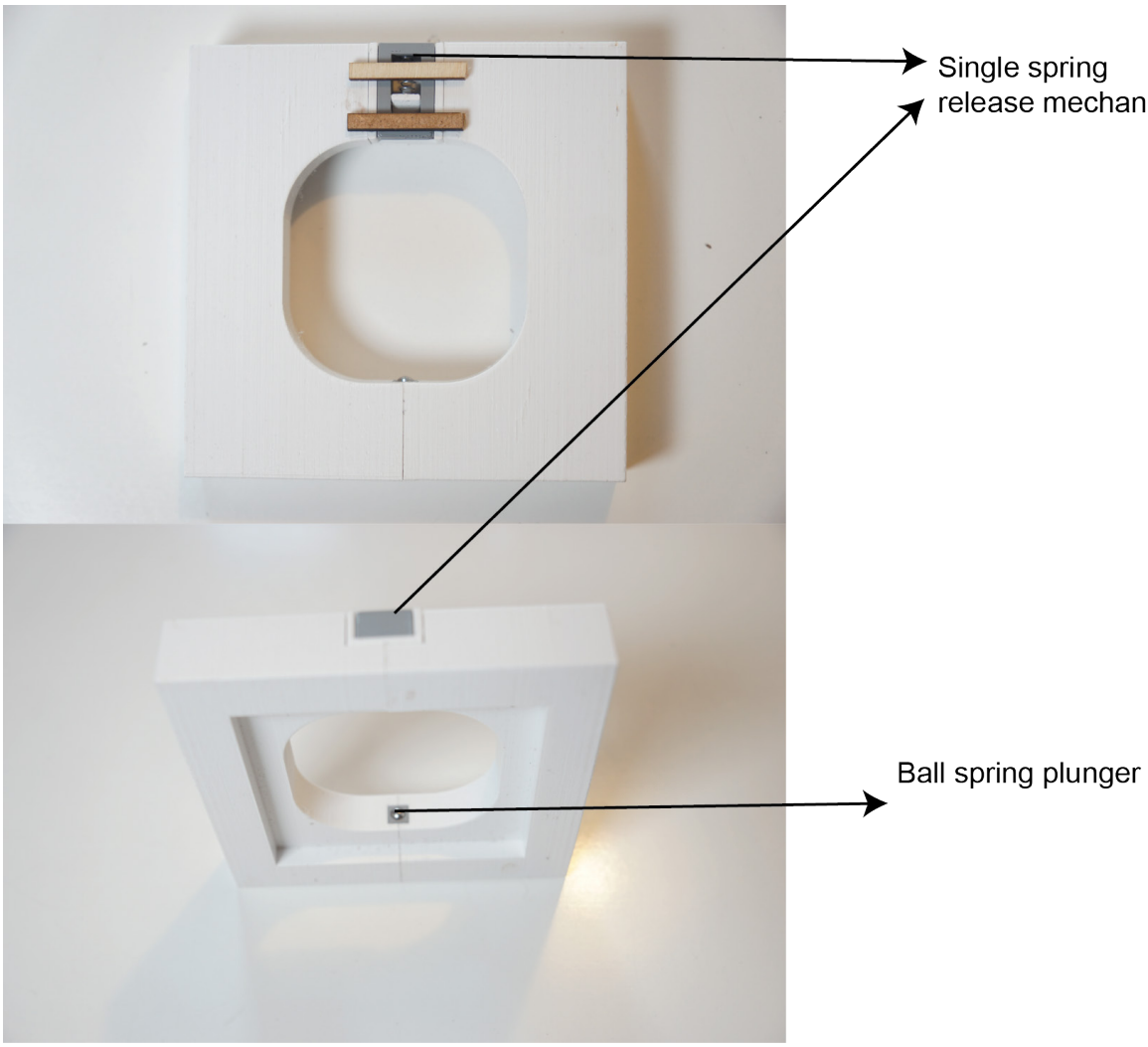


Figure 45. First working prototype to test the tolerance and release mechanisms

The first working prototype was created specifically for tolerance testing, serving as an experimental platform. Throughout the prototyping phase, three different iterations were developed, each incorporating minor adjustments based on the findings from previous tests.

Initially, the ball spring plunger exhibited excessive looseness, resulting in poor attachment of the pixels to the case. The protrusion of the metal ball was insufficient to secure a proper lock within the groove on the pixel. The smooth operation of the ball spring plunger relied heavily on the tolerance between the pixel and its slot, as well as the tolerance of the pixel itself. Similar considerations applied to the release mechanism, where an appropriate fit between the pixel and the case was crucial. If the fit was excessively tight, the mechanism failed, while a loose fit caused the ball spring plunger to malfunction.

Numerous tests were conducted, involving variations in the height of the ball spring plunger, types of springs used in the release mechanism, and the tolerance between the pixel and its slot. Adjustments were also required for the grooves in the pixels. Initially, the groove size matched that of the ball, but this proved ineffective. Subsequently, the groove diameter was increased to ensure a snug fit for the ball within the groove.

The iterative testing process aimed to fine-tune the various components and their interactions, ultimately refining the functionality and performance of the prototype.

Figure 46. First working prototype for a single pixel with plant
(use of plant pod available in the market)

Figure 47. First working prototype with custom pixel

Figure 48. Full scale protoype of front and back panel

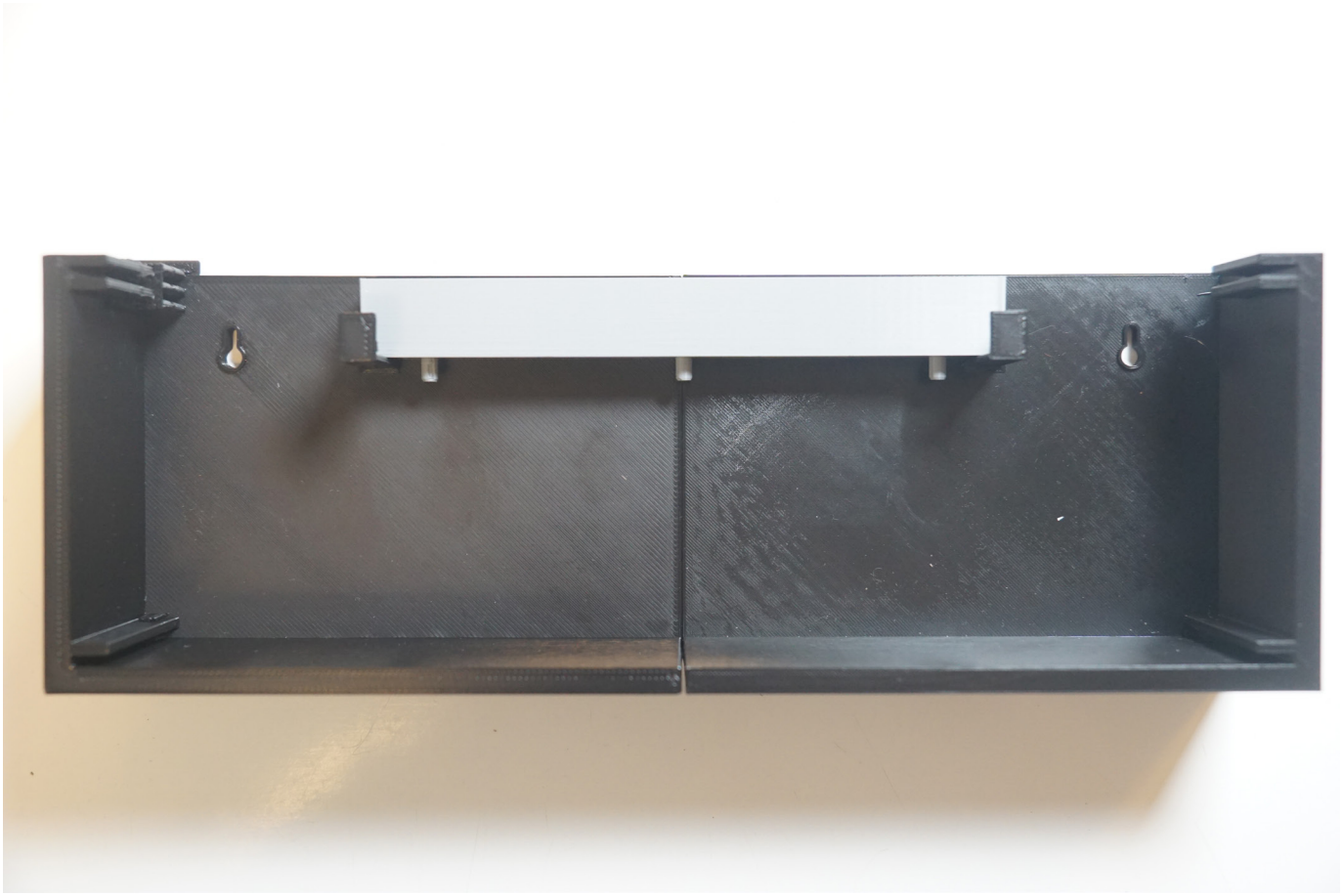


Figure 49. Full scale protoype of back panel with reservoir

Figure 50. Final prototype with variation of pixel covers

5.4.1 Testing the watering system

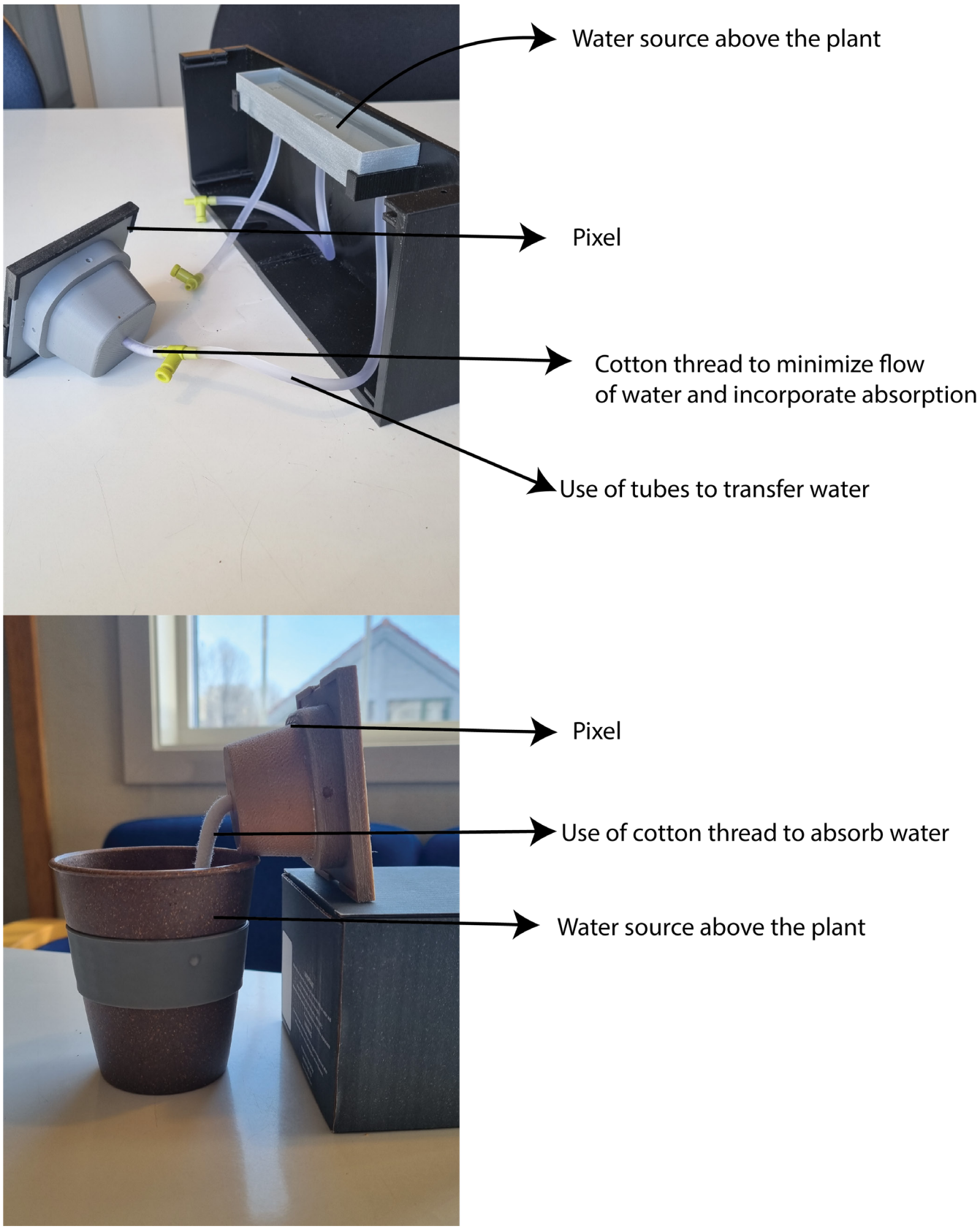


Figure 51. Tests conducted with different watering systems

The watering system played a crucial role in the overall setup, as it determined the plants' ability to thrive within the confined space. Designing an effective watering system required careful consideration of various factors.One key consideration was ensuring an adequate water supply for all three plants within the module, lasting for at least a week. This necessitated a water reservoir capable of holding a sufficient volume.Another important factor was the controlled transfer of water to the plants. It was essential to deliver water at a slow rate to prevent overflow from the pixel, which could create a messy environment inside the enclosure. This necessitated the implementation of measures to regulate water flow.

