COFFEE BASED

XL 3D PRINTING WITH COFFEE WASTE

A MASTER THESIS
AT COFFEE BASED,

IN COLLABORATION
WITH 10XL

Msc Integrated Product Design

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SUMMARY

This thesis investigates the potential of coffee-based granulate for Large Scale Additive Manufacturing (LSAM) in sustainable outdoor furniture design. The research is a collaboration between Coffee Based and 10XL, supported by Het Ooievaarsfonds. The project aims to determine whether materials from Coffee Based, made from spent coffee grounds (SCG), can be used to create large-scale 3D-printed furniture, and how their material behavior influences design and manufacturing decisions.

The research attempts to fill a clear gap in the literature. While SCG-based composites have been used in small-scale filament printing, their performance in Fused Granulate Fabrication (FGF) using LSAM has not yet been studied. The project uses a research-through-design approach and follows a double diamond process with the following clear parts: literature review and problem definition, material and printer exploration, design development, and final design and validation.

Three SCG-based compounds provided by Coffee Based were tested: SCG with recycled polypropylene (rPP), bio-based high-density polyethylene (bioHDPE), and thermoplastic starch (TPS). Their sustainable properties are different: rPP contributes to technical circularity through recycling within the technical cycle, bioHDPE is bio-based and derived from renewable feedstock, and TPS is bio-based, biodegradable, and compostable within the biological cycle. The material exploration phase is mainly focused on improving print quality rather than the mechanical properties of the compounds themselves.

Many print tests were performed at 10XL, mostly on a smaller extruder, and in the end, once on the large extruder. The main test variables were flow/extrusion rate, temperature, bed adhesion, print speed, and minimum layer time. Print quality was mainly focused on shape fidelity (overhang, bridging, radii, corner angles, and shrinkage), extrusion consistency, and surface finish. Performance was measured both qualitatively and quantitatively.

Shrinkage turned out to be a major challenge in this research. The TPS compound showed the lowest and most consistent shrinkage (below 0.5%) and had proper adhesion to the print bed without needing additional fixation. In contrast, the rPP and bioHDPE compound showed significant shrinkage levels, and therefore also needed additional fixation to the print bed. While adding chalk to these compounds reduced shrinkage, because it was manually mixed, it led to inhomogeneity and inconsistencies in print quality. Using the TPS compound, successful overhang angles reached up to 40 degrees, while bridging was mainly unsuccessful, due to the continuous flow nature of LSAM. Corner angles smaller than 40 degrees turned out to be unreliable. However, small radii were printable and reliable.

These findings led to the design of an XL 3D-printed prototype that combines the potential of the coffee-based material with the preferences of the stakeholders, within the found constraints of the printing technology.

Overall, this research shows that the provided granulates by Coffee Based have the potential to be used in LSAM with FGF, provided that further development is performed to minimize shrinkage and improve extrusion consistency on the large extruder. Design choices also have to align with material properties and printer possibilities.
Thus, while much is still unknown and challenges towards print quality remain, the project lays the groundwork for further development on using circular, biobased (or waste-based) materials in LSAM.

PREFACE AND ACKNOWLEDGEMENTS

Dear reader,

This paper you are about to read is my thesis project for the Master's Integrated Product Design at the TUDelft. It contains the work of the past six months and shows a project done in collaboration with the companies Coffee Based and 10XL. Granulate made from coffee waste was provided by Coffee Based, which is 3D printed at 10XL on a large scale. This project combines both my interests in sustainability and 3D printing, therefore I immediately knew this was the right project for me. Although there were some logistical issues and delays in the planning, I am happy with the result of my work. Of course, this result could not have been achieved alone, and therefore, I would like to thank the following people.

First, I want to thank Lisanne Addink-Dölle, my mentor from Coffee Based, for the great trust and guidance throughout this project. The rest of the team at Coffee Based, I am also very thankful for the warm welcome and support. They gave me the trust to work on their design project, to bring it to the next stage. Thanks a lot.
I would like to also thank the team at 10XL, who provided me with the opportunity to use their machinery for this project. I am thankful for their help and the knowledge they wanted to share.

Thanks to my supervisory team from the TUDelft, Jeremy Faludi and Stefan Persaud, for guiding me throughout this project and helping me with the next steps when I was lost. Jeremy, for his expertise on sustainability and 3D printing, and Stefan, for helping me take the necessary steps in the design process. I always experienced our meetings as pleasant and constructive.

Finally, I would like to thank my fellow students and friends at the TUDelft, who were always happy to help and support me when I got stuck.

This project has been a valuable learning experience, and I hope the outcome is inspiring.

In the writing of this paper, OpenAI and Grammarly were used for rewriting and reformulating sentences to improve clarity and remove grammatical errors. However, all content is firstly self-written and therefore my own work. Besides this, OpenAI helped me summarize this paper and provided the final touch on the rendering of the final design.

Enjoy!

Joas

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1. INTRODUCTION AND LIT. RESEARCH

There is a growing demand for larger, circular products made from bio-waste materials, yet their application in Large Scale Additive Manufacturing remains limited due to uncertainties around material behaviour and printability at scale.

1.1 Stakeholder needs

This graduation project is conducted in collaboration with the companies Coffee Based and 10XL, who are the primary stakeholders in the research. Another key stakeholder is Het Ooievaarsfonds. Through research and interviews, their needs have been analysed.

Coffee Based is a Dutch company that develops innovative products from spent coffee grounds. By upcycling a widely available bio-waste stream, the company aims to replace the conventional fossil-based materials with a circular alternative, made from coffee waste. Coffee Based already produces a large range of consumer and interior products using their material, examples of which are shown in the figure on the right.

While these products demonstrate the aesthetic and sustainable potential of the material, they are currently limited in size. Their largest existing product, the Bean House, is primarily constructed from plywood and finished with a thin, compostable coffee-based sheet material.

The origin of this project lies with **Het Ooievaarsfonds**, an organisation committed to projects that contribute to the sustainable development of the Alblasserwaard region. The foundation expressed an interest in sustainable, outdoor furniture objects to be placed near their supported projects. These objects would not only act as, for example, seating areas, but also as attractors and informers that tell the story and values of the project and the object itself.

Both Coffee Based and Het Ooievaarsfonds, therefore, share an interest in the development of larger-scale furniture objects with a strong sustainability narrative. However, the development of large-scale products made mostly or entirely from coffee-based material has yet to be explored. The production technique currently most used by Coffee Based is injection molding. This, however, requires expensive molds, especially considering the size of a furniture object. Which is why a collaboration was established with 10XL.

10XL is a design and manufacturing company specialising in Large Scale Additive Manufacturing (LSAM) using circular materials. Using custom-built 3D printing machines, they are capable of producing large objects such as bridges, boats, furniture, and interior products. Their work focuses on translating waste material streams into functional, large-format products. In addition, 10XL has previously conducted material research into the creation of circular composites, including wood–plastic composites, positioning them as a valuable partner in material development as well as fabrication for Coffee Based.

Figure 1: 10XL machine hall

Although both companies independently have key capabilities in the area, these have not yet been combined. Coffee Based has developed multiple sustainable materials using coffee grounds, but these have not been tested or adapted for LSAM. 10XL has extensive experience printing large furniture and structural objects, yet has limited experience using bio-waste materials such as recycled coffee grounds. This brings design and manufacturing challenges, and questions such as: What is possible with this kind of circular material in the area of XL 3D printing? Or how does the material behave, and how can you combine that with form and function in a design? These and other questions will be answered in this research.
Within this collaboration, this graduation project functions as a research-through-design exploration. Graduating at Coffee Based and working in partnership with 10XL and Het Ooievaarsfonds, the project investigates how the existing coffee-based materials can be integrated into Large Scale Additive Manufacturing. After that, the resulting insights will be translated into a meaningful public furniture object.

1.2 Structure

This report is structured based on the different phases that were gone through during this research. These phases are visualised in the figure below, in the shape of a double diamond.

1. **Discover and Define**: Literature review leading up to the problem statement (Chapter 1).
2. **Discover**: Material and printer exploration (Chapter 2).
3. **Develop**: Design exploration (Chapter 3).
4. **Deliver**: Final design, validation, and evaluation (Chapter 4).

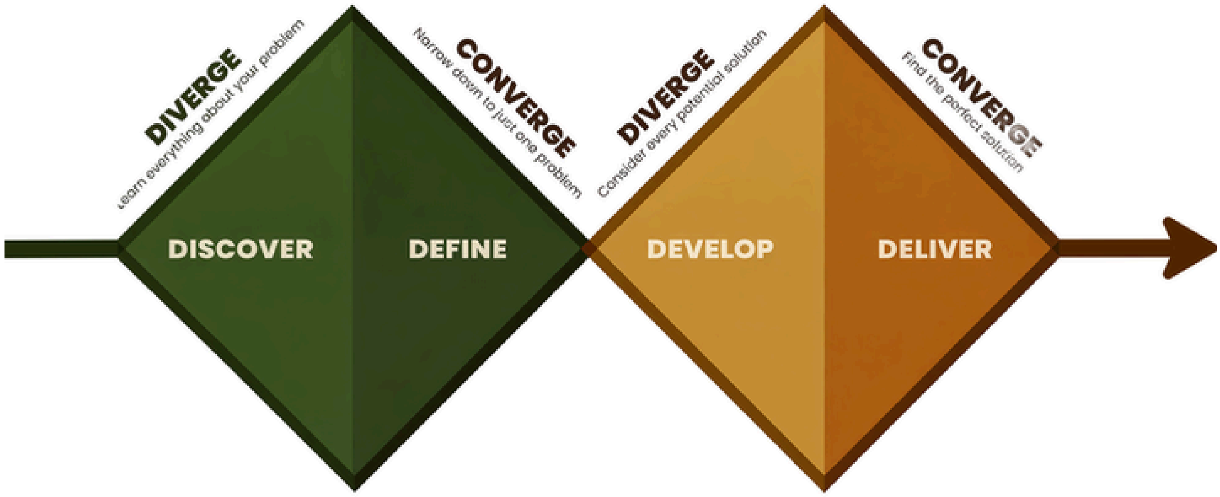


Figure 2: Double diamond visualising the process

1.3 Technology review

This chapter will explain the background knowledge needed for this research. First, an introduction and the applications of large-scale additive manufacturing (LSAM) are provided. The next chapters will give a review of the use of Spent Coffee Grounds (SCG) in plastic-based composites and their (dis)advantages. It will define the material and will lead to different print tests in this research.

1.3.1 Large Scale Additive Manufacturing (LSAM)

Large Scale Additive Manufacturing (LSAM), also known as Large Format Additive Manufacturing (LFAM) or large-scale 3D printing, is a form of Additive Manufacturing (AM), often using Fused Granulate Fabrication (FGF). In FGF, a screw conveys the thermoplastic pellets through multiple heating elements, where the melted material is extruded through a nozzle (Pignatelli, 2022). This differs from conventional Fused Deposition Modelling, where spooled filament is used (figure 3).

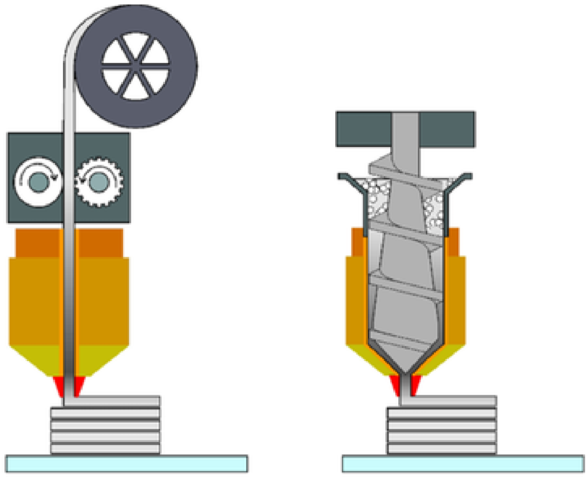


Figure 3: FDM on the left, FGF on the right (Gonzalez-Gutierrez, 2018)

Advantages of using LSAM as a production method are the freedom in forms, which can be altered quite easily. This results in “the elimination of molds, which significantly reduces production lead times, enabling rapid prototyping and iterative design adjustments based on user feedback and environmental constraints” (Kantaros et al., 2025).

Compared to other AM technologies, LSAM offers significant advantages and acts as a “true transition between prototypes and mass production techniques such as injection molding“ (Bishop, 2020). In the domain of interior design, this technology opens up possibilities for customisation, complex geometry, and even direct production of large components. However, to use LSAM meaningfully within this domain, it is important to understand the underlying technologies and materials, the process principles, advantages and limitations, and how they differ from more conventional 3D printing approaches.

1.3.2 Design and Slicing

When designing for LSAM, specific printing constraints associated with LSAM need to be taken into account. Conventional desktop FDM workflows often include filament retraction, small nozzle diameters (0.2-0.8 mm), fine layer heights, and thus a high resolution. In LSAM, on the other hand, material extrudes in a continuous flow, making retraction not applicable. Due to the higher layer height, the texture of the print will also be coarser. It is important to consider that designs must be tailored to the printer instead of the other way around. Due to the combination of a larger nozzle and higher speeds, for example, fine details will be unable to print.

Layer time is also important to consider. If the layer time is too short, the design has a higher risk of collapsing due to heat accumulation, while an excessive layer time often leads to poor layer adhesion or even delamination. This last aspect occurs when the previous layer has cooled down too much before the next layer is deposited on top of it (Vanerio et al., 2025).

After creating a printable design, it needs to be sliced, similarly to other FDM technologies. To do so, the 3D file needs to be imported as a .stl file into slicing software, such as Cura, to choose the print settings and create a G-code. This G-code needs to be translated to ‘printer language’ into software such as Eureka (depending on the type of robot used) to allow it to move according to the uploaded G-code file.

In the context of LSAM, design decisions cannot be separated from printing parameters. Choices regarding geometry, wall thickness, layer orientation, and toolpath strategy directly interact with parameters such as extrusion rate, layer height, and cooling time. As a result, design decisions strongly influence both print quality and structural performance. Designs that do not account for these interactions may lead to defects such as poor layer adhesion, inconsistent extrusion, or insufficient crystallization time between layers. Therefore, designing for LSAM requires an integrated approach in which geometry and slicing strategies are developed in parallel with an understanding of the printing process.

1.3.3 Printing

Printing a successful print strongly depends on the mechanical properties of both the printer and the material, such as extrusion rate and consistency, layer adhesion, crystallisation, and shrinkage of the material. To account for warping caused by possible shrinkage, bed adhesion is also critical. This is usually done by welding (melting) the first layer to the print bed, or by screwing the print to it.

When printing at 10XL, the printing setup consists of a large PP printbed and a Dyze robotic arm printer. As said before, Fused Granulate Fabrication (FGF), where granulate will enter a hopper leading to the extruder, which is heated in different zones. The temperatures of these zones can be changed separately, allowing for optimized control. Each layer will then be printed in a layer-by-layer manner, with enough time between the layers for the previous layer to crystallize.

Figure 4: Printer used at 10XL

Extrusion rates are set manually on the printer, which need to be adjusted to the layer speed. However, if layer length differs a lot in the same print, some type of ratio needs to be set to the rate to account for over- or under-extrusion and to allow for the previous layer to crystallize. Another way to counter this is by optimizing the print design.

1.3.4 Advantages and limitations

As mentioned before, LSAM has numerous advantages, such as form-freedom or customizability. Vanerio et al. (2025) also present it as a “faster, cost-effective alternative to traditional processes for producing large components”.
Nevertheless, LSAM also provides challenges. For example, the trade-off between scale and resolution. Printing larger objects with a larger bead size will typically result in a surface finish that is coarser, with visible layer lines. This may require additional finishing steps or design compensation for either functional or aesthetic reasons.

While surface finish is often the most visible limitation of LSAM, print quality extends beyond aesthetic considerations alone. Research by Vicente et al. (2023) identifies strong anisotropy and a high level of porosity as key limitations inherent to the LSAM process. Even though LSAM technologies often achieve mechanical properties comparable to those of traditional manufacturing processes, anisotropy is always present, and high porosity can sometimes make these technologies unfeasible alternatives for the production of mainly load-bearing structures (Vanerio et al., 2025). Other functional aspects of print quality, such as layer adhesion, dimensional accuracy, and consistency between the layers, play a critical role in applications such as furniture, where components are subject to repeated loads, environmental exposure, and long-term use.
Both visual appearance and functional performance thus need to be considered, especially when working with (less predictable) biocomposite materials, where material behavior may further influence layer adhesion, shrinkage, and other printing errors.

1.3.5 (Suitable) materials

Most studies concerning LSAM materials focus on thermoplastics, with an emphasis on fiber-reinforced thermoplastics. The most common ones used are polypropylene (PP), polyethylene (PE), and polystyrene (PS) (Cosson et al., 2022; Goh et al., 2024).

As this field of AM is still under development, so are the materials used. Research by Goh et al. (2024) shows that, for example, the dimensional stability of the print can be improved by including additives and fibre reinforcement. This is also said to be a solution to minimize shrinking (and thus warping) of the printed material (Vicente et al., 2023). Examples of these reinforcing additives are carbon fibers, glass fibers, or chalk (Cosson et al., 2022).

This study will focus on using compounds of thermoplastics (PP/HDPE/TPS) with Spent Coffee Grounds (SCG). However, using biomass waste materials in AM has almost only been studied on desktop-sized 3D printers, thus with polymer-based biowaste filaments. Literature shows that “LFAM systems are still scarcely considered as potential scaling up of polymer-based composites with biomass byproducts” (Paramatti, 2024; Romani, 2023).

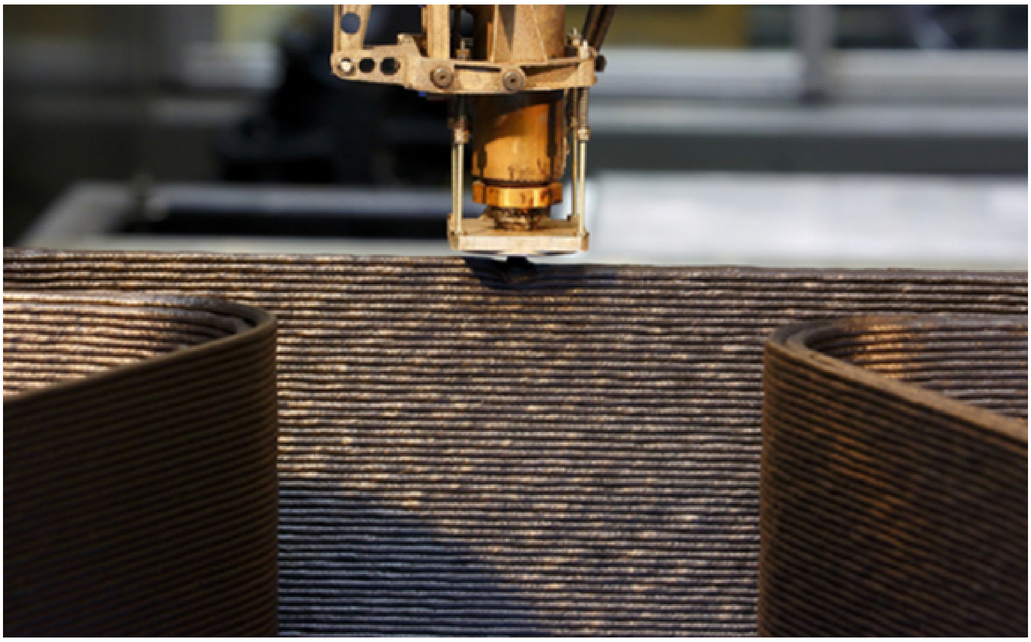


Figure 5: LSAM with thermoplastics (Sabic, 2017)

1.3.6 3D-printing furniture

The application of LSAM in furniture and interior design is still emerging, but shows significant promise. Considering outdoor furniture, research by Kantaros et al. (2025) claims “3D printing is believed to play a crucial role in future urban infrastructure planning.” The technology enables the production of large objects without requiring multiple sub-components or assemblies. It does, however, introduce challenges, such as durability, weather resistance (if used outdoors), finish quality, wear and cleaning cycles, modularity, transport/installation logistics, and ensuring long lifespan, considering repair and maintenance.

To increase the performance of (public/outdoor) furniture, a hybrid manufacturing approach is beneficial. This integrates 3D-printed elements with conventional materials, such as metal or wood, which provides “additional structural strength and ease of maintenance” (Kantaros et al., 2025). Examples of such an approach in practice are the products of the company Streetlife, which create customizable outdoor furniture by interlocking different materials in a way that increases its durability and repairability (StreetLife, 2025). Besides this, Kantaros et al. (2025) mention that a modular approach increases the adaptability and sustainability of furniture objects. LSAM is a method that removes the constraints of ‘traditional’ manufacturing methods, which are usually limited to standardization. As said before, 3D printing allows for a high level of customizability, and products can be tailored to the desires of the client.

There are already companies that use LSAM for creating outdoor furniture, such as The New Raw, with their ‘Print Your City’ initiative (Print Your City, 2016) and Model No. with both indoor and outdoor designs (Model No., z.d.). Both these companies use recycled thermoplastics for their prints.

Figure 6: Multi-material public furniture by Streetlife (Cliffhanger Curved Banken | Streetlife, z.d.)

Figure 7: Public LSAM furniture by Print your City (Print your city, 2016)

1.4 Material review: Spent Coffee Grounds (SCG)

Over the past decade, an increasing number of studies have explored the incorporation of Spent Coffee Grounds (SCG) into polymer-based composites, such as polypropylene (PP), polyethylene (PE), and polylactic acid (PLA). Research indicates that the addition of SCG in polymer composites can be promising, up to a certain amount. A trade-off needs to be made between its advantages and limitations. This chapter will delve deeper into this trade-off and will act as a case study into the SCG material in polymer-based compounds, in the area of FGF (fused granulate fabrication).

1.4.1 In Plastic-based composites

Plastics and biomaterials

Looking at sustainability, mixing conventional fossil-fuel-based plastics with biomaterials is a challenge. Especially when looking at the end-of-life of the created product. When biomaterials, such as SCG, are compounded with fossil-fuel-based plastics, the resulting composite loses the compostability of the biomaterial. At the same time, the recycling of the plastic component is negatively affected by the addition of the biomaterial.

Studies show that compounding fossil-fuel-based plastics with biomaterials leads to “material heterogeneity that complicates mechanical or chemical recycling” (Olonisakin, 2025). Most mechanical recycling streams are optimized for relatively pure and homogeneous polymers. Having biological residues in the compound leads to reduced mechanical performance in recycled batches.

As a result, such hybrid composites often do not fit within either the biological or the technical cycle. Thus creating a material that complicates any circular end-of-life scenarios. While biofillers or biomaterial additives might reduce the virgin fossil content in a material, adding them to fossil-fuel-based polymers requires careful consideration to prevent unintended sustainability trade-offs.

SCG as a plasticizer

When spent coffee grounds (SCG) are added to polymers such as PLA or PP, they often act as a plasticizer, making the material softer and more elastic, lowering the glass-transition temperature and thereby improving processing (Suaduang et al., 2019a). In the case of 3D printing, this plasticizing effect becomes noticeable when the SCG content increases, reducing the melt viscosity and improving the flow of the material (Paramatti et al., 2024; Waisarikit et al., 2025). Research by Paramatti et al. (2024) also concludes that a lower viscosity results in a more stable extrusion flow and improves the layer adhesion of the extruded material.

Some studies also connect the plasticizing effect to the extraction of oil in the material. For example, in a PP composite, the “tensile modulus of SCG-reinforced PP was reduced compared with oil-extracted SCGPP and neat PP, likely due to the plasticizing influence of coffee oil at the interface” (Wu et al., 2016).

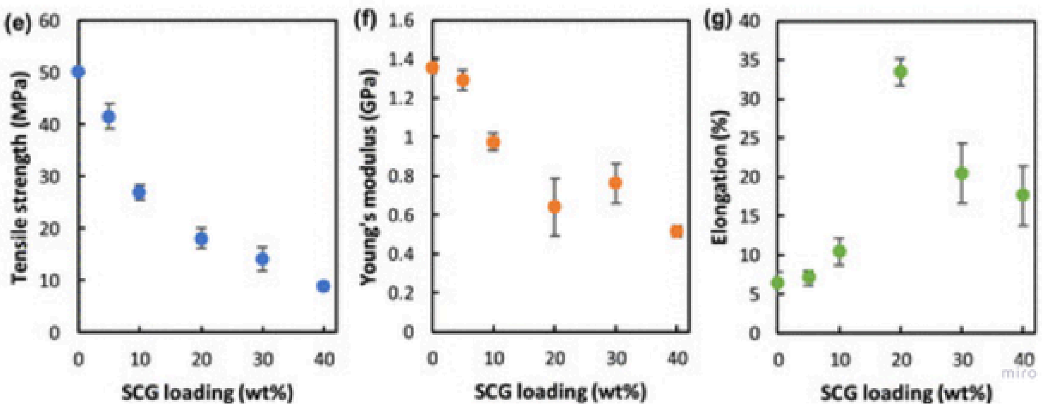


Figure 8: Decrease in Tensile strength when increasing SCG content (Yu et al., 2023)

SCG as a nucleating agent

Besides plasticization, studies also claim SCG can act as a nucleating agent, thus influencing crystallization behavior. When compounded with PP, it will lead to higher dimensional accuracy and less shrinkage if compounded stably (Girones et al., 2017). Boughanmi et al. (2024) say that this is due to the presence of cellulose and lignin in the material. Lignin, therefore, is also widely used as a reinforcement agent for many manufacturing composites, such as AM (Tanase-Opedal et al., 2019; Sabbatini et al., 2021).

In the field of 3D printing, however, research claims that using just extracted lignin seems to work less effectively as a nucleating agent than using an SCG compound with, for example, PLA or PP (Lage-Rivera et al., 2024). Using SCG in a polymer-based compound thus seems to affect the crystallization behavior in a positive way. The processed material, however, decreases in hardness, brittleness, and tensile strength if the SCG content rises above 5% (Suaduang et al., 2019a; Boughanmi et al., 2024; Menendez et al., 2024; Wu et al., 2016). Research by Yu et al. (2023) also shows this in the figure above, up to 40% of SCG content.

Decreasing mechanical properties

As with most paste-based sustainable materials, the increase in SCG content also results in a more brittle and weaker material, compared to regular thermoplastic materials (Bonfim et al., 2022; Suaduang et al., 2019b). Using it in furniture can prove to be challenging, as some studies mention the material as "not suitable for very strong loads" (Rivera et al., 2023). However, while many mechanical properties decreased, impact strength seemed to increase compared to the regular, 'pure' polymers PP (Bomfim et al., 2022), PLA (Sabattini et al., 2021), and PE (also PP)(Paramatti et al., 2024). It is worth mentioning that in the research by Bomfim et al., this was the case with 10% SCG content (the other studies did not mention the SCG percentage).

Limited SCG content

In addition, no research has been done with SCG in thermoplastic compounds exceeding 40% SCG content, which is remarkable, and the question arises as to why this is the case.
Some studies relate this to the "limited interaction between the polymer matrix and the SCG filler" at certain proportions of it in the compound, possibly caused by an incompatibility between the hydrophilic nature of SCG and the hydrophobic character of the polymers (Boughanmi et al., 2025). Yu et al. (2023) associate it with a disruption in the polymer structure, thus also implying a limited interaction between the two materials.

Most research concludes that SCG is a promising filler for polymer composites when used in compounds with less than 40% SCG content, despite its other limitations. Some studies aimed at AM, however, at small scales, or with FDM (using filament). Using SCG in thermoplastic compounds for LSAM is a field of study that is not yet investigated and will thus be targeted in this research.

1.4.2 Public furniture

Made with biocomposites

Research shows that biocomposites can have processing challenges when compared with conventional materials. Most studies mention the main challenges to be cost, availability, and (unpredictable) durability (Chayaamor-Heil et al., 2023; Mikola, 2023). For this research, durability is the most relevant challenge to focus on. Materials used in exterior furniture must withstand exposure to many environmental conditions, such as moisture, UV radiation, and temperature changes. If this is not the case, it can lead to unexpected failure (Parikka-Alhola, 2008).
Especially for products under constant load and with a 'variability in bio-resin/fibre properties' resulting in an inconsistency in the properties of biocomposites seems to be challenging (Manu et al., 2022). These inconsistencies are especially problematic in applications such as construction, where even the smallest variation in product quality can pose risks to structural integrity (Alaneme et al., 2023).

1.5 Problem statement

The previous chapter reviewed the literature on LSAM, suitable materials, and the behavior of Spent Coffee Grounds (SCG) in polymer-based composites. It shows both the opportunities and challenges of applying SCG within LSAM. While the technology allows for form freedom, modularity, and customized production for, among others, furniture products, it does bring in constraints such as anisotropy, porosity, shrinking (warping), and coarse resolution. In addition, though the current studies on SCG in polymer-based compounds show useful effects, such as plasticization, nucleation, and impact strength, they also show reductions in tensile strength, stiffness, and structural reliability beyond certain levels of SCG content. Most importantly, all current SCG-related research has been done at either small-scale levels or with FDM (filament-based), thereby leaving a significant knowledge gap on how SCG compounds behave within Fused Granulate Fabrication (FGF) at a large scale.

