Digital manufacturing in lighting design

Brightening nursing homes with natural and lively wall panels

Master thesis Integrated Product Design
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Summary

This master's thesis was completed at Tu Delft in collaboration with Signify, with the goal of providing guidance into the use of digital manufacturing in lighting design by creating a lighting system concept for the context of nursing homes.

The following design goal elements emerged in this context to improve the well-being of elderly residents. The goal was to incorporate these elements into a lighting system concept that is manifested in a working prototype.

- **Bright** – Many nursing homes are too dark for the elderly to perform tasks. Vertical illumination may improve the perception of brightness and spaciousness.
- **Natural** – From the perspective of biophilic design and healing environments, nursing homes could benefit from natural light, shapes, and materials to improve the space's restorative affordances.
- **Lively** – From the standpoint of lighting design, nursing homes could benefit from lively elements such as patterns and brilliance to balance the visual aesthetics.
- **Pleasant** – The aesthetics and light effect should not be annoying because several residents will glance at it daily.

The project started with literature research on lighting and biophilic design, visiting fairs on lighting and 3D printing, and meeting stakeholders from Signify and nursing homes. Prototypes were created iteratively and with increasing fidelity with light sources, cardboard, and 3D printing throughout the project to explore and evaluate ideas. Image-generating AI tools served as inspiration, and parametric design was used to model complex designs. The product experience design was guided by Nine Moments of Product Aesthetics, and the theory of Unity and Variety guided the product experience design in the detailing of the concept.

Livy, the final concept, consists of 3D wall panels and spotlights that together create a nature-inspired light effect. The lighting system increases the perceived brightness of the room by vertical illumination and reflecting diffuse light into the space from vertical wall panels. The light also improves the liveliness and brilliance of the lighting atmosphere by creating dynamic shadows and caustics. Natural materials are introduced through the wooden panels and filaments in a natural shape and pattern. The light is warm white and indirect for a pleasant feel.

A formal validation was conducted with elderly residents (N = 13) in a nursing home. Ratings of brightness, naturalness, liveliness, and pleasantness were rated on a four-point scale. The judgments revealed that the majority of these goal elements were judged positively. The prototype appeared bright (Mean = 3), lively (Mean = 3.2), and pleasant (Mean = 3.5) with the luminaires switched on. Several participants perceived the concept as natural (Mean = 2.4) and referred to natural metaphors. As expected, the brightness was rated significantly higher compared to the luminaires switched off, which was not true for the other ratings.

The project offers valuable insights and a practical example of how digital manufacturing can be used in lighting design within Signify. There is potential for designing illuminated surfaces that combine natural patterns and materials with lighting to create visually appealing spaces. This digital approach also demonstrates opportunities for Signify to develop products that cater to aesthetic preferences and, in particular, lighting needs in a context. Additionally, it identifies opportunities for further steps to make products better reusable or recyclable.

This video presents the final concept: https://youtu.be/HEwW515QFYg

Contents

Introduction

This Integrated Product Design master's thesis was performed in collaboration with Signify as the main client. The goal of the project is formulated with two components: to give Signify insights into digital manufacturing in lighting design by designing a lighting system for a specific context. The project aims to give direction on how and where digital manufacturing can be used in lighting design in practice with the design of a concept lighting system.

Performing the design project will result in valuable insights for Signify's digital manufacturing research team. Meanwhile, the goal for the concept to be developed evolved to be to improve the lighting conditions in elderly nursing homes and make the spaces more enjoyable. Improving these conditions could benefit the well-being of elderly patients and nursing staff.

This report will give a foundation and argumentation for the final concept lighting system which will be useful in further discussion within Signify. This is done by explaining the process of how the concept came to be and by showing its design details and features. In general, the double-diamond model was used to structure the project which is a constant flow of exploring many options and subsequently scoping down by selecting. On a broader scale, the project started with an exploration of relevant subjects, ideation, and concept detailing. Within these phases, exploring was done by visiting fairs and stakeholders. Prototyping with light, cardboard, and 3D printing aided in both exploring and scoping down. Finally, the concept was validated with stakeholders in context.

The first Chapter will discuss the exploration phase. Specifically, the topics of Signify, Elderly Care, Lighting, and 3D printing. From the insights gathered a design goal and vision were made, which will be explained in Chapter 2. The same chapter details the process of experimentation and ideation. A final concept idea will be detailed on product experience, manufacturing, and interaction, which will be discussed in Chapter 3. The validation of the final concept through a true-scale prototype will be explained in Chapter 4. The final part, Chapter 5, will give a conclusion and recommendation for the whole project.

Project and topic context

This project is in collaboration with Signify: "Signify is the world leader in lighting. We provide professional customers and consumers with quality products, systems and services." The research team that was specifically worked with is called Digital Workflow. They explore the impact of digital technologies in the space of luminaires and lighting, for example, 3D printing.

The research team is mainly experimenting with technologies, but a TU Delft design project also considers the context, the needs of users, and the environment. This combination of focus points is not commonly seen in technical research teams. It is therefore the idea that this Master project could bridge the gap between technological innovations and the potential it could have in future lighting products. This is done by proposing a direction in the form of an inspiring concept. The other challenge is to explain the methods and philosophy of what the concept stands for and the importance of considering the context of use.

Project Brief

The starting point of this project was the shared interest between supervisors in natural light elements and visualising these elements in a luminaire or light system design – for example, water reflections or light through trees. The inspirational images in Figure 1 indirectly capture aspects of these phenomena. 3D printing and digital manufacturing could fit well with these unique shapes. That is why the goal of the project is to explore the potential of 3D printing on the lighting effect and shape of luminaires. As mentioned, this is done by setting up an explorative design project in a specified context with the goal of designing a concept luminaire.

This starting goal contains a few specifications and subtopics. In addition to exploring possibilities in luminaire material, shape, and lighting effects with 3D printing, the lighting experience and function are also important. Could the lighting effect be dynamic and smart, for example? A stricter requirement is that the luminaire should be wall-mounted. The focus is on concept design and lighting effects, therefore there is no need for detailing tolerances, assembly, or interfaces.

This brief also took consumers as a general target group. However, a few weeks into the project, this shifted towards healthcare patients or residents. The full original project brief can be found in Appendix A.

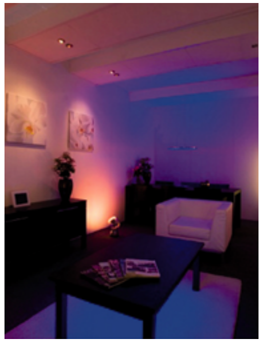
Figure 1: Project brief inspiration content. Notice the light compositions, brilliant effects and unique wall elements.

1 | Exploration phase

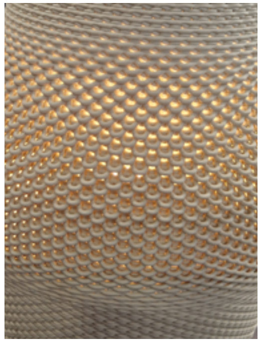
The first phase of the project involved exploration into four areas (see Figure 2). The areas of Signify, 3D printing, and Lighting logically emerged from the project brief. Elderly care was later added as this new target group became more relevant. Desk research, quick prototypes, interviews, and creativity methods were all activities in this phase.

Signify

Elderly Care



Lighting



3D printing

Figure 2: The four explored topics.
The area of elderly care became apparent during the project when healthcare came on the radar.

1.1 Signify

Signify was formerly known as Philips Lighting (Signify, 2018). The multinational is active in over seventy countries with about 35 thousand employees (Signify, n.d.-c). It is hard to give a complete summary of their portfolio and activities. Most people recognize the Philips brand though, which is still used by Signify to sell some of their products. Philips Hue is probably the most well-known brand that Signify makes for consumers. However, a visit to the experience centre in their headquarters in Eindhoven would reveal that they provide lighting systems for practically every industry - from tuned light systems in supermarkets to efficient systems for factories.

Eindhoven is also where the Digital Workflow research team is located. As a research team, they tackle projects that aim to discover what value certain technologies can have for the operations within Signify. Digital Workflow specifically looks at upcoming digital technologies like AR, AI, and 3D printing. For instance, AI tools can be used to develop creative new designs or support automated manufacturing. The form freedom of 3D printing can be leveraged to make simpler assemblies. 3D printing deserves its own section since it was included in the project brief.

3D printing within Signify

Recently, Signify started 3D printing luminaires. In 2019 the Philips MyCreation service launched across Europe (Signify, 2019), see Figure 3. They had to overcome various challenges in order to produce products with 3D printing that are without defects and ready for clients. Printing in a spiral mode, for example, ensures that the prints are reliable and fast. Spiral mode is a print setting where the print head prints with continuous extrusion. Signify also developed a custom slicer where they can adjust specific settings to fine-tune printing, all to improve the reliability of 3D printing in a larger-scale factory. This software, for example, is developed by the Digital Workflow research team. This illustrates how research flows into the actual production operations of the company.

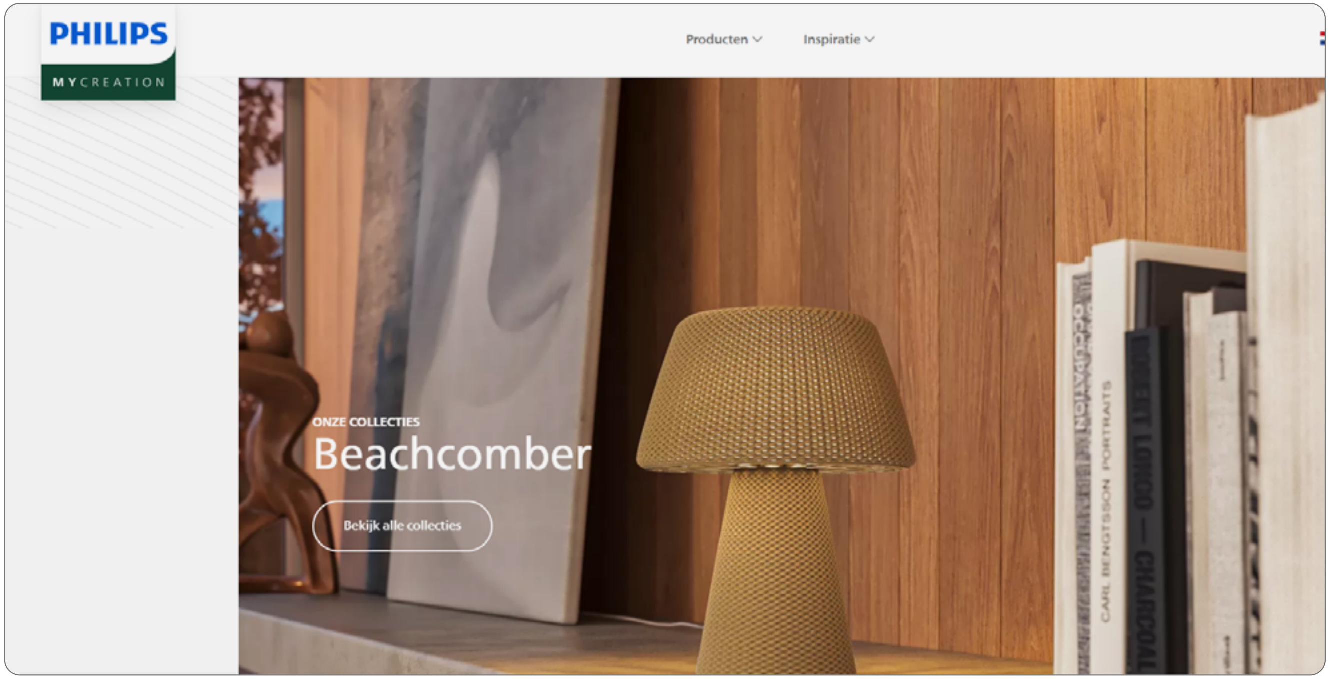


Figure 3: Homepage of Philips MyCreation website. It offers 3D printed luminaires to consumers. The luminaires are customisable in material and texture to be able to make a personalised luminaire for home. Next to consumer, these services are also offered for business clients.

Figure 5 shows the current portfolio of MyCreation 3D printed luminaires grouped by luminaire type. These products are sold to a variety of customers from consumers to businesses, and from small to large orders. That is the strength of 3D printing in production.

Interestingly, Signify has a gap in their portfolio: they do not offer any wall, floor, or linear luminaires yet. These areas are interesting for them to explore.

Philips HUE

Interest in dynamic light effects makes it necessary to look into the most well-known smart home lighting of Signify. Philips Hue is a large player in the smart home lighting branch (Business Wire, 2020). Their luminaires and bulbs are controlled either via the app or smart buttons. The app allows for various smart options such as groups, schedules, and scenes (Philips Hue, n.d.-a).

The products work with the ZigBee and Bluetooth protocols and are preferably controlled with a Hue Hub to have full options available. Their regular bulbs come in White, White ambiance, and White and color ambiance variants (Philips Hue, n.d.-b). See Figure 6 for the Hue wall luminaires portfolio.

Hue components can be used within Signify for prototyping purposes. This gives the option to test with the smart capabilities of the Hue ecosystem in custom products without the luminaire shells and to use Hue products as a light source for the final concept. Currently, Hue components are not yet used in 3D-printed luminaires, but Hue and 3D printing could be combined in the future.

Figure 4: NatureConnect offers a system of luminaires to mimic the colours and dynamics of natural daylight. The wall luminaire gives a gradient of vertical light. The white panels are designed to give the appropriate light levels and diffuse lighting. The middle blue panels give a touch of blue light and a sense of sunlight shining inside. The whole system adapts to the circadian rhythm of light, but can also be controlled manually for specific situations. It is mainly used in office spaces, but also in lobbies and healthcare in the near future (Signify, n.d. -b). The wow factor of the changing light scene in the space is the most memorable. The actual dynamics are meant to be unnoticeable.

Healthcare as a new market

The 3D printing venture of Signify sells its products to both businesses and consumers. The track lighting, for example, is installed in a Marks & Spencer supermarket (Signify, n.d. -a), and the customizable pendants are sold to consumers.

Although the project brief suggested consumers as a target group, there was an interest in other markets as well. The idea for healthcare came from the Nature Connect venture (Signify, n.d.-b), explained in Figure 4. Their focus on mimicking natural light and circadian lighting dynamics served as inspiration, and they also did research in healthcare as a market. What are the needs? What specific sectors are the most relevant to Signify? What people are important for decision-making? This research was the starting point for looking into healthcare, and more specifically one of the biggest sectors, elderly care. More on this in the next chapter.

Takeaways

- Looking at Signify's 3D printing portfolio, there is an opportunity for a wall luminaire.
- Signify has developed methods for 3D printing in production. In a later stage, design requirements from these methods could be considered.
- Philips Hue gives a platform for smart and dynamic lighting. Using this in prototyping and the final concept would spare the design of an interface or light engine.
- There is an interest in exploring 3D printing in new markets, such as healthcare.

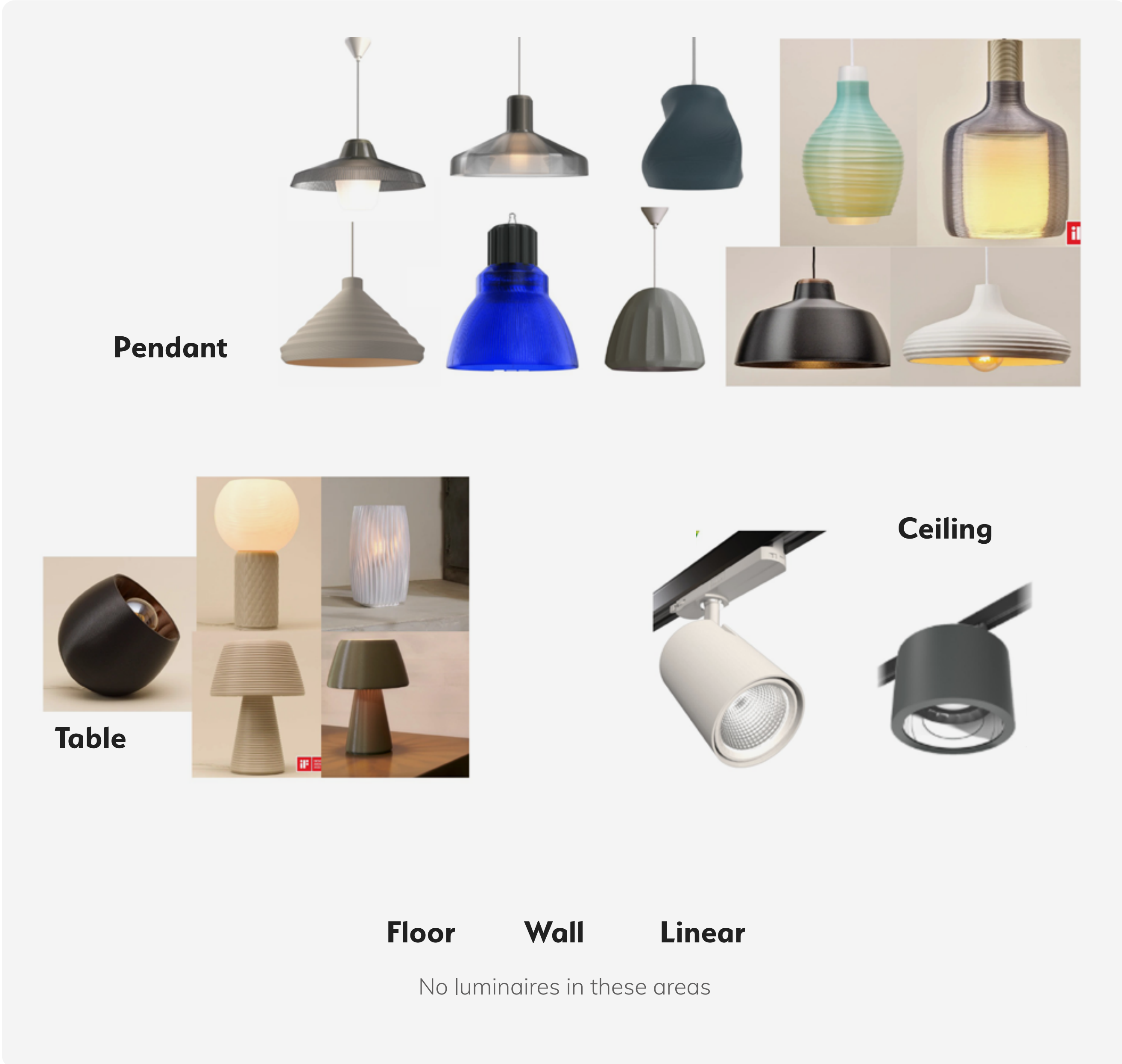


Figure 5: The product portfolio of 3D printed luminaires at Signify clustered by type. It shows the lack of floor, wall, and linear luminaires.

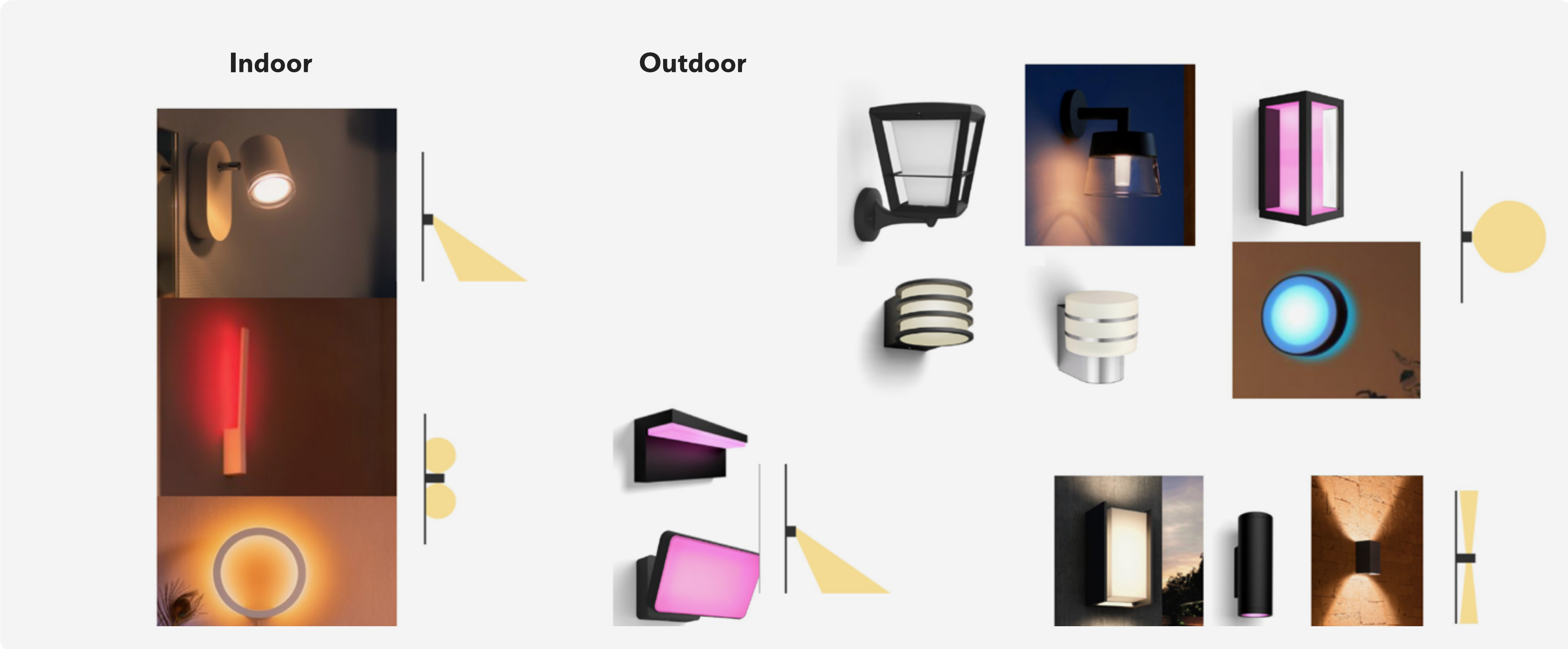


Figure 6: Product portfolio of Philips Hue wall luminaires.
Variants of the same product are left out.

1.2 Elderly care

The previous chapter concluded with Signify's interest in healthcare as a project focus. The following section will discuss this sector and why it was chosen as the target group.

Within long-term healthcare in the Netherlands, nursing care was responsible for one of the biggest costs during 2014-2017 (Ministerie van Volksgezondheid, Welzijn en Sport, n.d.). The majority of patients in this sector who live in nursing homes are over the age of 65 (CBS, 2018), and with the Netherlands' ageing population, the demand is only growing (CBS, n.d.). However, the sector is struggling to keep up while facing employee shortages (Actiz, 2022). Nevertheless, given the market size, this could be an interesting target group for a new luminaire - nursing homes, in particular, because they manage large buildings. This means that large orders are possible in comparison to the consumer market. Furthermore, 3D printing could provide affordable and specialised solutions for nursing homes that fit their needs. There are numerous lighting opportunities to make nursing homes more enjoyable for both staff and employees.

Two nursing homes in Eindhoven were visited to gather more insights into nursing homes (see Figure 8). A facility manager and well-being coach were interviewed during these visits. Besides detailed insights into what nursing homes look like and what life is like there, they also showed that employee shortages dictate many decisions made in nursing homes. Anything that could save work or effort for employees is valued highly. The rest of this chapter discusses the needs of both employees and the elderly.

Healing environments

In 1989, psychology professors Kaplan and Kaplan proposed the concept of restorative environments (1989). Earlier, Ulrich suggested in 1984 that a view on nature may influence patients' recovery (1984). Also related is the concept of biophilic design: *"Biophilic design encourages the use of natural elements and processes as design inspiration in the built environment"* (Gillis & Gatersleben, 2015). According to the Biophilia hypothesis, humans have a fundamental relationship with nature, so it is important to maintain that connection (Wilson, 1986). These concepts serve as the foundation for the trend of healing environments in architecture. This trend brings the benefits of the connection with nature to the users of the space, in this case, patients and nursing staff.

Two examples of healing environments can show what is understood by architects. Figure 7 shows a care centre in the UK (Pintos, n.d.). Van der Linden et al. (2016) describe the process of this design and suggest that architects associate healing environments with nature

Figure 7: Common room in a care centre in the UK (Pintos, n.d.). The centre was designed with healing environments in mind. Notice the use of wood, plants, soft lighting and natural shapes.

Figure 8: A grasp of the visited nursing homes. One might notice the use of simple ceiling mounted luminaires which are often the only intended source of light. It is not allowed to hang items on the wall with screws, so a hanging system is in place. The right two pictures show a common or living room which have some personal luminaires in most cases.

Figure 9: The Erasmus MC hospital (Archello, n.d.). Top left, a general space with wooden accents and lots of daylight. Right an example of a daylight mimicking solution, and below a ‘simple’ but effective restorative element, nature image wallpaper.

based on Kaplan's research. Terms used to describe the atmosphere by designers of the centre were 'calm', 'soft', 'relaxing', and 'comfortable'. Additionally, Pintos talks about the inspiration of tactile materials and soft lighting. The building has a wooden structure with an abundance of daylight and greenery. Gillis & Gatersleben also suggest that natural materials such as wood, the use of plants (especially without colour), and natural fractal structures could improve the restorative aspects of a space.

In the Netherlands, one example of healing environments is the Erasmus MC hospital designed by EGM architects (Archello, n.d.) (see Figure 9). The architects mention how natural materials, green colours, and natural lighting can play a role in creating the most enjoyable experience for patients and employees (EGM, n.d.). Where daylight is not present, they opted to emulate this with other solutions such as in Figure 9. Gillis & Gatersleben also state that both natural light (depending on weather) and simulated natural light increase restorative power. Aspects such as privacy also have an effect, as creating a healing environment involves integrating people's psychological needs. Feeling at ease and comfortable is key to a good recovery and well-being.

Often the implementation of healing environments is more basic than the examples of the Erasmus hospital. In many cases, due to the restriction of having existing buildings, the question arises: What can one do to improve the healing environment of spaces that are not designed with the philosophy in mind? A basic implementation is to install wallpaper with pictures of nature (see Figure 9). According to Gillis & Gatersleben, pictures could even have a stronger restorative effect than an actual view of nature through a window. This depends, of course, on what the view is like and what season it is.

Lighting needs

During the project, a few topics regarding the lighting needs of the elderly came forward. Among others, personal communication with M. Aarts (Oct 2022) helped to structure them. The following needs can be thought of as a combination of perceptual and physical (spectrum and intensity) elements to get a feeling of the important parameters. This is roughly based on the way we process light (see Figure 10).

Sufficient light levels - With age vision starts to degrade. Seeing up close gets harder, more light is needed, and the ability to see contrast and certain colours diminishes (Aarts & Westerlaken, 2007) (see Figure 12). This is caused by a decrease in pupil diameter and flexibility of the ciliary muscle as well as by yellowing and cloudiness of the transparent tissues. This results in the fact that the elderly have an increased need for higher light levels and contrast to see objects or perform tasks. With this knowledge, it is remarkable that research from Sinoo et al. (2011) showed that light levels are nevertheless too low for the elderly in Dutch nursing homes. They found that 55% of the measurements of horizontal lighting in living rooms were below 750lx. Only next to the window, the light levels are usually sufficient. For this argument the effects are perceptual, but light levels can also affect our biological processes.

Circadian lighting - Light levels and colour temperature are part of the daily rhythm of natural light (see Figure 11). This rhythm is in sync with our circadian rhythm or biological clock. The elderly, especially when suffering from dementia, could benefit from such dynamic light to help with a disturbed sleep rhythm (Aarts et al, 2014). Although evidence is still weak, dynamic light was preferred by nursing home employees. Experts from Halper (2022) in LEDs magazine argue that the influence of light intensity, wavelength, or age are not yet understood. Additionally, Kompier et al. (2020) emphasise the importance of taking into consideration personal preferences as dynamic light patterns and transitions could harm visual

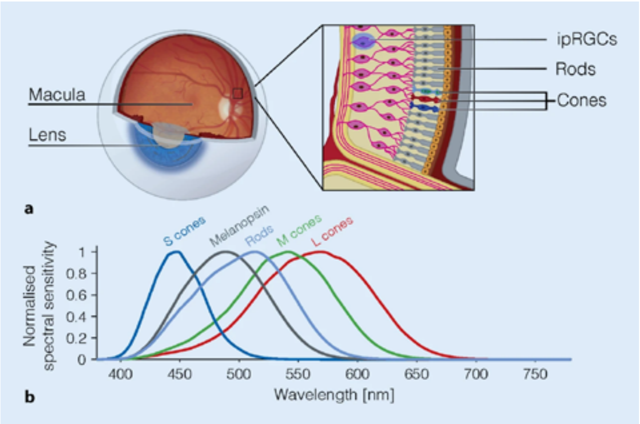


Figure 10: Photoreceptors on our retina (cones, rods and ipRGCs) sense different properties of light (Blume et al., 2019). The photic data mainly influences biological processes like circadian rhythm and melatonin suppression. Combined with non-photic data, this is used for vision.

Figure 11: Visualization of the natural daylight cycle. At sunrise and sunset the sunlight is more yellow. During the day, the light becomes less yellow. The atmosphere reflects mostly blue light on a clear day.

comfort. For example, they suggest that static bright light could be a good compromise between a circadian pattern and visual comfort. Similarly, bright light therapy is thought to improve sleep quality and depression (Shikder et al., 2011).

Natural light - This is also related to the philosophy of biophilic design. Being in an environment with natural light could benefit people in multiple ways. Osibona et al. (2021) also conclude for natural light that it *"improved health across all health domains (physical, mental and sleep health)"*. However, going outside is not always feasible for people in nursing homes. This is apparent in the fact that they often "do nothing" in the ward (den Ouden et al., 2015). Therefore, windows are currently vital in providing natural light.

Lighting atmosphere and aesthetics - A final opportunity is the perceived lighting atmosphere within nursing homes, as one might agree from personal experience or the pictures taken during the visits from earlier. Nursing homes are usually not attractive spaces in which to spend time. Since the elderly often feel gloomy on arrival (Huldtgren et al., 2015), enhancing the atmosphere could be beneficial. According to Kuijster et al. (2015), light atmospheres can positively impact the mood of the elderly. So one could enhance the liveliness or cosiness of a space depending on the needs, for example. Besides that, the visual aesthetics of the space could also be improved with lighting to make the nursing home a more enjoyable space.

All opportunities together should be improved in order to improve the comfort of the elderly physically and mentally. An indirect benefit for the staff is that a happier patient is easier to care for. Furthermore, as mentioned earlier, improved lighting could also directly benefit staff in their work. Küller et al. (2006), for example, concluded that light and colour can positively affect the mood of people working in an office, and increased light levels also benefit nursing tasks.

Figure 12: This impression of elderly vision is based on the insights on reduced contrast and blue light. On the left the original image and right the impression with reduced contrast and blue tones. Although the intensity of the effect is chosen arbitrarily, the image still gives some idea of what an aging vision could look like.

Takeaways

- The healthcare sector of long-term elderly care is likely to grow, but the resulting employee shortages dictate many decisions and budgets.
- The design of healing environments could improve people's well-being in a space. This architectural trend offers direction for the design of buildings and spaces.
- Natural materials and colours are often used. Think of wooden accents and plants where possible.
- Shapes, images, light, or a real nature view could improve the restorative affordances of a space.
- The elderly and staff could benefit from improved lighting in nursing homes.
- Light levels are low and should be increased.
- Dynamic light could be beneficial to the circadian rhythm of the elderly with positive health benefits.
- The light atmosphere and visual aesthetics of spaces could be enhanced. This could benefit the mood and comfort of a space.

