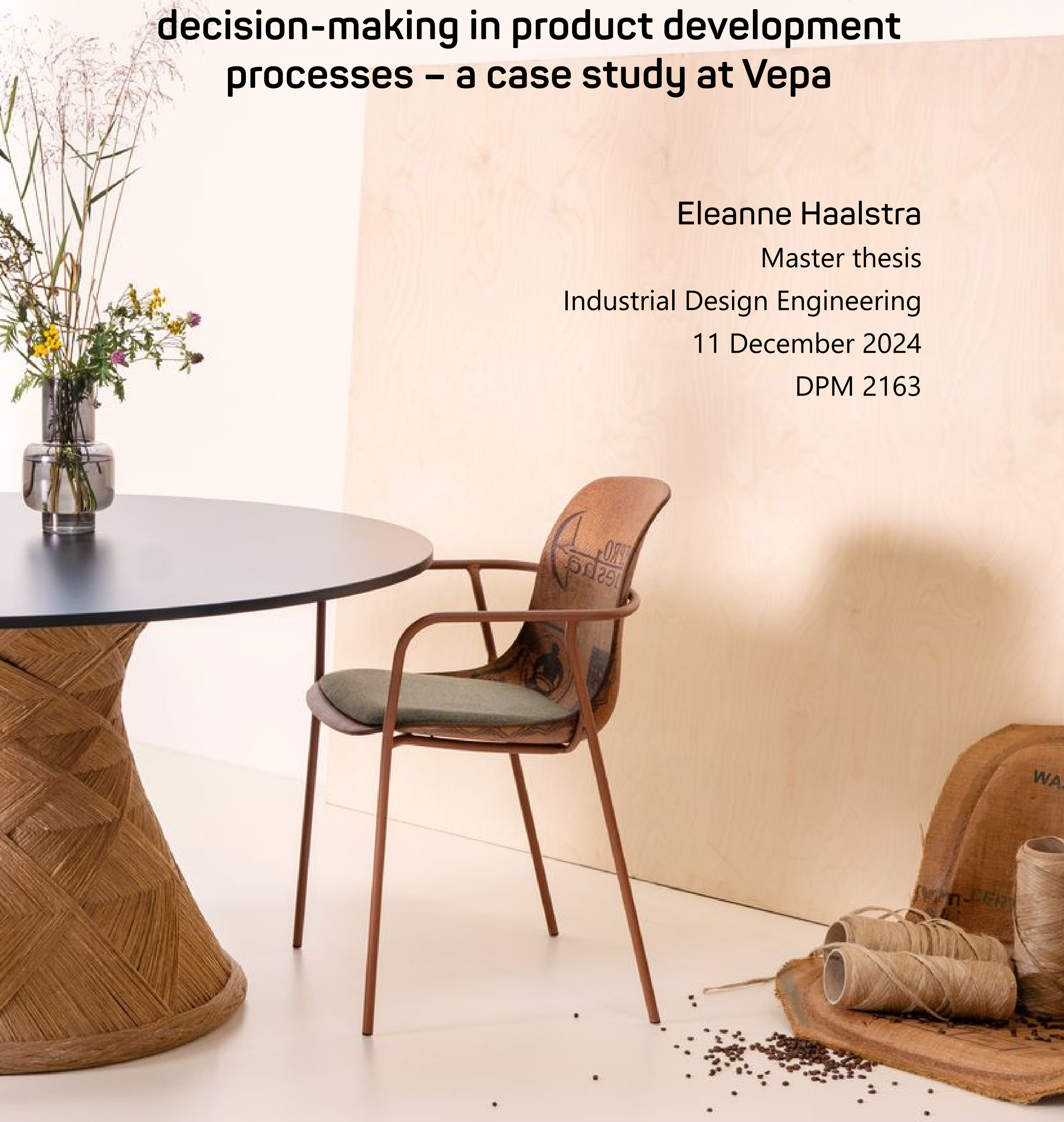
# Development of a solution to enable insightful decision-making in product development processes – a case study at Vepa



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vepa
the furniture factory

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# Preface

I am happy that I chose to study Industrial Design Engineering at the University of Twente six years ago. I have enjoyed both my studies and Enschede. As I near the completion of my Master thesis and have had my first eight months of practical experience in the field, I know for sure that I have chosen the right study. The combination of engineering and design has always appealed to me and will continue to do so.

I also value the experience I gained during this project. It was a magical moment to see my drawing on paper become a real product for the first time. I have realised that I enjoy engaging in the conversations and creative problem-solving that come with product development.

I finish my studies with pride and joy and I am looking forward to a job in product development where I can continue to learn and contribute.

# Acknowledgements

First of all, I would like to thank my supervisors for their support during this project. Gertjan, thank you for giving me my first practical insight into a furniture company, it has sparked my interest in the field. Thank you for supporting me in the development of the products, Vepa offers many opportunities. Eric, I would like to thank you for your guidance during this project and throughout my career at the UT. Our meetings always brought fresh insights and opportunities that I had not yet considered. There was always a solution and anything was possible. Of course, sometimes I was left with questions, but I guess that is part of the learning process. I would also like to compliment the program itself, both the Bachelor's and Master's, which I enjoyed.

Then I would like to thank Vepa, everyone was willing to help, share their expertise, collaborate and show me things. I would like to thank the hemp and production department, especially Daniel, for the support with producing the panels. I would also like to thank the product developers. Henk for sharing his insights and experiences from his own master's project at UT. Pieter, Mettina, Harry and all the product developers in Emmen for their contributions to my project.

I would also like to thank Plantics, especially Beer and Matthijs, for their assistance in developing the material samples.

Also, I would like to thank my friends. A special thanks to Esther and Laura, who have walked the same MoPD path. My housemates for providing the necessary distraction and conversations.

Lastly, a big thank you to my family. To my mother for driving along to Hoogeveen while discussing some of my experiences. My father for lending me the car, discussing some parts and sharing his view on management. My brothers, Matthias for his experience in the product development field, and Olaf, for introducing me to all the handy tools and skills I now use on the computer. Finally, to my boyfriend Jochem, thank you for all the brainstorming, checking my work and, most importantly, support and fun.

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# Summary

This research investigates how Vepa can enable insightful decision-making in its product development processes and develops a solution to this challenge through research by design.

Vepa has grown rapidly in recent years, leading to a feeling within the company that the current product development process is insufficiently supported to adequately fit the company's growth. Although Vepa has specific objectives for its product development, these are often not actively integrated into decision-making and clear decision moments are not always applied in practice.

Design for X methods were researched to identify key design factors and objectives for Vepa, including optimising for cost, sustainability, quality and modularity. However, these objectives often conflict, making trade-offs inevitable. Optimising these objectives is most effective when considered early in the design phase, rather than later when changes are more costly. To address these trade-offs, a conceptual framework of the development process was developed to foreground the important design factors and objectives. The framework was validated with an already developed product, a hemp chair, and demonstrated that decisions must be made at various phases, each affecting different attributes that influence Vepa's product development objectives.

The study also identified that insightful decision-making is difficult at Vepa due to unclear responsibilities, vague requirements and a lack of project planning and documentation. This results in decisions often being driven by gut feelings, taking too long to make, or being made under time pressure. These challenges highlight the need for Vepa for more insight into its product development processes, including requirements, responsibilities, planning and trade-offs, to enable better-informed decisions.

To address these challenges, a tool was developed through research by design by a case study of developing a hemp composite product for Vepa. The tool, developed in Excel and consisting of seven tabs, is designed to capture and communicate relevant project information, define clear product requirements, formulate a planning and visualise trade-offs effectively, all to facilitate insightful decision-making. The tool was validated with four products, seven end users and presented to senior management, all confirming its potential value in the product development process at Vepa. While some users noted that full integration might be a step too far for now, they all agreed on its potential to provide valuable insights. In addition, the product development manager also expressed confidence in its potential to improve decision-making in future projects.

This research concluded with a developed product that will be launched in mid-January and a tool that has proven valuable for Vepa's product developers and management. This tool enables insightful decision-making in product development processes for Vepa, and potentially other companies facing similar challenges, ultimately helping to stay ahead of the competition.

## Glossary

| | |
|---|---|
| **0-series** | The initial final product manufactured before full-scale production begins, also known as a pre-series or pilot production. |
| **Discrete product** | A final product that is distinct from one another and can be counted. Typically, it can be broken down in components [1]. |
| **EoL** | End-of-Life, meaning the moment a product reaches the end of its functioning and is no longer useful. |
| **Framework** | A conceptual scheme |
| **Head of Design** | A new function within Vepa, created in the later stages of this thesis. The person responsible for market research, portfolio management and new product ideas. |
| **Insight** | (The ability to have) a clear, deep, and sometimes sudden understanding of a complicated problem or situation [46]. |
| **Node** | A point in a diagram at which lines intersect or branch. |
| **Node attribute** | A property belonging to the node. |
| **PD manager** | Product development manager |
| **Pre-preg** | A pre-impregnated hemp mat with Plantics' biological binder. |
| **Plantics** | A company that develops a 100% biological binder. This binder is used in Vepa's hemp products. |
| **Special** | Customised product engineered-to-order with for example different sizes in comparison the standard product. Should often be delivered on the short-term. |
| **Sustainable development** | Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2]. |
| **Tool** | An instrument that enables performing a certain process within the overall development process [48]. |
| **Vepa** | A furniture manufacturer for the office, education and care sectors. The company includes four offices and three on-site manufacturing facilities, of which three are in the Netherlands and one in the United Kingdom. Unless stated otherwise, there is referred to the locations in Hoogeveen and Emmen since these product developers work in close cooperation. |

## Chapter

## .01

# Introduction

*This chapter begins with a brief overview of the project background, followed by an introduction to the company. Subsequently, the problem statement and the approach are described. The chapter also presents the value proposition and project scope. Finally, a schematic overview of the thesis contents is provided.*

## 1.1 Project background

Vepa the furniture factory, hereafter referred to as Vepa, is a manufacturer of furniture for the office, education and care sectors. Vepa developed the Hemp Fine chair, which contains a seat shell made of a hemp composite material. Vepa aspires to incorporate this material into more of its products, which served as the starting point for this thesis. Vepa is a growing company and succeeds in continuously bringing numerous products onto the market and generating profits. Despite these achievements, there is still a potential opportunity for improvement in its product development processes and related decision-making. This thesis focuses on finding and developing a solution for Vepa, using a case study approach, to provide it with insight into its product development processes in order to improve decision-making, ultimately leading to efficient product development.

## 1.2 Company introduction

In 2020, Vepa merged with Drentea in Emmen, which focused on producing steel parts. Vepa now has three offices with on-site manufacturing facilities, located in Hoogeveen, Emmen and Wijchen. Hoogeveen focuses on producing office furniture, Emmen on producing steel parts, and for two years also contains the hemp department, and Wijchen mainly produces educational furniture. Vepa started small in 1951 and has grown into a large company with around 150 employees and a factory with a surface area of over 60,000 m2 [3]. While writing this thesis, Vepa is still growing. Recently Vepa built an extra fully automated machine park, bought a new factory and hired new product developers. The company's recent growth presents potential challenges in terms of understanding and controlling its product development processes. Vepa is one of the leading furniture manufacturers in the Netherlands. Vepa distinguishes itself by manufacturing most of its products and components in-house, rather than acting merely as a product assembler only putting together components, as with some of its competitors.

The product developers in Hoogeveen and Emmen cooperate, with Wijchen operating as a distinct entity. Therefore, from here on, Vepa refers to only the facilities in Hoogeveen and Emmen. The product development team consists of ten people divided over the two locations and has one design manager. Vepa has product developers with varying levels of experience and backgrounds. Some have been with the company for over 40 years, while others have just started. All in all, there is plenty of experience within the company.

Vepa is part of the Fair Furniture Group (FFG), which started working together in 1998. The FFG consists of seven companies all focusing on furnishing. The FFG aims to build a future-proof economy by being fair to people, society and the planet. They want to be a leader in the industry with clean, sustainable and circular products [4]. Being sustainable and producing locally and circular is a central point within the FFG and therefore also for Vepa.

### *1.2.1 Hemp*

The commitment to sustainability was one of the reasons for Vepa to go into cooperation with Plantics, a company that develops a biological binder [5]. Together, they have developed a new material, namely hemp fibres and a bio-resin, from now on referred to as hemp composite. This material is 100% plant-based and biodegradable and will be explained in more detail in section 4.2. Vepa has already achieved to develop a seat and stool shell with the material, as shown in Figure 1, but wants to incorporate this fully biological and renewable material in more of its products. In doing so, Vepa capitalises on the biological cycle of the butterfly model, which will be explained in more detail in Chapter 3 of the report. Therefore, the question arises for the development of a product with the hemp composite for Vepa, a design project starting from a material. This design project is used as a case study in this project, as described in Approach, to arrive at a solution that responds to the challenges in product development related to Vepa's recent growth. Figure 2 shows the hemp department in Emmen.

**Figure 1** Hemp chair and stool

**Figure 2** Hemp manufacturing department

## 1.3 Problem statement

The initial objective was to identify new applications and good ways of incorporating the hemp composite into Vepa's products and to develop this product. However, as the development of this product progressed, it became apparent that the product development process within Vepa was a challenge for multiple reasons. Along the process, it was found there is a growing feeling in the company that the current product development process is insufficiently supported to adequately fit the company's growth.

Much of the daily working knowledge of Vepa resides in the employees' memory rather than being centrally available and easily accessible. Within Vepa there is no way yet in which project information is documented in a structured manner. There was little documented information available at the start of the design project. During decision-making processes, opinions from different experienced individuals play a major role rather than information or consultation outcomes. There is often a lack of clarity regarding the project status and the boundaries of the roles of the individuals within the project team. The design team is located at two different locations which further complicates communication. All in all, there is little structure and insight into the product development process which complicates decision-making.

These observations align with findings from interviews with the internal director, product developers and manufacturers as confirmed in Appendix O. Vepa's director expressed their intention to adopt a more structured approach to the product development process. The company aims to achieve more explainable behaviour, make better-informed decisions, and have the ability to recall the reasoning behind specific choices. Commenting on the current situation, the director stated:

> ***"Many decisions and trade-offs are made based on gut feeling"***

During this thesis, several problem statements at different levels will be discussed. As explained, the primary research question was found and clarified at a later stage and is stated as follows.

***How can Vepa improve decision-making in its product development processes?***

To answer this main question, the following sub-questions are formulated and will be answered.

1. *How does Vepa currently approach its product development processes?*
2. *What are the important design factors and design evaluation perspectives and their relationships in the product development process for Vepa?*
3. *What opportunities exist to improve Vepa's decision-making in its product development processes?*

After answering these questions, the following question could be answered.

4. *How can a solution assist in improving decision-making in Vepa's product development processes?*

In Chapter 5, this question will be further specified in sub-questions, as the current level of knowledge does not allow for a more detailed formulation. By conducting various types of research in the earlier chapters, it will become possible to refine and elaborate upon the formulation of this sub-question. Nevertheless, it is already assumed that having the right insights into various aspects of the product development process is closely related to decision-making. In any product development process, the ability to make informed decisions at the right time is crucial for ensuring the competitiveness of a company [6].

## 1.4 Approach

The research questions will be answered through research by design, where designing is a substantial part of the research process [6]. Developing a product with the hemp composite will serve as a case study to develop a possible solution for Vepa to provide it with more insight into/ enhance decision-making its product development processes. It is planned to go through almost the complete development cycle of one product to ensure that every stage of product development is addressed.

To develop a product for Vepa using the hemp composite, knowledge should be gained about the current material developments and possibilities. This will be achieved through interviews with product developers involved in creating the hemp composite chair shell. Plantics, the inventor of the bio-resin, will be visited as it is closely involved with the development of the hemp composite. The production challenges and successes of the hemp chair shell will be investigated. It is assumed that knowledge on the material and the tried production methods so far will be gained. A potential risk is that information resides in the heads of many different people, making it a time-consuming process to collect the necessary information. Unexplored possibilities in the production methods of the material will be explored by creating several material samples with Plantics' small hot flat press, deepening understanding of the material, process and function relationships. Once a product concept is defined, prototypes will be developed. New problems can arise from prototyping, since an idea on paper is different from a tangible product and should be solved accordingly. Unknown values about the material that are relevant to the to-be-designed product will also be investigated by testing. A potential risk is the inability to find and develop a suitable application for the hemp composite.

To gain knowledge about the current state of Vepa's product development processes, time will be spent in the company during which interviews will be conducted with various product developers and departments. Past project documents, if available, will be reviewed. Product development consultations will be attended. Most importantly, direct involvement in the development of a product at Vepa is expected to provide the clearest insights into Vepa's product development processes.

To identify key design factors and evaluation criteria for Vepa, both literature reviews and interviews with Vepa's employees will be carried out. The literature review focuses on a general introduction to product development and existing design methods relevant to Vepa. To know what factors, methods and relationships are specifically relevant to Vepa, several employees from different departments will be interviewed and products of Vepa will be analysed. A framework will be developed to contribute to a better understanding and application of the information.

To offer Vepa a solution to improve decision-making in its product development process, findings from the literature review, company observations and interviews and case study will be integrated. Potential areas for improvement will be formulated. This is described in Chapter 5. The solution will be evaluated by applying it to different product development projects and verifying the results through discussions with Vepa's product developers and management.

## 1.5 Value proposition

The envisioned future for Vepa is one where the product development process is characterised by efficiency, transparency and insight into ongoing projects, and where critical information is never lost. A working methodology where all team members are aligned in terms of goals and responsibilities is aspired. Each product requirement would be well-defined and all relevant information is easily accessible. Ideally, the design team is already informed on each other's projects and when consultations take place, the group can address only the critical issues. The individuals would feel accountable for their roles. Decision-making processes would be well-founded and data-driven, with alternatives considered and the important decisions well-documented and traceable. Prototyping would be carefully considered, allowing early identification of potential design problems and reducing the need for many iterations and the high cost of change in later stages. Overall, the aspired value is an efficient product development process that minimises frustration and costs and ensures transparent decision-making while improving product quality.

## 1.6 Scope

The scope of this report is on product development within Vepa at the locations Hoogeveen and Emmen, excluding the broader FFG context. The value proposition describes an ideal future scenario that cannot be fully achieved within the 8-month time frame of this thesis. However, the proposed solution and connected way of working aim to initiate steps toward achieving this envisioned future. The solution is developed for and from the designer's perspective. It focuses on effective project management when the initial project description is available, rather than generating new design ideas, an area where Vepa does not currently face challenges.

As stated, to arrive at this solution, the important design factors and their relationships during product development will be formulated first and a framework developed. These are based on the relationships within Vepa but may be applicable in a broader context, particularly for other furniture manufacturers. This context is limited to discrete manufacturing companies, that develop tangible products, and not process manufacturing companies that develop e.g. oil or software. For process manufacturing companies, the developed relationships are not relevant.

Although this report does not cover implementation and monitoring of the solution, an implementation plan is included and partially executed. Implementing a solution is likely to require a change in employee attitudes, which is beyond the scope of this report. Changing the culture of communication within Vepa is not part of this research and requires more time. Similarly, while a well-defined business strategy supports effective product development, refining Vepa's business strategy will not be addressed in this report.

Nevertheless, although the research, solution and accompanying approach are tailored specifically to Vepa, the findings may also apply to different companies facing similar product development objectives and challenges.

## 1.7 Thesis structure

Figure 3 presents a schematic overview of the thesis contents and information inputs.

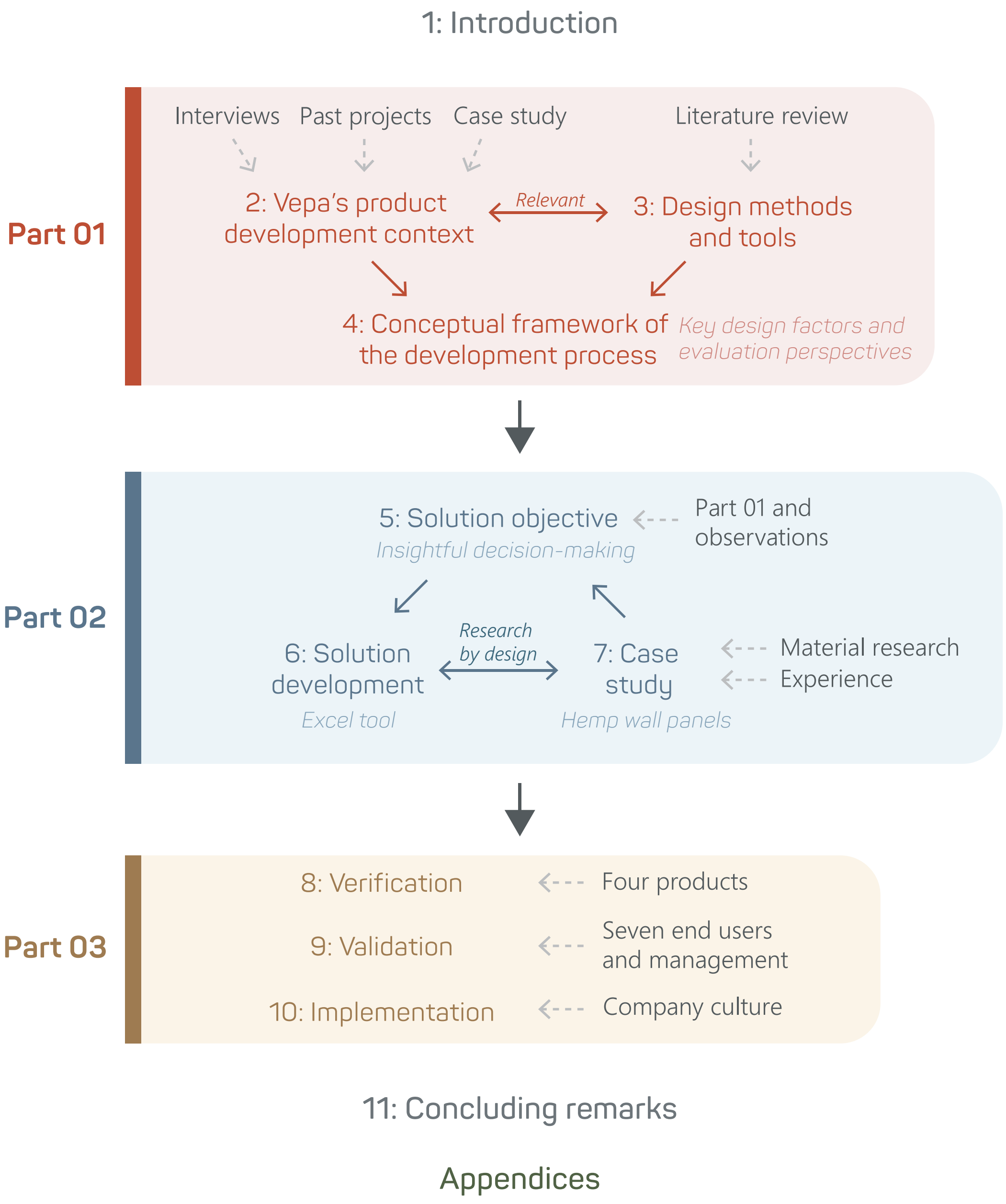


**Figure 3** Schematic overview of thesis structure

# Part .01

# Vepa's product development context

*Having introduced Vepa and formulated the problem statement, in chapter two, discrete product development and in chapter three, existing design methods and their relevance for Vepa will be explored. This part concludes with the development of a conceptual framework of product development in chapter four.*

Chapter

# .02

# Product development

*This chapter outlines the design process in general and for Vepa. Common stakeholders, used systems and tools and product complexity are explained. It ends with Vepa's strategy.*

## 2.1 Design process

### *2.1.1 General design process phases*

To understand the product development context at Vepa, it is first important to give a general introduction to a design process. A design process often starts with a market need or a new idea [8]. The first step involves defining all the (customer) needs that the product must address. These are the design requirements and translate the *functions* the product should have. The design requirements typically include 'must' criteria, that must be met, and 'wishes' that are nice to have but are not essential. Then the design process, in which the product requirements should be translated to a working product that satisfies the requirements, can begin. The design process can generally be described in three phases: conceptual, embodiment and detail design [8, 9, 10].

In the conceptual phase, concepts are being developed and the most promising are selected by evaluating against the design requirements. Still, all options are open. If the concept is feasible, the designer proceeds to the embodiment phase.

At the embodiment phase, the most promising concepts are developed further, with size and overall shape defined and *materials* considered that meet the requirements. Prototypes are often made for proof of concept. Initial performance and cost estimates are also made. If the outcome of these estimates is positive, the designer may then proceed to the detailing phase.

In the detailing phase, all aspects of the design are finalised, and a final choice of *shape* is made. Shape is the external geometry of a product and refers to the larger external shape, the macro-shape, and the smaller structure of the material, the micro-shape. Finally, the material and manufacturing *processes* are chosen.

By the end of these phases, the full product specification, the outlines of what the product is, is available. The product is ready for production, ensuring that the initial design requirements are successfully translated into a functional and manufacturable product.

The design process is not a linear process, but rather an iterative process, where multiple possible solutions are generated and evaluated against the established requirements and alternative solutions [11]. There is a strong link between the three phases as illustrated in Figure 4. Think of each of the many choices that could be made as a sequence of the circles in the design space. Where C1, C2, ... are possible concepts, E1, E2, ... are possible embodiments and D1, D2, ... are possible detailed elaborations [8].

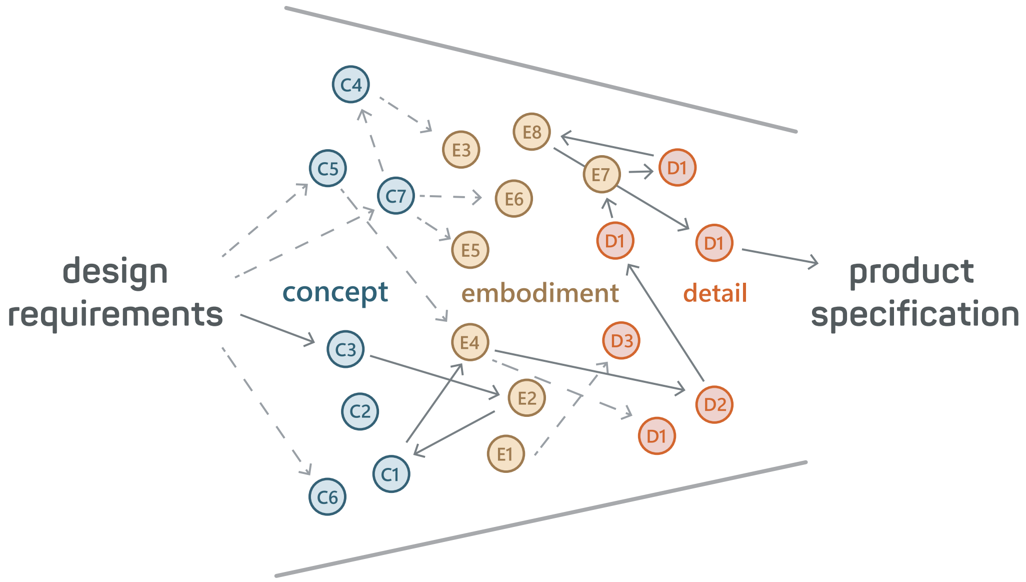


**Figure 4** From requirements to product specification (adapted from [7])

The path from the design requirements to the product specification should be determined. As can be seen, going back and forth between phases also happens. Iteration and looping back to explore alternatives, and therefore being flexible and the ability to explore alternatives quickly, is an essential part of the design process. The design starting point is vague and uncertain and ends up with a complete product specification answering the initial questions and corresponding design requirements, symbolised by the converging lines. All in all, the exact process to follow is unclear at the start of the process and is clarified during the project by learning during the execution of the project [6].

### *2.1.2 Vepa 's design process*

How does Vepa find the path from the design requirements to the final product? And what stages does Vepa have in its design process? Roughly spoken, Vepa currently manages its design process including three go/no-go moments discussed with the product development department. These moments are after defining a list of requirements, a (final) prototype and a pilot run. The overview of the design process is shown in Figure 5. Next to these go/no-go moments, there are also monthly consultations with the product development team to be able to discuss and keep each other up to date. Each project has one main responsible person. The design manager is the overarching manager of all the projects.

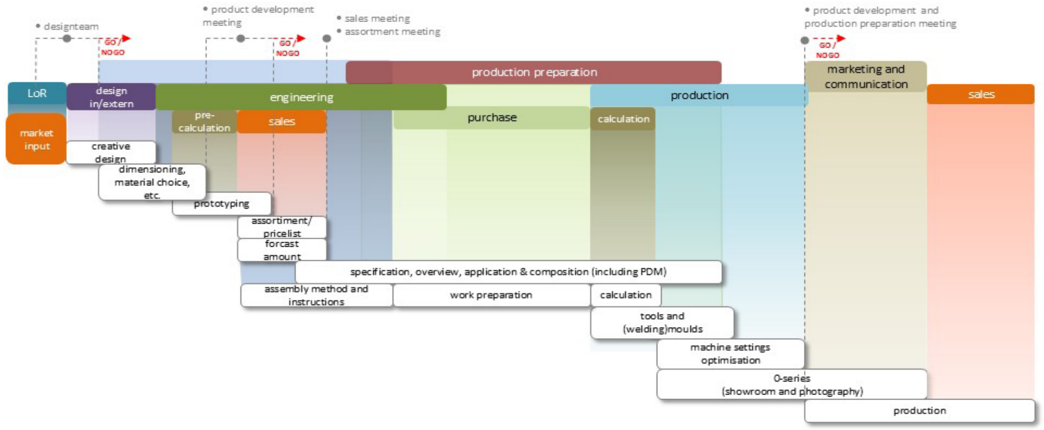


**Figure 5** Process steps product development (adapted from Vepa translated into English)

The process steps can be explained as follows. Although not explicitly outlined by the company, its development process can also be associated with the phases of requirements, conceptualisation, embodiment, and detailing.

A project starts with formulating requirements for the new project, either set by the company or provided by a client. Vepa works with the same clients but also finds new clients, therefore design initiatives are initiated from various starting points. Market research is also executed to indicate if the project is promising. An example requirements document for Vepa is given in Appendix E and will be discussed in more detail in section 5.1. The requirements are reviewed both with the product developers and the sales department, leading to an initial go/no-go decision on starting the project and thus proceeding to the conceptualisation phase.

Next, the conceptualisation phase begins, which means for Vepa that rough ideas and sketches are formulated. Sometimes, external designers are hired. Once a concept seems feasible, dimensions and materials are chosen, and a CAD model is developed.

Prototyping follows, part of the embodiment phase, and plays an important role in the development of Vepa's products. Both product development and manufacturing operate under the same roof, allowing for relatively quick collaboration. If the prototype is not satisfactory, a step is taken back, and the design is adjusted accordingly. Once satisfied with a final prototype, the project moves into the detailing phase.

In the detailing phase, the product is further engineered, meaning that all aspects of the design are finalised. Often consultation with the manufacturers occurs. Now the full product specification is ready, and the product is prepared for production. Sales and procurement help predict sales numbers, while production and calculation predict the price. The final assortment is determined. A pilot run of the final product is executed leading to the last go/no-go. If needed, the detailing phase should be executed again. In practice, however, Vepa's product development process does not always follow a formalised structure, and clear decision-making moments may not occur or may be made inexplicitly as elaborated upon in section 5.1.

As the industry is not a uniform domain, the link to the organisational context of Vepa will also be made, the framework developed by Nieberding [12] was used to describe the organisational context and the considered products are shown in Appendix A. Vepa's product development is mostly about batch production, e.g. 200 pieces. The product quantity affects the optimum trade-off between development time and production cost. For larger quantities, more time can be spent on development. Sometimes it is about new product development, designs that have not been developed before by Vepa or any company at all, and sometimes it is about redesign, where a product is adjusted, or a variant is made. Vepa's projects vary greatly in size. Some larger projects involve designing completely novel products where multiple people from the design team are involved. Also, projects exist where small adjustments to an existing product must be made and are handled by a single person. The product complexity is closely related to the project's complexity [12]. Vepa develops its products by make-to-order. Occasionally, Vepa develops customised products, called 'specials', which are engineered-to-order. Specials are often small projects and in that case, the approach is often less structured and "just do it" because of lower risks. This is also verified by literature [13]. Vepa has both short-term, e.g. 3 weeks, and long-term, e.g. 3 years, projects. The current product mix offered by Vepa is shown in Figure 6. The yellow products have been launched and the light blue products are ongoing projects during the eight-month time frame of this thesis.

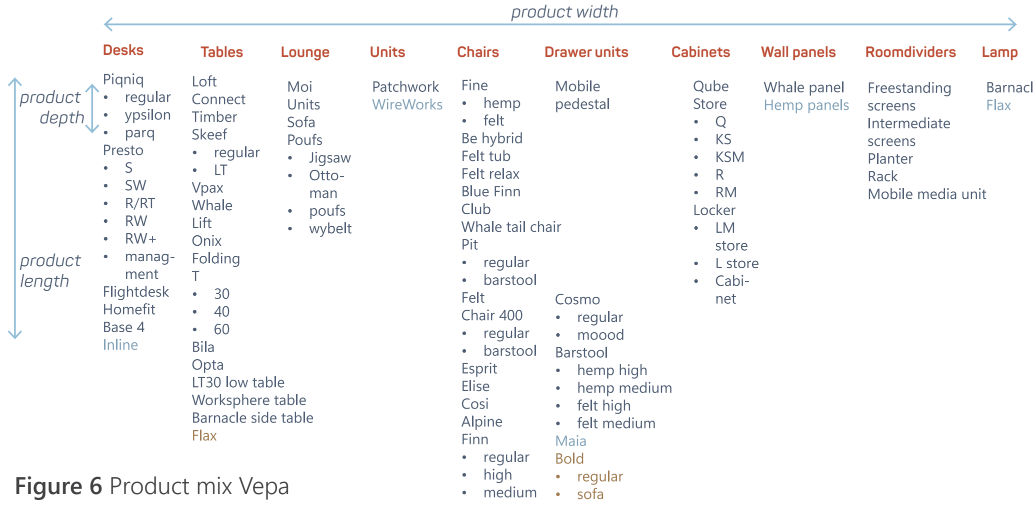


**Figure 6** Product mix Vepa

### 2.1.3 Stakeholders

Vepa is responsible for the entire product development process and not only for the design process, from generating its product definition to creating prototypes and final products to bringing it on the market. Vepa markets their products themselves and provides the service of setting up the furniture on-site. Various internal and external stakeholders are involved in Vepa's product development.

Figure 5 also shows the internal departments. Vepa contains the following departments: management, finance, indoor sales, outdoor sales, indoor international, outdoor international, order team, ICT/automation, marketing, studio, purchase, calculation, production preparation, supervisors, product development and production. For large projects, consultation occurs across many departments, while for smaller projects only a few people are involved. Currently, mainly production and product development are involved during product development.

External stakeholders include customers, tenders, dealers, architects, suppliers, sometimes external designers and suppliers' suppliers. Applications almost always go through a tendering process, where clients set the requirements for products and services that Vepa must deliver. When Vepa wins the tender, they get the job. Because it goes through a tendering process, the market competition plays a large role for Vepa. As explained, depending on the project, Vepa may either develop its own requirements or adhere to imposed requirements by clients. Vepa has both long-term clients but also often new clients. Sales are always made through dealers, like in the automotive industry.

The product developer is a central link between all these stakeholders. These stakeholders often have various interests as explained further in section 3.3. The designer influences outcomes that impact these varied interests, making the responsibilities for design decisions significant.

### 2.1.4 Systems and tools

Vepa utilises an Entreprise Resourse (ERP) system. The ERP system contains information on all the product's parts and costs and the orders are entered in there. Only a few individuals have the authority to make edits in this system. The Computer Aided-Design (CAD) drawings are made with SolidWorks. This is the support that is most used by Vepa's product developers. These drawings capture essential product information. However, the CAD files currently serve as the most comprehensive documentation of the decisions made during the development process. To manage all the CAD files, a Product Data Management (PDM) system is used, PDMWorks. This way, it is ensured that team members are always working on the latest versions and can share their files. Vepa does not use product lifecycle management (PLM) software. Moreover, the product development team and the entire company, rely mostly on calling, Email, Word, Excel and PowerPoint for communication during product development projects. One disadvantage of this approach is the potential for a significant volume of text to be exchanged, with no centralised location or single source of truth for the provision of information.

## 2.2 Product

### 2.2.1 *Interaction material, function, process and shape*

As described in section 2.1, during the design process the selection of a material and process cannot be separated from the choice of shape and function [8, 9]. This interaction is illustrated in Figure 7. From now on, these elements will be referred to as “nodes”.

To make a shape, the material is subjected to a manufacturing process. These processes include primary forming, material removal, finishing and joining processes. The function determines the choice of material and shape. The process is influenced by the material. The process also determines the shape. The interactions are two-way. Specifying the shape also limits the choice of material and process but equally specifying the process also limits the materials that can be used and the shapes they can take. The relation between process and function could not be found in literature but will be elaborated on in section 7.1. Consequently, material, process, function and shape interact. This interaction is seen as the central challenge within mechanical product development [8]. This interaction happens in discrete manufacturing (production of discrete products like furniture), as opposed to process manufacturing (production of homogeneous goods like oil). Furthermore, in industrial design, as opposed to mechanical design, function not only refers to the technical functioning but also considers aspects such as aesthetics, ergonomics and usability.

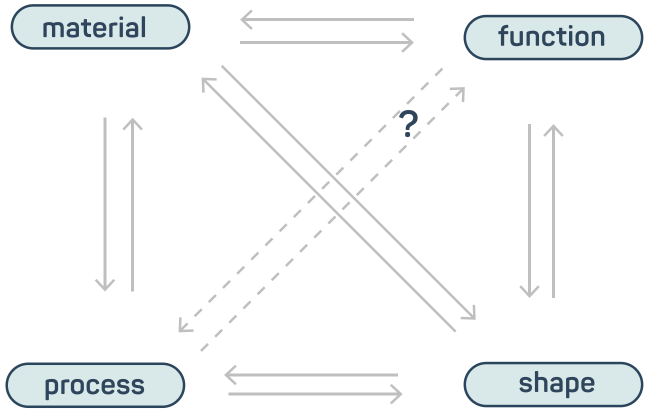


**Figure 7** Interaction material, function, process and shape (adapted from [8])

### 2.2.2 *Product complexity*

To better understand the interaction between function, material, shape and process in product development, an assembly tree of Vepa’s ”Felt Relax” chair was created and is shown in Figure 8. A product consists of an assembly with multiple parts and sub-assemblies with parts in them. Each part has its function, material, shape and process. The assemblies and/or parts are held together by connective parts. Note that an assembly tree is different from a process tree, which is a sequence of steps required to manufacture the product.