These gaps lead to the research direction of this project. This study determines whether coffee-based granulate can be a viable material for interior/exterior furniture applications and investigates how its performance is influenced by LSAM processing. The focus will be on the interaction between material behaviour, print parameters, and design constraints. This research, therefore, focuses on the design and production of XL 3D-printed models, enabling the exploration of material performance, print quality, and design potential in collaboration with the companies Coffee Based and 10XL.

This led to the following problem statement:

Design an XL 3D-printed prototype to explore and demonstrate the potential of coffee-based granulate for furniture products for the companies Coffee Based and 10XL, in the context of sustainable furniture design through large-scale additive manufacturing.

To guide the research, the following three main research objectives were created:

1. Assess the print quality of an XL 3D print produced with the provided Coffee Based material(s).
2. Evaluate the influence of key print parameter adjustments on the resulting print quality.
3. Explore and integrate client preferences to create a design that balances functionality, aesthetics, and sustainability for Coffee Based.

1. Assess the print quality of an XL 3D print produced with the provided Coffee Based material(s).
This first research objective focuses on establishing a baseline understanding of the print quality that can be achieved when processing the different types of provided Coffee Based granulates using Large Scale Additive Manufacturing. As mentioned earlier, the current literature on Spent Coffee Grounds (SCG) composites is limited to small-scale or filament-based printing, resulting in a lack of knowledge on how these materials behave in Fused Granulate Fabrication at an XL scale. By producing and evaluating XL 3D-printed samples, this objective aims to assess the print quality, to provide insight into the material's suitability for large-scale furniture applications, and form the foundation for further parameter optimization. Due to the material(s) being set by Coffee Based, this research will not focus on increasing the SCG percentage in the compound. Adding reinforcement materials to the compound, however, is possible and will be investigated.

2. Evaluate the influence of key print parameter adjustments on the resulting print quality.
Building upon the baseline assessment of print quality, this second objective investigates how variations in print parameters affect the performance of the different materials during LSAM. Parameters such as extrusion rate, temperature settings, layer height, and speed are known to influence print quality strongly. Due to the sensitive behavior of SCG-based compounds to processing conditions, understanding the relationship between print parameters and print quality is essential. This objective aims to identify critical parameters and their impact, enabling more controlled and reliable printing outcomes while exploring their design implications.

3. Explore and integrate client preferences to create a design that balances functionality, aesthetics, and sustainability for Coffee Based.
This objective addresses the design dimension of the project by focusing on the integration of client preferences into the final model. While material behavior and print quality define technical feasibility, the success of the application also depends on how well the design meets functional, aesthetic, and sustainability expectations of Coffee Based and its clients.
This objective aims to explore these preferences and translate them into design decisions that align with the constraints and opportunities of LSAM and coffee-based materials. By doing so, the research bridges technical experimentation with user-oriented design, resulting in a prototype that not only demonstrates material and process potential but also reflects the values and requirements of circular furniture design.

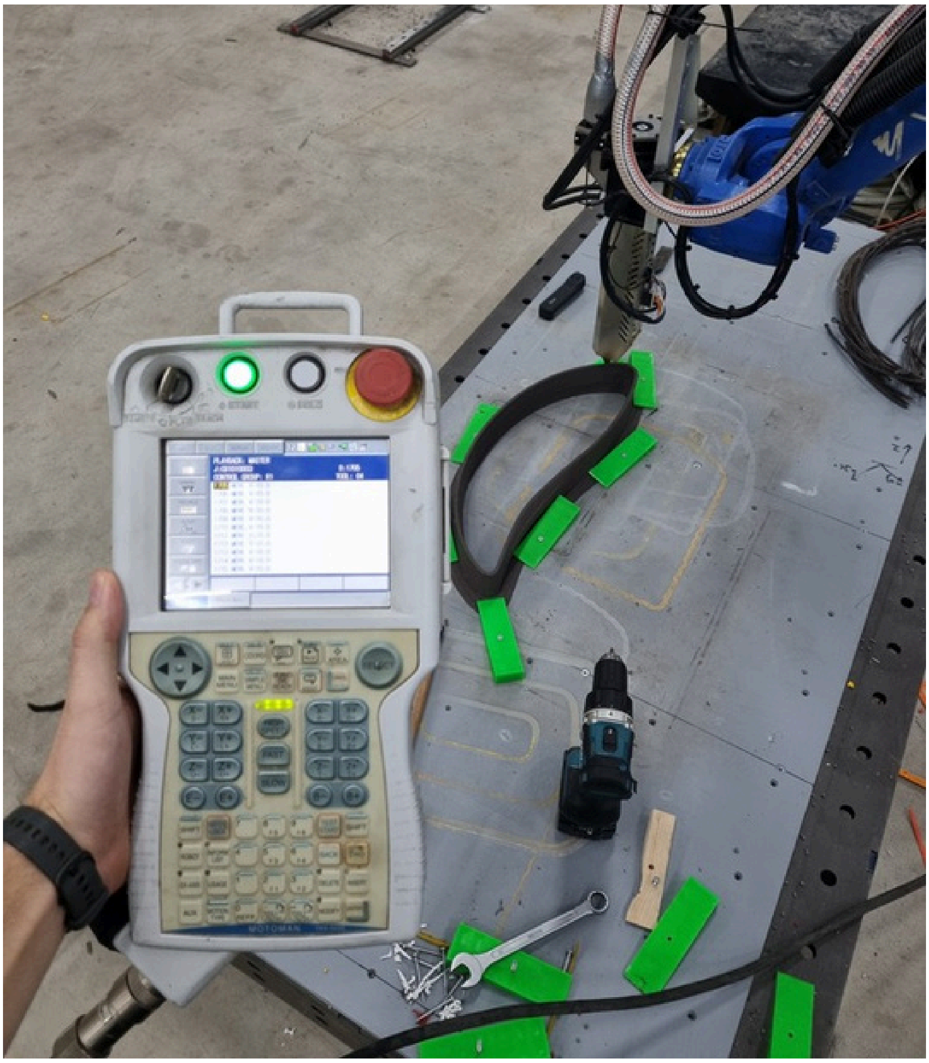


Figure 9: Operating the small extruder

2. MATERIAL EXPLORATION

In this chapter, research will be performed into XL 3D printing with the compounded materials provided by Coffee Based. These are compounds of SCG with three different types of polymers, rPP, bioHDPE, and TPS, which will be explained in this chapter. The primary aim was to explore the three different compounds and their qualities through tinkering. By doing so, research objectives 1 and 2 were addressed. First, the materials will be explained, followed by the tinkering method(s), and then the results will be analyzed.

2.1 Exploring the material: Properties

2.1.1 Recycled Polypropylene (rPP):

rPP is a thermoplastic polymer derived from the mechanical or chemical recycling of post-consumer or post-industrial PP waste. As most of the mechanical and chemical properties are equal to those of virgin polypropylene, rPP is widely used in applications requiring lightweight and durable materials. This contributes to sustainable and circular material flows by reducing reliance on virgin resources, therefore leaving a smaller environmental footprint. The compound made from rPP and SCG was used at Coffee Based for some of their plant pots in the past.

Figure 10: Plant pot made from the SCG-rPP compound

Figure 11: Coffee cup made from the SCG-bioHDPE compound

2.1.2 Bio-based High-Density Polyethylene (bioHDPE):

BioHDPE is a thermoplastic polymer created from renewable biomass feedstocks, such as sugarcane-derived ethanol, instead of fossil fuels. It exhibits mechanical and chemical properties equivalent to conventional HDPE, including high tensile strength and processability, while also offering a reduced carbon footprint and contributing to sustainable initiatives. At Coffee Based, the compound made from SCG and bioHDPE is used in many of their products, including their cups. The material is also classified as food-safe.

2.1.3 Thermoplastic Starch (TPS):

Lastly, TPS is a biodegradable polymer obtained by plasticizing natural starch with water, glycerol, or other plasticizers, allowing it to be processed as a thermoplastic material. TPS has a lower environmental impact compared to conventional plastics due to its renewable source and biodegradability. However, this causes the material to exhibit less mechanical performance and water sensitivity. Besides that, TPS is also compostable. “While a product must be able to biodegrade to be compostable, the reverse is not true” (Fletcher et al., 2020), meaning a biodegradable product is not necessarily always compostable. The compound made from TPS and SCG is also used at Coffee Based for other plant pots.

2.1.4 Sustainable properties

In Table 1, the sustainable properties of the three materials are analysed. Definitions of the properties are explained below.

Property	rPP	bioHDPE	TPS
Biobased	✗	✓	✓
Biodegradable	✗	✗	✓
Renewable feedstock	✗	✓	✓
Circular (intended cycle)	✓ (technical cycle)	✓ (technical cycle)	✓ (technical → biological cycle)
Waste based	✓	✓	✓

Table 1: Sustainable properties of the three Coffee Based compounds

In Europe, biobased materials are materials derived from biomass, with a carbon origin (Fletcher et al., 2020). Two out of three compounds are biobased; only the TPS compound is also biodegradable. Both bioHDPE and TPS use renewable feedstock, while the carbon from rPP originates from fossil resources. Using renewable feedstock, however, does not automatically imply circularity. Renewable materials may still follow a linear lifecycle if they are not designed for recovery, reuse, or a biological return. Conversely, materials made from non-renewable feedstocks, such as rPP, can contribute strongly to circularity through extended use and easy recycling within the technical cycle, as described by the Ellen MacArthur Foundation (MacArthur, 2013). Following their framework, circularity is understood as participation in either a technical cycle (where materials such as rPP are kept in use through recycling) or a biological cycle, in which biobased and biodegradable materials, such as TPS, return to the biosphere. In the case of TPS, the material can be processed in both the technical and the biological cycle. The preferred way is to keep the material within the technical cycle, through reuse or recycling, for as long as possible. When this is no longer viable, the material should be processed within the biological cycle at end-of-life.

In circular economy literature and EU policy, materials are considered waste-based when their primary feedstocks originate from secondary raw materials, defined as materials recovered from waste streams or industrial by-products rather than extracted from virgin resources (van Ewijk, 2020). When sourced accordingly, rPP, bioHDPE, and TPS can each be considered waste-based materials. For the materials provided by Coffee Based, this is the case.

2.2 Exploring the material: Tinkering

2.2.1 General method of all tests

The tinkering process is divided into two phases: the first one using a smaller extruder with a smaller nozzle, the second using a larger extruder with a larger nozzle. On the small extruder, the following print qualities were tested: shrinkage, overhang, bridging, radius, and corner angles. Of these qualities, only shrinkage was tested with all three compounds, due to issues with the printer availability. The other qualities were only tested with the SCG+TPS compound. Each test was attempted at least five times to take consistency into account. After that, tests continued on the large extruder, using the SCG+bioHDPE compound. All the tests performed on the small extruder can be found in Appendix 1.
In the designs, the constant flow nature of the LSAM FGF printing process needed to be considered, meaning that any jerking or excessive travel moves create problems and need to be eliminated as much as possible.

2.2.2 Print tests on the small extruder

Getting to know the printer
Part of the tinkering process was getting to know the printer. This entails all the steps before the first successful extrusion of the first compound tested, SCG+rPP. Models were created using Fusion360, whereafter they were sliced in Cura to create a G-code. In the slicing process, the most important variables to tinker with were the layer height, wall thickness, print speed, and the minimum layer time. Using the help and knowledge from 10XL, the G-code was converted to 'printer language' using their Eureka software and uploaded onto the printer.
Print speed played a crucial role throughout testing. Initial speeds were far too slow, causing material degradation and darker, burnt-looking prints. Increasing the speed improved results, though finding the balance proved to be a challenge since faster printing reduced accuracy and rounded off sharper corners. Adjusting the minimum layer time from one hundred seconds down to thirty or sixty seconds helped optimize this balance.

After a few tests, nozzle clogging ('baardvorming') was one of the main factors causing the surface quality to be insufficient or even the print to fail (Figure 12). Changing the nozzle size from 3mm to 5mm helped solve this problem.

Figure 12: Clogging of the print nozzle

Due to warping caused by the shrinking of the materials, bed adhesion was another challenge. Both the rPP and the bioHDPE needed to be screwed to the print bed (Figure 13). A pyramid-shaped brim structure was developed that provided better support than standard flat brims by eliminating the ninety-degree angle between the brim and walls. This also allowed the print to be secured with screws and wedges and improved bed adhesion significantly. However, even with these supports, straight walls still tended to collapse inward due to shrinkage. The TPS compound, on the other hand, adhered perfectly to the PP printbed.

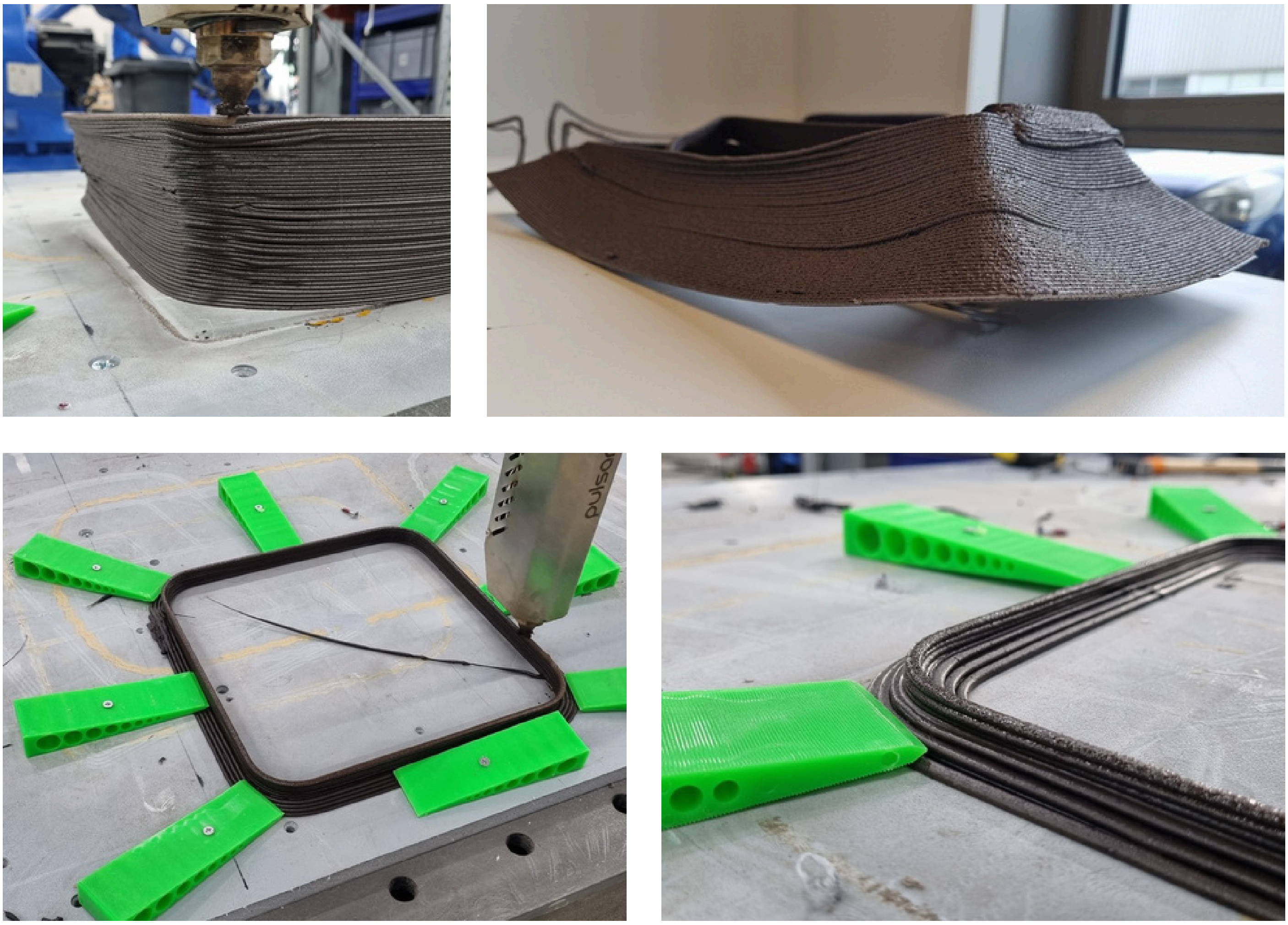


Figure 13: Top left and right: Warping of both bioHDPE and rPP. Bottom left: Screwed to print bed with wedges. Bottom right: Pyramid brim on the in- and outside

Shrinkage

To test the shrinkage, a square model was used (Figure 14). LSAM printing usually doesn't allow for the printing of sharp corners; the print was printed with a corner radius of 40 degrees. The model was printed around 5 times for each of the three compounds. After printing, the dimensional accuracy was measured, comparing it to the designed dimensions. For each compound, the average and standard deviation are calculated to allow for easy comparison.

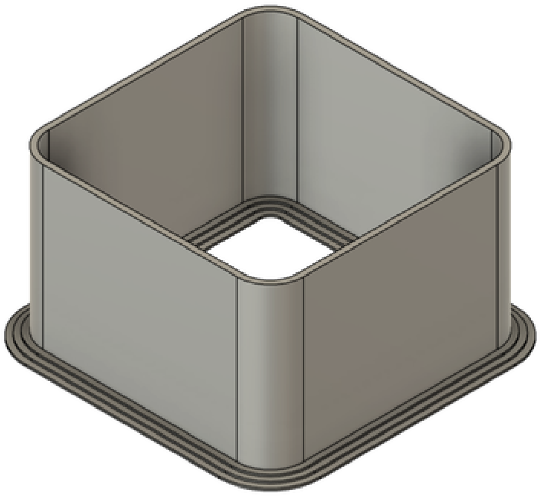


Figure 14: Square model to test shrinkage

As said before, shrinkage was one of the main problems in the printing process. The models either warped (or broke) loose from the printbed or sagged in or out (Figure 16). This is not an unusual error; however, it occurs more often when printing with compounds made with biomaterials. 10XL tackles this usually by adding either glass fiber or chalk. Keeping sustainability in account, chalk was added to the granulate, in increasing amounts (from 5% to 30%). The granulate mix was hard to get homogenously mixed, causing inconsistency in the print quality (Figure 15).

Figure 15: Inconsistency in granulate mix (colour difference)

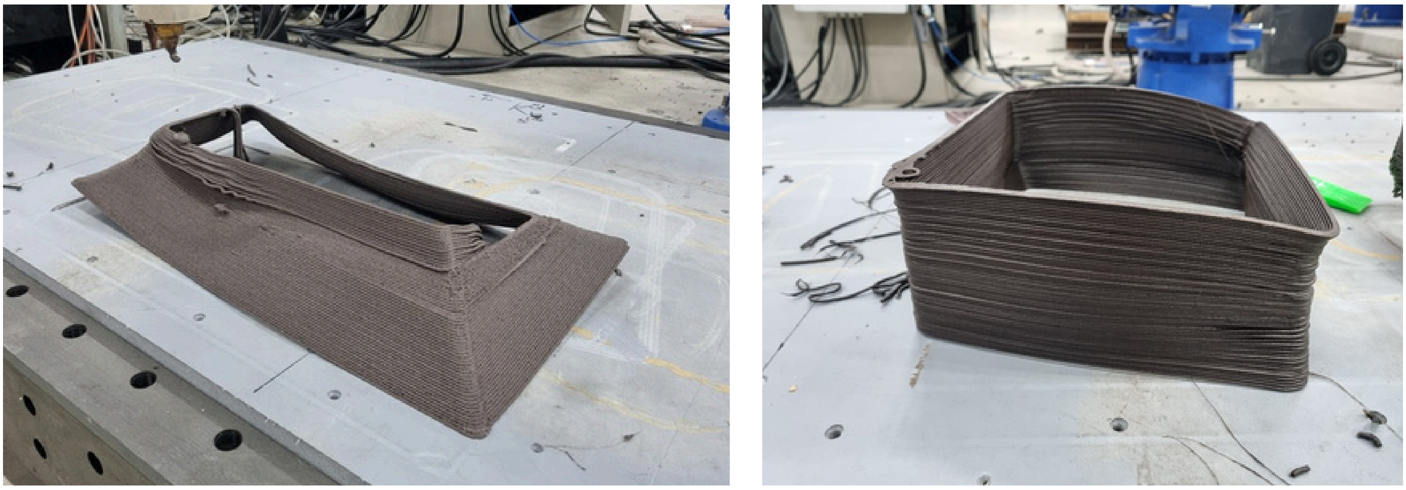


Figure 16: Sagging of the printed walls, rPP (left) and bioHDPE (right)

Overhang

The overhang was tested using the model shown in Figure 17. The design of this model is inspired by research done by Henssen (2023) and tests eight different overhang angles in one print, ranging from 15 to 50 degrees (Figure 18). Within the same model, it also tests dimensional accuracy (in width and height) at the back, and bridging at the front. The model is designed to minimize sharp corners as much as possible, thereby minimizing the disruption on print quality measurements. The rounded corners between each overhang angle also provided the printer with enough time to restore after potentially failing the previous angle. The seam of the print was placed on the back, to prevent it from disrupting any measurements. Due to a low printer availability, this model is only printed with the TPS compound, and once with rPP. Besides an inconsistency in the TPS material supply to the printer, the prints turned out successful and relevant.

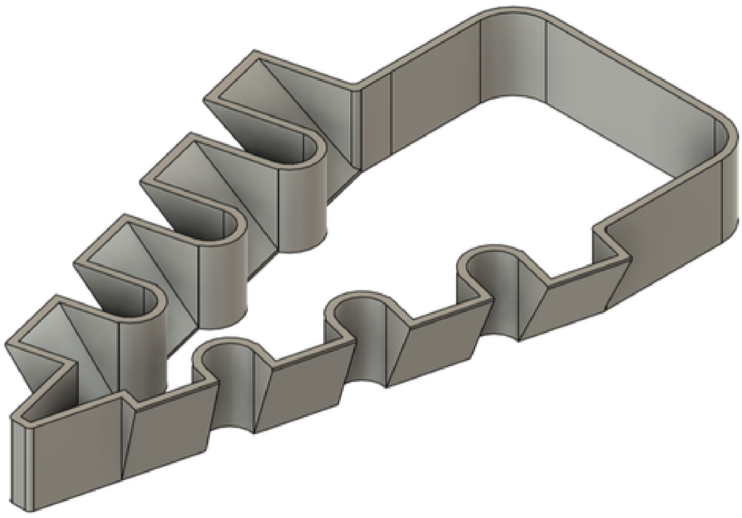


Figure 17: Print model for overhang and bridging

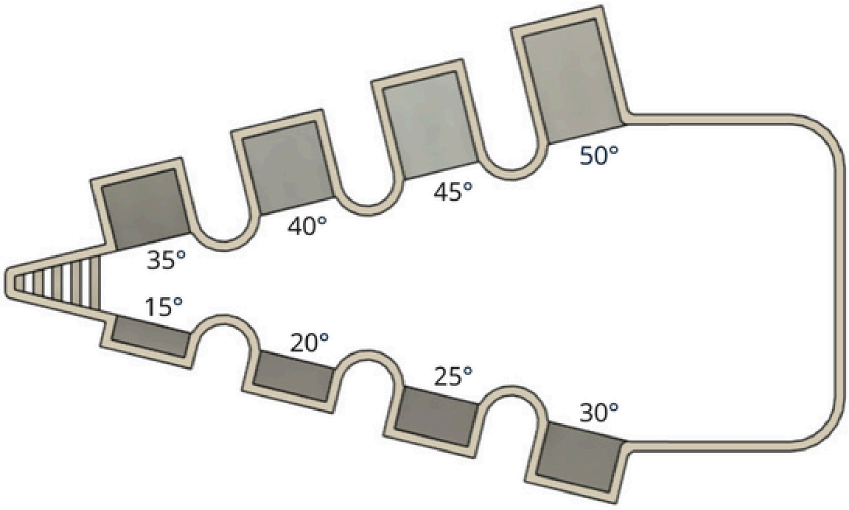


Figure 18: Top view of print model for overhang (and bridging)

Radius and corner angles

The following model (Figure 19) was created to investigate the minimal radius and corner angles possible with the material and technology. From left to right, the corner angle decreases (from 60 to 20 degrees), while the radius increases (from 2.5 to 20.0mm).

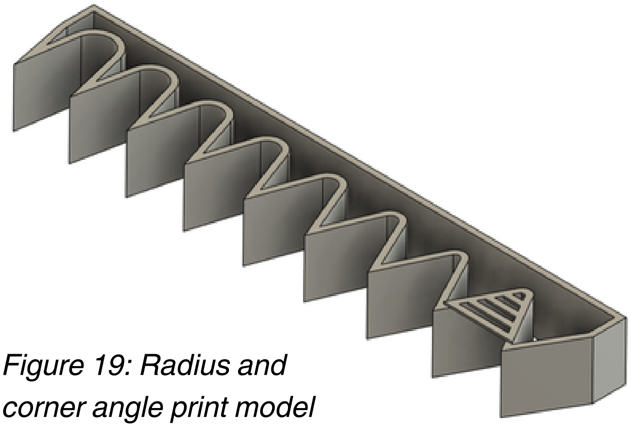


Figure 19: Radius and corner angle print model

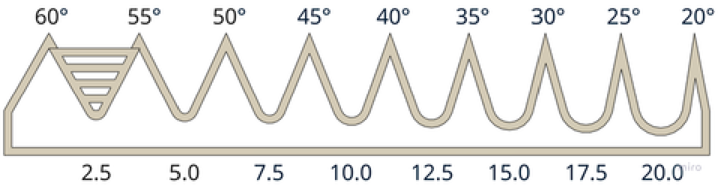


Figure 20: Top view of radius and corner angle model

To measure the succes of the radius, the print was measured at each corner angle as shown in Figure 21 and compared to the designed length. The straight part of the design tests the dimensional accuracy of the walls in the x and z direction. This design was again only printed with the TPS compound.

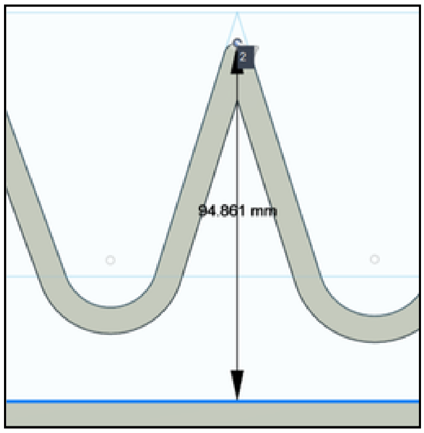


Figure 21: Measurement of accuracy

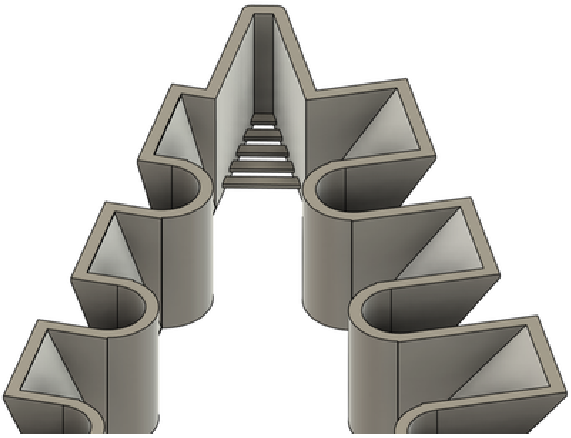


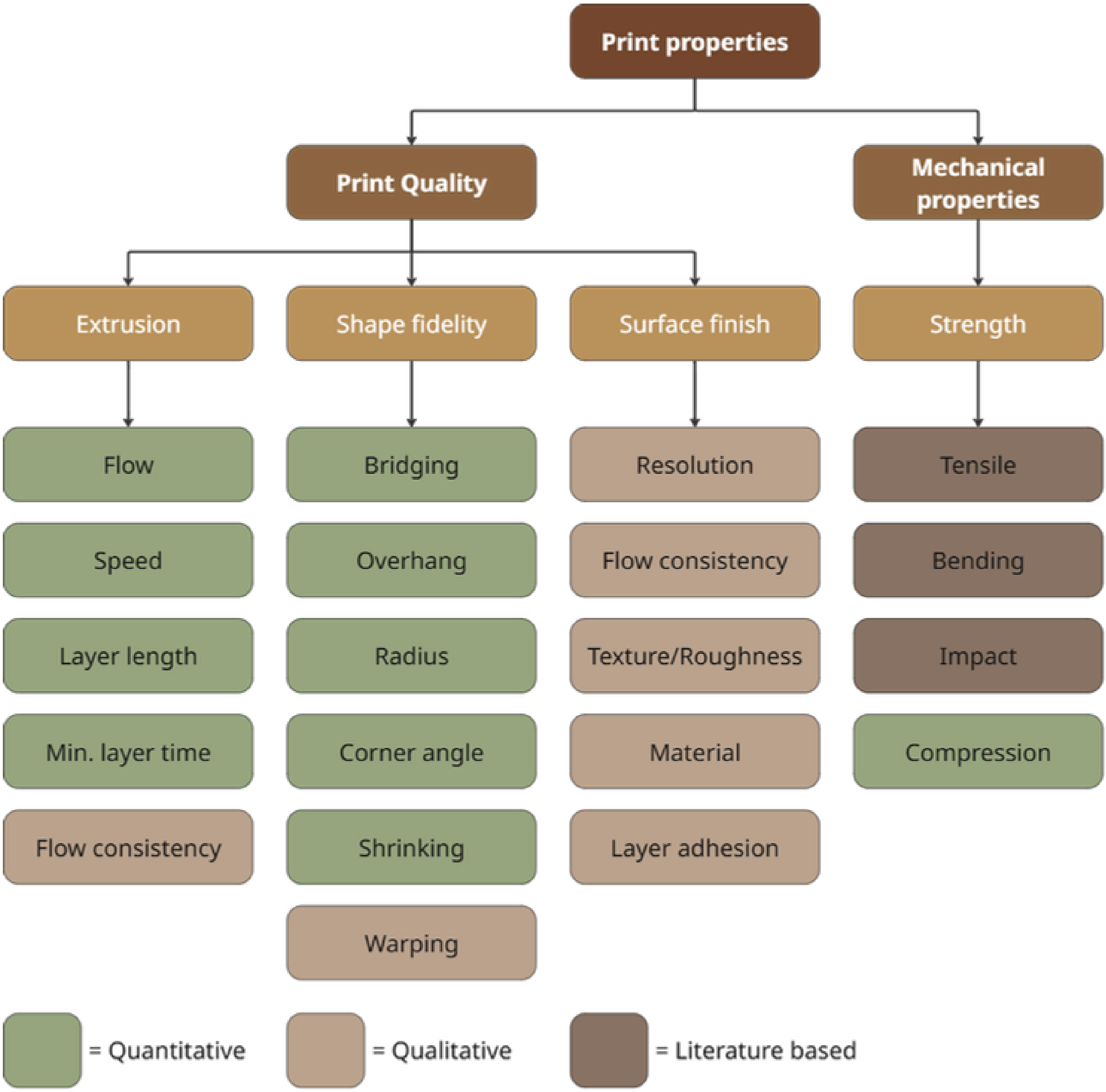
Figure 22: Bridging lines at the front

Bridging

At the front of the overhang test model, bridging lines with lengths ranging from 10 to 40mm were added (Figure 22). Since bridging is rarely applied within the LSAM FGF technology, the designed bridging strands were limited to a maximum of 40 mm. These were designed one layer above the print bed to easily assess the potential sagging of the strands when they rest on the bed. The bridging property was also tested within the radius and corner angle test model (Figure 19). On the far left, the bridging strands ranging from 15 to 60mm were printed. These were placed on the top surface of the model as a final layer, as the tests within the overhang model showed that the printer movement between the layers negatively affected the overall print quality.