The image provided depicts two main techniques considered for delivering water to the plants. These techniques were evaluated and explored during the design process to determine the most effective and efficient solution for the watering system.

Water source below the plants

The second approach depicted in the image showcased a more traditional and simplified method of watering the plants. The goal was to ensure user-friendly maintenance of the plants without any unnecessary complexities.

In this approach, a cup was utilized as the water reservoir, while the pixel was positioned above the water source. A cotton thread was inserted into the pixel and dipped into the water within the cup. Through capillary action, the water traveled gradually from the cup to the soil, saturating the soil inside the pixel. This setup offered convenience, as the absorption of water ceased once the soil reached its saturation point.

The simplicity and effectiveness of this approach allowed for easy plant care and reduced the likelihood of overwatering, promoting optimal plant growth within the enclosure.

Water source below the plants

Another approach was tested for watering the plants, which involved the utilization of a combination of cotton thread and a tube. This approach shared similarities with the previous method, where cotton thread was employed for water absorption and transfer.

In this setup, a tube was introduced to facilitate the transfer of water from the reservoir to the pixel. The cotton thread was tightly fixed at one end of the tube, allowing it to absorb water from the reservoir and transfer it to the plant. The inclusion of the cotton thread was essential to regulate the water flow, preventing overflow within the pixel.

To provide additional control over the water flow, valves were incorporated into each tube. These valves could be closed to halt the water flow when there were no plants present in the pixel, ensuring efficient water management.

This approach demonstrated the importance of combining different components, such as the cotton thread and tube, to achieve effective and controlled watering of the plants within the enclosure.

Parameters for the test on a single pixel

Number of days: 7 days

Length of cotton thread: 140 mm (water source below)
40 mm (water source above)
Volume of water: 80 ml

Both setups lasted for more than a week, primarily because the soil was already moist. The rate of water absorption in both setups was intentionally slow, with a preference for the second setup where the water source was placed beneath the soil. Surprisingly, this setup lasted an additional two days longer than the other. In the second setup, the valve remained fully open throughout, allowing unobstructed water flow. Although the valve could be partially closed to reduce water flow, it did not significantly affect the rate of absorption since the primary determinant was the cotton thread's characteristics.

5.4.2 Test to observe developement of mold

The purpose of this experiment was to observe the potential infection and development of molds, diseases, and insects in soil over a period of time. Additionally, it aimed to assess the significance of soil selection and aeration in the pixels. Two types of soil were chosen for the experiment: sterile soil, comprising a well-balanced mixture of potting soil, peat moss, and perlite in a 1:1:1 ratio, and non-sterile soil collected directly from the ground without any added fertilizers or mixtures.

The experiment spanned 28 days, during which the sterile soil was placed in a pixel container with proper aeration holes, while the non-sterile soil was housed in a pixel prototype without any ventilation. Both soil samples were watered every four days within the same controlled environment to ensure no leakage occurred.

At the end of the 28-day period, the sterile soil remained moist and displayed no signs of mold or bacterial growth. The soil mixture provided adequate space for root respiration, and when pressed, it exhibited a moist texture with a responsive bounce-back reaction.

Conversely, the non-sterile soil exhibited minor fungal development, although no visible insects were present. Some white discoloration was observed on the surface, and the soil appeared clumped, indicating poor air circulation. Additionally, the non-sterile soil emitted an unpleasant odor, suggesting the decay of roots within the soil.

Overall, this experiment highlighted the importance of soil selection and proper aeration, as the sterile soil maintained its integrity and avoided the growth of molds and bacteria, while the non-sterile soil demonstrated issues related to fungal development, lack of air circulation, and decaying roots

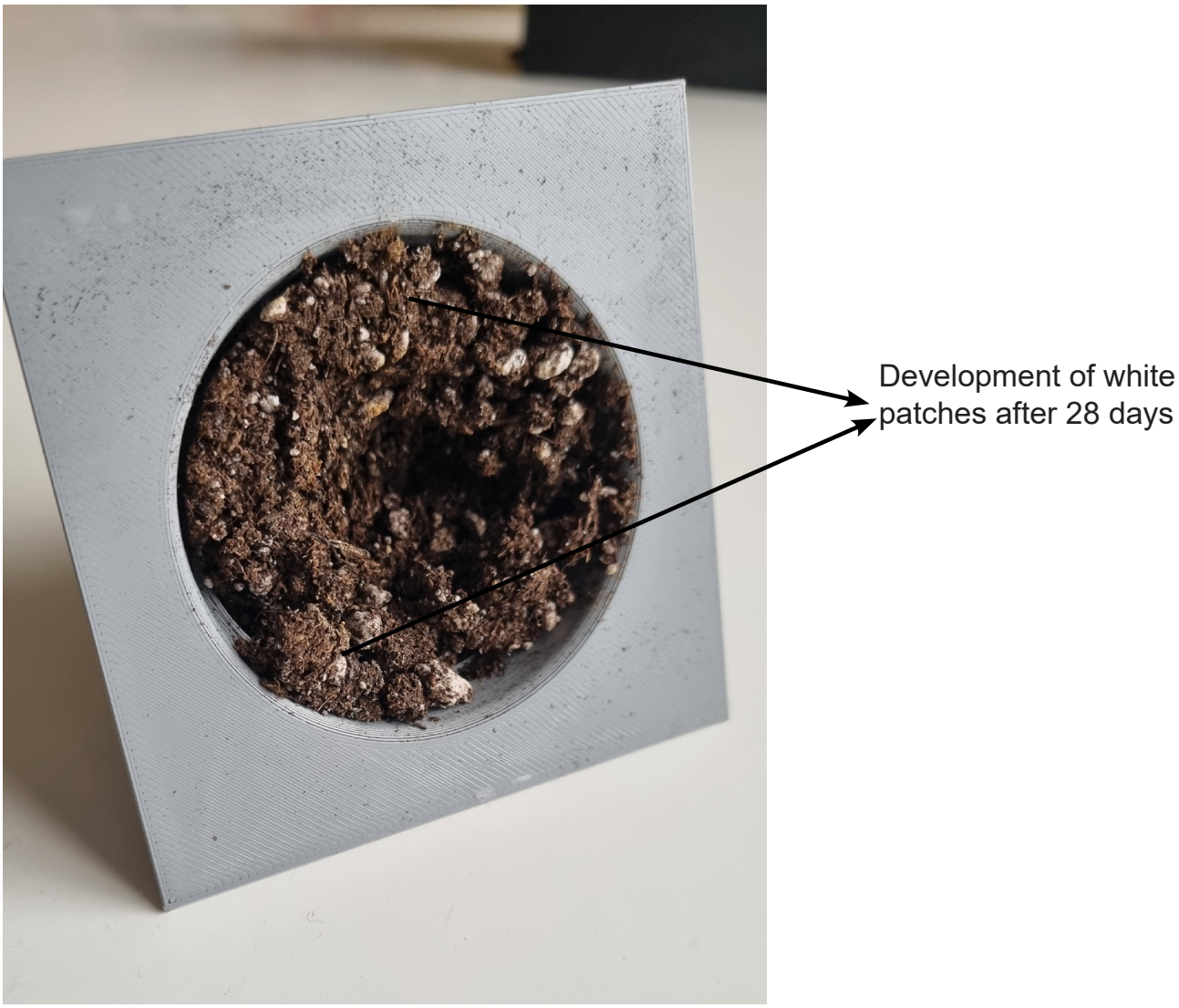
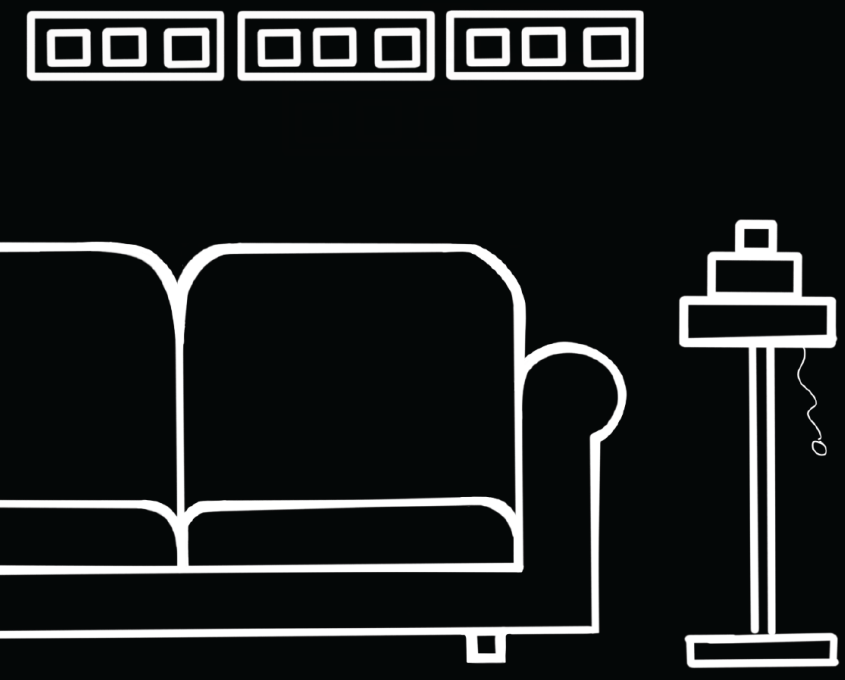


Figure 52. Result of test to observe mold formation

6. Final results



Throughout the completion of the project, a multitude of ideas were explored and tested. Some of these ideas proved to be viable and applicable, while others did not meet the desired criteria. The final results achieved were a culmination of numerous iterations of prototyping and testing, which were complemented by extensive background research and valuable user feedback.

The iterative process of prototyping and testing allowed for continuous improvement and refinement of the product. It enabled the identification of successful ideas that enhanced functionality, aesthetics, and usability, while also highlighting areas where certain concepts or approaches fell short. This combination of rigorous testing, research, and user input ultimately contributed to the development of the final product, which embodies the most effective and satisfactory solutions achieved through the project's journey.

6.1 Fitting of the pixels

After conducting numerous tests throughout the prototyping process, the final decisions regarding the design and functionality were reached. One notable decision involved the front face of the pixel, which was designed as a square surface that remained flush with the surface of the holder.

The selection of a square shape for the cover of the pixel was made with the primary goal of facilitating easy attachment and detachment. This choice ensured a straightforward and convenient process for users when interacting with the pixel, allowing them to effortlessly secure or remove the cover as needed.

By iteratively testing and refining the design, these decisions were made to optimize the user experience and streamline the functionality of the product.