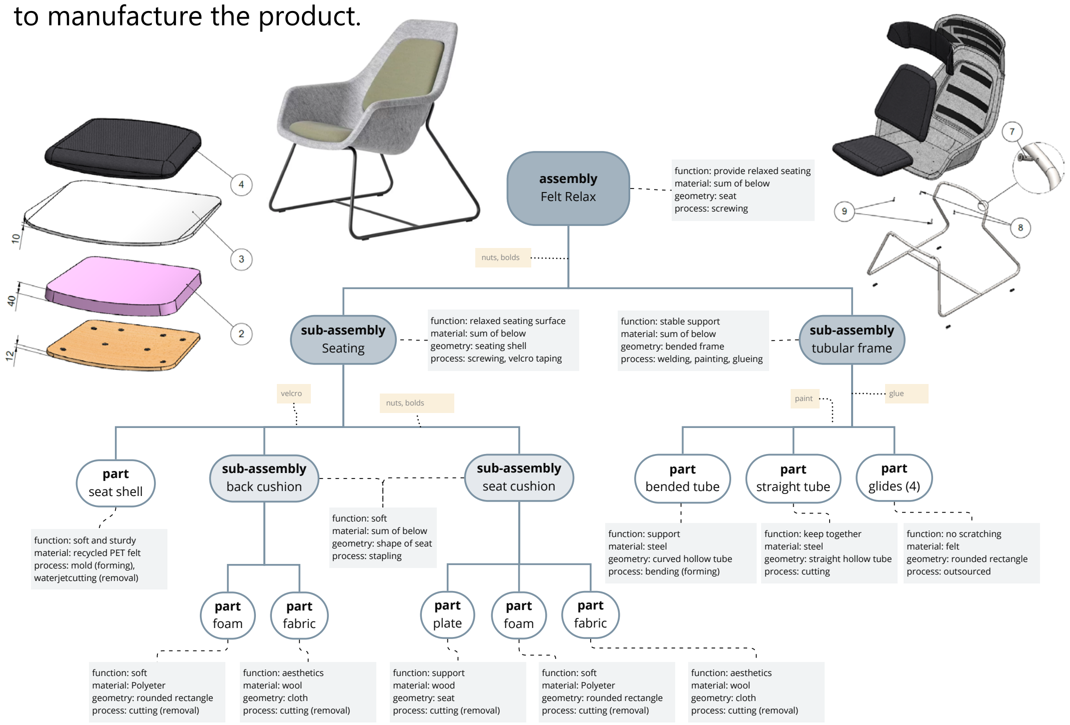


**Figure 8** Assebmly tree of Vepa’s ‘Felt Relax’ chair

The Felt Relax is a typical product from Vepa, comprising fewer than ten sub-assemblies. It incorporates materials commonly used by the company, including felt, steel, foam, fabric and wood. Unlike the complexities involved in designing an airplane, with its thousands of sub-assemblies and parts, furniture manufacturing is a low-technology industry. It does not rely on the most advanced technologies but can focus on optimising existing ones, providing room for focusing on higher objectives, for instance, costs or sustainability. Additionally, fewer regulatory constraints make product changes are easier to make. The relatively low complexity of products allows the product development process to be managed without extensive structural guidance to the product development team but this does not imply that there is no room for improvement.

Vepa manufactures most of its parts in-house, while some parts, like woodwork and connective parts, are outsourced and then assembled on-site. This approach differs from companies, like bike-selling companies, where assembly is the primary focus.

### *2.2.3 Product life cycle*

Every product and part of the product has its own life cycle. The product life cycle encompasses all issues from the beginning to the end of the existence of the physical product, often referred to as “cradle to grave”. It includes production, use and disposal. In a linear view, as depicted in Figure 9, the product life cycle begins with raw material extraction and is followed by manufacturing, distribution, use and ultimately, disposal. The non-linear, circular, view of the product life cycle is described in section 3.1.1. The production phase includes sourcing raw materials, manufacturing the parts and manufacturing the product. Raw materials can be either mined from finite resources or harvested from renewable resources. The materials are then made into parts by a parts manufacturer and assembled by a product manufacturer. The completed product is then sold, distributed and transported by a service provider to get to the end user. After the use phase, the product will ultimately be discarded as waste.

Vepa is involved with almost all the stages of the product life cycle, from manufacturing the parts, assembling the product to providing service. Consequently, for Vepa it is important to think not only about the production and use phase of the product, but from raw materials extraction to the disposal phase. By producing most of its components internally, Vepa has significant influence over the company’s broader strategic objectives.

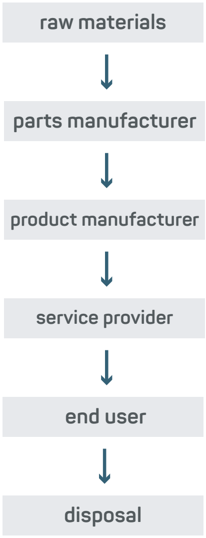


**Figure 9** Linear view product life cycle

## Vepa’s strategy

A company’s strategy outlines what the goals of the company are and how the company will act to reach those goals, ultimately to achieve competitive advantage. Ultimately, any company should generate profit to survive. But how to generate profit? For Vepa, this involves winning tenders and on occasion selling specials with higher profit margins. Continuous new product development and innovation are critical for growth and market relevance.

Referring to the product mix shown in Figure 6, new products must fit into this product portfolio. Some products are flagship products, like the hemp chair, that tell a story of how Vepa wishes to be seen by its clients. These products also contribute to the perceived innovativeness of the brand [14]. Usually, these ‘flagship’ products are not the highest in sales numbers, nor do they generate the most profit. On the other hand, other products, like a desk, are more of a commodity product that serves as a steady revenue generator and is produced in large quantities. However, it often lacks differentiation, and it is often perceived as interchangeable with similar products from other brands, where price is the primary factor influencing purchase decisions.

Satisfied clients will only be achieved if the products are delivered within a given time, at a price that reflects the value and if the product successfully serves the purposes of the user [15]. Clients often ask architects to help them with furnishing their offices, therefore the products should also appeal to the architects mainly in terms of aesthetics.

While providing the products to the end users, Vepa also aspires to achieve and represent core values. The company aspires to be a leader in the production of sustainable products, by striving for locally produced products, upcycling products and applying the principles of the butterfly model [16]. Sustainable development is ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ [2]. In addition, Vepa wants an approachable and transparent relationship with its customers. In Figure 10 Kapferer’s brand identity prism [17] is shown for reference as formulated by the author of this report and verified with the marketing department.

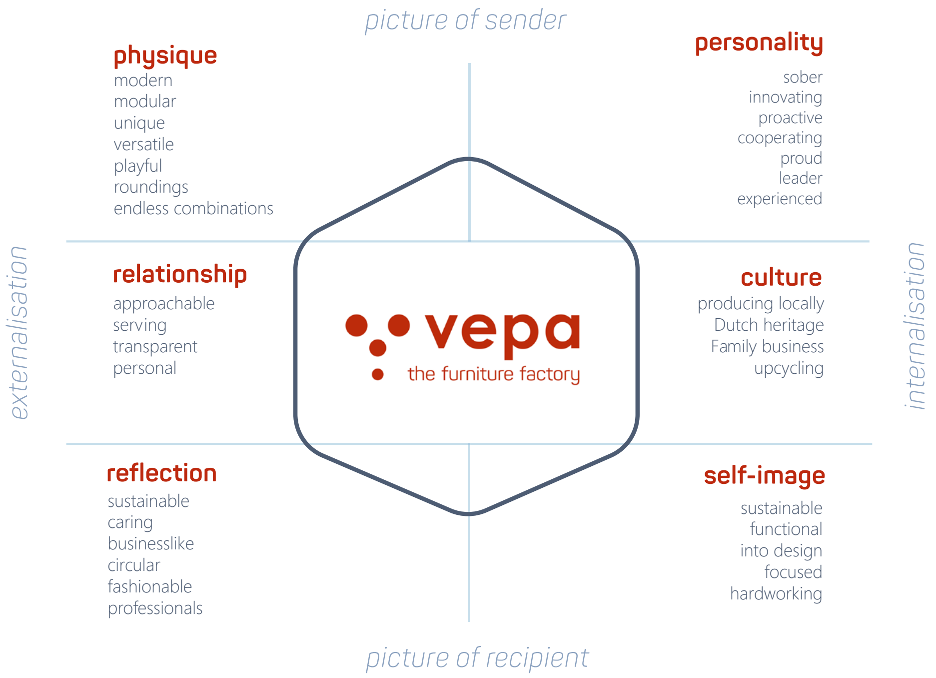


**Figure 10** Brand identity prism

To develop products that reflect Vepa’s brand identity, the primary responsibility ultimately is the designer. Insights from past projects, consultations with product developers and the director and a review of the company’s website reveal several factors that play or should play an important role in Vepa’s product development. Vepa aims to design products that are environmentally friendly, circular, easy to maintain, modular, easy to manufacture and assemble, cost-effective and of good quality.

These objectives are in line with Vepa's product portfolio, especially as the company's in-house manufacturing and assembly capabilities provide significant control over these factors. However, the absence of formal processes to ensure the consistent integration of strategic objectives, such as sustainability or modularity, into the design process could limit the company's ability to fully realise its ambitions. As Vepa is growing, along with its product mix and development team, formalising the integration of strategic objectives into its product development will be crucial to maintaining or supporting effectiveness of its product development. Therefore, in the next chapter, these objectives will be further explored.

## 2.3 Conclusion

The goal of this chapter was to provide a base understanding of product development, both in general and for Vepa specifically. The typical stages of the product development process include requirements formulation, conceptual, embodiment and detailed design, followed by manufacturing. Vepa also follows these stages and includes decision moments during this process after formulating the requirements, making a prototype and pilot run. Managing the interaction between material, function, process and shape is a core challenge in product development. Designing is a complex and iterative process. Vepa is responsible for the complete lifecycle from developing the designs to taking back products. Many internal and external stakeholders are involved, further complicating the process. To support its product development, Vepa utilises systems like ERP, SolidWorks and PDM, while communication tools mainly include Excel Email and Powerpoint. These systems do not necessarily ensure company objectives are consistently met. Vepa's projects and products vary in complexity, from simple adjustments to new designs. However, it is always about a low-technology industry characterised by less components and regulations, allowing for more flexibility and optimising on higher objectives. While these objectives, like sustainability, modularity or cost-effectiveness, are somewhere present, Vepa does not yet formally integrate these principles into its product development. There is currently no explicit way of working to ensure that these goals are implemented by the product development team. Additionally, the objectives of the product are not always explicitly stated. As a result, for Vepa it might be a challenge to efficiently find the path from the design requirements to the product specification and finally production. Consequently, further research is needed to explore the specific aspects of (DfX) methods and tools that Vepa is seeking to integrate to achieve its strategic goals.

# Chapter

# .03

# Design methods and tools

*This chapter explores the specific aspects of the (DfX) methods and tools that Vepa intends to integrate in order to achieve its strategic goals. Firstly, the DfX methods are described and the link with Vepa is established. Second, complementary and contradictory relationships are described. Finally, multiple perspectives on product development at Vepa will be explained.*

By looking at past projects of Vepa and interviews about what Vepa finds important it was identified what methods Vepa, explicitly or implicitly, wishes to include in its development process. Vepa wishes to include aspects of Design for Environment (DfE), Design for a Circular Economy (CE), Design for Manufacture and Assembly (DfMA), Design for Maintenance (DfMai), Design for Quality (DfQ), Design for Modularity (DfMod) and Design for Cost (DfC). Since there are so many 'design for ...' techniques, in 1983 the term "Design for X" appeared [15]. Where the X represents the many possible values that are important during product design. The many existing methods are shown in Appendix B. The many design methods already reveal that while managing the interaction of function, process, shape and material, many different aspects are influenced.

The design methods and their advantages and disadvantages are explained in this chapter and the connection is made with Vepa. Because Vepa seeks to work with a new material and this may happen more often in the future, the design method Material Driven Design is also discussed. Some closely related tools will also be described. Their cohesion will also be described.

The following are described:
Methods: DfE, CE, MDD, DfMA, DfMai, DfC, DfMod, DfQ
Tools: LCA, NPR 8313, CES Edupack

This chapter forms the base to take inspiration from these methods, of the subjects that Vepa finds important to include in its development, should be considered when making decisions and therefore should be integrated into the solution.

## 3.1 DfX

### *3.1.1 DfE*

The DfE concept aims to minimise the environmental impact of providing products and services. This is often achieved by reducing the amount of energy and materials used to provide the products and services [18]. To keep machine and inventory costs to a minimum, companies like Vepa often want to use the materials (and machines) they already have. As a result, for a company like Vepa, the link with materials is often already present and not a completely open choice. Therefore, minimising environmental impact can mostly be reached by minimising the amount of material or energy use.

Design decisions inherently have a profound and complex effect on the overall environmental impact of a product. Therefore, significant environmental improvements can be achieved by integrating environmental properties as an optimisation parameter during the design process. The material content, processing routes, efficiency during use, maintenance and recycling are important parameters of environmental effect and a cradle-to-grave approach is needed [19]. However, identifying the most impactful stage in the product's life cycle or supply chain to win the largest environmental impact remains a challenge.

Currently, a life-cycle-assessment (LCA) can be seen as the main tool for gathering information on the environmental impact of a product. An LCA involves a thorough inventory of the energy and materials used in the supply chain and product, and calculates the corresponding emissions to the environment accordingly [20]. Vepa also conducts LCAs on its products. However, these assessments are regarded as an outcome the product development process rather than as an optimisation factor integrated into it. As a product developer mentioned, the LCA is seen as the responsibility of the individual performing the calculations, instead of the entire company feeling responsibility for it.

A further challenge is that when optimising the environmental impact of a product often results in increased costs. Clients may not be willing to pay these higher costs unless the benefits are clearly communicated. Therefore, it is valuable to be able to demonstrate the environmental benefits for companies like Vepa.

### *3.1.2 CE*

Next to designing for the environment that aims at minimising the environmental impact while providing goods and services, there is another method that relates to DfE. This is called designing for the Circular Economy, meaning to upgrade the linear take-make-dispose economy to one where materials never become waste and nature is regenerated [21]. The Ellen MacArthur Foundation has developed the butterfly model for circular economy. The circular economy is based on three principles: eliminate waste and pollution, circulate products and materials (at their highest value) and regenerate nature. The butterfly model also aligns with the view of the Rijksoverheid on furniture, and the R-ladder which both emphasise the importance of Rethink, Reduce, Reuse, Repair, Recycle and Recover [22]. Vepa is aware of the butterfly model and aims to include these CE principles in its products.

The butterfly model has two material cycles, the technical and the biological, and is shown in Figure 11 on the next page. Note that the middle part shows the linear life cycle mentioned earlier in section 2.2.3.

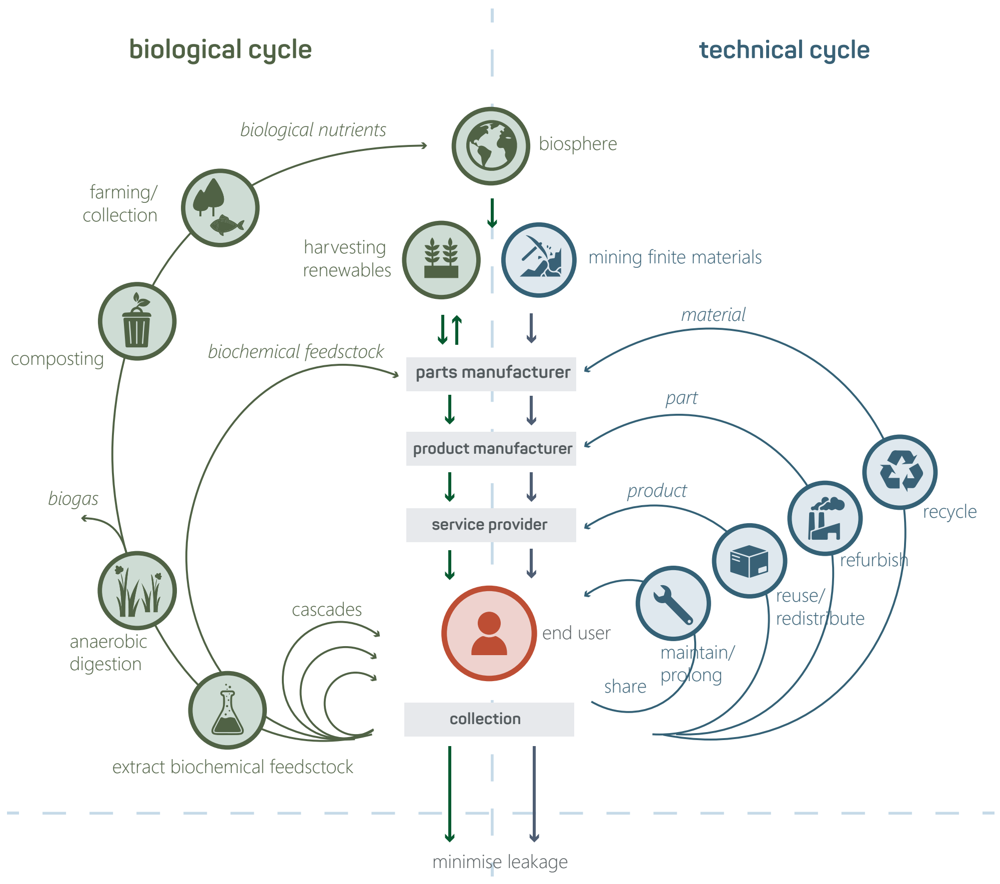


**Figure 11** Butterfly model for CE (adapted from [X])

The technical part (right side) includes durable materials that are continuously circled after their first use, preventing the discarding of the materials. This is helpful because the embedded labour, energy, material and costs are preserved. Products and materials can be kept in circulation by sharing, maintaining/prolonging, reusing/redistributing, refurbishing/remanufacturing and lastly recycling. Therefore, it is important to design with the intent to facilitate these processes, ensuring the product has the longest possible lifespan. The biological cycle (left side) is for materials that can biodegrade and safely return to the earth. It is about regenerating the earth, not only doing less harm to the environment but actively improving it. This can be done through farming, composting/anaerobic digestion, cascades, and extraction of biochemical feedstock. The overall goal is to minimise leakage, preventing products from ending up in landfills or incineration. For the right and left cycles, the optimal way of treating the materials differs. Materials can never go from the technical cycle to the biological cycle. However, by having a material with only a small part of non-renewable material in it that cannot be separated, it immediately belongs to the technical cycle. Therefore, it is important to be able to separate materials that belong to the different cycles since they have different preferred End of Life scenarios.

Guidelines have been developed in cooperation with Vepa to provide guidance on how to achieve circularity in furniture. This is called the NPR 8313 guidelines. These guidelines describe to design a product that is durable, can extend its lifetime, can be maintained or reused, prevents emissions, prevents resource depletion and prevents material losses.

A tool to assess these aspects is currently under development, as shown in Appendix D. It includes input fields to ultimately assess a product's circularity. These include the number of assembly steps, needed competence, needed and complexity of tools and the availability of product material passports. However, Vepa's product development does not use this tool already and it is rather an outcome that is not actively considered in the design process, like the LCA. Vepa mentions that they strive for these goals [23] but the designers do not actively apply them in the design process.

Lastly, a product can be designed with the intent of being suitable for circular economy, but that does not mean that it will be treated in that way by the user. The collection of products at the end of their lifecycle is important, as the benefits of using biological materials or designing for ease of maintenance become irrelevant if there is no assurance that the product will be returned by the consumer. Therefore, the return of products should also be facilitated. This is all to ensure that the design has as much circular potential as possible. Vepa facilitates the return of its products and processes in its refurbish centre [16]and has to look after maintenance.

### *3.1.3 DfMai*

In line with the principles of the CE, maintenance is an important aspect for Vepa. DfMai focuses on reducing the difficulties and costs of future maintenance efforts required to keep the product in good condition. As Vepa takes back products and provides a warranty, this method is relevant for Vepa. There are two strategies, avoiding maintenance by enhancing the reliability of the product or simplifying future maintenance actions [11]. Vepa's current primary objective is to streamline future maintenance procedures. It is of course also desirable to achieve greater reliability. However, accurately predicting this is challenging, which makes it difficult to optimise for. In LCAs of Vepa a lifetime of ten years for its products is assumed. Mechanically connecting parts is preferred because then products can be attached and detached again without breaking a product part. This becomes more important in the future, as the first requests without using staples and glue are already received. Currently, Vepa uses staples and glue sometimes, for example for the seat cushion in Figure 8. Improving from a maintenance perspective often raises new challenges in terms of manufacturability and assembly. DfMai is also closely linked to modular design, as both aim for the ability to replace parts efficiently.

### *3.1.4 DfMod*

The objective of DfMod is to create products that allow for flexibility and customisation through a modular built-up [24]. DfMod employs standardised modules that can be easily assembled, disassembled, and reconfigured to meet various user needs. Unlike the other methods stated so far, this method focuses on product ranges instead of product structures and components. It aims at products that are built up from a standardised assortment of modules and components. These standardised modules make it possible to make product variants. For instance, in the chair seating shown in Figure 8, the wooden plate in the seat cushion contains more holes than needed. This way, with the same part, different frames can be assembled to the chair. For Vepa defining the product assortment is an important step but is not necessarily defined in conjunction with what would be most optimal in terms of modularity. Instead, product assortment is frequently driven by client requests or aesthetic considerations. The decisions made regarding the product assortment impact the potential for standardisation of components.

The benefits of DfMod are reduced development time, scale of economy advantages, variants, easy to remain by module replacements and reduction of throughput times because of separate parallel projects. A comprehensive DfMod method is Modular Function Deployment, which consists of the following steps. First, the right design requirements are derived from the market needs. Next, (sub)functions and corresponding solutions are formed. Thirdly, concepts for every (sub)function are generated, resulting in a module for every (sub)function. Fourth, the modules are evaluated, and the results of changes are measured. Lastly, each module is improved using DfMA. While tools like a modularity evaluation chart exists, it does not provide visual output. This chart assesses factors such as the number of parts, assembly time, number of modules in a product, the development capacity (share of purchased modules), number of variants that can be built and the number of modules needed [24]. Overall, DfMod enforces a systematic approach, since the modular components are first described and what function each module needs to have, is thoroughly considered. Customer requirements per modular component are systematically developed. Moreover, the individual modular components are often effectively linked to a broader product planning.

### *3.1.5 DfMA*

DfMA, earlier two distinct methods Design for manufacturing (DFM) and Design for Assembly (DFA), aims to develop product designs that minimise manufacturing and assembly difficulties [15]. These methods have similar objectives, but they may also work against each other. A net gain from DFA could lead to a net loss in DFM, then the gain is worthless. To avoid such occurrences, these methods are considered at the same time in DfMA. For Vepa, having products that are easy to manufacture and assemble is important, as it helps reduce production costs. A drawback is that the easiest way of manufacture and assembly is often not the most sustainable and maintenance-proof way. Minimising manufacturing and assembly difficulties is often achieved by minimising part count and reorientation or standardisation of parts and encouraging modular design [15]. DfMA requires the designer to be aware of assembly time, part cost and assembly process and encourages to compare alternative designs and redesigns of an existing concept [25]. All in all, this method is aimed designing products in a way that simplifies their manufacturing and assembly processes with its potential to reduce time-to-market and the total production costs.

### *3.1.6 DfC*

DfC emphasises the importance of managing and optimising costs throughout the product development process to keep the product development costs as low as possible. According to the literature, design activities can dictate up to 70% of the total manufacturing cost of a product [19]. However, most costs are incurred in the later stages of development. The conceptual phase has the largest influence on the costs [26]. Therefore, making an early assumption of the product costs is advantageous. If designers lack sufficient knowledge of the costs involved in the manufacturing processes, coordination between the design and production planning departments is needed [26].

Costs can be calculated according to different methods, among others Activity Based Costing (ABC), where the costs of a product equal the sum of the costs of all activities that must be performed in the realisation of the product, and generation breakdown where the costs of a product is a sum of the costs of all the components [27]. At Vepa, the costs are calculated from the following aspects: material costs, machine running and setting costs, labour costs and overhead for material, logistics, indirect costs and indirect labour costs. So, Vepa uses both sources and activities to calculate its production costs. Vepa only sells to dealers, which are also companies, and therefore does not have to pay BTW. Currently, Vepa's calculation team conducts the initial cost estimate during the prototyping (embodiment) phase, which means the costs are not explicitly considered in the early (conceptualisation) phases. Often, the designers already made most of the decisions and feel less involved with the calculation but rather see it as an outcome. The cost price is not something that lives inside the heads of the designers. In a more ideal situation, costs and production processes are determined simultaneously, supported by a short feedback loop instead of a longer feedback loop [28].

There is however always a trade-off between the accuracy of the cost estimation and the time involved in costing. As already mentioned by Hundal it is well-established that, "Although in the earlier stages the cost estimation can only be approximate, decisions made in its absence can be costly" [29]. A method that addresses the issue of predicting costs in the early stages is hard is Conceptual Design to Cost (CDTC), CDTC combines DfC and the Pareto principle, focusing on the aspects that have the most significant impact on the overall cost [30]. Early cost estimation involves predicting costs in the early stages by analysing historical data related to materials, labour, sales and overhead. Not only the production costs of the actual product but also the costs of the development process, e.g. prototyping costs, should be minimised. All in all, the literature suggests that unnecessary costs can be avoided by integrating costs as a design parameter [31]. Additionally, DfC also suggests that setting a cost goal can help with keeping costs low. Ultimately, product quality and affordability should be balanced to stay competitive.

### 3.1.7 DfQ

Quality is a broad term, but it at least means that it is determined by the degree to which the product successfully serves the purposes of the user [15], or, the degree to which product requirements are met. Therefore, quality may have a different meaning per product, and this is mainly dependent on the functionality a product should have. For furniture, functioning can mean things like e.g. ergonomics, durability, customisation and aesthetics. As long as a product meets the customer expectations, it will in the end enhance company performance.

Design for Quality (DfQ) begins by explicitly defining the quality objectives, as outlined in [32]. Achieving these objectives requires verifying quality at various stages and, if necessary, proposing modifications to improve it. Compliance with International Organization for Standardization (ISO) standards—whether general or product-specific—is also a critical aspect of DfQ. ISO develops documents that outline essential requirements, with ISO 9000 focusing on quality management and ISO 14000 addressing environmental management. Vepa holds ISO 9001 and ISO 14001 certifications. Additionally, furniture products often need to meet specific standards, such as fire resistance tests, as well as certifications like FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification).

Quality should also be maintained in the workplace. Vepa has a system for reporting accidents at work, although further analysis of this is beyond the scope of this report. Although the furniture industry is subject to regulations, it is worth noting that there are fewer regulations than, for example, in the medical products or aerospace industries.

Lastly, documentation and communications contribute to quality. If documents of past projects are made available for the designer, the designer can take inspiration from them rather than being limited to its own knowledge. All in all, quality should be designed into the product not inspected into it [15].

### 3.1.8 MDD

Since around 2010, more attention has been drawn to the *"materials' active role in shaping our experiences with products"*. In 2015, Material Driven Design (MDD) was developed [33]. MDD means that the designer plays an active role in designing, developing or manipulating the material from the beginning, instead of selecting a material to fit the form at the end. In other words, the design process is initiated through the exploration of material [34]. In this method, next to investigating what the material is, the method also questions what the material does to the user, meaning how the material with its properties, potential applications and performance affects users and gives rise to unique user experiences.

One advantage of MDD is that a material is not just selected to fit a form, but a material is seen as a starting point of product development so that it is used as optimally as possible. MDD acknowledges that materials can also be designed, instead of being one material that always behaves the same.

The downside of this method is that the market need is not always considered, so a product is being developed, however, do people even want to buy it? Often the products are not suitable for batch or mass production, and therefore the advantage of why using the material in the first place does not have the desired impact. The risk of working with a new material is that it is unknown how the material behaves in certain circumstances.

Materials research constantly offers novel materials as better alternatives to conventional used materials, therefore, Vepa might in the future also want to incorporate other new materials. MDD emphasises that the unique properties of the materials should be first well understood [35]. CES Edupack is a material database that can be used to benchmark materials. Given Vepa's commitment to innovation, it might face new materials in the future, which can serve as a foundation for initiating a new design project.

### 3.1.9 Conclusion on methods

DfE emphasises minimising environmental impact through careful consideration of emissions, materials and processes. With an LCA the main tool to asses a product's impact. CE focuses on creating closed-loop systems that promote recycling and reuse. DfMai aims to facilitate easy maintenance. DfMA aims to simplify production, reduce cost and development time. DfC emphasises the importance of implementing cost as a design parameter to prevent unnecessary cost. DfQ ensures high standards are maintained to enhance product reliability and customer satisfaction. Multiple standards and regulations exist that products and companies must adhere to. MDD emphasises first fully understanding the material and its properties and what it expresses to the user.

All these methods provide a structured approach to product development, ensuring that their important objectives are met. A commonality among these methods is that they all require a comprehensive understanding of these objectives and clear requirements and evaluation, ensuring that design decisions align with overall product goals. Often, making a planning and defining limits are included in these methods.

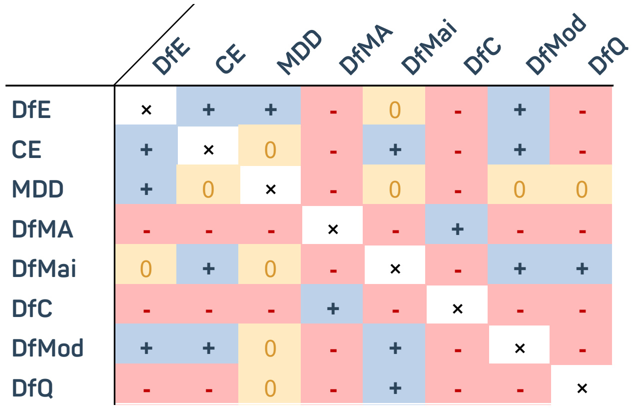
Continuous evaluation and (short) feedback loops are preferred, allowing the product developers to adapt to the progress and challenges. Often, impacts are quantified. This way, data-driven decisions can be made. The methods all emphasise that the objectives should be included in the design process as design parameters, rather than considering it as an assessment that is executed after the design process is finished. Especially in the early stages, the ability to influence final outcomes is greater. All methods are mostly helpful when already thought of in early stages. In addition, the methods emphasise the importance of collaboration across different departments. This importance of early involvement and collaboration between different departments should be taken into account for developing a solution for Vepa.

## 3.2 Complementary and conflicting relationships

The various DfX methods have both complementary and conflicting relationships when applied in practice.

DfE and CE share the common goal of minimising environmental impact, with DfE focusing on emission reductions and DfCE promoting long product life by reuse and recycling. CE aligns with DfMai and DfMod, as all contribute to making products easier to maintain and reuse, enhancing product circularity. However, these methods also have friction with others. For instance, DfE may conflict with DfC, when environmentally friendly choices lead to higher costs. Also, DfE, DfCE and MDD can conflict with DfMA, as these principles or materials might not be the easiest to process. This is also the case for the hemp composite, producing the seat shell of e.g. plastic would face fewer complications (and costs) than producing it of the hemp composite. Furthermore, DfMA may create a conflict with DfQ, as simplifying production can sometimes compromise product quality. What stands out is that optimising costs and manufacturability are mostly conflicting with the other objectives.

Roughly spoken, the complementary (+), conflicting (-) and neutral (0) relationships can be summarised as shown in Figure 12. Occasionally, it could also work the other way around, but most of the time, this is how these methods relate to each other.



| | DfE | CE | MDD | DfMA | DfMai | DfC | DfMod | DfQ |
|---|---|---|---|---|---|---|---|---|
| DfE | × | + | + | - | 0 | - | + | - |
| CE | + | × | 0 | - | + | - | + | - |
| MDD | + | 0 | × | - | 0 | - | 0 | 0 |
| DfMA | - | - | - | × | - | + | - | - |
| DfMai | 0 | + | 0 | - | × | - | + | + |
| DfC | - | - | - | + | - | × | - | - |
| DfMod | + | + | 0 | - | + | - | × | - |
| DfQ | - | - | 0 | - | + | - | - | × |

**Figure 12** Relationships among DfX methods

To excel from one method can mean lower performance according to another method, therefore, trade-offs are inevitable. From now on these methods will be referred to as perspectives. Perspectives at which Vepa, or any other company, can perform well. The many design methods already reveal that while managing the interaction of function, process, shape and material, also many other perspectives are influenced.

## 3.3 Multiple perspectives on product development at Vepa

For companies, performing well on the different design methods and thus navigating through the many perspectives they want to perform well on may be hard. Especially for a company like Vepa that does not have a structured way of executing its design process and sufficient insight into product development processes that supports the growth of its company. This is further explained in Chapter 5. Figure 13 shows some of the many perspectives that can be prioritised in product development, and these can always continue to grow. Although optimising all aspects simultaneously is not feasible, decisions should be prioritised based on a company strategy. The company strategy might change and the perspectives they find important may also change over time. The list of perspectives that can be optimised is practically infinite. Additionally, different products or clients might demand certain perspectives more than others. For now, the focus is on the coloured perspectives that will be considered in the decision-making process and, consequently for a solution, as agreed upon with the company.

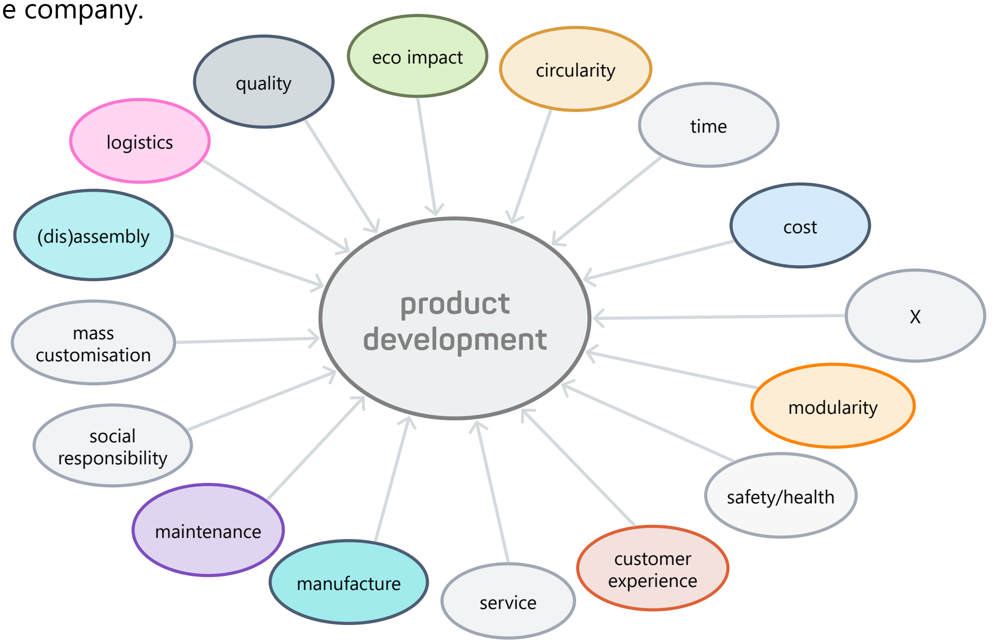


**Figure 13** Multiple perspectives to look at product development

Vepa states that it (inexplicitly or explicitly) wants to adopt the principles of these methods and wants to perform well on these perspectives. Still, these are currently applied informally, often as background thoughts rather than explicitly addressed in the design process or decision-making moments. The diversity of opinions within Vepa further complicates effective communication and decision-making. Every company department and even individuals portray their own perspectives and interests and have their own opinions. As stated by a product development employee of Vepa: *"It may actually feel like it is production against designers when decisions have to be made, while actually that is not the case".*

Numerous trade-offs are made at different design stages and many opinions are involved. On top of that, most DfX methods tell designers *what* to do, but not exactly *how* to achieve these goals in practice. The methods are often complex and time-consuming to implement, therefore also not meeting the needs of the users, which are in this case, the designers. In other words, the product developers at Vepa face the challenge of managing competing priorities without adequate guidance. Consequently, Vepa lacks and needs insight and structure in its product development to be able to make informed decisions and trade-offs accordingly. Next to what decisions have to be made, it is important to know when decisions have to be made. Therefore, designers, especially at a company like Vepa, would benefit from more simplified, user-friendly tools that can provide them with actionable insights without requiring extensive training or significant time investment. This will be taken into account for the development of the solution.

To make good decisions, a designer should be first aware of what is happening during product development and the influence their decisions have on the many perspectives. Therefore, in the next chapter, the important design factors and their relationships in the product development process for Vepa will be displayed in a framework, so that it can be made transparent what is happening during product development. This way, the developers can be more aware of all these perspectives and how these perspectives play a role in product development.

## 3.4 Conclusion

This chapter investigated the design methods that Vepa seeks to incorporate into its product development processes, including DfMA, DfM, DfE, CE, DfMai, DfQ, DfC and DfMod. These methods share commonalities, such as formulating clear requirements, evaluating designs continuously and emphasising the importance of managing objectives in the early design phases rather than afterwards. The analysis also revealed how Vepa currently addresses these perspectives, often balancing them through experience-based, unconscious decision-making without adequate guidance. Balancing the perspectives involves making trade-offs and prioritising goals for the specific product, as is explained by the complementary and conflicting relationships between the design methods. Managing these competing priorities is challenging, as each perspective resides within the minds of different individuals and remains somewhat backgrounded. To get these competing priorities out of the background and be able to take them into account for a solution, the next chapter will introduce a framework with the design factors and perspectives essential for Vepa's decision-making processes.

## Chapter

## .04

# Conceptual framework of product development process

*To develop a solution for Vepa that improves decision-making in its product development processes, the first step is to map what is important for Vepa. This chapter presents a framework that captures the important design factors, perspectives and relationships for Vepa in decision-making processes, to bring them to the forefront. The framework will be verified by applying it to the Hemp chair. This is intended to demonstrate that this information and the decisions derived from it are integral to the design process.*

*In this chapter first, the relationships between the important design factors (nodes) will be explained. Secondly, the attributes inside the nodes will be explained. Thirdly, the indirect relationships will be described. This aims to show that all this information, and thus making decisions about it, is involved in creating a design and that it is important to save it to have a better starting point for a related potential future project. Lastly, the perspectives explained in section 3.3 will be coupled to the node attributes.*

According to the Cambridge Dictionary, a framework is "a supporting structure around which something can be built; a system of rules, ideas, or beliefs that is used to plan or decide something" [35]. The objective of the framework is not to be complete, but rather to at least include the elements that are important for Vepa. The framework aims to give an overview of important aspects of product development for Vepa. To be able to get the perspectives out of the background, it is first important to make them explicit.