2.3 Exploring the material: Print Quality

The quality of the different material print tests is presented in this chapter. These results can be specified into three distinct areas, namely shape fidelity, extrusion, and surface finish. Each of these areas can then be divided even more into concrete qualities.



These qualities can be further specified in the way they are evaluated. Many print qualities are tested quantitatively, while others are evaluated qualitatively. When measured qualitatively, visual inspection is applied. Mechanical properties are largely outside the scope of this research and are therefore discussed based on insights from existing literature. Since compression strength is the most critical mechanical property when designing a seating object, this will be assesed quantitatively. How all these tests are performed, is described in the following chapters. The methods used to conduct these tests are described in the following chapters.

2.3.1 Shape fidelity

First of all, shape fidelity. This area contains bridging, overhang, radius, corner angle, shrinking, and warping.

Overhang

Overhang and bridging performance were only tested using the TPS compound, with one overhang test using rPP. The results of the overhang tests are shown in Figure 23. They show that overhang is successful until 40 degrees in all seven tests, of which four even up to 45 degrees. Overhang angles of 50 degrees failed in all prints. The success of an overhang angle was determined through visual assessment. Figures 24 and 25 shows examples of a printed overhang angle that was classified as successful (left) and one classified as failed (right). The visual assessment was sufficient to distinguish between structurally stable and unstable prints. Based on the determined success, overhang angles above 40 degrees cannot be considered reliable using the current printer and material configuration.

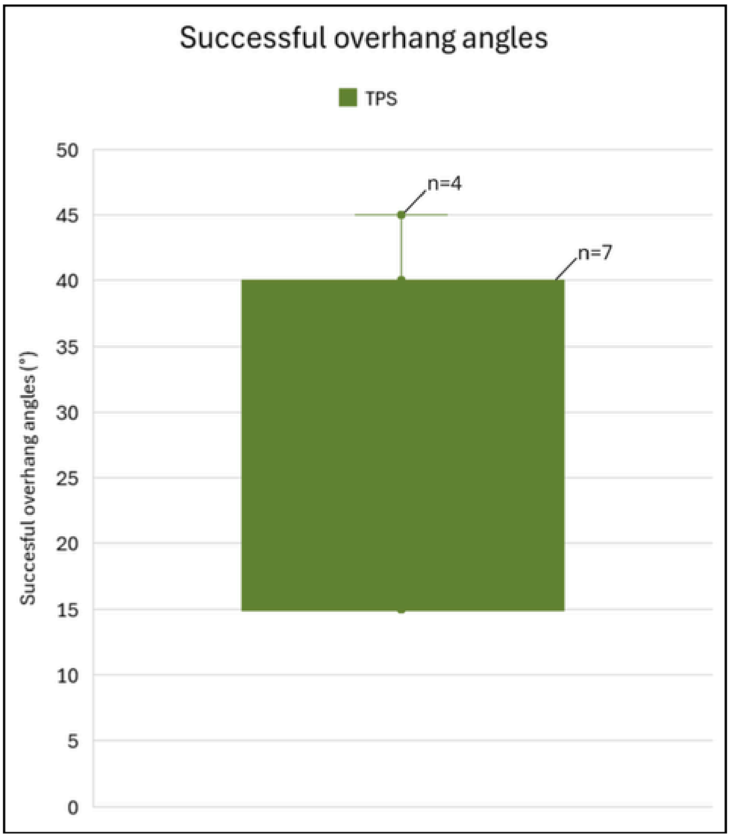


Figure 23: Successful overhang angles

Figure 24: Print samples overhang model

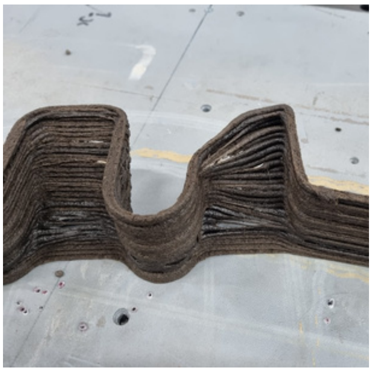


Figure 25: Successful overhang angle (left), failed overhang angle (right)

Bridging

From the results within the overhang test model, bridging was never successful (Figure 26). None of the attempts at bridging maintained its structure in the intended design. Within the design for testing and measuring the maximum radius and corner angle, bridging lines were printed as a final layer on top of the model. After testing with this model five times, bridging was successful for a length of 15mm once. The success of bridging is usually “evaluated based on the degree of sagging in the bridged strands” (He et al., 2025). However, the results show that most of the time the bridging strands were not connected to both sides of the model, and the degree of sagging could thus not be measured. Therefore, the results are visually assessed.

Figure 26: Bridging attempts

The observed failure in the overhang model can be connected to the fact that the printer 'hopped’ to the start of each bridging strand, instead of printing it continuously within the outer wall pattern. The printing process thus had excessive travel moves and retractions, which are usually incompatible with the continuous flow of the LSAM FGF technology (Vanerio et al., 2025). Therefore, in the other model, the bridging strands were added on top, resulting in slightly better (yet still mostly unsuccessful) results. Bridging thus cannot be considered a reliable design strategy (with the current printer and material). This aligns with the current state of the LSAM FGF technology, as 10XL also mentioned that bridging is rarely applied in their designs, due to its unreliability and low level of success.

Figure 27: Bridging attempt within the overhang model

Radius and corner angle

All designed radii, even the minimum radius of 2.5 mm, were printed successfully. This success was determined through visual assessment (See Figure 29).

The minimum successful corner angle, on the other hand, was assessed through quantitative measurements, as described in the methods section. Figure 28 shows how these were measured with the printed parts, with the results summarized in Figure 30 (next page). When the corner angle is equal to or greater than 40 degrees, the measured deviation in distance remains less than 10 mm. Between individual prints, deviations in distance can be observed, where some prints showed a deviation mostly exceeding 10mm, while others remained less than 8mm. With a corner angle of 60 degrees, the minimum measured deviation was 5.5 mm.

Figure 28: Measuring the distance

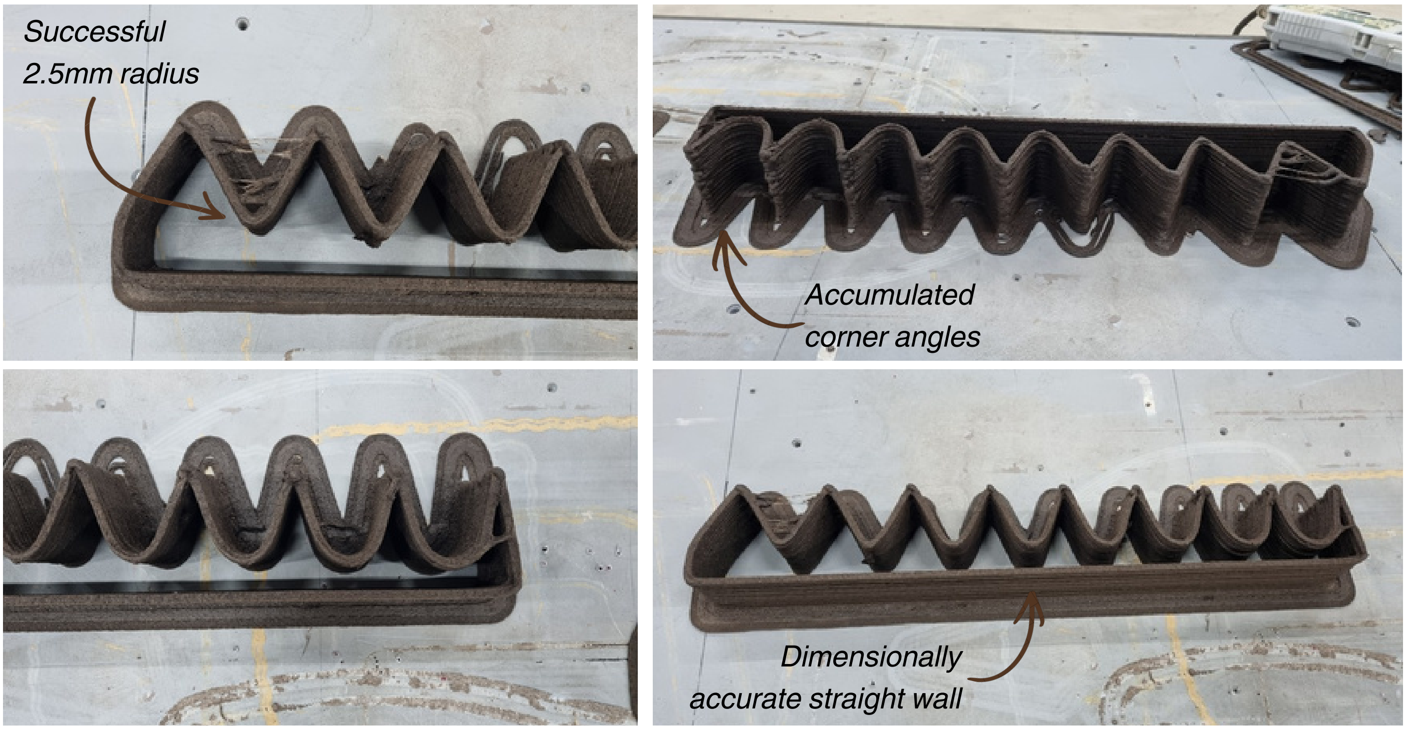


Figure 29: Print results

These results indicate that when the corner angle increases, the deviation in distance reduces (Figure 30). Angles exceeding 40 degrees showed more consistent outcomes. However, the inconsistency between the prints suggests that there might be other factors, besides the corner angle, that influence this print quality, which questions the reliability of the process under the current conditions. Besides this, the minimum deviation of 5.5 mm at a corner angle of 60 degrees remains significant, causing the material and technology to be less suitable for applications requiring high dimensional accuracy.

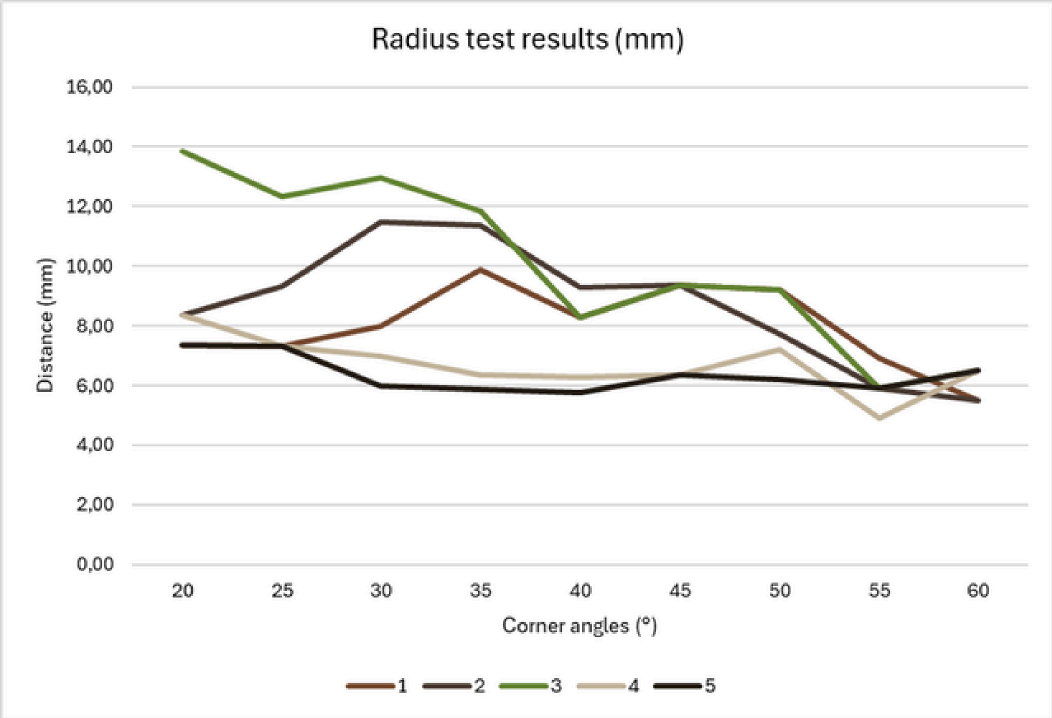


Figure 30: Results from the radius test

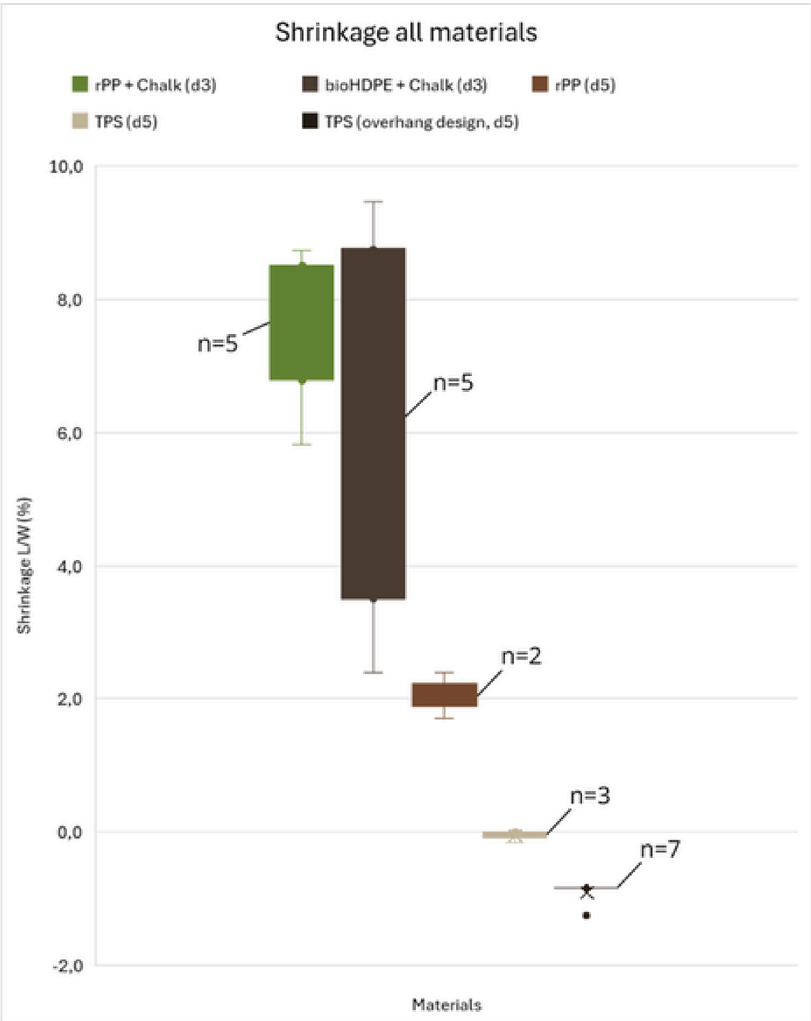


Figure 31: Results from the shrinkage test

Shrinkage

By printing the square described in the method section, the shrinkage of the material could be measured by comparing the printed dimensions with the designed dimensions. This was tested with all three material configurations (see Figure 31 and 32), with two different nozzle sizes (d3 and d5). Due to availability constraints, some material configurations were printed fewer times, indicated with ‘n’ in the graph. The TPS material showed an average shrinkage of less than 0.5%. The shrinkage of the bioHDPE with chalk ranged from 2.4% to 9.5%. The exact measured data of all tests can be found in Appendix 2. The results from the dimensional accuracy measurements within the overhang model are also included in the graph. These measurements showed negative shrinkage values, caused by slight outward warping. In addition, the rPP without chalk tests did not print until full height and are therefore less credible.

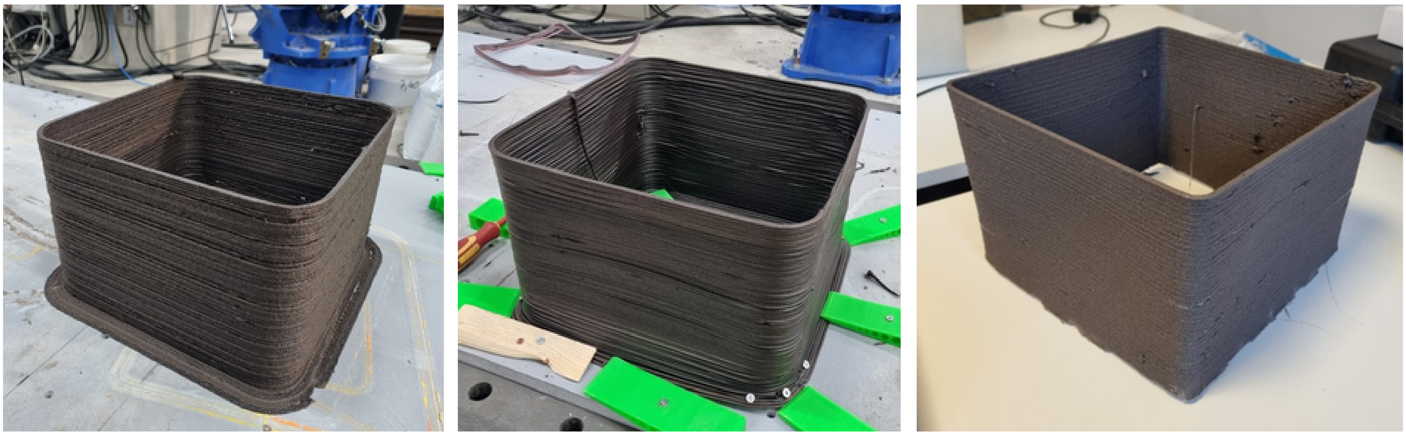


Figure 32: 3D printed square from TPS (left), bioHDPE (middle) and rPP (right)

The amount of shrinkage thus varies substantially between the different material compounds. Where TPS showed low and consistent values, bioHDPE (with chalk) showed a wider spread of higher percentages. Measurements from the overhang model confirmed the previous low shrinkage values of the TPS compound, demonstrating it to have the most desired dimensional accuracy, even without adding chalk. The bioHDPE compound (with chalk) also shows potential, if the print consistency is fixed. This compound was only printed with a 3mm nozzle, where other materials showed an increased performance with a larger nozzle. Additional prints with the rPP and bioHDPE compound using a larger nozzle will improve the credibility of the results.

Bed adhesion

Connected to the shrinkage is the bed adhesion. As stated in previous chapters, all prints were made on a PP print bed. Prints made with the rPP compound adhered to the print bed when it was preheated. Despite this, prints from both the rPP and the bioHDPE compound needed to be screwed to the print bed to prevent it from warping. To improve the bed adhesion, pyramid brims were used (Chapter 2.2.2). TPS prints adhered to the print bed using a standard brim, without needing to fix it to the bed.

These differences between the three compounds relate to their shrinkage behavior. Material compounds that exhibited higher shrinkage also showed a higher risk of warping loose from the print bed. The TPS compound shows the most reliable bed adhesion with the current variables. The need for fixation for the rPP and bioHDPE compound complicates the use of these materials; however, it remains possible, especially if the amount of shrinkage is lowered.

2.3.2 Extrusion

Another important factor that impacts the design is the extrusion of the material through the nozzle. Connected to this are the flow, speed, and layer length. These three are all interconnected, where the speed is limited by the flow and influenced by the layer length. In the slicing program (Cura), the minimal layer time needs to be calculated by dividing the layer length by the desired speed. For each material, a range of sufficient speed is shown in Table 2. Overall can be concluded that a slower speed means more accurate results, but also darker/more burnt results. While TPS prints slower than rPP and bioHDPE, the results in terms of dimensional accuracy and bed adhesion are more accurate.
After tinkering with the flow of the printer, a flow range of 50-85 in the printer turned out to have the best results, depending on the speed. A higher speed requires a higher flow.

Material	Speed range	Notes
rPP	30-60s minimum layer time	• For straight walls or simple geometry: aim for 30-40s/layer. • For complex features or overhangs: 50-60s/layer. • Slower = darker/more burnt but more accurate.
bioHDPE	30-60s minimum layer time	• Smoother texture allows slightly faster speeds than rPP in some cases.
TPS	60-100s minimum layer time	• Requires slower speeds than the other two. • 60s works best, 100s gave accurate results but may be unnecessarily slow. • Non-dried TPS can be printed faster than dried (less sticky).

Table 2: Range of speeds per material

2.3.3 Surface finish

The extrusion consistency, which impacts the surface finish and the texture, was harder to control, as can be seen in Figure 33. Some layers of this model were printed with less material than others due to clogging of the granulate in the hopper. The texture of the model was impacted by this, resulting in an uneven surface finish. It also influenced the layer adhesion, where the contact area with the previous layer is smaller when less material is extruded. The risk of failure is therefore also higher.

Between the materials, there was a noticeable difference in surface finish. The rPP and TPS turned out to have a much rougher surface finish than the bioHDPE, which had a more plastic-like and smoother surface (Figure 34). rPP had the most consistent layers, resulting in a clean layered texture.

Figure 33: Inconsistent layers (TPS)

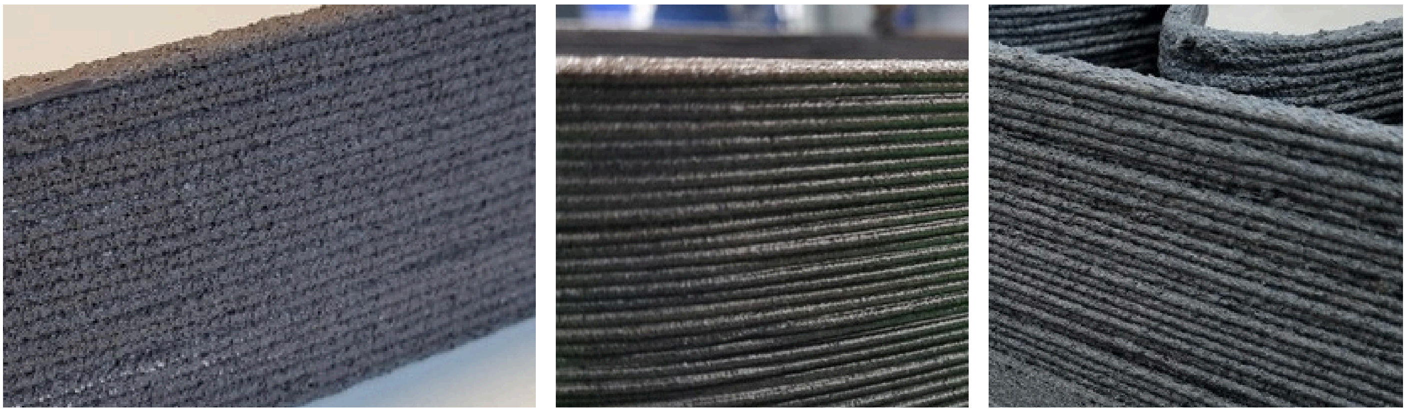


Figure 34: Texture of rPP, bioHDPE and TPS, from left to right

The main reason for a low extrusion consistency is an insufficient material supply. TPS appeared to have a worse material feed than rPP and rHDPE. The TPS granulate has a lower weight than the other two materials; therefore, the vacuum suction works less, causing the need for an external hopper on the small hopper from the extruder. Without the air pressure, however, the granulate gets stuck in the hopper, causing the extrusion inconsistency. This resulted in some layers receiving significantly less material than others, creating holes and compromising the structural integrity of prints. In an attempt to solve this issue, an extruder system was designed and printed to fit on the extruder of the printer (see Appendix 3). This would provide a more constant material supply to the extruder. However, this design unfortunately could not be tested due to issues at 10XL.

This inconsistency between the layers, however, resulted in an interesting and unique pattern, which was actually desired by Coffee Based. Nevertheless, prints on the larger printer will show that this is not possible to create on demand. Using the TPS compound, it was tested to print shapes on the walls as a 'texture'. For this, the shape of coffee beans was used. Taking the inconsistency of the material out of consideration, the shapes turned out good and recognisable, see Figure 35. This will allow for a higher level of customizability for the clients, which is in line with their desires.

Figure 35: Added texture in the walls of a print

2.4 Exploring the material: Mechanical properties

2.4.1 Strength

Compression

As printing with the large extruder has not succeeded yet, its structural strength could not directly be tested. However, structural strength is very important when designing a seating object. Therefore, a compression test was performed with a previously printed square sample. The sample made using the bioHDPE compound was used for this, as this is most likely the material that will be continued with. This choice will be explained in later chapters.

Nonetheless, for the sake of the research, the compression test was also performed with a sample made with the TPS compound (Figure 37).

As shown in the figures on the right, a wooden board was placed on top of the 3D prints, after which it was subjected to the weight of an average adult (~80kg), which it held easily. This result indicated that the strength of these prints, with a 5mm wall thickness, is already enough to carry the weight of a person, let alone if the prints are made with a 9-12mm wall thickness.

In future research, part of the bioHDPE material (as that is the material most likely to be continued with, Chapter 4) could be tested using a three-point bending test, with a small part of the material. This would result in more accurate data about the strength of the material. Due to logistical issues with 10XL, this is not incorporated in this research.

Figure 36: Person standing on square 3D print (bioHDPE)

Figure 37: Person standing on TPS 3D print

2.5 Exploring the material: Biodegradability

If the TPS compound will be used in the final design, biodegradability is an important factor. It is critical to know the rate at which the material biodegrades, to evaluate if and how it can be used in outdoor surroundings. Part of a previous TPS print, therefore, was partially dug into the ground (15cm deep). Since it is checked weekly. Figure 39 shows that after two weeks of being subjected to various weather conditions, such as sun, rain, and snow, no visible changes could be observed. However, the span of this project was too short to conclude anything valuable on this subject.

Figure 38: Material on the day it was planted

Figure 39: Material change after two weeks outside

2.6 Exploring the material: Large Extruder

2.6.1 Large vs small extruder

Towards the end of this research, the large extruder was shortly available for test printing. A feedback and design session with 10XL was organised to create a suitable design for this printer, after which it could be printed. Other steps in the process, such as slicing and translating the G-code into printer code, were similar to those previously used with a small extruder.