1.3 Lighting

It is necessary to give context on the topic of indoor lighting to get a feel for this domain of the project. The section afterwards explores what light innovations are out there and analyses the wall luminaires on the market.

Quantitative and qualitative light

A quantitative lighting approach relies on measurements of light levels and distribution to make a sufficient design. Examples of light distribution are given in Figure 13. Figure 14 is a common sight in non-residential buildings where light levels and distribution are leading in the lighting design. Often light levels are standardised for a specified amount of lux at a specified height for a task. When combined with a standard for light distribution, one gets a sufficient lighting scene. This method results in a scene that works for the task and is often the most efficient and cost-effective, but lighting can offer much more in terms of pleasantness and aesthetics when approached qualitatively.

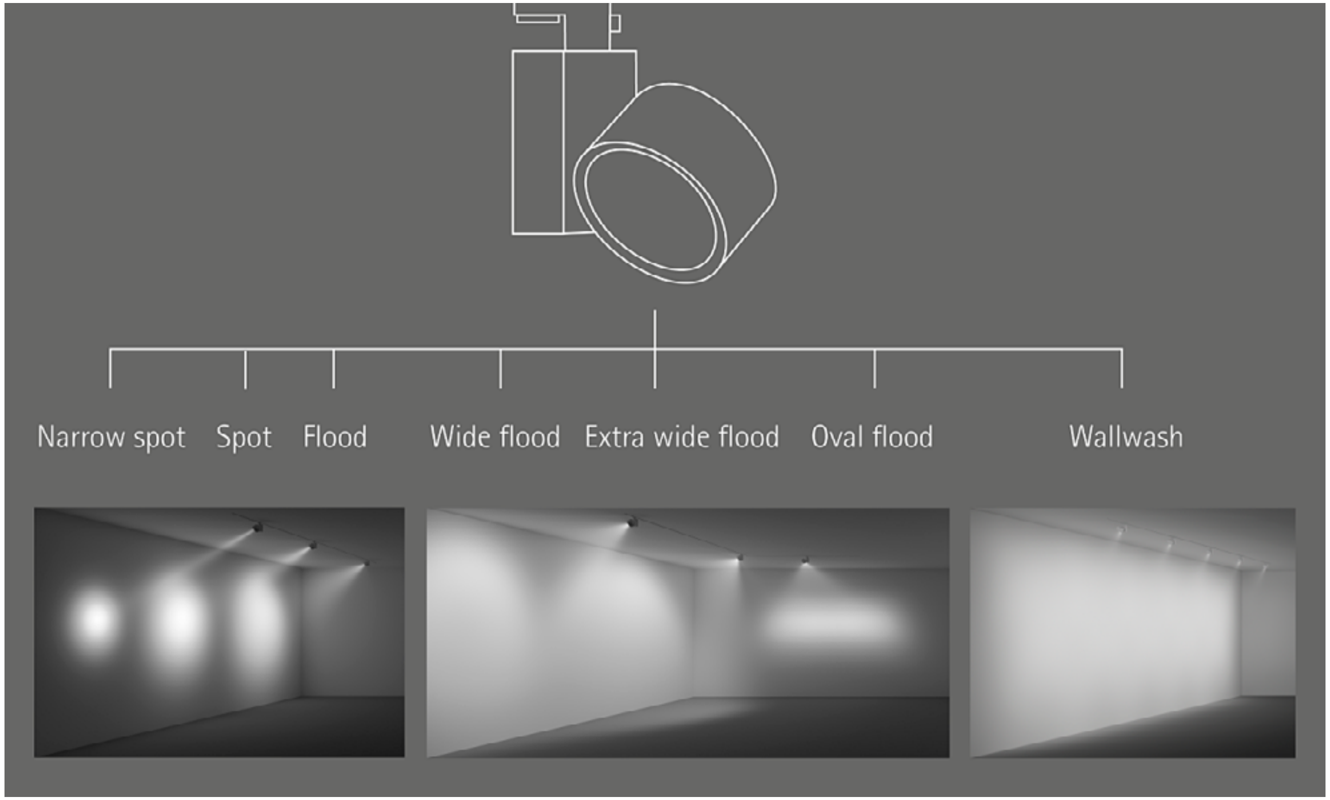


Figure 13: This modular luminaire from company ERCO shows what different light distributions can do, ranging from very uneven distribution from spots, to the even distribution of a wall washer on the right. Every amount of distribution has its own place and strengths.

Figure 14: The goal for the light scene in this office was probably to get even light with a specific light level at the desk. While this scene is not distracting and offers good visibility for tasks, It is not visually appealing.

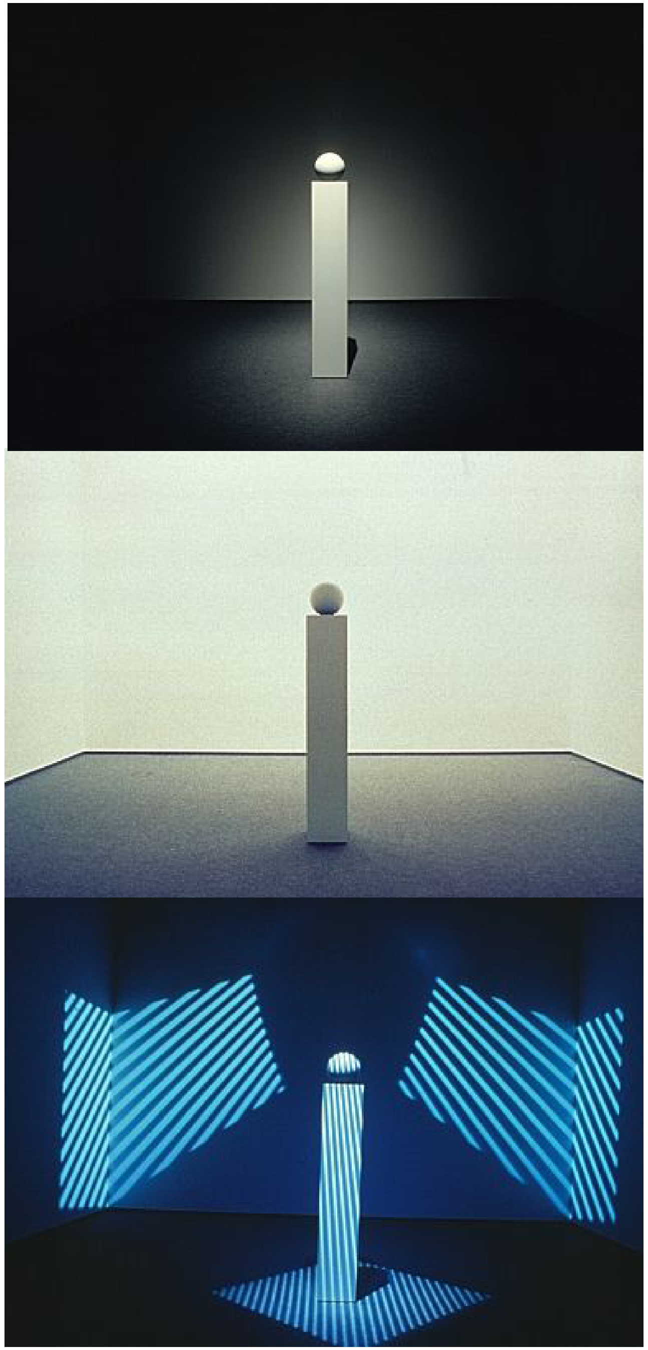


Figure 15: Light layers described by Kelly. He suggest to design a light scene starting with deciding the attention points, focal glow (top). Subsequently the amount of ambient luminescence (middle) is figured out. Finally, a layers of play of brilliants (bottom) is added.

Richard Kelly (1952) described three different layers of light: focal glow, ambient luminescence, and play of brilliants. Figure 15 shows these layers with an explanation. A well-designed lighting scene has a good balance between these layers specifically for the intended lighting atmosphere as in Figure 16. A cosy environment would have little ambient light with more pronounced elements of focus and brilliance. A lively atmosphere would see more ambient lighting, for example.

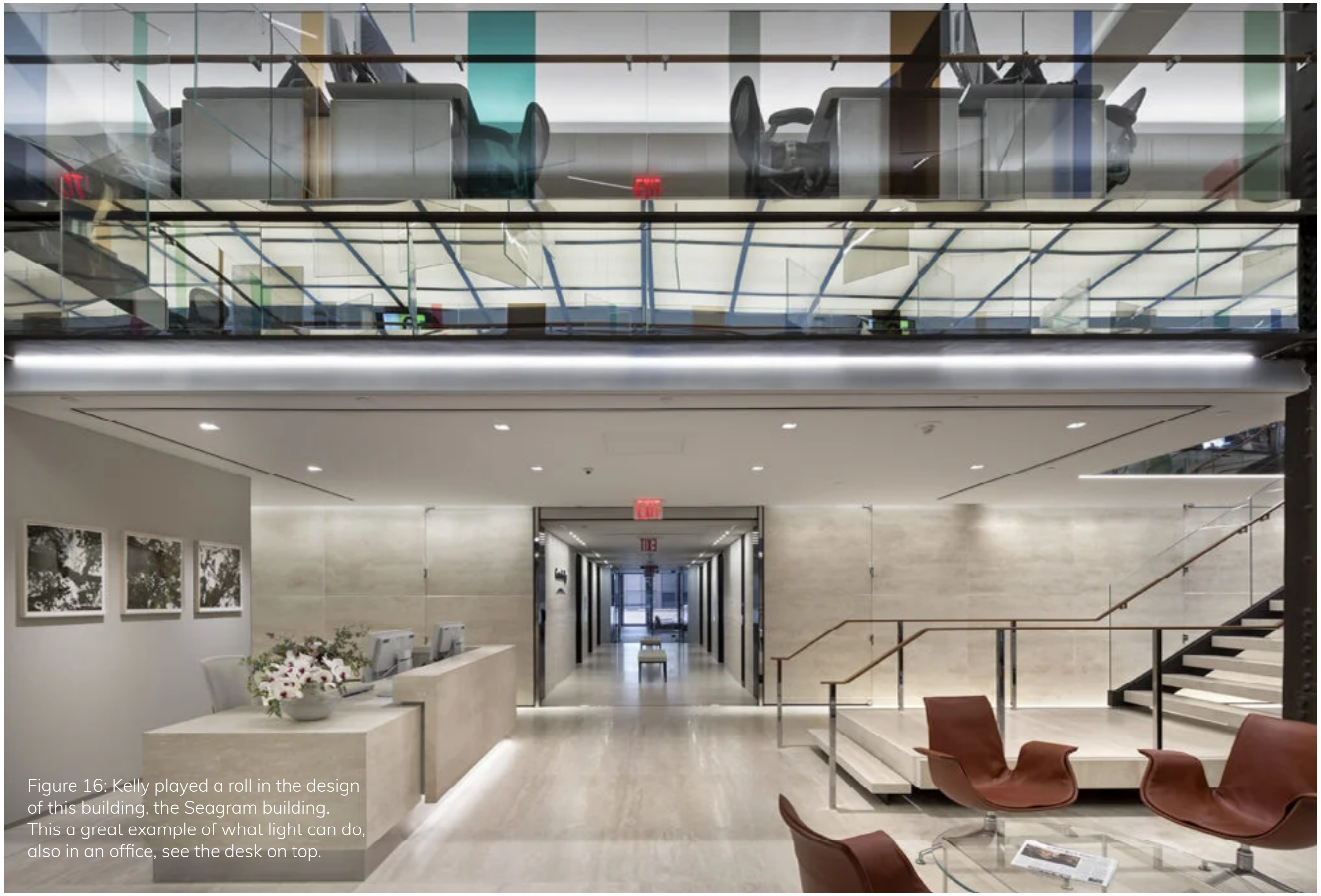


Figure 16: Kelly played a roll in the design of this building, the Seagram building. This a great example of what light can do, also in an office, see the desk on top.

Vertical illumination

Then to the topic of the illumination of walls. Lighting on walls specifically offers vertical illumination which can have the following functions according to ERCO (n.d.), a player in the lighting and luminaire industry.

- In rooms with a façade of windows, vertical illumination can help balance the contrast in the room during the day by illuminating the opposing wall. Because without adding vertical light, the walls would be seemingly dark compared to the bright windows (Figure 17).
- During the night the vertical lighting helps to gain an understanding of the size of the space. Figure 19 shows how different types of wall lighting can influence the perception of the size of the space. Wall illumination can also offer an element of ambient lighting since light bounces from the wall into the space.
- Figure 18 gives examples of how wall lighting can be used to create patterns of brilliance or grazing light to set the atmosphere.

Figure 19: Vertical light can influence the sense of spaciousness of a space which is influenced by what part of the wall is illuminated. Notice that the image on top feels smaller than the bottom one.

Figure 17: The same vertical light creates a contrast to the facade during the day, while at night, it gives a sense of space and additional ambient light.

Figure 18: The effect of grazing light on a textured wall. Depending on the texture, it gives a characteristic and brilliant effect.

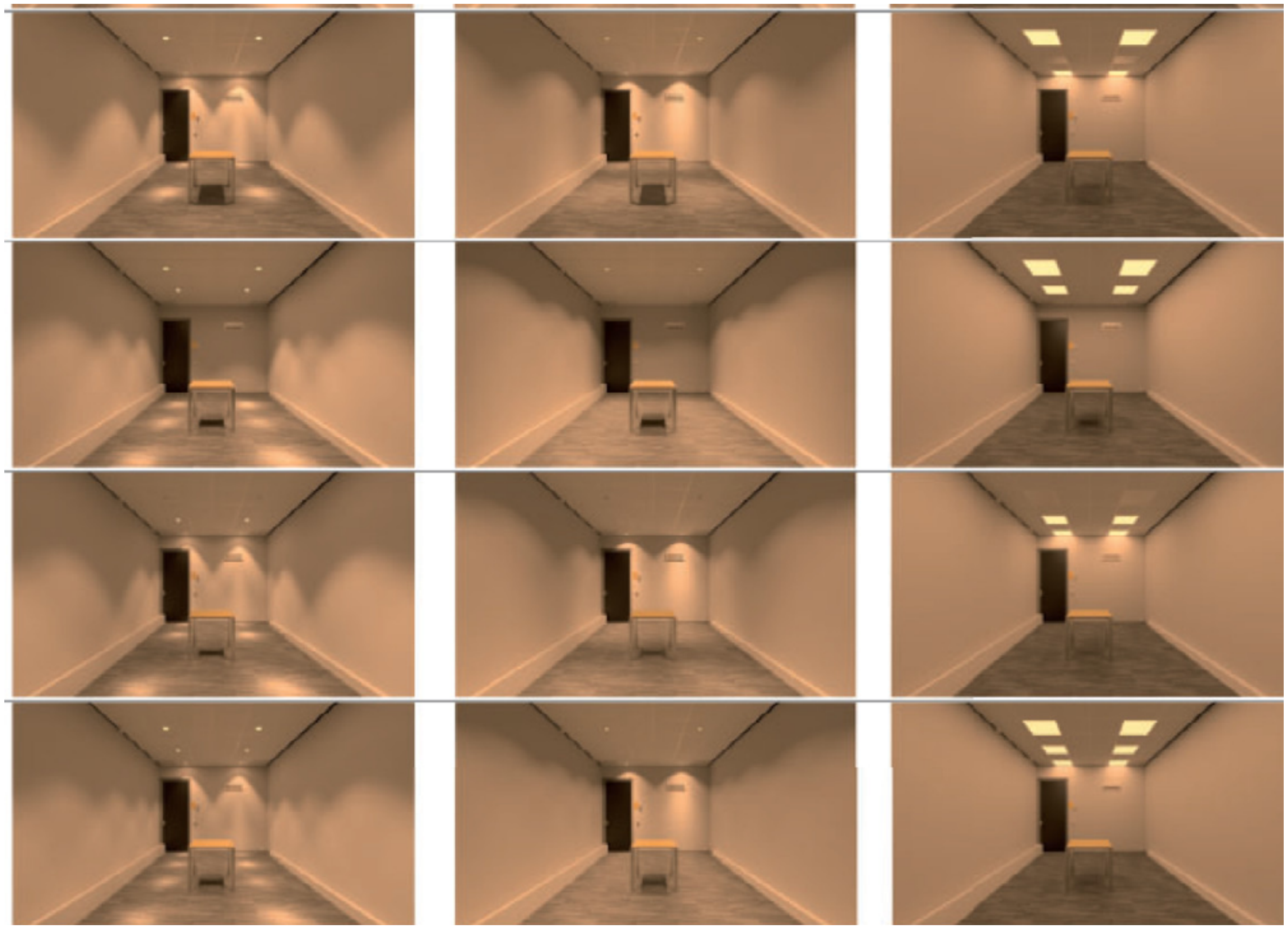


Figure 20: Two light atmospheres designed for the elderly that were part of a study by Kuijster et al. (2014). The top image shows a lively atmosphere and the bottom a cosy atmosphere. Both atmospheres have a monochrome colour scheme.

Figure 21: This figure shows a part of the researched visuals made by Stokkermans et al. (2017). The images vary in light distribution: rows have shifting beam angles and columns are different in the placement of luminaires.

Figure 22: A selection of words from the list created by Vogels (2008) that are used to describe the perceived atmosphere.

Dimensions	**Cosiness**	**Liveliness**	**Tenseness**	**Detachment**
Items	Cosy	Lively	Tense	Formal
	Pleasant	Stimulating	Threatening	Business-like
	Intimate	Exiting	Terrifying	

Perceived atmosphere

The basis for research on atmosphere, specifically the perceived atmosphere, is the atmosphere questionnaire developed by Vogels (2008). A list was developed of (Dutch) words that proved to describe an atmosphere in four dimensions: cosiness, liveliness, tenseness, and detachment. Figure 22 shows a selection of the words. The research continued to focus on how different aspects of light could influence the perceived atmosphere and what effect it has on people.

Kuijster et al. (2014) showed how scenes with different coloured lights can influence the perceived atmosphere (see Figure 20). They also developed and evaluated atmospheres that were specifically lively or cosy and discovered that the elderly can differentiate between these atmospheres. Interestingly, the elderly had different preferences than younger people: higher illuminance, no saturated blue, and a monochrome colour palette. A follow-up study verifies that atmospheres have the possibility of positively changing the mood of the elderly (Kuijster et al., 2015).

Next to that, Stokkermans et al (2017) looked into the relationship between light distribution and perceived atmosphere. This relation was found to exist, although complex. Figure 21 explains the findings from this research. Especially the influence of distribution on cosiness and liveliness could be relevant to this project.

Interior lighting trends

Now more on the luminaire innovations - the following relevant lighting trends were observed from a visit to Light + Building 2022, as shown in Figure 23.

Flexible LED strips and tubes with strips that could bend in multiple directions were ubiquitous. When combined with rigid frames, it allows for complex luminaire shapes. A standalone implementation provides even more freedom and may even make the function flexible by interacting with the light tube.

The miniaturisation of efficient high-power LED also gives rise to new opportunities. Aside from indication lights, small lights now can be used in luminaires. Clouds of LEDs could form compositions or small accent lights can be mounted unobtrusively.

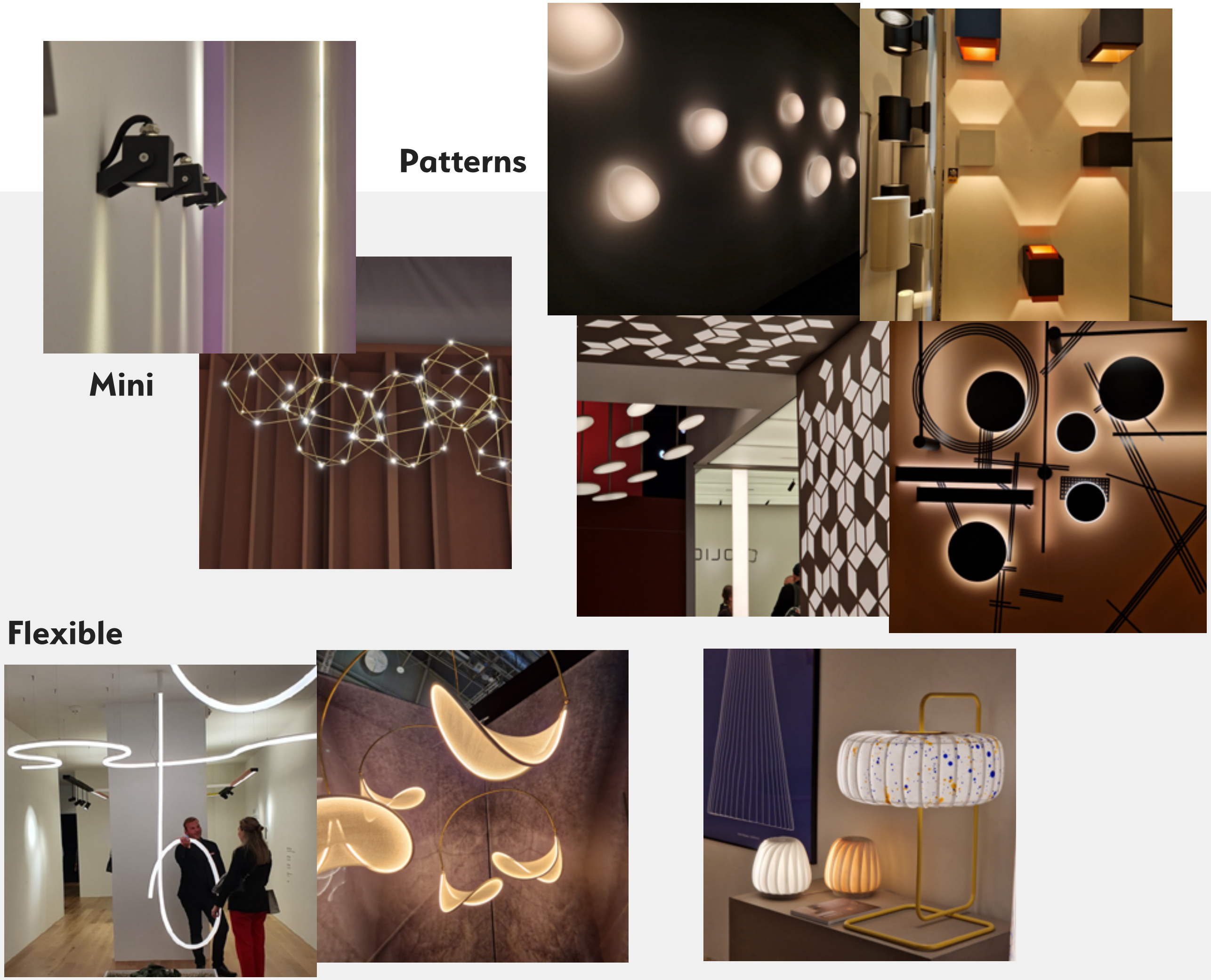


Figure 23: Examples of lighting trends at Light + Building 2022

These compositions were also noticeable at the fair. LED can be used to create unique shapes and patterns of light-emitting surfaces, usually in geometric shapes and circles. It was also interesting to see how casted light itself can be used to create patterns.

At Light + Building in particular, luminaires were often made from aluminium in grey tones - robust designs meant for business use. However, other materials and shapes started to appear as well - think of concrete, glass, or wooden luminaires. Additionally, the use of paper or felt, for example, added more variety, as did colour variation. This combination of a business use which needs a home-like aesthetic is especially interesting for this project.

Finally, as a bonus, Figure 24 shows a mood board created by the Light + Building organisation. It is interesting to see wooden accents, curved luminaires, and hidden light. These aspects could fit well within a healing environment.

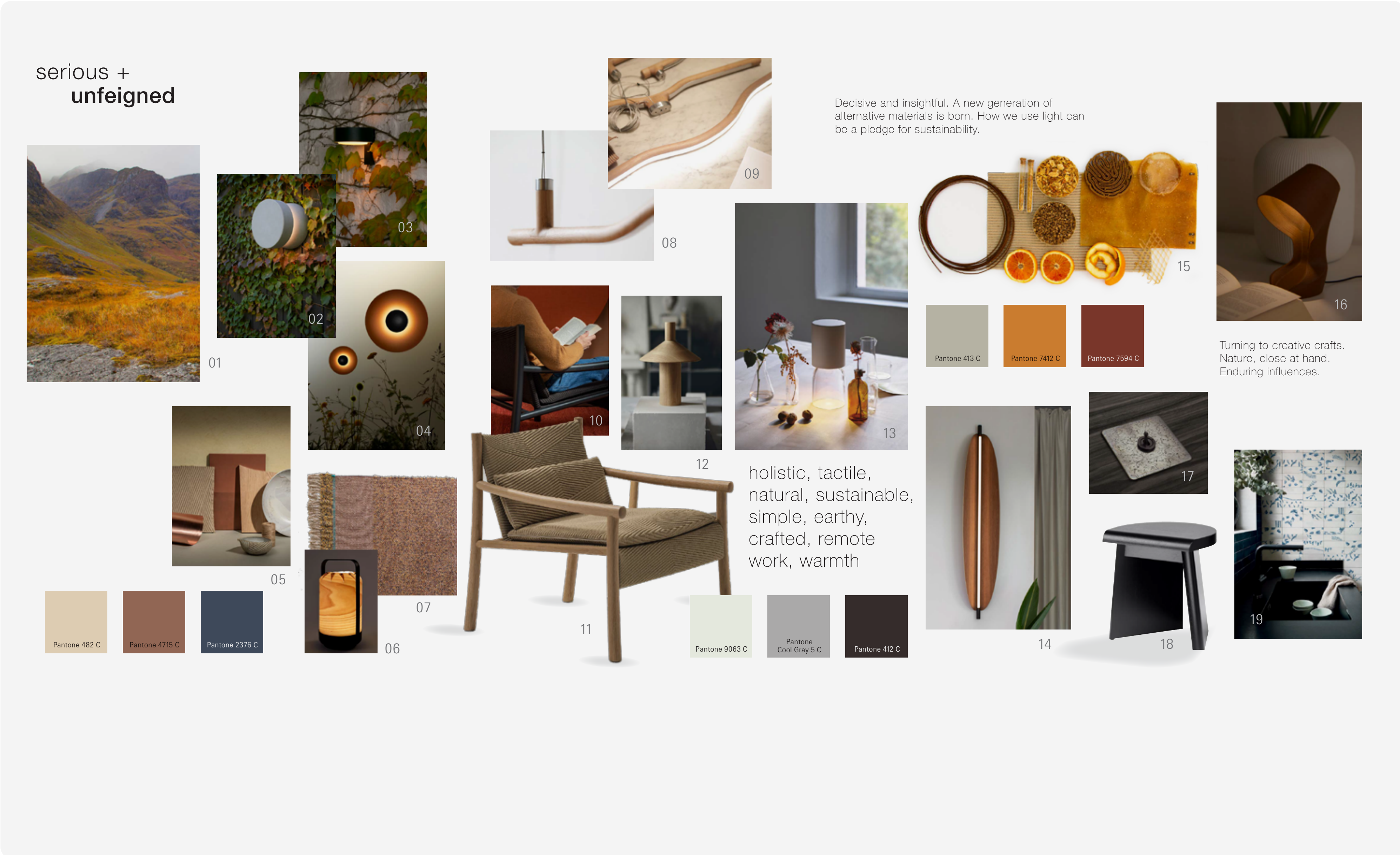


Figure 24: One of the mood boards created by the Light + Building organisation that fits within this project. Notice the use of natural materials, soft light and smooth shapes.

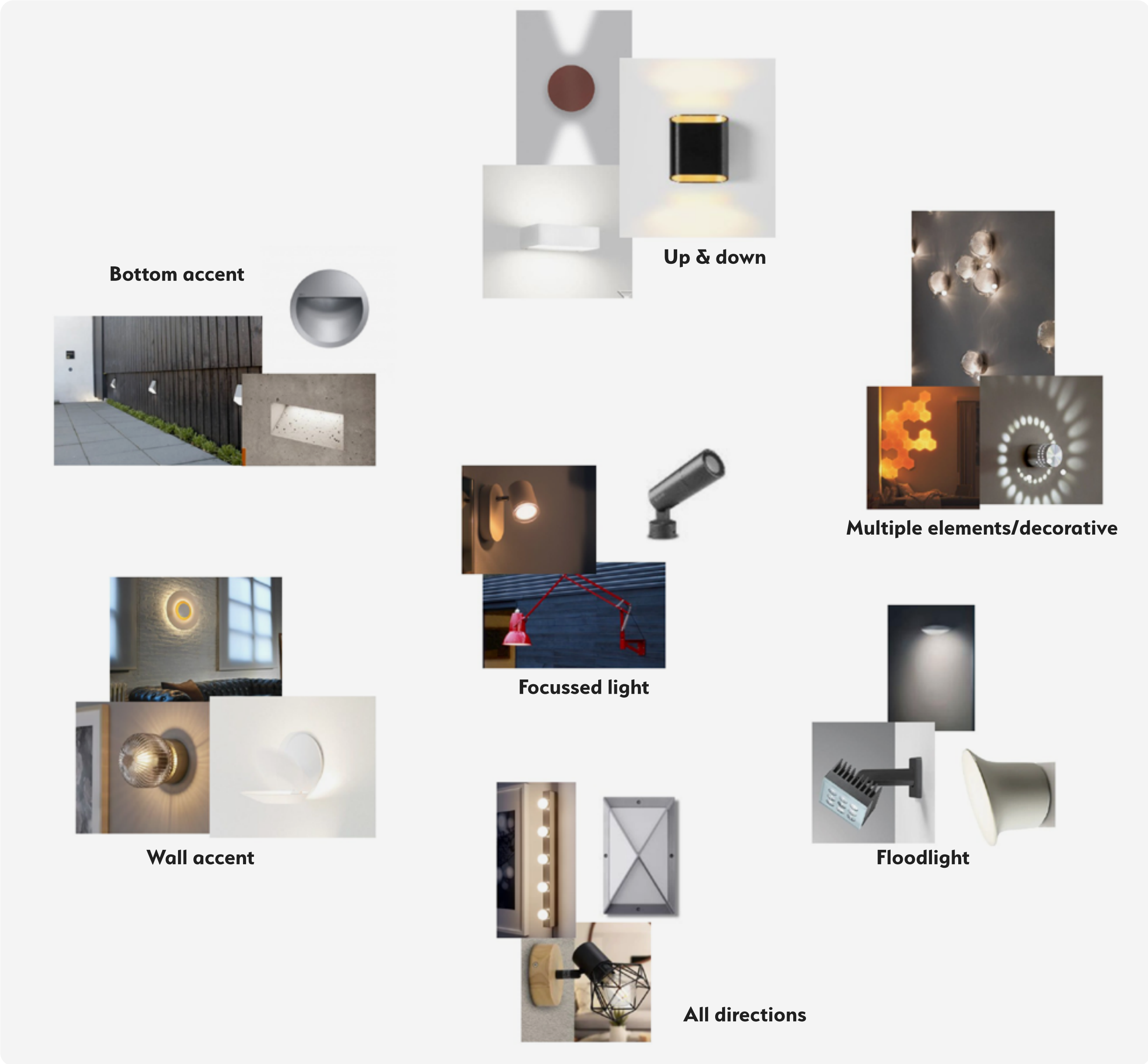


Figure 25: Analysis of available luminaires on the market showed several different clusters based on the light effect.