The four nodes of discrete product design shown in Figure 7 form a good basis for presenting the important design factors and their relationships in the product development process for Vepa in a framework, but these four nodes do not fulfil. For a company like Vepa, the market and company are closely related to the material, function, process and shape in product development. Vepa is dependent on the market input in deciding what to develop but also on the portfolio, machines, experience and strategy already integrated in the company to develop its products. Therefore, this interaction should be considered from a certain market context, but also from the company's context. If the market and company context are omitted, then the product interaction (function, material, process and shape) has less value. After all, Vepa's products have to fulfil a market need to survive as a company.

So, looking at the interaction during product development for Vepa, these are not the only four nodes – function, shape, material, process - that should be addressed. The market and company context are also essential to include. Therefore, Figure 7 should be expanded by two nodes, market and company, and the relationships between the nodes should be displayed. In short, the node market refers to both the market need, the user and the competitor landscape. The company refers to the company with a certain portfolio, strategy and brand identity that produces the product. The nodes are explained in detail in section 4.1.3.

### *Pugh*

Before extending the four nodes, inspiration was taken from an overview developed by product engineer Pugh. Pugh already tried to display every aspect that is important for product design as shown in Figure 14 and has developed a wheel that illustrates the elements of the Product Design Specification (PDS) [36]. The PDS is the document that outlines the constraints and criteria for the design of a product, acting as a detailed extension of the initial list of requirements. The design core represents the aspects of the design process that drive the development and evaluation of design concepts. Pugh's wheel identifies what to consider when designing a product but does not provide guidance on how these aspects should be considered. For instance, it indicates that the manufacturing facility should be considered for the PDS but does not tell us how to incorporate this aspect into the design process. In Figure 14 the design core is visualised as a perfect circle, suggesting that the aspects contribute to the same extent to the development process. However, probably certain aspects are more important than others, depending on the specific context of the product and company. These elements will also be used as a source of inspiration for the framework of Vepa's product design and perspectives.

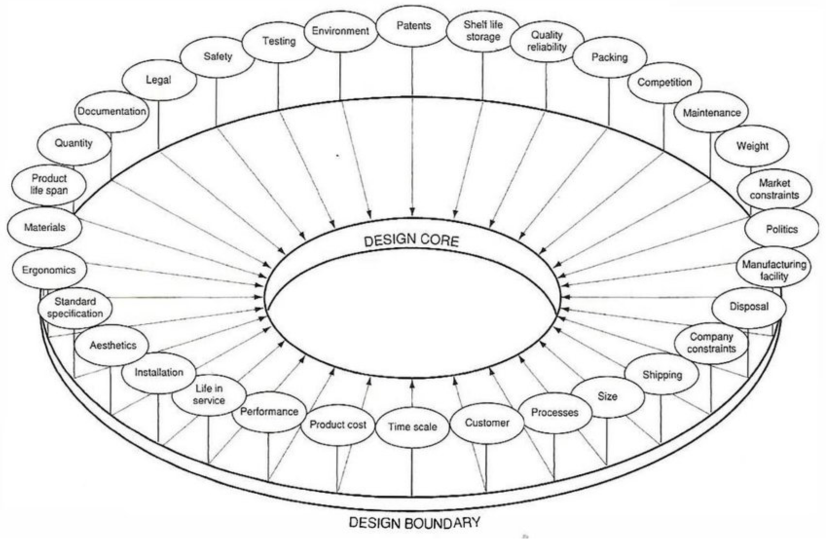


**Figure 14** Elements of  product design specification [36]

## 4.1 Nodes

The extended overview combines six nodes: the material, process, function, shape, market and company node, and is shown in Figure 15. These are the aspects that are interconnected during product development at Vepa. A node only shows information of the node whereas an arrow refers to a relationship and contains information of both nodes. The blue nodes indicate the product nodes and the red nodes indicate the context nodes, these are closely related. The dotted lines might be true and the and the solid lines are (almost) always true.

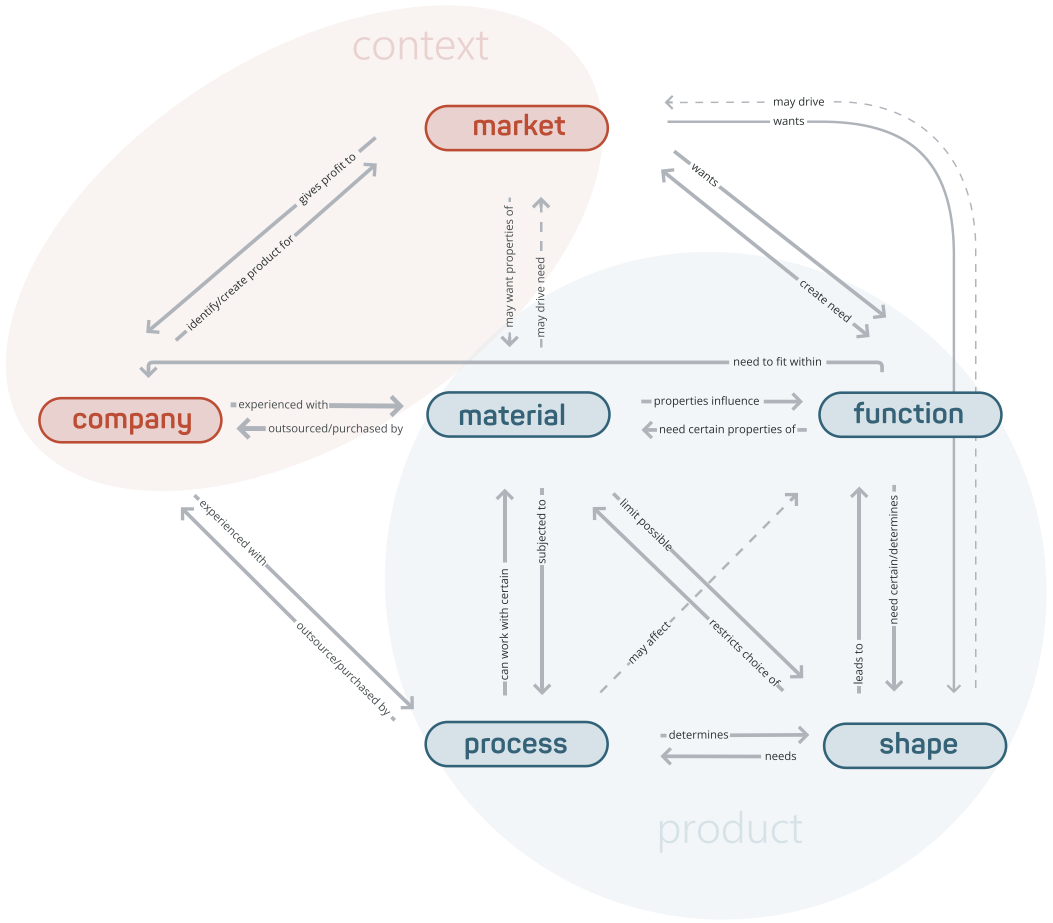


**Figure 15** Interaction of of the market, company, material, process, function and shape nodes in Vepa's product development

*Explanation of node relationships*

### *4.1.1 Relationships*

The relationships are described in the grey arrows and can be read as follows. Materials are *subjected to* a manufacturing process and on the other hand, a manufacturing process *can only work with certain* materials. The process *determines* the shape and to make a shape a specific process is *needed*. The shape *restricts the choice of* material and the material *limits* the shape that is *possible* to make. The material's *properties influence* the function a product can have and a function *needs certain properties of* materials. Also, a function *needs a certain* shape, but the shape also *leads to* the function of the product or part. Also, a production process *may affect* the function of the product. This relationship holds true for the hemp composite. The way of processing makes sure the material is suited for different functions as is further described in section 7.1.3. Companies like Vepa often want to work with the materials and processes they already have and are *experienced with* to keep costs to a minimum, and that might be a reason to choose those. On the other hand, processes and materials can also be *outsourced or purchased* by the company. Also, the market *may want properties* of materials, but also materials *may drive* the market need. The market *wants* certain functions and shapes, but functions also *create* a market *need* and shapes *may drive* a market need. Lastly, the function *needs to fit within* the company.

As can be seen, some relationships are also absent, including the relationship between market and process. This scheme is developed for Vepa which is a discrete product manufacturer selling business-to-business (B2B) in batches. In the context of a different type of discrete product development, namely business-to-consumer (B2C) and particularly traditional arts and crafts, a link between market and process is necessary. In such instances, the customer requests a specific process, for example, a moulded pot, a forged iron component, a mouth-blown glass or handcrafted woodwork. Therefore, the scheme already characterises the type of organisation. For a different kind of product developing company, the nodes may even be expanded further. For example, for an assembly company, a node such as a supplier may also play an important role in this scheme. For now, the focus is on Vepa, a discrete B2B product-developing company.

Prior efforts have been made to expand Figure 15, for example with the node 'use' and 'product personality' [37]. However, mapping these interactions does not add value for a company such as Vepa and may introduce unnecessary complexities, since these can be implicitly accommodated in these nodes.

These are all nodes that are needed to develop a product, and thus driving aspects of product development. Therefore, a node such as logistics or costs was not added, since these are the consequences, driven aspects, of product development and not the causes. This should not be confused with the previous findings that these considerations should be addressed from the beginning of a design project.

### 4.1.2 *Uncertainty and starting point*

When starting a new design project, especially if it is unfamiliar, the designer usually has limited knowledge about potential solutions and great design freedom because few decisions have been made and all options are open. In other words, decisions about a node or a pathway in Figure 15 are still unknown and have not determined yet. However, each decision defines the design more, reducing the freedom of making future decisions. As the project progresses, the understanding of the nodes and available options grows. But only towards the end of the design process do the designers possess the information that they really needed at the start but the designer than has lower design freedom. Design freedom is referred to as a measure of flexibility, or the degree to which changes in product characteristics are realistic [42]. So, being able to adapt as new information or challenges arise without incurring significant costs and effort. Additionally, when the cost of change is at its lowest, the knowledge is still at its smallest. This is called the design paradox and is depicted in Figure 16. Many variations on these curves exist in literature [38] – [42] but the curves considered most true in the case of Vepa have been displayed.

Due to occasionally suboptimal decisions made during the early phases, Vepa is sometimes required to implement changes in later phases, where making changes is more costly, therefore the cost of change is visualised. To name an example, there was once a cabinet designed that turned out not to fit into a truck. This issue was only identified in the later stages after the design had been completed. Since the design is already fully settled, the cost of change is high. Often also the incurred costs (the actual costs spent on development) and committed costs are displayed in these graphs. As design decisions are made, the committed costs increase and altering the product becomes more difficult and expensive. Committed costs are different from the incurred costs, those are made later in the project. Still, it is important to realise that costs are typically already settled in the early design stages because of decisions being made by designers.

In essence, the design paradoxes all come down to the same point. During the early phases of a project, the design freedom is large, but the knowledge is low. Changes can still be made with relatively low consequences in terms of cost and effort. At the end of the project, the design freedom is low, and the knowledge is high, but the design is already fully settled and altering it becomes more expensive.

The green area was added to the graph and depicts the effort that is put in the different design stages, referring to the MacLeamy curve [43]. Although this curve is developed for the architecture, engineering and construction industry, this also seems to be true for product development at Vepa. It was found currently at Vepa the requirements and conceptualisation phase are executed in a relatively rushed manner, resulting in more effort at the later stages. Referring to the example of the cabinet, if more effort was invested in defining the requirements, such as the cabinet must fit in a truck, the effort and costs involved in changing the design by 20 centimetres could have been prevented.

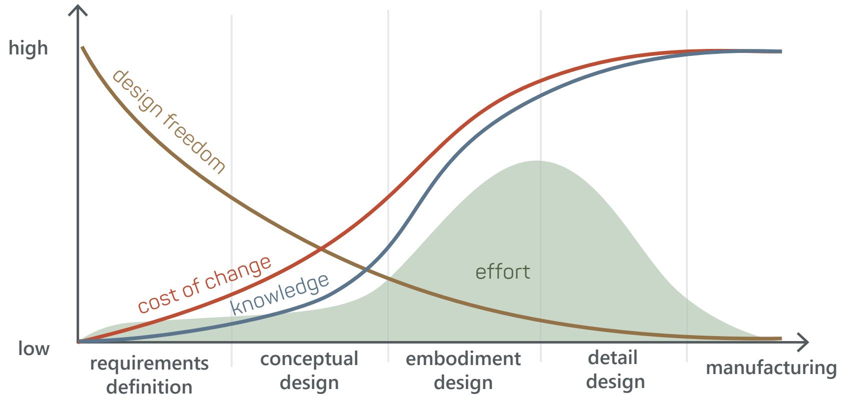


**Figure 16** Design paradox (adapted from [42])

Referring to the framework, the design initiative can be started from a different node and not only from the market need, as described in section 2.1.1. Therefore, the framework in Figure 15 can be seen as a path that can be taken in various ways, and as certain nodes are determined, the options for the other nodes become more limited, resulting in smaller design freedom.

A successful product launch is difficult without relevant information on these nodes. If steps are executed too quickly at the beginning of a project, probably more challenges will arise during the process and more effort is needed in the later stages of the project. Therefore, when a new project starts, insight should be gained first in the framework nodes so that the design process can begin with as much relevant information as possible to achieve the best result. But what is relevant information on these nodes for Vepa? Before the framework can become useful, it should be made more specific and attributes within the nodes should be defined to be able to translate it into actionable insights.

### *4.1.3 Node attributes*

Figure 17 shows attributes relevant to the nodes. The node attributes were defined by formulating relevant aspects to that node of multiple products of Vepa. The attributes mention aspects that are important to that node. These attributes play a role within Vepa specifically but can also apply to other batch production discrete product development companies. The node attributes are explained on the next page. The framework that will be developed in this chapter is however never fully complete, as elaborated further upon in the discussion section, but it at least shows the important and relevant aspects for Vepa's product development processes.

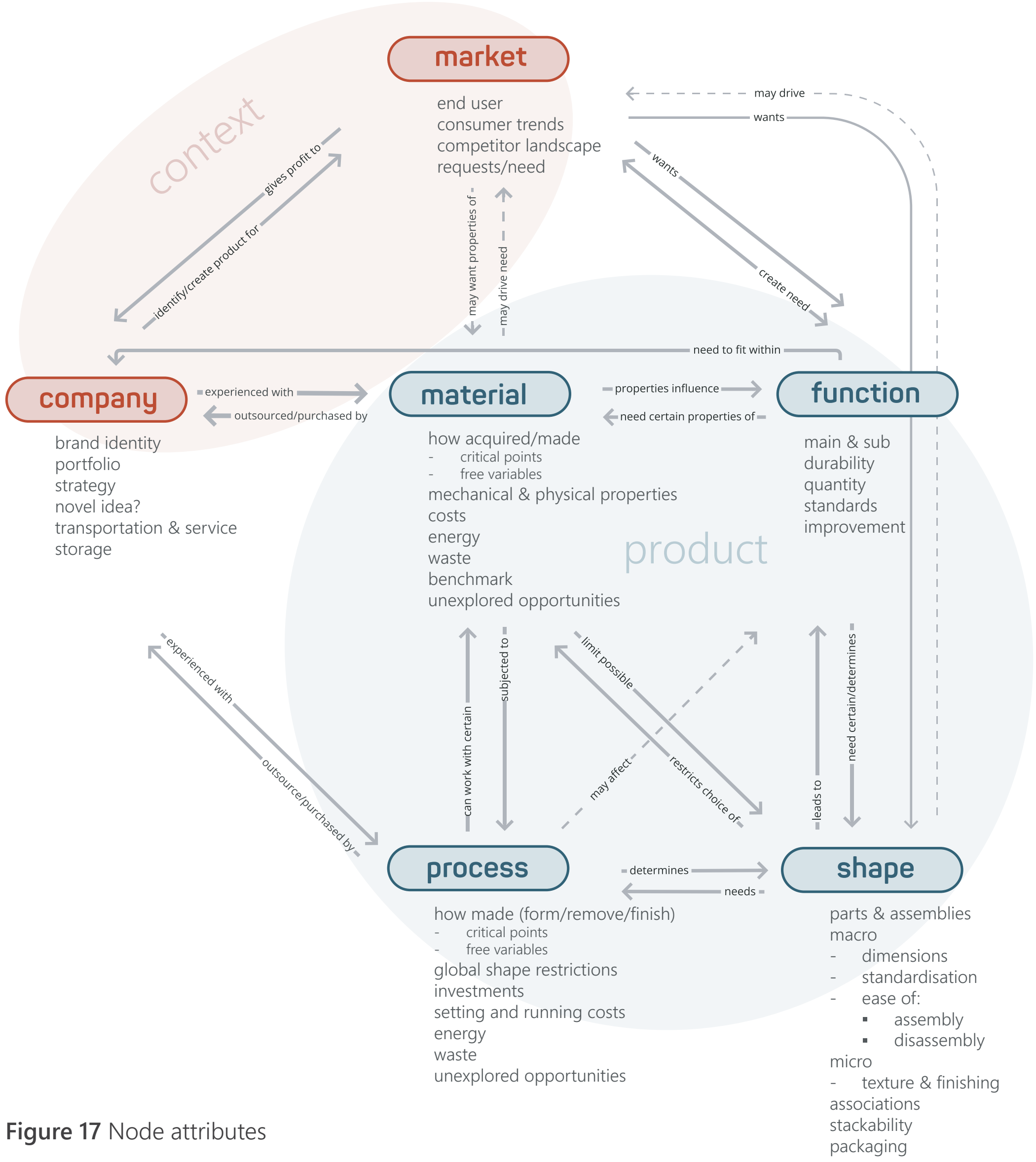


**Figure 17** Node attributes

*Nodes explanation*

**Company** means the company that wants to develop and sell the product, in this case, Vepa. Vepa has an existing *portfolio* which it can grow with a new product launch. Furthermore, it has a certain *brand identity*, encompassing how they have contact with its customers but also its internal values. Also, the company has their employees which should ultimately facilitate the production of the product that can have a *novel idea* for a product. Also, the company has a certain *strategy* that it wants to translate with its products. Furthermore, Vepa is responsible for providing *transportation*, *service* and *storage* of its products.

The **market** node refers to the market context. It includes the *end user* of the product. The market shows certain *consumer trends*, that may be lasting longer or shorter. Also, the *competitor landscape* plays an important role within the market node. The market may also have a specific *need* or *request*.

**Material** means the material before it is processed into its final shape. This material is often provided by an external supplier. However, the process of material production may involve *critical points* and *free variables*. The material has certain *physical and mechanical properties*. The material has certain *costs* and *energy* use and *waste* is developed by the extraction of the material. The material may be one material or be available with different properties or can even be designed, therefore the material may have *unexplored opportunities*. Furthermore, it has certain values that make it different from other materials to use as a *benchmark*.

**Processes** are the manufacturing processes that the materials undergo to get their shape. These processes include primary forming processes, material removal processes, finishing processes and joining processes. These processes may have *critical points* and *free variables*. The machines use certain *energy* while operating and *waste* may be developed. The processing machines have some global *shape restrictions*. Also, the machines often require *investments* and have *setting and running costs*. Furthermore, there may be *unexplored opportunities* within the processing possibilities.

With **shape** is meant both the *micro* and *macro* shape the product has. The macro shape includes the larger *dimensions* and *standardisation*. Macro shape also influences the *ease of assembly and disassembly*. The micro shape includes the *texture and finishing* of the product. The shape can lead to certain *associations*, *stackability* and required *packaging*.

**Function** is a description of what the product does and can refer to the technical operation but also to e.g. aesthetics. The product has a *main function* and *sub-functions*. Also, the functions are or should be *durable* for a particular time. The function is suitable for a certain *quantity*. Certain *standards* may apply to that specific function. A function (of an existing product) might also require *improvement*.

### *4.1.4 Indirect relationships*

The nodes and their direct relationships are described, however, it is important to also consider the indirect relationships. This allows the identification of the indirect effects of decisions being made. For example, when a designer determines the function and shape (nodes) this leads to certain use of materials and processes (nodes) and those greatly affect the costs (node attribute). So, following the framework indeed shows that decisions regarding the function and shape made by designers in an early stage can have significant implications for the final production costs. Furthermore, the market in the B2B branches typically demands specific functions and (micro) shapes and perhaps materials, rather than asking for a specific process. But those nodes in turn affect what shape and process are needed. Furthermore, a company choosing to work with a certain material already restricts the possible processes to be used and the possible shapes and functions a product or part can get.

## 4.2 Applying the framework


**Figure 18** Hemp Fine

The case study in this thesis is about the development of a product using the hemp composite. As explained, Vepa has experience with this material with its “Hemp Fine” chair (Figure 18), which is already available on the market for three years. Therefore, the nodes and most of its attributes are already established for this product and context. To better understand the development of this chair and leverage the knowledge gained, the framework will be applied with an emphasis on the hemp composite part. The gathered information through applying the framework should provide a deeper understanding of the product development process, which can be used in future projects, and therefore provides a better starting point for the design project with the hemp composite. Additionally, even improvements may be found to the current design.  This information was gathered through discussions with employees both at Vepa and Plantics who were directly involved in the development of the chair. The knowledge gained from the development of the chair is the starting point for the question of a new design with the hemp composite.

The framework can also be applied to a different product or product part. For instance, in developing a new product with a different material, one can analyse products containing that specific material. Similarly, for a specific function, one can analyse products with that function. In each case, applying the framework should demonstrate that the defined nodes and node attributes are indeed relevant to Vepa’s product development, and the knowledge gained from it can be reused and advantage taken of it for future product development.

A summary of each node is given in the next section and a more elaborated explanation is given in Appendix C.

### *Company*

Developing this chair fits Vepa’s brand identity of being a leader in making sustainable products. It fits in the portfolio mix. The strategy with the chair was to emphasise the story around the material, making it more of a flagship product. The idea came forth from the availability of the material by Plantics.

### *Shape*

The chair consists of two sub-assemblies: the steel frame and the hemp shell. As stated, the focus is on the hemp part since this is the material that will be used for developing a new design. The hemp part is a shell shape, this shape was chosen because this design was already present for another chair. Currently, the chair has a thickness of 8 mm to ensure the required strength. The shell and the frame can be easily assembled and disassembled. The finishing of the material gives a natural look and therefore the chair is already associated with sustainability. The chairs are stackable for transportation.

### *Material*

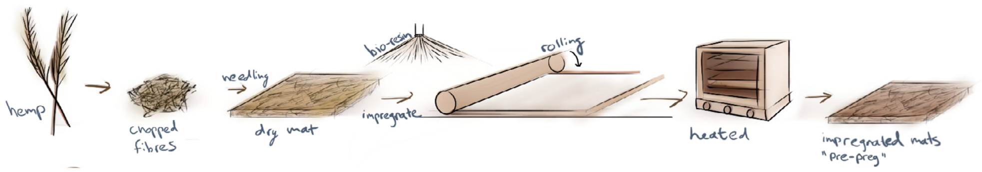


**Figure 19** Drawing from raw material to pre-preg

The material delivered by Plantics to Vepa is a pre-impregnated mat consisting of hemp fibres and bio-resin. In Figure 19 the processing technique from raw materials to impregnated mat can be seen. Currently, the ratio of hemp and resin is fifty-fifty. This is a semi-finished product that is still flexible and sticky and will become solid by applying heat. The material (both resin and fibres) is extracted from nature and therefore renewable and fully biological which is an advantage in comparison to other materials. The material can be designed by using other thicknesses of the dry mat, using different ratios of water in the resin and colouring the resin. Colouring the resin will however create other difficulties with cleaning the impregnation machine. The pre-pregs should be kept rather air-tight, otherwise, they will take up water again and the resin becomes viscous again. The labour intensiveness of the impregnation process and making the larger pre-pregs in the right size contribute most to the costs. The energy that is used for creating the pre-pregs is currently unknown.

### *Process*

For shaping the material to the shape of the chair, hot press moulding is used. The shaping process is labour-intensive compared to other processes as can be seen by the many steps involved in the process shown in Figure 20 on the next page.

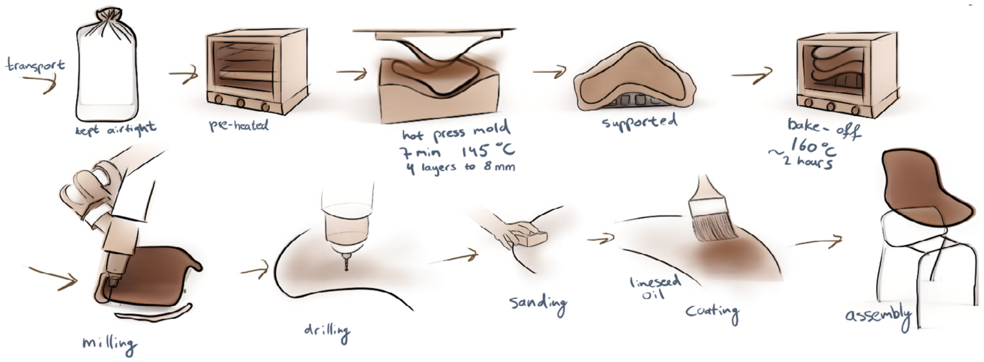


**Figure 20** Drawing from pre-preg to chair shell

The process greatly influences the material properties. For the chair, four layers of pre-preg are included in the mould and heated for 7 minutes. Afterward, they are baked off in the oven for two hours, so curing takes place. Once cured, finishing processes are applied. Unexplored opportunities are enabling the robot to also round off the shell. The material has a brownish look and is brittle but strong. The pressure in the mould greatly influences the density and therefore physical and mechanical properties. The temperature of the curing process influences the curing process. If the curing is not done sufficiently, the material softens again. The bio-resin is a thermoset bio-resin. Thermoset means the polymer becomes irreversibly hardened once it is cured. Once hardened, it cannot be re-melted. This provides opportunities for shaping the material since first it is soft and when heated it hardens. A pre-preg can be shaped without using a mould, when kept in place after curing it will keep its shape. For moulding, a surface texture can be included in the mould. Overall, the processing technique greatly influences the material behaviour and there remains much to discover in this area. The investment in a 3D mould shape contributes most to the costs and the four layers of pre-preg further contributes to the overall product costs.

#### *Function*

The hemp both functions as aesthetic material and constructive material. The pressed hemp is not flexible or soft, therefore also the option for a chair with a cushion exists. Current problems are that the chair is rather brittle and can break when the chair falls.

#### *Market*

Current trends include a growing interest in eco-friendly products. Vepa's hemp chair serves as a brand carrier, highlighting its commitment to sustainability and appealing to eco-conscious customers. The market did not request such a chair, since they did not even know this was possible, but rather Vepa created a market need with this design. The chair might be mostly appealing to customers who want to show off that they care about the environment and fit the trend of showing sustainability commitment. Customers request a broader range of colour options. In the Dutch market, this chair distinguishes itself from conventional alternatives.

### *4.2.1 Perspectives on the Hemp chair*

Now the chair has been developed, the driving aspects are defined, and the choices made within those nodes have consequences on the perspectives, the driven aspects. Referring to Figure 13, the following stand out with respect to the chair.

Environment: The EoL scenario is not yet defined for the chair shell. Currently, there are trials with shredding the material and press-moulding it again. Plantics is also exploring possibilities with the decomposition of the biological binder and the hemp fibres. And although the hemp material is a biological material at the company it is not exactly known how much energy is required for creating the pre-pregs.

Circularity: The seat shell and the legs easy to be (dis)assembled. Therefore, the biomaterial can be separated from non-renewable material.

Costs: Currently, the many processing steps, because of the many finishing steps, leads to many working hours. High investments for the 3D mould (typically around €10,000) contribute to the costs. The material costs for the chair are high because four hemp mats per chair are used. Recently (August 2024), Vepa has moved towards using three layers for the chair, since the density of the woven pre-pregs has improved. This change demonstrates that the material indeed influences the process.

Customer experience: The chair has a natural look, but the material does not provide the same level of comfort as, for example, a felt chair, because the hemp chair is relatively stiff.

Manufacture: The process is highly labour-intensive. Much time is spent on sanding the chair edges, while this can be done by the robot.

Maintenance: The legs and the seat can be detached.

Logistics: The mats are coming from Plantics and should be kept dry. The hemp shell and frame are made in Emmen while the leg frame is sprayed in Hoogeveen.

Quality: This perspective is highly dependent on the function of the product. The function of a chair is to provide comfortable seating and to be durable. The chair is brittle, which makes sure it can crack if it falls over. Currently, Plantics is experimenting with changing the impregnation process to not completely impregnate the fibres to keep the flexibility of the fibres.

Modularity: The legs and shell can be detached easily. But only one model of this chair exists, therefore modularity is less relevant for this product.

The perspectives show that not only valuable lessons can be learned from the driving aspects (nodes) but also from the driven aspects (perspectives).

### 4.2.2 *Conclusion*

Applying the framework to the chair shows that much information can be deduced after a product has been developed and parts of the knowledge can be reused for related new designs. Which information from which project is relevant to a subsequent project should be carefully considered by the designer. For the case study of this thesis, especially from the material and process nodes, much of the knowledge can be reused. The following considerations are important for future development with the hemp composite: The labour intensiveness of the development, the hemp mats containing a mesh on one side, the material's brittleness, the ongoing trials with shredding and reusing the material, unexplored opportunities regarding the material's processing technique and Vepa's recent purchase of a flat press.

This information was retrieved after the design had been developed. Importantly, it confirms the relevance of the information provided by the framework, and it demonstrates that all nodes are indeed interrelated, effectively verifying the framework's applicability. It would be unfortunate if the lessons learned from previous projects were not considered when creating new designs, or if valuable knowledge were lost due to employee turnover. It is therefore important to properly store this knowledge. This information should be considered as much as possible in a design project in advance.

Applying the framework aims to capture knowledge and provide a better starting point for a new related design project. As outlined in section 2.1.1 and section 3.1.9, all product development projects begin with establishing requirements. Consequently, the framework, that covers the important subjects for Vepa, can serve as a solid base to formulate product requirements.

The connection between the nodes and perspectives remains somewhat unclear up to this point. As stated in section 3.3 the perspectives currently play a background role but should be more explicitly addressed. Therefore, the perspectives will also be mapped in the framework.

## 4.3 Integrated framework of the development process

Ssection 3.3 and 4.1 described what nodes are working together in product development and what perspectives are important to consider. This section explains what the connection between these nodes and perspectives is. The perspectives are impacted by the decisions made regarding the different nodes. Therefore, an integrated framework of Vepa's product development process is proposed, which includes a collaboration of the nodes, node attributes and the perspectives that are influenced by them, see Figure 21.

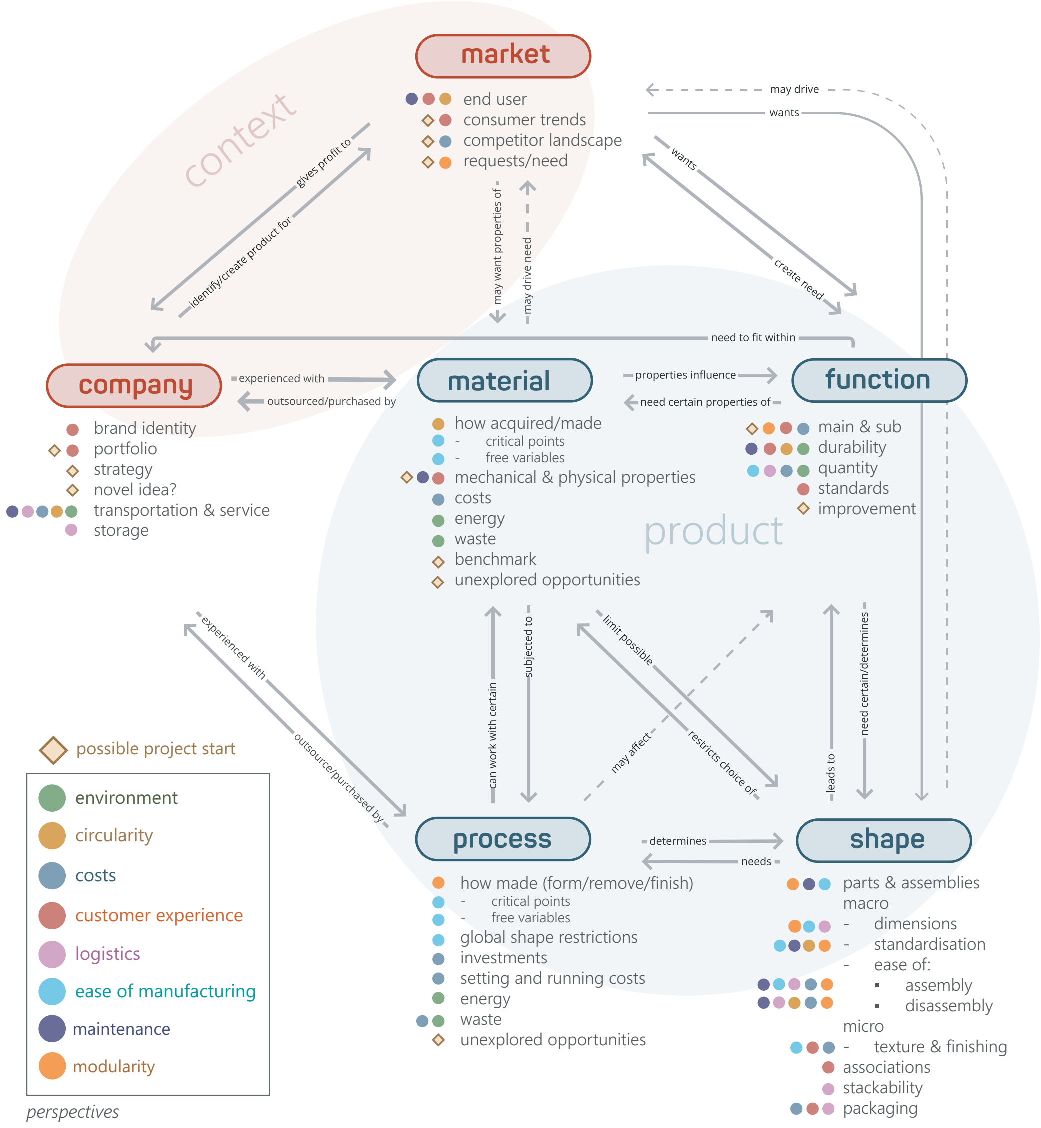


**Figure 21** Integrated framework of Vepa's development process

As explained, the nodes are considered a cause (driving aspects), while the perspectives are more of a consequence of the choices made regarding the nodes (driven aspects). A product requires a material, function, process and shape and is manufactured and serviced by a company for a specific market. These are essential elements and are something to design for. A product does not require an impact on the environment to be a product. However, the product itself, for instance through the material and processes used, may contribute to environmental issues. So, the consequences (perspectives) are influenced by the causes (node attributes) and can be derived from these nodes.

Before explaining the connections to the perspectives, it is important to state that the connections are valid and important for Vepa specifically. While this scheme can be adapted by other companies to find important aspects and connections, these may be different depending on the company. The perspectives mapped are important to Vepa. These are the perspectives corresponding to the DfX methods relevant to Vepa. In addition, logistics and customer experience are also mapped in the framework. Possible starting points are also included. Implicitly, the company strategy is depicted in this scheme by mapping the node attributes, starting points, perspectives and relationships that are essential for Vepa.

### *4.3.1 Explanation of connection perspectives and node attributes*

In the left corner of Figure 21, the perspectives are shown and connected to a colour. The coloured circles are positioned in front of the node attributes to indicate that those are impacted by that attribute. The potential project start is indicated with the yellow diamond.

**Environmental concerns** arise from the *energy* consumption and *waste* of production of materials and manufacturing processes. The environmental impact of a product is influenced by its *durability* and production *quantity*. A product manufactured in large quantities or with a longer life has a different environmental footprint. In addition, *transportation* also contributes to the environmental impact.

The **circularity** of a product is determined by several factors including *material sourcing*, *transport* and the company's *service* offering. Mainly ease of *disassembly* and *standardisation* also play a role. Product *durability* and consumer behaviour also has an impact on circularity, if *users* do not return products at the end of their lifecycle, companies are unable to reuse or recycle them.

**Cost** considerations in manufacturing involve the *cost of materials*, manufacturing *processes* and *investments*, *finishing, ease of assembly and disassembly*, *transportation* and *packaging*. Also, *waste* in the production process should be minimised. Market dynamics also play a significant role since *competitor* pricing can influence the maximum allowed price for the product and thus the maximum costs. Allowed costs are always connected to the *functioning* and *durability* of the product.

**Customer experience** is influenced by many factors, including *brand identity* and the material *mechanical and physical properties*, *texture and finish*. Product shape *associations* and *functionality*, as well as the user's personal interpretation and *consumer trends*, also influence the experience. The competitive landscape and the brand's broader *portfolio* also play a role, it was for a reason that Colgate's attempt to market lasagne failed.

**Logistics** arise from the *dimensions* and *stackability* and needed *packaging* of a shape, and the *ease of assembly and disassembly*. *Storage, transportation* and the *quantity* of products are part of the logistics. Handling many products is different from only a few pieces.

**Ease of manufacturing** is determined by the *critical points* and *free variables* of the material sourcing and manufacturing process. The *number of parts* and *assemblies* required, along with product *dimensions*, *texture* and *finishing*, influence the ease of manufacturing. Additionally, the production *quantity*, mass production or limited orders, affects the ease of manufacturing. *Standardisation* of parts also affects the ease of manufacturing.

**Maintenance** is influenced by several factors, including the ease of *assembly and disassembly*. The *durability*, also because of the *mechanical and physical material properties*, of the product and its components also influences maintenance. Lastly, maintenance is influenced by the level of *service* the company aims to provide, and the way the *end user* uses the product.

**Modularity** is mainly influenced by the shape attributes, *parts and assemblies, dimension, standardisation,* and thus how the part is made. The ease of *assembly and disassembly* also influences the modularity. Modularity is closely related to the user *needs or requests* and the *main- and sub-function* the product should have.