6.2 Mechanisms used in the final product

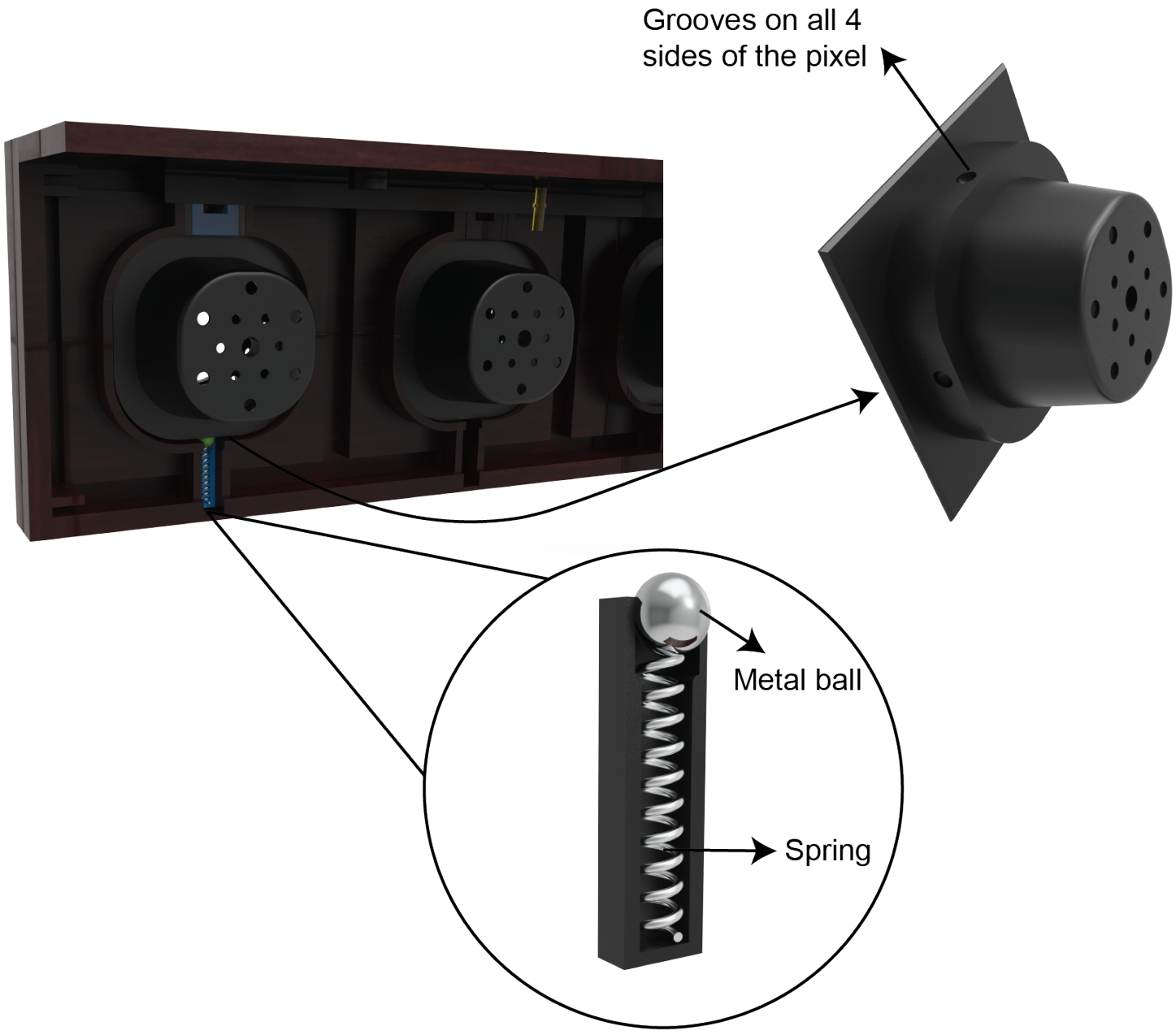


Figure 53. Final result for the ball spring plunger mechanism

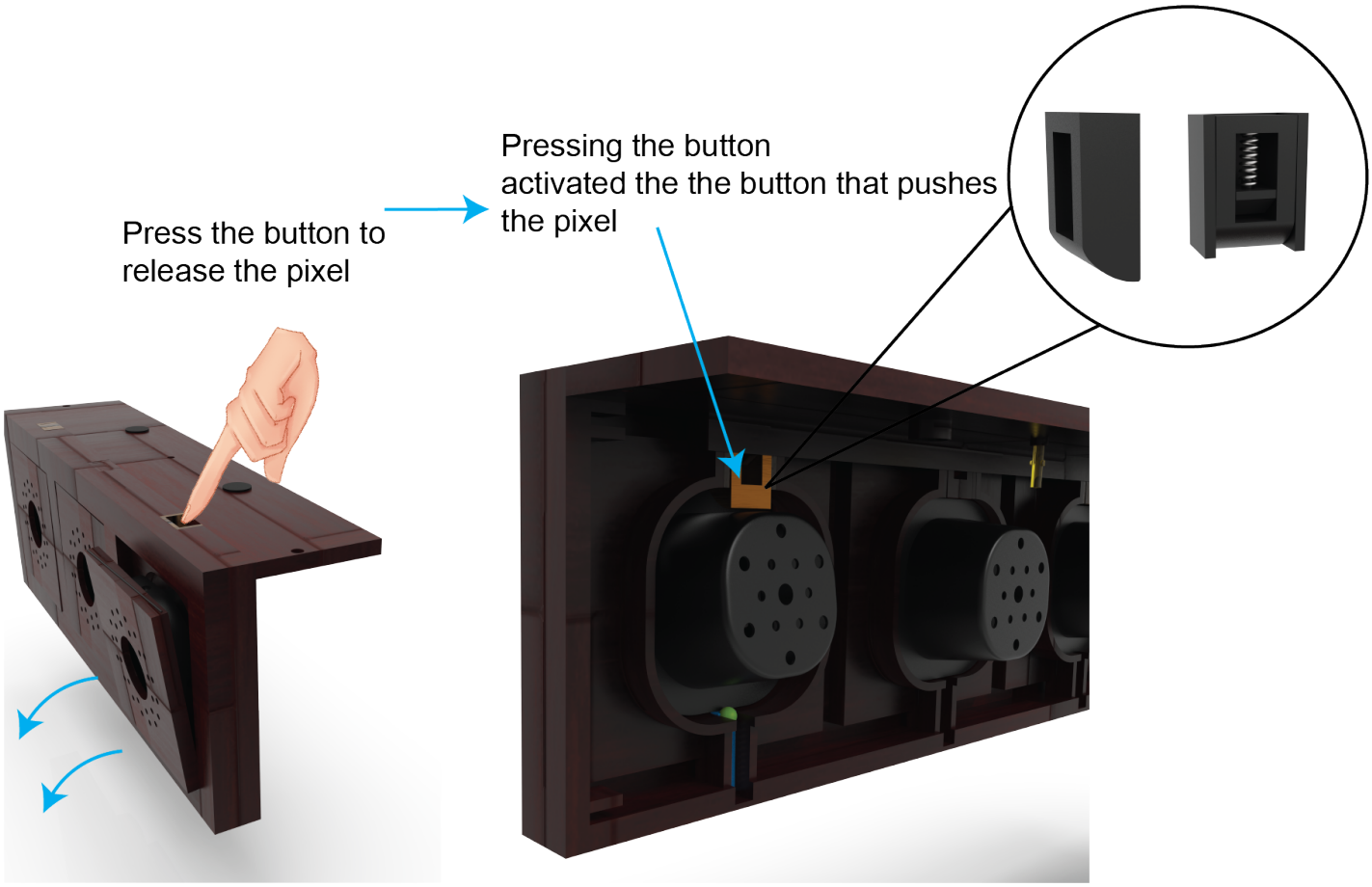


Figure 54. Final release mechanims used in the product

The top part of the product features three buttons, each assigned to the release of a specific pixel. These buttons are integrated with a spring-loaded release mechanism. When pressed, the mechanism activates, pushing the corresponding pixel outward. Once released, the button returns to its original position.

The use of a single spring mechanism ensures that pressing the buttons requires minimal effort, as excessive pressure is not necessary. This functionality not only serves a practical purpose but also provides an interactive element for users to engage with the product. The short yet pleasant interaction between the user and the buttons helps foster a sense of connection and familiarity.

This unique feature sets the product apart from other vertical green walls, giving it a distinct presence. While being functional, the mechanism is designed to eject the pixel to a manageable distance for easy retrieval by hand. This deliberate design choice aims to prevent accidental drops or damage to the pixel, as well as to minimize any potential mess or inconvenience.

By combining functionality, user interaction, and thoughtful design considerations, this release mechanism enhances the overall experience and value of the product.

6.3 Layout of the final watering system

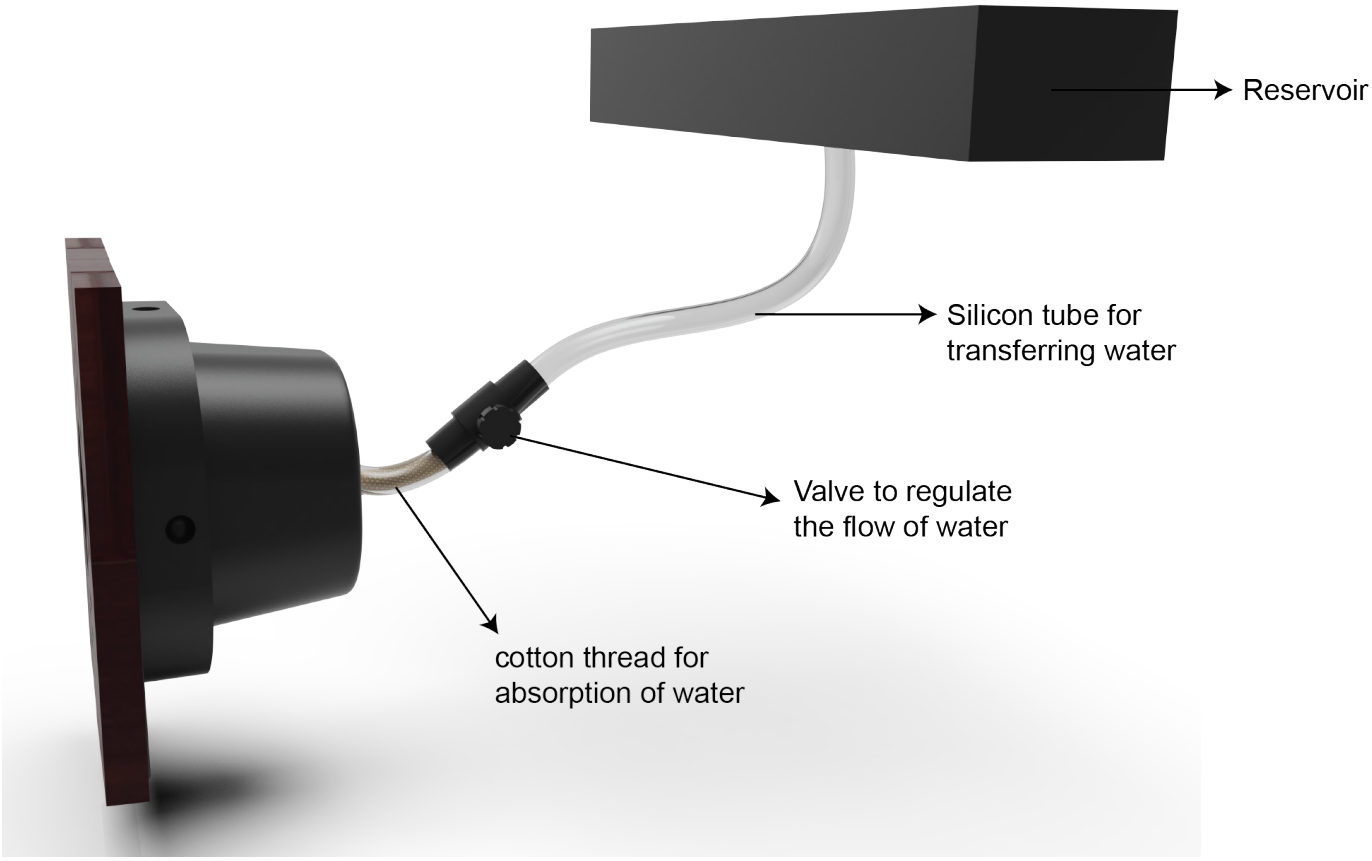


Figure 55. Overhead watering system with valves

In the final design, an overhead watering system was chosen for implementation. However, there were challenges that needed to be addressed to ensure controlled water flow and prevent overflowing of the pixels. While the addition of a valve in the mechanism helped partially control the flow, its main purpose was to stop water flow during pixel changes. Without the valve, water would spill out when the pixels were detached from the reservoir.