Wall Lighting

An analysis was done to gather insights into the variety of wall luminaires out there, both in general and in Philips Hue's portfolio. In general, a few clusters emerged (see Figure 25). Of particular interest are the luminaires that create light patterns with multiple elements as it fits the first project brief. Up/down accents are mostly seen outdoors but could be relevant as well. Diffuse wall accents also offer some inspiring options in light patterns and dynamics.

Takeaways

- Spaces with light that are installed based on light level requirements are often cost-effective and sufficient for a specific task. However, with the philosophy of Kelly in mind, a space can be much more enjoyable.
- With the project goal in mind, a balance needs to be found between (existing) cost-effective lighting and aesthetic lighting. They might go hand in hand. Decomposing the scene with light layers could help to form a solution.
- From an architectural point of view, wall lighting or vertical illuminance can have multiple effects.
- It can decrease the contrast between a light façade and a wall during the day.
- Vertical illuminance also creates diffuse lighting in the room.
- Depending on the distribution on the wall, light guides the visual perception of a room - not only the size, but also the atmosphere.
- The elderly could benefit from fitting light atmospheres at the right moment. They prefer high intensity and a monochrome colour palette.
- Organic shapes, luminaire compositions, and unobtrusive designs are possible with the rise of miniature and flexible LED. Combined with materials like wood and fabrics, new luminaires could fit well in a healing environment.

1.4 3D printing

This chapter describes the main insights of research in 3D printing innovations within the sector and within Signify. Information was gathered by consulting company experts, desk research, and attending the Formnext 3D printing fair.

3D printing technologies

Shahrubudin et al. (2019) provide an overview of seven 3D printing technologies, however many variations exist. The four most interesting technologies are discussed, selected based on their relevance to the project, the context of healing environments, and Signify's interest.

FDM: fused deposition modelling

Signify themselves run production with FDM printers, which is why from the start FDM printing has more focus. The first innovation to discuss is organic additives in filaments. The industry is experimenting with many different additives such as wood, cork, and shells. Commercially available additives are mixed in different ratios between 10 and 40 per cent. They give the material a widely different look and feel than bare PLA.

A trend that goes hand in hand with adding additives, is pallet extrusion FDM. Instead of a roll of filament, material in the form of pallets is extruded. This gives the benefit of mixing custom materials (pallets) for different prints. Innovation in the extruder heads has made it possible to mount them on a 3D printer head, even on more advanced machines.

Examples of more advanced machines are printers that have more degrees of freedom. Five-axis printers enable the machine to make parts in a non-planar way. This opens up more custom shapes without support. Current printers used at Signify can print in a non-planar way but only on one axis.

The final innovation is the nozzle size of 3D printers. A large variety exists, and even adjustable ones as in Figure 26. Of course, the nozzle diameter influences the amount of detail that can be printed. However, there is also a factor of print speed. Signify chose to print with a large nozzle in production because it was able to produce a strong part quickly, however detailed printing is being considered as well.

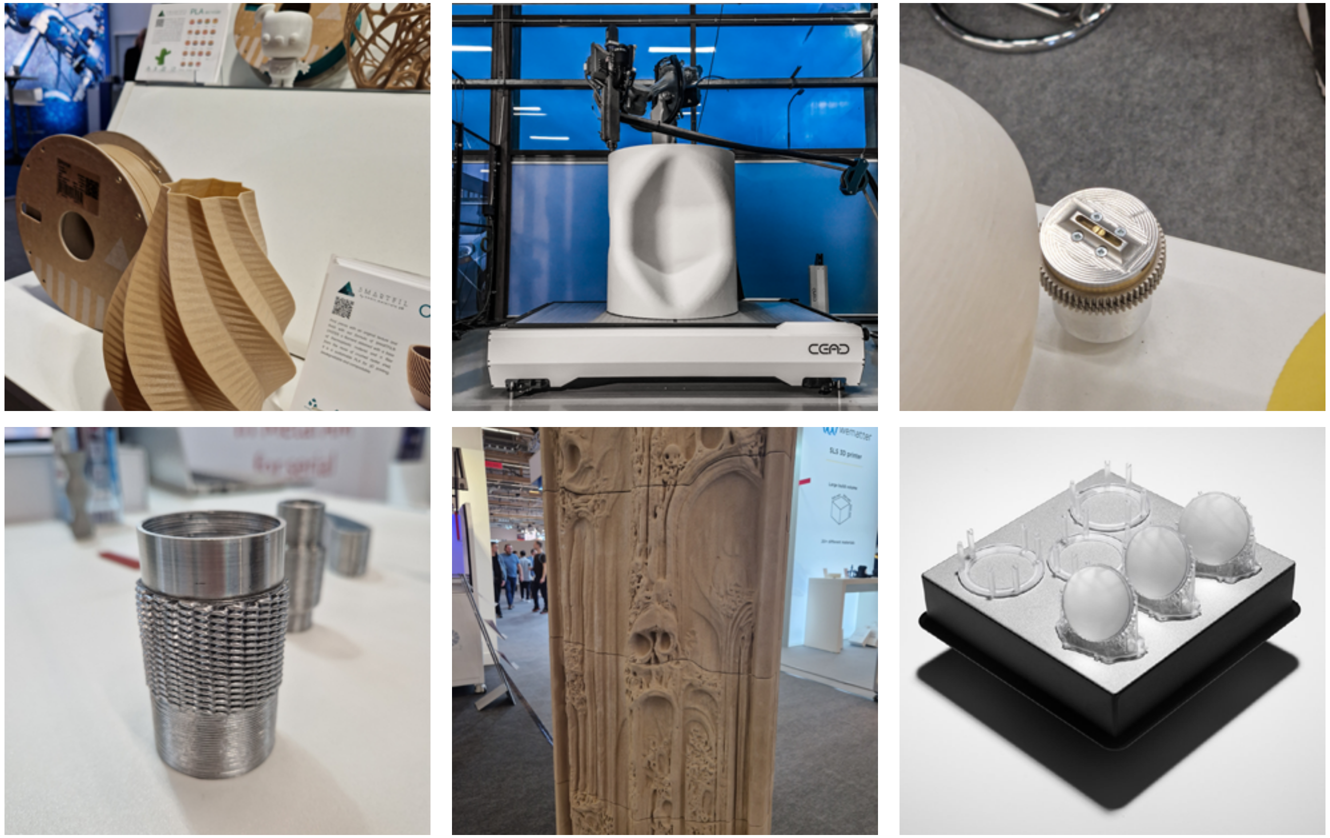
WAAM: wire arc additive manufacturing

3D printing metals are increasing in the industry as the cost price is getting more competitive with other production methods. Signify is especially interested in WAAM printing, where a welding head is mounted on a robotic arm. There are possibilities for thin-walled stainless steel or aluminium parts. This would make it suitable for printing structural parts in, for example, outdoor luminaires, where requirements are more demanding. Purely aesthetically, it also opens up new possibilities for metal surfaces or even glossy parts with a mirror finish.

Binder jet printing of concrete

Printing with concrete is also in development within Signify. This is done with binder jet printing, in which concrete powder is added layer by layer to create a 3D object. With this technology even fine detail is possible. It only offers less strength structurally, and the resulting luminaires are not as impact-resistant as regular concrete. However, it allows parts that require weight to blend in within the outdoor environment if necessary.

Figure 26: This figure shows examples of six 3D printing developments. The top three images illustrate three FDM technologies: recycled additives, extrusion printing, and a variable nozzle. The bottom images show resulting prints of Waam, binder jet, and SLA.



SLA: Stereolithography

Finally, Signify is also experimenting with the use of SLA resin printing to create custom lenses for their luminaires. This would mean that lens characteristics could be customised for each occasion or per LED.

These technologies could inspire new and interesting luminaire designs. However, as Signify is experiencing, it requires great control of the 3D printing process to achieve suitable results for production. Therefore, print quality, error rate, and finishing are important. 3D printing is also still a slow technology when compared to injection moulding of luminaires, but it provides greater order flexibility, requires less investment, and allows for production in low quantities.

3D printing and light

Some examples of what is commonly done with 3D printing of luminaires are shown in Figure 27.

Complex patterns of light can be created by varying individual layers of the 3D print either in the slicer or CAD model. Variables to play with include the wall thickness or the creation of small holes. Different materials such as transparent, diffusing, or wood-like materials give different looks and options to play with. Furthermore, the form freedom of 3D printing facilitates the creation of complex shadow patterns or mechanisms.

Creating slightly different luminaires each time gives the possibility to make unique luminaires. An entire composition of luminaires could even be created without extra costs

With all these possibilities it is up to the designer to take advantage of them. Within Signify, Rhinoceros Grasshopper is commonly used as CAD software to design complex shapes and patterns parametrically. These would not be easy to make in other programs such as Solidworks.

Takeaways

- FDM printing remains the most applicable to the project. Signify is already very familiar with the technology and is improving its workflow constantly.
- FDM is one of the most affordable 3D printing technologies
- The rise of organic materials and pallet extrusion on multiple axes fit with a healing environment aesthetic, where natural colours, textures, and shapes are desired.
- With the sacrifice of form freedom over other 3D printing technologies, FDM remains quick, and therefore lends itself to luminaire design.
- 3D printing in luminaire design can be used to play with complex patterns, shapes, and compositions. These possibilities could enrich the light visual of a luminaire.

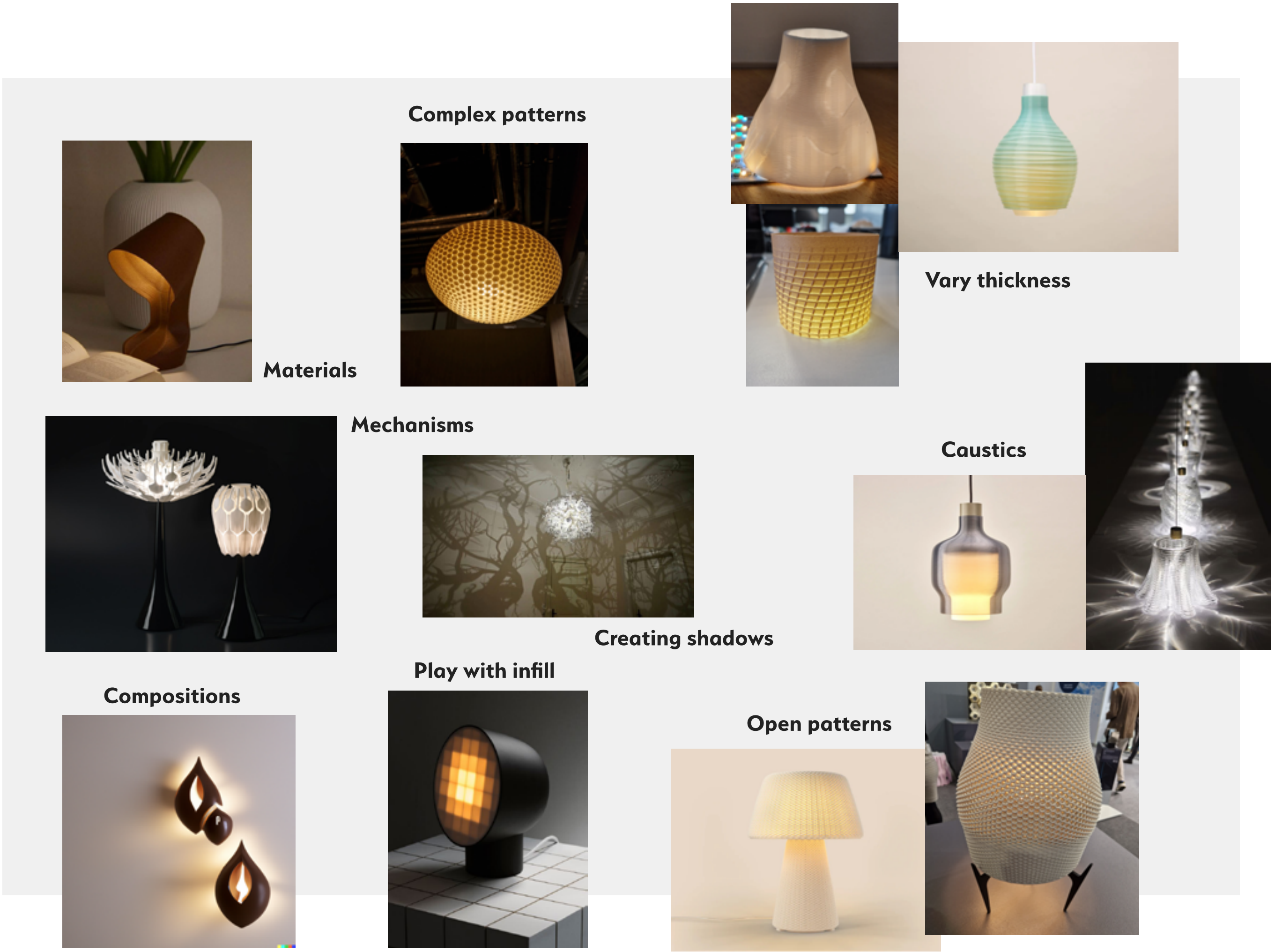


Figure 27: This figure shows a mood board of examples of a combination of 3D printing and light.

1.5 Design goal: bright, natural, lively, and pleasant

A design goal was formulated which can be seen to the right. It is a combination of the project brief and the relevant insights from the explored fields of Signify, elderly care, lighting, and 3D printing.

The design goal uses the term 'lighting system' instead of 'luminaire' to avoid limiting the ideas in the next phase. "Bright, natural, lively, and pleasant" are four qualities that summarise the goal of the lighting system. The exploration phase revealed that light levels in nursing homes were too low, that enhanced natural features can benefit the restorative affordances of a space, that the atmosphere could be enhanced with more brilliance, and that the space should be pleasing aesthetically with comfortable light. These aspects would create a space that is more enjoyable for both the elderly and staff.

- **Bright** – the design should make the room look bright(er).
- **Natural** – the design should simulate aspects of natural light and shapes.
- **Lively** – the design should offer variety and a brilliance effect.
- **Pleasant** – the design should be perceived as pleasant.

With the insights, the following block explains what a solution to the design goal would offer to the main stakeholders in an attempt to solve their needs that emerged from the previous chapters. These main stakeholders were extracted from the stakeholder map in Figure 28.

I want to stimulate aspects of **natural light** in **nursing homes** by designing a **lighting system** that creates a **bright, natural, lively and pleasant light effect.**

Signify (Digital workflow)

Exploring 3D-printing strengths for a real-life luminaire (Brief)
- Unique objects
- Complex patterns & shapes
- Small scale production

Exploring new market (Brief & elderly care exploration)
- Elderly care: opportunities for lighting
- Growing sector

Explore portfolio expansion (Signify exploration)
- Wall luminaires

Nursing homes

Improve patient quality of life (elderly care exploration)

Staff (elderly care exploration)
- Maintenance-free solution
- Automated light, control-free
- Happier patients means less stress
- More enjoyable space improves work environment

Costs (elderly care exploration)
- Adapt light to existing building with 3D printing

Elderly

Improve connection with nature (elderly care exploration)
- Natural light, materials and shapes
- Personalized design

Improve lighting atmosphere (lighting exploration)
- Increased diffuse light
- Increased brilliant effect for an enjoyable space

Better sense of space and less contrast with vertical lighting (lighting exploration)

Part of a circadian lighting system (elderly care exploration)

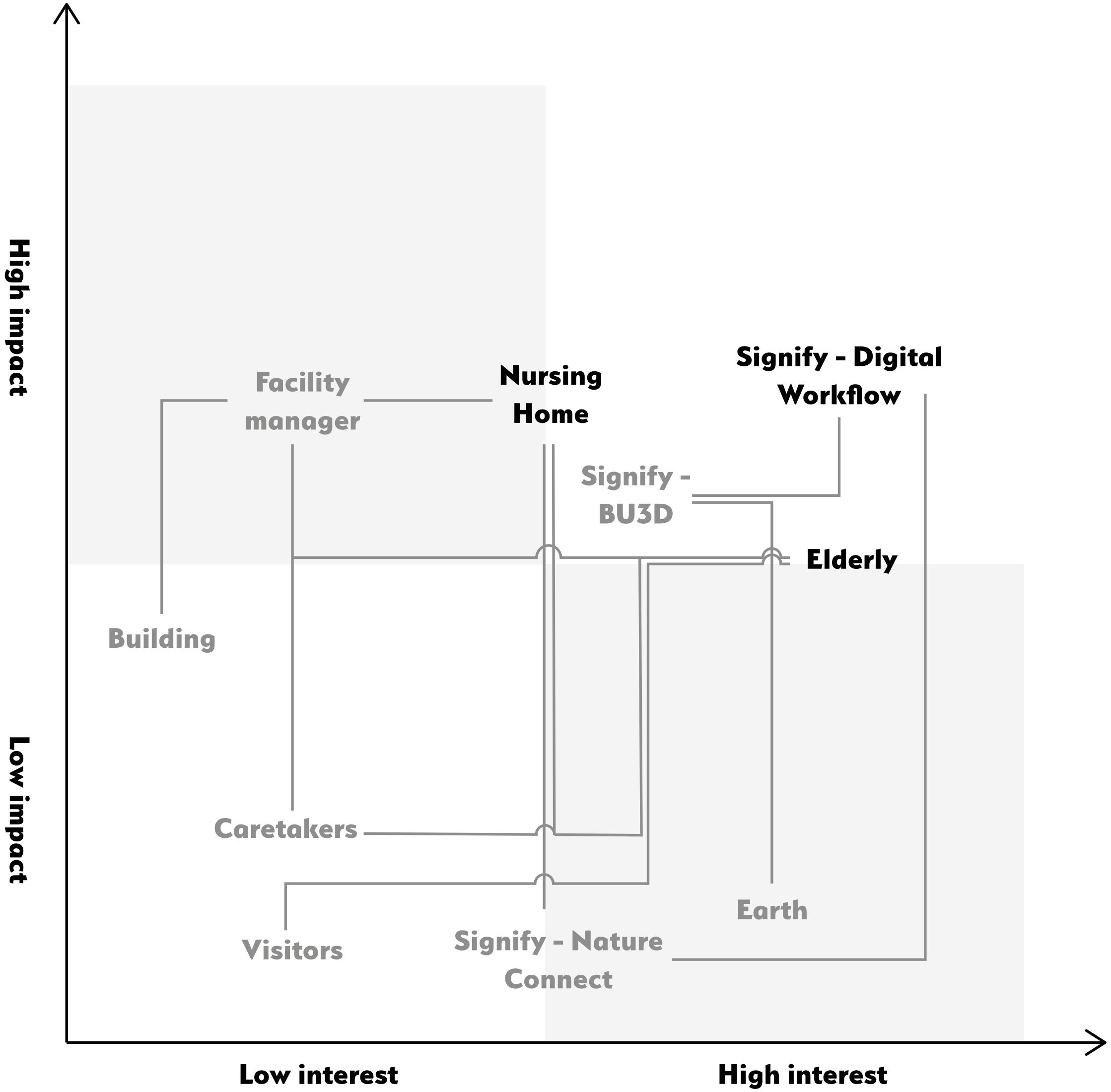
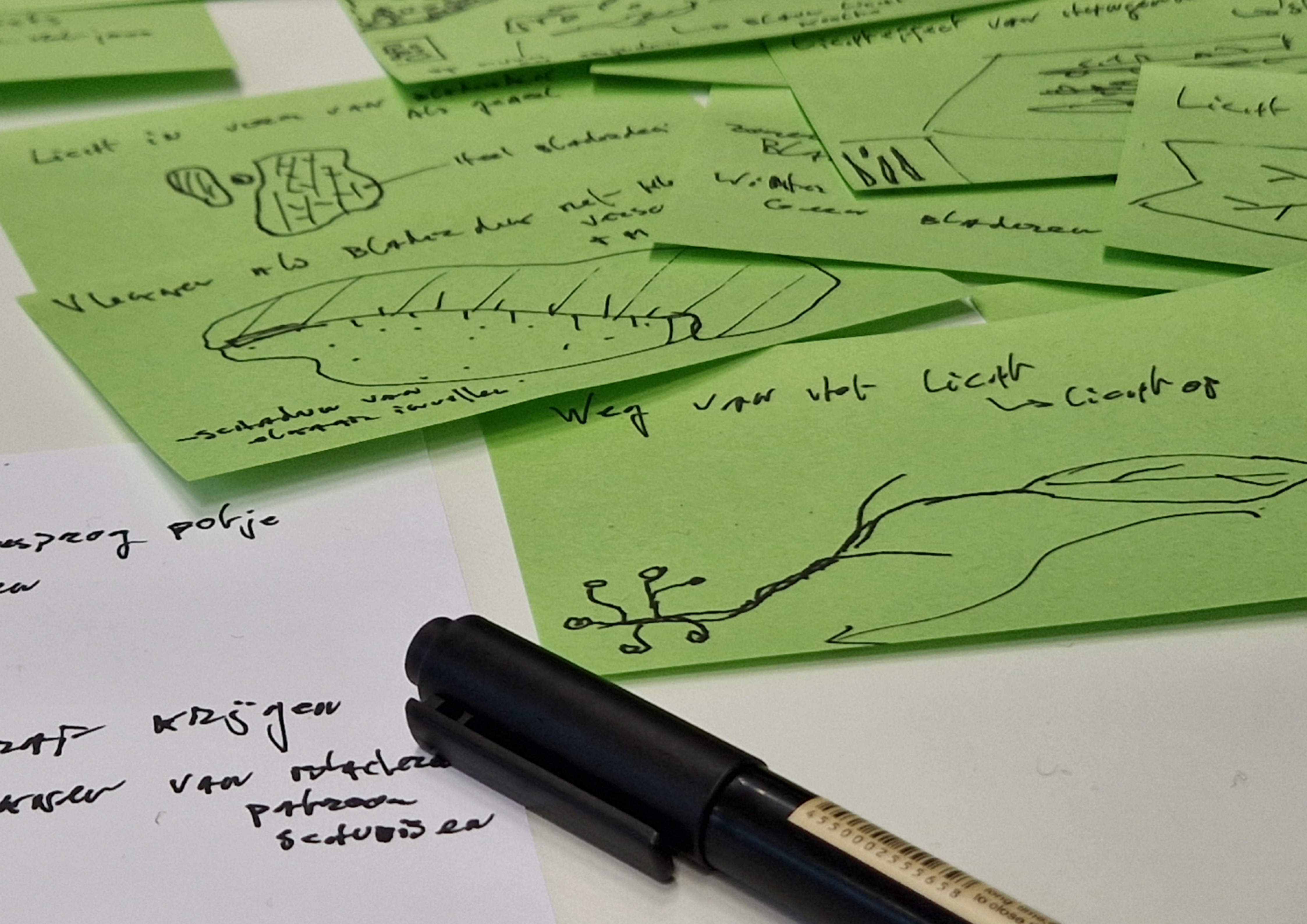


Figure 28: This figure maps the stakeholders on impact and interest into the project. Signify Digital Workflow is the most important stakeholder: it is the client of the project and most time is spend with this stakeholder. They have a strong relation with the 3D printing business unit (BU3D) and Nature Connect. Signify's sustainability (Earth) accountability is weaved into the 3D printing business. Second would be the elderly, residents in the nursing homes. Their needs are important to the client since they seek a concept that is designed for a realistic context too. Finally, nursing homes, these organisations would be the client for buying the final concept. They care about the elderly and especially their staff. The facility manager often has a big say in furniture related decisions. He or she has a good view on the building, needs from the staff and the elderly, and on what is feasible and necessary.

2 | Vision and ideation

The second phase of the project is all about creativity and prototyping. The design goal that was chosen is further substantiated with a vision of how to solve it. Subsequently, ideas are generated, prototyped, and developed into concepts in an iterative process.


Weg van het Licht
Bladeren
krijgen

2.1 Design vision

In what ways could the design goal be solved with a lighting system concept? This chapter discusses in more detail the scope of the design goal, how healing environments should be incorporated, the introduction of a metaphor, and how the luminaire should fit within the nursing home lighting context. These discussions give substantiation to the design goal for the upcoming ideation.

Implementing healing environments

As earlier discussed, healing environments play a major role in new healthcare design, so a new lighting system design should also fit within this philosophy. From the exploration, it became clear that several elements fit within healing environments: natural materials such as wood and plants, natural shapes, colours and patterns, and of course natural daylight features. Artificial light was often soft.

Figures 29 and 30 show a collage and mood board that were made with elements of healing environments. This mood board is used to guide ideation and validate ideas. 3D print filament with additives such as wood fibre fits with natural materials. It could also offer a more natural, rough, texture which would softly catch the light as well. Light is emitted from these patterns, indirectly, inspired by light interacting with nature. The light could also form in patterns either cast on a surface or emitting from itself. With 3D printing, one could make beautiful natural patterns, irregular and mathematically defined, as within ivy, which is discussed next.

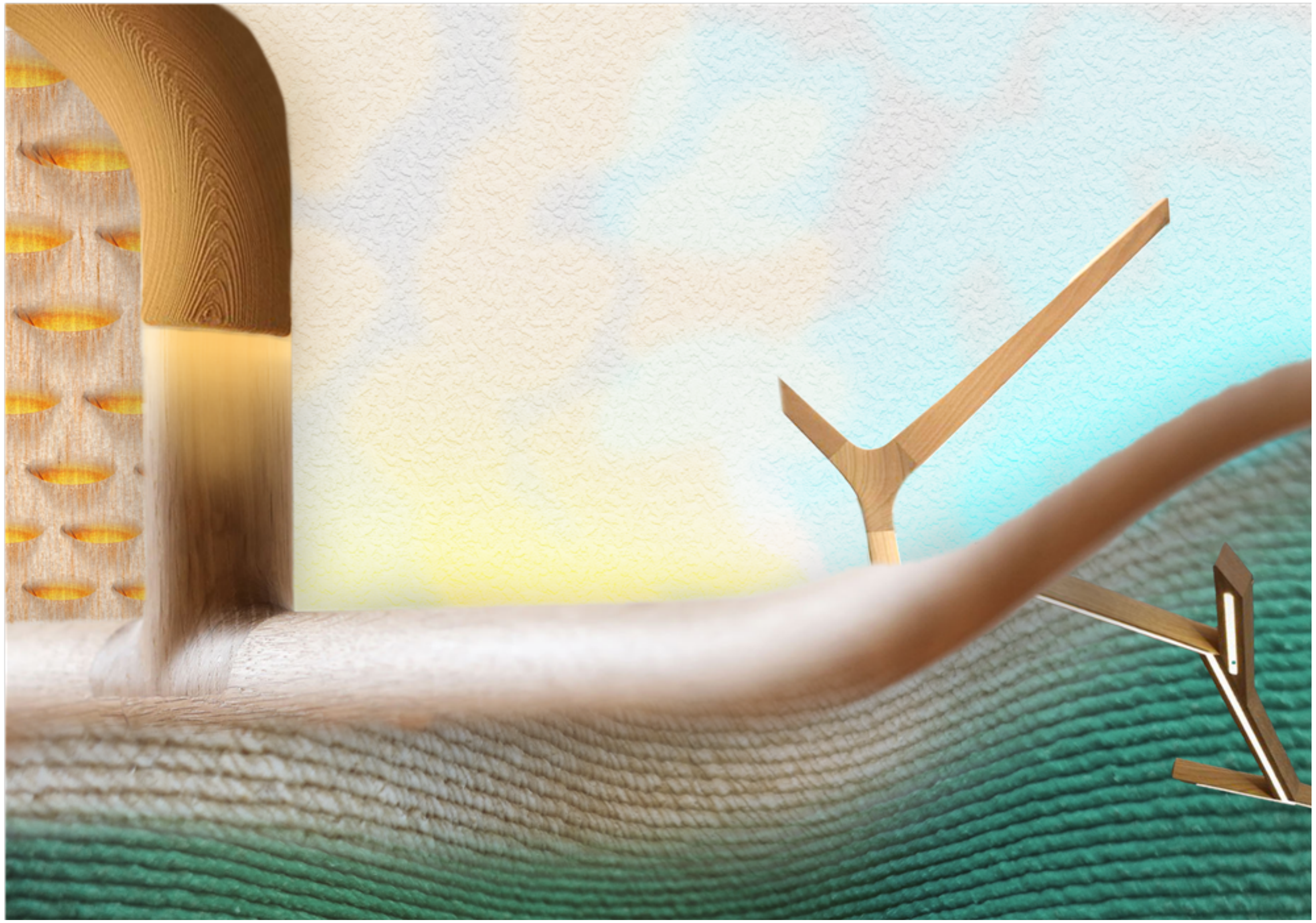
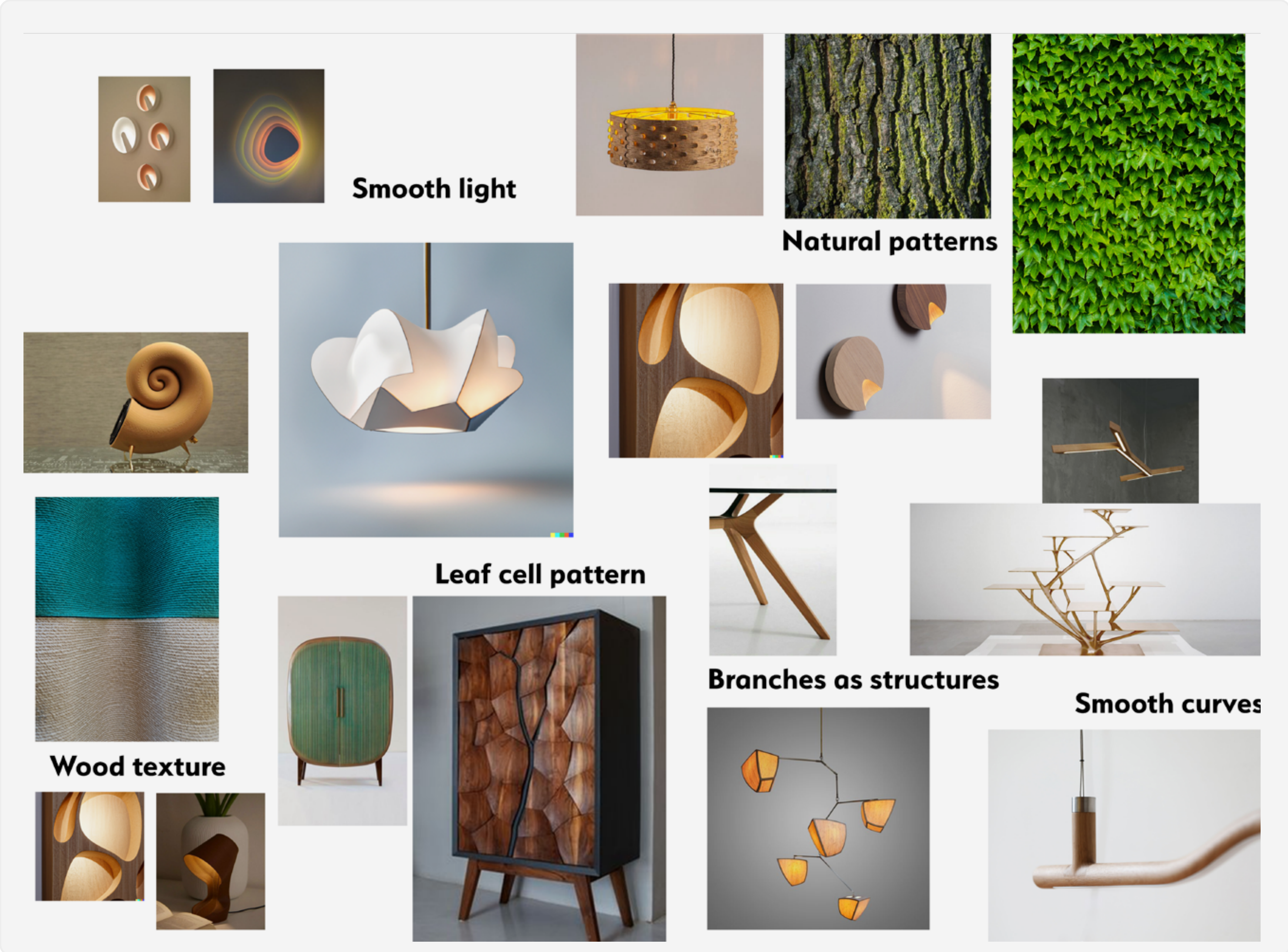


Figure 29: This mood board shows natural colours, shapes and textures that fit with healing environments. Next to that it shows indirect light in a pattern and two tones.