**Project start** As stated before, a project is not only started from a *market need*. The starting point can be several. It can be started because of certain *consumer trends* that are seen or *competitors* that offer certain products. Furthermore, a project can be initiated by a company because it wants to extend its *portfolio*, it fits in a certain *strategy* or there might be a *novel idea* within the company. Furthermore, a material having advantageous *mechanical or physical properties* in comparison to other materials or *unexplored opportunities* may drive a project to start. This is similar for the production process. Lastly, a certain product's functioning might need to be *improved* or added to a company's portfolio. The concept of a 'technology push' refers to the situation in which a new technology is invented, and the designer wishes to create a new product based on it. In contrast, the 'market pull' scenario arises when consumers have a need or desire for a particular product. In the case of the nodes market and function, the starting point is probably a market pull, whereas in the case of the company, material and process nodes, it is more likely that the starting point is a technology push.

### 4.3.2 Conclusion

The perspectives are linked to the framework. It is demonstrated that the perspectives recur at several nodes. There is a high degree of interconnectedness. To illustrate, if the shape is changed to achieve a superior outcome in terms of assembly, this can result in a change to the production method, which could in turn lead to a poorer outcome in terms of ease of manufacturing. When designing, once a decision is made regarding a node or even an attribute within the node, the other nodes are also affected as a consequence. The design freedom or solution space is reduced and new constraints emerge. Once a decision is made, there should be a valid reason to change it again, since efforts need to be made to change it again. Suboptimal decisions should be prevented. Once a decision is made the "road" can continue to another node to settle the remaining issues. The framework thus captures the trade-offs made when making decisions.

Vepa's product developers acknowledge that the framework represents Vepa's product development in practice and stated it is a useful way to discuss the status or initiative of a project. They state that it provides a comprehensive representation. However, this information is currently all managed in people's heads. As a result, there is little insight into the decisions made, the product's performance from the multiple perspectives, whether these are adequately being addressed and the overall project's status.

## 4.4 Conclusion

A framework consisting of six nodes, corresponding node attributes and perspectives, was developed to visualise the important design factors and perspectives and their interrelationships for Vepa, addressing sub-question two. These interactions represent a fundamental aspect of the product development process at Vepa, and probably for similar companies. These are the aspects on which Vepa has to make decisions throughout its product development. A successful product launch is difficult without relevant information on these aspects, as decisions regarding these are essential. The framework represents a route where there can be several starting points and from which a path should be followed during the product development process. At the project start, the designer has great freedom but has limited knowledge and, in the end, the designer has greater knowledge but less freedom. Later in the process, changes are more costly and these should be prevented. The framework depicts what Vepa needs to think about and can therefore serve as a reminder to avoid overlooking aspects and a basis for defining product requirements. It showed that much knowledge can be deduced when a product has been made. Applying the framework to the hemp chair already verified the framework's applicability and thus provides a foundation to build upon for developing the solution for Vepa. It would be unfortunate if the lessons learned from old projects were not considered when creating new designs. A company should reflect on its product design or suffer the consequences of ignoring it. Vepa should prioritise bringing the perspectives to the forefront. Ultimately, the company, and the designer in particular, is responsible for the impact of its products on the perspectives. The solution to be developed should facilitate managing the framework connections, be intuitive and provide insights that support making the right design choices. In the next chapter, the objective for Vepa's product development will be outlined.

## Part

# .02

# Solution objective, tool development and case study

*In part one the current product development context of Vepa was described. Relevant DfX methods were investigated so that inspiration can be taken from them for the solution. The important design factors and design evaluation perspectives and their relationships were put into a framework, to display what is happening at the work floor at Vepa. The framework was verified with a product of Vepa and by discussing the connections with the product developers, to show that these node and node attributes indeed must be dealt with in Vepa's product development. The perspectives that Vepa wishes to incorporate are also linked to the framework.*

*In this part, a more specific objective for Vepa's product development will be described. This is informed by the research of part one and the observations and working within the company. Solution requirements will be described and the development of a tool as the solution proposed. This tool will be developed through research by design since the tool will be developed in tandem with creating a product with the hemp composite for Vepa. The case study shows the design process of a hemp composite wall (and ceiling) panel with the application of the tool.*

Chapter

# .05

# Solution objective

*In this chapter, first, the further defined challenges of Vepa will be described, secondly, the objective for a solution that helps Vepa in its product development will be described, lastly, requirements for this solution will be formulated.*

## 5.1 Further defined challenges

Building on the research in the preceding part and personal experiences in developing a product at Vepa, it is now possible to more clearly articulate what the exploration in part one has delivered, and consequently, more precisely articulate the objective for Vepa's product development processes and the connected research question. To do this, first, the challenges Vepa is facing are described. Vepa's product development process faces several challenges that hinder efficiency and cause frustration among employees. These challenges were identified and verified based on the research, (informal) discussions with the employees and developing the hemp product at Vepa.

Overall, it became clear that these challenges cause a lack of insight into product development processes at Vepa. As stated by a relatively new employee of Vepa: *"I am also trying to figure out how products actually come into being here"*. This insight is in the end needed to enhance the decision-making process and this can in the end enhance efficiency and reduce frustration among employees. The identified challenges will be described below and the requirements to resolve these challenges through implementing a solution are introduced in section 5.4.

### *5.1.1 Capturing relevant information*

Little information from past projects is stored in a structured way, thereby learning from past projects is harder and the starting point may be difficult. Capturing relevant information would allow employees to learn from past projects and make sure less information gets lost when an employee retires. The framework captures what relevant information is for Vepa. Better documentation can make starting future projects easier.

### *5.1.2 Specific requirements*

Although Vepa states that they develop requirements, in fact, this is more akin to a project description than measurable requirements. Referring to Appendix E, Vepa's project requirements are too generic and can therefore not be used as consequential statements in the development cycle. For example: "the size of investments should be proportional to the intended sales numbers". So, Vepa has a general description of the project and sometimes updates it, but there is no clarity on the origin of requirements and their importance. As Pugh [36] already pointed out, poor requirements will lead to poor designs. Generic requirements make it challenging to achieve optimal designs. Developing more specific product requirements early in the design process can help to overcome problems later in development. This also corresponds to the SMART method, which emphasises that requirements should be specific, measurable, achievable, relevant and testable [44]. If requirements are not specific, how can it be known that they are being met? Also, the distinction between "wish" and "must-have" requirements significantly impacts decision-making and is often not so clearly defined or changed along the process for Vepa. Specific requirements are necessary, but not sufficient for a good design, therefore the solution requires more than setting up explicit requirements.

### 5.1.3 Prototyping

With the company focused on making a profit, the commercial manager and manufacturers do not always recognise the essential role prototyping plays in product development. While there is a general awareness that prototyping is part of the design process, the current planning in Figure 5 only accounts for one prototype before the 0-series, while in practice smaller proof-of-concept prototypes are always developed first. These initial prototypes currently feel like something that should be executed quickly and in the background, while in fact, it is an important aspect that should be emphasised more and has a large influence on decisions that must be made. Furthermore, prototyping outcomes are not documented, which does not allow Vepa to learn from past experiences, especially when employees leave the company. The absence of documentation also leads to inefficiencies, as considerable time is often spent on updating team members, sometimes even during general meetings.

### 5.1.4 Project planning

Although the scheme in Figure 5 has similarities with the Stage-Gate Process or milestone planning, which is a structured approach where you can only move to the next stage if this stage is fulfilled and the gate serves as a decision point [45], for Vepa it is sometimes not so clear what the status is, when to move to the next phase and what to decide. Also, the phases before coming to the final prototype (conceptualisation and embodiment) are not well defined or extensive for Vepa and are often executed quickly, causing problems and much effort in the detailing phase. Although there are go/no-go moments defined. In practice, these do not always take place or even once a go/no-go moment was planned, but there was not a prototype available yet. Until now, no product-specific project planning has ever been available for any of Vepa's projects. When there is no planning, it is also difficult to stay on track and crucial decisions may be made because of time constraints. Having a project planning would help prevent such situations by allowing for more proactive decision-making and ensuring that deadlines are met without the need for last-minute decisions. Additionally, there is no consistent way of working within the design team and some employees take a more structured approach than others.

### 5.1.5 Responsibilities

Similar to the project's status, responsibilities are often unclear within the product development team. Three years ago, Vepa operated as a smaller company at one location, where all product development employees could contribute to decision-making and be actively involved in each process. However, as the company has grown, this level of involvement in every project for every member is no longer feasible. Still, some team members may still strive to be involved with every project and or make decisions about tasks that are not explicitly assigned. This lack of clarity regarding responsibilities can lead to situations where decisions are sometimes made and then reconsidered due to input from other parties, resulting in delays in the completion of a project.

### 5.1.6 Trade-offs

In the product development process, numerous trade-offs, related to the framework's subjects, must be frequently made. However, at Vepa these decisions are often made implicitly and on a gut feeling basis, as mentioned in the problem statement. To gain greater control of these trade-off decision-making processes, it is necessary to coordinate and evaluate trade-offs throughout the product development process. This is also emphasised by the researched DfX methods. The ability to communicate and evaluate trade-offs is essential to avoid design solutions that excel from one perspective but fail from another. Moreover, evaluating trade-offs should occur not only at the end of the design process but as soon as possible, since early design decisions significantly impact the overall project success and costs.

### 5.1.7 Conclusion: insight and decision making

All in all, at Vepa, projects sometimes take longer and involve more frustration and effort than necessary. This inefficiency is often because making decisions can be challenging. Multiple trade-offs must be made without adequate support, leading to inefficiency or frustration among the members of Vepa. Additionally, a lack of formal structure, which was less critical when the product development team was smaller, further complicates decision-making as the team grows.

To enable well-founded decisions, actionable insights into the challenges described above are needed. To be able to make decisions about the framework, this relies on accurate data and insights. For example, not creating specific requirements introduces ambiguity into the design process, potentially leading to decisions that are misaligned with project goals. Not formalising prototyping, and especially smaller proof-of-concept prototyping, as a key step of the product development process does not allow the company to make well-founded decisions regarding the interaction of material, process, shape and functions. If no clear project planning is available, achieving and managing time goals is challenging. While having a product planning is not a goal in itself, not having a clear planning could obstruct decision-making because the designer either has to make decisions because time is running short or keeps on elaborating because time is infinite.

Overall, the framework serves as an overview of what Vepa should consider for decision-making. Although certain aspects already play a role in the background, also many aspects are not explicitly addressed. However, before strategic decisions can be made effectively, the foundation of insights into the explained challenges of product development is required first. Decisions made implicitly introduce increased risks of unforeseen changes at later stages. On top of that, to make sure the framework subjects are consistently taken into account in designing, these aspects should be included as memory support in the solution.

In light of these findings, the research question can now be revised and extended.

## 5.3 Extended research question

Referring to the research question stated at the beginning of this thesis, the current state of knowledge allows us to pose a more refined question. Therefore, achieving insight should be added to sub-question four regarding the solution. Insight means (the ability to have) a clear, deep, and sometimes sudden understanding of a complicated problem or situation [46]. Of course, only having insight is not the goal itself for Vepa's product development, rather, this insight is needed for making many decisions and trade-offs in the product development process. Therefore, the insight created can be used to enhance decision-making, as well-founded decisions rely on having the right insights. This will enable insightful decision-making, which is the objective for Vepa and addresses the problem imposed by the director that currently decisions are made based on gut feeling. The revised research question is stated as follows.

***How can Vepa enable insightful decision-making in its product development processes?***

Based on the current state of knowledge, the sub-questions of the solution are formulated as follows.

*What solution can assist in achieving insight and enhancing decision-making in Vepa's product development?*

- How can Vepa be helped in capturing and communicating relevant project information?
- How can Vepa be helped in the formulation of explicit product requirements?
- How can Vepa be helped in making decisions at the right time?
- How can Vepa have more control over product development trade-offs?

## 5.2 Solution objective

The value proposition stated in the beginning of the report in section 1.5 is confirmed by the found challenges and indeed serves as the objective for Vepa's future approach of its product development processes. In short, it means that there is more insight, things are made explicit, clearer responsibilities, better communications and different people have excess to one source of information all intending to enhance early-stage knowledge, design freedom and thus decision-making. This can prevent frustration, costly changes and effort to be made in the later stages, thereby improving the efficiency of the product development process.

Referring to Figure 16, the improved future design process is visualised with the dotted lines and striped area in Figure 22. Although the design paradox will always be present, the goal is first to understand the possibilities and constraints of various options before locking decisions. Focusing efforts on the early stages makes more design knowledge available when decisions are locked, keeping design freedom longer when costs of change are still relatively low. Note that the cost of change displays the same curve, as costs of change are always present in the later stages, but benefits for Vepa to be achieved are involved with making the right decisions before the costs and efforts of change increase. The goal is to shift efforts to the earlier phases of product development, ultimately reducing the overall effort required for the entire process.

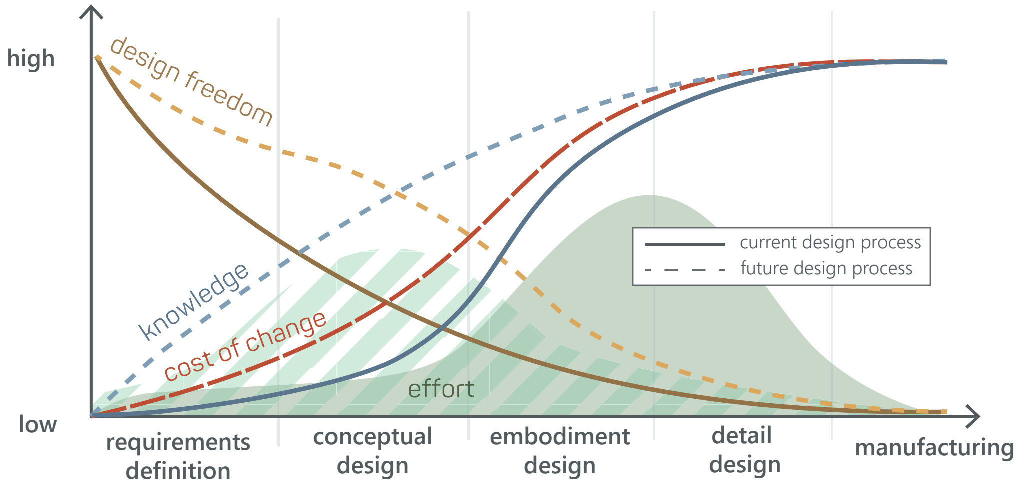


**Figure 22** Improved future design process inspired by [39] and [42]

Consequently, a solution is required to improve insight and therefore the design knowledge. This can make sure design freedom is lost in a later stage and enhance decision-making processes. This solution preferably also captures decisions as a means for communication and preserving of information. Preserving information from past projects enables starting new projects with greater knowledge and offers the possibility to review previous decisions. In this way case-based reasoning is enhanced, the principle of utilising past experiences to solve similar problems today [47]. Nevertheless, design remains a subjective and creative process, not being able to be captured by any solution. However, understanding the possibilities and constraints of different options and simultaneously analysing concepts from various perspectives can significantly enhance (early-stage) design knowledge.

In summary, the to-be-developed solution should translate the findings from the theory and practice into something supporting Vepa's product development and help designers in decision-making based on the right insights.

## 5.4 Solution requirements

The objective can be formulated in requirements. The requirements are grouped into three subjects: aim, implementation and usability. Aim requirements describe the aim of the solution and are mostly based on the literature review and experience within the company as described in section 5.1. Implementation requirements are about the implementation of the solution and are mainly based on the company and employees. Usability requirements are about the use and are based on interviews with product developers, the way of working within Vepa and the director and product manager. Wishes describe the nice to have's and are based on all the preceding findings and the working atmosphere within Vepa.

**The solution..**

Aim:

- Captures, updates and centralises relevant project information
- Provides a better starting point for future projects
- Forces designers to think about aspects that might be forgotten otherwise
- Enhances decision-making
- Helps in defining clear product requirements
- Aids in defining a project planning
- Makes the product development process more efficient than without the solution
- (Wish) aids in defining and clarifying responsibilities
- (Wish) creates consistency across different projects

Implementation:

- Can be easily adopted/implemented by Vepa on the short term
- Does not require extensive explanation
- Fit in approach of company's current product development process
- Accessible without additional software
- Is complementary to already used life cycle engineering tools (LCA, NPR, ERP, SolidWorks)
- Low implementation and operational costs
- Adheres to the Most Advance Yet Acceptable principle
- Is flexible in use/allows for future customisation in line with changing needs

Usability:

- Is quickly interpret
- Contains a manageable amount of information
- (Wish) can make a self-explanatory summary of relevant information
- Requires only purposeful information input/is not cumbersome
- Supports using general information before more specific information is available
- Can expand if there is a need for more complexity

These requirements will be evaluated in Chapter 9. In accordance with the research-by-design methodology, the requirements for now represent the preliminary requirements for the concept stage of the solution. Subsequently, the concept is developed concurrently with the development of the hemp product. Therefore, the requirements were made more precise and SMART throughout the product and solution development process.

### *5.4.1 Tool*

To meet the requirements of the solution, the development of a tool is proposed. A tool is "an instrument that enables performing a certain process within the overall development process."[48]. The aim requirements of the solution form a basis for the different aspects the tool should accommodate.

While alternative approaches to meeting the solution requirements - such as developing custom software, hiring an additional manager, or enrolling employees in specialised training programs - could be considered, these options are likely to impose significant additional costs on the organisation. The advantage of using a tool lies in its feasibility within the organisation's current situation. A tool can be integrated without the need for significant additional resources, apart from a possible time investment. Ideally, this time investment will be outweighed by the improvements achieved through the implementation of the tool. Moreover, the solution should effectively capture, manage and update relevant information, making guidelines or manuals insufficient to address the company's current needs.

The integration of a tool into the product development process of Vepa is intended to provide Vepa with more insight and will be explained in the next chapter. By utilising the tool, the product developers should be prompted to reflect on the aspects that will give them more insight into the design process. Also, for management and during product development consultations, the tool can be used to provide quick insight in the project's status. By utilising a tool, additionally, a more structured approach of the product development process can be achieved. The use of the tool is not a goal in itself, but an important aid to achieve the solution objective.

In order to meet the usability requirements, the tool will be developed in Excel. In this way, the tool can meet the usability requirements. As mentioned before in section 2.1.4, Vepa currently uses mainly Microsoft Office applications for documentation. In addition, Excel offers many more possibilities than are typically used, therefore the choice was made to use these capabilities before developing or buying other software. Additionally, Excel is an effective tool for performing calculations and implementing conditional formatting. Excel provides flexibility to customise the tool as Vepa's needs change. The familiar interface ensures that team members can readily navigate and utilise the tool without extensive training. Given the current state of Vepa's product development process, using Excel is considered to align with the MAYA principle [49]. The ease of use hopefully promotes adoption.

Now that the solution has been identified as a tool within Excel, a few overarching usability requirements of the solution can be added.

**The tool..**

Usability:

- Makes clear what information to fill in and what is a template or automatically calculated
- Shows metadata: source, status (e.g. validity and certainty), date
- Allows linking to external resources
- Contains a manageable amount of information
- Provides visual overview
- (wish) Considers colour blindness

### *5.4.2 Visual overview*

To address the solution requirement of is quickly interpret, visual output is preferred. To provide information in an effective manner, visual insight is important. This also aligns with the well-known adage "A picture is worth a thousand words". As becomes apparent from the first part, much information arises during product development and much time is spent on updating each other. Furthermore, the documents Vepa currently creates contain much text. Dashboards are a way of providing data visualisations in one view. Therefore, research has been conducted to product dashboards and visual overviews. The dashboards are shown in appendix D.

*Gispen CE-Label*

Gispen has a CE-label that shows a score about production, reuse, logistics, (dis)assembly, maintenance and material. For the reader, it is however not clear what each factor resembles and how it is calculated.

*Gispen sustainability sheet*

This sheet is focused on the sustainability aspect, it shows the material weight and percentage in the product. It shows the percentage of recycled materials that go in the product and the percentage of materials that can be recycled and the percentage of renewable materials.

*Vepa NPR*

This sheet aims to measure the circularity aspect based on the amount of assembly steps, needed competence, needed and complexity of tools and whether product material passports are available. It however shows no visual output.

*Vepa Product sheet*

Vepa had previously attempted to create a product sheet. This sheet aims to centralise product information during the development process and leaves room for common errors. This sheet was not developed further due to a lack of responsibility for this further development, but the need is still present.

*TNO circularity self-assessment tool*

This tool focuses on comparing two products. However, many information input steps are required.

The analysis of existing product dashboards further reveals a need for visual insight into products and projects. Currently, most of the available product dashboards are only about the sustainability or circularity aspect. Some sheets are very extensive, however, do not create visual output. All dashboards confirm that customers and product developers are seeking visual overviews, so why not create a visual overview as a support for designers during the design process? Visual overviews provide a way to quickly communicate information.

## 5.5 Conclusion

The challenges that complicate Vepa's decision-making processes have been identified. Insight is needed into relevant project information, including prototyping outcomes, project planning, responsibilities and trade-offs. Therefore, the research question was extended and reformulated as follows: "*How can Vepa enable insightful decision-making in its product development processes?*". An objective is displayed, where more early-stage knowledge is available and therefore the design freedom is kept longer, minimising costly changes in the later phases, all by shifting effort to the early stages. The objective is that critical decisions can be made based on the right insights, ultimately leading to more informed decision-making and efficiency throughout the product development process. To achieve this objective, a solution is proposed in the form of a tool that provides important insights and quick overview for Vepa. In the next chapter, the tool development will be described.

Chapter

# .06

# Tool development

*This chapter begins with an explanation of the tools' area of support and global structure, consisting of seven tabs. Subsequently, each individual tab with its corresponding requirements will be explained. These requirements have been derived based on the insights gained in part one, as well as from the practical experience of developing a product within Vepa. The chapter ends with a proposed scenario with the tool, followed by a new global planning for Vepa.*

The tool is in the first place developed from, and for, the designer's perspective, but may also be useful to other stakeholders. The tool is designed to support Vepa's product developers as depicted in the grey area in Figure 23. It has the potential to play an important role in Vepa's product development by bringing clarity, where previously little insight or documentation was present. The tool is not meant to be a designing tool, to come up with ideas and help in ideation, but rather focuses on providing insight, monitoring status and acting as a memory aid. It focuses on the early stages since this is where the greatest potential for improvement lies, as indicated by the largest differences between the lines in Figure 22. Therefore, the tool provides means for analysis and communication for multiple company departments, offering additional value to management by enabling access to updates or details about ongoing projects. All in all, the tool should make the product development process of Vepa more efficient than without the tool. Furthermore, the tool should be more company-specific than general tools. The tool may also apply to other discrete product development companies but is in the first place developed for Vepa.

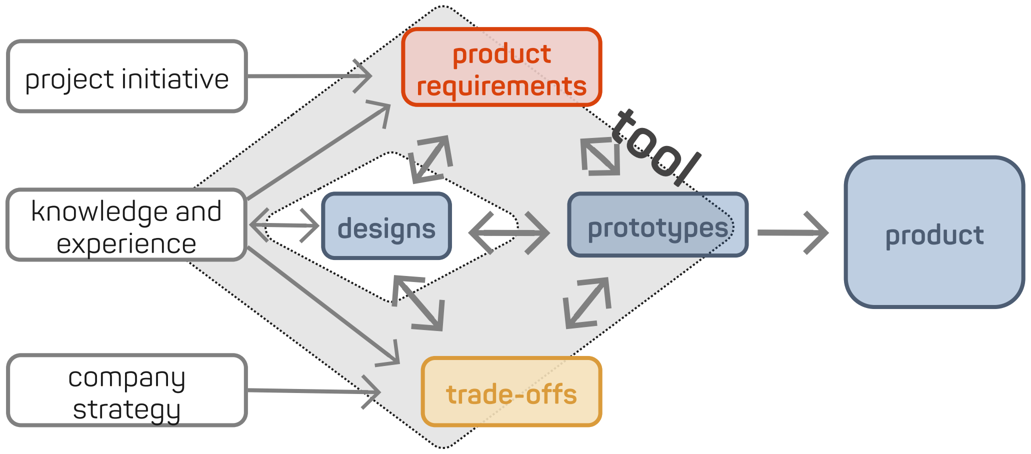


**Figure 23** Area of tool support (in grey)

## 6.1 Tool structure

The tool consists of seven tabs: framework requirements, planning, prototyping, calculations, comparison and summary. The tool is developed through research by design, in this case, the design of a hemp composite wall panel. This was an iterative process, with many steps in between before arriving at the final tool. As with any design project, the development of the tool went through the phases of requirements, conceptualisation, detail, and embodiment. Please refer to Appendix F for the starting point of each tab. For each tab requirements were formulated and these were further defined during the design process of the tool. In section 8.1 the further defined requirements will be shown and verificated.

The main subjects and functions accommodated within each tab are listed in Figure 24. Ideally, all tabs would be straightforward and contain as little information as possible, but they must cover the necessary functionalities. Each tab and the corresponding preliminary requirements that preceded the development of these tabs are explained in the next sections. This division was found to be the most appropriate to provide insight into the challenges listed in section 5.1 and was developed collaboratively with the case study described in the next chapter, where a link will be provided to the Excel tool in use. The requirements came forth from user interviews and practical experience. In the next sections, the empty tool will be described.

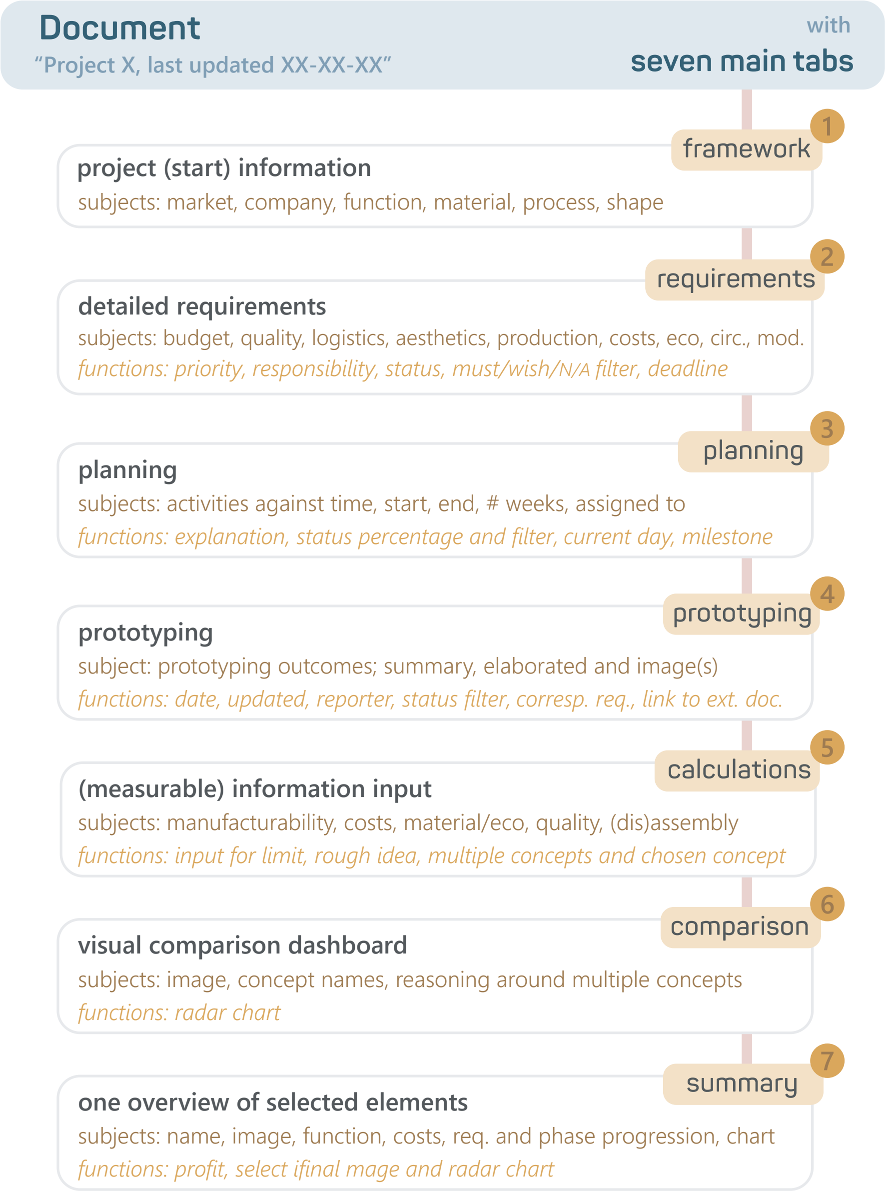


**Figure 24** Tool structure

### *6.1.1 framework*

The framework captures relevant information and can serve as a starting point for new projects, as outlined in section 4.2. In the tab, the subjects of the framework should be captured. The tab is referred to as the 'project info' tab, as the term 'framework' might be unclear to the users. By organising relevant information, the framework provides a foundation for creating a clear and consistent project description. By having to input information, the users will be encouraged to investigate unknown information.

The project information tab should..

- Include the project name and main functioning
- Capture information on the framework/serve as a memory aid
- Allow for division of parts and/or assemblies
- (Wish) indicate if something is unknown
- (Wish) explain what to fill in

| | | | | |
|---|---|---|---|---|
| **Product description:** | insert product name here | **last updated:** | date **by:** name | |
| **main objective:** | insert product main function here | | | |
| **market** | *What end user, competitor landscape, need?* | **company** | *Why develop the product and what service to provide?* | ***context*** |
| end user | insert end user here | brand identity | | |
| consumer trends | | portfolio | | |
| | | strategy | | *company* |
| competitor landscape | | novel idea | | |
| (products and prices) | average prices | transportation | | |
| | | service | | |
| requests or need | | storage | | *market* |
| | **part 1:** part/sub-assembly 1 | **part 2:** part/sub-assembly 2 | **part X:** ... *optionally add more parts...* | ***product*** |
| **function** | *what are the main and sub-functioning of the parts or assemblies?* | | | |
| main | main function of first part | main function of second part | | |
| & sub | sub function of first part | sub function of second part | | |
| durability | *this is unknown and therefore shows yellow italics* | | | |
| quantity | | | | |
| improvement | | | | *function* |
| **material** | *what is known about the material?* | | | |
| name | | | | |
| how made | | | | |
| critical points | | | | |
| free variables | | | | |
| mech properties | | | | |
| physical properties | | | | |
| costs | | | | |
| energy | | | | |
| waste | | | | |
| benchmark | | | | |
| unexplored opportunities | | | | *material* |
| **process** | *how are the parts and assemblies manufactured?* | | | |
| how made | | | | |
| critical points | | | | |
| free variables | | | | |
| global shape restrictions | | | | |
| investments | | | | |
| setting and running costs | | | | |
| energy | | | | |
| waste | | | | |
| unexplored opportunities | | | | *process* |
| **shape** | *What is the shape of the parts and assemblies?* | | | |
| parts & assembly | | | | |
| macro.. | should not be filled in, therefore background colour | | | |
| ..dimensions | | | | |
| ..ease of assembly | | | | |
| ..ease of disassembly | | | | |
| micro.. | | | | |
| ..texture & finishing | | | | |
| associations | | | | |
| stackability | | | | |
| packaging | | | | *shape* |

**Figure 25** First tool tab

The first tab of the tool is shown in Figure 25. It may be impractical to record all the details in a written format, therefore, it is possible to note down highlights only. Nevertheless, space is allocated for the inclusion of any relevant information to the design project. The project info tab serves to assist the designer in not overlooking aspects and helps to formulate a summary of the framework nodes. The user is forced to think about critical points that might be forgotten otherwise. Unknown information can be sought from other departments within the company. This tab is a living document that can be updated as the project progresses. The tab also requires defining the main and sub-functions of the product, as well as its parts or sub-assemblies. This helps designers to conceptualise a function tree in their head, which is crucial for developing the product's quality requirements. The information in this tab can serve as a foundation for formulating the product requirements on the next tab.

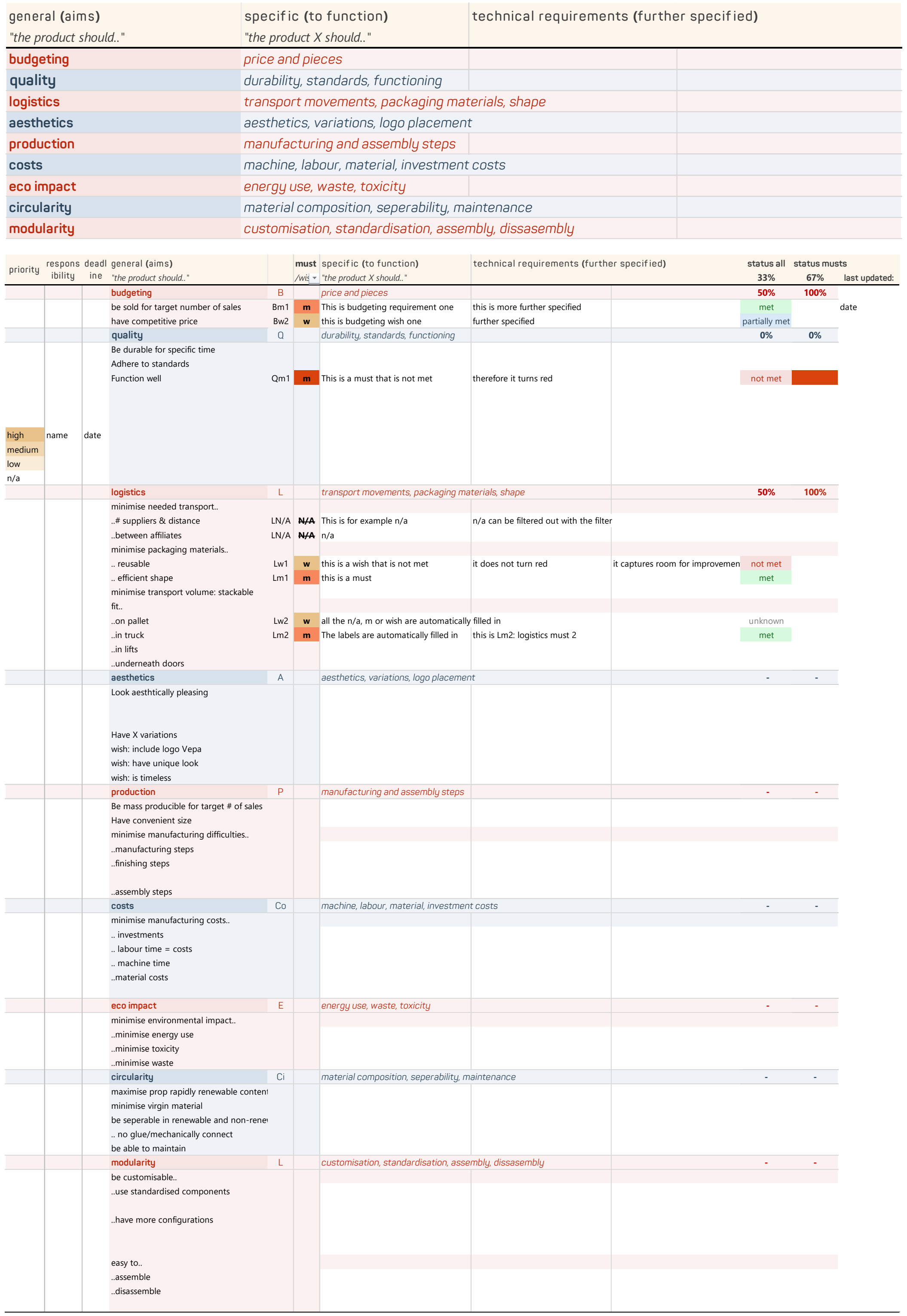
### *6.1.2 Product requirements*

To address the requirements of the solution "helps in defining clear product requirements", a requirements template is proposed. It is suggested to begin with broad requirements, as Vepa currently formulates them, and make them more specific before entering the conceptual design phase. By filling in a template, the designer is forced to think about all these aspects early on, which will help not to forget them. This would prevent scenarios that do not meet logistic requirements, such as designing a cabinet that does not fit in a truck, as previously discussed. However, sometimes aspects might be irrelevant for a specific product, and it would be preferred to have the ability to switch requirements on or off. In practice, requirements are often also formulated during the project, so there should be space to add more and make them more specific as the project progresses. As explained, the distinction between "wish" and "must-have" requirements significantly impacts decision-making and is often not so clear for Vepa, so the tool should include functionality to specify this distinction. The following requirements are formulated for the second tab, the list of requirements template.

The project information tab should..