To prevent water flow solely due to gravity, a tightly fitted cotton thread with a diameter of 6 mm was used. This thread served two purposes: it stopped water flow and ensured that the plants were not overwatered. The thread absorbed the water from the reservoir and transferred it to the soil. The soil would absorb the water until saturation, at which point the flow would cease, preventing overwatering. It is important to note that the cotton thread should fit tightly in the opening to prevent any water leakage, which could lead to overflowing and harm the plants.

Due to size limitations of the reservoir in the overall product design, a fully filled reservoir was found to be sufficient to water the plants for a week before requiring a refill. The positioning of the water tank at the bottom and dipping the thread in the water was considered as an alternative watering option. However, implementing this setup in the design proved challenging. It was difficult to determine if the thread was properly soaked in water when placed in the slot, as the opening was not wide enough. Through testing, it was discovered that the thread missed the bottom reservoir entirely, making it impractical to use in the design.

Ultimately, the overhead watering system with a tightly fitted cotton thread proved to be the most viable option, ensuring controlled and efficient watering while avoiding water overflow and overwatering of the plants.

6.4 Indicator

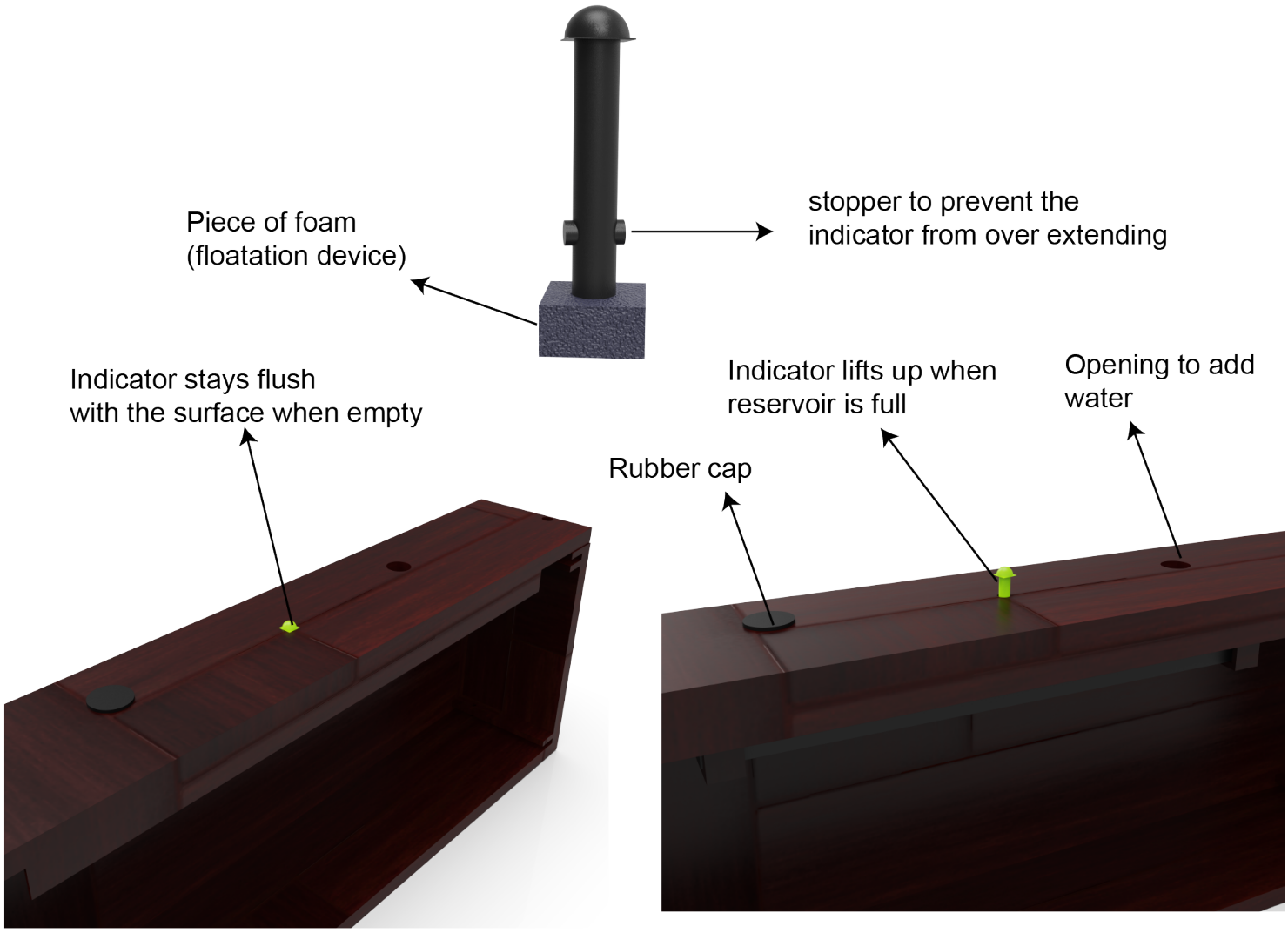


Figure 56. Working of the indicator in the final product

To facilitate easy filling of water, two holes were incorporated on the top of the product. When not in use, these openings were closed off using rubber caps to ensure a secure seal. As for the design of the indicator, it was positioned on the top surface. This decision was made to maintain a clean and minimalist look on the sides and front of the product, without any additional features.

The indicator consists of a circular knob on the top surface, designed to prevent it from going through the top panel. Attached to the bottom of the indicator is a piece of foam, serving as a flotation device. When the reservoir is filled with water, the foam is lifted along with the indicator, indicating a full reservoir. As the water level gradually decreases over time, the indicator slowly drops down, eventually returning to its original position and remaining flush with the surface. This provides a visual cue to the user regarding the water level in the reservoir.

6.5 desk stand

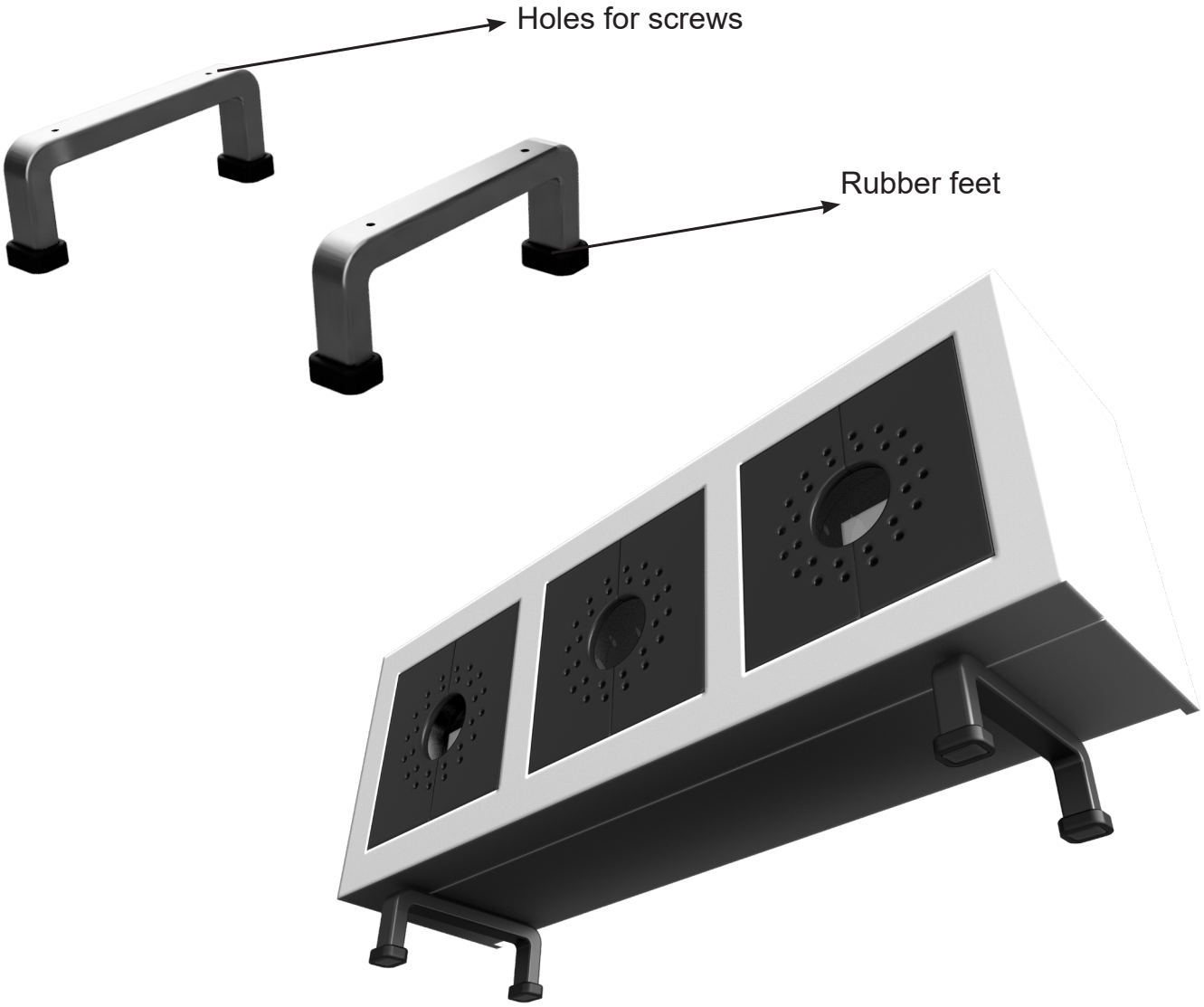


Figure 57. Use of stands in the final product

Considering that the product was also designed for office desks, it was essential to incorporate a detachable stand. The stand is attached to the main body using four screws. At first, the inclusion of a stand seemed unnecessary because the product had a sufficiently wide base to sit directly on flat surfaces. However, during testing, it was discovered that when the product was placed on any surface, the plants came into contact with the table, necessitating some form of elevation. As a result, a pair of stands was incorperated, featuring rubber feet on the base to prevent unwanted movement.

6.6 Materials and manufacturing

Ensuring the feasibility of manufacturing is a crucial aspect of product design. A product must be manufacturable in order to be practical and applicable in real-world scenarios. In the case of this product, it consists of numerous small components that require precise assembly to ensure seamless integration. There are various methods available to achieve this level of precision, but injection molding stands out as the most cost-effective and efficient approach for achieving intricate details.