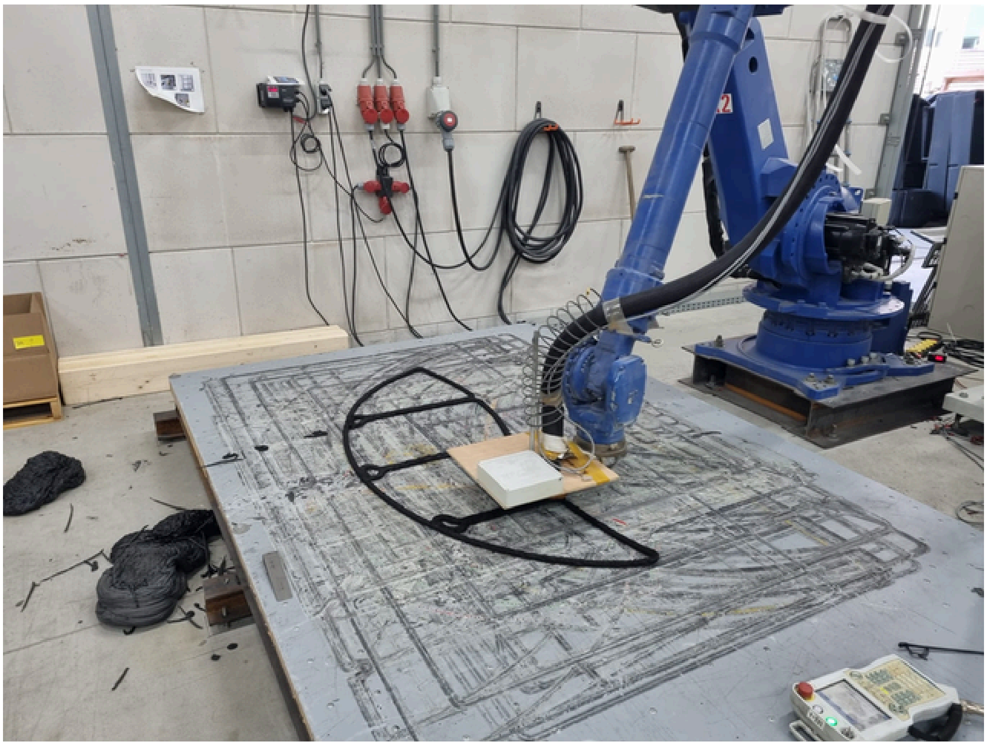


Figure 40: First test on the large extruder

Differences with the small extruder
Apart from having a larger print bed (also made of PP) and a larger nozzle (9mm instead of 5mm), the large extruder differs from the small extruder in a few ways. First of all, the extruder has a built-in compounder. This allows additives, such as chalk, to be added to the material more easily, as they will be homogenously mixed with the thermoplastic granulate. The system also dries the material within the printer, thereby integrating this step into the production process in a more efficient way. Furthermore, the torque of the extruder can also be directly adjusted, giving the user more control over the flow of the material. Unlike with the other printer, the extruder is not directly attached to the nozzle, but connected with a 6m tube. This causes the degradation time of the material to be more important. If the material degrades before it reaches the nozzle, the print will not succeed due to the material burning. Besides this, the printer has a fan mounted on the roof above the print bed, which is needed to dry the material during the print. This becomes more important when using the larger nozzle, as the thicker walls have longer cooling and drying times due to higher internal temperatures.

2.6.2 Results

Due to time and availability constraints at 10XL, only one test print has been performed with the larger extruder, using the bioHDPE compound. The choice for this compound will be explained in Chapter 4. Despite knowing the material is prone to shrinkage and warping, no chalk was added in this first print. The goal was to observe how the material would perform on the large extruder compared to the small extruder. The design that was chosen was one of the seating components from the final design described in Chapter 4. It was printed on a cold print bed, with a fan turned on from above. During the printing process, the torque settings were changed to find the configuration with the best material flow.

However, after printing three layers, the print was stopped due to a failure. Other technical difficulties prevented the printer from being used again that day. The material flow was consistent, but the surface finish was very rough and inconsistent. This was a surprising result compared to the smooth surface finish from previous tests on the small extruder. In addition, the print was already warped loose from the print bed on both corners of the design. In future prints, chalk needs to be added to reduce this shrinking effect.

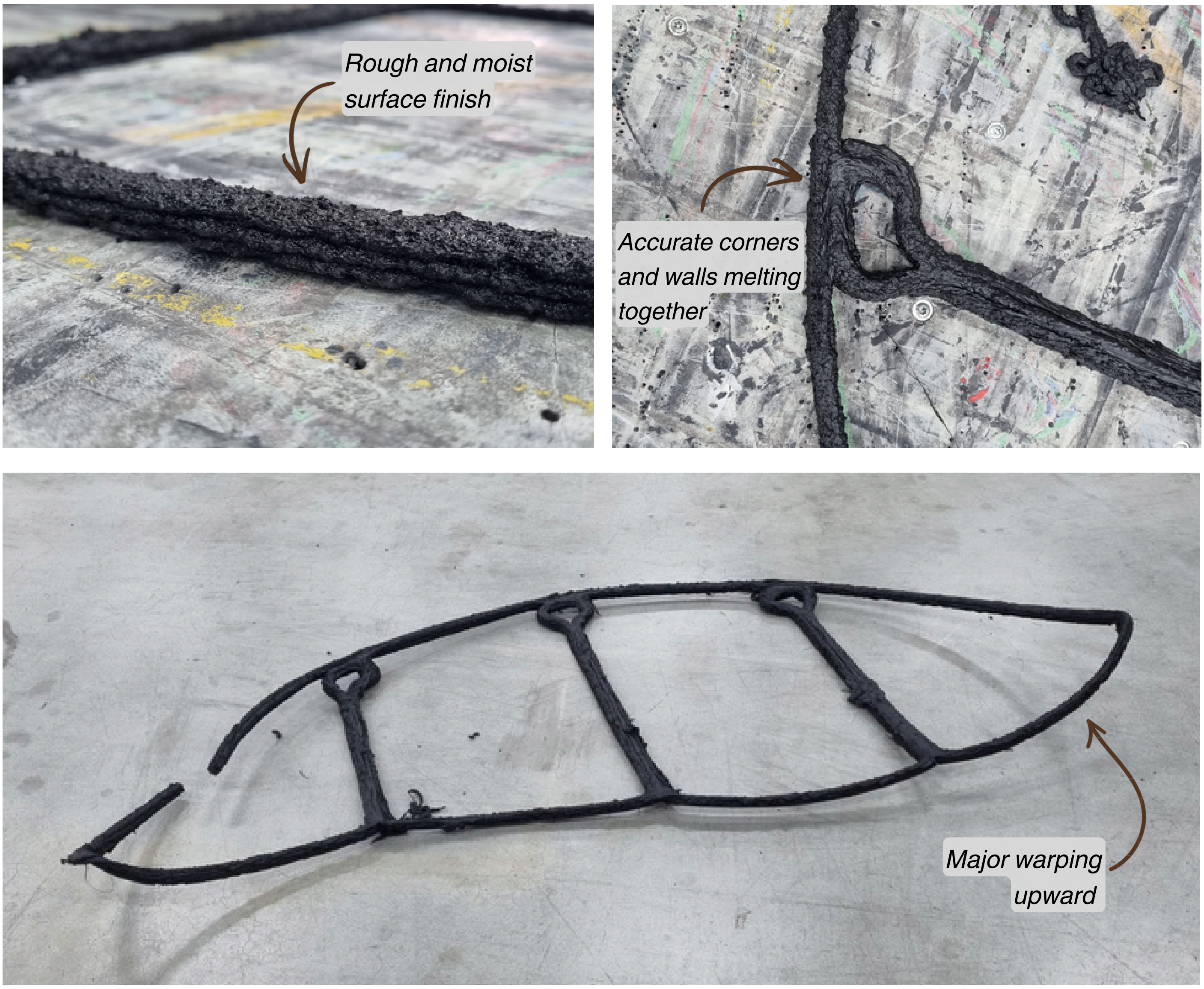


Figure 41: Print results of first test on the large extruder

3. DESIGN EXPLORATION

While exploring most of the material and printing qualities, the design phase also started. The interests of the relevant stakeholders were analyzed, which led to a range of ideas. These ideas were then refined into three concrete concepts, which are presented in this chapter. These concepts were shared with the relevant stakeholders, after which one concept was selected and further developed.

3.1 Exploring the design: Method

This exploration phase started with an analysis of the stakeholder interests, which mainly consisted of desktop research into the current clients of Coffee Based, combined with existing data received from colleagues at Coffee Based. The clients that were analysed were KRS clients, as the interests of Het Ooievaarsfonds were already known before starting this project. These are mapped out in the figure below. Connected to each category are main interests for possible product usage, and already some directions for design ideas. Despite many of these KRS clients desiring an indoor product, this research is focused on creating an outdoor product. An object with possible future indoor potential would, however, thus be favorable.

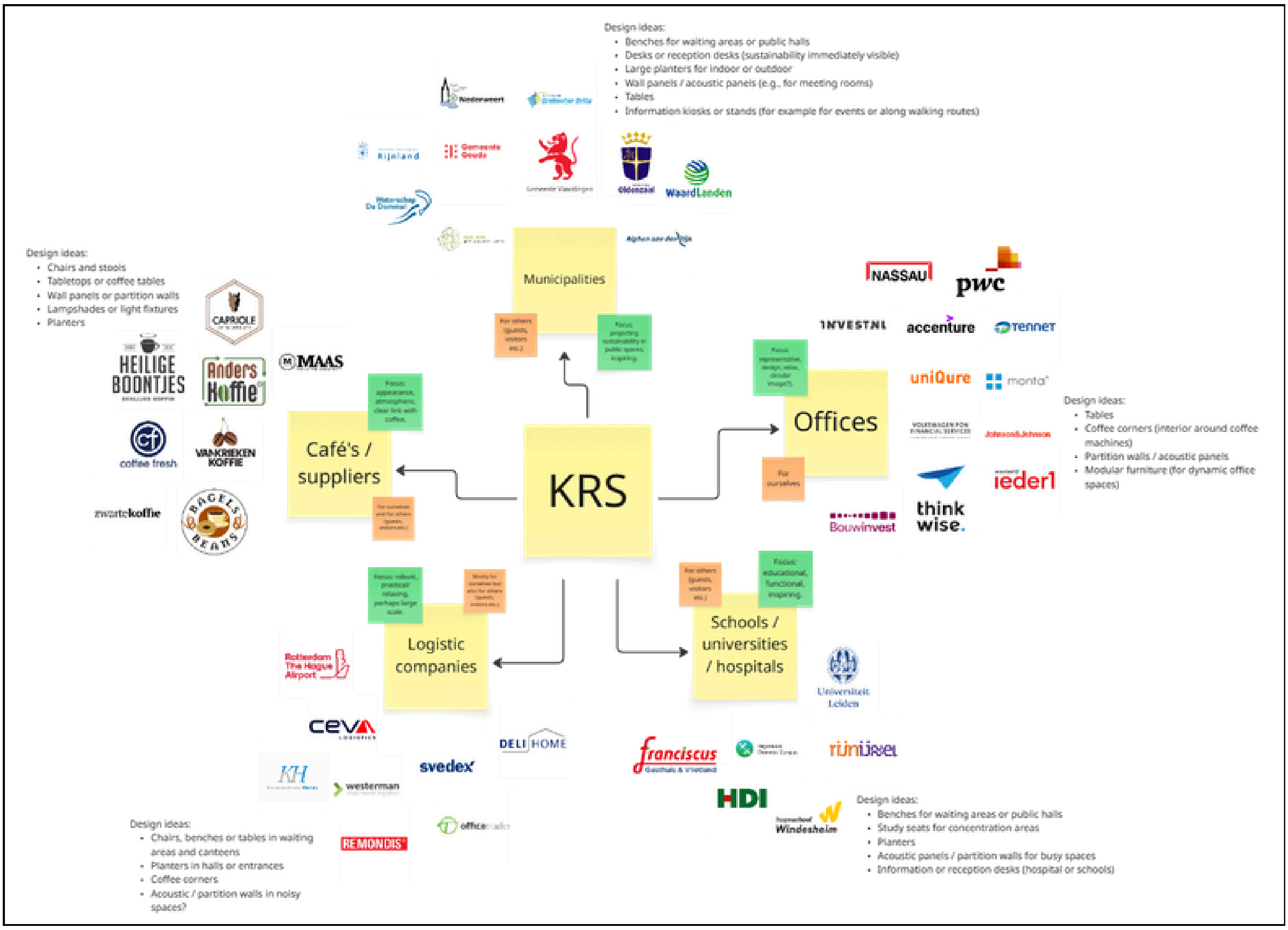


Figure 42: Mapped out KRS client analysis

3.2 Exploring the design: List of Requirements

Through research, print tests, and stakeholder analysis, requirements are formed. These can be divided into three categories: Public and outdoor use, Functional and technical constraints, and Product identity and communication. Each requirement is explained in the right column of the tables.

3.1.1 Public and outdoor use

Requirement	Explanation
The design must be suitable for intensive public outdoor use.	The product is placed in public outdoor spaces and must withstand rough or improper use.
The design must be vandalism resistant ("hufter proof").	The design should resist intentional misuse without critical damage.
The design must be theft resistant.	The design must be fixed to its location or be very difficult to remove.
The design must be weather resistant.	The design must withstand rain, frost and temperature fluctuations. (UV exposure is accepted)
The design must have an outdoor durability baseline.	If the design is durable enough to withstand outdoor conditions, it will also withstand indoor conditions.
The design must meet basic public safety standards.	The product must have no sharp edges, splintering, or unstable elements.
The design must have an expected lifespan of at least 5 years.	Replacement or renewal of the product within 5 years would be economically and environmentally undesirable.

Table 3: List of requirements: Public and outdoor use

3.1.2 Functional and technical constraints

Requirement	Explanation
The design must support a minimum load of 3000 N (~300 kg).	The seating must safely support at least three adults (~100kg) simultaneously.
The design must be modular.	Modularity enables customization, scalability, repair, and adaptation to different locations.
The design must include seating and integrated space for plants.	The product combines a seating function with greenery.
The design must be safe for plant growth.	Materials must be non-toxic and not harm the plants or the soil.
The design must fit within a maximum volume of 2 × 2 × 1 m (L × W × H).	This is the maximum printable size of the available LSAM printer.

Table 4: List of requirements: Functional and technical constraints

3.1.3 Product identity and communication

Requirement	Explanation
The design must align with the existing Coffee Based products.	The product will be sold by Coffee Based and should visually and conceptually fit their portfolio.
The design must clearly communicate its material origin.	The material is central to the identity of the design and should be recognizable to users.
The design must include an informative sign.	The sign must communicate information about the bench, the supported project, and Het Ooievaarsfonds.

Table 5: List of requirements: Product identity and communication

3.3 Exploring the design: Concept Development

The purpose of the concept development stage is to design an outdoor furniture object, using LSAM with the coffee-based compounds. The ideation phase started with a brainstorming session to explore possible furniture directions. To visualise, moodboards were created about in- and outdoor objects and already existing LSAM furniture objects. It was important that the ideas would fit or make use of the qualities that came out of the exploration. This is, however, a criterion that is not accounted for until the concepting phase, as these phases were paralel.

3.2.1 Ideation phase

One of the most important criteria the product should have is the association with coffee. Based on the association of the darker colour of the material and the rougher, irregular texture of a coffee bean, the same kind of shape can be implemented in the concept. The strength of the material also allows for weight-bearing constructions, such as benches or chairs, aligning with the interest of one of the stakeholders, Het Ooievaarsfonds.
The material exploration phase also showed that printing the model in multiple smaller parts results in less print failure. Besides, when a part fails, not the entire object needs to be printed again. Applying this knowledge to the interests of the stakeholders, modularity in the design is also desired.

3.2.2 Inspiration

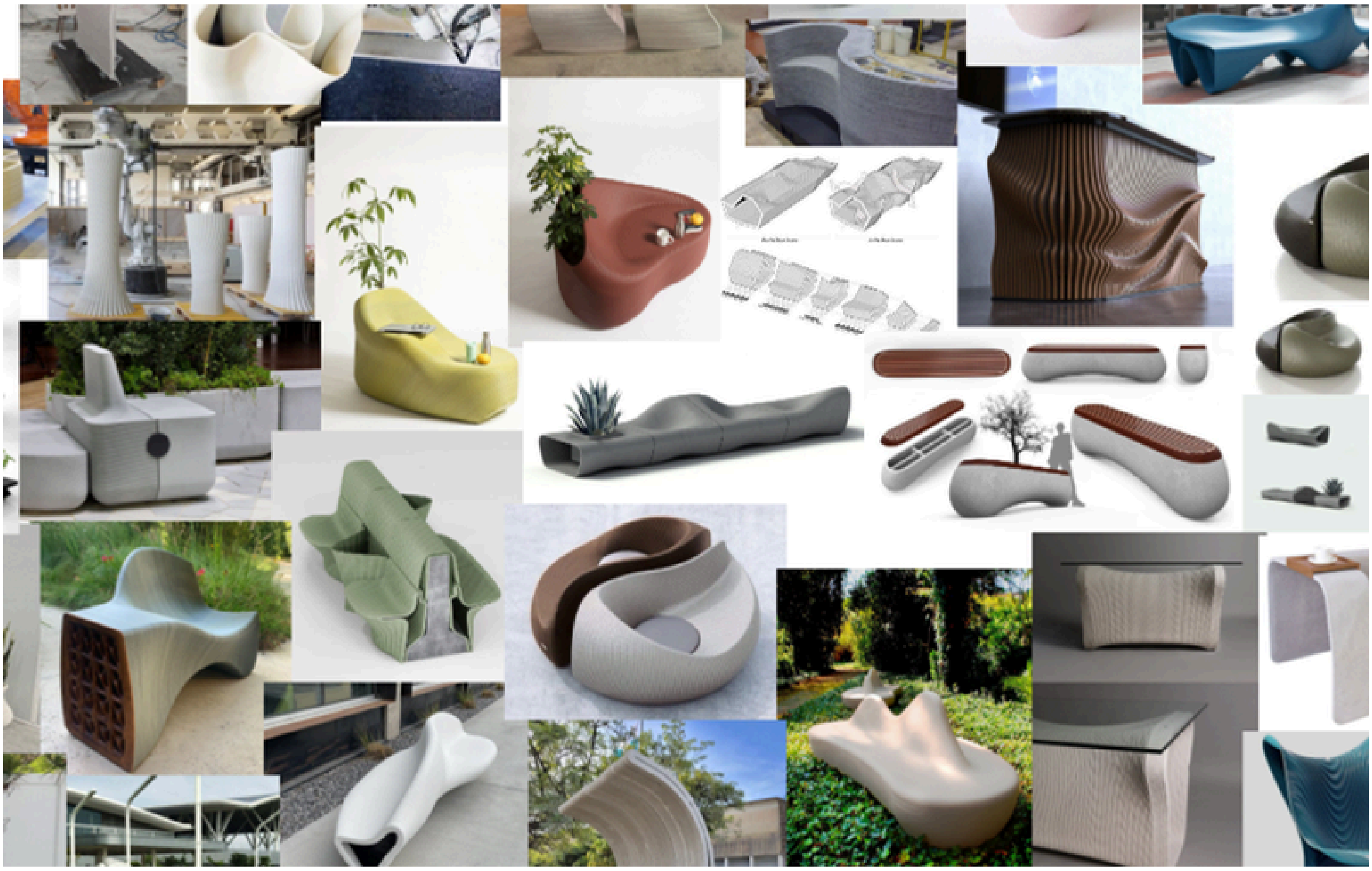


Figure 43: Inspiration moodboard

3.2.3 Concepting phase

From the insights and inspiration, many ideas were created, some of which were printed small scale in regular PETG and shown in Figure 44. Printing the models helped visualise the ideas, to immediately create a ‘feel’ for the designs, which helped in the brainstorming of iteration steps. In collaboration with Coffee Based, the ideas were reduced and combined into three main concepts: the Modular Bean, the Organic Bean, and the Modular Pods. These will be described in the following chapters.

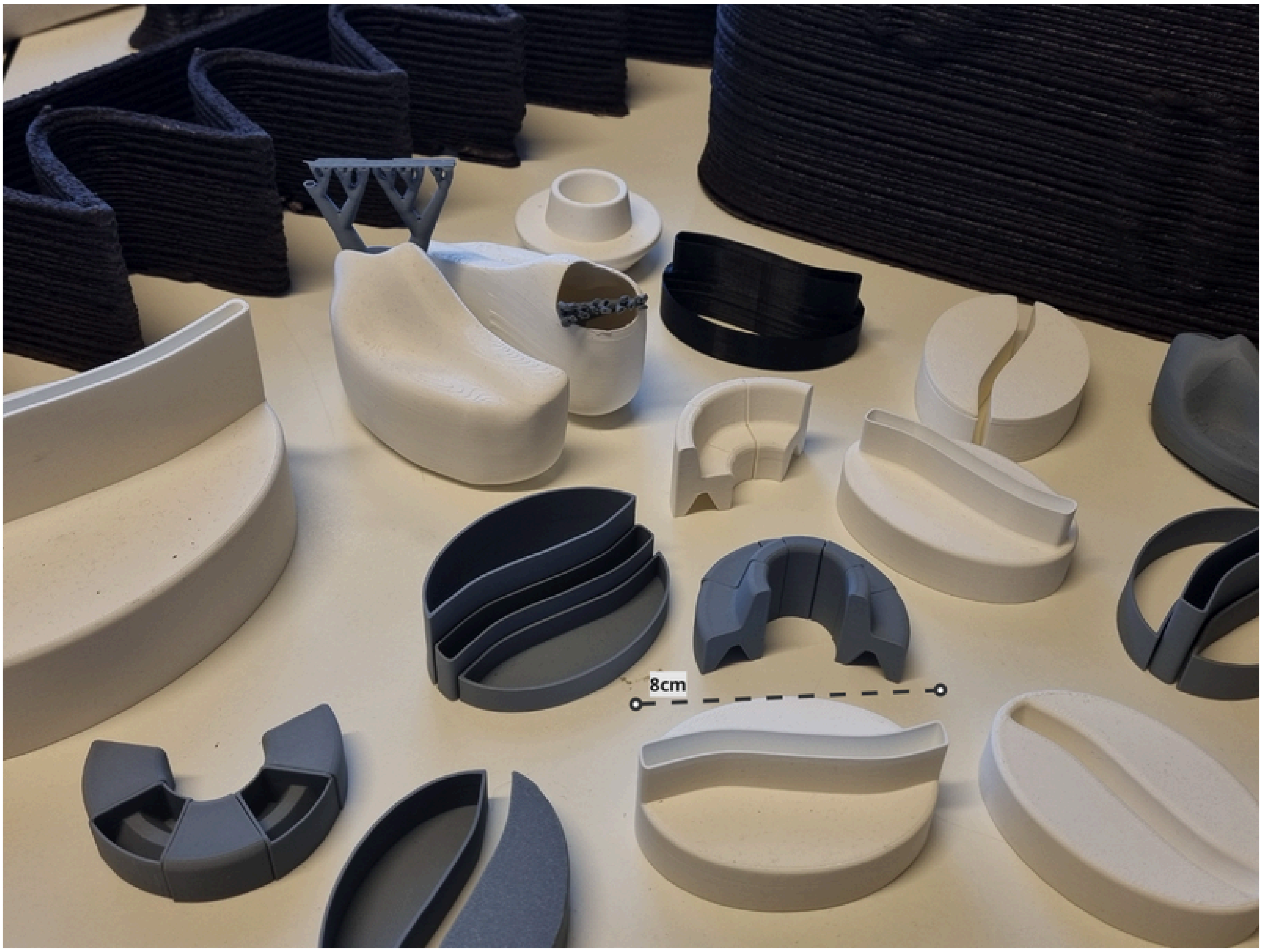


Figure 44: Printed ideas from regular PETG at scale 1cm : ~23cm

Concept 1: Modular Bean

Figure 45: Printed models of concept 1

The first concept is (coffee) bean-shaped and functions as a 3-part couch. It contains 2 seating areas, on each side of a curved plant box in the middle. The seating area will be made out of wooden beams. Feedback on the material (texture) showed that sitting directly on the material is not desired. Besides that, many public furniture objects, such as the products from Streetlife (2025), also combine a wooden seating area with a base from another material.

The object will be printed in three separate parts, allowing for modularity (figure 46). Clients can customize the design in height, if desired.

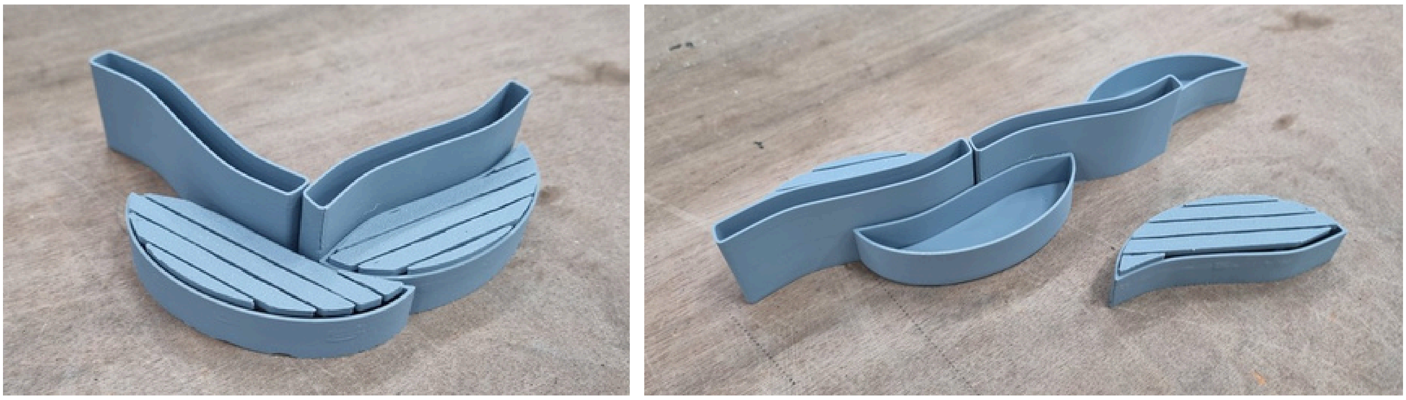


Figure 46: Modularity of concept 1

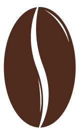
Price:	
Customizability:	
Modularity:	

Concept 2: Organic Bean

Figure 47: Printed models of concept 2

Figure 48: Seat separate from 3D print

The organic bean is a more 'artistically' shaped couch, where two couches resemble the shape of a coffee bean. This design aligns with the already existing products from Coffee Based and the organic look and feel of the material. At the top of the couch, there is a large opening for plants. The design is large and quite complex to print, causing it to be more of an artistic object. This association was confirmed by client feedback. The price is therefore estimated to be the highest out of the three concepts. Modularity in the design is low. The seating area will be separate from the rest, and will be made out of wooden beams, unlike what the 3D print in Figure 48 shows.

Price:	
Customizability:	
Modularity:	

Concept 3: Modular Pods

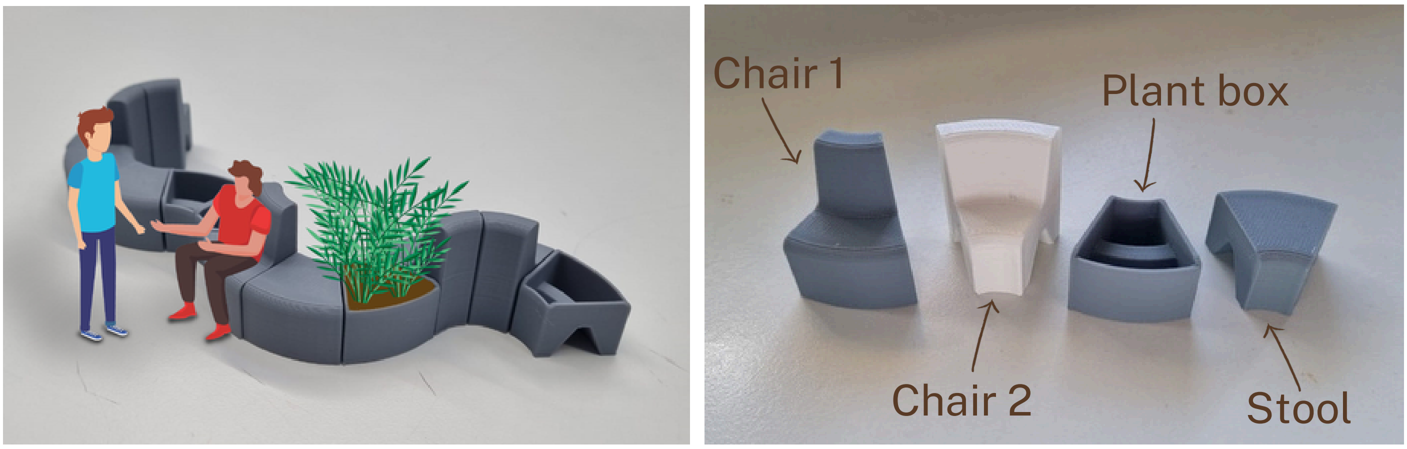


Figure 49: Printed models of concept 3

The last design is centred around modularity. It is more small-scale than the other two concepts, where it consists of multiple 'modular pods', which can be connected in a way the customer desires. In this concept, there are four types of pods, stools, plant boxes, and two types of chairs.

A client could order the pods wanted and create whatever arrangement they want. The figure shows multiple colours; however, the pods will be the same colour for now.

The high level of modularity allows it to be perfect for organic offices, without fixed places. Because the design is smaller, the price of each pod will be lower than the other two concepts. The pods don't have a designed association with coffee, other than the material they are made of.

Figure 50: Combination of all 4 types

Price:	
Customizability:	
Modularity:	

3.4 Exploring the design: Evaluating concepts

The three concepts described above were presented to two types of stakeholders: a client from the KRS and a board member of Het Ooievaarsfonds. The primary aim of these user tests was to gather feedback on the designs and assess the stakeholders' interest in them, as well as to identify any necessary improvements. In addition, the sessions were used to get a better understanding of the stakeholders' values, supporting a well-informed decision between the concepts. The interview questions used can be found in Appendix 4.