- Aid in structuring and not forgetting requirements
- Allows for further (SMART) specification of the requirements
- Aid in defining whether a requirement is a must or a wish
- Allows requirements to be switched on and off
- Allows requirements to be updated on status
- (Wish) is movable in order of subject
- (Wish) is movable in order within the subject
- (Wish) show metadata
- (Wish) show how many requirements (musts and all) are met
- (Wish) clearly indicate if a must is not met

Figure 26 shows the empty requirements template fully collapsed and unfolded.



| general (aims)<br>*"the product should.."* | specific (to function)<br>*"the product X should.."* | technical requirements (further specified) |
|---|---|---|
| **budgeting** | *price and pieces* | |
| **quality** | *durability, standards, functioning* | |
| **logistics** | *transport movements, packaging materials, shape* | |
| **aesthetics** | *aesthetics, variations, logo placement* | |
| **production** | *manufacturing and assembly steps* | |
| **costs** | *machine, labour, material, investment costs* | |
| **eco impact** | *energy use, waste, toxicity* | |
| **circularity** | *material composition, seperability, maintenance* | |
| **modularity** | *customisation, standardisation, assembly, dissasembly* | |

| priority | respons ibility | deadl ine | general (aims)<br>*"the product should.."* | | must /wis | specific (to function)<br>*"the product X should.."* | technical requirements (further specified) | | status all<br>33% | status musts<br>67% | last updated: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **budgeting** | B | | *price and pieces* | | | **50%** | **100%** | |
| | | | be sold for target number of sales | Bm1 | **m** | This is budgeting requirement one | this is more further specified | | met | | date |
| | | | have competitive price | Bw2 | **w** | this is budgeting wish one | further specified | | partially met | | |
| | | | **quality** | Q | | *durability, standards, functioning* | | | **0%** | **0%** | |
| | | | Be durable for specific time | | | | | | | | |
| | | | Adhere to standards | | | | | | | | |
| | | | Function well | Qm1 | **m** | This is a must that is not met | therefore it turns red | | not met | 🟥 | |
| high | name | date | | | | | | | | | |
| medium | | | | | | | | | | | |
| low | | | | | | | | | | | |
| n/a | | | | | | | | | | | |
| | | | **logistics** | L | | *transport movements, packaging materials, shape* | | | **50%** | **100%** | |
| | | | minimise needed transport.. | | | | | | | | |
| | | | ..# suppliers & distance | LN/A | ~~N/A~~ | This is for example n/a | n/a can be filtered out with the filter | | | | |
| | | | ..between affiliates | LN/A | ~~N/A~~ | n/a | | | | | |
| | | | minimise packaging materials.. | | | | | | | | |
| | | | .. reusable | Lw1 | **w** | this is a wish that is not met | it does not turn red | it captures room for improvemen | not met | | |
| | | | .. efficient shape | Lm1 | **m** | this is a must | | | met | | |
| | | | minimise transport volume: stackable | | | | | | | | |
| | | | fit.. | | | | | | | | |
| | | | ..on pallet | Lw2 | **w** | all the n/a, m or wish are automatically filled in | | | unknown | | |
| | | | ..in truck | Lm2 | **m** | The labels are automatically filled in | this is Lm2: logistics must 2 | | met | | |
| | | | ..in lifts | | | | | | | | |
| | | | ..underneath doors | | | | | | | | |
| | | | **aesthetics** | A | | *aesthetics, variations, logo placement* | | | - | - | |
| | | | Look aesthtically pleasing | | | | | | | | |
| | | | Have X variations | | | | | | | | |
| | | | wish: include logo Vepa | | | | | | | | |
| | | | wish: have unique look | | | | | | | | |
| | | | wish: is timeless | | | | | | | | |
| | | | **production** | P | | *manufacturing and assembly steps* | | | - | - | |
| | | | Be mass producible for target # of sales | | | | | | | | |
| | | | Have convenient size | | | | | | | | |
| | | | minimise manufacturing difficulties.. | | | | | | | | |
| | | | ..manufacturing steps | | | | | | | | |
| | | | ..finishing steps | | | | | | | | |
| | | | ..assembly steps | | | | | | | | |
| | | | **costs** | Co | | *machine, labour, material, investment costs* | | | - | - | |
| | | | minimise manufacturing costs.. | | | | | | | | |
| | | | .. investments | | | | | | | | |
| | | | .. labour time = costs | | | | | | | | |
| | | | .. machine time | | | | | | | | |
| | | | ..material costs | | | | | | | | |
| | | | **eco impact** | E | | *energy use, waste, toxicity* | | | - | - | |
| | | | minimise environmental impact.. | | | | | | | | |
| | | | ..minimise energy use | | | | | | | | |
| | | | ..minimise toxicity | | | | | | | | |
| | | | ..minimise waste | | | | | | | | |
| | | | **circularity** | Ci | | *material composition, seperability, maintenance* | | | - | - | |
| | | | maximise prop rapidly renewable content | | | | | | | | |
| | | | minimise virgin material | | | | | | | | |
| | | | be seperable in renewable and non-renev | | | | | | | | |
| | | | .. no glue/mechanically connect | | | | | | | | |
| | | | be able to maintain | | | | | | | | |
| | | | **modularity** | L | | *customisation, standardisation, assembly, dissasembly* | | | - | - | |
| | | | be customisable.. | | | | | | | | |
| | | | ..use standardised components | | | | | | | | |
| | | | ..have more configurations | | | | | | | | |
| | | | easy to.. | | | | | | | | |
| | | | ..assemble | | | | | | | | |
| | | | ..disassemble | | | | | | | | |

**Figure 26** Second tab of tool, folded and unfolded

*Categories*

Careful consideration has been given to defining the categories of the list of requirements template to ensure they encompass the relevant aspects for Vepa. The categories are budgeting, quality, logistics, aesthetics, production, costs, environmental impact, circularity and modularity. The categories and subjects within the categories were defined by generating requirements for several products of Vepa, such as tables chairs and wall panels, where similar subdivisions consistently were found. Additionally, the requirements description that Vepa often works with, as shown in Appendix E, has been compared to the formulated categories and subjects and missing subjects were integrated into these categories. The categories align with the perspectives found earlier and the requirements under the headings are expanded mostly with topics corresponding to the node attributes of the framework. Gaining knowledge on the framework enables the formulation and specification of the list of requirements.

*Increasing detailed requirements*

From left to right the columns are structured to define the requirements in increasing detail. The leftmost column captures the general requirements applicable to all of Vepa’s products. Once the product’s function is determined, the increasingly detailed requirements can be filled in. For example, the product should “function properly”, which for a wall panel means the wall panel should absorb as much sound as possible. Then, the function-specific requirement can be made more specific. For example, the wall panel should absorb more than 30% of sound. This can then translate to even more specific (technical) requirements such as; the panel should contain at least 80% area of two-layered 10 mm hemp composite. The case study will further demonstrate the use of the tool. Note that the “function well” requirement is inherently dependent on the function of the product, therefore it is only a broad requirement in the first column but will have many requirements in the specific requirement column.

*Functions*

Most importantly the requirements are clearly labelled as a **“must” or a “wish”** using the labels “m” and “w”. By default, any new requirement entered is **automatically labelled** as a “must”. If the user types the word “wish” in the requirement, automatically it is labelled as a “wish”. Additionally, users can manually override the label by clicking the alternate letter. For example, quality wish 1 will get the number “Qw1” and production must one and two will get the labels “Pm1” and “Pm2”. This enables easy linking and referencing to requirements. If a requirement is **not applicable,** it will be labelled as ‘~~N/A~~’. A **filter** function in the must or wish column allows users to quickly display only musts or filter out any requirement not applicable to the current project, without losing data.

The **status** of each requirement can be updated through an added status column in the template, which includes the following options: “met,” “partially met,” “in progress,” “not met,” and “unknown”. This status is also represented as a percentage. The “Status all” field displays the percentage of met requirements relative to all requirements, while the “Status musts” field shows the percentage of met must-have requirements. If a must-have requirement is not met, it is highlighted in red, indicating that it needs to be resolved.

The **priority** column enables users to indicate whether a requirement is of low, medium, or high priority. This helps users prioritise which requirements need to be addressed first and facilitates easy identification and discussion of the most important requirements for the project. The **responsibility** column allows users to assign a person responsible for ensuring the requirement is met. Additionally, the deadline column provides space to set a date by which the requirement must be fulfilled.

The **last updated** column allows to record when a requirement was updated.

Grouping subjects allows to **toggle the visibility** of certain requirements subjects and the above-mentioned functions. While requirements could be moved in order, this requires copying and pasting and the time investment might probably not outweigh the advantages of moving the order of the subjects. Even requirements could be moved in order, but this requires some copy-and-paste actions and this time investment might probably not outweigh the advantages of moving the order of the subjects.

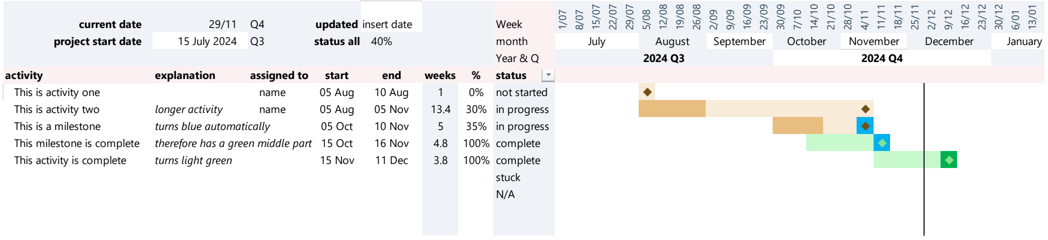
### *6.1.3 Planning*

To address the requirement “helps in defining project planning” the planning tab was created. Vepa has never had a product-specific timeline, only a general product planning sheet exists that provides a broad overview of all projects and their status. Therefore, implementing a separate product planning can be highly valuable in offering insight into the project’s progress. While it may not be possible to provide precise timelines at the start of a design project, a product-specific plan can at least help establish a general time frame. Furthermore, by being able to visually capture percentages of certain tasks, other stakeholders can be easily updated on status. Additionally, once a project is completed, this plan can serve as a reference for similar projects, helping to identify potential pitfalls and improve future planning. Furthermore, having a clear timeline can help designers feel less overwhelmed when making decisions, as they will have a better understanding of critical decision points throughout the project.

The planning tab should..

- Visually show activities against time
- Allow for adjustment of activities and time
- Show the start and end date of the activity
- Display the current date visually
- Display Quartile
- Should be able to cover more than a year
- (Wish) count duration of activity
- (Wish) start at a quartile start and on Monday
- (Wish) help with filling in standard activities
- (Wish) help with assigning standard departments
- (Wish) show if on track
- (Wish) clearly indicate milestones

To fulfil the requirements for the planning tab, inspiration was taken from a Gantt Chart since this is one of the most popular and useful ways of visually showing activities against time [50]. With the planning tab, activities can be planned and tracked during the process. The following functions are included, see Figure 27.



**current date** 29/11 Q4 **updated** insert date

**project start date** 15 July 2024 Q3 **status all** 40%

| **activity** | **explanation** | **assigned to** | **start** | **end** | **weeks** | **%** | **status** |
|---|---|---|---|---|---|---|---|
| This is activity one | | name | 05 Aug | 10 Aug | 1 | 0% | not started |
| This is activity two | *longer activity* | name | 05 Aug | 05 Nov | 13.4 | 30% | in progress |
| This is a milestone | *turns blue automatically* | | 05 Oct | 10 Nov | 5 | 35% | in progress |
| This milestone is complete | *therefore has a green middle part* | | 15 Oct | 16 Nov | 4.8 | 100% | complete |
| This activity is complete | *turns light green* | | 15 Nov | 11 Dec | 3.8 | 100% | complete |
| | | | | | | | stuck |
| | | | | | | | N/A |

**Figure 27** Third tab of tool

By entering the **start date,** the planning automatically aligns with the first Monday of that quartile. The timeline displays weeks, months, year and quartiles. Also, the current and project **start quartile** are shown. To make sure the user needs less time to fill in the planning a standard planning, that was developed in a later stage, is pre-filled as a starting point. By putting in the start and end date, the tool automatically **counts the weeks** and the visual chart is created with a diamond marker on the final day. The user can enter the date the sheet was **last updated** so that another member will know whether the status is up to date. The planning can be extended as far as needed.

A **status percentage** can be entered, which is automatically reflected in the progress bar with corresponding colours. By default, 0% is labelled “Not Started,” 1-99% is labelled “in progress,” and 100% is labelled “complete.” These statuses can be overridden manually, or the status “stuck”  status can be selected if needed. Once an activity is complete, the bar colour lightens, and the diamond turns green to indicate a reduced focus on that task. **The current day** is marked with a vertical line, providing a clear visual cue for tracking the project’s progress. Additionally, **milestones**, important checkpoints to assess progress, are automatically highlighted with a different colour when the word “milestone” is included in the activity description.

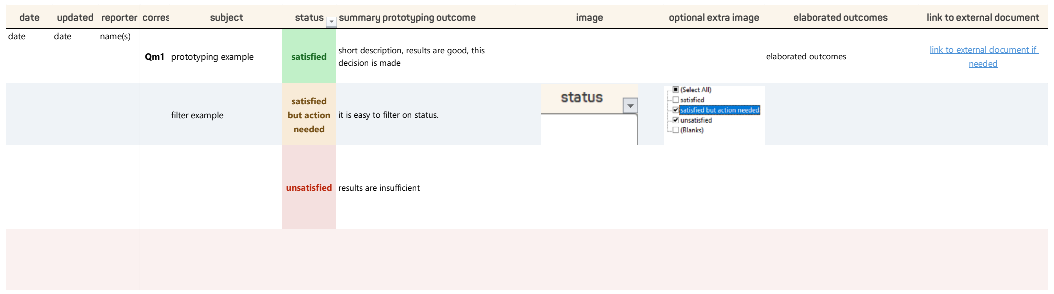
### *6.1.4 Prototyping*

Developing and testing a prototype provides valuable information and insight into the design decisions that have been, or should be, made. The potential benefits to be derived from prototyping lie in properly recording the findings. However, before writing down findings, careful thought should be given to what needs to be tested. By thinking carefully about what needs to be found out in advance, the number of prototypes that need to be made can be minimised, thereby minimising the cost and effort. Also, being able to look at the results of previous prototyping can prevent the same things from being tested again. Based on the prototyping results, the requirements can be even further specified, and the unknown values of the framework may be filled in. In addition, having a prototyping overview can save a significant amount of time in updating each other on prototyping outcomes, which is especially important for the product development manager who needs to stay informed about the progress.

The prototyping tab should..

- Allow planning of prototyping
- Effectively capture outcomes
- Support documenting elaborated outcomes
- Help user reflect on outcomes
- Inserting images
- Showing relevant metadata: reporter, date

This resulted in the tab shown in Figure 28 which allows for planning and reporting of prototyping.



| date | updated | reporter | corres | subject | status | summary prototyping outcome | image | optional extra image | elaborated outcomes | link to external document |
|---|---|---|---|---|---|---|---|---|---|---|
| date | date | name(s) | **Qm1** | prototyping example | **satisfied** | short description, results are good, this decision is made | | | elaborated outcomes | link to external document if needed |
| | | | | filter example | **satisfied but action needed** | it is easy to filter on status. | status | ■ (Select All)<br>☐ satisfied<br>☑ satisfied but action needed<br>☑ unsatisfied<br>☐ (Blanks) | | |
| | | | | | **unsatisfied** | results are insufficient | | | | |

**Figure 28** Fourth tab of tool

This sheet provides a structured way to report and plan prototyping activities. Each prototyping task can be linked to the **corresponding requirement,** as prototyping is typically conducted to address unmet requirements. The **subject** and **summary** prototyping outcome columns serve as a concise overview of what was tested, while the designer is encouraged to clearly state and reflect on the outcome. The **status** indicates whether the designer is satisfied, unsatisfied or if action is needed, making the decisions resulting from prototyping explicit. This status can be **filtered** to quickly identify the issues that are unsatisfactory or require action. An **image** or optionally an extra image can be added to the sheet. The **elaborated outcomes** and links to external documents can serve as more in-depth reports of prototyping. By using this tab, the designer is forced to think carefully about why and what to test, ensuring that outcomes and decisions are captured.

### *6.1.5 Calculations*

All the DfX methods emphasise the importance of considering certain explicit values from an early stage, for instance, a quick production cost estimation. The calculations tab was created to assist the designer in explicitly addressing and incorporating the aspects that Vepa considers important in its product development.

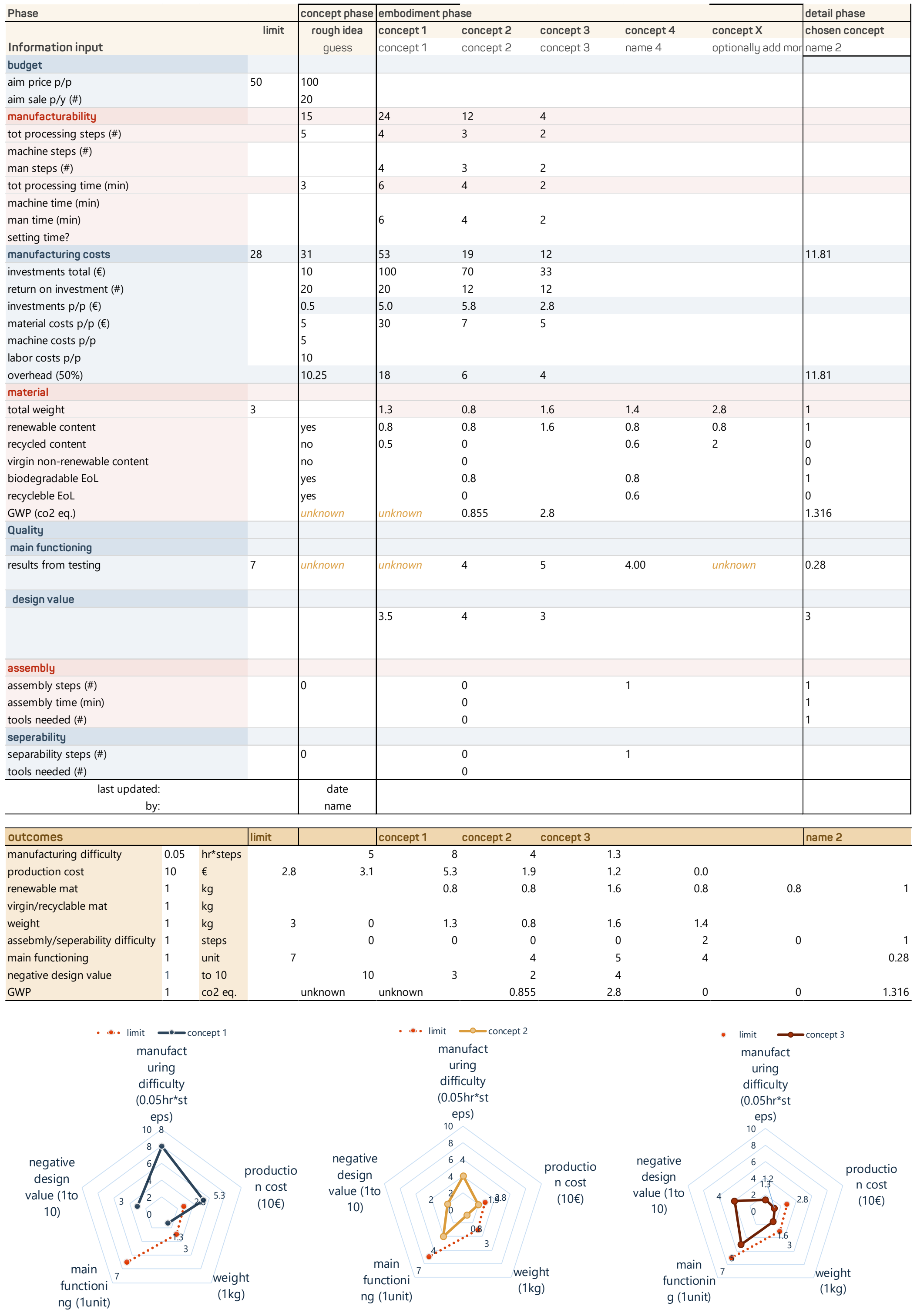
The calculation tab should accommodate..

- Filling in a limit
- Fill in a guesstimate in the early stages of designing
- Fill in multiple concepts in more detailed stages of designing
- Fill in the chosen concept with more specific information
- Show relevant metadata
- Understanding what to fill in

But which aspects should be filled in and compared? It is only meaningful to compare information that will have influence on decision-making. To determine the information input, an interview was conducted with Vepa's development director. Based on the insights from this interview, it was determined that at least the following aspects should be incorporated: manufacturability, costs, material composition or circularity, quality, and design value.

In the conceptualisation phase, when a rough idea of the product is formed, basic information can be entered to provide an initial estimate of the product's potential. Aspects can be filled in, and a preliminary evaluation can be made. As the process progresses, these estimates will become more refined. Information can be entered at multiple stages in the product development process. Likely, different concepts will need to be compared. As soon as there is similar information available for two product concepts or even parts, a comparison can be drawn. In later stages, more specific data can be entered, making the evaluation more precise. In addition, company-imposed limits or non-negotiable factors can be included. Finally, the values of the selected concept can be entered for a more detailed evaluation.

The outcomes of these values, from now on called performance indicators, have been inspired by the DfX methods and Vepa's current approach to calculating its circularity and cost prices. However, the calculations of the values are still under development as discussed in section 11.2. The outcomes will be visualised in a radar chart, as further explained in the next section. Therefore, a function to keep all units on the right scale is also included in this tab. The calculations tab is shown in Figure 29.



| Phase | | concept phase | embodiment phase | | | | | detail phase |
|---|---|---|---|---|---|---|---|---|
| | limit | rough idea | concept 1 | concept 2 | concept 3 | concept 4 | concept X | chosen concept |
| Information input | | guess | concept 1 | concept 2 | concept 3 | name 4 | optionally add mor | name 2 |
| **budget** | | | | | | | | |
| aim price p/p | 50 | 100 | | | | | | |
| aim sale p/y (#) | | 20 | | | | | | |
| **manufacturability** | | 15 | 24 | 12 | 4 | | | |
| tot processing steps (#) | | 5 | 4 | 3 | 2 | | | |
| machine steps (#) | | | | | | | | |
| man steps (#) | | | 4 | 3 | 2 | | | |
| tot processing time (min) | | 3 | 6 | 4 | 2 | | | |
| machine time (min) | | | | | | | | |
| man time (min) | | | 6 | 4 | 2 | | | |
| setting time? | | | | | | | | |
| **manufacturing costs** | 28 | 31 | 53 | 19 | 12 | | | 11.81 |
| investments total (€) | | 10 | 100 | 70 | 33 | | | |
| return on investment (#) | | 20 | 20 | 12 | 12 | | | |
| investments p/p (€) | | 0.5 | 5.0 | 5.8 | 2.8 | | | |
| material costs p/p (€) | | 5 | 30 | 7 | 5 | | | |
| machine costs p/p | | 5 | | | | | | |
| labor costs p/p | | 10 | | | | | | |
| overhead (50%) | | 10.25 | 18 | 6 | 4 | | | 11.81 |
| **material** | | | | | | | | |
| total weight | 3 | | 1.3 | 0.8 | 1.6 | 1.4 | 2.8 | 1 |
| renewable content | | yes | 0.8 | 0.8 | 1.6 | 0.8 | 0.8 | 1 |
| recycled content | | no | 0.5 | 0 | | 0.6 | 2 | 0 |
| virgin non-renewable content | | no | | 0 | | | | 0 |
| biodegradable EoL | | yes | | 0.8 | | 0.8 | | 1 |
| recycleble EoL | | yes | | 0 | | 0.6 | | 0 |
| GWP (co2 eq.) | | *unknown* | *unknown* | 0.855 | 2.8 | | | 1.316 |
| **Quality** | | | | | | | | |
| **main functioning** | | | | | | | | |
| results from testing | 7 | *unknown* | *unknown* | 4 | 5 | 4.00 | *unknown* | 0.28 |
| **design value** | | | | | | | | |
| | | | 3.5 | 4 | 3 | | | 3 |
| **assembly** | | | | | | | | |
| assembly steps (#) | | 0 | | 0 | | 1 | | 1 |
| assembly time (min) | | | | 0 | | | | 1 |
| tools needed (#) | | | | 0 | | | | 1 |
| **seperability** | | | | | | | | |
| separability steps (#) | | 0 | | 0 | | 1 | | |
| tools needed (#) | | | | 0 | | | | |
| last updated: | | date | | | | | | |
| by: | | name | | | | | | |

| **outcomes** | | | limit | | concept 1 | concept 2 | concept 3 | | | name 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| manufacturing difficulty | 0.05 | hr*steps | | 5 | 8 | 4 | 1.3 | | | |
| production cost | 10 | € | 2.8 | 3.1 | 5.3 | 1.9 | 1.2 | 0.0 | | |
| renewable mat | 1 | kg | | | 0.8 | 0.8 | 1.6 | 0.8 | 0.8 | 1 |
| virgin/recyclable mat | 1 | kg | | | | | | | | |
| weight | 1 | kg | 3 | 0 | 1.3 | 0.8 | 1.6 | 1.4 | | |
| assebmly/seperability difficulty | 1 | steps | | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| main functioning | 1 | unit | 7 | | | 4 | 5 | 4 | | 0.28 |
| negative design value | 1 | to 10 | | 10 | 3 | 2 | 4 | | | |
| GWP | 1 | co2 eq. | | unknown | unknown | 0.855 | 2.8 | 0 | 0 | 1.316 |

**Figure 29** Fifth tool tab

### *Manufacturability*

Inputs include preliminary estimates of processing steps and processing time, which can later be refined into machine steps, man steps, machine time, and man time.

The output is calculated as steps×time, as both steps and time should be minimised.

### *Production costs*

Inputs include the total investments, the targeted return on investment after a certain number of pieces, material costs, machine and labour costs, and overheads. Initially, machine and labour costs can be combined as an estimate, but later on, a distinction can be made between the two.

The output is the sum of the total investments divided by pieces after return on investment, material costs, machine costs, labour costs, and overhead (covering storage, energy, lease cars or damage cost). The target sales number is used to estimate when return on investment is achieved. The overhead is set to 50% of the material, machine and labour costs. Based on several product calculation documents of the ERP system, this seemed to be a realistic estimate to account for all the overheads. This output was based on the way Vepa calculates its product prices. With these inputs already a close estimate can be obtained from some initial guesses, in line with the Pareto principle, according to which 80% of the consequences come from 20% of the causes [51].

### *Material*

Inputs include the inputs of renewable content, recycled content and virgin content and the output of recycled content and biodegradable content. Weight should also be put in, since minimising weight is generally advantageous from a sustainability perspective.

With the material inputs, a score for circularity can be given, for example, total material – 0.5 * recyclable material – renewable material. Also, the weight can be displayed.

### *Sustainability*

The global warming potential (GWP) in kg $CO_2$ equivalent can be filled in after an LCA is conducted. However, even in the conceptual stage, an early LCA can give a rough GWP estimate. This value is chosen because Vepa prioritises it most in its sustainability efforts. While other LCA factors, such as water usage, are also significant, including them all are outside the scope of this report. The first step is for the designers to start considering sustainability earlier in the development process.

### *Quality*

Quality values are determined by the product's function, so these are subject to variation depending on the specific product or part being developed.

### *Design value*

Design value is the most abstract value. The design value refers to the perceptions of a product. Perceptions refer to the reactions the product induces in an observer, the way it makes someone feel. Because of being in furniture development, the design value is frequently a significant consideration for users and consequently for the product's development. This is the only value where highly subjective values are allowed, any information is better than none. This can for example be measured by assigning a value to the following attributes:

"I perceive the product as..." Innovative - conservative, Expensive – cheap, Sophisticated – course, Remarkable – unremarkable, Hand-made – mass-produced.

These represent perceived attributes of products and their opposites, as described in chapter 17 of Ashby's book [8]. All opposites can be rated on a scale from 1 to 5, rather than 1 to 10, to avoid respondents having difficulty assigning numbers below 6. These perceptions may also be based on the specific design objectives of Vepa. Currently, Vepa does not assign a quantifiable value to aesthetic appeal, this is rather a subjective interpretation of individuals. The output is a single score as the average of these values.

### *Limit*

Maximum values can be defined. Not every parameter may require a constraint, simply comparing the values of two products and ensuring they remain as low as possible can be sufficient in some cases. However, for key factors such as production costs or quality aspects, formulating a more defined limit, or "no-go" threshold, can be valuable. These limits can be agreed upon by the entire design team or the stakeholders involved in the specific project and management, ensuring alignment and setting clear expectations for what is acceptable.

A cost limit will be set through target costing, where product costs are aligned with customer willingness to pay. In other words, the market price can be converted to a limit for manufacturing costs. Vepa usually wants to sell its products at 23% higher than the production costs, but this is in practice not always achieved, therefore the limit is set to ensure a 20% profit margin. Furthermore, Vepa gives a sale to dealers. Usually, Vepa gives around 50% sale to dealers. However, the limit will be calculated by giving less sale, 40%, to dealers. The price before giving sale to dealers, at Vepa referred to as bruto price, is comparable to the market price since the dealers will give their clients some sale, but clients also have to pay BTW. Therefore, the limit for the production costs is set at the (market price – market price×0.4)/1.2 = market price×0.5. So, the maximum manufacturing costs (including overheads) can be aimed at the market price×0.5.

For certain products a weight limit can be set. In the end, reducing weight is one of the best ways to achieve better in terms of sustainability, costs and logistics.

A quality limit can be set for products but this will vary per product. For example, a table may have a maximum bend tolerance under a specific force.

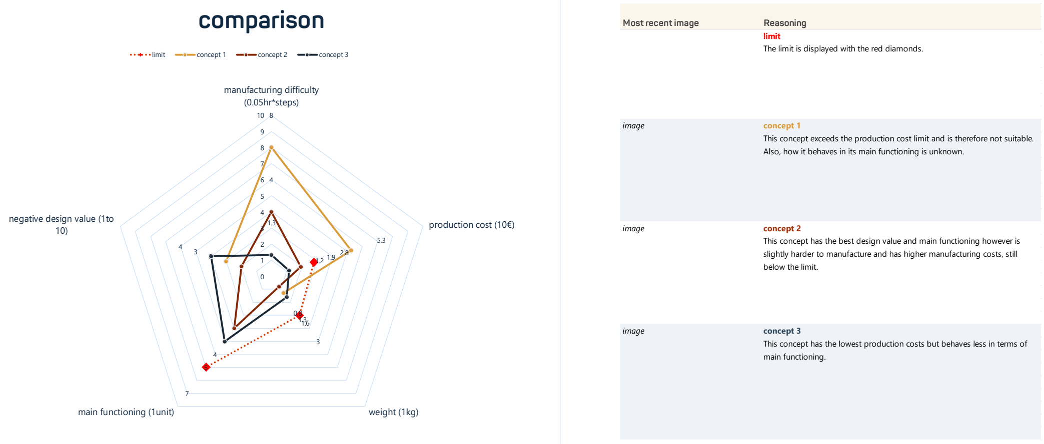
### 6.1.6 Comparison

Making trade-offs in product development is inherently comparative. Consequently, multiple products or concepts should be able to be compared. A visual comparison simplifies understanding the differences between products, showing trade-offs and enabling communication and clearer decision-making. This will facilitate transparency by providing a clear representation of the trade-offs between concepts or products. Members of product development teams are thus able to assess the consequences of decisions and compare alternatives. Consequently, this will facilitate insight and contribute to communication about trade-offs during product development. The comparison tab should visually display a comparison of the performance indices based on the information input of the calculations tab and provide space for the reasoning behind them.

A radar chart was chosen to visualise the multiple concepts. In the radar chart, the aim is to have an as low as possible surface area. The order of performance indexes is very important since a different order would result in a completely different surface area, despite identical values. Topics that are most closely related, referring to the comparison of the DfX methods, could be placed together to clearly illustrate where the chart performs best. It is preferable to avoid including too many aspects under a single topic and in the chart and having too many subjects in the chart, as this may result in a reduction in the differences observed between products, thereby complicating the comparison process. At this stage, the radar chart comprises five topics. The following requirements were formulated for the comparison tab. The tab is shown in Figure 30.

The comparison tab should..

- Visually compare products or concepts: includes radar chart
- Capture reasoning around comparison



| Most recent image | Reasoning |
|---|---|
| | **limit**<br>The limit is displayed with the red diamonds. |
| *image* | **concept 1**<br>This concept exceeds the production cost limit and is therefore not suitable. Also, how it behaves in its main functioning is unknown. |
| *image* | **concept 2**<br>This concept has the best design value and main functioning however is slightly harder to manufacture and has higher manufacturing costs, still below the limit. |
| *image* | **concept 3**<br>This concept has the lowest production costs but behaves less in terms of main functioning. |

**Figure 30** Sixth tool tab

The **radar chart** can be used to compare not only concepts, but also product parts or product assemblies. By documenting the **rationale** behind the comparison chart, decisions are made transparent and concepts that are not developed further are retained for potential relevance in future projects. The **image** allows for a quick interpretation of what is being compared. As stated, the decision was taken to make all performance indicators negative, thereby indicating that a smaller value for all indicators is preferable. The units can be calibrated in such a way that all product performance indexes can be represented on a scale of 0-10. It is essential that the units used for the comparison of products within the same chart are consistent.

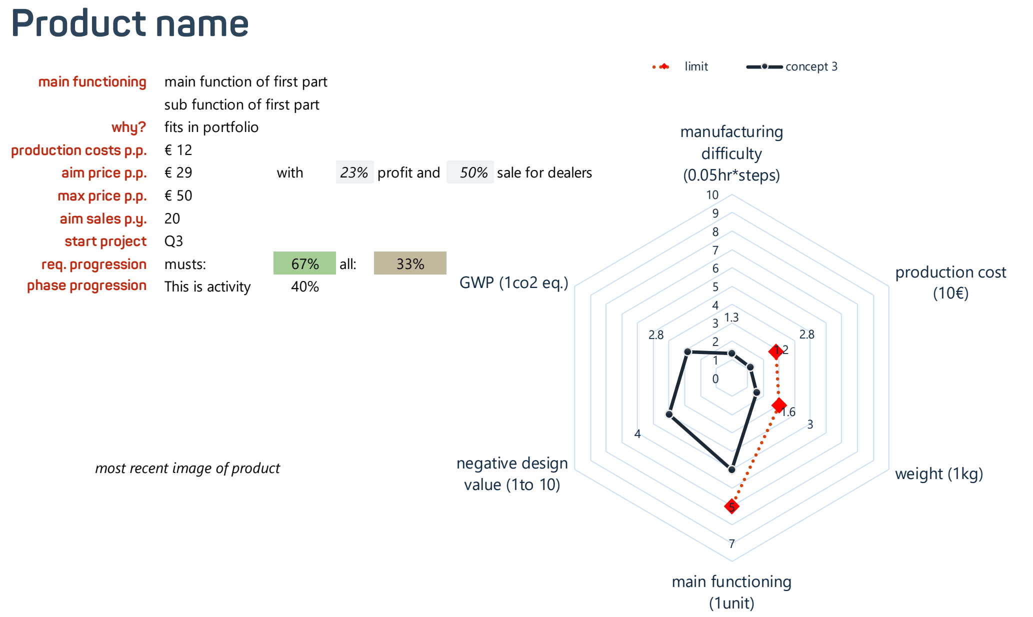
### 6.1.7 Summary

The summary tab addresses the requirement of “can make self-explanatory summary of relevant information”. The following requirements were defined.

The summary tab should..

- Automatically fill in relevant elements to provide means for consultation:
    - Product information: name, main function
    - Progression: start of project, requirements progression, phase progression
    - Costs: production costs, aim price, aim sales number, (wish) percentage of profit and sale for dealers
    - Radar chart of the chosen concept

This sheet, shown in Figure 31, provides an **automatically filled-in summary of selected elements.** This overview can aid during product development consultation, facilitating easier discussions about project progression.


**Product name**

**main functioning** main function of first part
sub function of first part
**why?** fits in portfolio
**production costs p.p.** € 12
**aim price p.p.** € 29 with *23%* profit and *50%* sale for dealers
**max price p.p.** € 50
**aim sales p.y.** 20
**start project** Q3
**req. progression** musts: 67% all: 33%
**phase progression** This is activity 40%

**Figure 31** Seventh tool tab

## 6.2 Scenario with the tool

To give a sense of how the tool can be used in Vepa's product development process, this section describes an improved potential future scenario.

### *Design initiative*

Vepa receives a new design request to develop a new product. The project starts with a rough product description and broad requirements, outlined by the head of design based on the received request. The project is presented by the head of design (a recently created function, primarily responsible for the company's portfolio) and it is agreed that this is a new project that Vepa wants to start. A person is appointed as the main responsible for this project, the project lead. The head of design, or an external designer, develops sketches and carries out market research on similar products and prices to establish some reference points. A global description and sketches of what the product needs to be is now available. Since Vepa often works with the same materials, the product materials are already considered.

### *Setting up the tool*

The project lead opens a new version of the tool 'Product X' for this project, which is automatically opened as a copy because the standard Excel document is available in the shared folder as a template. The first step involves gaining knowledge on the framework information (first tab) as much as possible. The 'market' and 'company' information is provided by the head of the design as indicated in the global project description, and the project lead is mainly concerned with completing the 'function', 'material', 'process' and 'shape' nodes. Missing details, such as critical points or specific processing techniques, are sourced from other (production) employees. Summaries of market research findings, including competitor pricing, are added to this tab. At this stage, known and unknown aspects are clarified, critical points identified, and the main and sub-functions of the product and its components established.

### *Requirements, planning and prototyping plans*

Next, the list of requirements is developed in the requirements tab. The main functionalities and broad requirements from the product description are translated into quantifiable requirements as much as possible. Factors crucial for concept evaluation, such as the cost, manufacturability or aesthetics, are determined. Requirements are categorised as "musts" or "wishes," and preliminary prototyping plans are outlined in the prototyping tab, linked to relevant requirements. On the planning tab, a rough timeline is formulated, encouraging the designer to anticipate potential milestones and challenges. In a product development meeting the plans are reviewed. Using the requirements tab, the project requirements are discussed. Disagreements about whether requirements are a "must" or a "wish" are resolved collaboratively. The provisional assortment is determined, the overall timeline of the project is discussed using the planning tab and a target for the duration of the project is agreed upon. Some prototyping plans are explained using the prototyping tab and responsibilities are clarified. If the project remains feasible, the decision is made to proceed.

### *Concept generation and rapid prototyping*

With this foundation, different design concepts are generated, and preliminary data is incorporated into the information sheet. Limits are implemented, e.g. costs based on the market research and some functionality limits based on the function of the product. The project lead collaborates with the calculations team for an initial cost estimate and with sales to assess the viability of the project and its estimated pricing. If this is positive, the project proceeds. If this is negative, the problems are discussed with the product development manager, the PD manager. CAD drawings are created to support initial proof-of-concept prototypes. As these smaller prototype(s) are created, this information is quickly noted down in the prototyping tab. Outcomes from other employees are reported to the project lead. The project lead takes 10 minutes at the end of the day to update what was reported. Consultation takes place between production and the project lead. Whether the prototyping outcomes are satisfactory, unsatisfactory or action is needed, is clearly indicated. The project lead can now update accurate information that arises from the prototyping in the calculations tab and the list of requirements. The PD manager looks at the Excel tool prior to a consultation. Consultation takes place between the project lead and the PD manager where the PD manager is already aware of the project status because progress was monitored via the tool. The project lead and PD manager can now only discuss the challenges, unmet requirements and decisions that need to be taken to proceed with the project. The radar chart in the comparison tab aids in visualising trade-offs steering the direction of the final product. Management is also curious about the project status and takes a look at the planning and summary tab for a quick overview.