Figure 30: The figure to the right shows a collage that is less abstract. This ▶ mood board formed the base for the first.


Smooth light
Natural patterns
Leaf cell pattern
Branches as structures
Smooth curves
Wood texture

Ivy as a metaphor

Imagine: it is a warm, pleasant spring day. Nothing would make a person happier than to relax outside - bathing in the sun with some friends or family, while enjoying the view of a water feature, trees, or a lovely garden. Some would find themselves in the city centre with a coffee on a terrace, while others would prefer a serene patio or garden, more slow-paced, as in Figure 31. The walls are covered with ivy. It is always a beautiful sight where nature and man-made structures meet.

This scene was chosen as inspiration to get more in detail guidance on the natural aspects of the design. Ivy, or in Dutch “klimop”, grows on walls and adds a natural element to man-made structures. This makes it a good fit as a design metaphor for the aesthetic design. The metaphor fits with the design of a wall lighting system that should have a connection with nature. The use of plants is common in healthcare, but not possible everywhere. Therefore, the combination of ivy and light has the potential to be very attractive.

The mood board in Figure 32 shows an exploration of different aspects of ivy: the shape of roots or tendrils, complex patterns of leaf nerves in fractals, colour patterns in ivy as a whole, the variation in the shape of leaves, and the light that passes through hanging ivy. These aspects could inspire shapes, patterns, and colours in the ideas and finally concepts on a micro or macro level.

Figure 31: Illustration of elderly people enjoying the sun, ivy, and each others company. This figure was made using DALL-E.

Figure 32: The mood board on the right shows an exploration of the ivy ▶ metaphor and highlights the valuable aspects.

Ivy products

Wavy shapes

Light as leaves

Tendril structure on wall

Round wall elements

Cell pattern detail

Fractals

What could the fruit be?

Hanging vs. climbing

Structure of branches underneath

Layered shapes

Variety of leaves

Marbling

Spotty

Wide range of colours

Lighting context: a nursing home

The context of the designed lighting system is important. It has to fit within the physical context from the perception of the user. As discussed before, the current spaces in nursing homes could benefit from much higher light levels and possibly even a circadian system. Improving these aspects would arguably be a quick fix, although costly. Another angle to look at the lighting scene is to take the qualitative approach, starting with the light layers from Kelly that were discussed before.

So, what can be said about the elderly care common rooms? As can be seen in Figure 33, the main focus of lighting is ambient luminescence, which is provided by the down lighters combined. Furthermore, there is little focused light guiding the eye to important elements and no specific zones. Finally, there is almost no 'play of brilliants' elements such as lively light patterns or reflections. This scene of mainly focused light makes sense for the living room because vision is important. A better balance with brilliance and focused light, on the other hand, could benefit aesthetics, enjoyment, and atmosphere.

It is difficult to say what the current perceived atmosphere is in the example space. There is no data to be found on this concerning elderly care, but with the research from the exploration in mind, some changes could be suggested that would decrease the tenseness and detachment. These could be assumed negative atmospheres for a common room. Using non-uniform light is usually cosier and less detached, as is using warmer colours.

In the case of the example room, the vertical light is especially important. As discussed, it can provide a sense of space in a room and reduce contrast during the day. Current down lighters and custom floor lamps provide some light on the walls. This looks adequate, but better coverage on the walls could benefit the light scene during the day and night. Of course, this is also an assumption, but there is the opportunity for additional vertical light. The example room was also considered one of the best-looking rooms of that nursing home's department.

From these observations, it is clear that there are multiple opportunities to improve the lighting scene in the nursing home living rooms. These opportunities are considered in this project in the form of an envisioned living room space (see Figure 34). One luminaire or light system is not likely to make a huge impact on its own, so a more elaborate proposal for nursing homes is necessary. The designed lighting system is aimed to fit within this proposal and work together with the envisioned luminaires to develop a coherent light experience in the form of dynamics and scenes. This also fits the conceptual form of this project and makes the design more impactful in inspiring the stakeholders.

Figure 33: These pictures were taken of one common room during a visit of a nursing home. They show that the living space is dark and mostly illuminated by the luminaires in the ceiling. Daylight has little impact in this big space.

2.2 Program of requirements

The vision and ideas on how to solve the design goal are listed in a program of requirements. The list below shows the most important requirements in this stage. The full program of requirements can be found in Appendix B.

- The lighting system should be wall mounted and illuminate the vertical surfaces.
- The qualities of light should be soft and indirect.
- The light should follow a circadian rhythm in sync with other luminaires. This requires adjustable brightness and colour temperature of the light source.
- The aesthetic product experience is guided by the mood board (healing environment) and metaphor (ivy). Wood fill filament is used to create a rough natural texture.
- Light is shaped by nature-like patterns inspired by ivy as a metaphor.
- A brilliance effect is added to improve the balance of light layers in the space.

Together with the design goal, the requirements shape the scope and space for ideation. It is clear that the concept is going to be a wall lighting element with indirect light inspired by ivy. Some questions need to be considered though: what shape could the light be? What should the lighting system look like? What does the composition look like? Any patterns? How is the metaphor of ivy integrated? The following chapter will discuss how the problem space was navigated and how one concept emerged.

Figure 34: The figure on the right shows how the common room of this nursing home might be improved with focused light and vertical light. It is the same picture as below with an overlay of added light.

2.3 Experimentation, ideation and concepts

The process of coming up with ideas was divided into four phases. The first phase was experimentation, where inspiring features were tested throughout the exploration phase. The remaining three phases utilized a weekly sprint model: a first ideation sprint, a second ideation sprint, and finally a concept sprint.

1. Experimentation

Figure 35 captures an overview of the experimentation during the exploration phase. These helped to shape exploration and develop the design vision. Notable experiments included varying the wall thickness to create patterns, creating reflections and caustic effects from different prints, and experimenting with the composition of lighting elements.

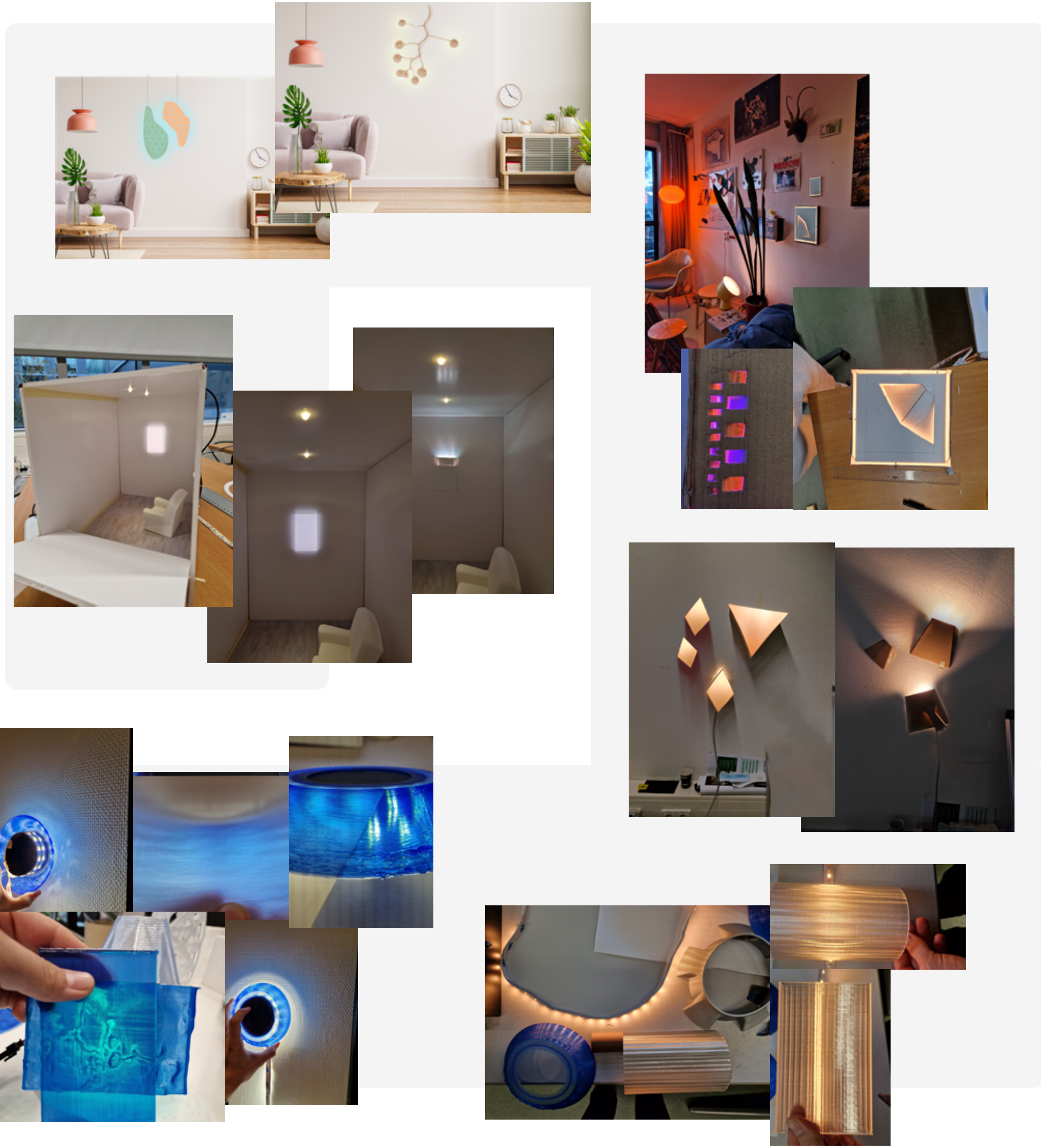


Figure 35: This figure shows clusters of experiments that were carried out throughout the project. The clusters are chronologically organised from the bottom left to the middle.

2. First ideation sprint

The first sprint week was about brainstorming and evaluating ideas for the light effect and for the shape of the lighting system separately. This ensured that ideation could focus on one or the other, making it more goal-oriented and practical, which is appropriate at this stage.

A diorama turned out to be a great way to play with the lighting effect on a wall. It gives the possibility to play with light freely and effortlessly, while simultaneously visualising a bit of the context. The ideas were based on brainstorms and How-Might-We's on the topic. Figure 36 shows this process and Figure 38 shows the main inspiration chosen. A more detailed overview of the options that were prototyped can be found in Appendix C.

3D printing was used to ideate on lighting system shape, again with ivy as inspiration (Figure 37). Options were generated through an individual brainstorm and How Might We's. The prototypes were used for the visualisation and evaluation of the ideas.

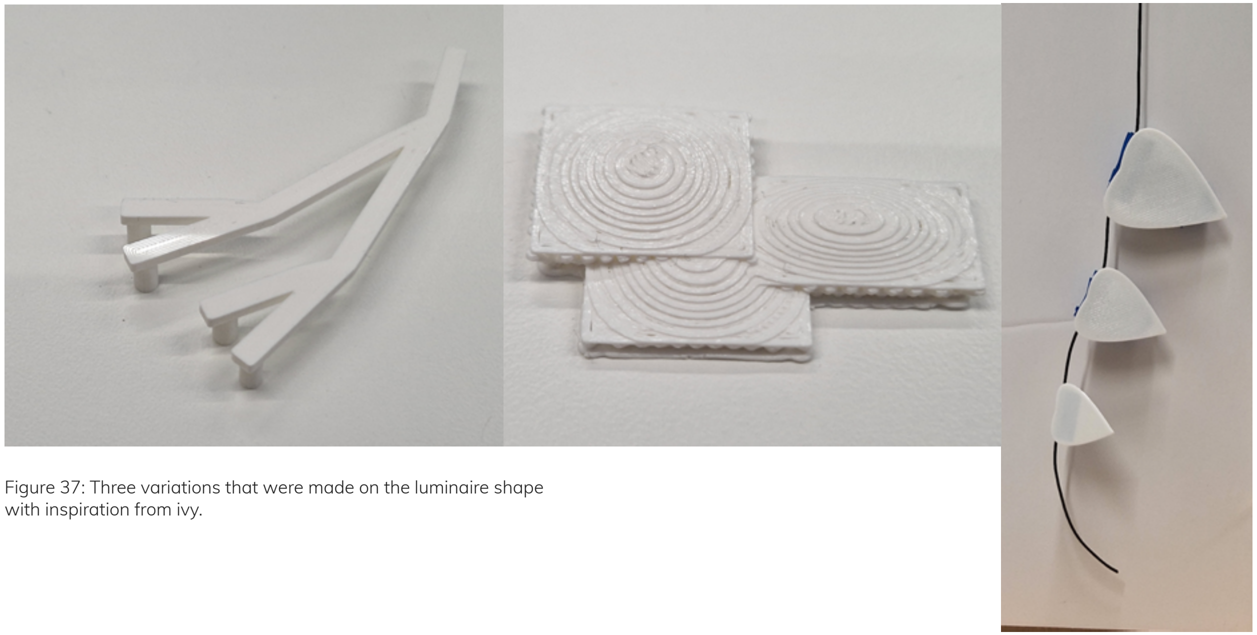


Figure 37: Three variations that were made on the luminaire shape with inspiration from ivy.

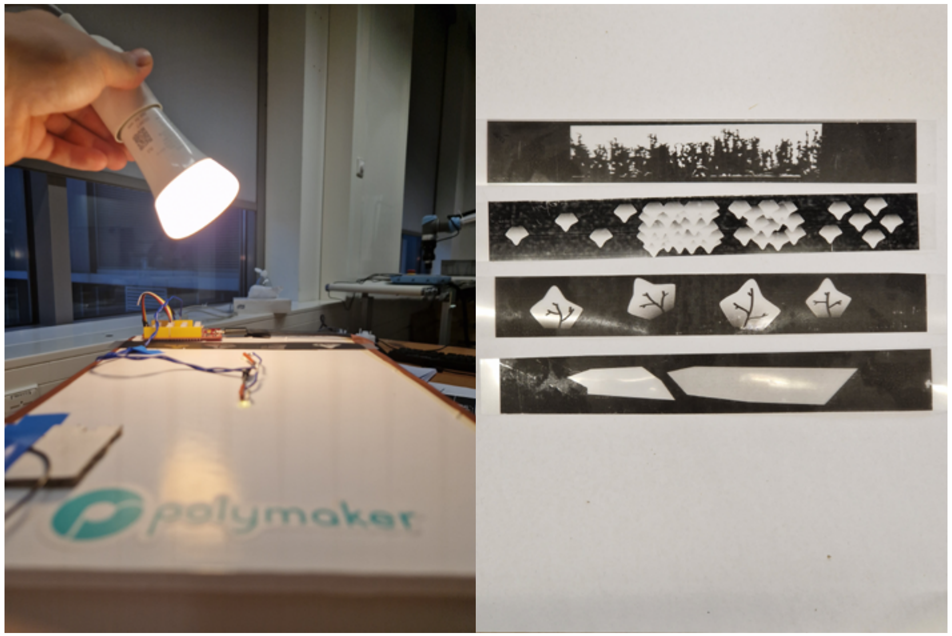


Figure 36: This figure illustrates how the ideation on light effect was performed. A diorama box was used with a light and stencil to create the desired effect in the box.

Figure 38: The main inspiration chosen in the first idea sprint to inspire ideas on the light effect in the second sprint.

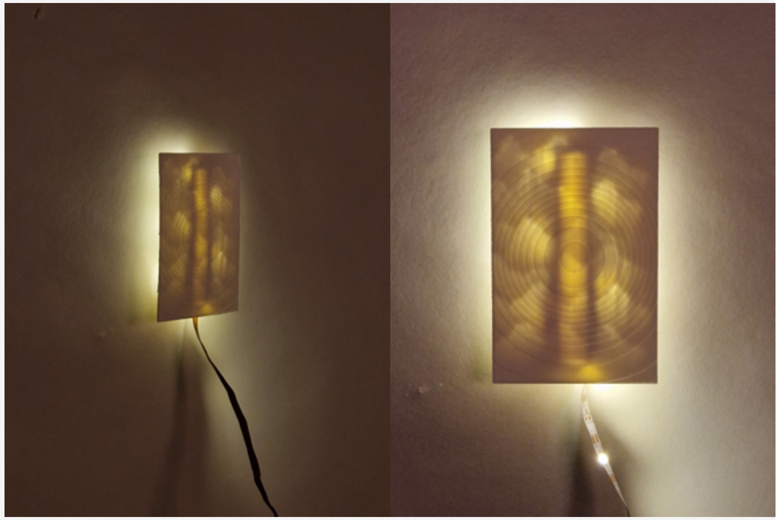
3. Second ideation sprint

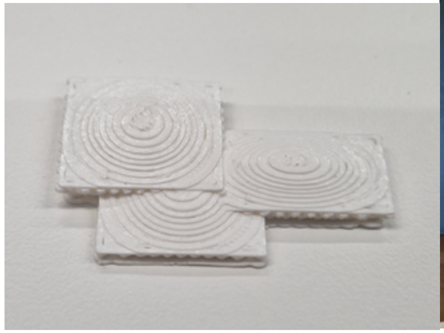
Subsequently, the promising aspects of each idea were chosen using the Dot method, where dots are placed at ideas that are valuable or that spark interest. This enforced a selection based on intuition and inspiration in this early stage of ideation. Further prototyping resulted in a secondary evaluation in week two of the ideation sprints (see next pages). These ideas were evaluated with the Plus Minus Interesting method (PMI) and a Harris Profile (see Appendix D). The PMI method was used to keep the inspiration and interesting elements from being lost. The Harris Profile aided a decision based on requirements to protect relevance. Ideas 1, 4, and 5 were chosen with these methods. The next paragraph explains the reasoning for this decision.

The first idea was overall strong in concept. It is interesting to make use of the environment for mounting, but the impact of the lighting effect could be improved. The fourth idea fits well within healing environments and features an intriguing simple light pattern. Although, it could be made to have a wider light spread on the wall. Finally, the fifth idea offered a simple electrical installation with an interesting light pattern and a large illuminated surface, but it is more costly during production in terms of 3D printing and assembly. This final idea emerged after the first cycle of ideation with input from Signify on the importance of electrical installation.

Idea 1

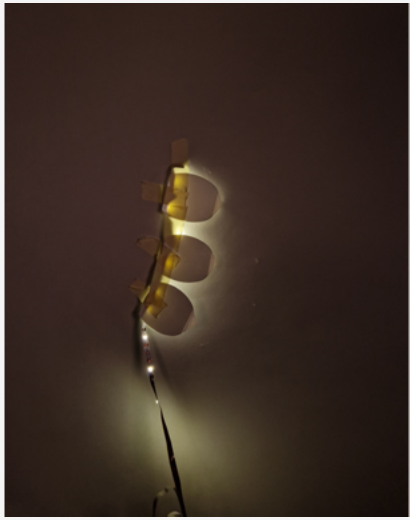
The luminaire gives soft diffuse lighting indirectly via the wall. The front lets through a pattern that is inspired by ivy leaves in sunlight. This is accomplished by varying the thickness of the part.
It consists of two parts: a wall mounting bracket and a front cover. The luminaire is 3D printed with a fibre PLA in the same colour as the wall.
It is intended to have multiple luminaires on one wall.

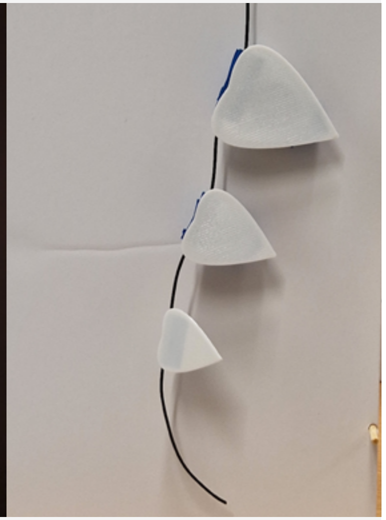




Idea 2

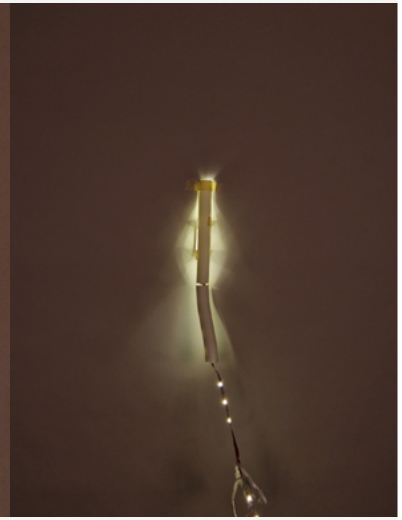
The inspiration for this idea came from the use of a wire to connect luminaires. Like the roots of ivy, for example, connect the leaves. Gravity pulls the luminaire in a curve, and light shines indirectly on the wall from each leaf.
The leaves are printed from opaque plastic and mounted by three to five panels on one wire. It is intended to have several luminaires in a single room.





Idea 3

This idea aims to create a light pattern inspired by the vein structure of a leaf. The light pattern is shaped like a leaf with overlapping shadows that recreate the vein structure.
The luminaire measures 60 cm in length and can be printed in multiple parts from wood fibre PLA, with an LED strip inside the profile. It is intended to have multiple luminaires per wall, but they do not have to be next to each other.

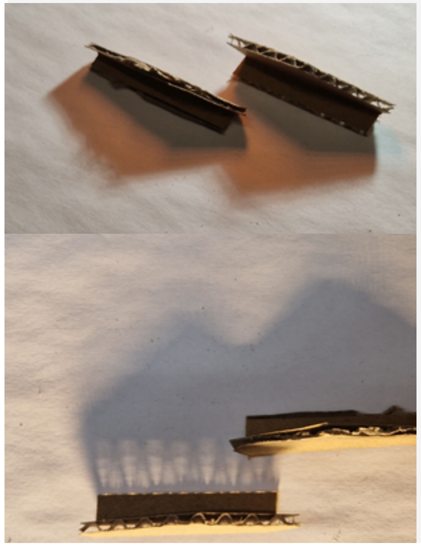


Idea 4

This idea was inspired by light passing through a group of hanging ivy branches. A similar light pattern is created that varies between a wide and narrow shape by varying the distance to the wall. Together with multiple luminaires next to each other, it forms an interesting light pattern. Similar to idea 3, it is printed in multiple components from wood-filled plastic that are about 60 cm in length.

Idea 5

The grazing light from above that shines on the panels creates a light pattern that is inspired by actual leaves on a wall. Different light colours can create coloured shadows, and an open structure in the leaves can be used to create a vein-like pattern.
The leaves are 3D printed individually and mounted on the wall panels.



4. Concept sprint

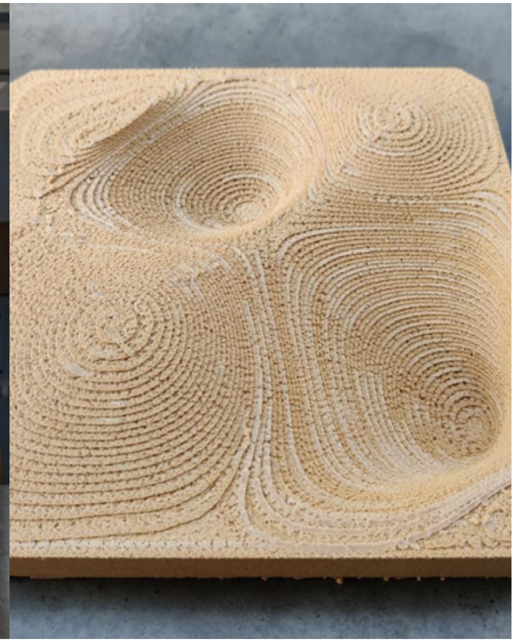
The three chosen ideas needed to be further detailed to evaluate their light effect. Prototyping on a true scale made the effect more real and made it easy to imagine what it would be like in the intended context. The figures on the next pages showcase the concepts.

Bladlijst (idea 1) - Continuing on idea 1, the "Bladlijst" or leaf frame concept was prototyped with laser-cut foam board instead of 3D printing for the sake of prototyping time. The idea of mounting it like a picture frame formed the main inspiration as it fits within the context. It consists of a panel of foam with an LED strip behind that creates indirect light via the wall. The pattern inside is inspired by the branches of ivy. This could be further developed in interesting complex patterns with 3D printing. The concept is intended for multiple luminaires per wall.

Lichtwortel (idea 4) - The concept of "lichtwortel" or light root aims to create a light pattern inspired by the light shining through hanging ivy. The wavy shape of the luminaire is inspired by the roots or branches of ivy. It creates an uneven light effect by varying the distance to the wall. The profile is 3D printed with fibre-filled filament and houses an LED strip inside. This concept relies on multiple luminaires hanging adjacent to each other.

Groene lichtwand (idea 5) - The final concept is inspired by ivy covering a wall - the fusion of man-made objects and nature. This concept also follows the trend of indoor green walls, and is therefore named "Groene lichtwand" or Green Light Wall. In contrast to the other concepts, multiple central light fixtures are used to create a light pattern with shadows. Several similar elements are printed or placed on a panel which is mounted on the wall. One particularly intriguing aspect is the overlap of shadows. This could be leveraged to create a dynamic light pattern by pulsing the light sources.

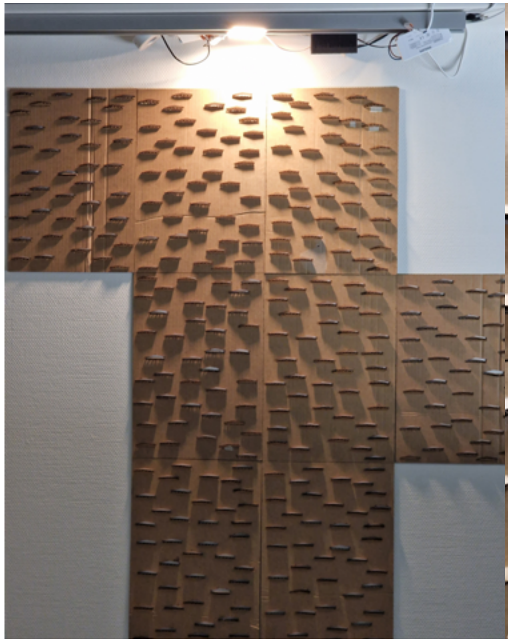



Bladlijst

Vertical illumination that is created by a hanging frame inspired on leafs and leaf veins.

- 3D printed with light wood fibre filament that is made from semi-translucent PLA
- Assembly of two components: LED strip mounting attached to the wall and a translucent pattern plate
- A LED strip behind the semi-translucent panel illuminates the wall and creates a pattern through the panel.
- Intended for a couple of luminaires per room, 40cm high

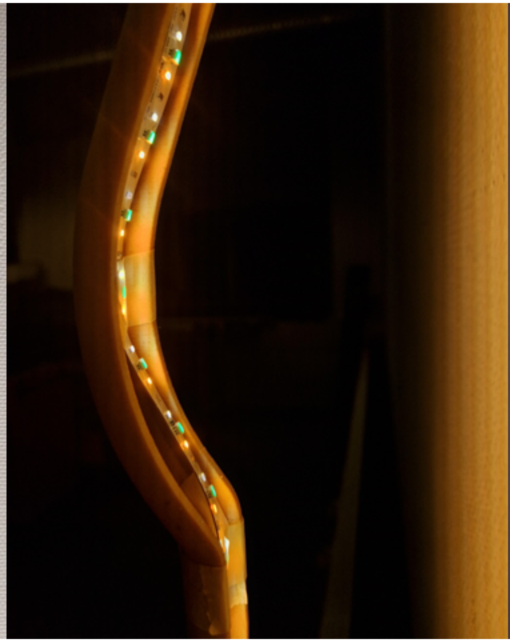


Groene lichtwand

Vertical illumination in the shape of a green wall created with grazing light and shadow patterns.

- 3D printed with light wood fibre filament that is made from opaque PLA
- 3D printed elements are printed on a base surface or fabric that covers the wall in strips of 20cm by 100cm. The strips are illuminated from the top.
- Variation in material colour and transparency creates a interesting light pattern.





Lichtwortel

Vertical illumination in an irregular shape inspired on light through ivy vines.

- 3D printed with light wood fibre filament that is made from opaque PLA
- Made from a 3D printed profile with an LED strip inside. The luminaire is hung from a mounting strip near the ceiling.
- To get the intended effect, multiple luminaires should be hung next to each other.

Figure 39: An overview of the three concepts next to each other. This was the setup for the test with colleagues.

Selecting one concept

To make an informed decision on what concept to take further in the process, a combination of Weighted Criteria and testing with colleagues was used. The Weighted Criteria method aided in a substantiated decision based on the relevant requirements and their importance. The interviews helped to gather external input and feedback on the concepts. The Green Light Wall was chosen to take to the detail and embodiment phase.

Weighted criteria - From the weighted criteria (see Figure 40), the Green Light Wall scored the highest, with the Light Roots ranking in a close second. The green wall concept offers great opportunities in playing with light and creating variations. It also contributes significantly to the vertical lighting in the room due to the use of standard fixtures designed for that purpose. This means that it could provide more diffuse lighting and a sense of space in the room, as well as a high brilliance effect. It is also simple to install and could fit well within a healing environment style. The challenge for this concept is the production of a large number of elements and their placement.

Light Roots also offered a strong healing environment style and simple production. However, the concept has arguably less impact on the light scene and is more complex in electrical installation. The Bladlijst concept was considered robust due to its simplicity, but scored mediocre on the other requirements.

Test with colleagues - The results of the test with colleagues confirmed the lack of spark in the Bladlijst concept, as shown in Figure 41. The Lichtwortel concept, in particular, was associated with positive characteristics. The main value of this test is the qualitative analysis of explanations provided during the interview. These insights led to the following recommendations for the chosen Bladlijst concept. Because these recommendations were considered fixable, the concept was not abandoned following this test. Appendix E describes the test setup, results, and conclusions in greater depth. Figure 39 shows the setup.

- Light from the bottom is not natural and glary. Fix: light from the top
- The light effect (of linear light) is considered boring, formal, and detached. Fix: point source creates a cosier atmosphere and distinctive shadows.

- The pattern was considered boring. Fix: create unity & variety.
- Contrast can be intense in a dark environment. Fix: dynamic light intensity.
- Also without specific light, the panels could form a lively 3D wallpaper.