While some parts used in the design, such as the 6mm steel ball, springs, valves, and tubes for water transfer, are readily available in the market, the individual sections of the product need to be manufactured using injection molding. To determine the suitability of each part for injection molding, draft analysis was conducted. This analysis helps to assess the feasibility and compatibility of each component with the injection molding process, ensuring that they can be effectively manufactured

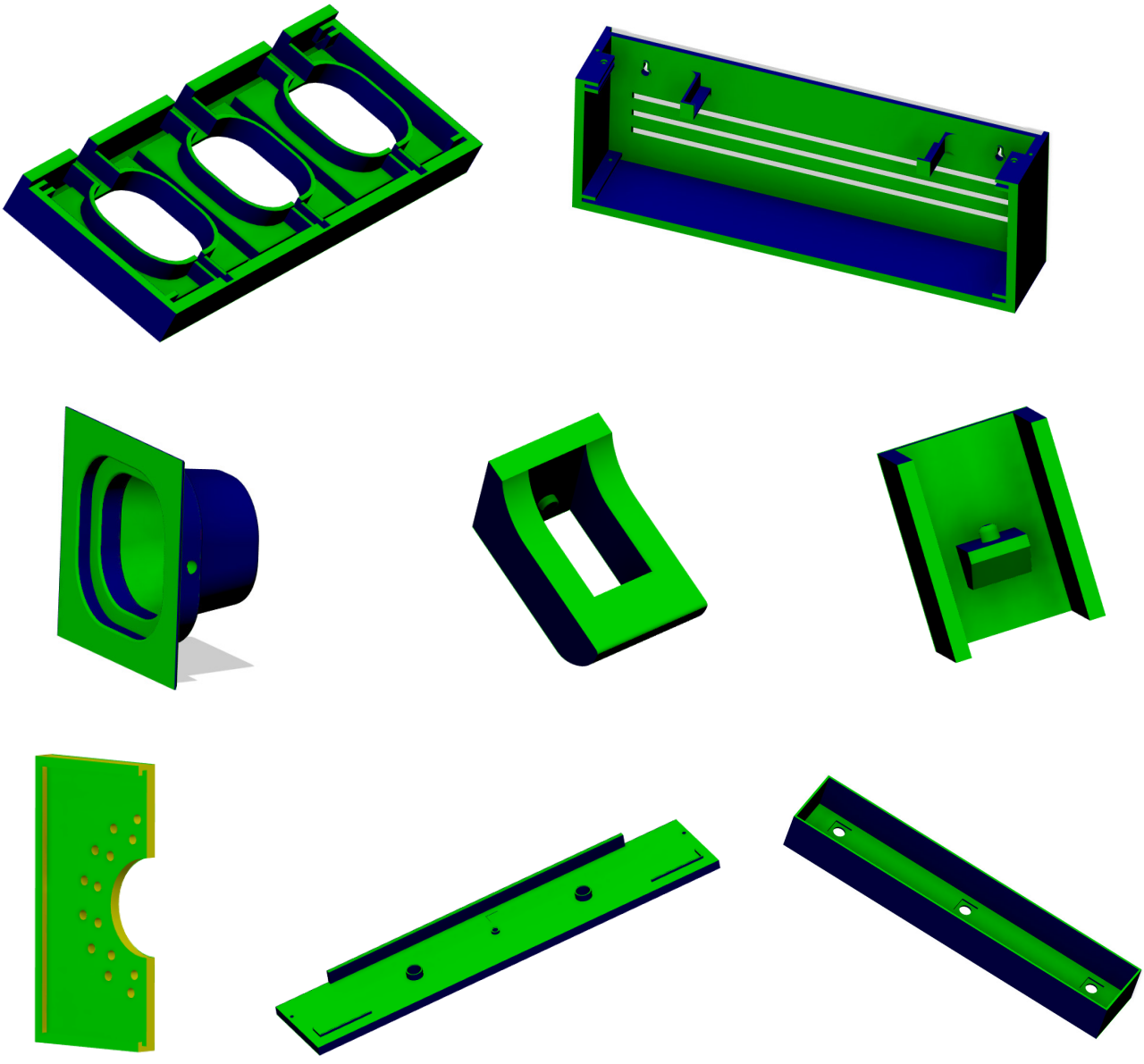


Figure 58. Draft analysis of different parts of the final product

The draft analysis is a crucial step in determining the moldability of the parts. In general, a mold consists of two sections: the inner mold and the outer mold. The green area represents the surface in contact with the inner mold, while the blue area represents the surface in contact with the outer mold. The molds may differ depending on the direction in which the mold is cast.

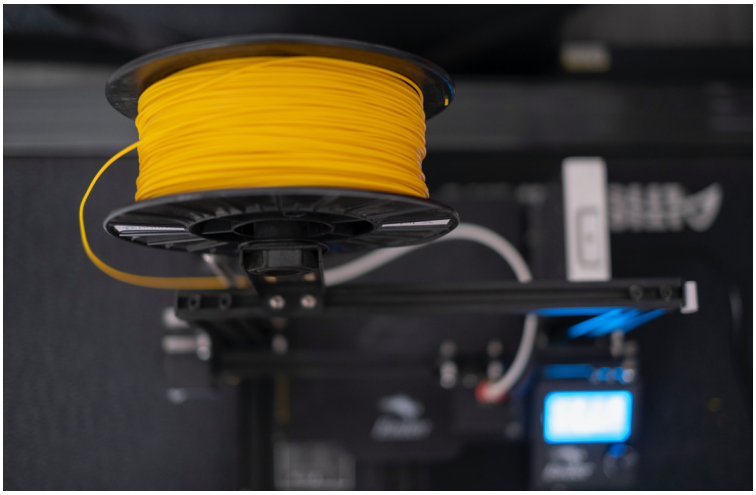
During the draft analysis, the angles and dimensions of the surfaces of the parts are examined to ensure that they can be effectively molded. Adequate draft angles are necessary to facilitate easy ejection of the part from the mold without causing any damage or sticking. The analysis helps determine if the design of the parts allows for smooth and successful molding, taking into consideration factors such as draft angles, undercuts, and the overall geometry of the components.

6.6.1 List of Parts

PARTS	NUMBER	MANUFACTURE	Size
Front panel	1 pcs	injection molding	326.5*120 *22 mm
Back panel	1 pcs	injection molding	326.5*120*63 mm
Pixel	3 pcs	injection modling	82.9*82.9 mm
Pixel cover	6 pcs	injection molding	86*43 mm
Reservoir	1 pcs	injection molding	280*40*22 mm
Release button	3 pcs	injection molding	15.6*14.8*26.7 mm
Release button shell	3 pcs	injection molding	20.4*16.9*26.7 mm
Springs	6 pcs	ready made	4.3 dia , 30mm
Metal ball	3 pcs	ready made	6mm dia
Screws	6 pcs	ready made	M2 6*.25
Attachment piece	4 pcs	injection molding	43*9.8 mm
Top panel	1 pcs	injection molding	326.5*58 mm
Indicator	1 pcs	injection molding	24 mm
Silicon tube	3 pcs	ready made	130mm ,6mm int dia
Valve	1 pcs	ready made	8mm int dia
Cotton thread	3 pcs	ready made	130 mm
Stand	2 pcs	injection molding	76*30 mm

Table 3. All the parts used in the final product along with their dimesnions

6.6.2 Choice of material



he intital thought was to make the product out of wood. This idea was short lived since wooden products increases the cost of the the product and also have problems regarding mass production. Since the product has minor details that needs to be precise, using wood as the primary material would have caused problem in fittings. This was one of the reasons why use of plastic for production was more practical.

ABS is the most widely used plastic for injection molding because of its desirable properties. ABS has high strenth, low melting temperature, it is recyclable, and provides good resistance to chemicals and heat. Recycled ABS has increased in popularity since raw ABS is more expensive.

6.7 Dimensional CAD drawings

All the dimensions are represesnted in millimeters (mm)

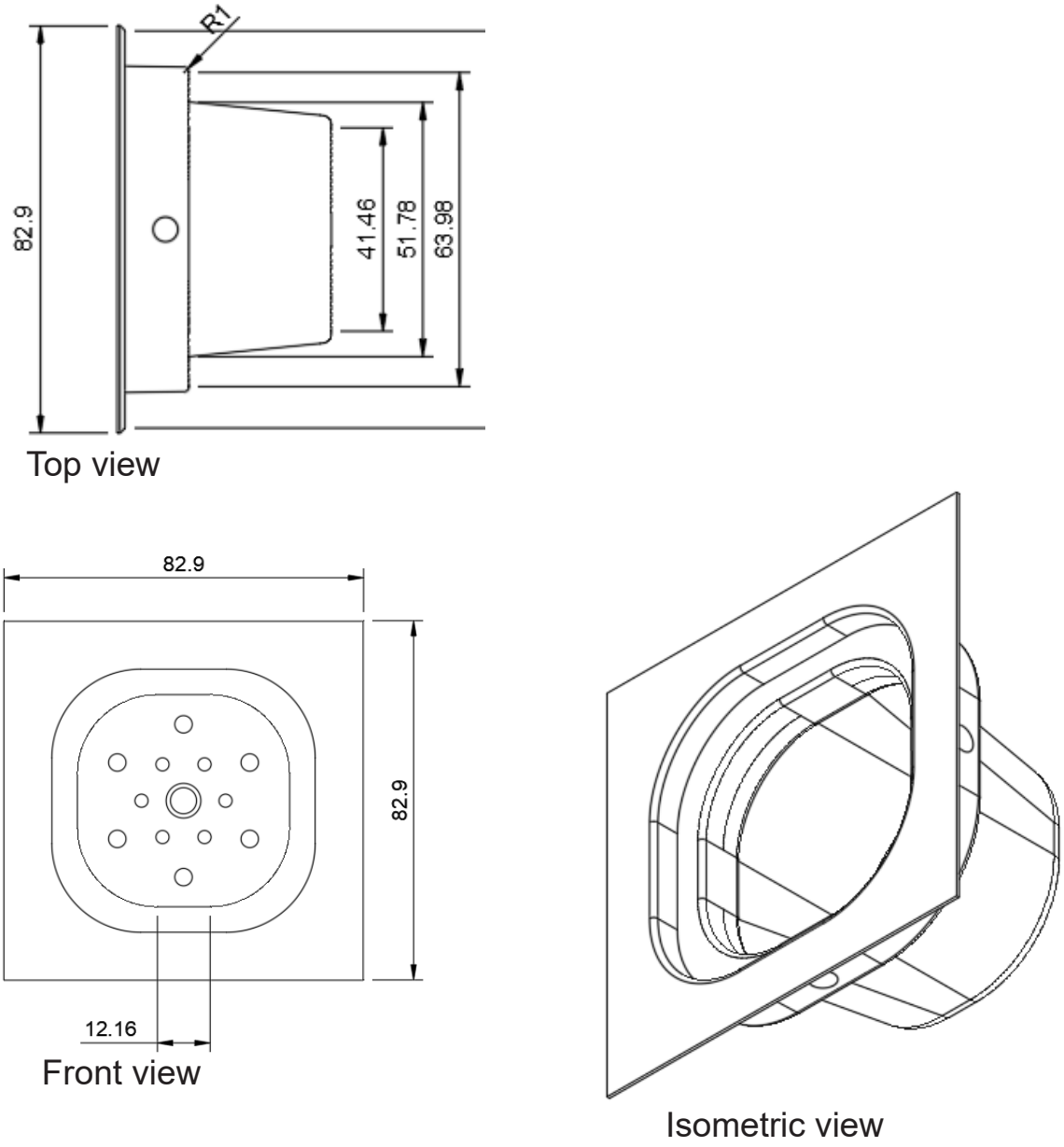
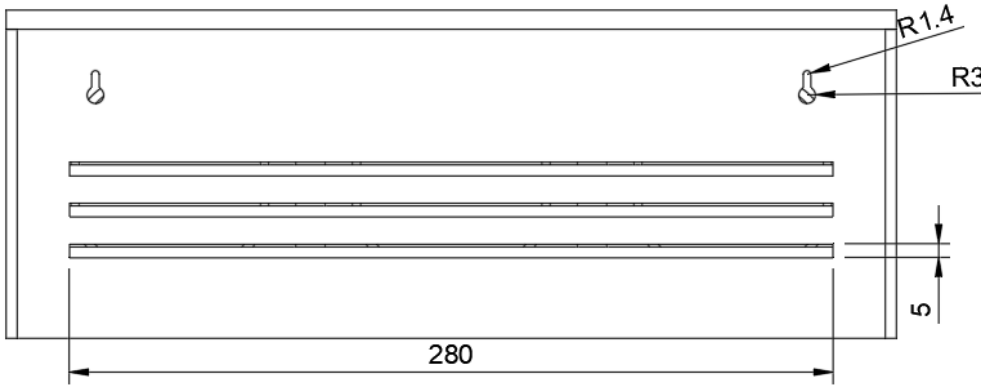
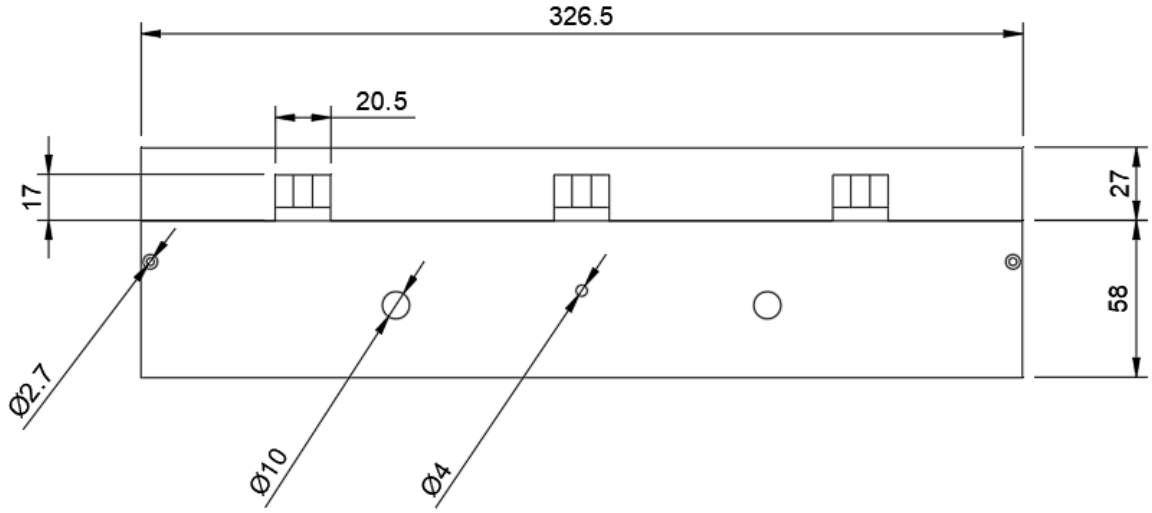