3.3.2 General conclusions feedback sessions clients

From the KRS client

The feedback session with the KRS client (a university) showed a clear preference for the **Modular Bean** concept, for its attractive design and strong connection to coffee through the shape resembling a coffee bean. The **Organic Bean** was also seen as appealing but more niche, fitting mainly natural or specific interiors or exteriors. The **Modular Pods** were considered fun, yet less distinctive due to similar existing designs. For this client, desired placements for the products would include coffee corners, reception halls, offices, and some outdoor spaces, with moveability being a key requirement. The products must be movable but not too easily displaced by their students. Greenery and subtle references to coffee were desired. Other important concerns include fire safety certifications, material safety for plants, durability, cleanability, weight, drainage, and the possibility of color customization. Overall, the product should function as an eye-catcher that visibly communicates the environmental ambitions of the client.

From Het Ooievaarsfonds

The second feedback session was with Het Ooievaarsfonds. As signage is an important requirement of this stakeholder, this session is slightly more focused on that. The **Modular Pods** were received very positively, especially their modular use and collectability. The **Organic Bean** ranked lowest, as it felt less clearly connected to coffee and was harder to place in general environments. The **Modular Bean** design was marked as the clear favorite, again due to its attractive design and strong coffee-bean reference. A positive remark was the combination of seating with planting. A possible addition would be a trash bin. For Het Ooievaarsfonds, modularity is not essential but considered a nice extra. Color variation and natural UV fading were viewed positively instead of as a problem.

The design of the sign should also be coffee-related, according to the client. It should be visible, yet not too distracting. In short, the product should also function as an eye-catcher in the outdoor areas, telling a sustainable story on an information sign nearby.

3.3.1 Sign design

A key requirement from Het Ooievaarsfonds was the addition of a sign informing the reader about the organization and its supported project, and the bench itself. Designs were made that add a sign to the existing design of the Modular bean (see Appendix 5). These first designs were then presented to Het Ooievaarsfonds and Coffee Based colleagues for feedback, resulting in the refined sign designs shown in Figure 51.

An important insight from the feedback session was that the sign should be integrated into the overall design, rather than being a stand-alone or obligatory addition. They also mentioned that the users should be able to read the information on the sign when they are seated.

The designs from the figure below were evaluated in a small-scale feedback session with fellow students. When asked to pick their preferred option, number four was selected most often. In future research, these designs should also be presented to Het Ooievaarsfonds again to receive their feedback.

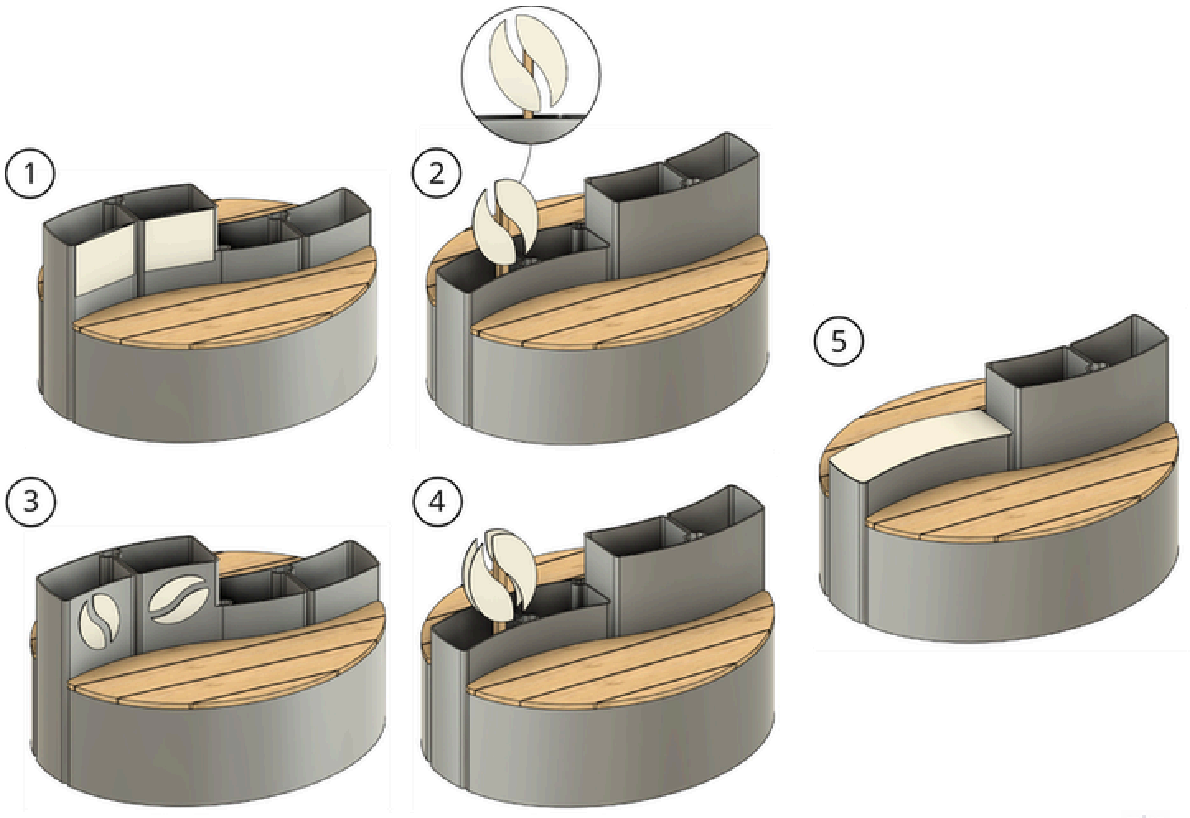


Figure 51: Designs of the signs

3.5 Exploring the design: Conclusions

Taking the conclusions from both feedback sessions into account, combined with a session with Coffee Based, the decision was made to continue developing the first concept: the Modular Bean, with sign number 4 in the image above. This concept best aligns with the shared preferences of the stakeholders, in particular concerning the visible coffee reference, and the possible use as a sustainable eye-catcher for both indoor and outdoor environments. The feedback also showed important design considerations related to practical requirements such as fire safety, moveability, and cleanability, as well as the design of the signage. These insights form the basis for the development of the final design, which will be addressed in the following chapter.

4. FINAL DESIGN | THE BOONBANK

Figure 52: Final design of the Boonbank

4.1 Final Design: Overview

The final design, the Boonbank, is based on the earlier Concept 1: the Modular Bean. As described in that chapter, its form resembles the shape of a coffee bean. This visual reference helps the user associate the product with the material it is actually made of by just looking at it.

The Boonbank is a three-part modular bench, consisting of two identical seating elements with a swirl-shaped planter in between. Connected to it is an information sign, informing the user about Het Ooievaarsfonds, the surrounding area, and the Boonbank itself. In addition to the use of sustainable and biobased materials, the choice of local production contributes to the overall sustainability of the design.

The current design of the Boonbank is created for outdoor environments. As shown in Figure 52, the product will be positioned in natural settings, most likely along walking routes in the Alblasserwaard. The Boonbank is designed to offer users, primarily walkers, a 'sustainable moment of rest'. At the same time, they can learn about the environment, indirectly contributing to the brand awareness of both Het Ooievaarsfonds and Coffee Based. The product aims to invite users to pause and appreciate their surroundings, while sitting on a bench made from recycled coffee grounds; perhaps even while enjoying a cup of coffee themselves!

4.2 Final Design: Material

After investigating the three materials supplied by Coffee Based (SCG with rPP, bioHDPE, and TPS), the decision was made to continue with the SCG–bioHDPE compound. Although most tests were conducted using the TPS compound, its biodegradability makes it unsuitable for untreated outdoor applications. When comparing the results of the rPP and bioHDPE compounds, bioHDPE demonstrated more promising results regarding its consistency and shrinkage.
Both interviews presented in the previous chapter showed a concern towards the texture of the material. If the material has a rough surface, it is perceived as less inviting. This supports the choice of the bioHDPE compound, as it showed the smoothest surface among the three tested materials.

Another important reason for selecting the SCG–bioHDPE compound is its consistency with Coffee Based's existing material portfolio. This compound is used in nearly all of the company's current products, whereas the rPP compound was used in the past and would require the creation of a separate, custom material stream. It should be noted that the bioHDPE compound is slightly more expensive to produce than the rPP compound.

In addition, bioHDPE is biobased and created from renewable feedstock, which adds value to the product from a sustainability perspective. Material testing further showed that chalk needed to be added to compensate for the shrinkage of the material. This chalk is therefore mixed into the granulate within the printer, where it is compounded homogeneously into the material. To determine the percentage of chalk needed, further tests need to be performed on the large extruder.

4.3 Final Design: Components

4.3.1 Stability, height and geometry

The Boonbank has an open bottom to improve printability, water drainage, and simplify the overall design. As shown in Figure 53, the bench is partially buried in the ground to increase both stability and theft resistance. It also supports plant growth, as the open bottom allows roots to extend directly into the soil. Because the individual parts are each partially buried and partially filled with soil, each part of the Boonbank is difficult to move and therefore less susceptible to theft and vandalism.

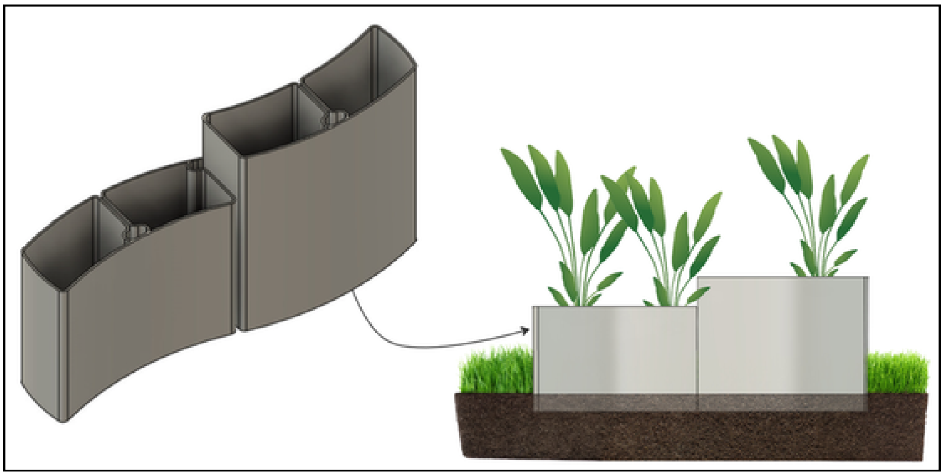


Figure 53: Model partially buried

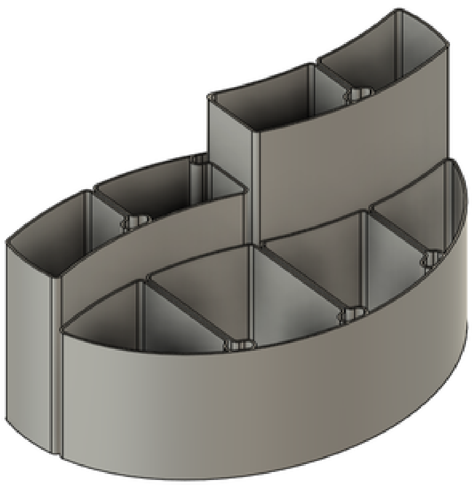


Figure 54: Model with connector ribs

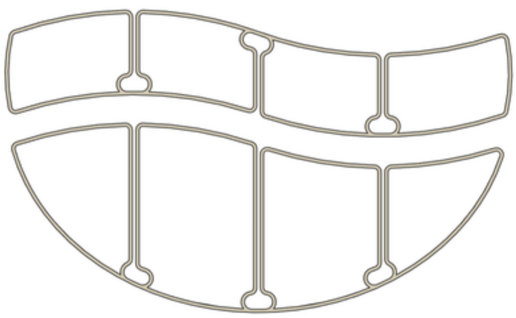


Figure 55: Model with connector ribs (top view)

The height of the two seating elements of the Boonbank was set based on ergonomic considerations. An optimal seating height ranges between 41 and 46cm (Güngör & Felek, 2023); for this design, a height of 46 cm was selected. Any additional height can be taken care of by embedding the bench into the ground. Assuming an embedment depth of 10 cm, the use of 3cm thick wooden planks, and an additional 1cm required to screw the print to the print bed, the two seating elements require a printed height of 54cm. The middle section was constrained by the printer's maximum height of 100cm; this dimension was therefore also applied to this part, resulting in a total height of 89cm above ground level.

Within the three components, internal 'connector ribs' are designed to provide structural stability during printing and, more importantly, during use. Without these ribs, the walls would be prone to sag outward when subjected to load, either from the dirt on the inside or users sitting on the bench. The design of these ribs is shown in Figure 55. Each rib is placed 40cm apart. According to 10XL, this will result in enough strength and stability for the print. It is said that this distance needs to be in a range of 30 to 50cm, where 40cm is the safest option.

Figure 56: Example of information on the sign

4.3.2 Information sign

Purpose:
One of the requirements set by Het Ooievaarsfonds was the inclusion of an information sign within the design. The primary aim of the Boonbank is to offer walkers in the Alblasserwaard a moment of rest. When seeingthe Boonbank, it should invite users to pause and take a seat. Ideally, while seated, users should be able to read the information sign, allowing them to enjoy the surrounding landscape while simultaneously learning more about what they see. These formed key requirements for the design of the information sign.
Additionally, the sign must provide information about the sponsored project (by Het Ooievaarsfonds), Het Ooievaarsfonds itself, and the Boonbank (See Figure 56 for an example of this). The Boonbank and the information sign should therefore stand out together and form a coherent product. This requirement has been integrated into the design of the sign by extending it above the bench and by giving it the shape of a coffee bean. In this way, users recognise the connection to the material from which the bench is made more quickly.
Returning to the requirement of modularity mentioned earlier, it is important that the information sign can be replaced or even removed entirely. For this reason, the sign and its supporting pole are designed as separate components from the Boonbank, making them easy to replace or detach when needed. The shape and information of the sign can be created on demand.

Technical aspects:
The information sign will be produced from a fully biobased composite made of cardboard and wood fibres sourced from sustainably managed forests (PEFC certified). The panel is UV-resistant, and the desired print is pressed into the material, making it “highly scratch-resistant, colourfast, and graffiti-resistant” (PressArt, 2026).
In selecting this material, multiple alternatives were considered, including aluminium composites, Trespa panels, plastics, and engraved wood. The primary factors guiding the material choice were durability and costs. Compared to alternatives, the cardboard and wood fibre composite offers a longer lifespan at the same cost, making it the preferred option.

4.3.3 Seating part

Purpose:
As described in the previous chapter on the information sign, the Boonbank should invite users to sit down and rest. The material of the seating surface plays an important role in achieving this. Previous studies have indicated that wooden surfaces "give a warm and friendly character" (Grabiec, 2022). In addition, feedback sessions showed that the texture of the current 3D prints is not perceived as inviting for seating and may even pose a risk of damaging clothing. Therefore, the seating surface is created with wooden planks.

Technical aspects:
The planks used for the seating surface are 300 x 20 x 3 cm and will be cut to the length and width of the curved seat. The individual planks are connected using crossbeams made with the spare material of the original planks. After assembly, the final seating shape is cut out so that it precisely aligns with the curved shape of the seat. During this process, the internal ribs of the 3D-printed structure should be considered, ensuring that the cross beams on the bottom do not collide with them. The production and connection method of the planks to the printed frame are described in Chapter 4.**X**.

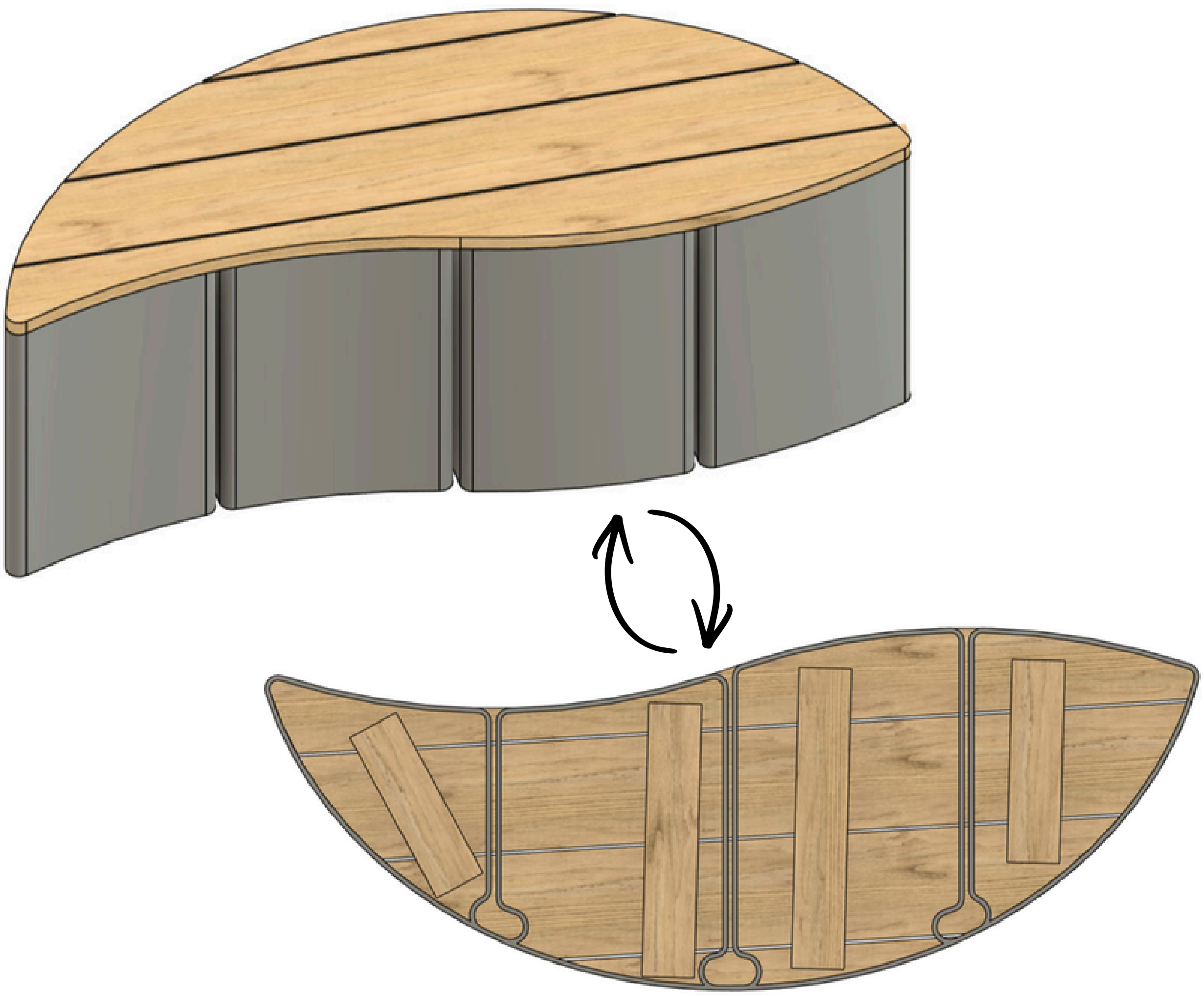


Figure 57: Wood seat

4.3.4 Planter swirl

As described earlier, the middle section is dedicated to greenery and will be filled with soil. Once printed, the material must be tested to ensure its water-tightness and its influence on plant growth. If this is not sufficient, the interior of the middle part could be lined with EPDM sheets. Because of the three internal ribs, it is divided into four separate compartments, ensuring stability and strength. Feedback sessions also showed interest in an integrated or separate waste bin. One of the outer compartments could potentially be adapted to serve this function in future designs.

Half of the planter swirl is lower than the other half. This makes the shape more dynamic and allows the placement of the sign at eye level of the reader once seated. The shape will still be printed at once, where the printer will continue with only the upper half after printing the lower part. Tests need to be done to ensure its capability to do so, taking the previously mentioned minimal layer time into account.

If desired, the two parts of the planter could be covered with wood planks. This is visualised for the lower half in the figure below.

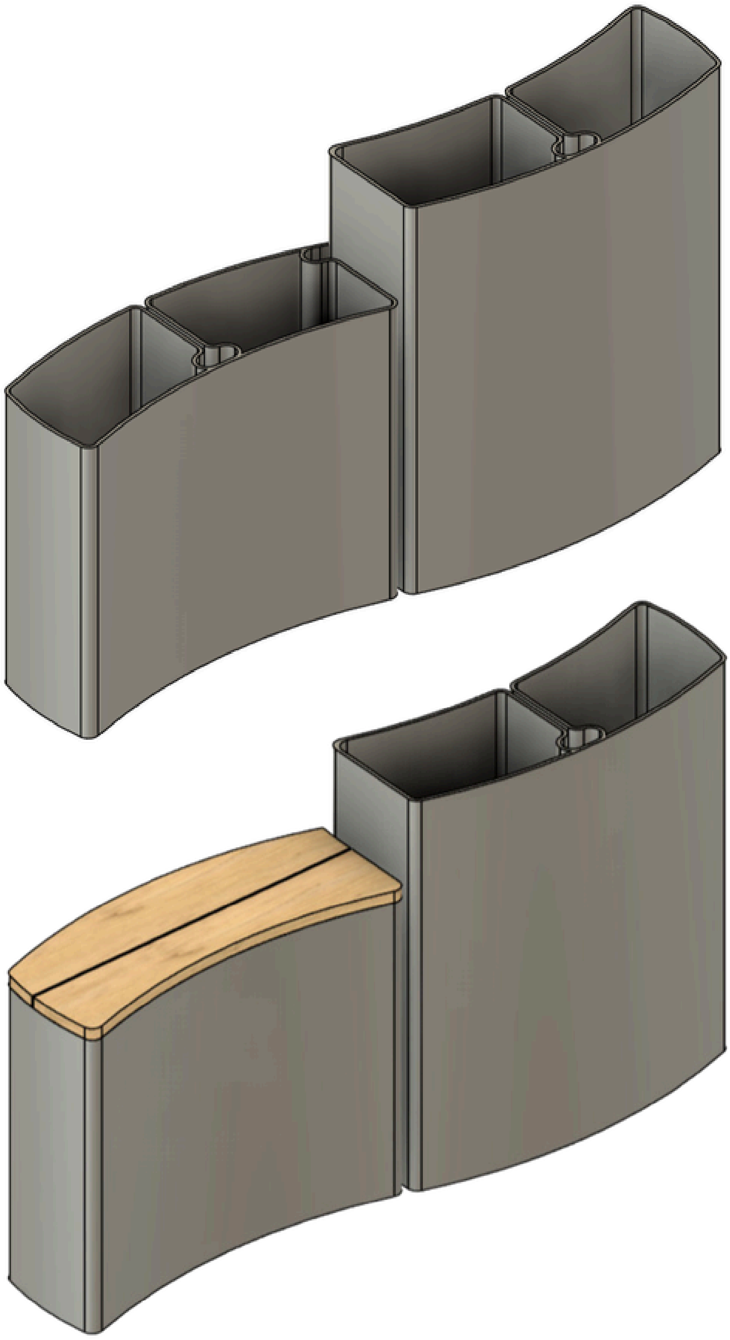


Figure 58: Planter swirl design, with and without wood planks

4.4 Final Design: Assembly

This chapter describes the production and assembly steps needed to create the current design of the Boonbank. It will first describe the assembly of the sign, then the production of the planks for the seating area and lastly the connection to the 3D printed structure.

4.4.1 Information sign assembly

The sign will be printed, pressed, and cut by the company PressArt and will be 8mm thick. Holes will be drilled through the sign, through which the sign will be connected to a wooden pole. Considering balancing, stability, and rigidity, this will be done with two screws for each part of the bean shape.

4.4.2 Seating assembly

The wooden seat is made from 3m of oak wooden planks. The cutting and assembling steps are visualised in Figure 59. The spare pieces are added as construction connector beams at the bottom. This way, the wooden planks are used most efficiently, attempting to have as little waste material as possible. The connector beams are screwed tightly to the planks from the bottom side to avoid screws in the seating area.
This wooden structure is then connected to the 3D printed frame by safety screws from the outside. These screws have specialized fasteners designed with non-standard heads to prevent unauthorised removal, theft, or vandalism. Fastening the wooden structure from the inside is not possible, as it needs to be dug into the ground and partially filled with dirt. By placing the screws on the side of the object, they hinder the user as little as possible. Screw holes need to be drilled after printing; this is how it is usually done, according to 10XL.

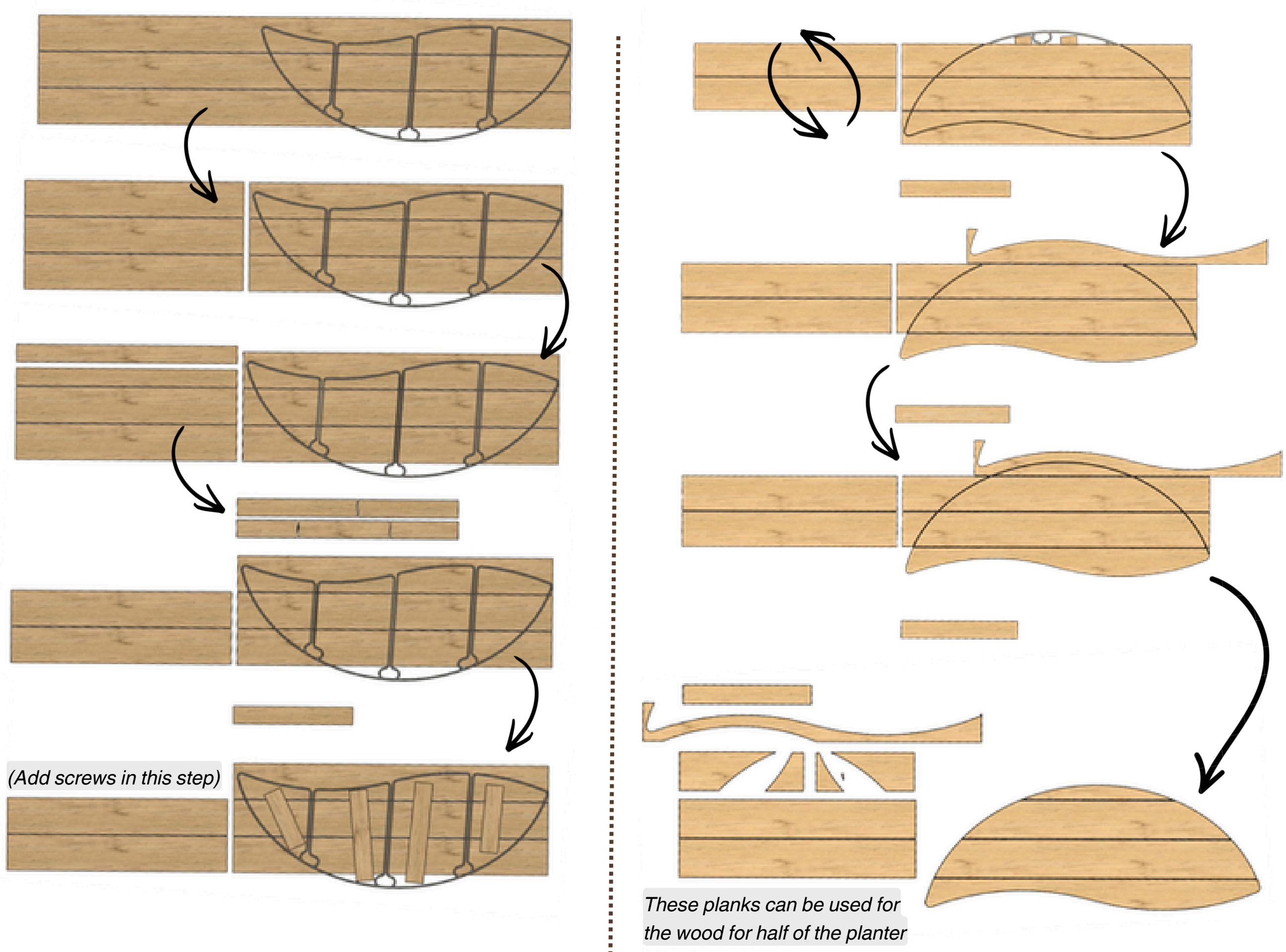


Figure 59: Assembly of the wooden seat

4.5 Final Design: Cost Estimation

The production cost per unit is estimated at around €4.000, for a batch size of 1, excluding two currently unknown cost factors. The cost calculation is shown in Table 6. Most cost factors are based on assumptions of the materials used. It consists of the costs of the actual 3D printing of the Boonbank, the production of the wooden seats, the information sign, the planting of the planter swirl, transport costs, and the purchase of all the necessary materials for all of this. The weight and actual size are estimated in collaboration with the knowledge of a 10XL worker, as the product is not yet printed. These costs could thus differ slightly. A precise calculation and explanation of all costs can be found in Appendix 6. These costs also include just the production and transport costs, without adding a profit margin for Coffee Based. For the customers of the Boonbank, the costs will thus be higher.

Some costs are still unknown, as the design of the Boonbank is not production-ready. An attempt is made to find the most information, but factors such as assembly costs and installation costs prove challenging to estimate. Depending on which company will, for example, assemble the seat, transport costs will change. Total costs can thus be roughly estimated between €4.000 and €5.000 euros.