The deciding factor was at the core of the project. In a discussion with the mentor at Signify it was decided that the Green Light Wall concept spoke more to Signify. 3D-printed wall structures are not seen often within the company, and this direction could therefore inspire and evoke discussion. This aligns with the goal of the project within Signify to show possible directions for 3D printing in practice. A concession on production could be made since the project is conceptual. It also fits within automation trends in 3D printing within the company, such as parametric design and sales tools, automated 3D printed production, and robotic assembly of luminaires.

Making this decision means that Signify is seen as the main client in this project, though the intent is to design for a real context, namely nursing homes. This is a balance between two main stakeholders, and in this decision, Signify was deemed more important. Up to this point, contact with elderly care was limited, therefore it was decided to focus the project on the original project goal in this regard.

	Weight	**Bladlijst**	**Lichtwortel**	**Groene lichtwand**
Variety of possibilities for dynamic play in light colour and ditribution (PoR 7.4)	18	6	7	8
Area of the vertical surface that is illuminated (PoR 7.2)	16	8	7	9
Fitting of the briliance effect with the space (PoR 7.1.3)	16	6	7	8
Ease of instalaltion of physical and electronic components (PoR 8.1 & 10.1)	13	7	6	9
Costs based on light sources, material price and printability (PoR 8.2)	13	7	8	6
Fitness with natural healing environment style in light and shape (PoR 9.3)	10	7	9	9
Efficiency of light on the the wall in energy use (PoR 7.3 & 8.4)	9	6	5	9
Physical robustness (PoR 10.2)	5	8	7	9
+	100	**678**	**718**	**811**

Figure 40: This figure shows the results of the Weighted Criteria method. Eight desires were chosen from the program of requirements and subsequently given a weight based on their importance. Subsequently all concepts were given a score which was multiplied with the weight.

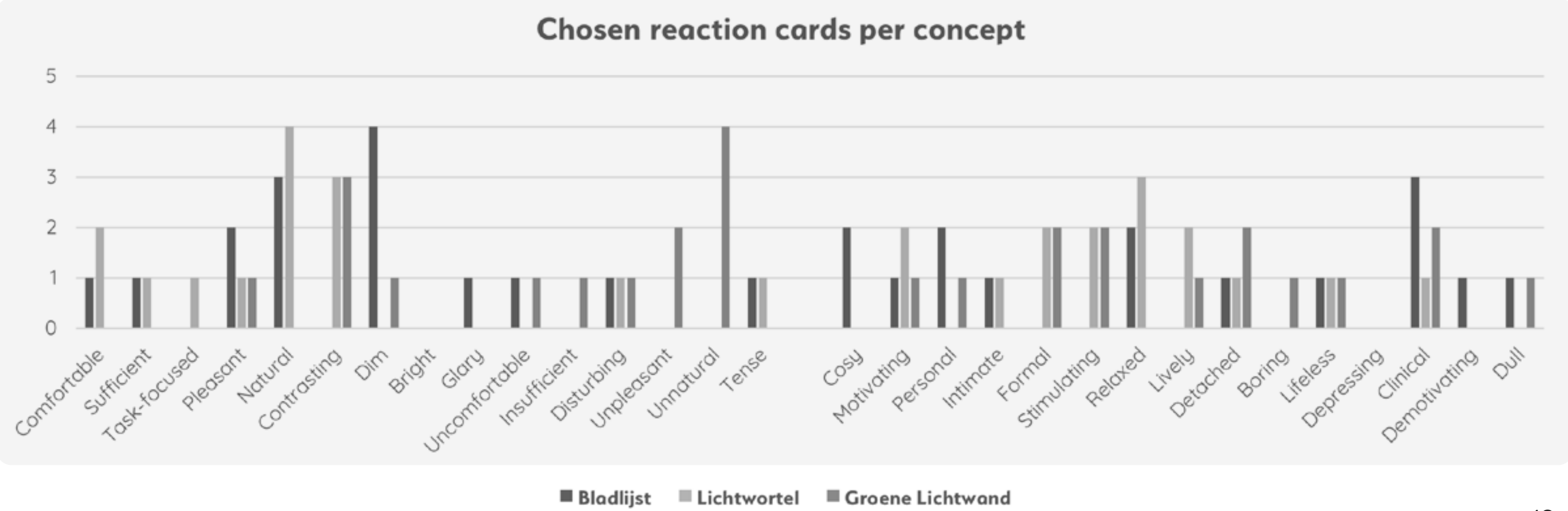


Figure 41: The results of the test with colleagues. It shows the number of times a reaction card was chosen for each concept.

3 | Detailing

This chapter will discuss the detailing of the chosen concept which is the third phase of the project. As the previous chapter concluded, several aspects require attention - see Figure 32 for an overview. During the project, these aspects were tackled in parallel to each other. However, in this section, each aspect will be addressed separately.

The following main subjects were addressed:

- The product experience of the panels, pucks, and light effect
- The process of manufacturing and installation
- The interaction and controls of the product and light with the context

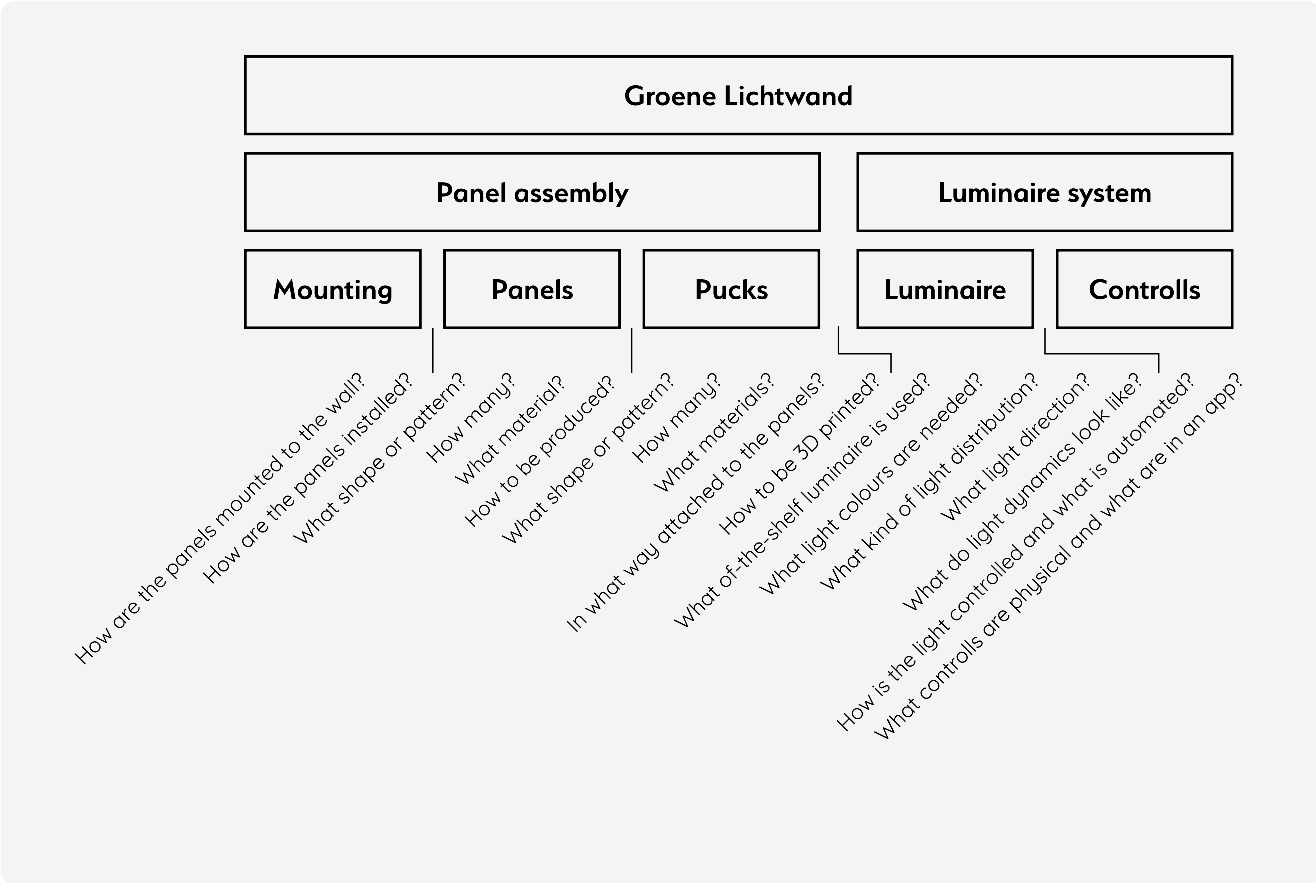
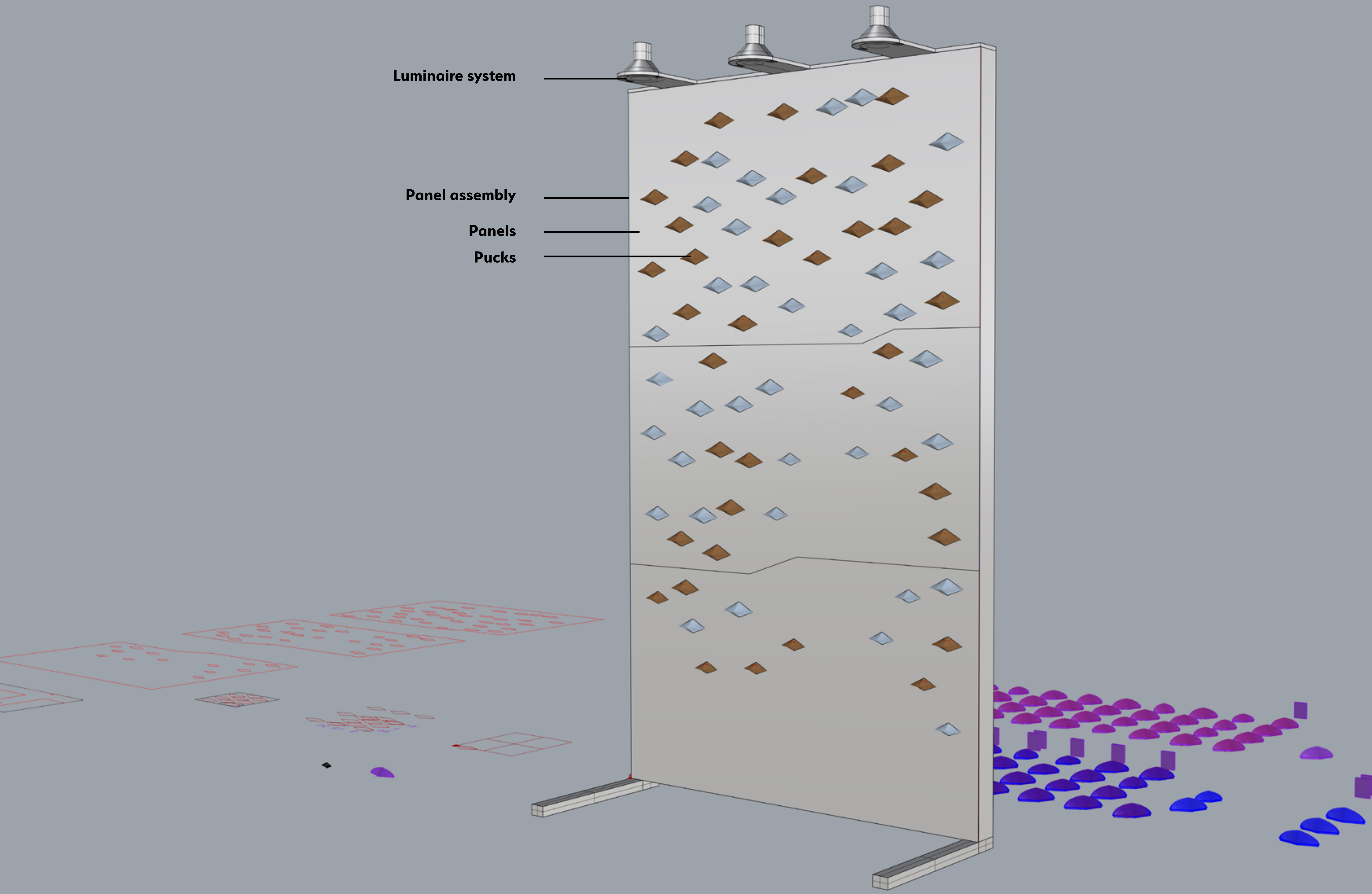


Figure 42: This figure illustrates the build up of the chosen concept. It consists of two assemblies: the panel assembly and the luminaire system. Each assembly contains multiple parts. The bottom questions tell what topics should be addressed in the detailing phase.



Luminaire system
Panel assembly
Panels
Pucks

3.1 Product experience

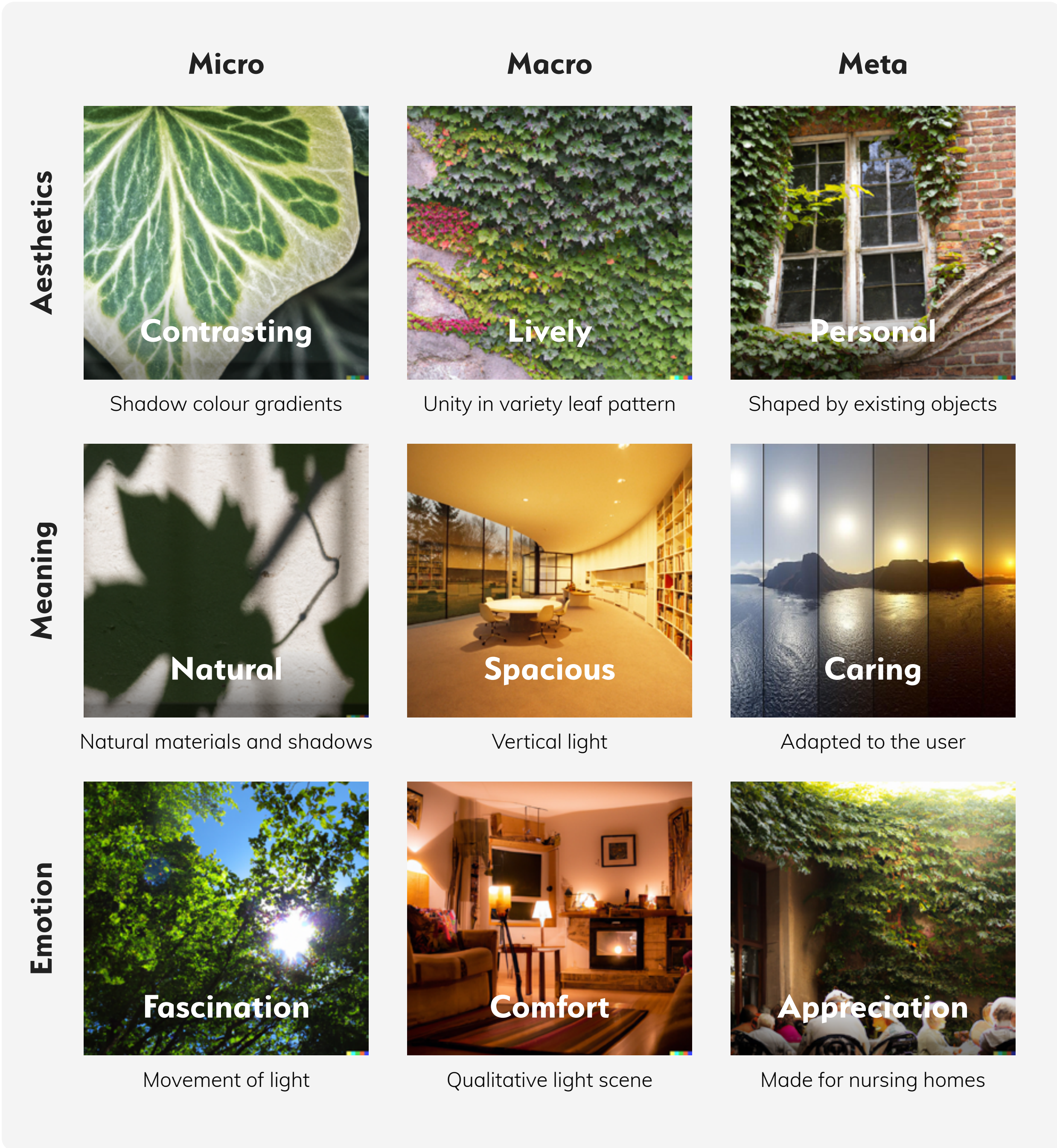
The Nine Moments of Product Aesthetics were used as a guide on the visual and interactive experience of the concept (E. Özcan, teaching material, 2016) (see Figure 44). Here the model was applied to the shape and material of the pucks, the overall pattern of the pucks, and the light qualities.

Puck design

As Figure 43 shows, several iterations were made on the design of the puck with clay modelling and 3D printing. Referring to the micro experience, the aim was to make it look natural and give a leaf-like shadow. The thin and flat designs were thought to be too sharp and contrasting with the wall. The final design forms a leaf shape with the shadow and puck combined. It blends with the wall and still has sharply curved shapes reminiscent of a leaf. Although people would also recognize the shape as that of a turkey tail mushroom (Dutch: elfenbankje), this is not a problem for the goal of the design. The metaphor of ivy was used as inspiration to arrive at a natural feeling design on a wall. The reminiscence of a mushroom still fits that goal. It also fits with the other ivy-like patterns in a scene where ivy and turkey tail grow together. Therefore, the turkey tail look was embraced in the design.

The ivy metaphor was also implemented on a smaller scale. The shadows of transparent pucks are filled with refracted light, reminiscent of colours in leaves. Additionally, a fuzzy skin print setting aids in creating a natural look compared to bare plastic.

Figure 45 also shows the difference in materials for the puck. A wood-fill PLA filament works well within the healing environment context whereas other coloured filaments appear less natural and more plastic-like. Still, a compromise was made by varying the puck material with transparent PLA. The clear material produces caustic effects within the shadow, creating a contrasting micro aesthetic. This contributes to the variety of the puck patterns, as will be discussed next.



◀ Figure 44: The Nine Moments of Product Experience filled in for the final concept. It illustrates what the concept should evoke and where to take inspiration from. This is done on three layers: micro, macro, and meta. Within these layers again three types of experience are addressed: aesthetics, meaning, and emotion.

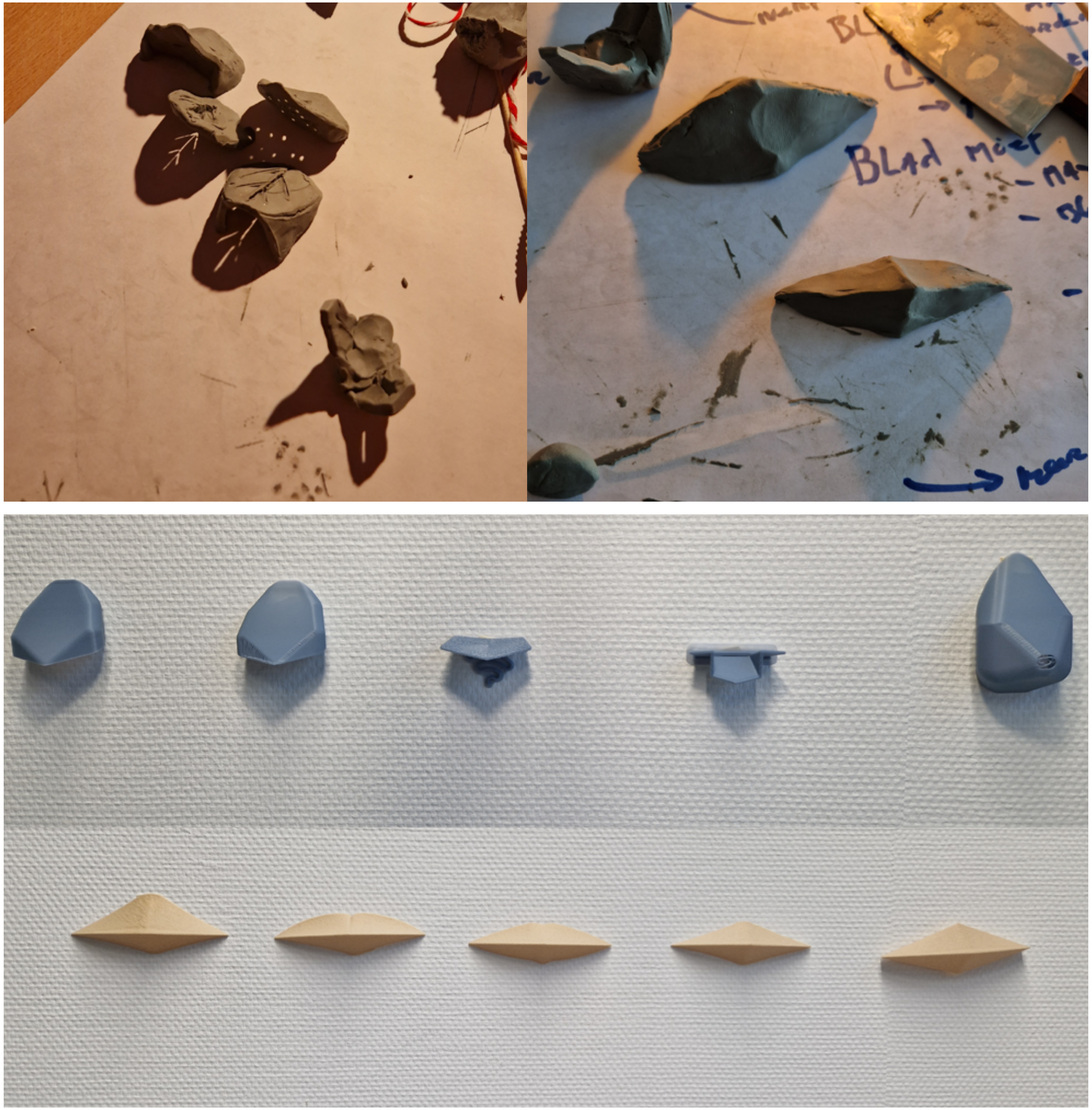


Figure 43: These images show the results of the exploration and ideation of the puck shape. Clay modelling was used to quickly iterate and 3D printing allowed for high fidelity prototype. The middle row shows different shape ideas and the bottom row a more detailed exploration of the final shape.

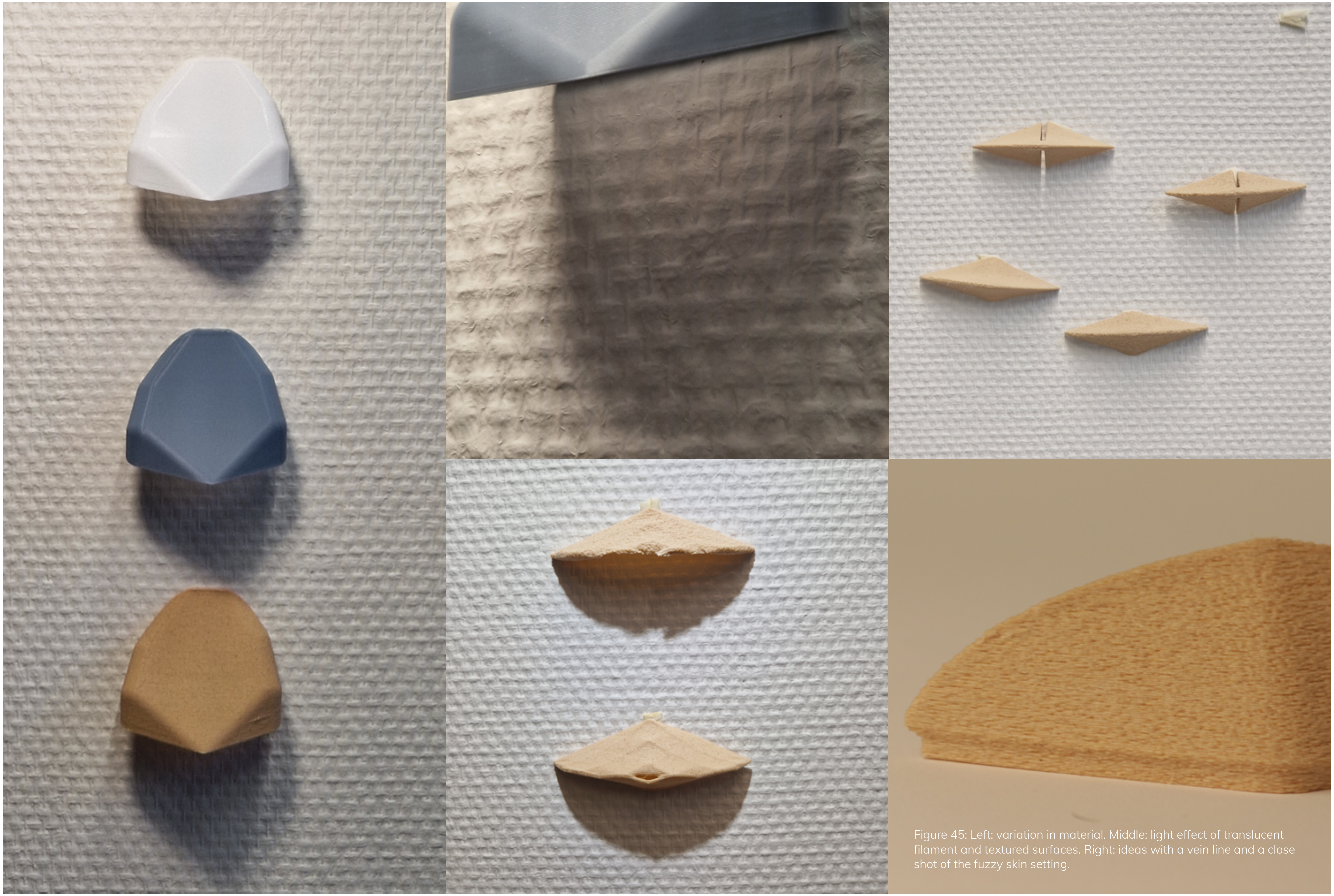
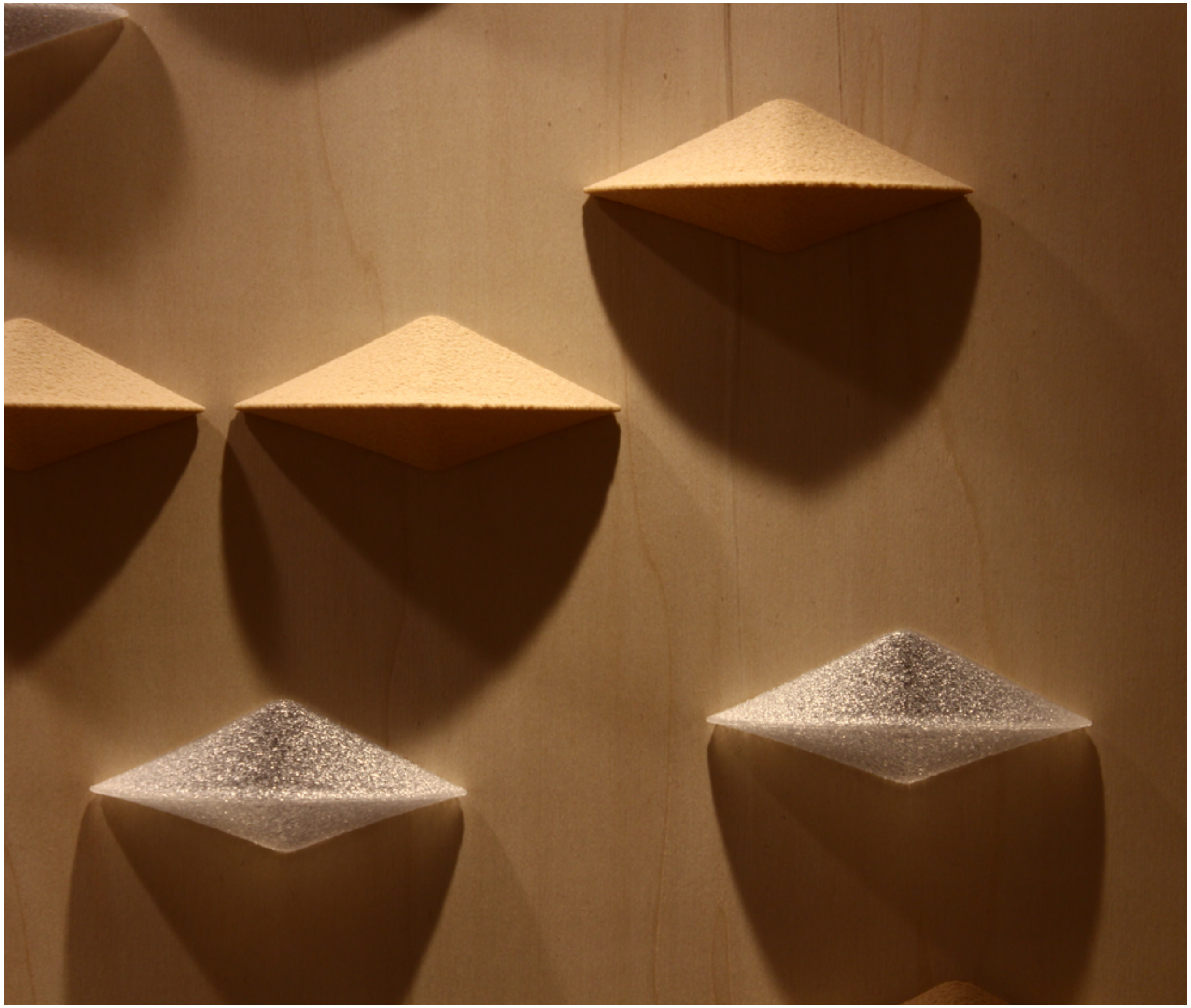


Figure 45: Left: variation in material. Middle: light effect of translucent filament and textured surfaces. Right: ideas with a vein line and a close shot of the fuzzy skin setting.



Puck pattern design

The concept from the ideation stage had a uniform random pattern of pucks. This was considered boring and monotonous. Therefore, pattern variants were created in Grasshopper and Keyshot, as shown in Figure 47, with the help of the laws of Gestalt and the aesthetic principle of unity in variety (Post et al., 2016) in order to make it visually interesting and cohesive. The final design is inspired by hanging ivy branches. Proximity groups these pucks together, while the random pattern creates variety and naturalness. The pucks are also made to vary in size with the distance to the branch and vertically as well to create a more even shadow effect.

The panel material and shape also play a role in the pattern composition. The panels are purposely non-rectangular, emphasising the random and natural features of the design, resembling a Voronoi cell structure found in leaves. This was also necessary in order to fit all of the pucks within the panel boundaries without any of them being on an edge. From a healing environment point of view, the panel material should be wood or another nature-like material that blends with the pucks (see Figure 49)

A small experiment with a custom-trained Stable Diffusion AI model was also done to create pattern alternatives. This is a model that creates images based on text prompts. Figure 48 shows one option that was inspiring for the way the panels play along in the composition with colour. The created options were mainly useful for inspiration and out-of-the-box ideas, but did not result in new designs.

Figure 46: The final puck shape shown in the chosen two different materials. The pucks are printed with fuzzy skin and create a ivy-inspired shadow. The transparent PLA variant creates a infill in the shadow reminiscent of the leaf veins and colour variations.