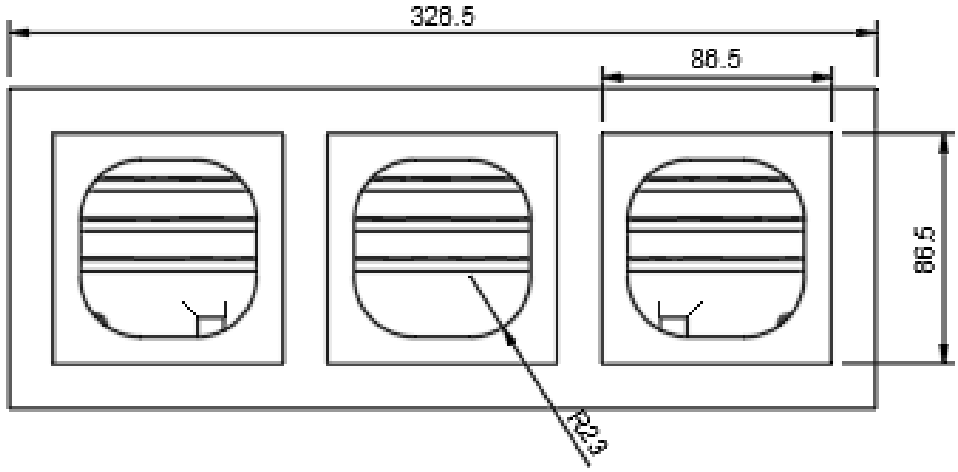
Figure 59. Dimensional CAD drawing of the pixel



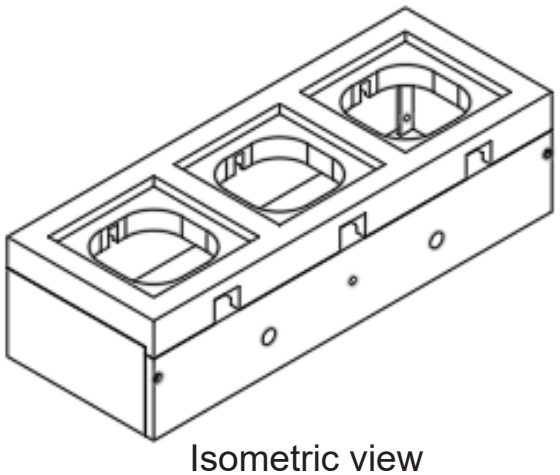
Back view



Top view

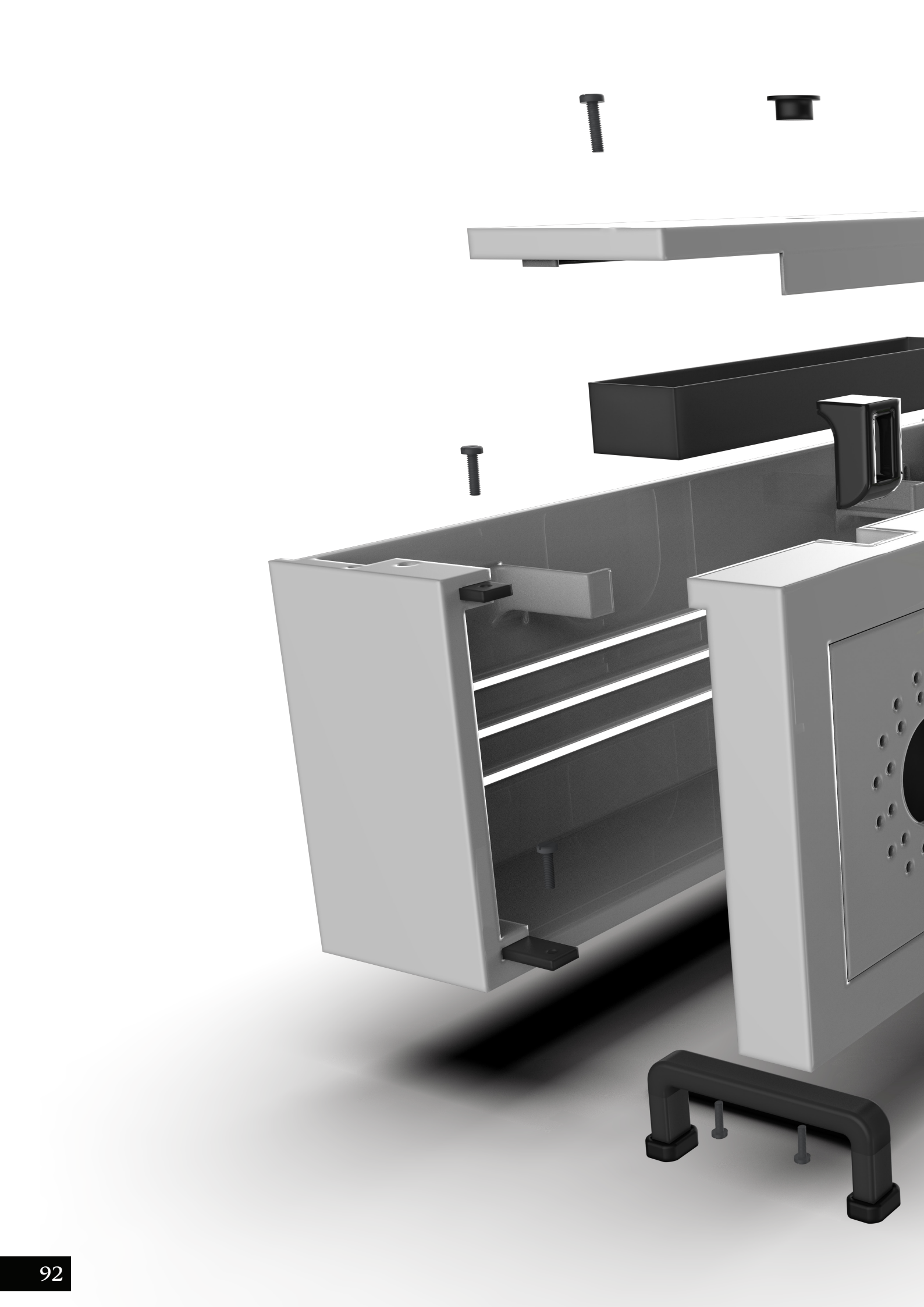


Front view



Isometric view

Figure 60. Dimensional CAD drawing of the case



7. Discussion

7.1 Problem Statement

The existing vertical garden available in the market are designed for large scale applications and are often unsuitable and economically unviable for small spaces or residential use.

The main objective of this project was to create a smaller and more compact version of a vertical green wall that could be enjoyed by individuals in their own personal spaces. While additional criteria were added throughout the project, the primary goal was to design a personal green wall that people could easily purchase and incorporate into their homes.

Typically, vertical walls are seen in larger, more formal settings such as shopping malls, conference halls, and offices for partitioning purposes. However, these vertical walls are often large and expensive, making them inaccessible to the average person. The intention of this project was to address this issue by offering a more affordable and manageable alternative.

The final design successfully achieved many of the project's goals. It is more cost-effective compared to commercially available personal vertical walls, and its maintenance is also relatively simple. The compact size allows it to be placed anywhere in a room, while still attracting attention with its unique and distinct character. Furthermore, the design is intentionally user-friendly, enabling users to easily maintain and repair the product themselves if necessary.

An important aspect of the design is the orientation of the plants. Unlike traditional norms of growing plants vertically, the design incorporates horizontal placement of the plants, which was a challenging task. However, through testing and experimentation, it was proven to be achievable and provided a unique and visually appealing aspect to the product. This horizontal growth creates an illusion that the plants are growing out of the frame, leading to the frequent use of the term "live picture frame" throughout the project.

The product was designed to be used in patterns, allowing users to expand their plant collection if desired. While certain design restrictions exist, such as the inability to connect all the products in a single watering system, sets of three offer flexibility in arranging them on a wall. The workshop conducted, along with observations and extensive research, played a significant role in defining the specific character and features of the product.

Overall, despite areas for improvement, the project successfully met its core objective of creating an affordable, user-friendly, and visually captivating personal green wall that can be enjoyed in individual living spaces.

7.2 Refelction on the Process

The project had various approaches and proved to be an enlightening journey. Throughout the process, I acquired new techniques that were previously unfamiliar to me. As a former engineering student, my exposure to these tools and methods was limited to my 1.5 years in Norway. Initially, familiarizing myself with the diverse set of tools utilized by designers in different projects posed a challenge. Nonetheless, conducting workshops, particularly my first workshop with a company, proved to be enjoyable. The positive attitude of the participants further enhanced the experience.

While the results achieved were not everything I had envisioned, they provided a solid foundation to build upon. Looking ahead, I believe involving individuals from the target user group in workshops would prove more beneficial to the project. These workshops also played a vital role in my personal development as a leader. Informal interviews were primarily conducted with students due to the absence of a language barrier. However, when attempting the same approach with Plantsjen, the language barrier became apparent and led to moments of awkward silence.

The initial stages of sketching were particularly enjoyable, as there were no design constraints at this point. It was a phase of exploration, with different ideas and narratives being sketched out. The 3D modeling process posed certain challenges. Ensuring that all parts could be manufactured accurately, especially considering intricate details, proved to be demanding and time-consuming. Additionally, I had the opportunity to experiment with prototyping using various materials. While the final prototype was 3D printed, the initial stages involved the use of recycled materials such as old cardboard and paper cups, effectively reducing project costs while serving the same purpose.I also gained valuable knowledge in rendering products, primarily utilizing KeyShot. Learning new techniques to enhance the visual appeal of a product provided a competitive advantage in terms of its overall marketability.

Having a fixed timeline for task completion proved to be highly beneficial for the project. Setting deadlines for each task ensured a smooth and efficient process, with fewer obstacles along the way. The adherence to a pre-planned schedule was instrumental in completing the project on time, which was particularly crucial given the unforeseen challenges encountered. Establishing a pace for the thesis was, in my opinion, the most significant aspect of the project.

Throughout the project, I had weekly meetings with my supervisor, Prof. Andre Liem, and frequent meetings with the company, albeit on unscheduled dates. Despite the lack of pre-planning for these meetings, they turned out to be effective considering the limited time available to complete the project. While I believe that more research could have been conducted on the specific topic at hand, it was not feasible due to the inability to continue my specialization project from the previous semester.In conclusion, maintaining a well-defined timeline and actively engaging in regular meetings with my supervisor and the company played a crucial role in the successful completion of the project. Although there were limitations in terms of research, the project was accomplished within the allotted timeframe, ensuring its timely delivery.

The weekly meetings with Prof. Andre Liem, my supervisor, proved to be highly beneficial and fruitful. There were moments during the project when it felt like progress was stagnant, and I struggled with the feeling that my efforts were not yielding presentable results. However, Andre's professional guidance and support were instrumental in navigating through such challenges. His advice not only provided direction on what steps to take next but also served as a source of motivation during times when my ideas were not yielding the desired outcomes.