Cost types	Costs
Production (10XL):	€1.200,-
Material (bioHDPE granulate):	€1.056,-
Transport (10XL - Coffee Based:	€162,-
Compost (dirt, incl. transport):	€107,-
Plants (incl. transport):	€85,-
Seat (oak wood, incl. transport):	€236,-
Sign (incl. transport)	€567,-
Screws, sign pole, etc.	€40,-
Transport to installation site:	€200,-
Assembly of sign and seat:	tbd
Installation of Boonbank on-site:	tbd
10% unexpected costs	€365,-
Total costs:	**~ €4.000,-**

Table 6: Cost estimation

4.6 Prototyping

As described in Chapter 2, a real-size model of the final design could not be created successfully with the large extruder. Therefore, two small-scale prototypes were created to give an expression of what the design would look like. The first one is made with PETG filament, on 10% scale. The wooden planks of this design are printed using Woodfill filament. The second prototype is 3D printed on the small extruder. It is printed with the TPS compound, but gives the same impression as the bioHDPE compound, except for the texture. The creation of the wooden planks resembles that shown in Chapter 4.3.3.

4.6.1 Regular 3D printed prototype

Instead of just visualising the seat like the other prototype, this one aims to visualise the design as a whole. It shows the combination of all elements, presented at 10% scale. The grey color of the print does not resemble the actual color of the coffee material. As said before, the wooden parts are made using woodfill filament to resemble the actual look and feel of that part of the design. The sign is also 3D printed to visualise its position within the overall design. The height of the seat looks a bit high; this is because it needs to be partially embedded into the ground.

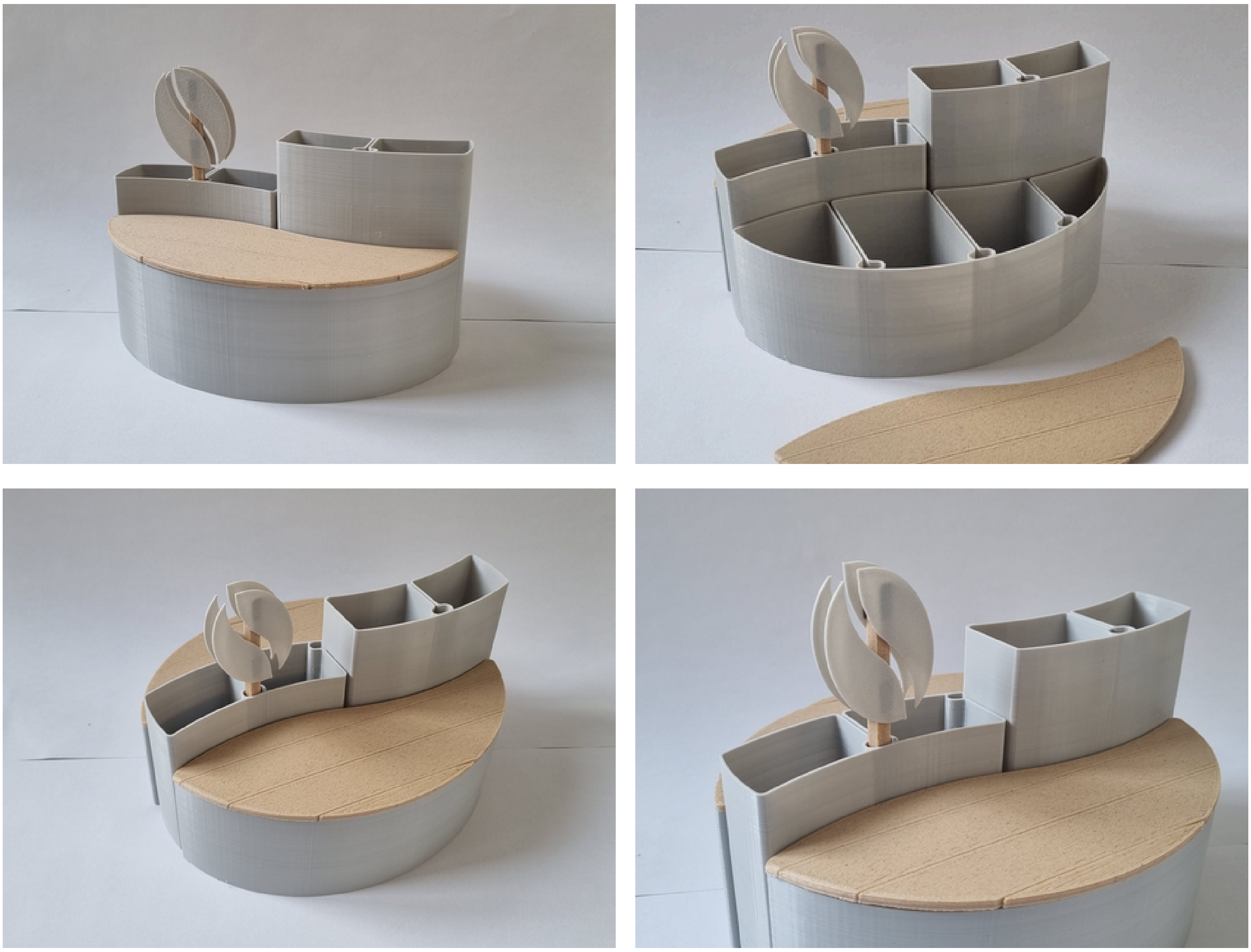


Figure 60: Regular 3D printed prototype

4.6.2 3D printed prototype on small extruder

This prototype was primarily developed to visualize the seating element of the final design. As mentioned earlier, the 3D-printed frame was produced using the TPS compound instead of the bioHDPE compound, due to logistical constraints at 10XL. For the same reason, the middle section of the design was not 3D printed.
The wooden seat was fabricated from a 1.2m oak beam. This beam was first sawn into planks using a table saw. The planks were then cut into the required shapes, as well as into the cross beams, using a jigsaw. Further production photos can be found in Appendix 7. Achieving an accurate alignment between the wooden seat and the 3D-printed frame proved to be a challenge. To help with this, a cardboard template was created to trace the correct contour. For the full-scale design, a similar template or mold will be necessary to ensure precise shaping when using a jigsaw. If a CNC or a laser-cutting machine is used, this would be easier.

Figure 61: 3D printed prototype on small extruder with wood seat

4.7 Validation

4.7.1 Feasibility

The feasibility of the Boonbank includes whether this design can be realistically produced, manufactured, installed, and used as designed. The shape of the bench has been designed to fit the discussed technical limits of Large Scale Additive Manufacturing (LSAM). The rounded shape avoids strong overhangs, bridging, and sharp corners that could decrease the print quality. Its wall thickness and internal rib structure ensure enough strength and stability for seating.
The choice of material also affects the feasibility of the design. The selected coffee-based bioHDPE compound shows enough strength when printed at a small scale, let alone at a large scale. The bench is designed as three modular pieces, making it easier to transport. Because the design has an open bottom, less material is needed. It also allows it to be partially embedded into the soil. This improves stability without needing extra and complicated anchoring systems, making it cheaper, more sustainable, and easier to place on-site. Besides this, the open bottom also improves root growth in the middle part of the design.

4.7.2 Viability

The viability of the Boonbank is connected to its financial and strategic value as a final product. Unlike injection-molded objects, the Boonbank does not need an expensive mold, making small production runs financially possible. So even though the LSAM technology takes longer and consumes more energy, the ability to adapt shapes makes up for these issues if the batch size is limited. The design and production method (LSAM) also allows for customization or easy context-related changes (e.g. in-/outdoor). Its sustainable value is also in line with Coffee Based's focus on circular, narrative-driven products.
This said, the Boonbank is an example of material innovation, which increases its value for the clients and partners of Coffee Based, such as Het Ooievaarsfonds. Its modularity allows each client to place the product in a different configuration, enabling them to personalize it into a unique setup, without Coffee Based having to make a redesign.
For the Boonbank, viability does not rely on a large-scale commercial production; instead, it depends on its strategic placement in sustainability-related public projects, where storytelling, circularity, and (material) innovation are important.

4.7.3 Desirability

The desirability of the Boonbank is caused by its shape, materials, and design. The bean-shaped form of the bench, as well as the sign, clearly shows its coffee roots, creating a direct link between its material and shape.
The addition of the plant swirl in the middle improves the experience by supporting small-scale biodiversity. The plants, combined with the smooth and rounded edges, can also invite and encourage people to sit on it. The information sign is merged into the design, rather than added on, so it does not feel like two separate objects. The information sign allows users to learn about the object they are sitting on and its environment. The Boonbank thus serves both as public furniture and a way to communicate.
The look of the product also adds to its desirability. The visible 3D-printed layer lines add value by showing how it was made.
The Boonbank thus represents more than just a seating object; it shows how innovative, biobased materials can be used in public spaces, while educating the user about the companies and the object.

5. DISCUSSION AND RECOMMENDATIONS

5.1 Discussion

This project contributes to a relatively underexplored area of design: the application of Spent Coffee Grounds (SCG) composites in Fused Granulate Fabrication (FGF) in the area of Large Scale Additive Manufacturing (LSAM). While literature discusses SCG in small-scale filament-based 3D printing, little research addresses its behaviour within the LSAM technology. By experimentally testing shrinkage, overhang, bridging, dimensional accuracy, and other print parameters, this research begins to fill that gap.

In doing so, one key observation was the difference between theoretical material properties described in literature and the practical print behaviour when printing at a large scale. While studies, for example, report nucleating effects, low shrinkage, and an improved flow of SCG composites, practical printing revealed challenges such as nozzle clogging, inconsistent extrusion, and high shrinkage.
In LSAM, small inconsistencies in granulate homogeneity or flow also tended to have a great impact due to the continuous extrusion of the technology. The addition of chalk to a compound is a common practice in LSAM to counter the shrinking effect. However, the manual mixing of chalk into the compounds, for example, likely contributed to extrusion inconsistency and variations in dimensional accuracy of both the bioHDPE and rPP compounds. This suggests that some observed limitations are not inherent to the use of SCG composites themselves but are linked to, for example, compounding quality.

Another important observation is the so far observed difference between the success using the small extruder and the large extruder. While the small extruder provided relatively stable results and a smooth surface finish, the initial test on the large extruder resulted in a rough surface finish. This highlights that scaling in additive manufacturing is not linear, even though 10XL claimed it to be. For example, thermal mass and cooling dynamics differ significantly, requiring a different optimization rather than a simple parameter change or scale transfer.

Regarding sustainability, trade-offs needed to be made. TPS offered good print stability and minimal shrinkage, but raised concerns regarding long-term outdoor durability. BioHDPE aligned better with durability and the product portfolio of Coffee Based but required more technical intervention to control shrinkage. A trade-off needed to be made between environmental ambitions and printing feasibility.

Furthermore, this research focused primarily on print quality and geometric feasibility, rather than long-term mechanical testing and environmental effects on the material. Literature shows that anisotropy and porosity are inherent to LSAM, and these characteristics may influence the product under repeated loading. Without extended testing, conclusions about the structural lifespan remain uncertain.

The scope of experimentation was also limited by printer availability and time constraints. Not all material and nozzle combinations were tested equally, and some print quality tests had lower sample sizes. This reduces statistical strength and needs further validation. Nevertheless, the iterative tinkering process that was possible provided valuable insights into the use of SCG in the LSAM technology.

During this project, two trajectories were developed simultaneously: a material exploration and a stakeholder-driven design process. Due to time and logistical constraints, these trajectories continuously informed each other, instead of happening sequentially.
Material exploration defined the boundaries of feasibility within the design. Design exploration then tested whether meaningful and desirable products could exist within those boundaries. Conversely, stakeholder values and interviews influenced material choice. For example, surface smoothness and how the quality is perceived influenced the decision to continue with the bioHDPE compound rather than the rPP compound, despite having similar technical challenges.

Running both trajectories in parallel strengthened the project's relevance but also caused complexity. Design ambitions occasionally had to be reconsidered in light of technical constraints, while technical optimization had to account for user perception and sustainability choices. These trade-offs are common in research-through-design: knowledge is not only received from actual testing but from the combination of feasibility, desirability, and viability.
The Boonbank is an attempt to combine all results. However, full validation at a large scale remains incomplete due to limited access to the large extruder.

5.2 Recommendations

This research demonstrates the potential of coffee-based granulate in Large Scale Additive Manufacturing, while also revealing technical, material, and design-related limitations that require further development before reaching the actual implementation phase.

Material and technical feasibility

First, further research into reducing shrinkage is recommended. While adding chalk showed potential in reducing this, systematic testing of filler percentages (and possibly other additives) could lead to improved dimensional accuracy.

Long-term outdoor performance testing is also required. Since the intended application of the Boonbank is exterior public space for at least five years, tests regarding weather and UV resistance should be conducted. This would clarify the durability of SCG–bioHDPE composites and assess whether protective coatings or other surface treatments are necessary. The ongoing test regarding the biodegradability of the SCG-TPS compound should also be continued. For now, it has just been two weeks outside, which does not provide accurate data. If the compound shows a low biodegradability rate after a long time, it has the potential to be used instead. However, research must be performed in ways to simulate this, as there is not enough time to leave it outside for several years.

In addition, validating the technical feasibility of the large extruder is crucial. The discrepancy between the small extruder and the initial large extruder results shows that the scaling step introduces new thermal and/or mechanical variables. More tests are needed on this large extruder to optimize the parameters.

Print tests and guidelines

The research shows that the design of the geometry and process parameters is inseparable in LSAM. Therefore, future work could formalize design-for-LSAM guidelines specific to the Coffee Based composites. These could include validated maximum overhang angles, recommended temperatures, flow rates, advised layer times, optimal bead widths, and preferred corner radii. Some of these tests are already performed, but as said before, not with all compounds and not the same number of test samples.

Design Development and Validation

While the Boonbank shows a translation of the material constraints into form, further validation with a full-scale print is recommended. This would allow further evaluation of surface finish, dimensional accuracy, assembly, and mechanical performance under load. Structural testing should be conducted to verify its load-bearing capacity. Because it is a non-standard material, digital analysis of this is insufficient. Testing it with a large-scale 3D printed sample would strengthen the technical credibility of the design.

From a usability perspective, user observation and testing of the full-scale prototype would provide insight into ergonomics, perceived comfort, and ways of interaction. Interviews conducted during the design phase informed conceptual decisions, but an evaluation with a real-sized prototype would validate these assumptions in practice.

Practical and logistical

Other practical recommendations include investigating the current logistical uncertainties surrounding the assembly and installation. Future research should be performed on how all the different components of the Boonbank would be transported, positioned, and assembled on site. Finding suitable partners for installation, such as social workshops, landscaping companies, or other specialized placement services, is necessary to determine the feasibility of the design. A preliminary cost estimation of transport, assembly, installation, and required equipment would provide further insight into the economic viability.

Addressing the recommendations related to the material research inherently influences the ongoing design exploration. However, the current design should also be presented to Het Ooievaarsfonds. Their feedback can validate whether the Boonbank aligns with their expectations, values, and desires. Incorporating this feedback (together with the insights from the material research) allows the iterative research-through-design process to continue. In this way, material and technical refinements and design development continue to support one another, gradually moving the project and design toward a higher technical and contextual level.

Concrete next steps

This project positions the designed Boonbank as a demonstrator of potential, rather than a finalized and production-ready product. The visual on the right shows the following concrete and essential next steps towards reaching this 'industrial readiness':

1. Researching how to get a consistent material supply.
2. Large extruder parameter optimization.
3. Structural and durability validation for outdoor standards.
4. Desirability validation with Het Ooievaarsfonds.
5. Economic feasibility assessment.

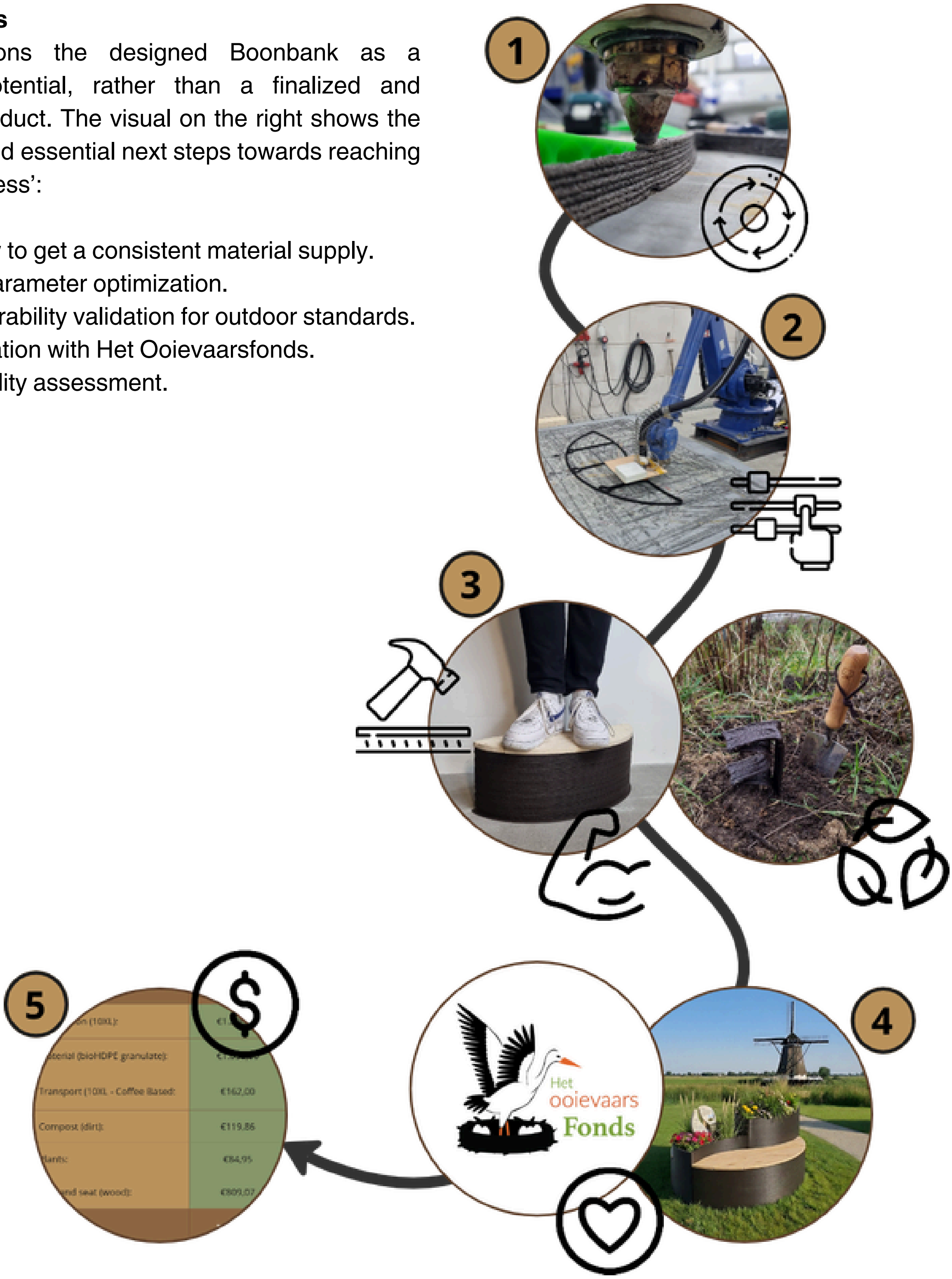


Figure 62: Concrete next steps visualized

6. CONCLUSION

This research aimed to explore and demonstrate the potential of coffee-based granulate for furniture applications through Large Scale Additive Manufacturing (LSAM). It was performed in collaboration with Coffee Based and 10XL. It involved collaboration with Coffee Based and 10XL. The project assessed print quality and evaluated the influence of different print parameters. The goal was to turn these insights into a valuable large scale 3D-printable design for outdoor furniture. Simultaneously, a parallel design path was followed to convert these technical findings into a meaningful prototype that aligns with the needs of stakeholders.

The results show that the three coffee-based compounds (with rPP, bioHDPE and TPS) can be processed using LSAM, but their suitability strongly depends on the printing configuration. Among the tested materials, the SCG-TPS compound demonstrated the most stable and predictable behaviour during printing. It showed minimal shrinkage (average below 0.5%), proper bed adhesion without additional fixation, and consistent dimensional accuracy. With the compound, overhang angles up to 40 degrees proved reliable, and even 45 degrees was occasionally successful. Bridging, however, was unsuccessful in multiple tests and cannot be considered a feasible design strategy within the current LSAM FGF (Fused Granulate Fabrication) setup at 10XL. Nonetheless, the biodegradability of the TPS compound limits its suitability for long-term outdoor use in public furniture. Besides this, due to extrusion inconsistency, a stable surface finish and layer adhesion proved a challenge with the compound.

The SCG-bioHDPE compound also demonstrated potential, but required additional measures to manage shrinkage and warping. Even when chalk was manually mixed into the compound to counter the shrinkage, the shrinkage values still ranged between 2.4% and 9.5%, and prints required additional fixation to the print bed. Despite this lower level of success, it proved more aligned with durability and sustainability requirements and Coffee Based's existing material portfolio than the TPS compound. With the addition of chalk, and if the process is further optimized, it could also show potential for outdoor applications.

The SCG-rPP compound showed similar challenges regarding shrinking and warping. It showed less consistent results, partly due to incomplete (failed) prints. The manual addition of chalk as a reinforcing filler reduced shrinkage, but remained inconsistent. Manually adding the chalk to the compound proved hard to do homogeneously without a built-in mixing device in the extruder.

The research confirms that material behavior, print settings, and design shape depend on one another in LSAM with FGF. Print speed, nozzle diameter, minimum layer time, and extrusion rate/consistency all significantly affect print quality and dimensional accuracy. When the nozzle diameter increased from 3 mm to 5 mm, it reduced issues like clogging. Additionally, optimizing layer times improved layer adhesion. These findings show that successful LSAM with coffee-based compounds requires careful consideration of the printing process when designing.

The Boonbank translates these technical insights into a suitable design. Its design avoids excessive bridging and overhangs and contains curved shapes instead of sharp angles. The modular division into three separate components reduces the risk of print failure. The open-bottom design improves printability while enabling partial embedding for stability purposes.

The combination of material experimentation with stakeholder-driven design exploration and development proved essential. The material research defined technical design constraints (and possibilities), while interviews and feedback sessions ensured that these constraints did not compromise its feasibility and desirability. The choice for SCG–bioHDPE, for instance, was influenced not only by print behaviour but also by the perception of surface quality and the consistency with the Coffee Based portfolio.

Overall, this research demonstrates that coffee-based granulate can be used in LSAM, but the scale is still uncertain. Initial experiments with the large extruder proved unsuccessful and require more testing.
However, the Boonbank shows future perspective. Not as proof of full industrial readiness, but as evidence that a feasible, viable, and desirable design space exists when combining LSAM technology with the materials of Coffee Based.

7. PERSONAL REFLECTION

In creating this reflection, the reflection dice method was used (Persaud, 2024). Rather than addressing each question separately, this chapter integrates them throughout this reflection on the overall process.

At the start of the project, I approached the assignment with ambitious plans and a relatively linear expectation of progress. I assumed that once the material exploration started, consistent testing and gradual optimization would follow. In practice, the project turned out to be much less predictable. Challenges at 10XL, such as organizational changes and limited machine availability, changed the original plan a lot. Printing issues, material inconsistencies, drying times, and the need to switch between different material configurations also delayed the process. This showed that when working with multiple stakeholders and dealing with many variables and unpredictable technologies, unexpected changes need to be accounted for during the planning phase.
It also showed me that a clear scope is needed. However, you also have to account for the fact that the scope can keep on changing during the entirety of the project and thus needs continuous adjustment.

Despite these technical and organizational challenges happening at 10XL, I experienced the collaboration with Coffee Based as really positive. The team was open and welcoming towards me and remained supportive even though I didn't have many proper results due to the printing issues. Until the end of the project, I experienced the collaboration with 10XL as less productive, mainly due to the factors mentioned before. Because I was not working for them, but rather using their machines, I noticed less support was provided. However, a key moment for me in this was when I was trusted with the small extruder to perform tests on my own. This gave me the possibility to test freely, instead of having to wait for the printer operator.

Additionally, the opportunity to continue at Coffee Based after graduating was reassuring. In my opinion, this meant that they had trust in the process, even if the large-scale prototype had not yet been successful.

Midway through the project, I was quite demotivated. The challenges at 10XL created uncertainty, and my original planning kept on delaying. It turned out my expectations were not in line with the possibilities. As a result of not being able to print at 10XL, my focus had to be shifted toward the design exploration. However, before detailing one design entirely, I wanted to have more technical validation of its feasibility. Before I was able to print again, I organized feedback sessions with clients and received positive responses, which helped increase my confidence in the design again.

What I want to look into more is creating a proper print on the large extruder with the bioHDPE compound. For now, the material does not look dry, although it was dried long enough. It also shrinks, even with chalk added to the compound. I want to research other ways to counter shrinkage, while keeping the compound mostly the same.

My next concrete steps will be to continue with the design at Coffee Based. I will continue with the print tests on the large extruder by changing the material configuration and printer parameters. In parallel, I will present my concept to relevant stakeholders for feedback.

These iterative steps are in line with the rest of this research-through-design project. It integrates two separate exploration phases, both of material and design, happening simultaneously. While they happened at the same time, it also showed an indirect feedback loop, as follows:

- The material research informed the feasibility in the design space.
- The design exploration tested whether that space allowed meaningful, desirable, and viable outcomes.
- Stakeholder (client, partner, and company) input and feedback that refined the technical testing priorities.

Even though this research-through-design process had a rough start, it proved valuable in the end because it provided context for the material exploration and a technical basis for the design exploration. However, this structure also results in a final prototype that serves mainly as a demonstrator of potential, rather than a fully validated production-ready object.

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9. APPENDICES

Appendix 1: Tests performed on the small extruder

TEST 01

Settings (change):
- Material (rPP) dried 3h ~90 - 100 degrees
- Layer height 1.4mm
- Cold print bed
- Temperature as in images
- Print design: 45 degree angle pyramid

Notes:
- Print seems to have air in it, maybe needs longer drying.
- Print comes loose from the base plate.
- Surprisingly good first print with material.
- Material has a rough structure.
- Material warps from the print bed (due to shrinking).

Next steps:
- Change layer height to 1.6mm, to lower clogging outside of nozzle.
- Preheat the PP printbed with a heatgun for better attachment.

IMAGES

Preliminary conclusions:
- Material has printing potential if shrinking can be fixed.

Assumptions:
- Rough texture is due to the fibers in the material.

TEST 02

Settings (change):
- Material (rPP) dried 3h ~90 - 100 degrees
- Layer height 1.6mm
- Cold print bed
- Temperature as in images, last zone ~10 degrees lower than first test.
- Print design: 45 degree angle pyramid

Notes:
- Material degrades less, better lighter colour.
- Print not fully on printbed, needed to abort soon.
- Bed wasn't preheated, thus the corners still came loose (due to shrinking).

Next steps:
- Move print so it fits on the printbed and print again with same settings.
- Preheat the PP printbed with a heatgun for better attachment.

IMAGES

Preliminary conclusions:
- The material doesn't have to be heated above 205 degrees to print.

Assumptions:
- A heated print bed affects the bed adhesion in a positive way.

TEST 03

Settings (change):
- Material (rPP) dried 3h ~90 - 100 degrees
- Layer height 1.6mm
- Preheated print bed
- Temperature of first and last heating zone changed during print
- Print design: 45 degree angle pyramid

Notes:
- Bed was preheated with a heat gun, works good.
- Start of the print is really good, 45 degree angle overhang works fine.
- Eventually broke loose from the print bed again, due to shrinking.
- Material looks pourous.
- Material has a high 'baardvorming' at the nozzle, eventually resulting in blobs in the print.
  - We removed this by hand in the beginning, but reappears after 1-2 layers.
- After a while of unsupervised printing 3 out of 4 corners snapped loose, resulting in a failed print.
- Walls collapsed and warped due to shrinking.

Next steps:
- Print a straight up print (without overhang) to investigate the layer height.
- Change layer height (higher) to prevent 'baardvorming'.

IMAGES

Preliminary conclusions:
- The material and printer have no trouble with an overhang of 45 degrees.

Assumptions:
- Overhang can be even a little more than 45 degrees.
- Layer height impacts the 'baardvorming'.

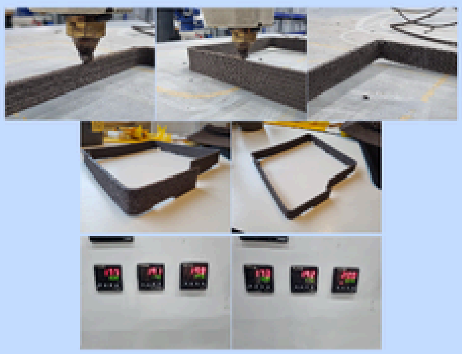
TEST 04

Settings (change):
- Material (rPP) dried 3h ~90 - 100 degrees
- Layer height **1.7mm**
- Preheated print bed
- Temperature of last heating zone changed during print
- Print design: Square

Notes:
- The 'baardvorming' is still a lot at the nozzle.
- Print broke when taking it off the print bed.
- Print is dimensionally accurate.
- Wall thickness of print is 5mm, design had 4mm.

Next steps:
- Wrap nozzle in aluminium foil, to keep the temperature stable and lower the 'baardvorming'
- Screw print to printbed.

IMAGES



Preliminary conclusions:
- The material has good dimensional accuracy.