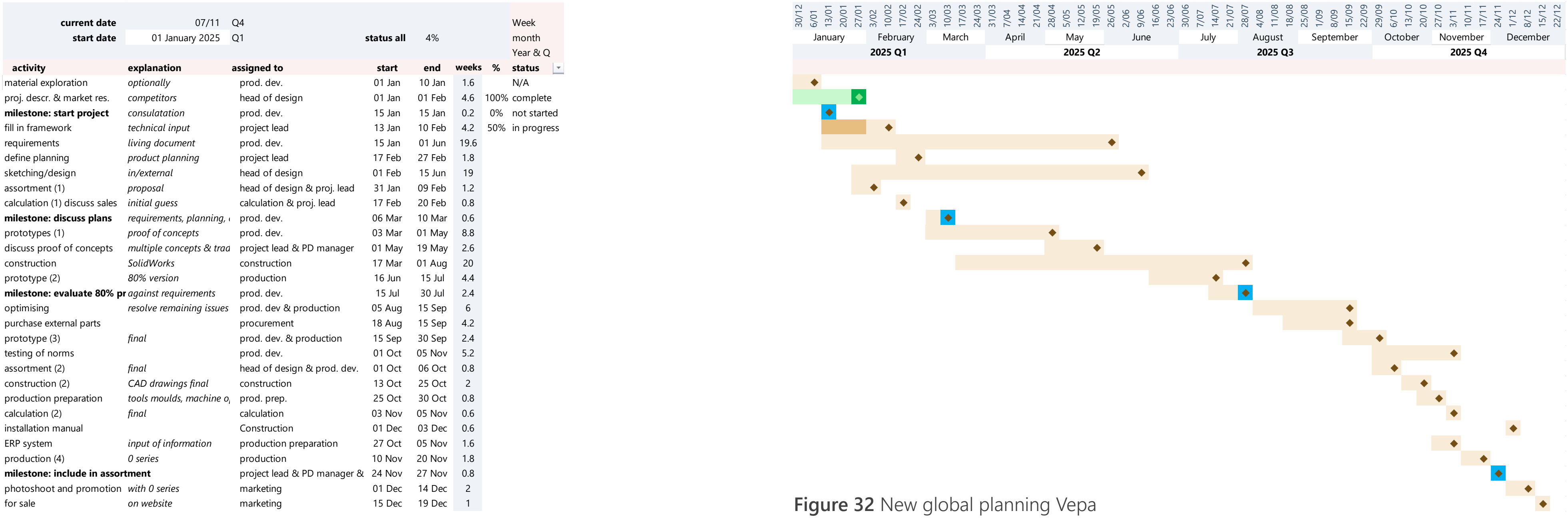
### *Final stage*

The next step involves creating CAD drawings and an 80% complete prototype. This prototype, though not meant to be perfect, enables the identification of challenges, which are discussed between the project lead and production staff. This 80% version is discussed with the complete product development team and evaluated against the requirements, the requirements status is updated. The final assortment is determined, and a final calculation is made. Responsibilities are clearly defined for certain requirements that still must be met. After resolving outstanding issues, the final CAD drawings can be finished, and a final prototype can be made. Norms are tested using this final prototype. The project concludes with a final consultation by the product development team, where the summary chart and the final prototype are reviewed. In essence, nothing needs to change in this prototype. If adjustments are required, these are addressed before transitioning to production. Production preparation takes place so the 0-series can be ordered, and assembly manuals are created. The 0-series is reviewed with the project lead and the PD manager. If everything is as expected, sales give the final go on including this product in Vepa's assortment. The 0-series is showcased in the canteen, and positive reactions are received. To prepare for the market launch, photographs are taken, and the product is listed on the website. The project formally concludes, with all failed prototypes and concepts also documented. This more structured approach with the tool enables the design team to reflect on the project's evolution, learn from past decisions and enhance insightful decision-making.

### 6.2.1 *New global planning*

The planning tab was used to display Vepa's new global planning, corresponding to the previously proposed scenario, as illustrated in Figure 32. While it is never possible to establish a fully detailed planning at the start of a project, it is often feasible to outline certain elements at a global level. In practice, some critical deadlines are typically known, and important decision moments can be planned around these milestones. The planning is structured within a one-year timeframe. Additionally, creating this initial plan serves as a preliminary validation of the functionality of the planning tab. This planning can serve as a reusable template for product developers within the planning tab of the tool.

What stands out is that the project lead allocates additional time at the start to gain knowledge on the framework and seeks technical input from relevant departments as needed. In this new scenario, greater emphasis is placed on proof-of-concept prototyping during the early phases of the project. During these initial phases, a cost estimate is collaboratively prepared by the project lead and the calculation team and is also integrated into the tool. Requirements and planning are reviewed in detail with the product development team. Proof-of-concept prototypes and trade-offs are discussed between the project lead and the PD manager, while the PD manager is already well-informed about the project's progress. The 80% prototype is subsequently evaluated by the product development team against the defined requirements. Additionally, tasks that might otherwise be overlooked, such as testing compliance with norms and making an installation manual, are explicitly included in the planning. At the conclusion of the project, relevant information is retained, enabling future reference to assess the project's development and outcomes after several years.



**current date** 07/11 Q4
**start date** 01 January 2025 Q1
**status all** 4%
Week
month
Year & Q

| activity | explanation | assigned to | start | end | weeks | % | status |
|---|---|---|---|---|---|---|---|
| material exploration | *optionally* | prod. dev. | 01 Jan | 10 Jan | 1.6 | | N/A |
| proj. descr. & market res. | *competitors* | head of design | 01 Jan | 01 Feb | 4.6 | 100% | complete |
| **milestone: start project** | *consulatation* | prod. dev. | 15 Jan | 15 Jan | 0.2 | 0% | not started |
| fill in framework | *technical input* | project lead | 13 Jan | 10 Feb | 4.2 | 50% | in progress |
| requirements | *living document* | prod. dev. | 15 Jan | 01 Jun | 19.6 | | |
| define planning | *product planning* | project lead | 17 Feb | 27 Feb | 1.8 | | |
| sketching/design | *in/external* | head of design | 01 Feb | 15 Jun | 19 | | |
| assortment (1) | *proposal* | head of design & proj. lead | 31 Jan | 09 Feb | 1.2 | | |
| calculation (1) discuss sales | *initial guess* | calculation & proj. lead | 17 Feb | 20 Feb | 0.8 | | |
| **milestone: discuss plans** | *requirements, planning,* | prod. dev. | 06 Mar | 10 Mar | 0.6 | | |
| prototypes (1) | *proof of concepts* | prod. dev. | 03 Mar | 01 May | 8.8 | | |
| discuss proof of concepts | *multiple concepts & trad* | project lead & PD manager | 01 May | 19 May | 2.6 | | |
| construction | *SolidWorks* | construction | 17 Mar | 01 Aug | 20 | | |
| prototype (2) | *80% version* | production | 16 Jun | 15 Jul | 4.4 | | |
| **milestone: evaluate 80% pr** | *against requirements* | prod. dev. | 15 Jul | 30 Jul | 2.4 | | |
| optimising | *resolve remaining issues* | prod. dev & production | 05 Aug | 15 Sep | 6 | | |
| purchase external parts | | procurement | 18 Aug | 15 Sep | 4.2 | | |
| prototype (3) | *final* | prod. dev. & production | 15 Sep | 30 Sep | 2.4 | | |
| testing of norms | | prod. dev. | 01 Oct | 05 Nov | 5.2 | | |
| assortment (2) | *final* | head of design & prod. dev. | 01 Oct | 06 Oct | 0.8 | | |
| construction (2) | *CAD drawings final* | construction | 13 Oct | 25 Oct | 2 | | |
| production preparation | *tools moulds, machine o* | prod. prep. | 25 Oct | 30 Oct | 0.8 | | |
| calculation (2) | *final* | calculation | 03 Nov | 05 Nov | 0.6 | | |
| installation manual | | Construction | 01 Dec | 03 Dec | 0.6 | | |
| ERP system | *input of information* | production preparation | 27 Oct | 05 Nov | 1.6 | | |
| production (4) | *0 series* | production | 10 Nov | 20 Nov | 1.8 | | |
| **milestone: include in assortment** | | project lead & PD manager & | 24 Nov | 27 Nov | 0.8 | | |
| photoshoot and promotion | *with 0 series* | marketing | 01 Dec | 14 Dec | 2 | | |
| for sale | *on website* | marketing | 15 Dec | 19 Dec | 1 | | |

**Figure 32** New global planning Vepa

## 6.3 Conclusion

The tool's structure, comprising seven tabs, was introduced, with each tab having its own requirements and design trajectory. The framework tab allows for inputting or finding project start information. The requirements tab facilitates defining detailed requirements. The planning tab supports the creation of a project plan and assigning responsibilities to activities. The prototyping tab enables the planning of prototyping activities while capturing outcomes and decisions. The information input tab forces the designer to explicitly consider and document certain trade-offs. The comparison tab provides a visual representation of these trade-offs and captures the reasoning around them. Lastly, the summary tab presents a concise overview of selected elements. A scenario is introduced with a corresponding global planning. In this scenario, greater emphasis is placed on setting up projects and consultation utilising the tool.

By requiring users to complete specific sections and listing important items, it pushes the users to make things clear, especially in areas where information used to be vague or implicit. With the tool, what previously was shared informally is now clearly documented, improving insight into the product requirements, prototyping, trade-offs and keeping knowledge and experience inside the company. The tool additionally provides more consistency and structure across design projects.

Overall, the tool aims to facilitate the development of a product with more deliberate and insightful decision-making, thereby reducing frustration related to unclear responsibilities and minimising the need for corrective actions and associated effort and costs in later stages. In the following section, the use of the tool is demonstrated through the case study.

Chapter

# .07

# Case study

*This chapter will demonstrate each of the tool's tabs in use through a case study. The starting point for the case study was the company's desire to incorporate the hemp composite in more of its products, which resulted in four wall panels. As previously explained, the initial experience with this material involved the development of the hemp chair. The tool was developed through research by design with the development of these products.*

Over the course of this project, a four-panel of the hemp composite was developed by the author of this report, as illustrated in Figure 33. Each panel represents one of the four elements of nature: wind/air, water, earth and fire. Nature often includes fluent lines, therefore fluent lines are suited best to the nature of the hemp composite. Further explanation and exploration of the created designs can be found in Appendix K.

**Figure 33** Four hemp composite wall panels

The tool was developed through research by design of these wall panels. **The tool utilised in this case study can be accessed by following this[1] link.** Please refer to this link before continuing reading the case study. The following sections will provide a detailed explanation of the case study.

---

[1] https://universiteittwente-my.sharepoint.com/:x:/g/personal/e_c_t_haalstra_student_utwente_nl/EXAaMRF6iYRAquJ-bGZJHS8B29Ak1sXPwd96f9K-CLJonA

## 7.1 Framework

In this section, first, the connections of the framework will be described. There will be elaborated upon the process node, given the many unexplored opportunities of the manufacturing process. Lastly, the framework tab inside the tool will be displayed.

As the introduction states, Vepa wants to incorporate the hemp composite in more of its products. The relationship between company and material was therefore already established.

Therefore, this design question began with a company wanting to work with an available material and possible production processes connected to it, rather than finding a material, process and shape for a certain market demand or function.

Generally, the relationships during the case study design process were established in the following order shown in Figure 34. Going through this development cycle has again validated the connections of the framework. The 'route' followed is described next.

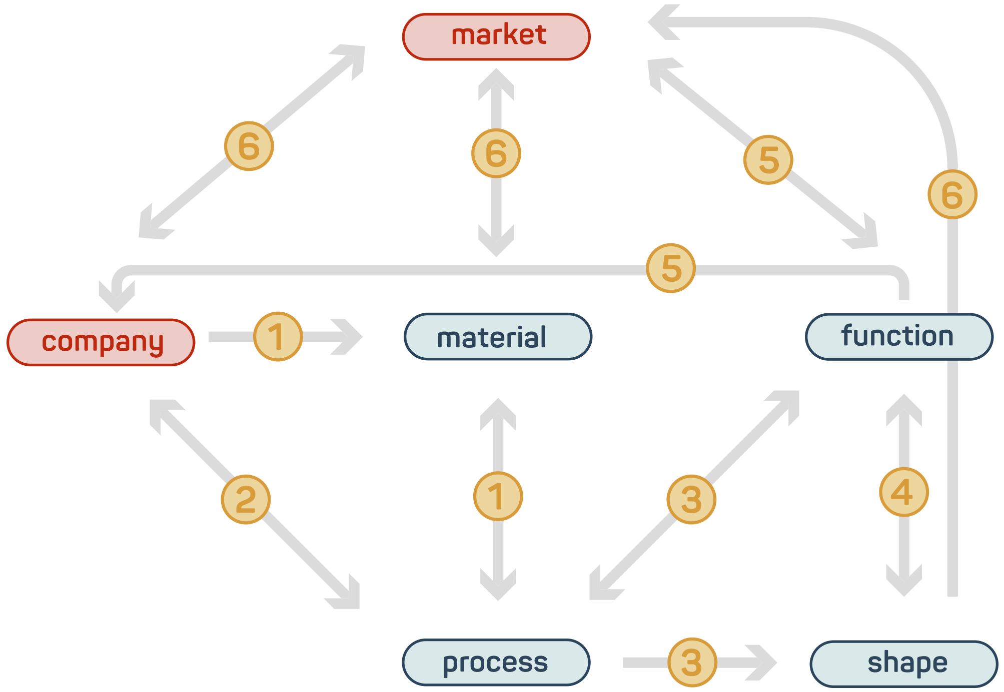
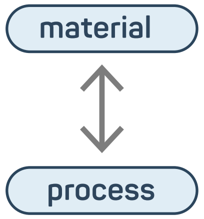


**Figure 34** Order of established relationships

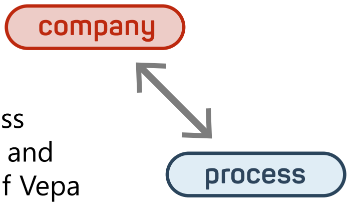
### 7.1.1 Material

The material delivered to Vepa is the same as for the hemp chair. This is a designable material. For example, the density and thickness of the dry mat have influence and the ratio of resin to hemp has influence. For now, a ratio of 50% fibres and 50% resin is used, since this is something that was worked on before. This material stands out compared to other materials because it is fully renewable and biodegradable. This material can only work with certain processes and should always be baked off in an oven, which is standing in Emmen. The relationship between material and process is determined.



### 7.1.2 Company

Vepa wants to work with this material to emphasise its commitment to sustainability and to expand its product portfolio. Vepa cannot afford too high investments. Recently (April 2024) Vepa has a large flat hot press next to the press mould of the chairs. The relationship between the company and process is also established since it would be advantageous if Vepa could use the processing machines it already has.



*in-depth analysis*

### 7.1.3 Process

A hot press mould was used for the hemp chair shell, but further processing techniques with the pre-preg are possible. As little was known about the possibilities offered by the processing techniques, this was initially explored further, in line with MDD. Several material samples have been developed, utilising the same material input but different processing techniques. Below, the most important findings are summarised. The full list of samples created is presented in Appendix G.

*Material sample exploration key takeaways*

- Different densities can be achieved, affecting both colour and surface roughness, see Figure 35.
- Different thicknesses can be achieved by using different layers of pre-preg, see Figure 36.
- Combining materials of varying densities is possible and may provide desired properties from each as shown in Figure 37. A table design was considered incorporating this benefit as illustrated in Appendix K.1.
- Imprints can be easily created using made laser-cut moulds, as demonstrated in the pattern sample in Figure 38 and Figure 39.
- Shaping without a hot press mould is possible, as shown in Figure 40, offering a manufacturing process with fewer steps and no need for expensive moulds
- Complex shapes can be made with relative ease compared to other materials.
- The free variables of the production process are the time and the pressure and an optimum should be found.

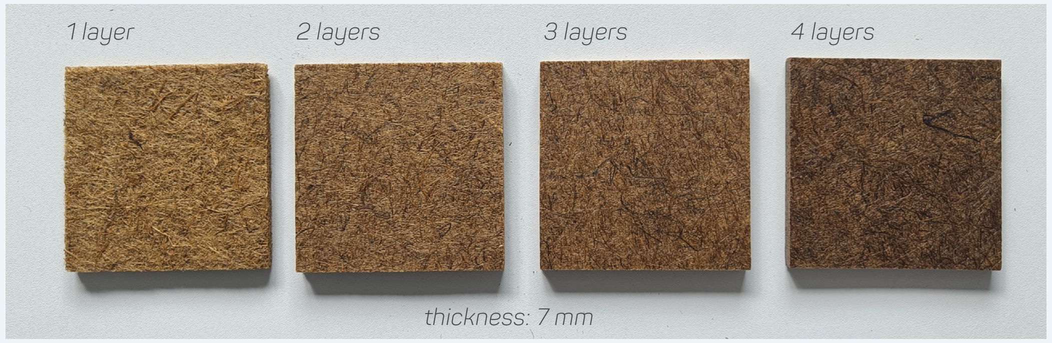


**Figure 35** Different densities

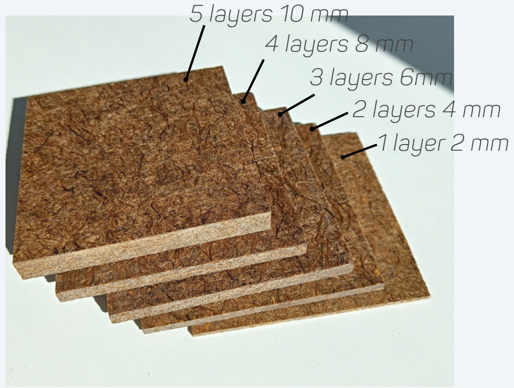


**Figure 36** Different thicknesses

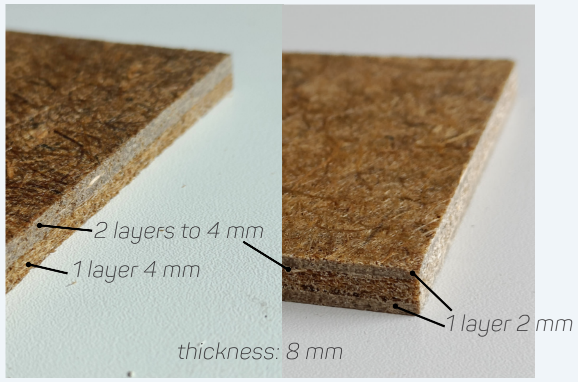


**Figure 37** Combined densities

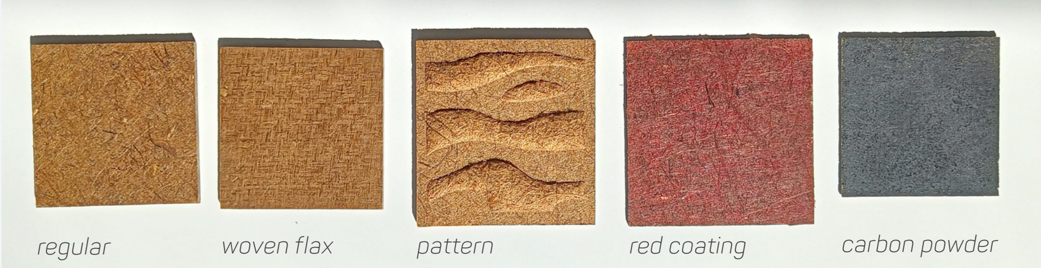


**Figure 38** Different surface finishings

**Figure 39** Negative mould

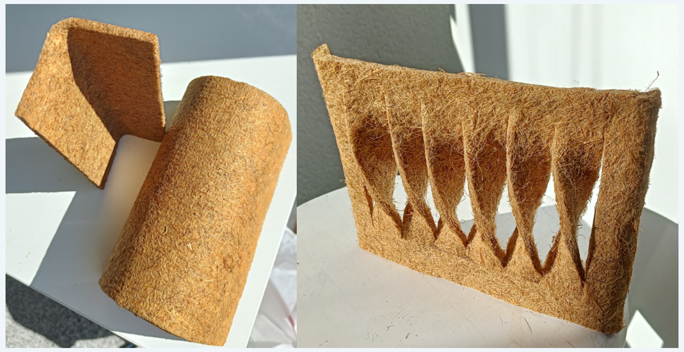
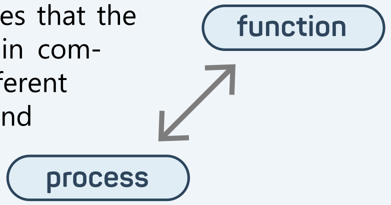


**Figure 40** 3D shapes without hot press mould

Overall, the material sample exploration demonstrates that the processing technique of the same material results in completely different properties suitable for completely different functions. Therefore, a relationship between process and function exists in this case. The exact relationship between the two should be explored further.



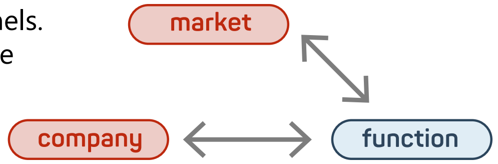
### 7.1.4 Shape

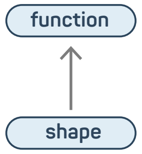
A decision was made to utilise the flat press. With the flat press, flat panels can be made with a maximum dimension of 2.30×1.15 meters. For making three-dimensional shapes, a three-dimensional mould is needed, just like for the chair. Therefore, the connection between process and shape is established.

### 7.1.5 Function

Since the looks of the material, it can function for the aesthetics. It will be a product that is linked with nature. Secondly, because of the different densities the material can have it can function as something strong and lightweight. Also, the porosity of the unpressed hemp suggests that it is a good sound absorber [52], therefore it might also function as a product for noise control. Imprinting can not only function for aesthetic purposes but also for markings purposes to improve ease of assembly.

It was chosen to focus on developing wall panels. There is a gap in the portfolio of Vepa so the function fits into this gap. The connection between the function to company and market is established.





Ceiling panels were also considered, providing a clear example of where shape influences function. By modifying the shape, the wall panel can also be used as a ceiling panel. Specifically, with dimensions of 600x600 mm and a broad flat profile around.

### 7.1.6 Market

The market demands indoor environments that are connected to nature. Also, wall panels are popular. For example, moss panels, which are sold at high prices, illustrate this trend. Competitor products range around €400 per square meter, as shown in the link to the market research in the tool's first tab. The brownish colour of the hemp composite brings warmth to the room. Hopefully, the material and shape drive a market need and the market wants the properties of this material. This interaction can be confirmed through displaying the panels at the Orgatec fair.

All this information can be summarised in the tool, as shown in Figure 41. This tab functions as a living document throughout the product development process. While most of the information could be filled in at the start of the project, updates were made as the project progressed. If a tool for the hemp chair existed, material information could be taken over from the development of the hemp chair.

| | | | | |
|---|---|---|---|---|
| **Product description:** | Hemp wall panel | last updated: 09/09/2024 | by: Eleanne | |
| **main objective:** | acoustic and aesthetic wall panel | | | |
| **market** | *What end user, competitor landscape, need?* | **company** | *Why develop the product and what service to provide?* | ***context*** |
| end user | silent indoor environments connected to nature | brand identity | commitment to sustainability | |
| consumer trends | moss panels, felt panels, felt and wood | portfolio | expanding wall panel and hemp assortment | |
| | | strategy | brand-carrier | *company* |
| competitor landscape | No hemp panels, mainly felt wall panels | novel idea | | |
| prices | On average 400euros per m2 and at least 30% absor | transportation | 4 per pack | |
| optional market research | drive.google.com/file/d/1j6c6OxjrWdldPN5gubAaYxd | service | screw and hang on site | |
| requests or need | silent indoor environments connected to nature | storage | hemp mats should be stored dry | *market* |
| **part 1:** | hemp part | **part 2:** mounting mechanism | **part X:** ... *optionally add more parts...* | ***product*** |
| **function** | *what are the main and sub-functioning of the parts or assemblies?* | | | |
| main & sub | manage sound: absorb (reduce reflections) and diffus | onubstrusive hang panel on wall | | |
| | aesthetic appeal: look aesthetically pleasing, customis | | | |
| durability | *unknown, but expected to be long* | *unknown* | | |
| quantity | multiple in one order | 2 to 4 per panel | | |
| improvement | higher sound absorption | no glue | | *function* |
| **material** | *what is known about the material?* | | | |
| name | Hemp material: hemp fibres + bioresin | stainless steel | | |
| how made | Made by impregnating fibres with the resin | lasercut in Emmen | | |
| critical points | pre-preg has one side with mesh | should be powdercoated | | |
| free variables | ratio resin and fibres, for now 50/50 | | | |
| mech properties | *unknown for unpressed hemp* | | | |
| physical properties | unpressed parts light, pressed parts darker | | | |
| costs | €7,50 for a 75x75 cm pre-preg | | | |
| energy | *unknown of both oven and press* | | | |
| waste | cutting edges should be minimised | | | |
| benchmark | fully biological | | | |
| unexplored opportunities | Use sticking property of pre-preg for less assembly st | Using magnets | | *material* |
| **process** | *how are the parts and assemblies manufactured?* | | | |
| how made | place, press, oven, milling | | | |
| critical points | flat oven rack needed | | | |
| free variables | time, pressure, contour | | | |
| global shape restrictions | flat | | | |
| investments | only steel contra shape and anti-stick | | | |
| setting and running costs | | | | |
| energy | *unknown* | | | |
| waste | 1 cm pre-preg edges | | | |
| unexplored opportunities | | pressing mounting mechanism in panel | | *process* |
| **shape** | *What is the shape of the parts and assemblies?* | | | |
| parts & assembly | | | | |
| macro.. | | | | |
| ..dimensions | | | | |
| ..ease of assembly | | | | |
| ..ease of disassembly | | | | |
| micro.. | | | | |
| ..texture & finishing | no finishing needed! | | | |
| associations | four elements, nature | | | |
| stackability | | harder with mounting mechanism | | |
| packaging | 4 panels per package | | | *shape* |

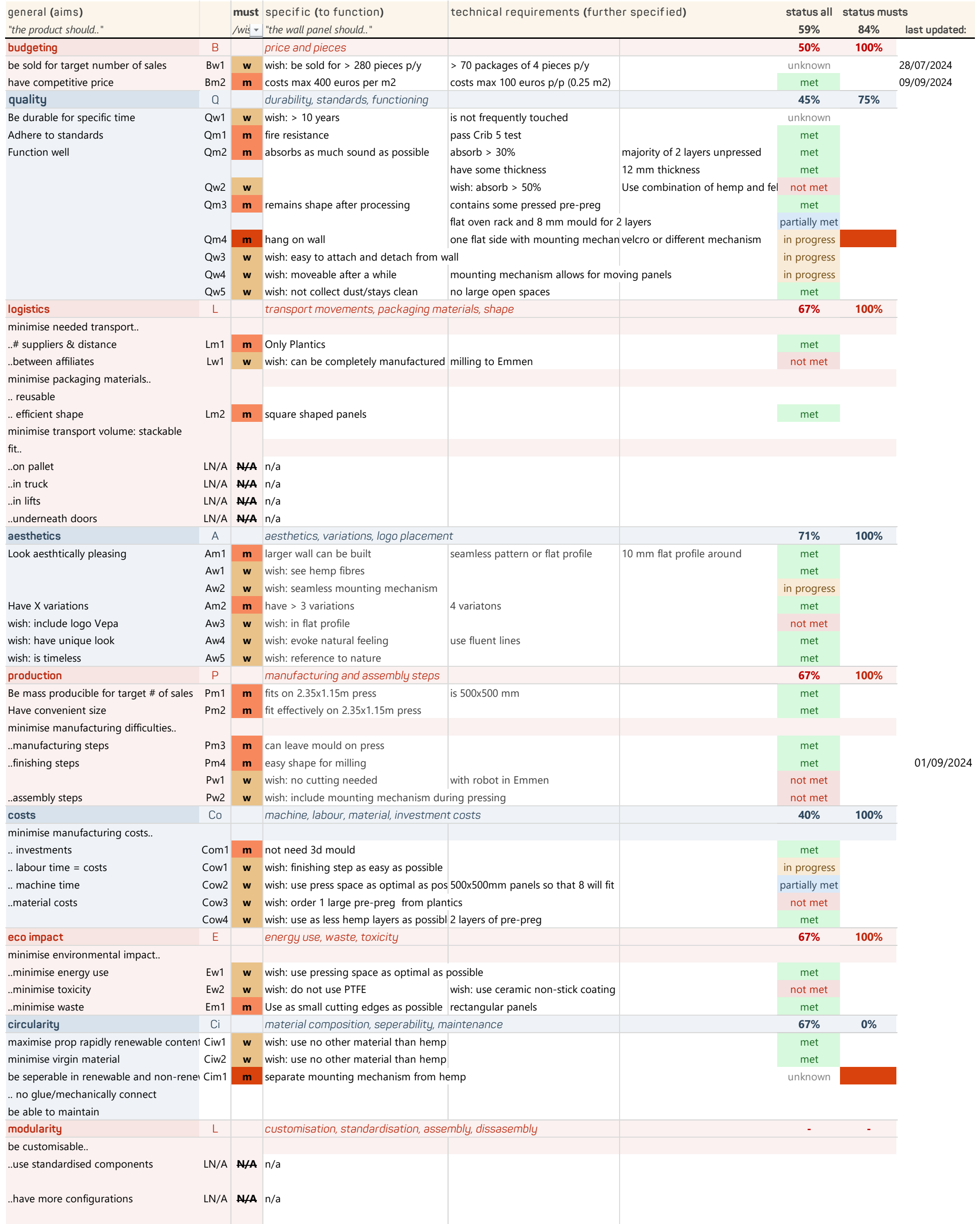
**Figure 41** First tool tab in use

**Figure 42** Mesh

To highlight an example that could have been prevented with this scheme is the presence of the hemp composite on one side containing a mesh, resulting from the impregnation process at Plantics, as shown in Figure 42. This issue was still a question mark in the middle of the embodiment phase and it took some time to determine how to prevent this. However, this information was already known, because of the development of the chairs.

## 7.2 Requirements

Figure 43 shows the requirements of developing the wall panels and its status.



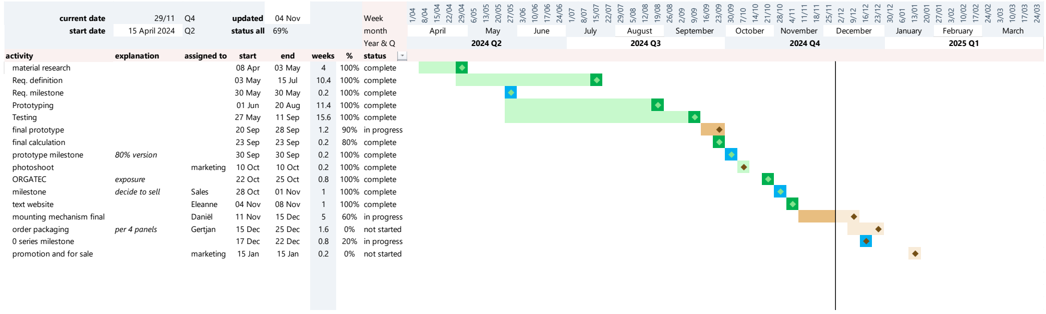
| general (aims) | | must | specific (to function) | technical requirements (further specified) | | status all | status musts | |
|---|---|---|---|---|---|---|---|---|
| *"the product should.."* | | /wis | *"the wall panel should.."* | | | 59% | 84% | last updated: |
| **budgeting** | B | | *price and pieces* | | | **50%** | **100%** | |
| be sold for target number of sales | Bw1 | w | wish: be sold for > 280 pieces p/y | > 70 packages of 4 pieces p/y | | unknown | | 28/07/2024 |
| have competitive price | Bm2 | m | costs max 400 euros per m2 | costs max 100 euros p/p (0.25 m2) | | met | | 09/09/2024 |
| **quality** | Q | | *durability, standards, functioning* | | | **45%** | **75%** | |
| Be durable for specific time | Qw1 | w | wish: > 10 years | is not frequently touched | | unknown | | |
| Adhere to standards | Qm1 | m | fire resistance | pass Crib 5 test | | met | | |
| Function well | Qm2 | m | absorbs as much sound as possible | absorb > 30% | majority of 2 layers unpressed | met | | |
| | | | | have some thickness | 12 mm thickness | met | | |
| | Qw2 | w | | wish: absorb > 50% | Use combination of hemp and fel | not met | | |
| | Qm3 | m | remains shape after processing | contains some pressed pre-preg | | met | | |
| | | | | flat oven rack and 8 mm mould for 2 layers | | partially met | | |
| | Qm4 | m | hang on wall | one flat side with mounting mechan | velcro or different mechanism | in progress | 🟧 | |
| | Qw3 | w | wish: easy to attach and detach from wall | | | in progress | | |
| | Qw4 | w | wish: moveable after a while | mounting mechanism allows for moving panels | | in progress | | |
| | Qw5 | w | wish: not collect dust/stays clean | no large open spaces | | met | | |
| **logistics** | L | | *transport movements, packaging materials, shape* | | | **67%** | **100%** | |
| minimise needed transport.. | | | | | | | | |
| ..# suppliers & distance | Lm1 | m | Only Plantics | | | met | | |
| ..between affiliates | Lw1 | w | wish: can be completely manufactured | milling to Emmen | | not met | | |
| minimise packaging materials.. | | | | | | | | |
| .. reusable | | | | | | | | |
| .. efficient shape | Lm2 | m | square shaped panels | | | met | | |
| minimise transport volume: stackable | | | | | | | | |
| fit.. | | | | | | | | |
| ..on pallet | LN/A | ~~N/A~~ | n/a | | | | | |
| ..in truck | LN/A | ~~N/A~~ | n/a | | | | | |
| ..in lifts | LN/A | ~~N/A~~ | n/a | | | | | |
| ..underneath doors | LN/A | ~~N/A~~ | n/a | | | | | |
| **aesthetics** | A | | *aesthetics, variations, logo placement* | | | **71%** | **100%** | |
| Look aesthtically pleasing | Am1 | m | larger wall can be built | seamless pattern or flat profile | 10 mm flat profile around | met | | |
| | Aw1 | w | wish: see hemp fibres | | | met | | |
| | Aw2 | w | wish: seamless mounting mechanism | | | in progress | | |
| Have X variations | Am2 | m | have > 3 variations | 4 variatons | | met | | |
| wish: include logo Vepa | Aw3 | w | wish: in flat profile | | | not met | | |
| wish: have unique look | Aw4 | w | wish: evoke natural feeling | use fluent lines | | met | | |
| wish: is timeless | Aw5 | w | wish: reference to nature | | | met | | |
| **production** | P | | *manufacturing and assembly steps* | | | **67%** | **100%** | |
| Be mass producible for target # of sales | Pm1 | m | fits on 2.35x1.15m press | is 500x500 mm | | met | | |
| Have convenient size | Pm2 | m | fit effectively on 2.35x1.15m press | | | met | | |
| minimise manufacturing difficulties.. | | | | | | | | |
| ..manufacturing steps | Pm3 | m | can leave mould on press | | | met | | |
| ..finishing steps | Pm4 | m | easy shape for milling | | | met | | 01/09/2024 |
| | Pw1 | w | wish: no cutting needed | with robot in Emmen | | not met | | |
| ..assembly steps | Pw2 | w | wish: include mounting mechanism during pressing | | | not met | | |
| **costs** | Co | | *machine, labour, material, investment costs* | | | **40%** | **100%** | |
| minimise manufacturing costs.. | | | | | | | | |
| .. investments | Com1 | m | not need 3d mould | | | met | | |
| .. labour time = costs | Cow1 | w | wish: finishing step as easy as possible | | | in progress | | |
| .. machine time | Cow2 | w | wish: use press space as optimal as pos | 500x500mm panels so that 8 will fit | | partially met | | |
| ..material costs | Cow3 | w | wish: order 1 large pre-preg from plantics | | | not met | | |
| | Cow4 | w | wish: use as less hemp layers as possibl | 2 layers of pre-preg | | met | | |
| **eco impact** | E | | *energy use, waste, toxicity* | | | **67%** | **100%** | |
| minimise environmental impact.. | | | | | | | | |
| ..minimise energy use | Ew1 | w | wish: use pressing space as optimal as possible | | | met | | |
| ..minimise toxicity | Ew2 | w | wish: do not use PTFE | wish: use ceramic non-stick coating | | not met | | |
| ..minimise waste | Em1 | m | Use as small cutting edges as possible | rectangular panels | | met | | |
| **circularity** | Ci | | *material composition, seperability, maintenance* | | | **67%** | **0%** | |
| maximise prop rapidly renewable content | Ciw1 | w | wish: use no other material than hemp | | | met | | |
| minimise virgin material | Ciw2 | w | wish: use no other material than hemp | | | met | | |
| be seperable in renewable and non-rene | Cim1 | m | separate mounting mechanism from hemp | | | unknown | 🟧 | |
| .. no glue/mechanically connect | | | | | | | | |
| be able to maintain | | | | | | | | |
| **modularity** | L | | *customisation, standardisation, assembly, dissassembly* | | | **-** | **-** | |
| be customisable.. | | | | | | | | |
| ..use standardised components | LN/A | ~~N/A~~ | n/a | | | | | |
| ..have more configurations | LN/A | ~~N/A~~ | n/a | | | | | |

**Figure 43** Second tool tab in use

What stands out is that the mounting mechanism is identified as the most critical part to be resolved at this stage. This is a must that is not met and therefore is marked red. Consequently, it remains unknown whether the renewable and non-renewable materials can be separated. Furthermore, the final dimensions are also included in this scheme. Wishes that are not met, highlighting areas for future improvement, can be easily found. "Status all" shows the average of all the individual percentages and shows that there is room for improvement. The "status musts" indicates that the panel development is nearly 100%, which aligns with the current stage of the project. The products are planned to be launched mid-January.