In addition to Prof.Liem's guidance, the interactions with my classmates played a significant role in my journey. Engaging in conversations with them, whether discussing my own design or learning about their projects, provided valuable perspectives and insights that influenced my approach. These interactions broadened my understanding and enriched the experience of the project.Overall, the combination of Prof. Liem's guidance and the interactions with my classmates served as a constant source of inspiration and helped me overcome obstacles along the way. Their input and perspectives contributed to the evolution of my project and played a vital role in shaping the final outcome

7.3 Complexity along the way

The process of completing this project was filled with both challenges and learning experiences. As someone with limited experience in the field of design, I encountered difficulties along the way. One of the initial challenges I faced was creating sketches that were visually appealing and presentable. To overcome this, I had to start from the basics and learn perspective drawings, which was a time-consuming but valuable learning process.

Prototyping also presented its own set of challenges, which were expected. It is common for sketches to undergo changes and adjustments when translated into physical prototypes. I encountered instances where the tests failed despite multiple design modifications. This was particularly true for the watering system, which posed numerous initial problems. Inaccuracies in 3D models sometimes led to leaks in the prototypes, hindering the progress of experiments with the watering system. The fitting of components was also a recurring issue that required attention.

Furthermore, the availability of 3D printers in the department posed additional obstacles. As other students were preparing for their finals, the printers were in high demand, and the fact that several of them were out of order exacerbated the situation. Failed prints further prolonged the process, as some prints took hours to complete and required constant monitoring.

Another aspect of the project that took more time than anticipated was finalizing the overall shape of the product. Initially, the idea was to create a design that resembled wood or timber, deviating from a plain square shape. However, after considering various factors and weighing the pros and cons of different design choices, the development process led to a boxy design.Despite the challenges and unexpected setbacks, the journey allowed me to acquire valuable skills, overcome obstacles, and refine the overall design of the product.

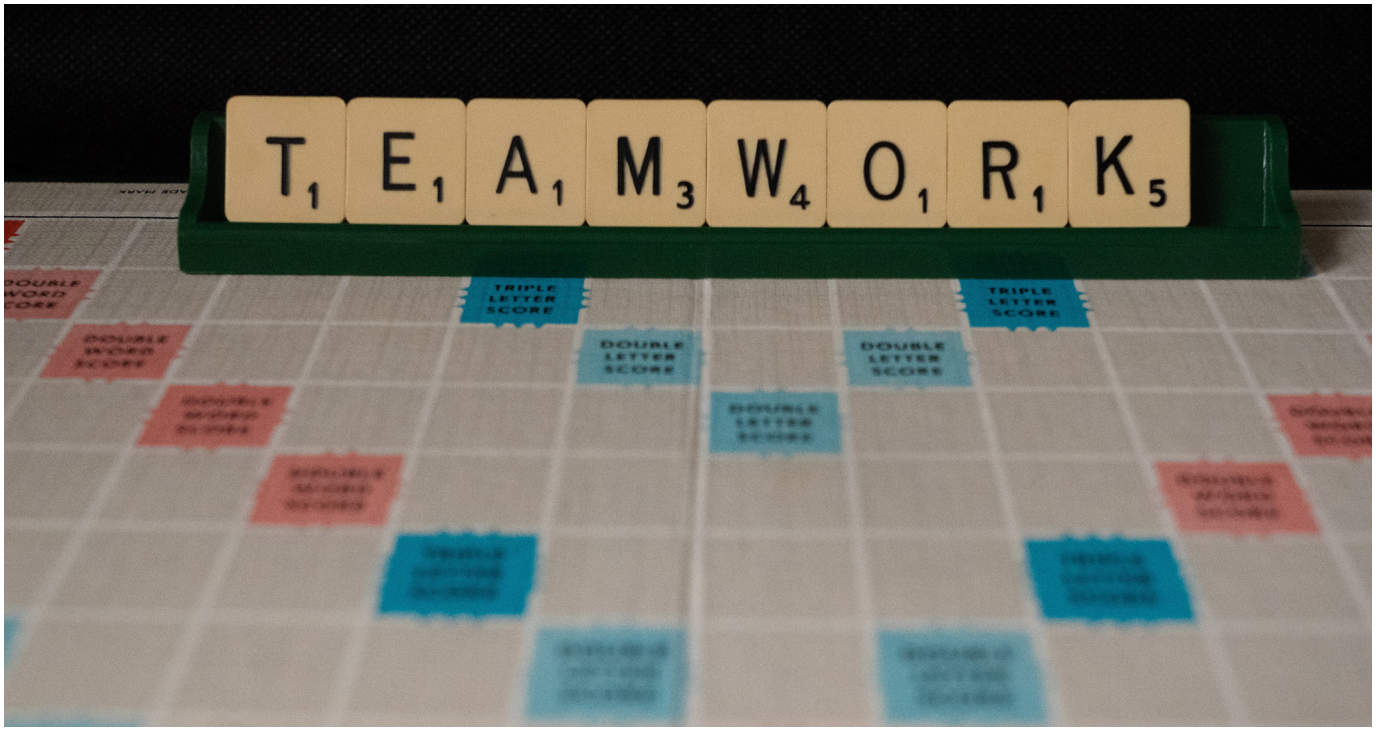
7.4 User's interaction with the product

The bond between humans and products is a complex relationship that goes beyond mere utility or functionality. It encompasses emotional connections, personal experiences, and a sense of identity. When a product resonates with an individual on a deeper level, a strong bond is formed, leading to increased satisfaction, loyalty, and even advocacy.

Additionally, the aesthetics and design of a product play a crucial role in forging a bond. Humans have an innate appreciation for beauty and are drawn to products that are visually appealing. Aesthetics can evoke emotions and reflect personal tastes, allowing individuals to express their identity through the products they choose. Whether it's a sleek and minimalist design or a vibrant and playful color scheme, these elements contribute to a strong human-product bond. A product that is intuitive, easy to use, and provides a seamless experience enhances the connection with the user. When a product aligns with the user's expectations, it fosters a sense of satisfaction and trust, strengthening the bond.

The product desgined through this thesis touches all the above mentioned points to increase its credibility. Small actions like pressing a button to release the pixel from its case, or the click heard when the pixel is placed in its slot adds to the experience providing a sense of satisfaction which overtime can promote habit formation. These little interaction that the users have with the product requires minimum effort hence encouraging the users to explore the functionality of the product.

7.5 Collaborating with Greenfall



Collaborating with Green Fall was an exceptional experience. They demonstrated unwavering support and eagerness to assist throughout the entire process, providing me with the necessary tools and information to develop a comprehensive product. It was my first time collaborating with a company to design a product with the potential for functionality upon completion.

Given my limited expertise in the field of green walls and plants, the team members proved invaluable in sharing their experiential knowledge, which could not be found through online research. Each meeting with the team was well-prepared, ensuring efficient use of time, but they were also readily available to provide assistance even outside of scheduled meetings. I had the privilege of having my inquiries addressed late at night, showcasing their enthusiasm for the project.

Working with the company not only allowed me to gain valuable insights into green walls and plant-related aspects but also facilitated the development of my interpersonal skills and teamwork abilities. The experience refined my approach to collaborative work and enhanced my overall interaction skills.

7.6 Future possibilities and expansion

Initially intended for residential and limited space applications, Pixels were originally designed to maximize their functionality within a confined area. Nevertheless, their versatility extends beyond their original purpose, allowing for a broader range of applications. Presently, Pixels are housed in compact bodies, prioritizing cost efficiency and user-friendly operation. With careful system design, these Pixels can also be effectively employed in larger green walls, expanding their potential usage scenarios

Smaller system

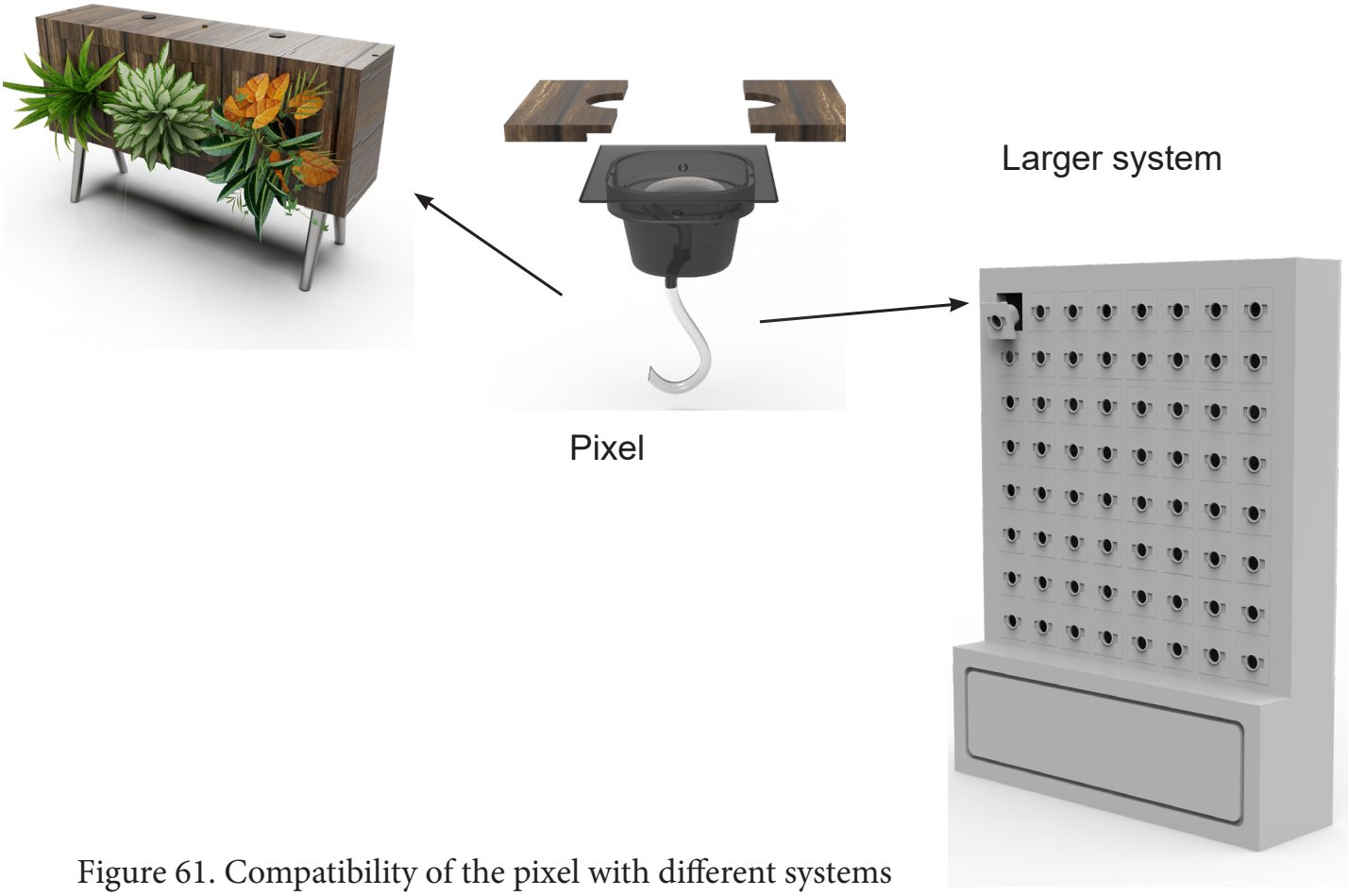


Figure 61. Compatibility of the pixel with different systems

The inherent versatility of Pixels enables seamless integration into diverse systems. As we consider larger-scale implementations, the product cost naturally increases, presenting opportunities for incorporating new technologies. In the context of larger systems, the utilization of motors for water distribution among the pixels becomes more feasible and efficient. Moreover, sensor-based indicators can be strategically positioned to notify users about the water level within the system. To optimize user experience, a magnetic release mechanism proves advantageous, eliminating the need for numerous buttons on the vertical wall. This approach not only saves time but also enhances usability in systems comprising a multitude of pixels