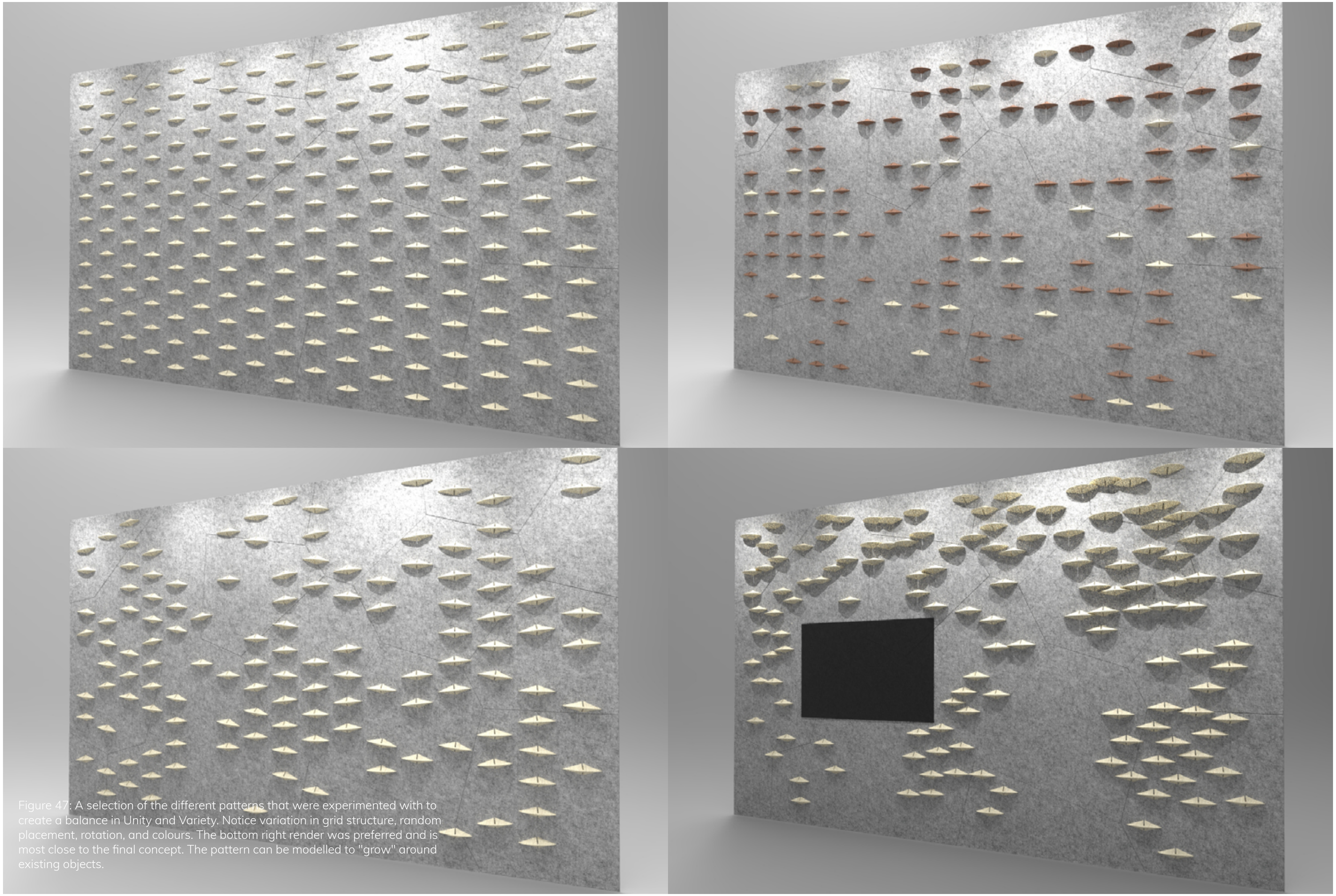


Figure 47: A selection of the different patterns that were experimented with to create a balance in Unity and Variety. Notice variation in grid structure, random placement, rotation, and colours. The bottom right render was preferred and is most close to the final concept. The pattern can be modelled to "grow" around existing objects.

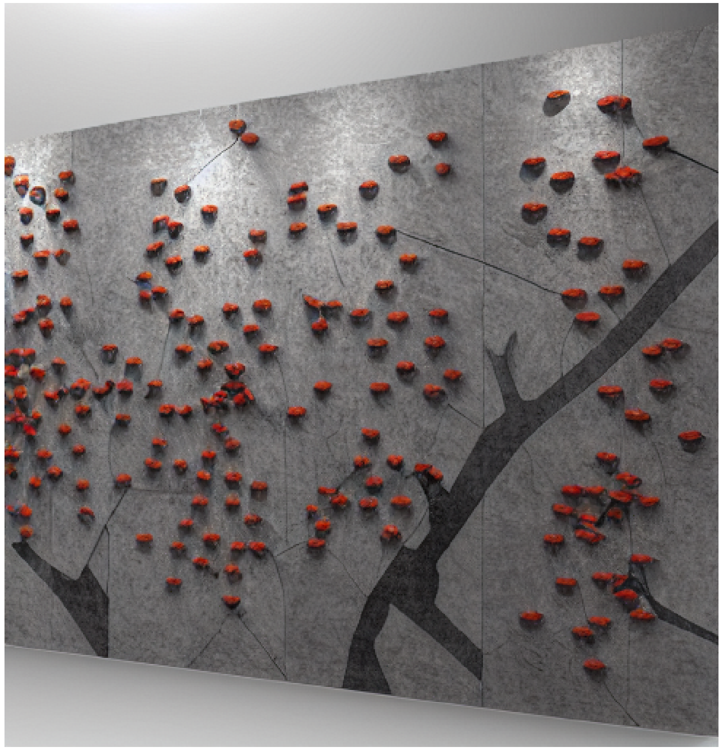


Figure 48: AI programs aided in inspiration by creating variations on existing renders. Interesting within this figure is how he back panel contributes to the composition as well.

Figure 49: This figure shows two variations of the same composition in a wood and felt material.

Luminaire type

From the test with colleagues at the end of the ideation phase, it was concluded that a point light source would be better suited than linear light. This difference is illustrated in Figure 51. Therefore, the final idea is to have multiple point sources above the panels. These will illuminate the wall with a moderately even distribution that creates a balance between cosiness and spaciousness.

The exploration phase revealed how coloured light can change the atmosphere of a room. Figure 51 shows how colours can be used to create interesting shadow effects with the pucks as well. The elderly prefer monochromatic colour schemes, though, and do not like fully saturated colours. Therefore, it was decided to constrain the possible light colours to only white colour temperatures. This prevents the light from being annoying and still gives the option to adapt to a circadian rhythm. The warm and cool tones are also sufficient to be used to create a cosy or lively atmosphere respectively. A GU10 Philips Hue spot in a White Ambiance variant is therefore the chosen luminaire as shown in Figure 50.

Configurable design

Aesthetics and product experience are always subjective, and this is also the case for a luminaire. With digital manufacturing and workflow methods, luminaire designs can easily play into different tastes with custom designs. To create a personal aesthetic, the puck pattern is adapted to the intended space for the luminaire as shown in the scenario in Figure 54. Within the designed limits, clients can personalise the luminaire to their taste. The pattern can be adapted to existing architectural features. The ratio between wooden and clear pucks can be altered as well as both the panel material and dimensions. This freedom for the clients ensures that it can be made to their taste and that of the elderly. Additionally, special pucks designed for hanging picture frames or paintings are chosen if necessary. This ensures that the existing function of the wall in this regard is not changed.

Figure 50: The preferred light source: Philips Hue White Ambiance GU10 bulb.

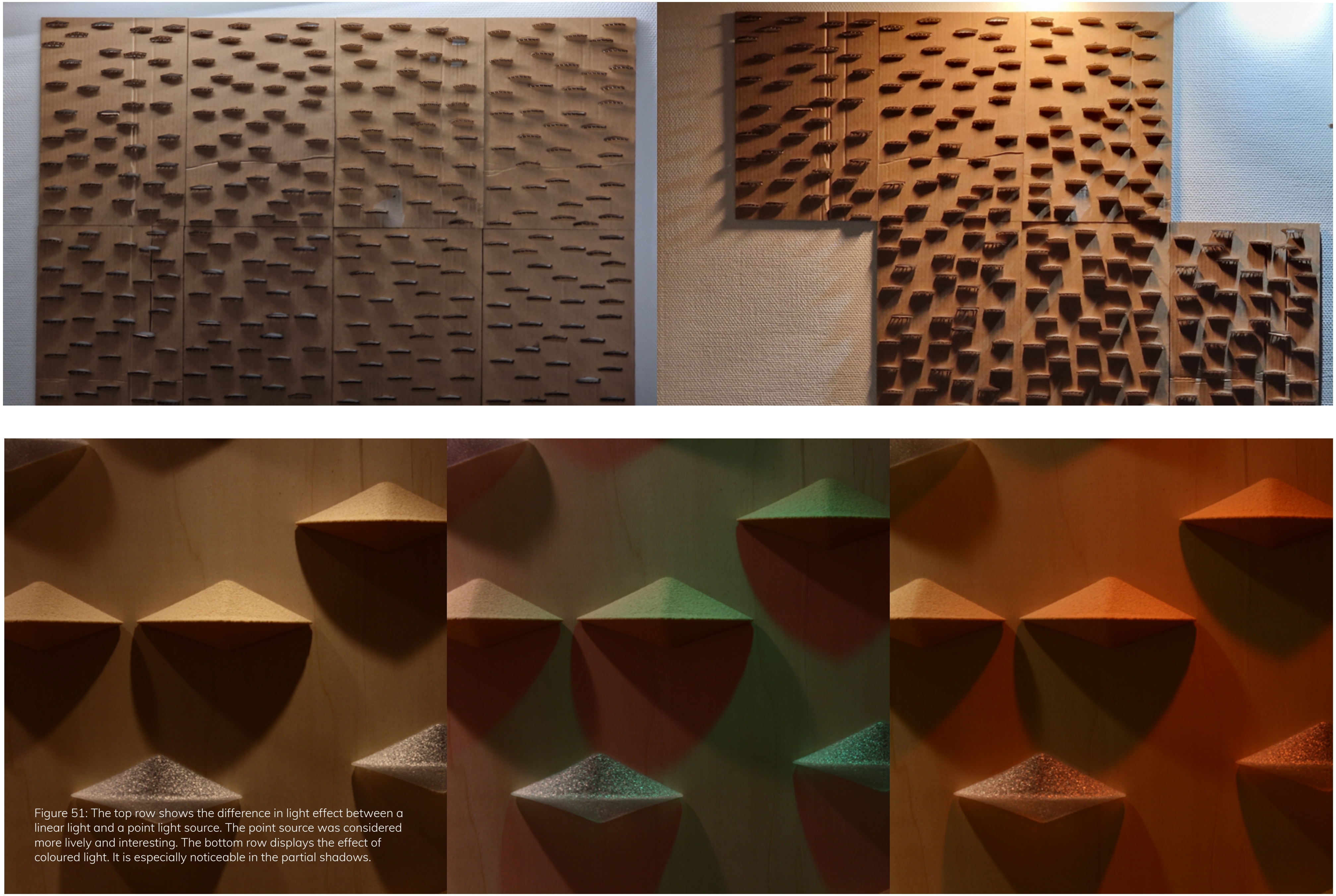


Figure 51: The top row shows the difference in light effect between a linear light and a point light source. The point source was considered more lively and interesting. The bottom row displays the effect of coloured light. It is especially noticeable in the partial shadows.

Figure 52: The final aesthetics prototype as a result from the detailing phase.

3.2 Production and installation

The following section discusses the consideration concerning the production, assembly, and installation of the concept. Figure 54 and 55 on the next page visualise the final scenario for these processes.

Puck and panel material

Choosing a material for the panels and pucks is mainly a matter of product aesthetics, but manufacturing requirements also constrain the choice. The whole product is preferably made with computer-aided machines to facilitate an automated design and manufacturing process.

The pucks are 3D printed. This is a requirement of the assignment, but it is also required to be able to give every puck a unique shape, which will be discussed later in relation to puck patterns. From the standpoint of the product experience, a wooden and transparent look is required. Because wood fill filament is currently only available in PLA plastic, it is necessary to use PLA for the puck material. Conveniently, PLA can also be found in a transparent variant. Furthermore, PLA is based on starch from plants, a natural source. However, without fillers, it is less resistant to heat and UV radiation.

The panel material choice is based on the manufacturing and puck mounting. The requirements are to be able to produce the panel shapes fully automatically and with a custom design. A laser cutter, CNC router, or possibly a vinyl cutter could be feasible options to achieve flexibility in thin sheets. A reasonably stiff material is also necessary since a mechanical fit with the pucks is desired for disassembly. Thin yet stiff materials can often be cut with a laser cutter which is faster than a CNC router. Material options from aesthetics that fit these requirements are felt and thin plywood. These options are left as configurable options for clients.

Mounting panels to the wall

Research into existing methods of mounting wall objects gave insight into common mechanisms. Figure 53 shows the different methods and their strengths and weaknesses. 3D wall panels are usually stuck with double-sided adhesive tape to the wall, but it is also interesting to hang the panels from the top to each other. Factors that influence the decision for a mounting system are aesthetics, robustness, and ease of manufacturing and installation. In the end, the option of double-sided adhesive tape was chosen because it is easy to install and not invasive to the existing building. Besides that, it sits flush with the wall, which makes it blend in with the wall. Additionally, it is available in very reliable and strong variants.

Figure 53 visualises different assembly options for attaching the pucks to the panels. Depending on the panel material it could be directly printed onto the panels. This is possible with open fabrics by overlaying the fabric on a

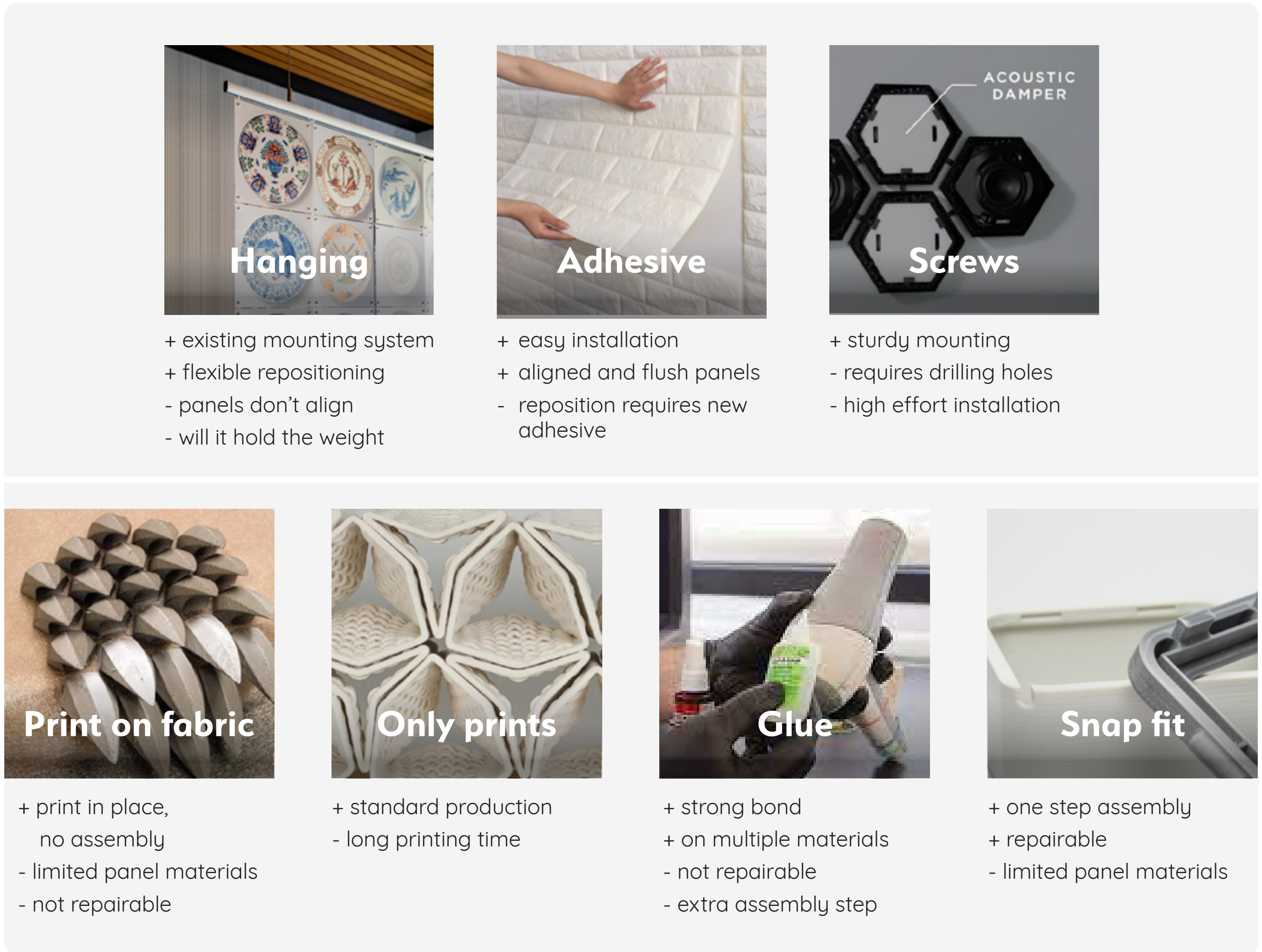
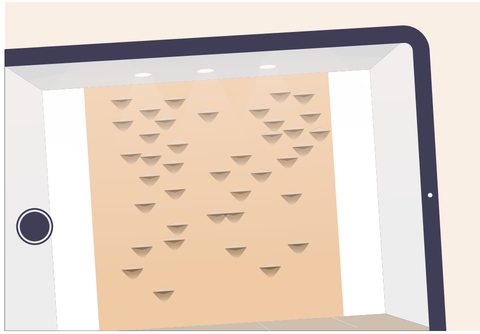


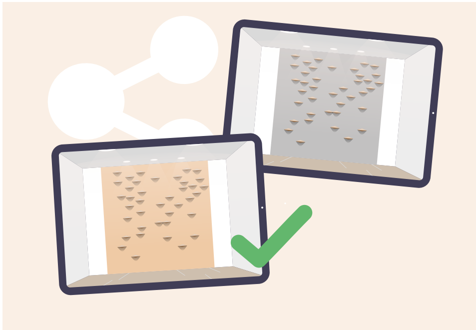
Figure 53: The top row shows a comparison of mounting options and the bottom row displays the pros and cons of several assembly techniques.

Manufacturing scenario

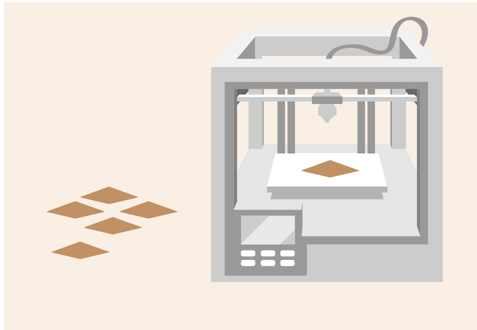
Figure 54: Envisioned scenario of the manufacturing of the final concept.



Together with a salesperson, the facility manager of the nursing home creates a design proposal for the common room space. A picture is taken on which a design is automatically formed. The pattern forms around existing objects on the wall. Restricted areas can be drawn in or objects can be deleted. With sliders clients can adjust a random seed, the back panel material can be selected that fits within the space, and the ratio between transparent and wooden pucks can be adjusted.



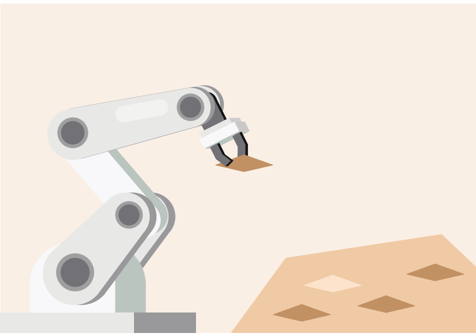
The design proposal can be sent easily via a link to a preview mode to other decision-makers. The preview mode shows a scene where light modes can be tested out digitally, even a video is available. These visuals are all generated with AI tools and renders.



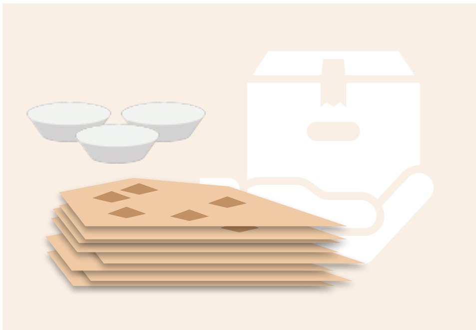
When the design is approved, it will go into production. The necessary files are automatically generated so 3D printing and laser cutting can begin.

Filaments are from sustainable and recycled sources, creating a natural and recycled look. This is also the case for panel material.

There is no stock needed for parts, only raw materials, as they are produced on demand.

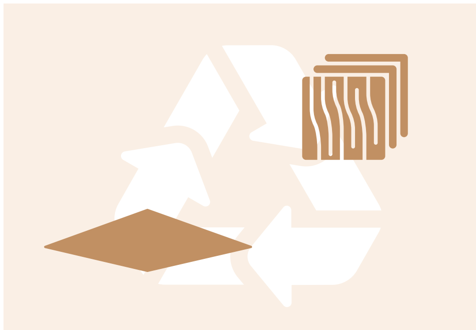


The parts are identified based on an identifier, shape and material. The 3D-printed pucks are gripped and clicked into place on each panel. The panels have adhesive pads on the back.



The panels are stacked in order and packed into a box. Additional mounting pucks for paintings are thrown in separately.

The product is shipped to the local client as production can be done locally in an automated Signify factory.



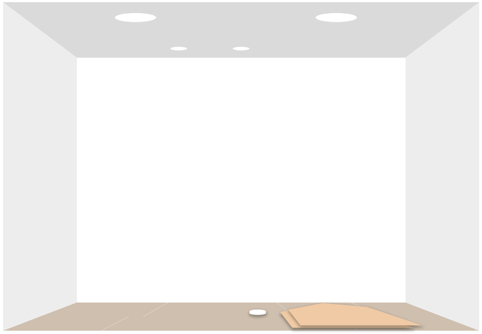
Panels that come back for recycling are disassembled. Pressing the panels down ensures that the pucks fall out. The pucks can be shredded for new filament, after separating the transparent and wooden pucks.

Wooden panels can be sold for rest wood or used in custom wood filament filling.

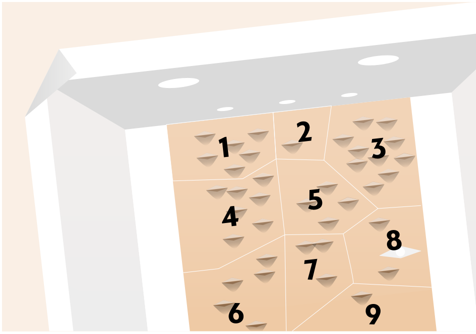
Replacement parts can easily be produced as a one-off with little additional setup costs and shipped to the client.

Installation scenario

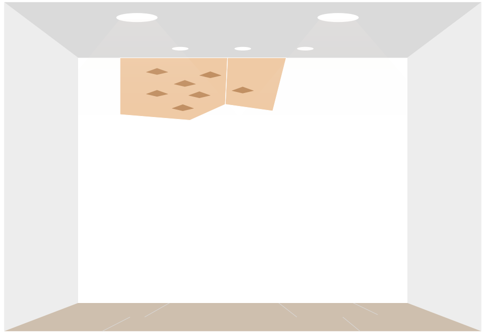
Figure 55: Envisioned scenario of the installation of the final concept.



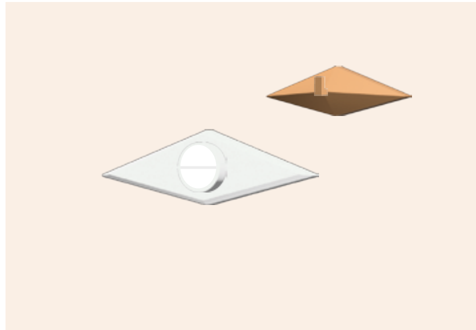
Facility staff unpacks the boxes with the luminaires and panels. The luminaires are standard and can easily be installed in a recessed ceiling or surface mount.



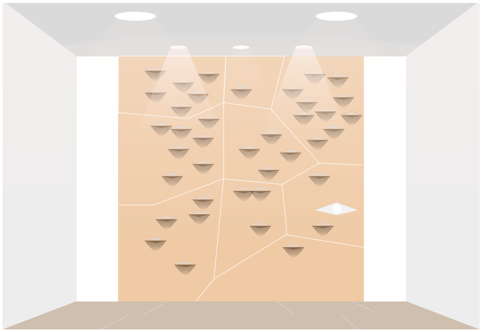
The pictures in the box show exactly where the luminaires and panels should be mounted in the space. It is an overlay of the pictures taken by the sales team.



The panels are in order from top to bottom. From the top left to the bottom right the panels can be glued on the wall with peel adhesive while making sure that the edges are aligned. The panels correspond to AR pictures making it easy to see which panel goes where. The panels also have a number on the back of the 3D prints.



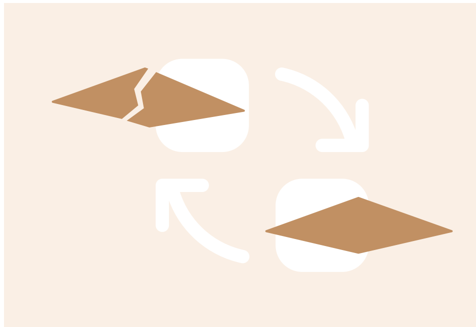
Subsequently, the facility staff installs the special pucks themselves: the puck for the control button and the pucks for hanging a painting. This last one needs to be screwed into the wall. Every puck can be converted to a hanging puck if desired.



With the luminaires installed and the panels mounted to the wall, the installation is ready. The luminaires are integrated with the Hue system by a technician and the control knob for the luminaire is placed on the wall. It is already paired with the luminaires.

Together with the elderly, a staff member adjusts some settings in the app: the speed of the leaf flow animation, and the min and max colour temperatures for circadian automation.

The brightness is controlled via the button which also has a toggle to switch between dynamics on and off, and a mode for auto-circadian rhythm.



Maintenance is easy, the panels can be dusted off with a plume and the luminaires can be replaced as standard spots. A replacement puck can be ordered from Signify when a puck breaks.

A change of furniture layout. No problem. The panels can be removed when needed. The adhesive should not leave a mark. There are multiple end-of-life options:

- The panels can be handed in at Signify where they will be recycled into new products. This will earn the client money back or a discount on a new system.
- The client can order a new panel design for the existing pucks.
- The panels can be separated from the pucks. Each material can be recycled in its intended waste stream.

print after a few layers. Printing directly on fabric works if it has a plastic coating to which the prints can adhere. Other options would be to glue the pucks onto the panels or to use mechanical fits like friction fits or snap fits. The decision was made to connect the parts through a friction fit because it is sufficiently strong and recyclable.

Assembly and installation

Just like manufacturing the parts, assembly is automated as much as possible. Robotic assembly is currently also an increasing topic of interest within research at Signify and is essential for this concept. One could imagine that it would be difficult to recognize all unique pucks and to put them in the right spot by hand. A robotic arm can easily pick up the pucks and press them into place on the panels. A special feature has to be designed into the part for recognition. The final prototype made use of numbers so a human was able to install the prototype (see Figure 56).

Because every panel assembly is unique, installation is also made easy with upcoming technologies in virtual and augmented reality, another area of research within Signify. An AR phone app guides the facility staff in identifying the panels and mounting them correctly.

Cost estimate

A rough estimate of the production costs resulted in an amount of around 30 euros per square metre. The calculation is explained in Appendix F. It includes the cost of the wall panels but excludes the cost of the luminaires. The printing time per square metre was estimated to be eight hours for an average of 32 pucks per square metre. In this estimate, the bare material costs for filament and plywood sheets account for roughly 60% of the production costs, showing a strong dependence on the price of the filament and back panel material. With a margin factor of three, this could result in a consumer price of 85 euros per square metre and around 195 euros for the final prototype.

Figure 56: This figure shows the designed features to facilitate assembly: a friction fit ridge with chamfer to hide the seam and a number to identify the unique puck. The bottom image shows the puck from the back when assembled..

3.3 Interaction

The Nine Moments of Product Experience also come to the surface in the interaction with the concept. The lighting dynamics were designed to give a fascinating experience and enhance the natural effect. Requirements for controls mostly come from the context of the nursing home. A scenario for the daily interaction with the concept can be seen in Figure 57.

Control system

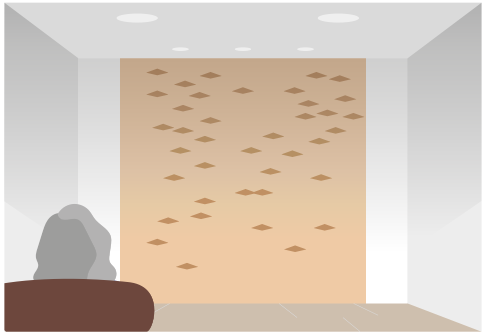
Preferably, both the elderly and nursing staff would be able to control the light settings. That is why a simple physical button is designed to change basic settings. Brightness/On/Off is controlled with the outer ring, like a round dimmer. Two buttons correspond to toggle the leaf-like light dynamics and the auto circadian lighting (see Figure 59). Bong et al. (2020) performed research on the usability of nostalgic tangible user interfaces for the elderly. They found that references to controls users are familiar with greatly increase usability. The user already has the correct mental model. That is why the light can be fully controlled like a classic dimmer switch (see Figure 58) and why the colour of the dial is white. The additional buttons are non-traditional and would require learning. It is expected that nursing staff will be able to learn this so they can adjust the settings for the elderly as well. Default behaviour settings can be adjusted in the Philips Hue app as it is intended that it will be a Philips Hue system.

Light dynamics

Niemantsverdriet et al. (2017) argued that light settings are highly subjective and that preferences are not static. A more social control system is needed, but beyond the scope of this project. Therefore, it is best to avoid conflicts where possible. Especially fast-changing colours or brightness can be perceived as annoying. That is why dynamic light is implemented in the form of only changing colour temperature and brightness in a soft flow. The dynamics aim to create the effect of moving leaves and to spark a moment of fascination when someone observes the

Use scenario

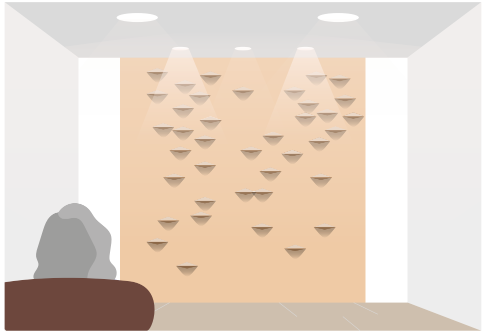
Figure 57: Envisioned scenario of the use of the concept.



Sitting in the common room. People enjoy the view outside. But inside it is a bit dark. A large contrast. This gives the idea that there is a large gap between outside and inside.