## 7.3 Planning

The planning tab was developed at the end of the case study and, as such, did not serve as a tool during the early stages of the design process. Ultimately, the planning was outlined globally, as shown in Figure 44. However, it would have been valuable to have had this tool available throughout the project. To illustrate how this tab could have been used, for this project limited information on the planning was initially available. Once the project progress was going well, it was planned that the wall panels would be displayed at the ORGATEC fair, a big international fair for office furniture. This creates a firm deadline, allowing the planning to be structured around this milestone and tasks to be scheduled accordingly. For example, the final dimensions of the panel must be determined by this date, and the panels should be ordered by this date. Even currently in the later stages, the planning tab provides a clear overview of the status, remaining tasks and responsibilities.



| | | | | |
|---|---|---|---|---|
| **current date** | 29/11 | Q4 | **updated** | 04 Nov |
| **start date** | 15 April 2024 | Q2 | **status all** | 69% |

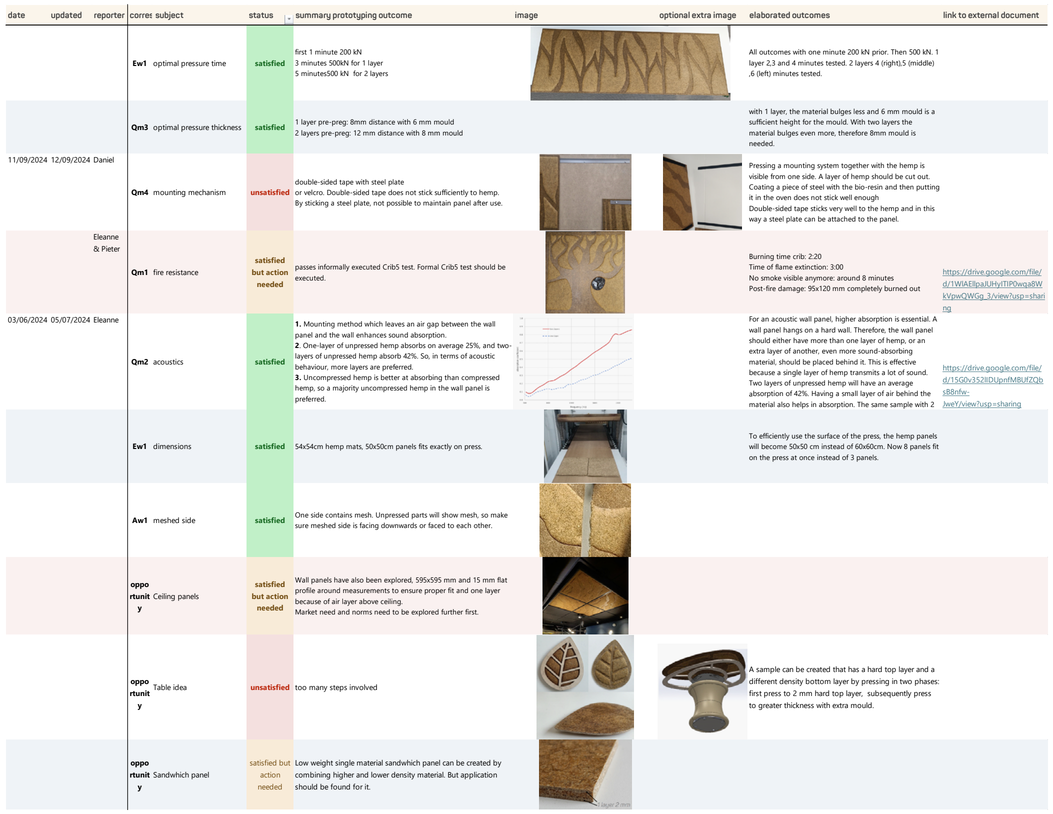
| **activity** | **explanation** | **assigned to** | **start** | **end** | **weeks** | **%** | **status** |
|---|---|---|---|---|---|---|---|
| material research | | | 08 Apr | 03 May | 4 | 100% | complete |
| Req. definition | | | 03 May | 15 Jul | 10.4 | 100% | complete |
| Req. milestone | | | 30 May | 30 May | 0.2 | 100% | complete |
| Prototyping | | | 01 Jun | 20 Aug | 11.4 | 100% | complete |
| Testing | | | 27 May | 11 Sep | 15.6 | 100% | complete |
| final prototype | | | 20 Sep | 28 Sep | 1.2 | 90% | in progress |
| final calculation | | | 23 Sep | 23 Sep | 0.2 | 80% | complete |
| prototype milestone | *80% version* | | 30 Sep | 30 Sep | 0.2 | 100% | complete |
| photoshoot | | marketing | 10 Oct | 10 Oct | 0.2 | 100% | complete |
| ORGATEC | *exposure* | | 22 Oct | 25 Oct | 0.8 | 100% | complete |
| milestone | *decide to sell* | Sales | 28 Oct | 01 Nov | 1 | 100% | complete |
| text website | | Eleanne | 04 Nov | 08 Nov | 1 | 100% | complete |
| mounting mechanism final | | Daniël | 11 Nov | 15 Dec | 5 | 60% | in progress |
| order packaging | *per 4 panels* | Gertjan | 15 Dec | 25 Dec | 1.6 | 0% | not started |
| 0 series milestone | | | 17 Dec | 22 Dec | 0.8 | 20% | in progress |
| promotion and for sale | | marketing | 15 Jan | 15 Jan | 0.2 | 0% | not started |

**Figure 44** Third tool tab in use

## 7.4 Prototyping

The development of the hemp wall panels required multiple prototypes, each contributing valuable insights. The most important ones that informed decision-making were testing the acoustic behaviour, determining the optimal mould and pressure thickness and dimensions. These prototyping outcomes are discussed in the next section, describing the prototyping outcomes, resulting in long texts, further highlights that much information arises from prototyping and testing. Updating each other on the outcomes can be time-consuming. Therefore, a prototyping tab to summarise and share these outcomes is valuable. A summary of all the prototypes is provided in the prototyping tab, as shown in Figure 45. Additionally, future opportunities can be captured in the tab.

Note that these prototyping outcomes were spread across several tests. The results are clearly presented in the prototyping tab, summarising what decisions have been made and whether the outcomes are satisfactory, unsatisfactory or if further action is needed.



| date | updated | reporter | corres | subject | status | summary prototyping outcome | image | optional extra image | elaborated outcomes | link to external document |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Ew1** | optimal pressure time | **satisfied** | first 1 minute 200 kN<br>3 minutes 500kN for 1 layer<br>5 minutes500 kN for 2 layers | | | All outcomes with one minute 200 kN prior. Then 500 kN. 1 layer 2,3 and 4 minutes tested. 2 layers 4 (right),5 (middle) ,6 (left) minutes tested. | |
| | | | **Qm3** | optimal pressure thickness | **satisfied** | 1 layer pre-preg: 8mm distance with 6 mm mould<br>2 layers pre-preg: 12 mm distance with 8 mm mould | | | with 1 layer, the material bulges less and 6 mm mould is a sufficient height for the mould. With two layers the material bulges even more, therefore 8mm mould is needed. | |
| 11/09/2024 | 12/09/2024 | Daniel | **Qm4** | mounting mechanism | **unsatisfied** | double-sided tape with steel plate<br>or velcro. Double-sided tape does not stick sufficiently to hemp.<br>By sticking a steel plate, not possible to maintain panel after use. | | | Pressing a mounting system together with the hemp is visible from one side. A layer of hemp should be cut out.<br>Coating a piece of steel with the bio-resin and then putting it in the oven does not stick well enough<br>Double-sided tape sticks very well to the hemp and in this way a steel plate can be attached to the panel. | |
| | | Eleanne & Pieter | **Qm1** | fire resistance | **satisfied but action needed** | passes informally executed Crib5 test. Formal Crib5 test should be executed. | | | Burning time crib: 2:20<br>Time of flame extinction: 3:00<br>No smoke visible anymore: around 8 minutes<br>Post-fire damage: 95x120 mm completely burned out | https://drive.google.com/file/d/1WIAEllpaJUHyITIP0wqa8WkVpwQWGg_3/view?usp=sharing |
| 03/06/2024 | 05/07/2024 | Eleanne | **Qm2** | acoustics | **satisfied** | **1.** Mounting method which leaves an air gap between the wall panel and the wall enhances sound absorption.<br>**2**. One-layer of unpressed hemp absorbs on average 25%, and two-layers of unpressed hemp absorb 42%. So, in terms of acoustic behaviour, more layers are preferred.<br>**3.** Uncompressed hemp is better at absorbing than compressed hemp, so a majority uncompressed hemp in the wall panel is preferred. | | | For an acoustic wall panel, higher absorption is essential. A wall panel hangs on a hard wall. Therefore, the wall panel should either have more than one layer of hemp, or an extra layer of another, even more sound-absorbing material, should be placed behind it. This is effective because a single layer of hemp transmits a lot of sound. Two layers of unpressed hemp will have an average absorption of 42%. Having a small layer of air behind the material also helps in absorption. The same sample with 2 | https://drive.google.com/file/d/15G0v352IIDUpnfMBUfZQbsB8nfw-JweY/view?usp=sharing |
| | | | **Ew1** | dimensions | **satisfied** | 54x54cm hemp mats, 50x50cm panels fits exactly on press. | | | To efficiently use the surface of the press, the hemp panels will become 50x50 cm instead of 60x60cm. Now 8 panels fit on the press at once instead of 3 panels. | |
| | | | **Aw1** | meshed side | **satisfied** | One side contains mesh. Unpressed parts will show mesh, so make sure meshed side is facing downwards or faced to each other. | | | | |
| | | | **opportunity** | Ceiling panels | **satisfied but action needed** | Wall panels have also been explored, 595x595 mm and 15 mm flat profile around measurements to ensure proper fit and one layer because of air layer above ceiling.<br>Market need and norms need to be explored further first. | | | | |
| | | | **opportunity** | Table idea | **unsatisfied** | too many steps involved | | | A sample can be created that has a hard top layer and a different density bottom layer by pressing in two phases: first press to 2 mm hard top layer, subsequently press to greater thickness with extra mould. | |
| | | | **opportunity** | Sandwhich panel | satisfied but action needed | Low weight single material sandwhich panel can be created by combining higher and lower density material. But application should be found for it. | | | | |

**Figure 45** Fourth tool tab in use

### 7.4.1 Acoustic behaviour

As the function describes, one of the two main functions is sound management. However, nothing was known about this subject. This is a problem definition on the functional level: *What is the acoustic behaviour of the hemp composite?* Therefore, this was investigated and several hemp composite samples, with either one or two layers of hemp with different densities, have been measured on their absorbing and transmitting behaviour in the impedance tube standing at the University of Twente. Below, the concluding results are described. The extensive research findings can be found in Appendix H or via the linked document in the prototyping tab.

#### *Introduction to acoustics*

The absorbing and transmitting behaviour of a material can be measured in a so-called impedance tube with a small sample of the material. Sound absorbing behaviour is often described by the absorption coefficient (α), defined by: α = 1 - r, with (r) the reflection coefficient. An absorption coefficient of 1.0 means that sound waves are completely absorbed and an absorption coefficient of 0.0 means that waves are completely reflected. It represents the portion of incident energy absorbed (not reflected) by the material. The transmission coefficient (τ), the ratio of the transmitted sound power to the incident sound power, describes how well sound can pass through the barrier and ranges from 0 to 1. A transmission coefficient of 0.0 means that no sound is transmitted through the material, then the material is a good sound blocker, and a transmission coefficient of 1.0 means that all sound is transmitted through the material. So, a good sound absorber is not by definition a good sound blocker. The amount of dissipation, reflection and transmission of sound is different for every frequency. An impedance tube works on the principle of normal incidence of sound waves since the dimensions of the tube only allow for horizontal propagation of the sound waves. Therefore, the diffusing effect (scattering the reflections around the room in different directions which reduces the effect of sound bounces) of the curve in the panels is not taken into account in these measurements. For understanding the effect of diffused sound or for real applications, a reverberation room can be used for the testing acoustic properties of materials.

#### *Conclusion absorption*

Many material samples have been tested and a few absorption curves are highlighted in Figure 46. The less compressed the hemp composite, the better it is at absorbing sound. However, with only one layer of hemp. A maximum absorption is found that gradually increases from 10% to 50% at a frequency range of 500 to 2600 Hz. A profile with compressed and uncompressed hemp behaves in between the compressed and uncompressed absorbing behaviour. With two (medium) compressed layers, already better absorption is found, namely a gradual absorption from 10% to around 80% in the same frequency range. A layer of air behind a material sample also enhances sound absorption. This was validated by the fact that the same material sample showed higher absorption values when a small air gap was behind the sample.

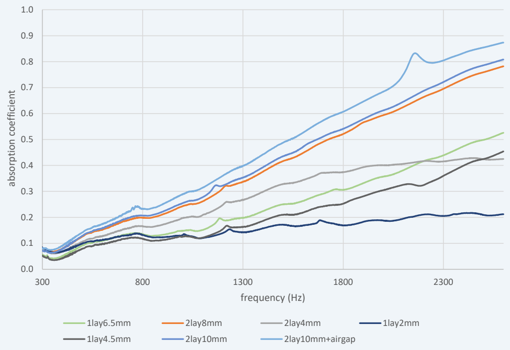


**Figure 46** Absorption curves

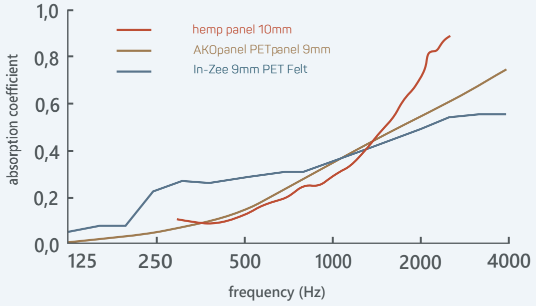


**Figure 47** Comparison to competitors

#### *Wall panel conclusion*

For an acoustic wall panel, higher absorption is essential. A wall panel hangs on a hard wall. Therefore, the wall panel should either have more than one layer of hemp, or an extra layer of another even more sound-absorbing material should be placed behind it. This is effective because a single layer of hemp transmits a lot of sound. Two layers of unpressed hemp will have an average absorption of 42%. Having a small layer of air behind the material also helps in absorption. The same sample with 2 mm air behind it shows an average absorption of 48%. Therefore, it is preferred to mount the wall panels with an air gap between them and the wall. By comparing the 10 mm 2-layered hemp sample to competitors felt products, as shown in Figure 47, it can be concluded that it is comparable in behaviour and shows higher absorption for frequencies above 1300 Hz.

#### *Key takeaways*

- Mounting method which leaves an air gap between the wall panel and the wall enhances sound absorption.
- One-layer of unpressed hemp absorbs on average 25%, and two-layers of unpressed hemp absorb 42%. So, in terms of acoustic behaviour, more layers are preferred.
- Uncompressed hemp is better at absorbing than compressed hemp, so a majority of uncompressed hemp in the wall panel is preferred.

#### *Ceiling panel conclusion*

The application of a ceiling panel was also considered. For a ceiling panel, it is mostly important that is it not reflective, since a layer of air is also above the ceiling panel. The perceived absorption is the sum of the dissipation within the material and the sound that is transmitted through the material, or at least, the layer of air above the panel has a large influence on the perceived reflection. For transmission holds, the fewer layers and the lower density of the material, the more sound it transmits, which means if there is no hard wall behind the material, not much sound will be reflected. The transmission measurement showed that especially a single layer indeed transmits a lot of sound. To show the influence of a layer of air behind the material, which is also the case for ceiling panels, 2-microphone sound absorption measurements have been executed with samples and 10 cm of air behind it. Although being the same samples as tested on a hard wall, the absorption comparison with a layer of air behind it shows that high absorption and therefore low reflection is achieved due to a layer of air behind the sample and the hard wall. Therefore, the perceived absorption for a person under the ceiling with a layer of air indeed is high and depends on the layer of air behind it. Therefore, for a ceiling panel a single layer of hemp can be used. If necessary, sound-absorbing material can be placed above the ceiling panel.

*Key takeaway*

For a ceiling panel, transmission also adds to the perceived sound absorption, since there is a layer of air above the suspended ceiling. Therefore, the effect of more hemp layers is not as large as with a wall panel hanging on a hard wall. So, for a ceiling panel, a single layer of hemp can be used. This is an example of the function node influencing the shape node.

### 7.4.2 Optimum pressure time, thickness and panel size

The pressure time and thickness are open variables for the processing technique, therefore, an optimum should be found. The elaborate findings can be found in Appendix I.

The steel negative mould sticks to the pre-preg after being pressed in the mould (Figure 48). A non-sticking coating is needed. It should be carefully considered which side of the pre-preg is facing upwards since one side contains a meshed pattern (Figure 49). The optimum pressure time depends on the number of layers and on the amount of colour difference that is preferred. The longer the pressure time, the darker the hemp composite gets. For 1 layer, a pressure time of 2-4 minutes is recommended. For 2 layers, a pressure time between 4 and 6 minutes is recommended. Finishing the edges can be executed with a sawing machine in Hoogeveen. Because it is hard to align the mould with the pre-preg a hand mill following the contours is also possible (Figure 50), the finishing step can then also be executed in Emmen. By making the panels 500×500 mm as opposed to 600×600 mm, 8 instead of 3 panels can be placed in the press at a time (Figure 51). First, it was said that it would be preferred if the wall panels could also be used as ceiling panels, but soon it became clear that those are two products with different optimisations.


**Figure 48** Hemp sticking to steel


**Figure 49** Mesh on one side


**Figure 50** Inlay for milling

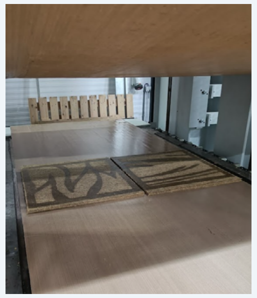


**Figure 51** Efficient dimensioning

*Key takeaways*

A non-stick coating is needed on the steel mould. A wall panel has different optimisations than a ceiling panel. For example, a wall panel should be 600×600 mm but because a wall panel the sides are not seen this provides opportunities for easier finishing methods. By making the wall panels 500×500 mm as opposed to 600×600 mm, eight panels fit on the press in one go instead of three. It is hard to align the mould with the pre-preg therefore, milling the panels with the use of an inlay is preferred over sawing. All in all, the shape has a great influence on the required processing time and thus energy. The choice of finishing steps has a great influence on the required logistics. Small choices greatly affect the impact on the perspectives.

### 7.4.3 Fire test

For wall and especially ceiling panels, flammability is an important quality factor. The Crib 5 test was conducted informally. Figure 52 shows the burning crib on the panel. Appendix Appendix J shows the full results. The material is self-extinguishing and passes informally the Crib 5 test. Figure 53 shows the panel after the test.


**Figure 52** Panel during Crib 5 test


**Figure 53** Panel after Crib 5 test

*Key takeaway*

The informally executed Crib5 test was passed. An official test should still be executed.

### 7.4.4 Conclusion

After the acoustic measurements, the list of requirements element “absorb > 30% could be verified”. After making the panels, the requirement “is 500×500 mm”, “is 12 mm thick” and “10 mm flat profile around” could be added. The requirements “can leave mould on press” and “pass Crib 5 test” could be verified. This testing results in conscious choices of the number of layers to be used and the size of the panels, instead of immediately choosing for one layer because this is cheaper or 600×600mm because this is most common.

## 7.5 Calculation

During this project, three concepts were compared: a previous concept of a single-layered wall panel developed by students from Hochschule Mainz, which involved carving the material and using a 3D mould (referred to as open panel), a single-layered panel and a double-layered panel designed by the writer of this report, as shown in Figure 54 to 56. To decide which concept is best, information on these panels was included in the calculation tab in order to explicitly make and communicate about trade-offs. Figure 57 shows the inputs, outputs and resulting radar charts.

**Figure 54** Open panel

**Figure 55** Single-layered

**Figure 56** Double-layered

### 7.5.1 *Explanation of information input and performance indicators*

### *Manufacturability*

To keep all the indicators on a scale of one to ten, the unit for the wall panel was set at 0.25hr×steps. The single- and double-layered panel involve the same steps, whereas the open panel involves more steps.

### *Manufacturing costs*

The unit for manufacturing costs is set at 10 euros per wall panel. The mould investment for the open panel was based on Vepa's hemp department employee experience.

### *Quality*

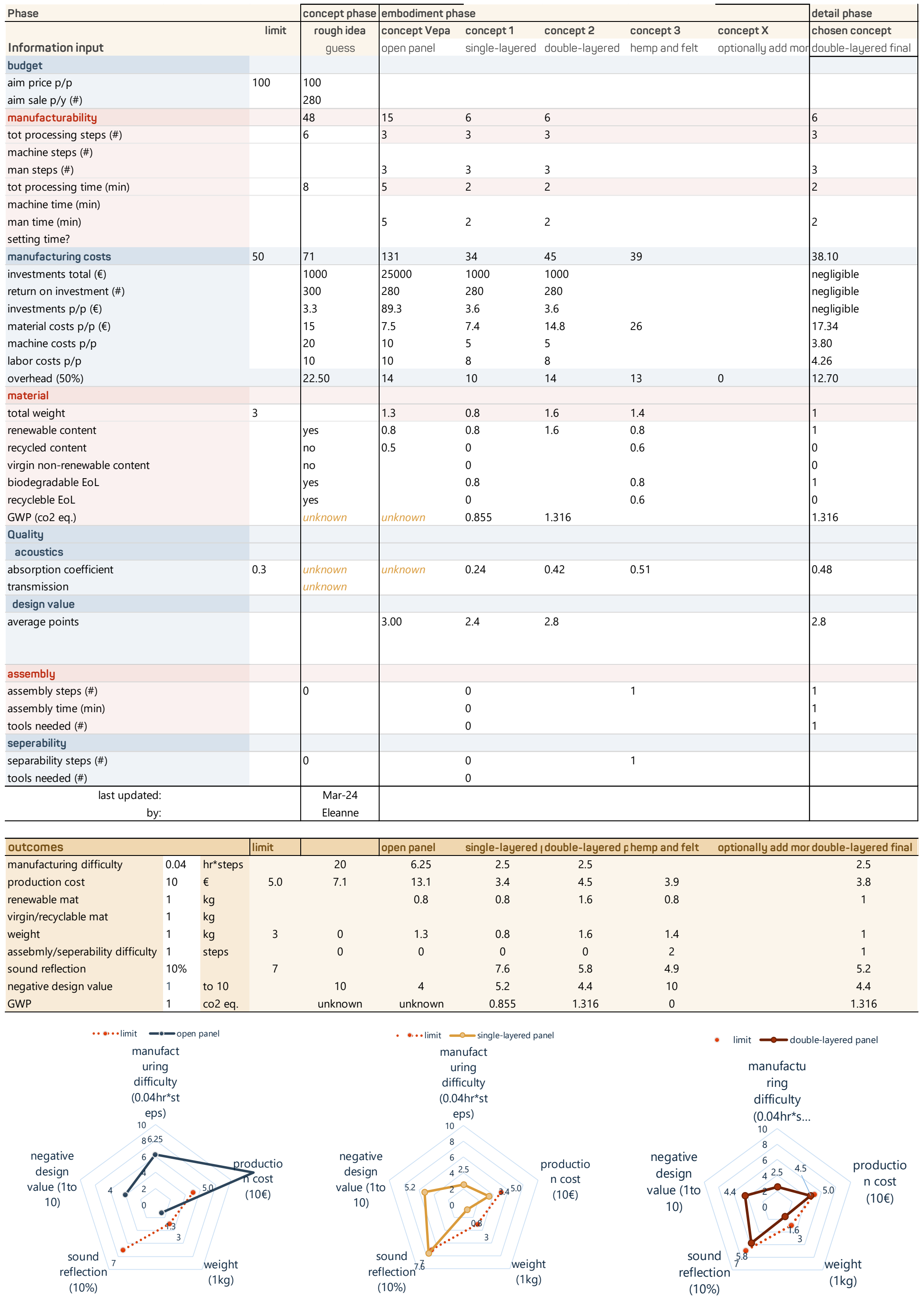
The quality performance indicator is in this case the sound absorption of the panel. The flammability is a value that can be reached or not and therefore is not plotted, but sufficient to capture in the requirements tab.

Since for absorption a higher value is in this case better, the performance indicator is displayed in the reflection coefficient, since Reflection = 1 – absorption. The lower the reflection, the better. Unit for wall panel was set at 10%.

### *Weight*

The total weight of the components is considered, with the unit being kilograms (kg).

*(continued on page 110)*



| Phase | | concept phase | embodiment phase | | | | | detail phase |
|---|---|---|---|---|---|---|---|---|
| | limit | rough idea | concept Vepa | concept 1 | concept 2 | concept 3 | concept X | chosen concept |
| **Information input** | | guess | open panel | single-layered | double-layered | hemp and felt | optionally add mor | double-layered final |
| **budget** | | | | | | | | |
| aim price p/p | 100 | 100 | | | | | | |
| aim sale p/y (#) | | 280 | | | | | | |
| **manufacturability** | | 48 | 15 | 6 | 6 | | | 6 |
| tot processing steps (#) | | 6 | 3 | 3 | 3 | | | 3 |
| machine steps (#) | | | | | | | | |
| man steps (#) | | | 3 | 3 | 3 | | | 3 |
| tot processing time (min) | | 8 | 5 | 2 | 2 | | | 2 |
| machine time (min) | | | | | | | | |
| man time (min) | | | 5 | 2 | 2 | | | 2 |
| setting time? | | | | | | | | |
| **manufacturing costs** | 50 | 71 | 131 | 34 | 45 | 39 | | 38.10 |
| investments total (€) | | 1000 | 25000 | 1000 | 1000 | | | negligible |
| return on investment (#) | | 300 | 280 | 280 | 280 | | | negligible |
| investments p/p (€) | | 3.3 | 89.3 | 3.6 | 3.6 | | | negligible |
| material costs p/p (€) | | 15 | 7.5 | 7.4 | 14.8 | 26 | | 17.34 |
| machine costs p/p | | 20 | 10 | 5 | 5 | | | 3.80 |
| labor costs p/p | | 10 | 10 | 8 | 8 | | | 4.26 |
| overhead (50%) | | 22.50 | 14 | 10 | 14 | 13 | 0 | 12.70 |
| **material** | | | | | | | | |
| total weight | 3 | | 1.3 | 0.8 | 1.6 | 1.4 | | 1 |
| renewable content | | yes | 0.8 | 0.8 | 1.6 | 0.8 | | 1 |
| recycled content | | no | 0.5 | 0 | | 0.6 | | 0 |
| virgin non-renewable content | | no | | 0 | | | | 0 |
| biodegradable EoL | | yes | | 0.8 | | 0.8 | | 1 |
| recycleble EoL | | yes | | 0 | | 0.6 | | 0 |
| GWP (co2 eq.) | | *unknown* | *unknown* | 0.855 | 1.316 | | | 1.316 |
| **Quality** | | | | | | | | |
| **acoustics** | | | | | | | | |
| absorption coefficient | 0.3 | *unknown* | *unknown* | 0.24 | 0.42 | 0.51 | | 0.48 |
| transmission | | *unknown* | | | | | | |
| **design value** | | | | | | | | |
| average points | | | 3.00 | 2.4 | 2.8 | | | 2.8 |
| **assembly** | | | | | | | | |
| assembly steps (#) | | 0 | | 0 | | 1 | | 1 |
| assembly time (min) | | | | 0 | | | | 1 |
| tools needed (#) | | | | 0 | | | | 1 |
| **seperability** | | | | | | | | |
| separability steps (#) | | 0 | | 0 | | 1 | | |
| tools needed (#) | | | | 0 | | | | |
| last updated: | | Mar-24 | | | | | | |
| by: | | Eleanne | | | | | | |

| **outcomes** | | | limit | | open panel | single-layered | double-layered p | hemp and felt | optionally add mor | double-layered final |
|---|---|---|---|---|---|---|---|---|---|---|
| manufacturing difficulty | 0.04 | hr*steps | | 20 | 6.25 | 2.5 | 2.5 | | | 2.5 |
| production cost | 10 | € | 5.0 | 7.1 | 13.1 | 3.4 | 4.5 | 3.9 | | 3.8 |
| renewable mat | 1 | kg | | | 0.8 | 0.8 | 1.6 | 0.8 | | 1 |
| virgin/recyclable mat | 1 | kg | | | | | | | | |
| weight | 1 | kg | 3 | 0 | 1.3 | 0.8 | 1.6 | 1.4 | | 1 |
| assebmly/seperability difficulty | 1 | steps | | 0 | 0 | 0 | 0 | 2 | | 1 |
| sound reflection | 10% | | 7 | | | 7.6 | 5.8 | 4.9 | | 5.2 |
| negative design value | 1 | to 10 | | 10 | 4 | 5.2 | 4.4 | 10 | | 4.4 |
| GWP | 1 | co2 eq. | | unknown | unknown | 0.855 | 1.316 | 0 | | 1.316 |

**Figure 57** Fifth tool tab in use

*Negative design value*

In addition to the perceptions mentioned in section 6.1.5, for these panels the association busy versus calm was also taken into account, since the panels should convey a calm environment. This aspect was assessed by multiple employees within Vepa, who assigned corresponding values.

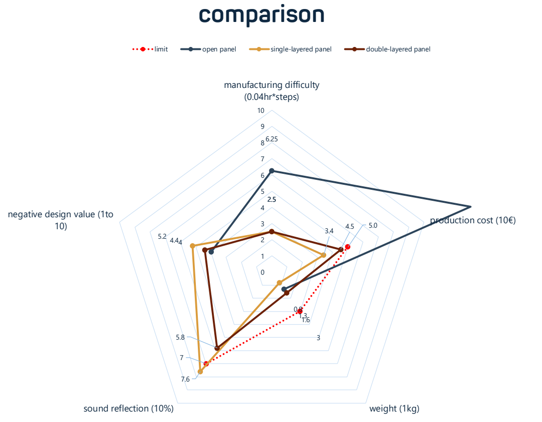
*Limits*

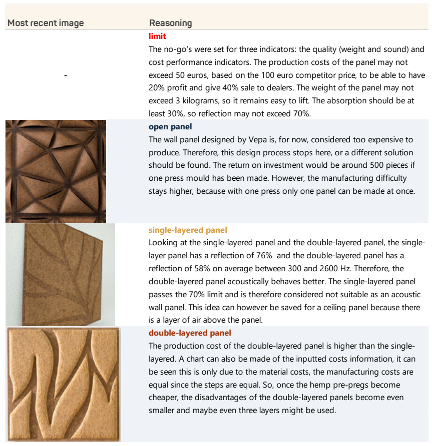
For the wall panel, Vepa might aim to achieve at least 30% sound absorption on average, meaning a maximum of 70% reflection, based on competitor products.

Weight is also a potential limitation, with Vepa for example specifying that the wall panels should not exceed 3 kilograms in weight.

## 7.6 Comparison

The comparison dashboard automatically provides a visual summary of the values entered in the calculations tab, as shown in Figure 58. This chart serves as a communication tool to easily display the differences between products or concepts. Additionally, space is provided next to the summary to document the rationale behind the chart, allowing for easy capture of decisions and the preservation of concepts developed up to that point.





**Most recent image**

**Reasoning**

**limit**

The no-go's were set for three indicators: the quality (weight and sound) and cost performance indicators. The production costs of the panel may not exceed 50 euros, based on the 100 euro competitor price, to be able to have 20% profit and give 40% sale to dealers. The weight of the panel may not exceed 3 kilograms, so it remains easy to lift. The absorption should be at least 30%, so reflection may not exceed 70%.

**open panel**

The wall panel designed by Vepa is, for now, considered too expensive to produce. Therefore, this design process stops here, or a different solution should be found. The return on investment would be around 500 pieces if one press mould has been made. However, the manufacturing difficulty stays higher, because with one press only one panel can be made at once.

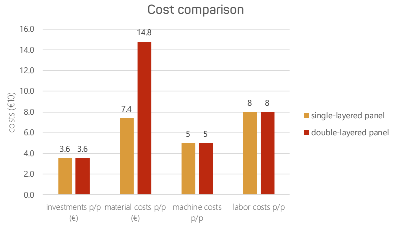
**single-layered panel**

Looking at the single-layered panel and the double-layered panel, the single-layer panel has a reflection of 76%  and the double-layered panel has a reflection of 58% on average between 300 and 2600 Hz. Therefore, the double-layered panel acoustically behaves better. The single-layered panel passes the 70% limit and is therefore considered not suitable as an acoustic wall panel. This idea can however be saved for a ceiling panel because there is a layer of air above the panel.

**double-layered panel**

The production cost of the double-layered panel is higher than the single-layered. A chart can also be made of the inputted costs information, it can be seen this is only due to the material costs, the manufacturing costs are equal since the steps are equal. So, once the hemp pre-pregs become cheaper, the disadvantages of the double-layered panels become even smaller and maybe even three layers might be used.

**Figure 58** Sixth tool tab in use



### 7.6.1 *Reasoning around the comparison chart*

From the comparison chart, the following design decisions can be concluded. These design decisions are clearly displayed in the tool next to the chart. The decisions are explained below.

*Limit*

The red dotted line displays the limit. If these requirements, or performance indicators, are not met, the design is considered not feasible to produce. In this case, the limits were set for three indicators: the quality (weight and sound) and cost performance indicators. The production costs of the panel may not exceed 50 euros, to be able to sell the product of maximum 100 euros which is the aimed price per piece to be able to have 20% profit and give 40% to dealers. The weight of the panel may not exceed 3 kilograms, so it remains easy to lift. The absorption should be at least 30% because otherwise the absorption will be almost negligible and this was slightly above the lowest value seen at competitor products, as can be seen in the link to the market research on the first tool tab, so reflection may not exceed 70%.

*Open panel*

The wall panel designed by Vepa is, for now, considered too expensive to produce. Therefore, this design process stops here, or a different solution should be found. The return on investment would be around 500 pieces if one press mould has been made. However, the manufacturing difficulty will stay higher than the other panels, because with one press only one panel can be made at once.

*Single-layered panel*

Looking at the single-layered and double-layered panels, the single-layered panel has a reflection of 82% on average between 300 and 2600 Hz and the double-layered panel has a reflection of 72%. Therefore, the double-layered panel behaves better in terms of acoustic behaviour. The single-layered panel passes the 70% reflection limit and is hence not suitable as a wall panel. The single-layered panel idea can however be saved for a ceiling panel because then, there is a layer of air above the panel which can help in acoustic behaviour.

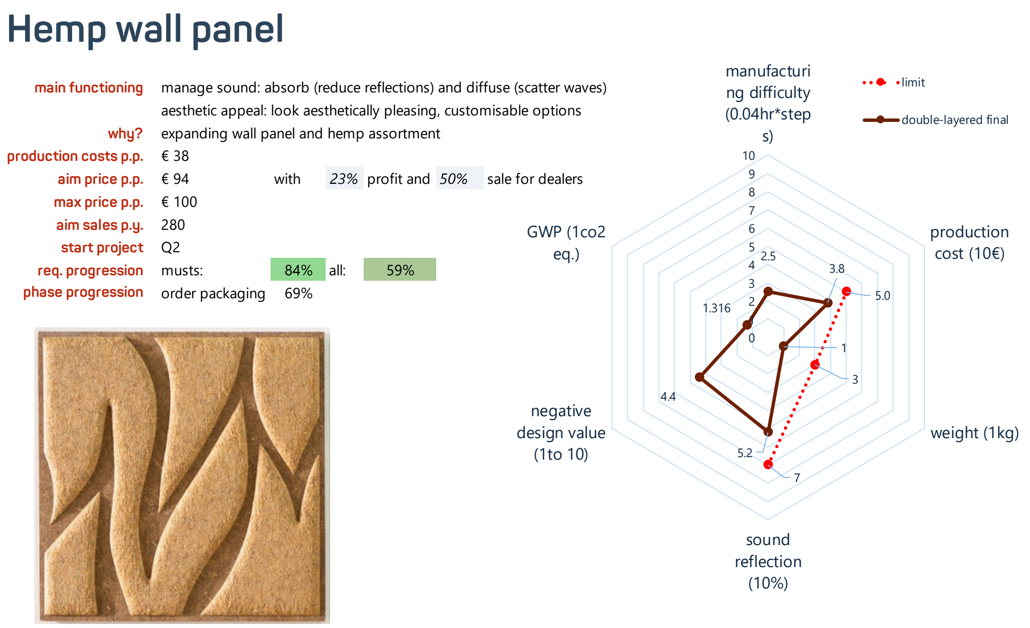
*Double-layered panel*

The production cost of the double-layered panel is higher. With the available costs data, it can be clearly seen this is only due to the material costs, the manufacturing costs are equal since the steps are equal. So, once the hemp pre-pregs become cheaper, the disadvantages of the double-layered panels become even smaller and maybe even three layers might be used. This is something that could be easily plotted in the chart.

For now, these three panels have been plotted to demonstrate the use of the tabs. However, it would also be interesting to include additional variations, such as a three-layered panel or one that incorporates felt and visualises its trade-offs.

## 7.7 Summary

The summary tab shown in Figure 59 gets filled in automatically. Eventually, more detailed information of the final chosen concept can be displayed in the chart. For example, in this case study, the GWP was included, reflecting the outcomes of a preliminary LCA conducted with the LCA expert in the company. This summary tab offers a concise overview of the project's overall status, providing an effective means for communication.



Hemp wall panel

| | | | | | | |
|---|---|---|---|---|---|---|
| **main functioning** | manage sound: absorb (reduce reflections) and diffuse (scatter waves) | | | | | |
| | aesthetic appeal: look aesthetically pleasing, customisable options | | | | | |
| **why?** | expanding wall panel and hemp assortment | | | | | |
| **production costs p.p.** | € 38 | | | | | |
| **aim price p.p.** | € 94 | with | *23%* | profit and | *50%* | sale for dealers |
| **max price p.p.** | € 100 | | | | | |
| **aim sales p.y.** | 280 | | | | | |
| **start project** | Q2 | | | | | |
| **req. progression** | musts: | 84% | all: | 59% | | |
| **phase progression** | order packaging | 69% | | | | |

**Figure 59** Seventh tool tab in use

## 7.8 Conclusion

The tool's application is demonstrated in the development of the hemp wall panels and the tool was created through research by design with this product. This process led to both the tool and the hemp wall products. Figure 60 displays the wall panels in the showroom in Berlin. The tool proved to be a useful aid in the product development process, helping to reach the solution requirements described in section 5.4. In the next sections, this tool will be evaluated with other products and the actual users to assess its effectiveness in practice. Additionally, the author of this report serves as an example of an individual who joins the company, acquires expertise in a particular area and eventually leaves. This reflects a small cycle of an employee who works at the company for many years, develops valuable expertise, and then leaves. Potentially, critical information is lost. By utilising this tool this information loss is minimised, ensuring that important insights are preserved and accessible for future development.