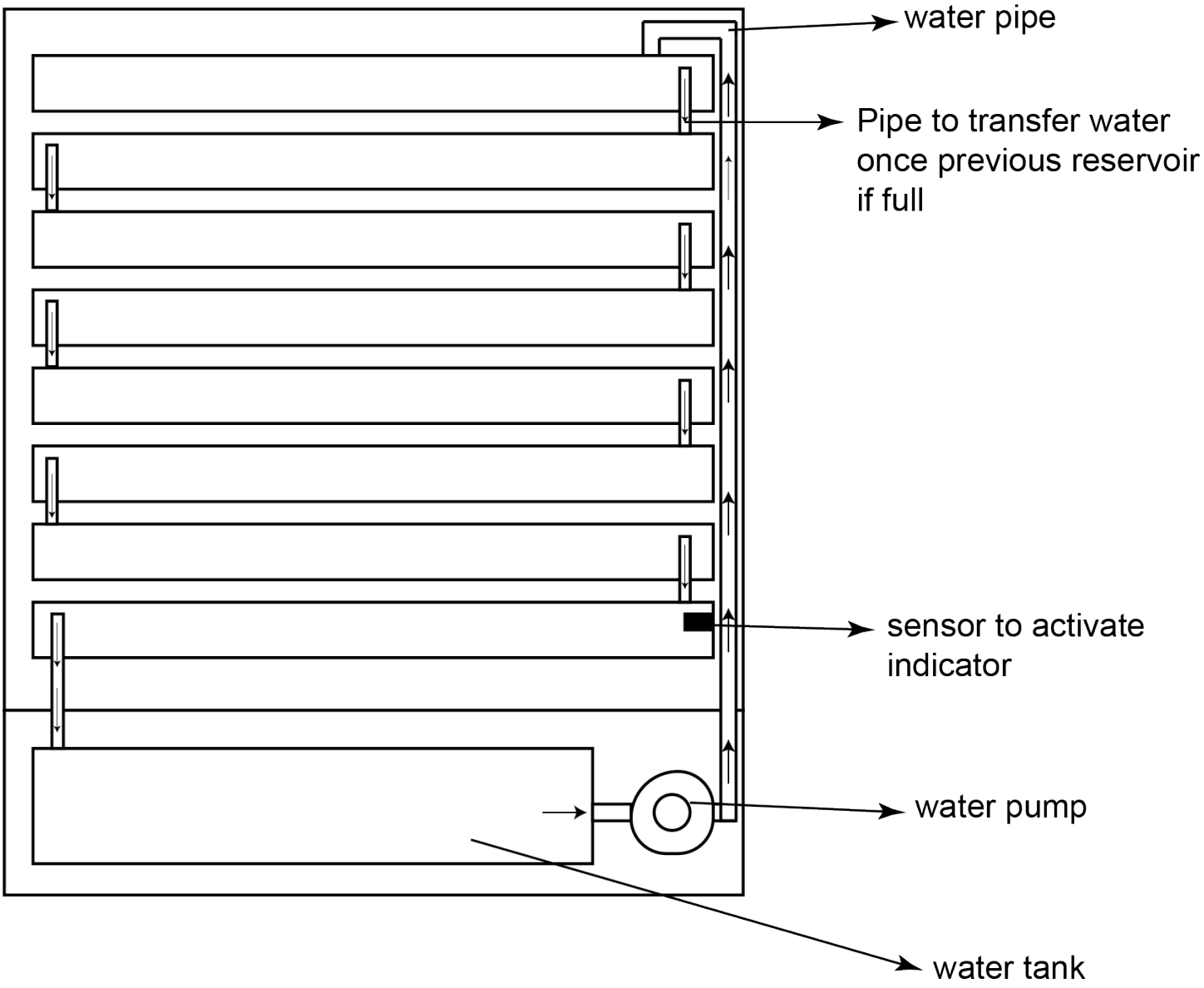


Figure 62. Representation of possible arrangement in larger vertical wall system with pixels

7.6.1 Customizable modules

Originally, the plan entailed incorporating modules as replacements for pixels, in case immediate plant replacements were not available, resulting in vacant slots within the product. These modules possessed identical dimensions to the pixel covers but featured diverse surface textures, such as grass, wood, sand, or even customized user images, imitating their respective materials. However, given that the final product only contained three slots, the addition of these modules appeared redundant as it disrupted the product's balance. While this idea was unsuitable for the current product, it could prove valuable for larger systems. In such cases, these modules could be utilized to fill gaps and create patterns in a vertical green wall. By employing different modules to simulate various scenarios, the visual appeal of the vertical wall could be enhanced, further evoking the sensation of an outdoor environment.

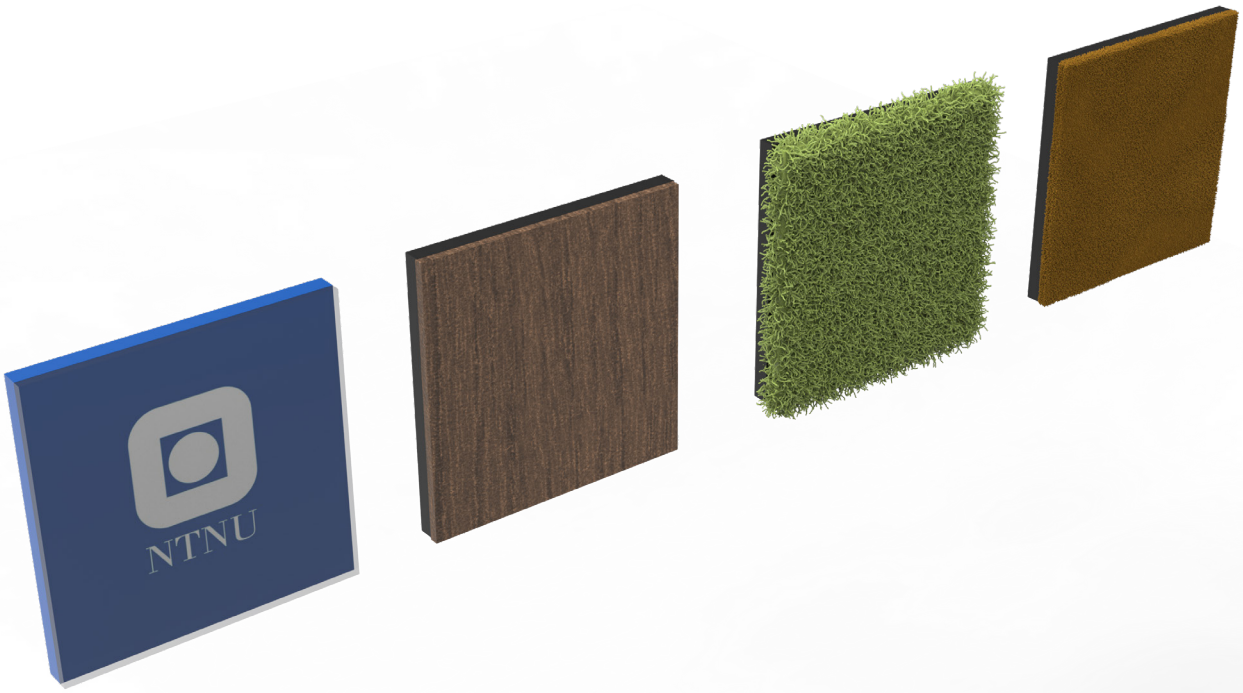


Figure 63. Customizable modules with different surface textures

8. Conclusion

The thesis revolved around the concept of developing a personalized vertical green garden, recognizing the numerous benefits it brings to human lives. Despite some limitations, the final product showcases a system that is suitable for small spaces and is cost-effective, while still delivering a captivating visual experience. With its user-friendly approach, the product sparks a newfound interest in individuals, encouraging them to embrace plants in their living spaces, even if they had never previously considered it. The pixels exemplify a unique and innovative method of incorporating greenery into one's surroundings, offering the versatility to be utilized in large-scale vertical green walls that people are familiar with. Moreover, the modular nature of the pixel and its compatibility with different systems present exciting prospects for future expansion and the sustainable growth of the product.

9. References

Adachi, M., Rohde, C., & Kendle, A. (2000). Effects of floral and foliage displays on human emotions. HortTechnology, 10(1), 59-63.

Bergman, H. F. (1920). The relation of aeration to the growth and activity of roots and its influence on the ecesis of plants in swamps. Annals of Botany, 34(133), 13-33.

Chang, C.-Y., & Chen, P.-K. (2005). Human response to window views and indoor plants in the workplace. HortScience, 40(5), 1354-1359.

Coleman, C. K., & Mattson, R. K. (1995). Influences of foliage plants on human stress during thermal biofeedback training. HortTechnology, 5(2), 137-140.

Doxey, J. S., Waliczek, T. M., & Zajicek, J. M. (2009). The impact of interior plants in univer sity classrooms on student course performance and on student perceptions of the course and instructor. HortScience, 44(2), 384-391.

Han, K.-T. (2009). Influence of limitedly visible leafy indoor plants on the psychology, behavior, and health of students at a junior high school in Taiwan. Environment and behavior, 41(5), 658-692.

Imanishi, H., Namao, M., & Inamoto, K. (2002). Effects of plants in the workplace on attitudes and perceptions of employees. Horticultural Research (Japan).

Kaplan, R. (2001). The nature of the view from home: Psychological benefits. Environment and behavior, 33(4), 507-542.

Lambe, R. C. (1980). Identification and management of diseases of indoor plants.

Larsen, L., Adams, J., Deal, B., Kweon, B. S., & Tyler, E. (1998). Plants in the workplace: The effects of plant density on productivity, attitudes, and perceptions. Environment and behavior, 30(3), 261-281.

Li, Y., Niu, W., Cao, X., Wang, J., Zhang, M., Duan, X., & Zhang, Z. (2019). Effect of soil aeration on root morphology and photosynthetic characteristics of potted tomato plants (Solanum lycopersicum) at different NaCl salinity levels. BMC plant biology, 19(1), 1-15.

Live picture 2 (n.d). https://artigardenandhome.co.uk/products/live-picture-2-plant-frame-112cm-x-72cm?variant=34892729909404

McConnell D.B (1978). The indoor Garderner's Companion: A Definitive, Color-Illustrated Guide to the Selection and Care of Houseplants. Van Nostrand Reinhold Company. New York, NY

Naava one (n.d.). https://www.naava.io/products#choose-product

Nishina, H. (2008). Recent researches on psychological effect of green amenity. Journal of Science and High Technology in Agriculture (Japan).

Park, S.-H., Mattson, R., & Kim, E. (2002). Pain tolerance effects of ornamental plants in a simulated hospital patient room. XXVI International Horticultural Congress: Ex panding Roles for Horticulture in Improving Human Well-Being and Life Quality 639,

Park, S.-H., & Mattson, R. H. (2008). Effects of flowering and foliage plants in hospital rooms on patients recovering from abdominal surgery. HortTechnology, 18(4), 563-568.

Pennisi S. V. (2009). Growing indoor plants with success.

Plantbox green wall (n.d). https://www.green-tech.co.uk/green-roofs-and-living-walls/green-walls-and-ivy-screens/plantbox-green-wall#productDescriptionTab

Shibata, S., & Suzuki, N. (2001). Effects of indoor foliage plants on subjects' recovery from mental fatigue. North American Journal of Psychology, 3(3), 385-396.

Shoemaker, C. A., Randall, K., Relf, P. D., & Geller, E. S. (1992). Relationships between plants, behavior, and attitudes in an office environment. HortTechnology, 2(2), 205-206.

Skogluft living wall kit (n.d.). https://www.skogluft.com/en-no/products/living-wall?pr_prod_strat=use_description&pr_rec_id=bef87732b&pr_rec_pid=7112204386460&pr_ref_pid=8428747587930&pr_seq=uniform

Suhaimi, M. M., Leman, A., Afandi, A., Hariri, A., Idris, A. F. a., Dzulkifli, S. M., & Gani, P. (2017). Effectiveness of indoor plant to reduce CO2 in indoor environment. MATEC Web of Conferences,

Toyoda, M., Yokota, Y., Barnes, M., & Kaneko, M. (2020). Potential of a small indoor plant on the desk for reducing office workers' stress. HortTechnology, 30(1), 55-63.

Ulrich, R. S., & Simons, R. F. (1986). Recovery from stress during exposure to everyday outdoor environments. Proceedings of EDRA,