Assumptions:
- The 'baardvorming' is affected by the nozzle temperature consistency. (Gerbert)

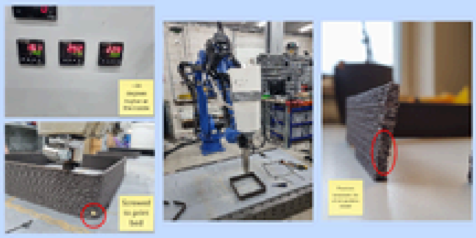
TEST 05

Settings (change):
- Material (rPP) dried 3h ~90 - 100 degrees
- Layer height 1.7mm
- Preheated print bed
- Temperature of last heating zone + ~30 degrees
- Print design: Square

Notes:
- After a few layers the print was screwed to the printbed to stop it from warping upwards.
- Wrapped it in aluminium foil, to keep the heat in the nozzle stable, didn't work unfortunately.
- Texture is still rough.
  - Possible reasons:
    - Inconsistent material
    - Not enough drying time (only ~3h)
- There is still 'baardvorming' on the nozzle.
- Left printing unsupervised.

Next steps:
- Add a material to the mix that prevents shrinkage, such as chalk.

IMAGES



Preliminary conclusions:
- -

Assumptions:
- The shrinkage is connected to the drying of the material and the air pockets inside. (Me)
- Chalk affects the shrinkage of the material. (Gerbert from experience)

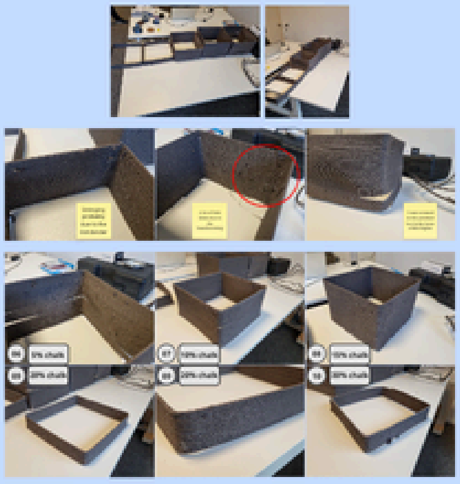
TEST 06 - 10

Settings (change):
- Material (rPP) dried 4h(?) ~90 - 100 degrees
- Layer height 1.7mm
- Preheated print bed
- Temperature changed during printing, unsure.
- Print design: Square

Notes:
- Printed by Gerbert (10XL) alone.
- Material still shrinks a lot.
- To counteract the shrinking, chalk was added, which helped, but not enough.
  - Chalk percentage was gradually increased with each print, 5 - 10 - 15 - 20 - 30 %
  - We don't want to add more than 30%, then we will be printing with chalk instead of coffeebased material.
- Speed was doubled; instead of 60s/layer just 30s/layer.

Next steps:
- Print with a different compound material. Instead of rPP and coffee grounds, HDPE and coffee grounds (same material as their cups).
  - Different binder, Iperex instead of EVA.
- Increase speed to counter the 'baardvorming'.

IMAGES



Preliminary conclusions:
- Chalk reduces the shrinkage of the print.
- To account for the large level of shrinkage, more than 30% chalk is needed.
- The material is not suitable for 3D printing in its current state. (Gerbert)

Assumptions:
- More chalk = less shrinkage.

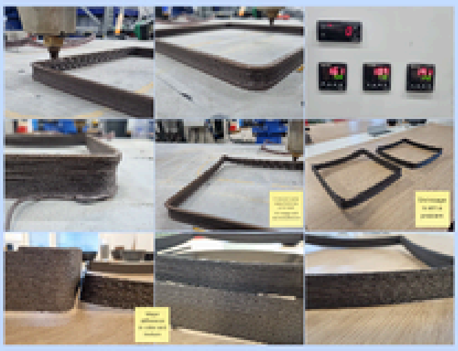
TEST 11

Settings (change):
- Material (**HDPE** granulate) dried ~100 degrees overnight
- **Layer height 2mm**
- Preheated print bed
- **Temperature lower than with the rPP.**
- Print design: Square

Notes:
- First prints with HDPE instead of rPP.
- Print bed is PP, so this PE didn't attach to the bed well. Corners snapped loose quickly.
- Material is softer and more flexible than the rPP one. Screwing therefore didn't work.
- Texture of material is a lot smoother and more plastic-like. However the amount of coffee in it is equal to the rPP print.
- Printed with 30% of chalk.
- There still is some 'baardvorming', but it is less harmful than before (probably due to the higher speed).

Next steps:
- Print with a brim to increase bed adhesion and keep it from warping upwards.

IMAGES



Preliminary conclusions:
- Material is stronger and more plastic-like than the previous material.
- The material has more potential for 3D printing.

Assumptions:
- Shrinkage can be 'fixed'.

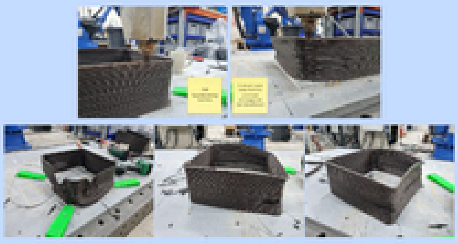
TEST 12

Settings (change):
- Material (HDPE granulate) dried ~100 degrees overnight
- Layer height 2mm
- **Cold print bed**
- Temperature same as previous test.
- Print design: Square

Notes:
- Same settings as before, but we tried to let it run for a longer time.
- When shrinking happens, the walls collapse, resulting in a misalignment on higher layers; the sagging visible in the photos.
- There still is some 'baardvorming', but less than with the rPP.
- We tried to secure the brim with wedges on the outside, but had too little grip.
- The print bed was not preheated, as this works less with the difference in materials (PP printbed with HDPE material).

Next steps:
- Print with a brim to increase bed adhesion and keep it from warping upwards.

IMAGES



Preliminary conclusions:
- -

Assumptions:
- A brim will strengthen the bed adhesion.

Preliminary conclusions:
- -

Assumptions:
- A brim will strengthen the bed adhesion.

miro

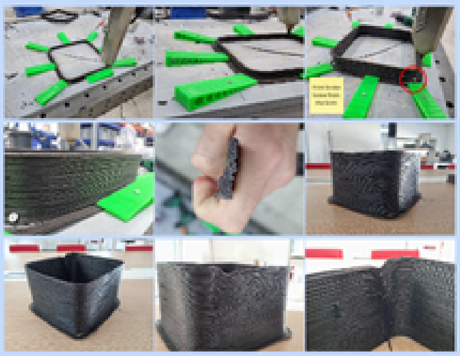
TEST 13

Settings (change):
- Material (HDPE granulate) dried ~100 degrees overnight
- Layer height 2mm
- Cold print bed
- Temperature same as previous test.
- Print design: Square with brim

Notes:
- Tried with a 'regular' flat brim on the outside (setting in Cura).
- The brim allowed the print to be secured with a lot of plastic wedges, screwed to the print bed. (green objects in the photos)
  - This kept it from warping a bit, but the shrinkage still needed to go somewhere, thus walls 'collapsed';
  - The print also broke loose above the brim (see photo).
- There still are a lot of air pockets inside the material.
  - Gerbert is very sure that this doesn't have anything to do with shrinkage, but I doubt it.

Next steps:
- Manually create a stronger and more supportive brim
  - Without perpendicular angle.

IMAGES



Preliminary conclusions:
- A brim helps with bed adhesion and reduces shrinkage upward.

Assumptions:
- The pourous structure and the air pockets are the cause of the shrinking. (Me)
- The drying of the material impacts the shrinking. (Me)
- The drying and the air pockets don't affect the shrinking. (Gerbert)

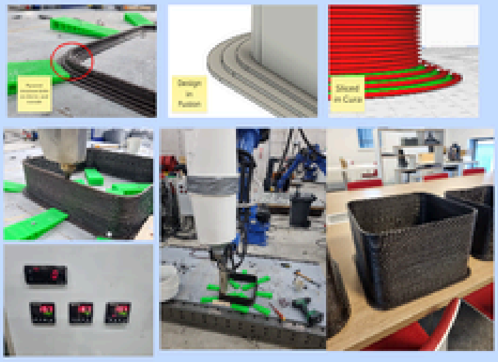
TEST 14

Settings (change):
- Material (HDPE granulate) dried ~100 degrees overnight
- Layer height 2mm
- Cold print bed
- Temperature same as previous test.
- Print design: Square with pyramid brim

Notes:
- Designed a pyramid supportive structure brim on the in- and outside.
  - This prevented the 90 degree angle between the flat brim and the straight walls, allowing for a better division of forces.
- The brim on the inside allowed us to secure the print on the inside as well with the wedges.
- We noticed the consistency of the mix was far from optimal. This print for example, was almost all Coffee Based granulate and almost no chalk (where it has to be 30% chalk!).

Next steps:
- Use a better mix of the material and the chalk. Now it sometimes is just the coffeebased material printing, as the distribution isn't optimal.
  - Do this by manually mixing smaller batches, to have more control.
  - Find out better ways to mix the materials.
- Use a bigger nozzle?

IMAGES



Preliminary conclusions:
- The pyramid brim structure is more effective than the flat brim.

Assumptions:
- The brim could replace the screws in the side of the model. (Gerbert)
- A consistent material mix could positively impact shrinking.

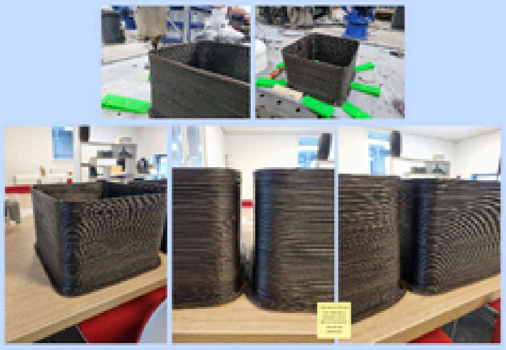
TEST 15

Settings (change):
- Material (HDPE granulate) dried ~100 degrees overnight
- Layer height 2mm
- Cold print bed
- Temperature same as previous test.
- Print design: Square with pyramid brim

Notes:
- Manually made a mix of the granulate and the chalk and added these during printing by hand.
- Control over the mix was higher.
  - Resulting in a lighter (browner) print, with less shrinkage.
  - However, it was still not consistent enough.
- Print head changed directions at some points during the print, probably a wrong setting in Cura.
  - This caused some errors in the print, due to layers not having enough time to dry.

Next steps:
- Research the possibility to add the chalk in the compound, to create a universal granulate.
- Try using a bigger nozzle?
- Fix error during slicing.
- Try using the grinded HDPE material instead of the granulated version. This is rougher and maybe will hold the chalk better.

IMAGES



Preliminary conclusions:
- A more consistent material mix reduces the shrinking of the 3D print.

Assumptions:
- An even more consistent material mix could 'solve' shrinking.

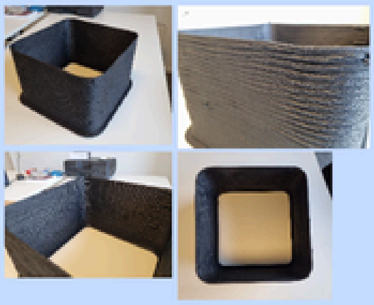
TEST 16

Settings (change):
- Material (**HDPE shredded**) dried ~100 degrees overnight
- Layer height 2mm
- Cold print bed
- Temperature unsure.
- Print design: Square with pyramid brim

Notes:
- Good result with about 30% chalk.
- Shrinkage is less than before but still present.
- Texture is again a bit rougher.

Next steps:
- Research the possibility to add the chalk in the compound, to create a universal granulate.
- Try using a bigger nozzle for thicker walls and less shrinkage.

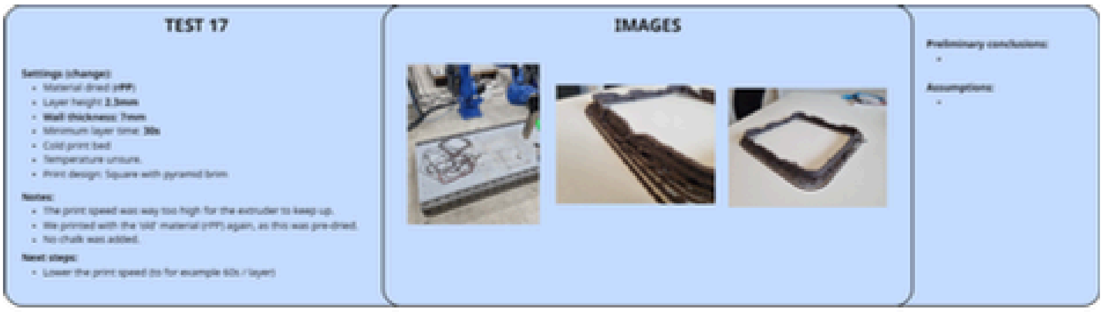
IMAGES

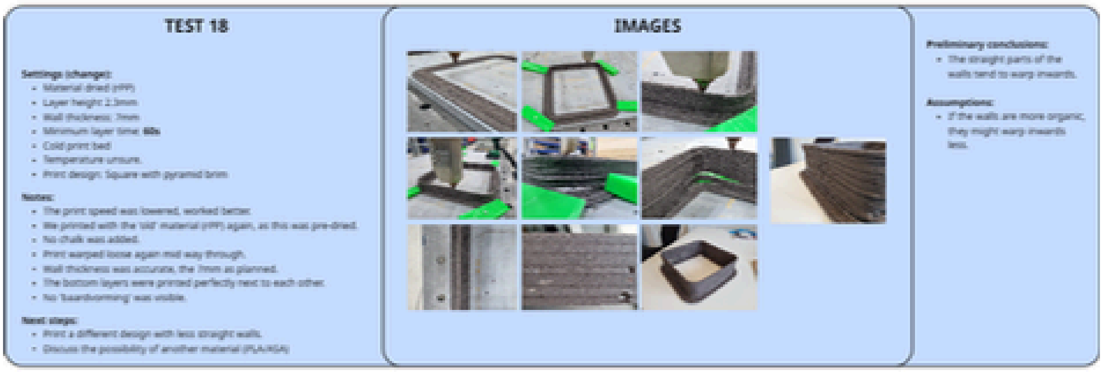


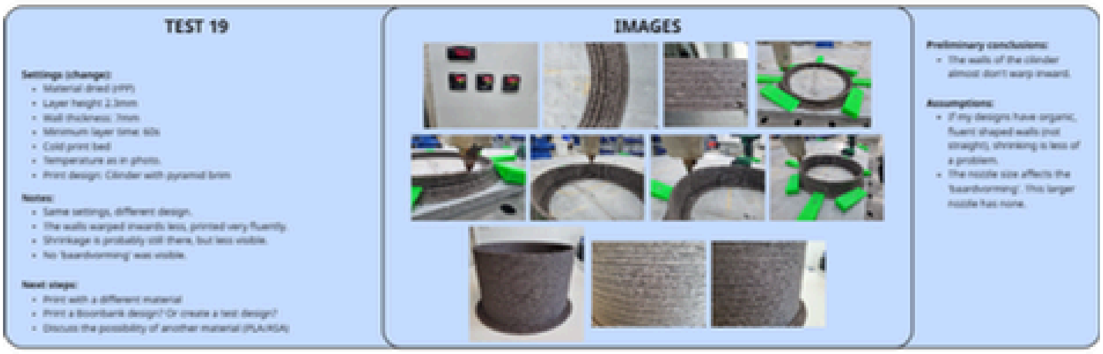
Preliminary conclusions:
- Shredded material keeps the chalk mix better.

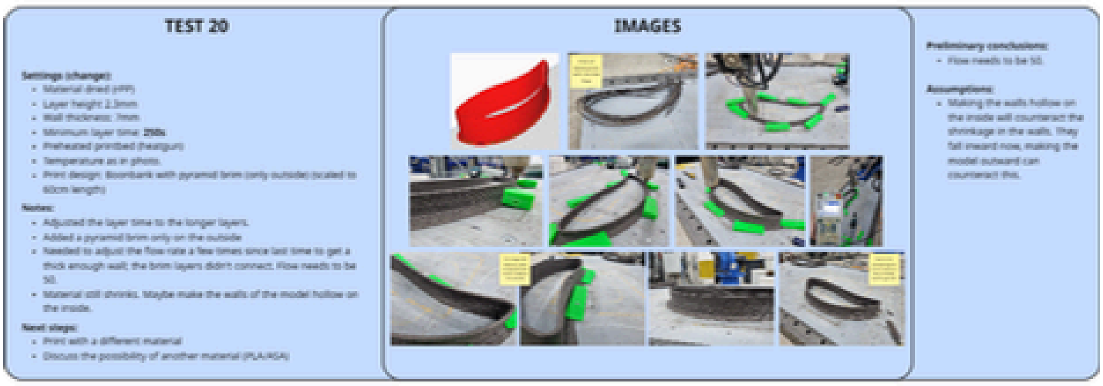
Assumptions:
- Material has higher potential than before.

miro


TEST 17
Settings (change):
Material dried (rPP)
Layer height 2.3mm
Wall thickness: 7mm
Minimum layer time: 30s
Cold print bed
Temperature unsure.
Print design: Square with pyramid brim
Notes:
The print speed was way too high for the extruder to keep up.
We printed with the 'old' material (rPP) again, as this was pre-dried.
No chalk was added.
Next steps:
Lower the print speed (to for example 60s / layer)
IMAGES
Preliminary conclusions:
Assumptions:

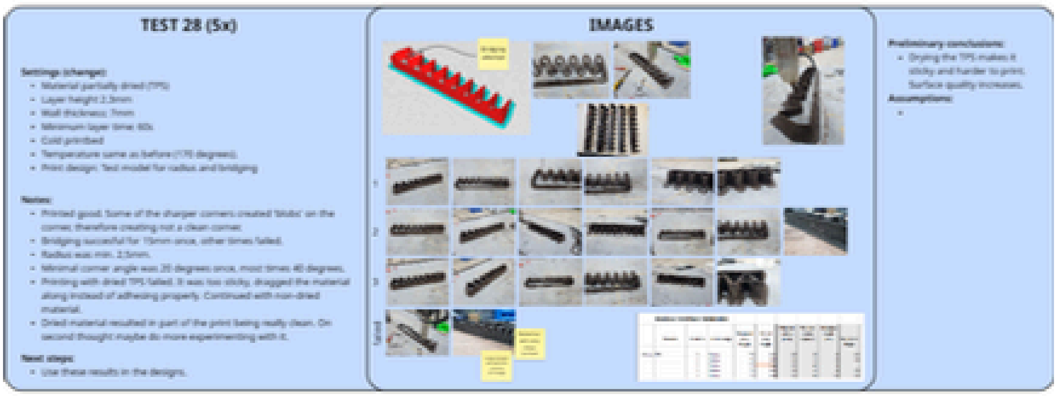

TEST 18
Settings (change):
Material dried (rPP)
Layer height 2.3mm
Wall thickness: 7mm
Minimum layer time: 60s
Cold print bed
Temperature unsure.
Print design: Square with pyramid brim
Notes:
The print speed was lowered, worked better.
We printed with the 'old' material (rPP) again, as this was pre-dried.
No chalk was added.
Print warped loose again mid way through.
Wall thickness was accurate, the 7mm as planned.
The bottom layers were printed perfectly next to each other.
No 'baardvorming' was visible.
Next steps:
Print a different design with less straight walls.
Discuss the possibility of another material (PLA/ASA)
IMAGES
Preliminary conclusions:
The straight parts of the walls tend to warp inwards.
Assumptions:
If the walls are more organic, they might warp inwards less.

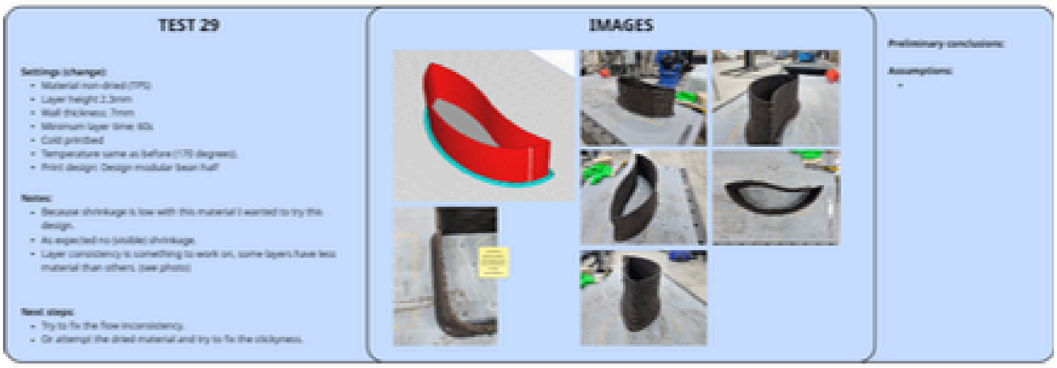

TEST 19
Settings (change):
Material dried (rPP)
Layer height 2.3mm
Wall thickness: 7mm
Minimum layer time: 60s
Cold print bed
Temperature as in photo.
Print design: Cilinder with pyramid brim
Notes:
Same settings, different design.
The walls warped inwards less, printed very fluently.
Shrinkage is probably still there, but less visible.
No 'baardvorming' was visible.
Next steps:
Print with a different material
Print a Boonbank design? Or create a test design?
Discuss the possibility of another material (PLA/ASA)
IMAGES
Preliminary conclusions:
The walls of the cilinder almost don't warp inward.
Assumptions:
If my designs have organic, fluent shaped walls (not straight), shrinking is less of a problem.
The nozzle size affects the 'baardvorming'. This larger nozzle has none.

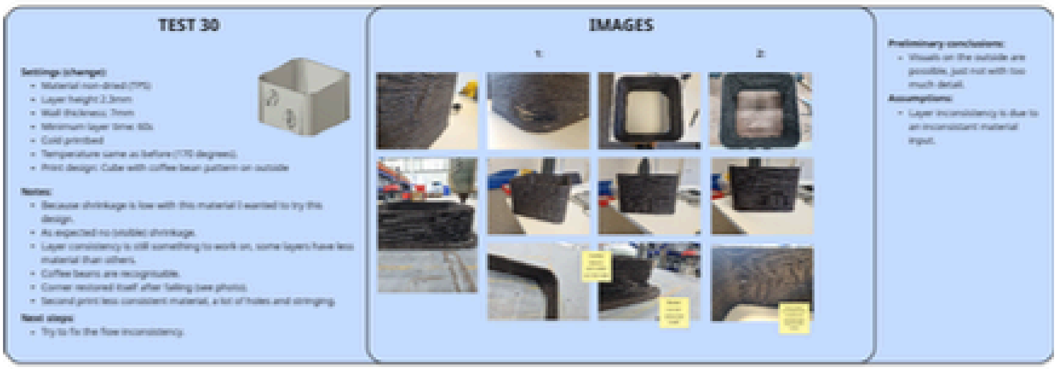

TEST 20
Settings (change):
Material dried (rPP)
Layer height 2.3mm
Wall thickness: 7mm
Minimum layer time: 250s
Preheated printbed (heatgun)
Temperature as in photo.
Print design: Boonbank with pyramid brim (only outside) (scaled to 60cm length)
Notes:
Adjusted the layer time to the longer layers.
Added a pyramid brim only on the outside
Needed to adjust the flow rate a few times since last time to get a thick enough wall; the brim layers didn't connect. Flow needs to be 50.
Material still shrinks. Maybe make the walls of the model hollow on the inside.
Next steps:
Print with a different material
Discuss the possibility of another material (PLA/ASA)
IMAGES
Preliminary conclusions:
Flow needs to be 50.
Assumptions:
Making the walls hollow on the inside will counteract the shrinkage in the walls. They fall inward now, making the model outward can counteract this.

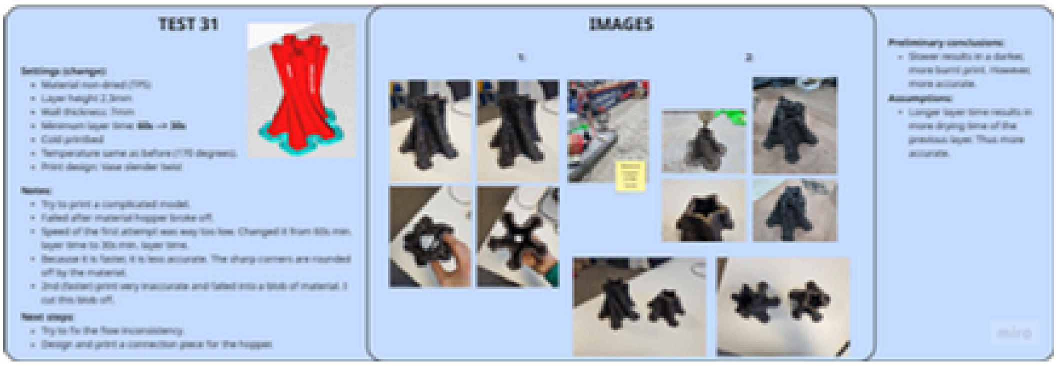

TEST 21
Settings (change):
Material dried (rPP)
Layer height 2.3mm
Wall thickness: 7mm
Minimum layer time: 125s
Preheated printbed (heatgun)
Temperature same as before.
Print design: Test model for overhang
Notes:
Higher speed. Can be even higher.
Forgot the bridging part.
Printed without a brim, so it would be easier to take off of the print bed, however, this resulted in too little attachment.
45 and 50 degree angles were too much, they sagged.
Some parts had underextrusion due to too little material input.
Next steps:
Print with a bridging part.
Print with a brim.
IMAGES
Preliminary conclusions:
To test more accurately, material input needs to be more constant.
Assumptions:
miro


TEST 26 & 27
IMAGES


TEST 28 (5x)
IMAGES


TEST 29
IMAGES


TEST 30
IMAGES


TEST 31
IMAGES

Appendix 2: Measured test results

DIMENSIONAL ACCURACY

Material	Nozzle size (mm)	Chalk %	Print design	Designed: Length	Designed: Width	Designed: Height	Actual size: Length	Actual size: Width	Actual size: Height	Shrink %: Length	Shrink %: Width	Shrink %: Height	Av. Shrink L/W (%)
rPP	3	5	Square	30,0	30,0	20,0	28,5	27,7	20,1	5,3	8,3	-0,5	6,8
rPP	3	10	Square	30,0	30,0	20,0	28,1	27,1	15,0	6,8	10,7	-	8,7
rPP	3	15	Square	30,0	30,0	20,0	27,9	27,4	21,1	7,5	9,5	-5,2	8,5
rPP	3	20	Square	30,0	30,0	20,0	27,9	27,4	5,4	7,5	9,5	-	8,5
rPP	3	30	Square	30,0	30,0	20,0	28,5	28,2	2,6	5,3	6,4	-	5,8
rHDPE	3	30	Square	30,0	30,0	20,0	29,1	25,9	12,4	3,1	15,8	-	9,5
rHDPE	3	30	Square	30,0	30,0	20,0	28,2	27,0	12,5	6,4	11,1	-	8,7
rHDPE	3	30	Square	30,0	30,0	20,0	28,3	26,9	27,7	6,0	11,5	-	8,8
rHDPE	3	30	Square	30,0	30,0	20,0	29,7	28,3	20,0	1,0	6,0	0,0	3,5
rHDPE	3	30	Square	30,0	30,0	20,0	29,5	29,1	20,1	1,7	3,1	-0,5	2,4
rHDPE shredded	3	30	Square	30,0	30,0	20,0	29,5	29,0	20,0	1,7	3,4	0,0	2,6
rPP	5	0	Square	30,0	30,0	20,0	29,9	29,1	10,1	0,3	3,1	-	1,7
rPP	5	0	Square	30,0	30,0	20,0	29,5	29,1	2,9	1,7	3,1	-	2,4
TPS	5	0	Square	30,0	30,0	20,0	30,1	29,9	19,9	-0,3	0,3	0,5	0,0
TPS	5	0	Square	30,0	30,0	20,0	30,2	29,9	19,8	-0,7	0,3	1,0	-0,2
TPS	5	0	Square	30,0	30,0	20,0	30,1	29,9	19,8	-0,3	0,3	1,0	0,0

OVERHANG / BRIDGING

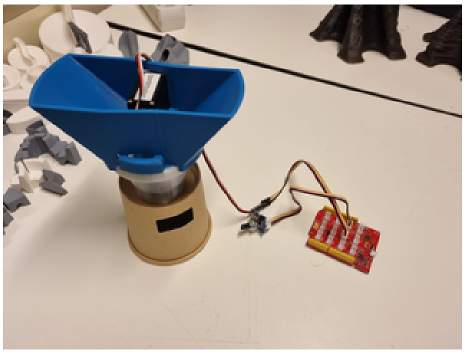
Material	Chalk %	Print design	Designed: Width	Designed: Height	Actual size: Width	Actual size: Height	Overhang angle (°)	Bridging length	Shrink %: Width	Shrink %: Height
rPP	0	Overhang	23,6	7,2	23,5	7,1	45	-	0,4	1,8
TPS	0	Overhang	23,6	7,2	-	3,1	45	0	-	-
	0	Overhang	23,6	7,2	23,9	7,0	45	0	-1,3	3,3
	0	Overhang	23,6	7,2	23,8	3,8	40	0	-0,8	-
	0	Overhang	23,6	7,2	23,8	7,0	45	0	-0,8	3,3
	0	Overhang	23,6	7,2	23,8	7,1	40	0	-0,8	1,8
	0	Overhang	23,6	7,2	23,8	7,0	45	0	-0,8	3,3
	0	Overhang	23,6	7,2	23,8	6,0	40	0	-0,8	-

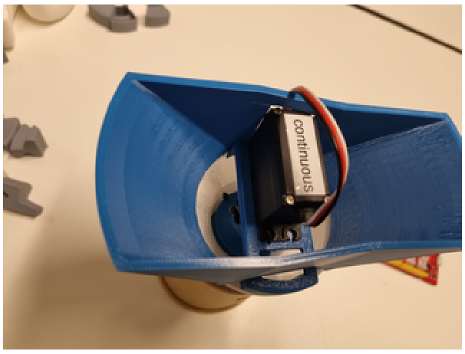
RADIUS / CORNER / BRIDGING

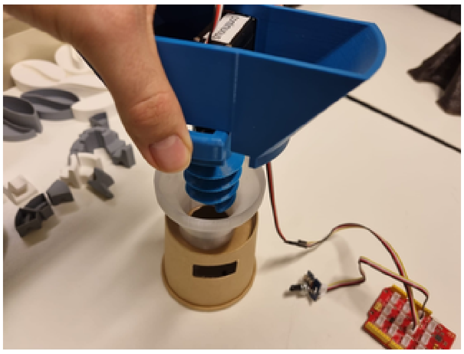
Material	Chalk %	Print design	Designed size: Height	Actual size: Height	Minimal radius (mm)	Minimal corner angle (°)	Bridging length (mm)	Shrink %: Height
TPS	0	Radius	7,0	6,8	2,5	20	0	2,9
	0	Radius	7,0	6,8	2,5	45	0	2,9
	0	Radius	7,0	6,4	2,5	40	0	-
	0	Radius	7,0	6,8	2,5	40	0	2,9
	0	Radius	7,0	6,8	2,5	40	15	2,9

Appendix 3: Hopper adjustment

This 3D printed hopper with extruder could be placed on the hopper of the XL 3D printer. It has an adjustable speed, to manually control the granulate supply to the heated extruder. This way material is less susceptible to get stuck in the hopper of the printer, which will effect the consistency of the material flow. Unfortunately, it could not be tested, due to issues at 10XL. It was tested with granulate separate from the printer, which worked fine.