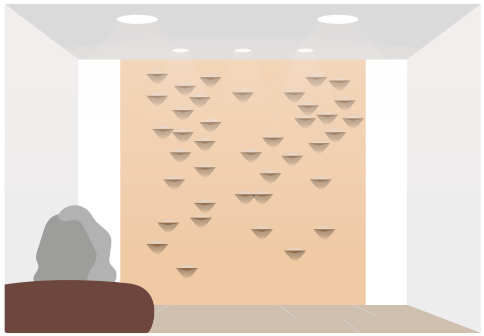
The staff switches on the luminaire with the automatic circadian light button. This changes the colour temperature and brightness. The other lights in the room adapt to it which creates a coherent light scene. The lights have the same colour temperature but fluctuate in brightness for a dynamic effect.

At any time, rotating the brightness ring will overwrite the circadian mode with a manual brightness. The colour temperature will adjust based on the set brightness. Switching off is done by fully decreasing the brightness.

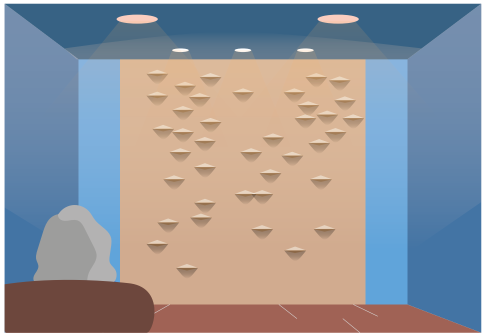


The elderly enjoy the space more now. In the background, nature elements and a slight dynamic movement reduce the contrast between the outside and inside. Additionally, the light levels are increased.

But one resident doesn't like the dynamics. So the staff switches with the button to static mode. Circadian mode is still activated. But the lights don't fluctuate in brightness anymore.



The luminaires now follow a circadian rhythm without fluctuating brightness in a leaf flow dynamic. This might be less lively but also less likely to annoy one of the residents.



At night the luminaires are warm and the dynamics very slow. The wall luminaires give pleasant diffuse light, also reflected on the ceiling. The natural pattern is something that draws your attention from time to time. Picture frames or paintings on the wall are also illuminated.

change. A nursing home must cater to multiple residents, likely with different tastes, so an understated effect is preferred with only colour temperature change, not other colours. The elderly anyway prefer monochromatic colour schemes. Light dynamics are hard to convey in a report, but Figure 60 shows different possible states. Settings for dynamic intensity can be adjusted in the app as the concept is a Philips Hue system. Within the app, settings for circadian lighting can be adjusted as well.

Co-operating in a larger context

The designed concept is aimed to work together with the other luminaires in the space. Together the luminaires form a coherent light scene in either a circadian rhythm or a designed atmosphere for the common room. Making every luminaire connected would be a costly investment for a nursing home, and the control of all the lights is challenging to figure out. However, a full system could improve the light scene in all aspects: increasing light levels, simulating natural light, creating liveliness, and feeling pleasant.

Figure 58: A classic dimmer switch.

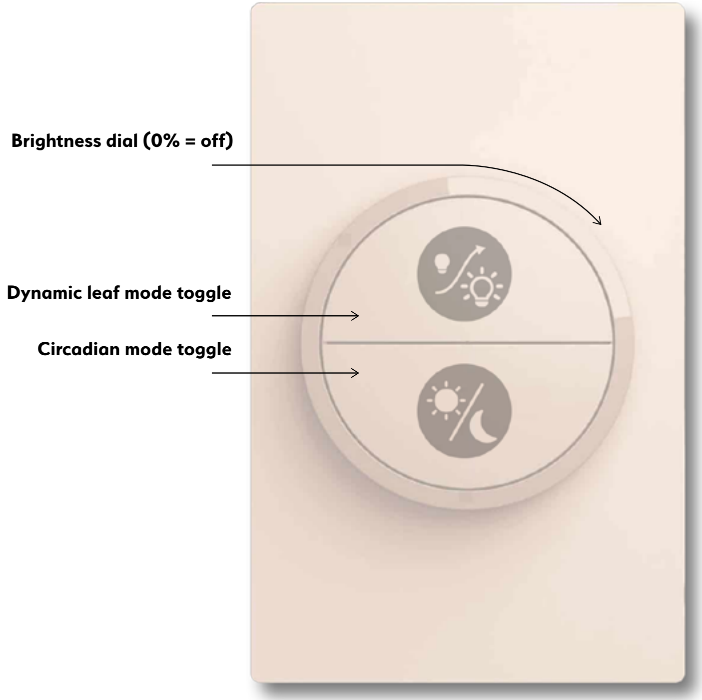


Figure 59: Envisioned switch of the final concept inspired on the Hue Tap Dial. The button has three functions: brightness dial, button for toggling the dynamic leaf mode, and a button to toggle the circadian mode.

Dynamic leaf mode

Circadian mode

Figure 60: The top row shows different states of an extreme version of the dynamic leaf mode and the bottom row displays the dynamic mode. It is intended to have both modes enabled in parallel.

4 | Validation in context

Finally, the concept will be evaluated. Does the design accomplish its intended goal? This is tested in a nursing home with residents.

To understand the final test, the design goal is specified for the final concept:

We aim to simulate aspects of **natural light** in **nursing homes** by designing a **lighting system** with **wall panels** that create a **bright, natural, lively** and **pleasant light pattern.**

The intended product qualities (in On and Off state):

- **Bright** – the design should make the room look bright(er).
- **Natural** – the design should simulate aspects of natural light.
- **Lively**– the design should offer variety and a brilliance effect.
- **Pleasant** – the design should be perceived as pleasant.

The goal is to determine if the designed lighting prototype is perceived as such by the elderly in a nursing home and if indeed the light effect evokes these qualities. Therefore, the research question is the following.

- How do the elderly in a nursing home common room judge the designed lighting prototype on scales relating to the desired product qualities?
    - How does the perception of the desired product qualities compare to the intended qualities?
    - How does the perception of the product qualities change between On and Off states?

4.1 Test setup

The test is performed in two similar common living rooms in a nursing home. The prototype consists of a 1.90m by 1.2m lightweight wall panel with 3D printed “pucks” that will attach to it. The panels are illuminated from the top with standard commercially available Signify spot lamps. The prototype is mounted on a stable frame and put against one of the walls (see Figure 61). Participants are seated in direct view of the luminaire, 3 metres from it. The material of the panels is such that they are kept very light and the whole structure is stable.

The prototype, if On, will be kept on one setting of light intensity, colour temperature, and dynamics during testing. The dynamics are very smooth and very low frequency.

4.2 Participants

The elderly in a nursing home (N=10) are asked to participate in this research. This is a vulnerable group of people, so the staff of the nursing home is asked to help with selecting participants that are willing to participate and have the cognitive capabilities to do so. This research is designed to not take longer than 15 minutes to avoid tiring the participants. Nevertheless, they can pause the test at any moment without reason, and the researcher will stop the test if he feels that it is necessary.

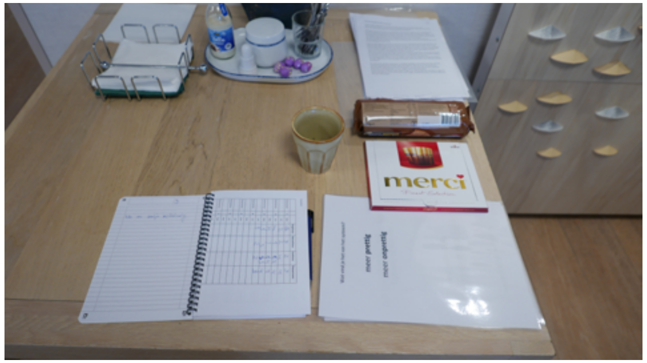


Figure 61: This figure shows the test setup in two living rooms and details of the test setup. A laptop was used to control the dynamic light effect of the prototype.

4.3 Method

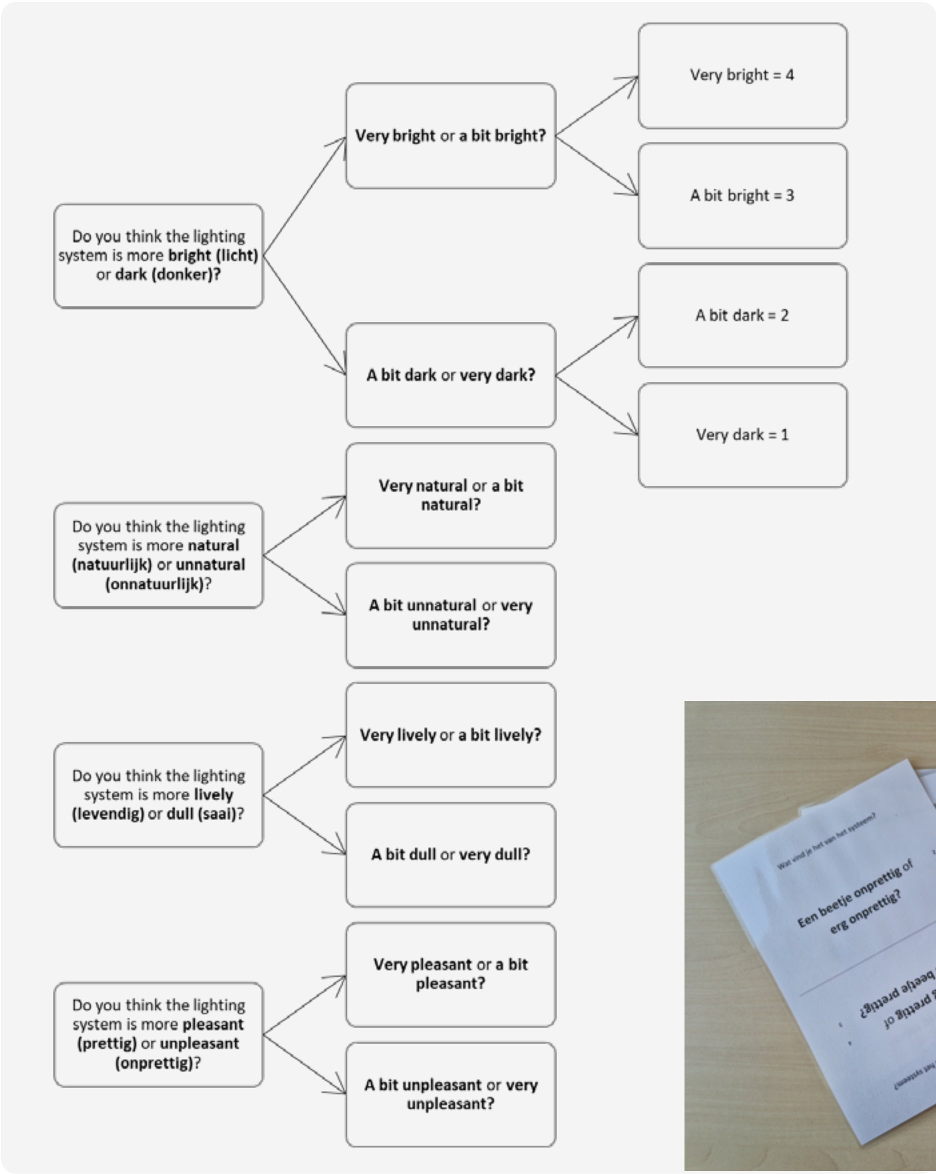
The luminaire is tested in the intended space in a nursing home. The test is performed switched On and Off in an evenly distributed order between participants.

Participants are placed at the same location in the room. This eliminates the risk of differences between participants because of a different view of the prototype or other elements in the space.

To simplify the test for our target group the test consists of an interview structured by an adaptation of a semantic differential scale. This scale is often used to determine people's perception of a product (C. McDaniel & R. Gates, 2001). The scale is used with dimensions of the four desired product qualities and fitting antonyms. A 4-point scale is used, inspired by the use of a 4-point Likert scale in interview form used in research with the elderly by Boger et al. (2013). They broke down the 4-point scale into two questions (see Figure 2), so the elderly were able to understand these questions. A 4-point scale is also often used in quality-of-life questionnaires done with the elderly (Yang et al., 2017). It offers a balance between granularity and difficulty in answering. Additionally, these choices are shown to the participants on cards, making the choice clear to participants. The cards show both ends of the semantic differential scale.

Participants are asked to select one reaction card for each scale question. Subsequently, they are asked to choose from two follow-up cards with more granularity. Then they are asked for more explanation if possible. This is done in an interview format. The questions are evenly mixed up between participants.

Since the focus of the prototype is mostly visual and not usability, participants are not asked to control the prototype. Switching power is done by the researcher.



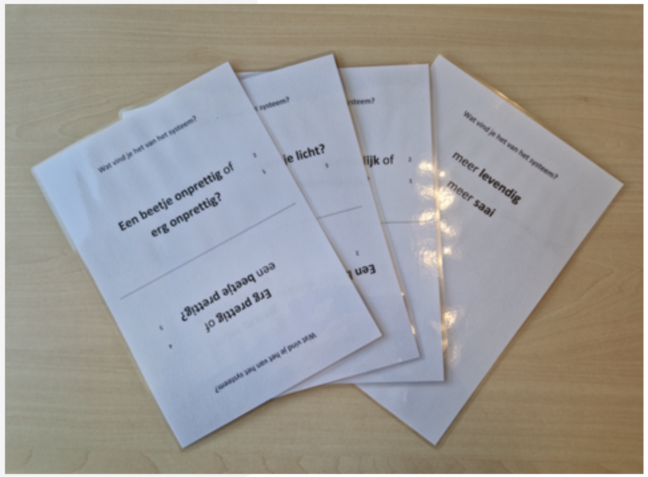


Figure 62: Interview flow for the four scales on the product qualities: brightness, naturalness, liveliness and pleasantness. The results determine the place on the 4-point scale. This is shown in the first question series. The bold words will be physically shown for each question in Dutch.

4.4 Results

The answers from the test were converted to their corresponding numeric value on the semantic differential scale and visualised in a box plot in Figure 63. With the lights Off, the brightness was on average perceived between a bit dark to a bit light (*M* = 2.5, *SD* = 0.66), the naturalness as a bit unnatural (*M* = 2, *SD* = 0.82), the liveliness slightly less than a bit lively (*M* = 2.8, *SD* = 0.93) and the pleasantness was perceived as a bit pleasant (*M* = 3, *SD* = 1). For the prototype with the lights On, the participants rated the brightness on average as a bit bright (*M* = 3, *SD* = 0.49), the naturalness in between a bit unnatural and a bit natural (*M* = 2.4, *SD* = 1.19), the liveliness slightly more than a bit lively (*M* = 3.2, *SD* = 0.73) and the pleasantness was perceived as in between a bit pleasant and very pleasant (*M* = 3.5, *SD* = 0.52). Nobody perceived the prototype as unpleasant with the lights switched On.

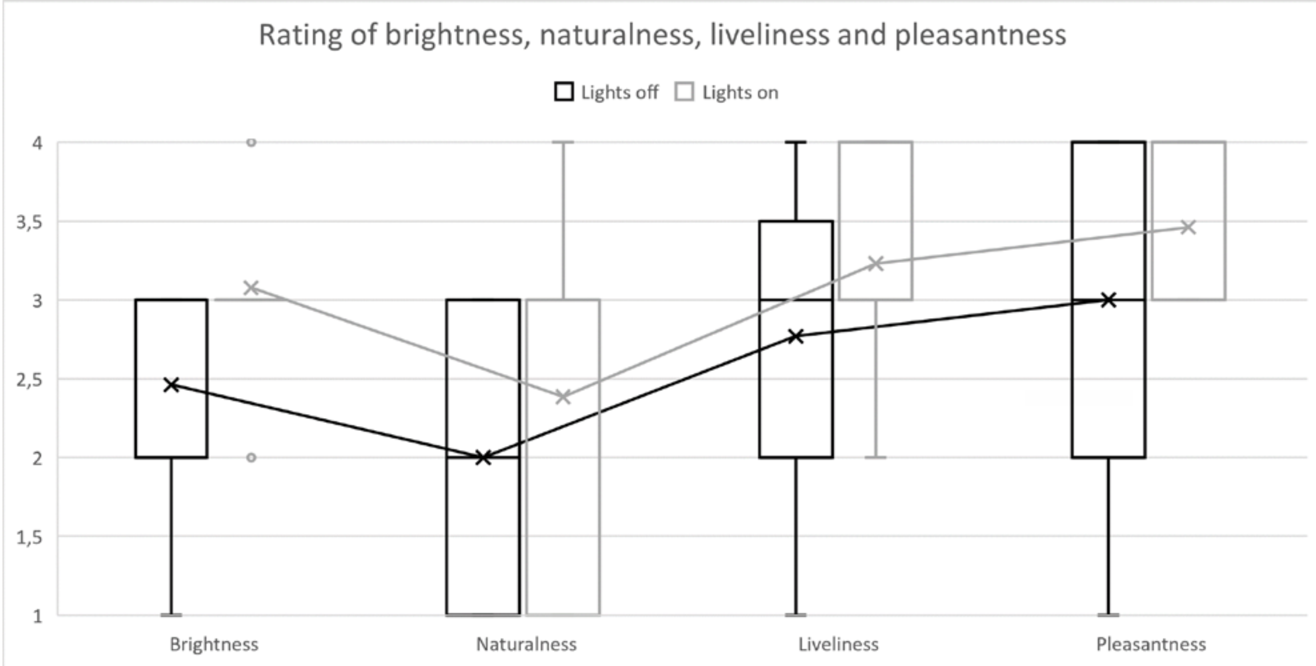


Figure 63: This figure shows the rating of the four dimensions in a box plot

The difference between the perception of the prototype with the lights Off and On is also part of the research question. The means were analysed with a one-tailed paired t-test to evaluate if there is a significant difference between the states for each dimension. If the *p*-value is under 0.05, the results are considered statistically significant. The prototype was perceived as 0.5 points brighter with the lights On, $t(12) = -2.89$, $p = 0.014$. Regarding naturalness, the illuminated prototype scored 0.4 points higher, though this resulted as insignificant, $t(12) = -1.59$, $p = 0.137$. The liveliness was perceived as 0.6 points higher with the lights switched On, which was also not considered significant, $t(12) = -1.58$, $p = 0.139$. The pleasantness scored an insignificant 0.5 points higher with the prototype illuminated, $t(12) = -1.90$, $p = 0.082$. This shows that the prototype scored significantly higher only concerning brightness. The other dimensions all show trends in the expected directions.

Discussion during and after the test also resulted in qualitative insights into the concept. Regarding naturalness, eight people perceived the prototype as more natural and noticed elements of rocks, flowing water, or turkey tails. Five participants found the prototype unnatural because it was a product made by a human. One of the participants also remarked that it was nice that the prototype was not too natural since an exaggerated metaphor would be unfavourable. Furthermore, the details in puck shape, such as the fuzzy skin, for example, were often not visible to the participants. This was also the case for the type of materials and light dynamics. Only three people showed interest in the material and manufacturing of the prototype. The visual difference in colour between the wooden and transparent pucks was mentioned several times as a reason for liveliness. Participants suggested colours or moving components to increase liveliness. When participants stated a preference for the material, they liked the wooden pucks better. Finally, some people stated that they just liked the prototype, and found it attractive and even soothing. Participants often thought the prototype was decorative in nature.

4.5 Conclusion

How do the residents of a nursing home judge the prototype on the design qualities? The results show that the concept is perceived as a bit bright and significantly brighter with the lights On. This aligns with the design goal and makes sense since the prototype adds extra light to the space. Though, there is room to increase the brightness in order to add more light and strengthen the contrast in the light effect. The latter could improve the perceived liveliness as well.

The naturalness proved to be debatable. Overall, there was a split among the participants between their arguments for naturalness. Therefore, the data suggest that the prototype is a bit unnatural with some hints towards natural when metaphors were recognized. The light effect had no significant effect on naturalness. This means that the prototype lacks naturalness and that this could be improved. However, some participants found the prototype natural and mentioned various metaphors. Ivy was not mentioned, but the recognition of other natural metaphors still shows that the design goal is met for some people. A discussion can be held if the prototype should be more literal in naturalness or if an exaggerated design is unfavourable.

Both liveliness and pleasantness were perceived quite strongly in the prototype which is shown by an average result between 3 and 4 with the lights On. This is in line with the design goal. Regarding liveliness, the pattern and difference in material were mentioned as a cause for liveliness. However, liveliness could be improved with colours or moving parts according to the qualitative comments. This suggests that liveliness can be improved with a stronger dynamic effect. The perceived pleasantness is substantiated by the fact that some participants found the prototype to be attractive and soothing. This dimension, therefore, does not need further improvement. The soothing aspect could even be a result of the natural effect, which is its purpose in a healing environment, but concluding this would need further research. Finally, the difference between the On and Off state for liveliness and pleasantness resulted to be insignificant, though the reactions and qualitative data suggest that the light did improve both dimensions, especially the perceived liveliness of the prototype.

The purpose of the concept was mostly seen as decorative, which speaks to the liveliness, naturalness, and pleasantness goals. The benefit of added light on vertical surfaces was generally not recognized as beneficial. The brightness could have had a larger impact in a space with lower existing light levels. Nevertheless, this gives insight into how the concept could be pitched to nursing homes.

4.6 Discussion

Several remarks about the brightness and naturalness should be made, but first more general comments on the method and results. The lack of significance in the lively and pleasant dimensions can be explained by the number of participants. Thirteen participants is a low number for a parametric test such as the t-test, so further research should aim to test with more participants. This would likely require testing in multiple nursing homes. Testing with even more participants would also make it possible to mix the order of dimensions in the questions, which would mitigate any errors possibly caused by people getting used to the type of questioning.

The current research tested the reaction of participants within a few hours of first seeing the prototype. A longer-term test of multiple days could generate realistic results that could show if residents would like to keep the concept in their space which would be interesting to research for a further prototype. This would require a different test setup and preferably a more advanced and even larger prototype that is mounted to a wall.

Also, the research did not test the difference in perception of the space with and without the concept prototype. Such a test would likely show large differences in perception on all dimensions but would also likely be biased if performed in the short time frame of a day. For example, sympathy for the researcher could steer the results. Therefore, qualitative insights were used to gain a feel for the degree to which the residents liked the concept in their common room.

Existing lighting

The concept is meant to be in a space that has additional functional lighting installed. The existing lighting in the tested environment was already very bright and uniform compared to another visited nursing home. Nevertheless, it was decided to keep the existing light on in order to keep a realistic scenario. This meant that the light effect was not as visible as it could have been, lowering the brightness perception. In the envisioned space the concept works together with other functional lighting to create sufficient light levels and a lively, natural, and pleasant effect. In such a space, a solution can be made to create variation in the light plan and more focus on the concept.

Definition of natural or unnatural

As mentioned, the phrasing of the naturalness dimension caused variance in the perception of the prototype. Some participants found the prototype to be a bit or very natural as they imagined metaphors such as rocks, flowing water, or turkey tails. Other participants stated that it is not natural since it is man-made and not grown in nature. This is a semantic discussion and could have been avoided by choosing different phrasing. Some participants mentioned that the prototype was soothing which could be a biophilic effect. Focussing on the biophilic effect, in this case, could avoid a discussion about naturalness. On the other hand, the effect it has on a person is more difficult to test than product qualities. A follow-up discussion should be held on what specific biophilic effect is desirable for the concept. However, a more simple solution could be to state the question with more context on the purpose of the question - for example, whether or not the participants think that the prototype reminds them of elements from nature. Nevertheless, the discussion on naturalness with participants was fruitful to collect insights into their opinion and associations.

5 | Conclusion and recommendations

This chapter discusses the final results of the project and any recommendations for further development. Finally, three suggestions are made to Signify from the view of a product designer. The next pages display an overview of Livy, the final concept. However, it is recommended to watch the video below for a complete explanation of the concept.

This video presents the final concept: https://youtu.be/HEwW515QFYg

The pucks organically vary in size from top to bottom.

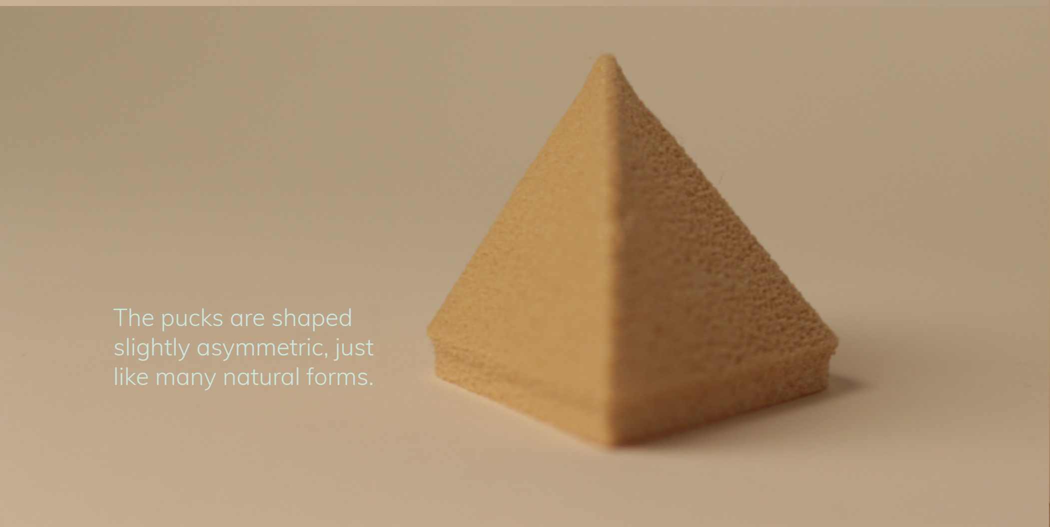
Livy

Illuminated 3D Wall Panels designed for Nursing Homes

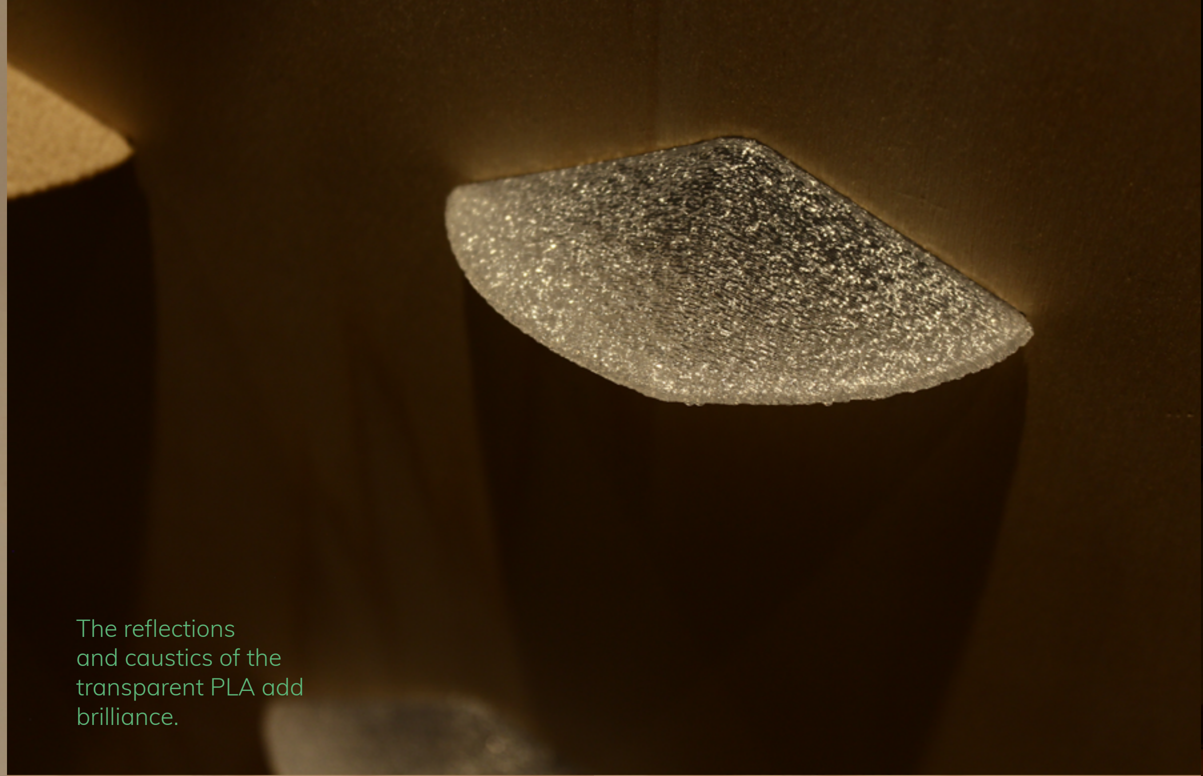
Livy illuminates the vertical surface, creating pleasant diffuse light.

The different look of the two materials creates liveliness in the pattern.

The fuzzy skin texture creates a rough surface that doesn't look like plastic.



The pucks are shaped slightly asymmetric, just like many natural forms.



The reflections and caustics of the transparent PLA add brilliance.

The light really brings the wall panels to life.

The dynamic leaf mode creates a lively light effect that shifts the brightness of the luminaires to create dynamic shadows.

The circadian mode adapts the colour temperature with the time of day for a biophilic connection.

The pattern can be adapted to the client's desires: change dimensions, ratio between puck materials, and back panel material.

The design can even be made to flow around existing objects on the wall.

5.1 Conclusion

To give a conclusion of the project, it is necessary to discuss the design goal.

I want to stimulate aspects of **natural light** in **nursing homes** by designing a **lighting system** that creates a **bright, natural, lively and pleasant light effect.**

The four elements - bright, natural, lively, and pleasant - are requirements that were found in the exploration phase. Nursing homes are frequently too dark for their residents to perform tasks well. Furthermore, from a biophilic and healing environment point of view, the spaces could benefit from more natural patterns and materials. Additionally, improved lighting could make the spaces feel more lively and pleasant. All of these elements had to be incorporated in a concept design for a wall-mounted lighting system that illuminated the vertical surface.

The final concept, called Livy, sought to accomplish this using a set of 3D wall panels with accompanying spotlights. The following pages show an overview of the concept. Illuminating the vertical surface increases the perceived brightness of the room, and the wall bounces diffuse light into the space. Natural materials are introduced through the wooden panels and filaments in a natural shape and pattern. The light also contributes to this natural pattern by casting shadows inspired by leaves. Additionally, it adds brilliance to this pattern with the transparent pucks. Finally, the entire scene provides soft, indirect light in a slow, pleasant dynamic.

The test in a nursing home revealed that the majority of these elements were recognised. The prototype appeared bright, and the elderly found the concept lively and pleasant. The light made a significant difference in brightness, and it was suggested that it makes the concept more lively. Half of the participants thought the concept was natural and referred to metaphors of rocks, flowing water, and turkey tails. They generally understood the decorative aspects, stating that the concept was attractive and soothing, which speaks to its pleasantness.

The goal for Signify was to develop ideas on the direction of digital manufacturing in the shape of a concept idea of a wall lighting system. This project set out to make it practical and focus on the context needs and light effect, something that is unique within research. The final concept hopefully inspires colleagues within the company, as time will tell. The recommendations offer more detail on the suggestions that are showcased with this concept.

5.2 Recommendations

If Livy would be taken further as a product, what would require more attention? This is not the goal as the project is conceptual. Still, some embodiment design topics were covered, and they strengthen the concept's acceptance within Signify. Therefore, it is good to discuss its shortcomings for further reference. The second part of the recommendations will go into depth about the design direction that the concept supports.

Desirability of liveliness

Liveliness arose from the exploration phase as one of the opportunities to improve the lighting in nursing homes. It was a designer's choice after experiencing the space and analysing the light layers. Although the experiment showed that the concept was perceived as quite lively and still pleasant, more research should be done on the desirability of liveliness in these spaces. Is it desired all the time or only at certain moments? Research into the full perceived lighting atmosphere in nursing homes would also be valuable for further lighting designs.