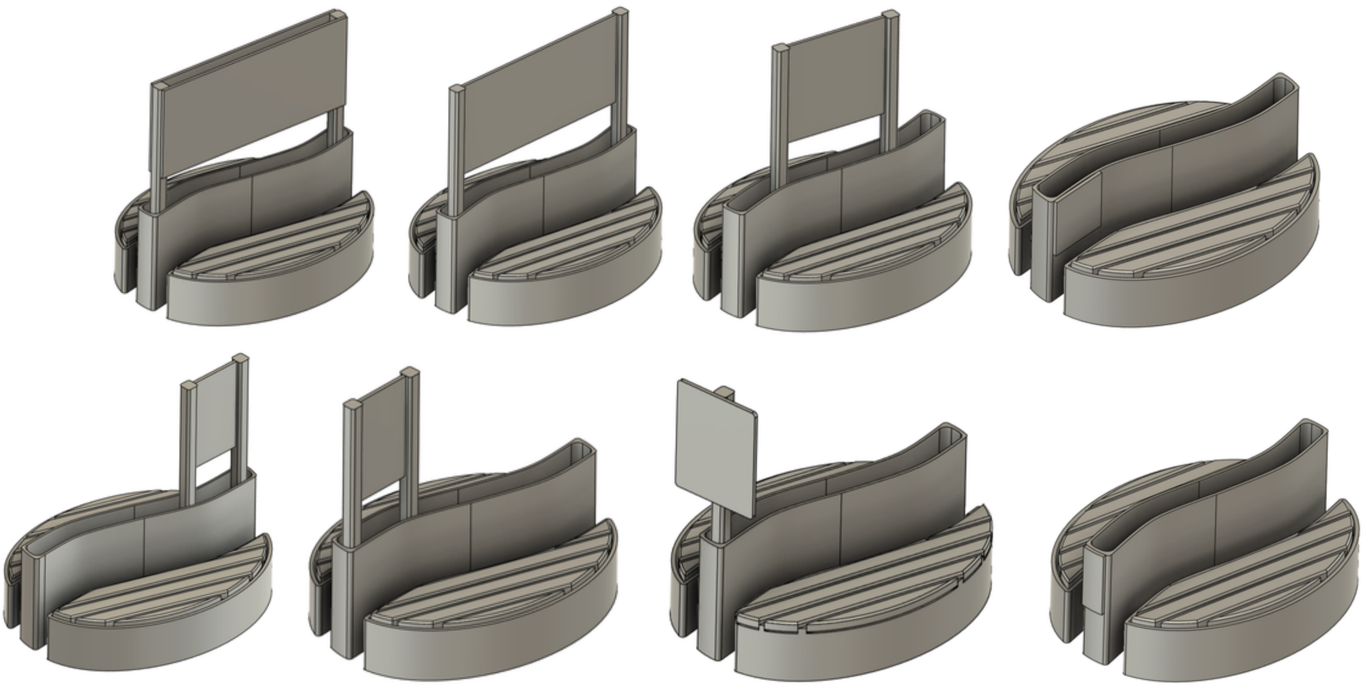
Appendix 4: Interview questions

As the interview were with Dutch speaking clients, the questions are also in Dutch. These were the general questions, leading the conversation through the feedback session.

1. Wat spreekt jullie het meest aan in elk concept? Of wat mist er?
2. Waar zouden jullie deze producten in jullie omgeving plaatsen?
3. Welke functies zouden jullie willen dat het product heeft? (Bijv. zitten/plantenbak) Welke rol speelt vergroening in jullie binnen- en buitenruimte?
4. Hoe belangrijk is modulariteit voor jullie?
5. Veranderen jullie bijv. vaak de binnen- of buitenruimte qua indeling?
6. Hoe belangrijk is het voor jullie dat het product zichtbaar verwijst naar koffie? (Bijv. in de vorm)
7. Zou de 3D print structuur een probleem zijn of heeft het juist een esthetische waarde?
8. Hebben jullie verder nog vragen of opmerkingen over een van de concepten?

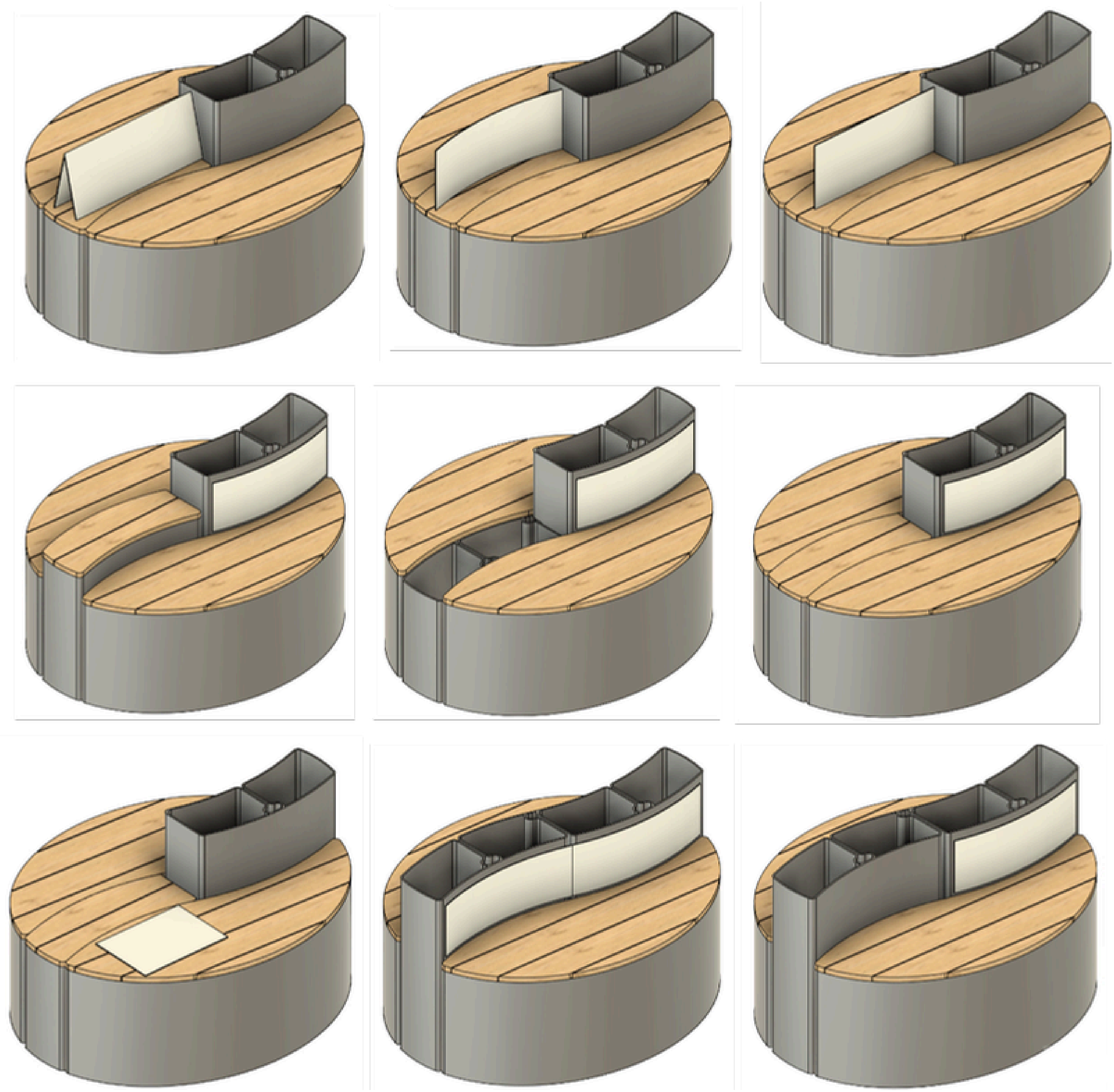
Appendix 5: Sign design iterations

First designs



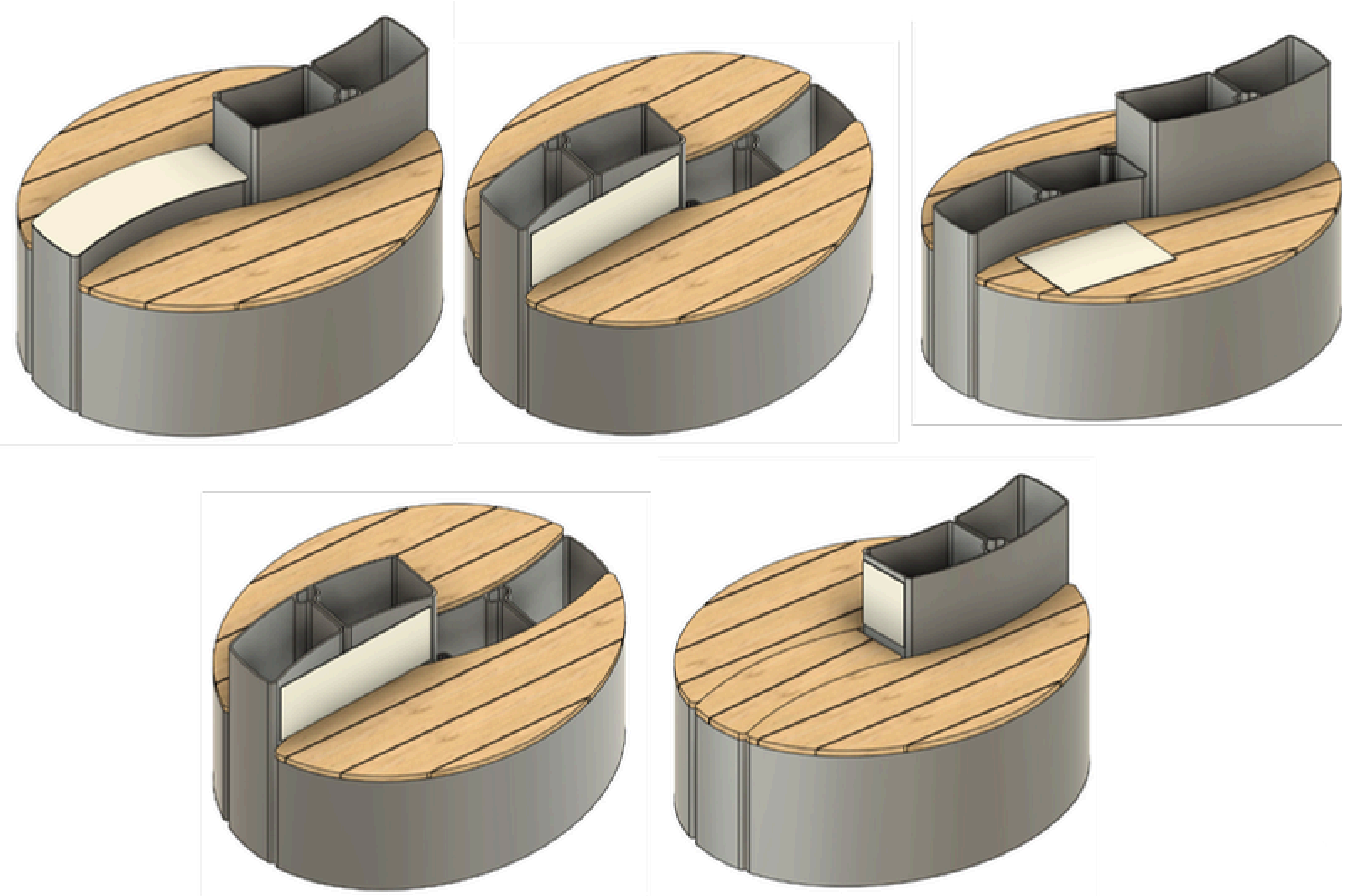
AI renders of some of these designs

Second iteration



Third iteration

As the material turned out not to be bendable, some of the previous designs were no longer possible. New designs were created in this iteration, only containing straight signs. After this iteration, the sign was designed in a way that it was more incorporated into the design; the result of this iteration can be found in Chapter 4.



Appendix 6: Cost calculation

Cost types:	Costs:
Production (10XL):	€ 1.200,00
Material (bioHDPE granulate):	€ 1.056,00
Transport Boonbank (10XL - Coffee Based):	€ 162,00
Compost (dirt, incl. transport):	€ 106,55
Plants (incl. transport):	€ 84,95
Seat (oak wood, incl. transport):	€ 235,95
Sign (incl. transport):	€ 567,00
Transport to installation site:	€ 200,00
Installation of Boonbank:	tbd
Assembly of sign and seat:	tbd
Screws, sign pole, etc.	€ 40,00
10% unexpected costs:	€ 365,24
Total costs	€ 4.017,69

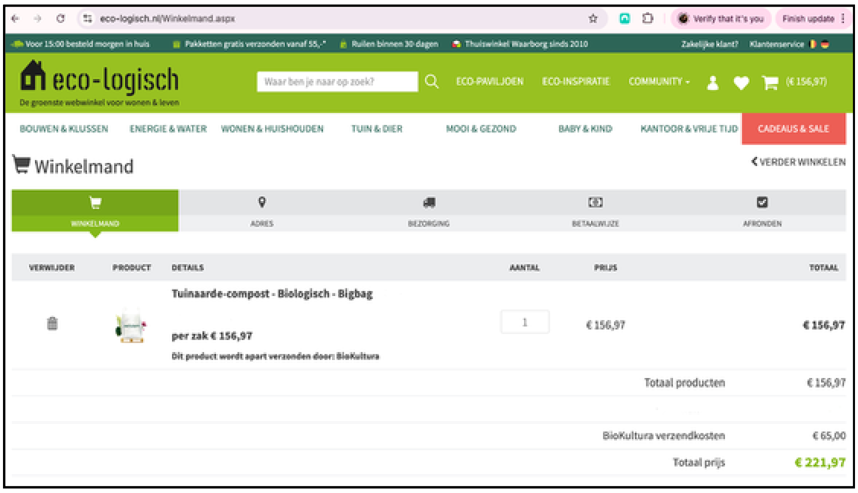
The production costs are calculated by 10XL, which created an invoice for the production of one Boonbank. Noteworthy is that these costs will be lower when the production unit is higher than one.

The material costs were received from Coffee Based in the form of an invoice for the material order. This was based on a price/kg. The weight of the Boonbank was estimated by 10XL to be around 300kg. This is thus an estimate, and the price could thus change.

Material (bioHDPE)	€ 3,52 /	1	kg
Estimated weight:		300	kg
Total material costs	**€ 1.056,00**		

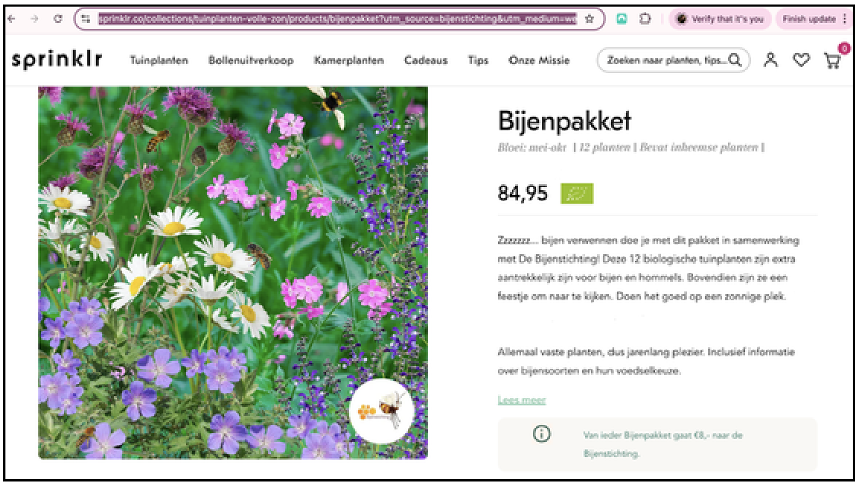
The transport costs are calculated based on the transport from 10XL to Coffee Based, with the help of Brenger.nl (Figure below)

The compost costs are calculated based on the usage of biological compost soil, ordered in a big bag (1.000L) from eco-logisch.nl. It also includes transport costs (to Coffee Based). The volume of the middle part of the Boonbank is calculated at around 480L ((18 x 3 x 10) - (9 x 3 x 2,5) dm, l x w x h whole object - l x w x h lower part of middle part).

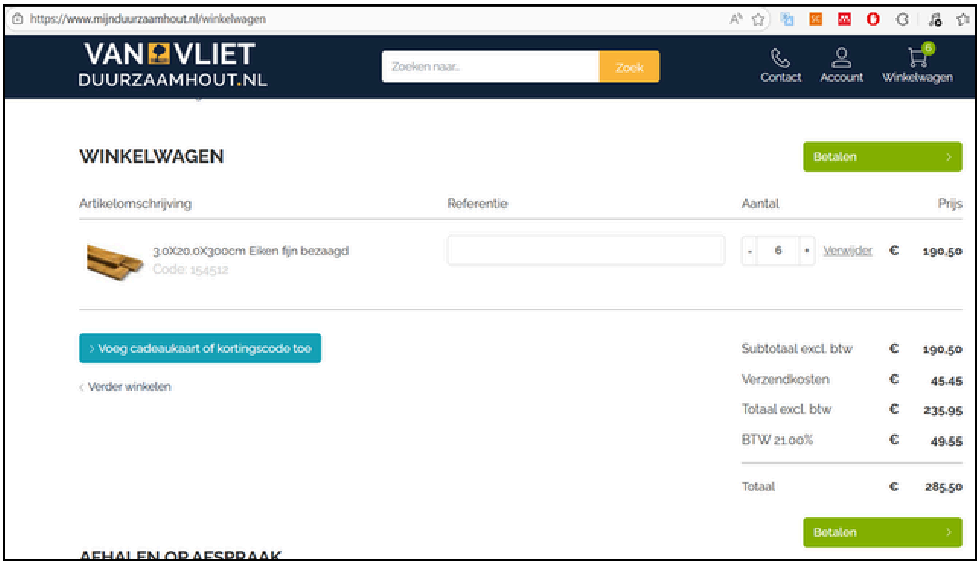


Compost (dirt):	€ 221,97 /	1000	L
Volume middle part		480	L
Total compost costs	**€ 106,55**		

For the plants placed in the middle part of the Boonbank a seed package from Sprinklr.co is used.



The costs of **the wooden seat and the sign** were based on the costs at mijnduurzaamhout.nl. This includes 6 wooden planks (3x20x300cm) and transport costs. These planks can be cut to the 180cm length of the seating area; the remaining 120cm can be used as crossbeams to connect these (See Chapter X).

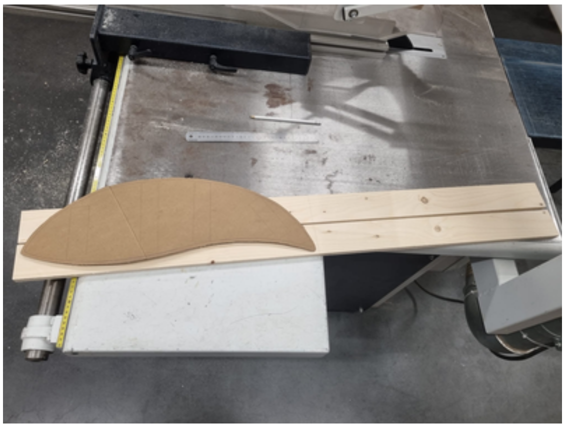
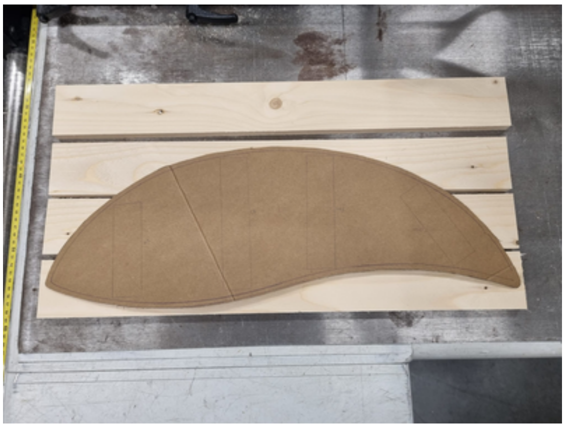


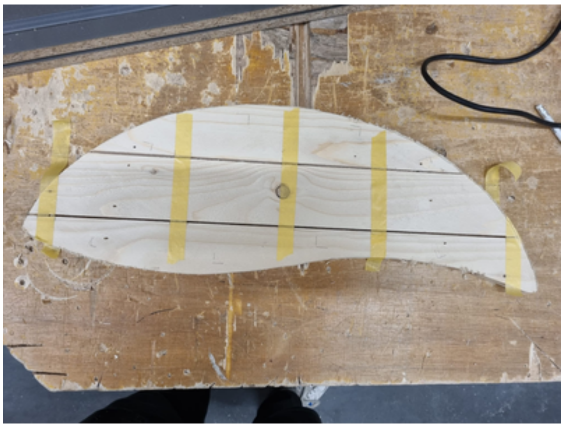
The sign will be made by PressArt. Cutting it into the bean shape will result in costs of 567,-. This includes 2 bean shaped signs (front and back) and transport costs.

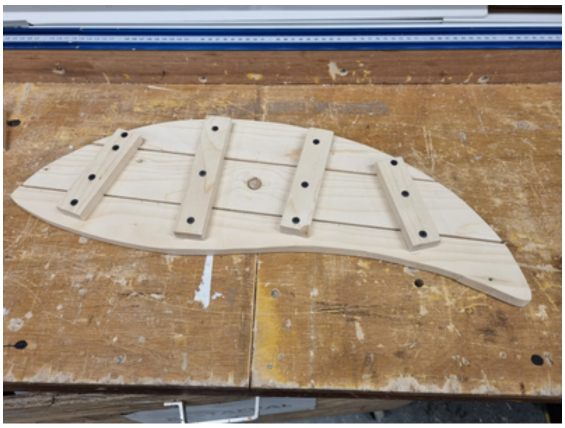
Omschrijving	Aantal	Prijs	Totaal incl. korting
#Transport Klein (los verpakt bord) NL	1 stuks	€ 67,00	€ 67,00
>Project organisatie + Plate-UV [400 x 500 x 8 mm]	**1 stuks**	**€ 250,00**	**€ 250,00**
			€ 317,00
Subtotaal		**€ 317,00**	
Totaal excl. BTW		**€ 317,00**	

Combining all these costs results in an expected production and transport cost of **€5.531,88**. This is the cost to create one single Boonbank. If more can be produced, costs will be lower. This cost calculation excludes the labour costs of the design, the assembly of the product, and the profit margin for Coffee Based. For the customers, this price will thus be higher.

Appendix 7: Production of prototype seat




Appendix 8: Original project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	van Brummelen
Initials	J.
Given name	Joas
Student number	5344018

IDE master(s)	IPD ✓ DfI ☐ SPD ☐
2nd non-IDE master	
Individual programme *(date of approval)*	
Medisign	☐
HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	J. Faludi	dept./section	CPD
mentor	S. Persaud	dept./section	DfS
2nd mentor	L. Addink-Dölle		
client:	Coffee Based		
city:	Gorinchem	country:	Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Jeremy Faludi Date [redacted] Signature [redacted]

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total EC

Of which, taking conditional requirements into account, can be part of the exam programme EC

★	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name K. Veldman Date [redacted] Signature [redacted]

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Joni Schuurman Date [redacted] Signature [redacted]

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Joas van Brummelen **Student number** [redacted]

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title 3D Printing large-scale biobased interior products with coffee waste

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This graduation project takes place in the domain of circular product design and large scale additive manufacturing. The project is a collaboration with the company Coffee Based in Gorinchem, who transform spent coffee grounds and husks into biobased granulate, to be used in new products, such as coffee cups and notebooks (figure 1). Another partner will be 10XL, who are specialized in XL 3D printing (figure 2) (not yet with biobased materials).
The main stakeholders include Coffee Based (as material innovator), 10XL (as large-scale 3D printing expert and printing facilitator) and the potential users or customers of the biobased interior products (mainly clients of Coffee Based's KRS (Koffie Recycle Service)).
Coffee Based wants to convert waste into useful products, by reducing the use of resources and the generation of waste. However, the design of the 3D-printable objects with their coffee granulate presents challenges in terms of material behavior and properties, print-ability and general feasibility.
This project will offer the opportunity to explore how circular design principles can be implemented in practice, specifically in the context of (XL) 3D printing. Meanwhile, it is necessary to consider the mechanical properties of the coffee-based material while taking design-for-printability into account.

→ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 Products made by CoffeeBased

image / figure 2 XL 3D Printing facility, 10XL

DESIGN FOR our future TUDelft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The clients of Coffee Based have expressed a desire for a larger coffee based product. Their current largest product is the Bean House, which is mainly made out of plywood with thin, compostable coffee sheets on top. However, the design of even more meaningful, large scale products made completely out of the recycled coffee material is yet to be explored.

All the "ingredients" for the project are known, but they have never been combined before. Coffee Based can already produce material using coffee grounds, but it has not yet been used for printing. 10XL can already print seating objects, but Coffee Based material has not yet been used for printing. This brings design and manufacturing challenges, and questions such as: What is possible with this kind of circular material in the area of XL 3D printing? Or how does the material behave and how can you combine that with form and function in a design?
In this project, I aim to explore these questions, thus not only by just by making something that works, but by creating products that add value and tell a story, products that reflect the circular ambitions of Coffee Based and fulfill the sustainable desires of its customers.

The company 10XL also has the desire to print more with biobased materials. Therefore I hope the research and experiments done during this project will also have added value for them.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design multiple XL 3D-Printed prototypes to explore and demonstrate the potential of coffee based granulate for circular interior products for the companies Coffee Based and 10XL, in the context of sustainable furniture design through large-scale additive manufacturing.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

For my graduation project, I will use an iterative research-through-design approach, combining material-driven exploration with stakeholder research. Together with 10XL, I will study the properties, limitations, and opportunities of the Coffee Based granulate, while also investigating stakeholder needs through interviews, user tests, and desktop research to identify relevant XL 3D-printable product opportunities. Initially, I will work with a smaller-nozzle printer, focusing on smaller, less load-bearing designs; if large-nozzle printing proves feasible, the focus will shift to larger and stronger products. Early on, I will 3D-print test parts to evaluate characteristics such as bending, tensile strength, overhang, bridging, and accuracy.

Insights from both research parts will guide the design criteria and concept development. Concepts will be iteratively refined through rapid prototyping, testing with 10XL, and feedback from Coffee Based and its clients. This process will result in one or two final designs per nozzle phase, shaped by design-for-3D-printing, material-driven, and co-creative design principles.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	23 sept 2025
Mid-term evaluation	18 Nov 2025
Green light meeting	12 jan 2026
Graduation ceremony	9 feb 2026

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I am excited to start this project because it aligns closely with my interests. During my studies I found a growing interest toward sustainability and circular design. In the past I have done some projects using biobased waste streams, such as a project where I 3D printed with tangerine peels (which was not the same as this large scale 3D printing but similar). This growing interest combined with an interest I have had for a longer time, namely creating tangible products (through for example 3D printing or other ways of prototyping), it seems to come together perfectly in this graduation project.
During the last semester I interned at the company Better Future Factory, who are all about recycling waste streams and creating products with a story, sparking my interest even further in this direction. I am curious to work even more with (and learn more about) pioneering companies such as Coffee Based and 10XL on sustainable and innovative solutions such as this project.