Natural or unnatural

Opinions differ on whether the concept contains natural elements or not, but the data showed that the concept was perceived as more unnatural. It would be interesting to further iterate on the natural inspiration and imagine ways to make the metaphors more literal. It is, however, a subjective matter because it is closely related to aesthetics. Some would argue that a metaphor should be used subtly, as is currently the case. Others may prefer more direct elements of nature in order to perceive it as natural. These decisions could also be configured by the client in some way. Even further development of the concept could research if residents experience biophilic benefits as a result of the concept, which was the underlying goal.

Light source and lighting context

Three Philips Hue White Ambiance GU10 bulbs were used in the final prototype. These were chosen because they are off-the-shelf HUE bulbs that produce the desired light distribution of a spot, but the bulbs might not be ideal. A specific wall washer luminaire could illuminate the panels more efficiently and with less glare. A specialised light source could aid in making the lighting system brighter and increase the contrast of the light effect. This would enhance the design qualities of the concept within a lighting context with existing luminaires. Also, more design research should go into designing a light scene with functional light that works together with this concept.

Further work on the concept could also explore using an addressable LED strip with proper lenses as a light source. The strip could be used to flow the light from side to side in more detail than a few bulbs can. Finally, experimenting with colour could garner interesting effects. Although is not recommended to use saturated colours in nursing homes, this could fit well within another context.

Light dynamics

Further testing could help to fine-tune the light dynamics, which is necessary. Do the dynamics evoke the intended goal of fascination and naturalness? What specific pattern and speed of dimming works best? There was not much time to put much research into the current dynamic pattern with three bulbs. This light pattern should be made more noticeable and it would be especially interesting to experiment with patterns that are derived from nature in order to add to the natural effect of moving leaves. Perhaps there is some pattern that can be mimicked from sunlight through leaves, or perhaps the movement of the sun through the day.

Detailed puck design

The design of the pucks themselves was kept simple as it is part of a more complex pattern. The shape was made to be perceived as natural, and it was made to blend in with the wall. 3D printing is used to create unique pucks that are all different. The design works, but more subtle details could enhance the natural and fascinating effect. For example, a 3D vein structure that varies the thickness of the walls of the pucks could give shadow or caustic effects that would look similar to the pictures in the first experiments. The final validation though, showed that these details might not get noticed by the residents due to their degraded vision. Further development should consider the value of added detail.

Aesthetically pleasing patterns

Inherent in the concept is the variety of patterns that can be created with the pucks on a flat surface. The client can tweak it to their liking. There is a balance between customizability and designed objects, though. The pattern should have clear constraints to which the client can adjust. These pattern constraints should be further designed to get an aesthetically pleasing pattern that is also customizable by the client.

As mentioned, the shape of the panels could also play a role in this pattern and composition. The current design is made with angular panels, reminiscent of a Voronoi cell pattern that is found in leaves. Further development of the concept could explore different shapes and ways of playing with aesthetics.

Material options

The materials of the panels and pucks are chosen for their natural effect and the way it interacts with the light. The transparent and wood-fill material for the pucks works well, but further development could look into coloured filaments as well. The panel material in particular needs further development. Felt is suggested but never tested yet. Clients can choose the material that fits the interior best, but the designers should curate a range of materials and finishes that work.

Reuse and recycle

The concept is linked to one of the sustainability efforts of Signify: using recycled materials in 3D printing. The wood fill filament is already made with recycled wood. This could even be taken a step further by using recycled wood from the production of the panels. The transparent filament could be made from recycled sources as well, but this requires research.

The concept includes that clients can order repair parts and send parts back for recycling. Currently, Signify does not have that infrastructure in place, so the feasibility and viability of such a service should be determined. This could also work well with their current portfolio of 3D-printed luminaires.

Automated assembly

That the concept can be produced has been proven by making the final prototype. The pucks were able printed without many errors. After adjusting for tolerances, the laser-cut panels were also made without any issues. The missing factor, though, is automated manufacturing. The ability of a robotic arm to assemble the pucks on panels has not yet been tested. Can a robot hold and push in the pucks? Can an automated system recognize the pucks and their position?

Furthermore, the mounting system could be reconsidered. A side-by-side comparison between adhesive or hanging mounting options could help determine what the most attractive and robust option is. In addition, prototyping showed that the panels might not be perfectly flat, which would result in misalignment between panels.

Controls and interface

Already from the beginning of the project, it was decided that control and user interface would not be part of the project. However, some ideas in this regard can be proposed. The whole design of a digital user interface and integration within the HUE system needs to be developed. It would also be interesting to design an adapted HUE button that integrates the features of dimming using the two toggles for dynamic mode and circadian rhythm, though a different way of controlling would likely work better for the elderly and nursing home staff. Insights into nostalgic user interfaces could aid this new design, as well as insights into smart home control conflicts with multiple users. See the research by Bong et al. (2020) and Niemantsverdriet et al. (2017) respectively for further reference.

Costs and viability

At some point in the decision between concepts, costs were taken into account in the print and installation time or effort. Additionally, a rough estimate was made of the production costs of the final concept. Further development should look more closely at the concept's viability. The concept requires a considerable amount of printing and complex assembly, which could be costly.

Client interface during sales

An important part of this concept is the configurability of the design. Clients can tweak the design digitally in order for it to fits their taste and interior. A sales workflow and interface should be developed to aid this process - think of sliders to see a preview change or AR to visualise the design. Another research topic would be how stakeholders share and approve the design. Finally, a personal identifying code of the design could be used to order replacement parts. This all needs infrastructure.

5.3 Designer's vision for digital manufacturing at Signify

The project sparked inspiration on areas of interest where Signify could develop more focus. These ideas are based on what would suit the final concept. The results of this project strongly reveal that the Livy concept would be able to enhance the experience in a nursing home, and therefore that it would be important for Signify to start such a project.

Decorative systems and illuminated surfaces

The final concept illustrates the opportunity that lies in designing the illuminated surfaces instead of the luminaires. Computer-aided designs in particular could generate intriguing and lively patterns in combination with light. These systems could add a decorative element as a way to improve the style and atmosphere of a space. In combination with specified luminaires, such a system could form a new product line for a market to which Signify does not currently cater.

Signify should of course learn how to produce and sell products that are more style-focused, which is a challenge. In the past, more projects were undertaken that had a similar objective which is why this concept seeks to push the idea again.

Adaptive digital design

With the team at Digital Workflow, Signify aims to research and develop digital technologies that improve its operations. These digital trends found their way into the concept, which gives an example of how the technologies can be combined into one product. Computer-aided manufacturing such as laser cutting and 3D printing in combination with automated assembly opens up a design space with complex patterns and shapes. Even beyond this, power lies in the fact that there is the possibility to configure these complex designs to the taste of the client because the manufacturing is largely quick and on-demand. This way the products can cater to the aesthetic preference of the clients. AR and VR technologies could help the client with visualising and configuring the design.

These opportunities are already recognized within Signify. However, the introduction of automated assembly gives more opportunities for complex designs and patterns that would otherwise not be possible to manufacture by hand. Furthermore, the design could be made to focus more on the lighting needs of a specific context. Adapting the design to a context can be done by a designer instead of giving all the choices to the client as this could be overwhelming.

Recycling a step further

The concept also addresses the subject of sustainability. The 3D printing business is one of Signify's sustainability efforts. They use recycled materials such as fish nets and CDs in their filaments, but sustainability in 3D printing can reach further. What the concept shows is that one must think about the end-of-life of the product and make it realistic. Recycling used luminaires is only likely if there is a service to collect them in order to make new filaments. Repairing broken luminaires is also only likely with such a service, but is this viable for Signify? Further steps could be taken to make designs reusable in a new situation. One element of a design can be recycled while another part could be used with a newly produced component. For example, the pucks in the concept can be reorganised into a pattern that fits another space only with new panels. This is another benefit of digital manufacturing. Further development of such ideas should look into the viability of these services.

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Appendix

A. Project Brief
B. Program of requirements
C. Ideation sprint 1: all ideas in clusters
D. Ideation sprint 2: Harris profile and PMI method
E. Test with colleagues
F. Production costs estimate

Appendix A | Project Brief

Design of a luminaire that shows 3D printing innovation potential

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 05 - 09 - 2022

end date 16 - 03 - 2023

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The client for this project is Signify. An explanation from their website: "Signify is the world leader in lighting. We provide professional customers and consumers with quality products, systems and services.".
At the Signify Research department, I will work with the team that explores opportunities in the space of luminaires and lighting by means of digital technologies. For example 3D printing. They showed interest in lighting applications where nature elements are visualised by the lighting (effect).

- Context
Signify's research team is constantly experimenting with new technologies like materials and production methods. They look for potential to improve their current lighting products in experience and function. The main focus of the team that I work with is innovation in 3D printing.
This design project could be the bridge between the technical innovations that this team creates and the potential it could have in future lighting products.

- Opportunity
The goal of this project is to explore the potential of 3D printing on lighting effects and shape of luminaires. These explorations are demonstrated in a luminaire design. What new lighting effects could be created by using 3D printing? In what way can different materials play a role? And how could the shape freedom of 3D printing be exploited?
Signify came with multiple directions on 3D printing technologies. These will be used as inspiration for concept design. But first, exploring the desired lighting effect is leading.

Regarding light effect, there is an interest in creating a dynamic and smart light experience. This would follow trends in smart lighting in creating a more nature like dynamic light effect. Like Nature Connect from Signify.
Could the final concept integrate these nature like dynamics? The images below serve as a start of inspiration for the project.

As a secondary focus, Signify is interested in wall luminaires. Currently the 3D printed luminaires in production cover pendants, table luminaires and ceiling track lights. Looking at this product portfolio, wall mounted luminaires are still to be explored for their current innovations.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

image / figure 1: Product portfolio of Signify's 3D printed luminaires. The majority is similar regarding light effect.

image / figure 2: Inspiration (bottom middle made by AI). Wall lighting, brilliance, natural effects, dynamics, variety

Initials & Name N.P. van de Kar Student number 4678613

Title of Project Design of a luminaire that shows 3D printing innovation potential

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Within this project the following topics are considered:
Light effect/experience: Ideation, experimentation and validation of the light effect of the luminaire. What function does the light provide? In what way is the light effect dynamic or smart and in what way is it triggered?
Inspiration on nature like lighting o dynamics is a starting point. But this needs to be validated and specified in the first phase. Design of the interface or control of the light effect is limited in this project. To save time a Philips HUE system can be used.

3D printing: How can 3D printing innovations contribute to the lighting effect and look & feel of the luminaire. There is an interest to compare the use of vairous materials like plastic, metal and concrete in different variations. Also unique shape freedom is interesting to explore in the luminaire with possibly different unqiue looking elements. But there is a distinction between modularity and using unique elements. Modularity often uses similar standardised components. This is out of scope for this project because it is not a key strength of 3D printing.

Detailing: Part of the project is testing and experimenting with prototypes to make iterations on the above topics. And in the end a working prototype is desired, so there will be detailing in such depth dat a realistic luminaire can be designed and made as a prototype. This means that the design should take into account manufacturing in some depth. But the focus of the project in this context is not to design a production ready product. Therefore, there will be less focus on details like tolerance, assembly costs etc.

Luminaire type: As a secondary interest, Signify is interested in wall mounted luminaires for the product portfolio, etiher in- or outdoor. When needed this will be taken as a focus, but this will be dependent on insights from lighting design experts and validation with consumers.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

For this project I will design a luminaire concept and working prototype that shows a new lighting experience of a consumer lighting product. This will function as a demonstration to Signify of the potential of current innovations in 3D printing and lighting in a real world context.

The end result is a working prototype that is 3D printed and controlled with open-source electronics/Philips Hue
- The prototype will demonstrate a lighting effect and look & feel to Signify that makes use of innovations in 3D printing and lighting.
- This prototype is used in a video that will show the design process and end result of the project in real world context.
- The prototype shows light experience, elements of interaction and look & feel of the luminaire.
- The prototype is used to validate and get feedback from stakeholders in context.

The following activities are part of this assignment to come to the end result.
- Research focussed on getting to know the industry and innovations rergarding consumer lighting design and 3D printing. What innovations are out there? And how is a consumer luminaire designed?
- During the whole project quick ideas will be prototyped and as much as possible validated with consumers. These activities lead to constant iterations of the ideas and concepts. Depending on the insights the focus of the project might shift to either light effect or look & feel.
- Ideation based on other products out there, insights from interviews and ideation methods. Image generation by AI is a side interests of me and the client. I will try to make use of this during ideation as an inspiration method or for quick visualisations.
- Making a final working prototype that is used to get new insights, tested in context and the topic of a final video.

Initials & Name N.P. van de Kar Student number 4678613

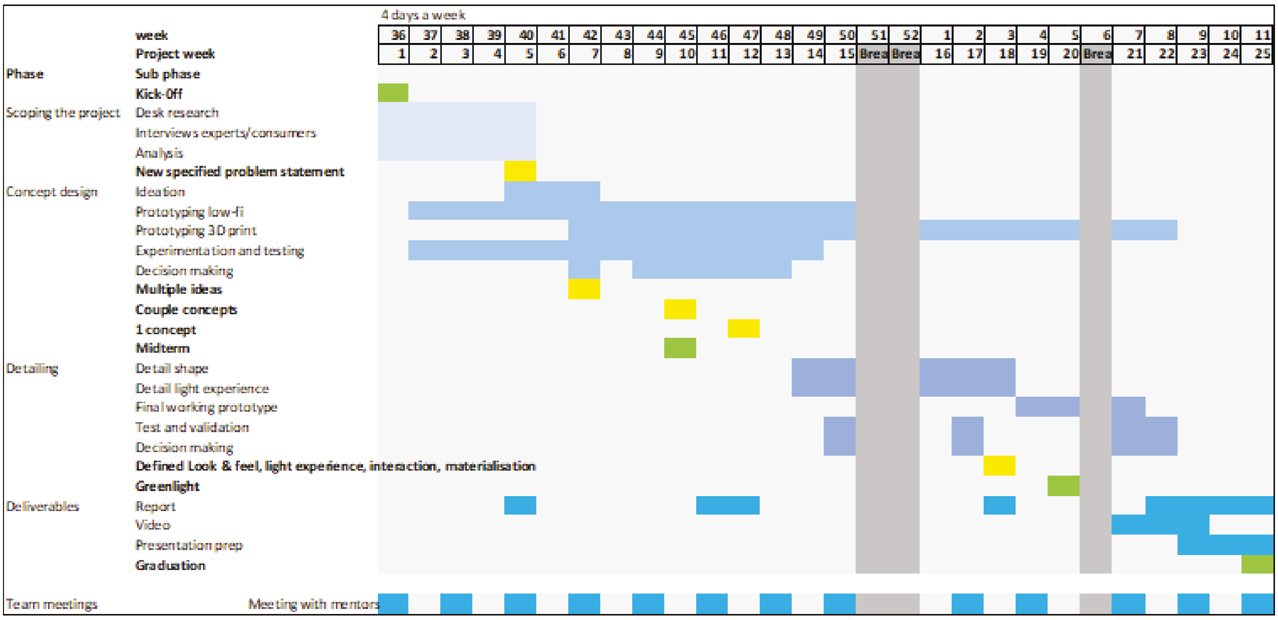
Title of Project Design of a luminaire that shows 3D printing innovation potential

Personal Project Brief - IDE Master Graduation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 5 - 9 - 2022 16 - 3 - 2023 end date



In the first phase I will dive deeper in the consumer lighting and 3D printing industry to find out what innovations could play a role in this project and what the process is of designing a consumer lighting product. Based on these insights this brief is specified on luminaire location and function, and the focus might shift to either light effect, interaction or look & feel. Also in this phase it is already desired to start prototyping or visualising first ideas to discuss and learn from them.

The second phase will involve iteratively designing concepts and testing prototypes that solve the problem statement. First, parts of the problem will be explored and later the concepts will try to solve the problem statement fully. The ideas will start broad and will slowly converge to a few promising concepts as can be seen from the milestones.

In the final phase a chosen concept will be further devolped and iterated on with more high fidelity prototypes. A detailed prototype is used to test in context and make a video with.

The project is 4 days a week. As a baseline, I will be at the company in Eindhoven for three days and one day at the faculty. This will mean that I can learn a lot by experiencing the company and still have one day where I can meet with my mentors.

Initials & Name N.P. van de Kar Student number 4678613

Title of Project Design of a luminaire that shows 3D printing innovation potential

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

- My interests are in embodiment design and lighting design, I wanted to combine these areas in one project. From AED, one of the big IPD courses, I really enjoyed fast prototyping aspects of one detailed concept and going in depth. From my internship and lighting design course, I took the interest in lighting with me.
I would like to learn more in these areas, about manufacturing with 3D printing and lighting in a home environment. What are the challenges of using 3D printing as a production method? And what is the process of designing a luminaire or lighting product for consumers?

- During this project, I expect to learn a lot about project management and working with stakeholders. These topics, were a large learning experience from past individual projects, so that will be no different for this graduation product.

- I would like to learn what a design job could look like in a big company. My only experience as an intern was within a relatively small architecture firm. Signify is a way bigger company. So that will bring new experiences on how the day to day is managed and what resources are available.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name N.P. van de Kar Student number 4678613

Title of Project Design of a luminaire that shows 3D printing innovation potential

Appendix B | Program of Requirements

Requirements

1 Control

1,1 The lighting system is controllable via an app
- The lighting system is integrated in the HUE system
- Possible extra settings can be configured in the HUE app.

1,2 The lighting system is controllable physically
- The lighting system can be switched on/off physically
- The lighting system can be dimmed physically

1,3 The control takes into account different users in one system
- The caretaker, elderly and visitors need to have access to controlling the lighting system

2 Lighting

2,1 The lighting is enhancing the light scene in the common room
- The lighting increases the brightness in the room.
- The lighting increases the natural feeling of the room.
- The lighting increases the liveliness of the room.
- The lighting is perceived as pleasant in the room.

2,2 The light illuminates the vertical surfaces in the room from the top.
2,3 The light pattern/visual is inspired by the shapes and characteristics of ivy
2,4 The light provides brilliance in the lighting effect
2,5 The light has a CRI of above 90.
2,6 The lighting is indirect
2,7 The lighting comes from multiple light sources in a composition
- The light sources dynamically dim to create the effect of moving shadows.

2,8 The colour temperature dynamically adapts to the circadian rhythm and with the other luminaires in the space.

3 Manufacturing

3,1 The lighting system should make use of 3D-printed parts
- The parts are made from woodfill PLA filament and transparent PLA.

3,2 The lighting system should be designed for repairability
- Replacement parts should be available to the user.

3,3 The lighting system should be able to be assembled automatically.
- The lighting system components should be recognizable and holdable by an asembly robot.

3,4 The lighting system should be printable without support with a 3 or 5 axes FDM printer
3,5 The source should be made from off-the-shelf parts.

4 Product Experience

4,1 The lighting system fits aesthetically within the interior style of the nursing home rooms
4,2 The lighting system should fit with trends in the lighting industry and healthcare
- The lighting system should incorporate elements from the mood board: natural materials, wood look, soothing shapes, hidde
- The lighting system incorporates textures and patterns based on leaf fractal patterns.

4,3 The lighting system consists of multiple light elements in a composition
- The composition is inspired on the structures in ivy

4,4 The lighting system should be configurable to the taste of the client
- The panel material can be configured in either plywood or felt.
- The puck pattern can be configured in shape, density and scale variety.
- The puck ratio between wood fill and transparent can be configured.

5 User ergonomics

5,1 The lighting system should be wall mounted
- The lighting system is mounted with adhesive to the wall.

5,2 The lighting system should be able to be installed, adjusted or removed within 30 minutes by the facility staff.
5,3 The lighting system should be able to be cleaned with a dry cloth in one minute.
5,4 The lighting system should be able to withstand a push from a resident without breaking.

Desires

6 **Control**

6,1 The elderly can control additional settings physically with a button.

7 **Lighting**

7,1 The lighting fits within the environment visually.
- The amount of lumen is proportional to the rest of the space.
- The amount of contrast it provides fits the space.
- The amount of brilliance fits the space.

7,2 The lighting covers a large part the vertical surface.
7,3 The lighting illuminates the vertical surface as efficiently as possible.
7,4 The lighting system has a wide variety of possibilities to play with the dynamic play of light colour and distribution

8 **Manufacturing**

8,1 Installation requires the least amount of adjustment of the wall/environment
8,2 The manufacturing costs should be as low as possible.
- The light sources should cost as little as possible.
- The lighting system can be 3D printed as fast as possible.
- Manufacturing should use as little material as possible.

8,3 Digital manufacturing methods should be used where possible.
8,4 The lighting source uses as little power as possible.

9 **Product Experience**

9,1 The lighting system shows the potential of different 3D print materials
- Showcase of wood filament

9,2 The lighting system consists of multiple unique elements.
9,3 The lighting system should fit the style of the healing environment as much as possible.
9,4 The unity and variety of the puck pattern are balanced.

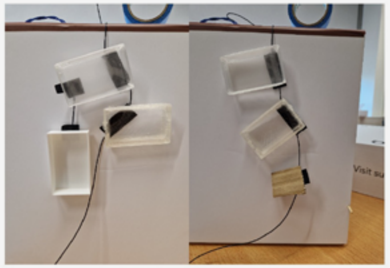
10 **User ergonomics**

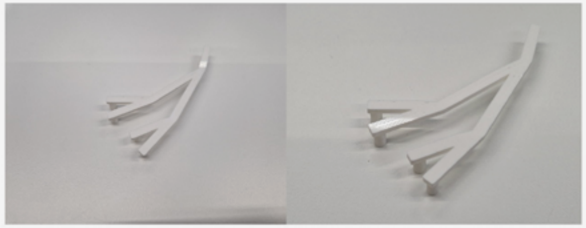
10,1 The installation of the lighting system requires as little electronic wiring as possible.
10,2 The lighting system should be as robust as possible.

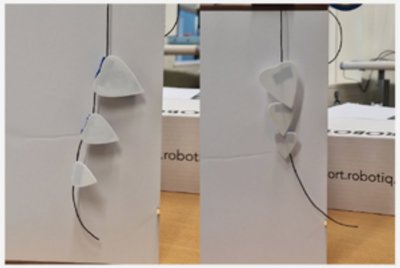
Appendix C | Ideation sprint 1: all ideas in clusters

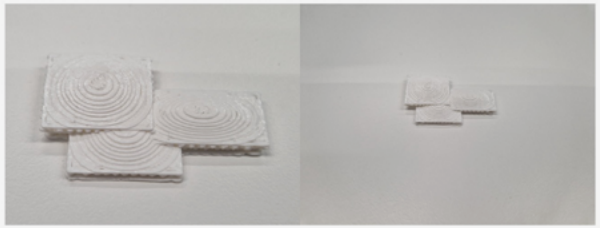
Light effect

Physical shape

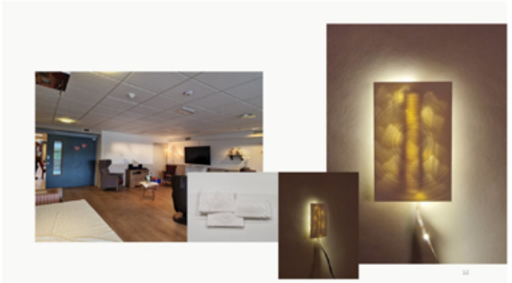


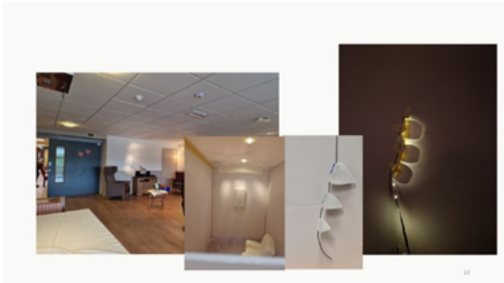






Appendix C | Ideation sprint 2: Harris profile and PMI method





Plus Minus Interesting (+ further exploration)

Individual luminaires with even lighting, familiar system	Strong inspiration from nature, similar to a hanging vine
Multiple needed to make an impact in the space	Low impact of light on the wall. Mounting system is fragile.
Combi of wall illumination and pattern from luminaire	Of centre hanging is natural and unique
Vary pattern in thickness or holes	Further play with multiple next to each other and colours

Harris profile

Options for variety in colour, intensity and distribution

Area of the wall that is illuminated

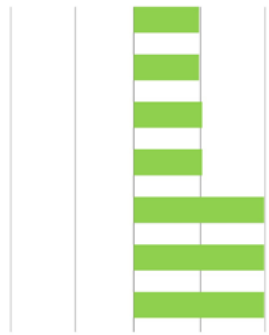
Accents of healing environments in light, shapes and materials

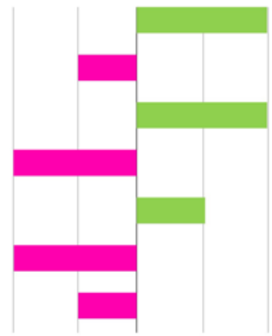
Ease of installation of physical and electronic components

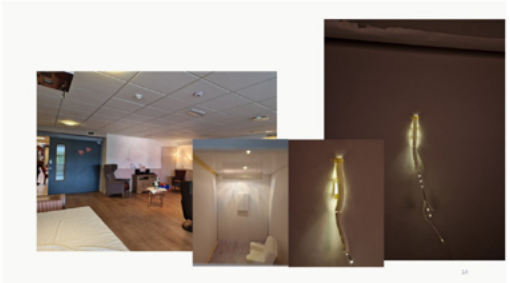
Costs based on light sources, material costs and printability

Efficiency of wall illumination

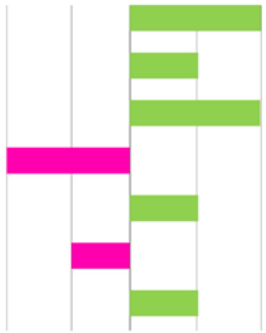
Robustness regarding physical touch

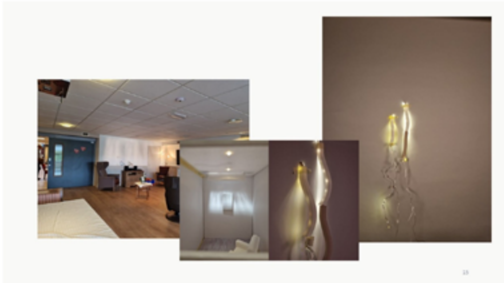




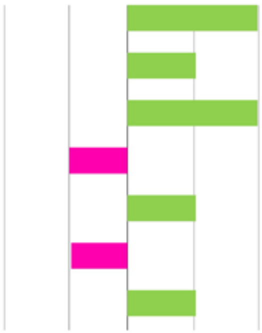


- Vertical hanging light feels natural
- Multiple needed to have a big impact on the space
- Vertical light pattern is reminiscent of ivy and is unique
- Play with height differences and curves

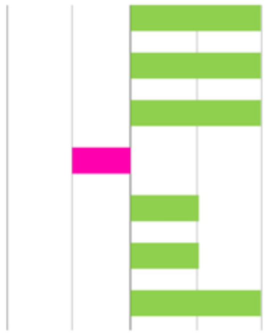




- Vertical hanging light feels natural
- Multiple needed to have a big impact on the space
- Vertical light pattern is reminiscent of ivy and is unique
- Play with multiple next to each other



- Light from top like the sun with a lot of vertical illumination
- Many panels needed for a nice effect
- High brilliance effect with few luminaires
- Play with patterns of leaves, double shadows with colour and vein patterns. Vary light distribution



Appendix E: Test with colleagues

The test with colleagues was performed to evaluate the three concepts in the ideation phase. As a secondary goal, the test formed a pilot on a possible evaluation method further in the project. The following research question was answered.

What is the difference between the concepts of perceived atmosphere and light qualities?

At the time, the perceived atmosphere formed the foundation for the design goal. Therefore, the difference in perceived atmosphere was important. It was also important to test the method of measuring perceived atmosphere. Light qualities were deemed important to gather insights into certain aspects such as naturalness and glare.

Method

The three prototypes of the concepts were hung next to each other in an already illuminated space. In a consistent order, the prototypes were switched on one after the other. The colour temperature was kept similar for each concept. This was set at cool white due to the limitations of one of the concepts. For each concept, the colleagues (N=5) were asked to choose six reaction cards from two stacks (see Figure A). The chosen reaction cards were noted down, and they were asked for a further explanation after each concept.

Light quality	**Atmosphere**
Comfortable	Cosy
Sufficient	Motivating
Task-focused	Personal
Pleasant	Intimate
Natural	Formal
Contrasting	Stimulating
Dim	Relaxed
Bright	Lively
Glary	Detached
Uncomfortable	Boring
Insufficient	Lifeless
Disturbing	Depressing
Unpleasant	Clinical
Unnatural	Demotivating
Tense	Dull

Figure A: The set of reaction cards used. The cards were grouped into two categories: light quality and atmosphere describing words. Every word was put on a separate paper card.

Results and conclusion

The results and conclusion from this test can be read in the main body of this report in Chapter 2.

Discussion

Testing with colleagues does not result in a representative test concerning the target group of the project, namely residents of nursing homes. The number of participants was also low, and participants knew about the project. Nevertheless, the test was helpful for the project at that time. The results highlighted points of improvement for each concept and the discussions were fruitful.

The test was also used to evaluate the research method. This proved to be too complex. Even for the colleagues it was hard to choose between the reaction cards. These tough decisions revealed great insights into their considerations, but it would be too demanding for the target group to participate. The number of reaction cards could be reduced or the method could be more drastically changed in order to decrease the complexity of the decisions.

Appendix F: Production costs estimate

Produciton costs estimate

Puck		Plywood			
0,005	Kg	3	mm		
15	min	9	euro/m2		
32	Number/m2	7	min		
44,33	euro/Kg				
Adhesive		Lacquer			
3	euro/m2	0,5	euro/m2		

Material costs /m2	19,59			
Laser cutting	1	euro/min	7	euro/m2
3D printing			1,77	euro/m2
Robotic assembly	2,5	euro/hour	0,083333	euro/m2
Production costs /m2	8,85			
Total product costs	28,45	euro/m2		
Margin factor	3			
Consumer costs	85,34	euro/m2		

Excluding recycling of left over multiplex material

Sources

Woodfill filament	https://www.123-3d.nl/colorFabb-Woodfill-filament-Hout-1-75-mm-0-6-kg-i6993-t7324.html
Transparent filament	https://elektronicavoorjou.nl/product/pla-transparant-1-75-mm-1-kg/
Plywood	https://www.houthandelonline.nl/multiplex-populieren-b-bb-3mm-250x122cm
Adhesive	https://dutch.alibaba.com/p-detail/large-60208066202.html?spm=a2700.galleryofferlist.normal_offer.d_title.4f674a49h1Cz43
Lacquer	https://dutch.alibaba.com/p-detail/Transparent-1600503960162.html?spm=a2700.galleryofferlist.normal_offer.d_title.69c74002icm9ly&s=p
Lasercutting	https://artizono.com/laser-cutting-cost/
3D printing	https://blog.prusa3d.com/3d-printing-price-calculator_38905/
Robotic assembly	https://www.roboticsbusinessreview.com/manufacturing/pick-place-profit-using-robot-labor-save-money/