**Figure 60** Wall panels in the showroom in Berlin

## Part

# .03

# Verification, validation and implementation

## Chapter .08
### Verification

Tool requirements
Different products
Different company

## Chapter .09
### Validation

The noticed challenges
The solution
General recommendations

## Chapter .10
### Implementation

Establish the need to change
Develop the vision
Pilot run
Communicate and manage resistance
Implement
Continuously evaluate

*In part two, the solution objective was further described and the solution, being a tool created. Its use has been shown with a hemp wall panel case study.*

*In this part, the tool will be verified and validated and an implementation plan of the tool will be proposed.*

*Verification, whether the tool is made right and whether the requirements are met, will be done by verifying the requirements with the requirements tab of the tool and by filling in the tool for different products. Additionally, a different company has also adapted a part of the tool.*

*Validation, whether the right tool is made and whether it fulfils the needs of the users, of the tool will be executed by discussing with product developers whether the tool is indeed easy to use and whether it provides them with more insight and enhanced decision-making.*

*The implementation section describes providing an implementation plan for achieving the new product development process approach with the tool. The implementation plan has already been partially executed.*

Chapter

# .08

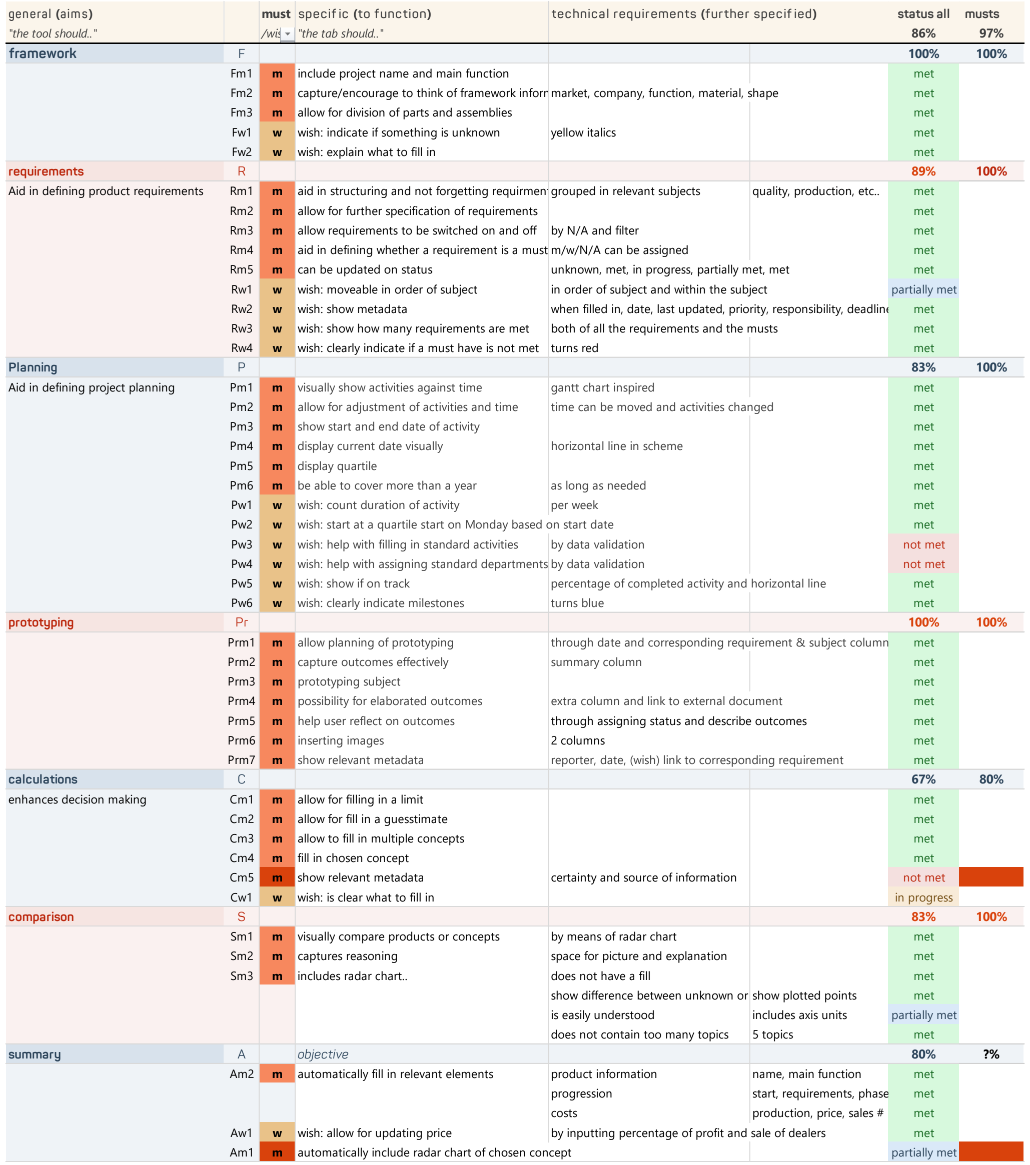
# Verification

*The purpose of this verification is to verify the adaptability, usability and effectiveness of the tool across a range of projects. Does the tool meet the specified requirements? Can the tool be effectively applied to different types of products and projects? Can users with varying levels of experience utilise the tool with minimal guidance? Does the tool extend beyond Vepa? The aim is to ensure that the tool can support a variety of product development processes.*

*First, the tool requirements are verified using the requirements tab. Secondly, different products are included in the tool. One was filled in in collaboration with a product developer, another was used individually by a product developer, one partly by the product development manager and a fourth partly by another product development company.*

## 8.1 Tool requirements

The tool requirements per tab are verified against the requirements with the requirements tab of the tool as is shown in Figure 61. It can be concluded that most of the requirements have been successfully met. Additionally, this verification further demonstrates that the template is adaptable and can be effectively applied to entirely different products, in this case, the tool itself. Improvements lie in a movable requirements list, clearer metadata for the calculation inputs and radar chart. For now, standard employees were not assigned to the planning because these differ per project. The unmet requirements reflect these suggested improvements.



| general (aims)<br>*"the tool should.."* | | must<br>*/wis* | specific (to function)<br>*"the tab should.."* | technical requirements (further specified) | | status all<br>86% | musts<br>97% |
|---|---|---|---|---|---|---|---|
| **framework** | F | | | | | **100%** | **100%** |
| | Fm1 | **m** | include project name and main function | | | met | |
| | Fm2 | **m** | capture/encourage to think of framework inforn | market, company, function, material, shape | | met | |
| | Fm3 | **m** | allow for division of parts and assemblies | | | met | |
| | Fw1 | **w** | wish: indicate if something is unknown | yellow italics | | met | |
| | Fw2 | **w** | wish: explain what to fill in | | | met | |
| **requirements** | R | | | | | **89%** | **100%** |
| Aid in defining product requirements | Rm1 | **m** | aid in structuring and not forgetting requiremen | grouped in relevant subjects | quality, production, etc.. | met | |
| | Rm2 | **m** | allow for further specification of requirements | | | met | |
| | Rm3 | **m** | allow requirements to be switched on and off | by N/A and filter | | met | |
| | Rm4 | **m** | aid in defining whether a requirement is a must | m/w/N/A can be assigned | | met | |
| | Rm5 | **m** | can be updated on status | unknown, met, in progress, partially met, met | | met | |
| | Rw1 | **w** | wish: moveable in order of subject | in order of subject and within the subject | | partially met | |
| | Rw2 | **w** | wish: show metadata | when filled in, date, last updated, priority, responsibility, deadline | | met | |
| | Rw3 | **w** | wish: show how many requirements are met | both of all the requirements and the musts | | met | |
| | Rw4 | **w** | wish: clearly indicate if a must have is not met | turns red | | met | |
| **Planning** | P | | | | | **83%** | **100%** |
| Aid in defining project planning | Pm1 | **m** | visually show activities against time | gantt chart inspired | | met | |
| | Pm2 | **m** | allow for adjustment of activities and time | time can be moved and activities changed | | met | |
| | Pm3 | **m** | show start and end date of activity | | | met | |
| | Pm4 | **m** | display current date visually | horizontal line in scheme | | met | |
| | Pm5 | **m** | display quartile | | | met | |
| | Pm6 | **m** | be able to cover more than a year | as long as needed | | met | |
| | Pw1 | **w** | wish: count duration of activity | per week | | met | |
| | Pw2 | **w** | wish: start at a quartile start on Monday based on start date | | | met | |
| | Pw3 | **w** | wish: help with filling in standard activities | by data validation | | not met | |
| | Pw4 | **w** | wish: help with assigning standard departments | by data validation | | not met | |
| | Pw5 | **w** | wish: show if on track | percentage of completed activity and horizontal line | | met | |
| | Pw6 | **w** | wish: clearly indicate milestones | turns blue | | met | |
| **prototyping** | Pr | | | | | **100%** | **100%** |
| | Prm1 | **m** | allow planning of prototyping | through date and corresponding requirement & subject column | | met | |
| | Prm2 | **m** | capture outcomes effectively | summary column | | met | |
| | Prm3 | **m** | prototyping subject | | | met | |
| | Prm4 | **m** | possibility for elaborated outcomes | extra column and link to external document | | met | |
| | Prm5 | **m** | help user reflect on outcomes | through assigning status and describe outcomes | | met | |
| | Prm6 | **m** | inserting images | 2 columns | | met | |
| | Prm7 | **m** | show relevant metadata | reporter, date, (wish) link to corresponding requirement | | met | |
| **calculations** | C | | | | | **67%** | **80%** |
| enhances decision making | Cm1 | **m** | allow for filling in a limit | | | met | |
| | Cm2 | **m** | allow for fill in a guesstimate | | | met | |
| | Cm3 | **m** | allow to fill in multiple concepts | | | met | |
| | Cm4 | **m** | fill in chosen concept | | | met | |
| | Cm5 | **m** | show relevant metadata | certainty and source of information | | not met | 🟥 |
| | Cw1 | **w** | wish: is clear what to fill in | | | in progress | |
| **comparison** | S | | | | | **83%** | **100%** |
| | Sm1 | **m** | visually compare products or concepts | by means of radar chart | | met | |
| | Sm2 | **m** | captures reasoning | space for picture and explanation | | met | |
| | Sm3 | **m** | includes radar chart.. | does not have a fill | | met | |
| | | | | show difference between unknown or | show plotted points | met | |
| | | | | is easily understood | includes axis units | partially met | |
| | | | | does not contain too many topics | 5 topics | met | |
| **summary** | A | | *objective* | | | **80%** | **?%** |
| | Am2 | **m** | automatically fill in relevant elements | product information | name, main function | met | |
| | | | | progression | start, requirements, phase | met | |
| | | | | costs | production, price, sales # | met | |
| | Aw1 | **w** | wish: allow for updating price | by inputting percentage of profit and sale of dealers | | met | |
| | Am1 | **m** | automatically include radar chart of chosen concept | | | partially met | 🟥 |

**Figure 61** Verification of tool requirements

## 8.2 Different products

### 8.2.1 WireWorks


**Figure 62** WireWorks

WireWorks, shown in Figure 62, is a project that is running in the company for around three years. Although it is quite far in progression, it is not yet finished, and it is unclear for the product developers and management when the product will be finished, what the status is, what is needed and why it is not going so well. This product will be partially filled in together with a product developer who has been most involved with it, the project lead. The aim is to provide Vepa with more insight into this project, to verify whether the tool can be used with a completely different product and to indicate how long it takes to fill in the document from scratch, as the tool for the wall panels was developed and filled in over a longer period of time.

The link to the tool applied to WireWorks can be found here,it was translated into Dutch for company reasons. Filling in the tool up to this point took approximately one hour. Therefore, it is reasonable to assume that filling in the tool can happen with taking around one hour at the start of the project, with subsequent updates requiring only around five minutes at the end of each day. The project info and planning tabs were filled in quickly, while the requirements tab was partially completed due to the unclarities of the team itself on all the requirements. The calculation tab was filled in with fictive numbers for demonstration purposes, to show how comparisons might look in this context. The comparison chart could be used for making a trade-off on the steel frame. For example, do three steel beams outweigh the advantages of the aesthetics compared to the rise in manufacturing difficulty and material use? Currently, a rather inexplicit decision was made to use three steel beams for the construction. The other lessons learned from this tool are that much attention was given to optimising the welding technique. Firstly, now it is known that this requires time, and secondly, in future projects attention on prototyping with steel in an earlier stage, so that this will prevent stagnating the process in future product development processes. Overall, the WireWorks application confirms that the tool also works for a different project, providing a structured and efficient means of managing relevant product development information.

### 8.2.2 Bold table


**Figure 63** Bold

To assess whether the product development team can use the tool without extensive guidance, a product developer was tasked to fill it in independently for a current product in development, the bold table depicted in Figure 63. The filled-in tool can be seen in Appendix L.1. The feedback was mainly positive. The tool's overall structure was intuitive, although the project information and requirements tab were noted to feel somewhat similar. The requirements tab was found highly effective, helping to formulate and organise product requirements. The prototyping tab was well-received as well, providing space for documenting the prototyping process and recording decision-making. According to the PD Manager, this tab provided valuable insight by providing an overview and clearly showing whether the outcomes were satisfactory or whether further action was required. Currently, much time is spent on asking about the status of each project. This sheet can help with updating each other and saving time. This way, only the important aspects can be discussed during consultation, allowing for faster decision-making. The planning tab was also considered comprehensible, although according to the product developer not the most enjoyable part to fill in. The calculation and comparison tabs were not used yet, but rather they were seen as something for the calculation department, demonstrating that currently considering explicit numbers is seen as something outside the scope of the product developer but rather for a different department. Overall, the application of the tool to the Bold Table project demonstrates its adaptability to different products and its usability without requiring extensive instructions.

### 8.2.3 Inline


**Figure 64** Inline

The Inline project involves Vepa's plans to redesign adjustable legs, a component used across multiple products, see Figure 65. This is an example of a change in function (faster and quieter height adjustment) that leads to a change in shape (larger circumference of legs needed). Given the project's broad impact on existing products, a more structured approach and having the right insights are essential. To address this, the PD manager adopted the tool, and by the conclusion of this thesis, the planning tab was already being utilised, see Appendix L.2. Additionally, the requirements and prototyping tabs are planned for future implementation. Notably, the planning tab was successfully completed in a single afternoon by an individual with limited Excel experience, demonstrating the tool's accessibility and ease of use.

## 8.3 Different company

The use of the tool also has extended beyond Vepa, as it has also been adopted by Optics11 Life, a company specialising in optical measurement instruments. The product manager has integrated the planning tab of the tool into his product development team. The planning tab was utilised to display the planning of all ongoing project, rather than the planning on a single product. The tab of the tool enables the team to monitor the status of ongoing projects effectively, as shown by the completed template provided in Appendix L.3. It took the manager ten minutes to understand this sheet without explanation, and approximately one hour to fill in the sheet. The planning tab thus offers a practical overview of the progress of all projects, helping to determine whether timelines are being met. Additionally, this tab was found understandable and does not require much time to adopt. This application further demonstrates the tool effectiveness, its use in varied contexts and its comprehensibility.

Chapter

# .09

# Validation

*The validation first aims to confirm whether the noticed challenges and lack of insights were perceived right. Secondly, the objective is to validate whether the right tool has been developed, whether it effectively addresses the challenges and whether it meets the needs of its users. This will be achieved by discussing the tool with Vepa's product developers and evaluating it against the solution requirements. In conclusion, the validation should prove the tool provides the right insights and, as a result, can improve decision-making processes. Lastly, recommendations may be identified that can be incorporated into the implementation plan.*

*The tool was discussed with five individual product developers, the end users, presented to the complete management of Vepa and more elaborately discussed with the assistant director. The findings are divided in a validation of the noticed problems, the solution (the tool), and recommendations.*

## 9.1 The noticed challenges

The noticed challenges – long decision-making times, knowledge being inside the employees' heads rather than centrally available, unclear responsibilities and little documentation and structure - were confirmed by all the individual members and management. Additionally, the assistant director has confirmed that "things really need to change at the product development department". These topics also arose in a product consultation at the end of this thesis, as indicated in Appendix N, and further confirmed the challenges. Consequently, the value proposition indicated in section 1.5 is indeed a more ideal scenario the company wants to move towards.

## 9.2 The solution

The solution – implementing a practical Excel tool in the way of working - was generally seen as valuable and meaningful to the product development department and thus to the company. Overall, the product developers believe it is a good idea to incorporate this, or a simplified version of this tool, in their product development processes. The following conclusions may be drawn from the individual discussions described in Appendix O.

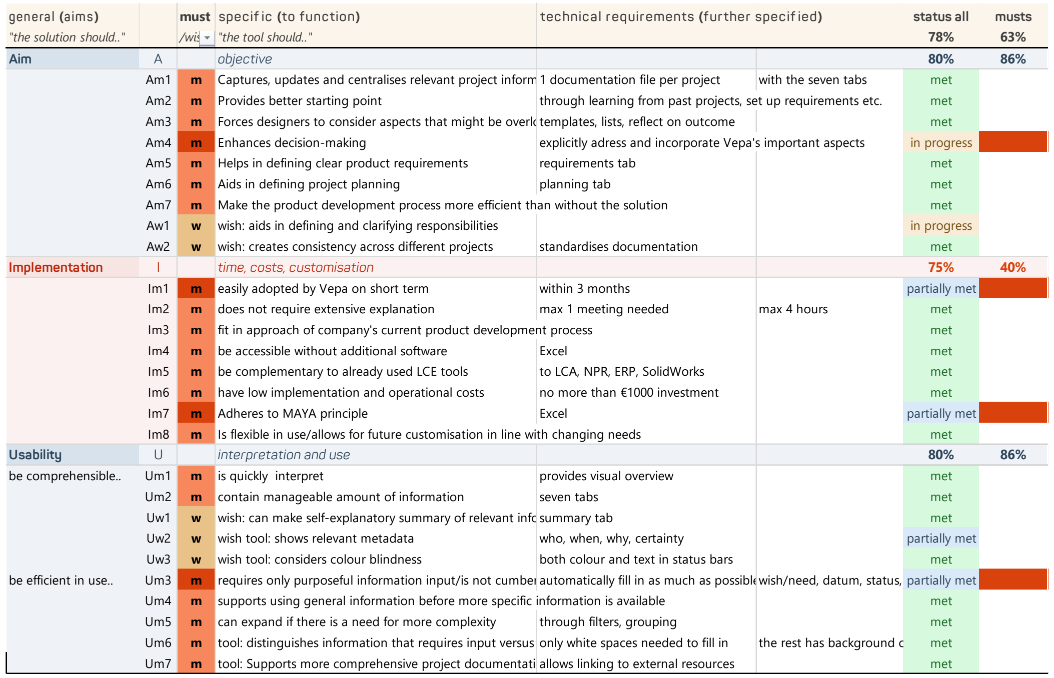
- First reactions to the tool were all positive, the tool looks well thought-out.
- Everyone is willing to fill in the tool and is interested in using it.
- Especially the option to make well-defined product requirements is highly appreciated. The template serves as a memory aid.
- Issues can be prevented with this tool, like missing certain requirements, norms, activities, that would have gone wrong otherwise.
- It helps in defining and providing insight in what is important and what responsibilities are for the specific project.
- It helps with having structure along different projects and that is preferred.

On top of that, the product development manager stated " ***I might really use the tool in a coming project, this is a project that really cannot go wrong because time is running".*** He also agreed with Figure 22 in section 5.2 that shifting efforts to the early stages can help gain more knowledge and prevent problems and higher cost of change in later stages.

This all indicates the solution - the implementation of this tool - is considered useful.

### *9.2.1 Solution requirements*

Figure 65 on the next page depicts the further specified solution requirements and its status. Most of them are met, as agreed upon with the product developers. Whether the tool enhances decision-making should be experienced by the product developers through using the tool. Wheter this tool is MAYA is open to debate because of the employees finding it somewhat overwhelming and on occasion, the tool requires some manual input, which would ideally even be less.



| general (aims) "the solution should.." | | must /wis | specific (to function) "the tool should.." | technical requirements (further specified) | | status all 78% | musts 63% |
|---|---|---|---|---|---|---|---|
| **Aim** | A | | *objective* | | | **80%** | **86%** |
| | Am1 | **m** | Captures, updates and centralises relevant project inform | 1 documentation file per project | with the seven tabs | met | |
| | Am2 | **m** | Provides better starting point | through learning from past projects, set up requirements etc. | | met | |
| | Am3 | **m** | Forces designers to consider aspects that might be overlc | templates, lists, reflect on outcome | | met | |
| | Am4 | **m** | Enhances decision-making | explicitly adress and incorporate Vepa's important aspects | | in progress | 🟥 |
| | Am5 | **m** | Helps in defining clear product requirements | requirements tab | | met | |
| | Am6 | **m** | Aids in defining project planning | planning tab | | met | |
| | Am7 | **m** | Make the product development process more efficient than without the solution | | | met | |
| | Aw1 | **w** | wish: aids in defining and clarifying responsibilities | | | in progress | |
| | Aw2 | **w** | wish: creates consistency across different projects | standardises documentation | | met | |
| **Implementation** | I | | *time, costs, customisation* | | | **75%** | **40%** |
| | Im1 | **m** | easily adopted by Vepa on short term | within 3 months | | partially met | 🟥 |
| | Im2 | **m** | does not require extensive explanation | max 1 meeting needed | max 4 hours | met | |
| | Im3 | **m** | fit in approach of company's current product development process | | | met | |
| | Im4 | **m** | be accessible without additional software | Excel | | met | |
| | Im5 | **m** | be complementary to already used LCE tools | to LCA, NPR, ERP, SolidWorks | | met | |
| | Im6 | **m** | have low implementation and operational costs | no more than €1000 investment | | met | |
| | Im7 | **m** | Adheres to MAYA principle | Excel | | partially met | 🟥 |
| | Im8 | **m** | Is flexible in use/allows for future customisation in line with changing needs | | | met | |
| **Usability** | U | | *interpretation and use* | | | **80%** | **86%** |
| be comprehensible.. | Um1 | **m** | is quickly interpret | provides visual overview | | met | |
| | Um2 | **m** | contain manageable amount of information | seven tabs | | met | |
| | Uw1 | **w** | wish: can make self-explanatory summary of relevant infc | summary tab | | met | |
| | Uw2 | **w** | wish tool: shows relevant metadata | who, when, why, certainty | | partially met | |
| | Uw3 | **w** | wish tool: considers colour blindness | both colour and text in status bars | | met | |
| be efficient in use.. | Um3 | **m** | requires only purposeful information input/is not cumber | automatically fill in as much as possible | wish/need, datum, status, | partially met | 🟥 |
| | Um4 | **m** | supports using general information before more specific information is available | | | met | |
| | Um5 | **m** | can expand if there is a need for more complexity | through filters, grouping | | met | |
| | Um6 | **m** | tool: distinguishes information that requires input versus | only white spaces needed to fill in | the rest has background c | met | |
| | Um7 | **m** | tool: Supports more comprehensive project documentati | allows linking to external resources | | met | |

**Figure 65** Validation of solution requirements

### 9.2.2 *Lean implementation*

An additional validation is the fact that recently an employee was hired to implement a 'lean' way of working within the company. This person also provided Vepa with an Excel template to make a product planning and a tab for noting down decisions. The sheets developed by the employee are shown in Appendix M. This template however does not use automatic fillings, therefore, much time will go to the team members for manually spending time on other things than only inserting essential information, which would not meet the requirements of the user. The documentation of both the planning and capturing decisions is also accommodated in the developed tool.

## 9.3 General recommendations

The following recommendations could be extracted from the individual interviews. For smaller projects such an extensive tool may cost more time than it will yield, a simplified version can be considered for these cases. The calculation and comparison tab might be too advanced for the current needs. Some team members lack experience with Excel, making the tool potentially overwhelming for them. Make the project leader the owner of this sheet, with the other members documenting to this person. It should be possible to add requirements along the process. To mimimise manual input, use a prefilled template as much as possible. Especially in planning, these steps are often the same. These feedback aspects will be used for the implementation plan discussed in the next chapter.

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Chapter

.10

# Implementation

*This chapter describes an implementation plan for the tool in the product development process of Vepa. This is needed to enhance the implementation of the tool. Six steps are proposed and explained.*

To enhance the effectiveness of the use of the new tool, it needs to be considered how it can be implemented within Vepa. The implementation plan will give the product developers at Vepa the ability to get started and ultimately reach the scenario that was described in section 6.2.

At the end phase of this thesis, there is a change of both the marketing manager and the product development manager. Before functioning as one department, now functioning as two separate departments with their own manager. This structural change might be the ideal opportunity to introduce the new, more structured, approach with the tool to the product development process.

Implementing this tool into Vepa's workflow is a change process, which requires to consider change management. Multiple models for change management exist [53] and most models share the steps of unfreezing, changing and refreezing [53], [54]. Parts of the implementation have already been initiated. To see how the tool is used by all members is considered outside this project's scope. Nevertheless, an implementation plan is proposed. The following steps need to be considered for Vepa's implementation, based on [53] - [55].

1. Establish the need to change. This includes being aware of what Vepa is changing from and communicating the present situation. - completed
2. Develop the vision. This includes thinking about; What is the direction of change? What is the new solution? What stakeholders are involved? How and on what timescale can the tool be implemented? - completed
3. Check before actual implementation and management support. A pilot run is proposed. Management should consider the consequences of change to make sure they are standing behind the process. - partially executed, can continue right now
4. Communicate to and train the workforce and manage resistance. - partially done
5. Actual Implementation (beginning of 2025)
6. Continuously monitor, evaluate and improve the tool and new way of working.

## 10.1 Establish the need to change

A need and thus motivation to change must exist within the product development team and management. This need is already identified by the observations and interviews conducted during this thesis. Vepa wanting to adopt a 'lean' product development approach, as mentioned in section 9.2, further emphasises the company's willingness and need to change. It is suggested to hold a meeting to explicitly discuss the reasons for change by openly discussing the current situation and its challenges as outlined in section 5.1. Additionally, the new vision should be communicated in this meeting.

## 10.2 Develop the vision

The new vision is a way of working where the challenges are resolved, leading to a decrease in consultation and frustration and enhanced insight and decision-making during product development. This vision is described in the value proposition. Stakeholder roles must also be clarified for this new way of working. The new way of working means that there is an Excel file created per project and managed by the project lead, as described in the scenario in section 6.2. A more structured start of a design project, investing some time in setting up requirements and prototyping plans, and keeping status updates is required. All in all, more documentation is asked of the product developers. Consequently, it is mainly product development that needs to change its way of working. Resistance to change is common. Some people might not be willing to fill in a sheet at all. Therefore, a filled-in version of the tool can be shown so that familiarity with the new solution is created. This way, hopefully, the barrier to the motivation for change is lowered. The complete team is already aware of the tool and has seen the filled-in version for the hemp panels and the Bold table. It should be announced that a pilot run will be held with the product manager and further implementation will follow at the start of the new year.

## 10.3 Check with a pilot run and management support

To check the consequences of change, a pilot project is proposed with a medium-complexity product with the product development manager. To execute a pilot run, the tool should first be translated into Dutch, which has already been done for the Bold table. Secondly, the product development manager must become acquainted with the tool. Therefore, the tool is already discussed and explained to him. In continuation of these steps, the pilot run has already partially begun by implementing the planning tab for the Inline project, as was described in section 8.2. This pilot run with the Inline project can proceed right now. Succes criteria for this trial include the time spent updating the tool, whether it provides more insight into the project and whether it saves consultation time. By keeping the tool up to date, the product development manager gets more acquainted with the tool. Some aspects may be customised based on his experiences. Therefore, a ReadMe file was created to be able to change the sheet according to the changing preferences, as shown in Appendix P. This supports the product development manager in understanding the tool and explaining it to other users.

Higher management support for the product developers using the tool is fundamental for successfully embedding the tool into the company's product development processes. Therefore, the tool was already presented to the managers of the company. They all confirmed the usefulness of the tool for the product developers. One of the managers explicitly mentioned that using the tool is something Vepa wants to move towards. Therefore, this demonstrates that management stands behind this shift. Additionally, hiring a dedicated person to implement a 'lean' way of working within the company further emphasises the managers standing behind the change. Management support is an essential point, as when management does not actively encourage the tool's use, the product developers are likely to feel less supported in adopting it and may perceive less value in its application.

## 10.4 Communicate, train and manage resistance

To achieve more recognisability, it is suggested to connect the implementation of the tool to a name, *The Excelerate Implementation*. The tool can be explained, and training can be led by the product development manager in a product development consultation to the other members. This can happen at the beginning of the new year. Initial reactions to the tool were that it looked overwhelming. Therefore, to overcome resistance, a gradual introduction of the tool is suggested. It should be mentioned that the requirements, planning and prototyping tabs should be used first, and the remaining can be left open. Still, it is recommended to provide the full version of the tool to the product developers, as it may be difficult to introduce the extended version later if a simplified version is in use first. It also gives employees who may be ready to use additional features the opportunity to do so. Open discussions for the team members to voice concerns and suggest improvements should take place, to give them also ownership over the change.

## 10.5 Implementation

By the start of 2025, all product development team members can begin utilising the tool. Whether they are working on a new project or an ongoing project, the tool proved useful as indicated in Chapter 8. While different members may value different tabs over others, using the tool will help everyone become familiar with it. Each member at least sees the usefulness of the individual tabs as indicated in Chapter 9. The overall usefulness of the tool can evolve over time as it is put into practice. It is designed to accommodate all information and includes many potential needed functionalities. Importantly, the tool does not require complete data entry on all tabs to be effective. Instead, the tool is built for growth. In future projects, as team members are more acquainted with the tool and way of working, they can utilise additional tabs. To ensure the team members have the idea that their effort is valued and the inputted data is being used meaningfully, the product development manager must review the filled-in tools, especially before consultations.

## 10.6 Continuously evaluate

The tool should be continuously evaluated on its impact on project efficiency and user satisfaction. Ultimately, a project should feel more efficient with the tool than without the tool. Feedback from the users, the product developers, should be gathered and changes made accordingly. All people from the design team should be able to report to the product development manager and the manager is allowed to change the template. The flexibility of Excel allows for adjustments to the tool to the changing user needs, such as adding new subjects under requirements, extra columns or functionalities. Changes can be implemented in the same way as described above. First, someone creates and tests the new functionality on their own tool, then explains it to the product development manager. The product development manager implements the change on the template and subsequently explains it to the other users.

Chapter

# .11

# Concluding remarks

*This chapter contains the conclusion, discussion and recommendations. In the discussion, each of the three parts of the report are adressed. Recommendations are provided for Vepa's product development, the tool and the hemp product.*

## 11.1 Conclusion

This research investigated how Vepa can enable insightful decision-making in its product development processes and identified and developed a solution to this challenge through research by design.

In response to the first sub-question answered in Chapter Two and Five, Vepa has experienced significant growth in recent years, which has led to a growing feeling within the company that the product development process is insufficiently supported to adequately fit the company's growth. Despite Vepa having certain objectives for product development, it was found that these are often not actively considered in the design process, but rather play a background role in decision-making. Although a planning exists with clearly defined decision moments, these are not always applied in practice.

Answering the second sub-question in Chapters Three and Four, the research identified that Vepa's product development process involves multiple design factors and objectives, including optimising for cost, sustainability, quality and modularity. These objectives were explored through the application of DfX methods. Important design factors and evaluation perspectives were identified. However, these perspectives often conflict, making trade-offs inevitable. As a result, the product development process requires constant decision-making. Optimising these perspectives can be best managed when considered in the early design phases, rather than later when changes are more costly.

In order to develop a solution that takes into account what is important for Vepa and to foreground the important design factors and evaluation perspectives, a conceptual framework of the product development process was developed in Chapter Four. Applying this framework to the hemp chair demonstrated that the framework captures indeed the information about which decisions need to be taken. The framework shows a path that can be followed and at each step, decisions have to be made that influence different node attributes, which in turn influence the perspectives that Vepa considers important.

In exploring opportunities for improving decision-making in product development processes at Vepa, it became clear that first having the right insight into the product development process is essential. If there is little insight, decisions are being made on a gut-feeling basis and can take a long time. It was found that decision-making is a challenge within Vepa because of multiple reasons. First, responsibilities within the team are unclear. Secondly, requirements remain rather vague and therefore it is hard to know whether requirements are met or if it is a must or a wish. A requirement being a must or a wish would however lead to different decisions. Thirdly, no planning is usually available which makes it harder to decide when a decision has to be made or leads to a decision being made under time pressure. Lastly, a lack of documentation further complicates learning from past projects, particularly in terms of prototyping outcomes. Therefore, these insights – past knowledge, requirements, responsibilities, planning, trade-offs - are needed to enable insightful decision-making. This relates to the third sub-question and was answered in Chapter Five.

To address these insights, the solution of implementing a tool into the way of working to enable informed decision-making was found. The tool was developed through research by design, using the development of a hemp composite wall panel as a case study. The tool, consisting of seven tabs, is designed to capture and communicate relevant project information, define clear product requirements, aid in making decisions at the right time and effectively visualise trade-offs. Chapters Six and Seven described the tool and the case study, answering sub-question four and its sub-questions.

Through verification with other products in Chapter Eight, it was found that different types of products fit into the tool. Through validation with the actual users in Chapter Nine, it was found that each user sees the added value of integrating this tool into their way of working. Although the users had different preferences and noted that using all the functionalities might be a step too far for now, they all agreed that it would be helpful to integrate the tool into the product development process. In addition, the product development manager stated that the tool could provide the necessary insight to make decisions and that he might use it in the upcoming project, as things cannot go wrong in this project. An implementation plan, *The Excelerate Implementation*, presented in Chapter Ten, which has already been partially executed, concluded that it is feasible to implement the tool in the short term after executing a pilot run.

This research concluded with a developed product, four hemp composite wall panels that will be launched in mid-January, and a tool that has proven valuable for Vepa's product developers and management. This tool will help Vepa to make more insightful and timely decisions and to manage trade-offs effectively. The tool offers Vepa a structured way to capture and communicate relevant product development information and formulate clear product requirements. Implementing this tool in Vepa's product development processes, which requires encouragement from management, has the potential to bring significant changes and improvements for Vepa. All to make decisions that align with company objectives, contributing to more efficient and informed decision-making, ultimately to stay ahead of the competition.

## 11.2 Discussion

### 11.2.1 Part 01. Vepa's product development context

*DfX*

Numerous DfX methods have been explored, but many others remain unstudied. For instance, time-to-market optimisation could also be investigated. However, it is currently assumed that the greatest time savings for Vepa can be achieved by making decisions faster or not having to change in later stages, which is made possible by the improved insights provided by the tool. Secondly, design for customer experience has not been explicitly explored because Vepa is often not in direct contact with the customer. Nevertheless, it is reasonable to assume that the customer experience is influenced by several factors, including material properties and brand identity. As such, the perspective of customer experience was included in the framework. Similarly, Design for Logistics has not been studied in depth. For now, the issues included in the framework - stackability, transport, service, storage, dimensions, packaging, quantity and ease of assembly - have been identified through experience and interviews within the company. Finally, some methods have been deliberately excluded. However, it is also likely that other potentially relevant methods have not yet been identified and would be relevant for further investigation. For example, Industry 4.0, lean and agile methodologies, or a combination of thereof, would be interesting to investigate further because of their potential to increase efficiency in the design process by eliminating 'waste' and rapidly adapting to changes [56].

*Framework*

The framework presented in Figure 21 provides a comprehensive overview of product development for Vepa and similar companies, highlighting important relationships and perspectives. Additional relationships or node attributes may be found since the framework is probably never complete. However, the current interplay of these six nodes effectively captures the aspects most relevant to Vepa's product development. This was confirmed through applying it with the hemp chair and interviews with the product developers, ensuring that the framework at least captures what is important to Vepa. It was therefore used as the basis for the solution and subjects to include inside the tool's tabs. The framework not only captures what is important to Vepa, but it also reflects what kind of company it is through the presence, or absence, of certain interactions. Keeping these interactions in mind can help communicate during the design process about what decisions are being made. Although counter-arguments may exist for some of the relationships, in most cases these relationships apply to Vepa. No similar comprehensive, integrated framework has been found in the literature. Finally, the framework emphasises the importance of understanding the potential consequences of different design decisions. To keep the framework manageable, the nodes are intentionally kept broad. The framework does not explicitly distinguish between what is general and what is specific to Vepa. Whether this distinction is necessary remains an open question.

### 11.2.2 Part 02. Objective, tool development and case study

*Solution objective*

Since the author of this report was not hired with the idea of "we have the problems as outlined in section 5.1, can you develop a solution for them?", time spent developing a solution became a priority later in the process. On the one hand, this meant that more time could have been spent on interviewing users about what they really needed from a solution. On the other hand, this allowed for a neutral perspective on Vepa's product development, leading to a solution that fits Vepa based on challenges that were observed and personally experienced within the company, without any bias.

*Design freedom, cost, knowledge*

Whether the lines shown in Figure 22 are exactly the curve for Vepa is not certain and would be difficult to measure and are different for every project, but the dotted lines compared to the solid lines are in the direction that the implementation of the tool is intended to achieve. Nevertheless, it can be assumed that by being able to look at the results of previous projects, the knowledge is not limited to the designer only, but also includes the knowledge gained in previous projects, and therefore the knowledge increases. Being forced to think about what the requirements are, what their priority is and whether the requirements are a must or a wish, helps designers to understand which criteria are critical and which are flexible, and therefore provides clarity about what alternatives can be explored. And while a planning may seem to limit design freedom, it can also focus time on exploration and rapid prototyping without risking deadlines and resources. The need to document prototyping can help the designer to think about what is unknown and what should be tested before committing to the final design, helping to prevent making costs at a later stage. Having to set things up and make them explicit in the tool will require more effort than before, but it may prevent major problems that would otherwise occur, reducing the effort and likely time and cost required at later stages.

The tool should not limit design freedom. Although the tool may initially seem to be a rigid framework that could potentially limit design freedom, it is expected that this will not be the case. The tool may have different emphases depending on the specific project in question. The tool rather clarifies the boundaries of design freedom and the constraints that define it. Thereby, it does not restrict design freedom but rather clarifies where the design freedom of that particular project lies. Moreover, the tool has a flexible structure that allows it to be adapted to the specific project in question.

*The tool itself*

In the end, it can be noted that the tool is still in the prototyping phase, and thus requires further iterations. This is also confirmed by the must status in section 9.2 which is not yet 100%. Nevertheless, the verification and validation have already demonstrated that the tool is a working prototype. However, it will require further use and modifications to become the final product.

In particular, the calculations and comparison tab require further elaboration. As it was found that these tabs would be a challenging addition for Vepa at this moment, the focus was shifted towards the integration within Vepa of the first four tabs. It is expected that these will yield the most results for Vepa's product development in the short term.

Moreover, the values in the radar chart may not be the exact representation. Nevertheless, it can provide valuable insights, and some information is preferable to none. In accordance with the Pareto principle, which states that approximately 80% of the effects come from 20% of the causes [51], it is reasonable to assume that focusing on the most crucial aspects in the calculation can already provide valuable insights. A radar chart has been selected as a visual representation in the comparison tab of the data in the calculation tab. Perhaps a different graph would be more appropriate for comparisons, but this was not considered to be the primary focus of the research. Research exists on considerations for visual comparisons [57]. Additionally, the tool's UI/UX can always be improved, but for now, the primary focus was ensuring clarity regarding what needs to be manually filled in and what is automatically filled in.

Some users have stated that the tool appears overwhelming. It is however expected that once familiarised with the setup, this perception will change. Furthermore, not all the functions need to be utilised from the beginning, as the tool is intended to accommodate future growth. The overwhelming factor may also be due to users' varying levels of expertise with Excel. However, the focus of this project was not to assist employees in working with Excel.

#### *Tool boundaries*

The tool has been developed specifically for Vepa, but what are its practical limitations? In other words, what types of projects and companies would benefit from using it, and in what cases would it be less effective?

While the tool fits Vepa's approach for larger projects, it may be less efficient for smaller projects, which Vepa often approaches with a 'just do it' approach, as described in section 2.1.2. These smaller projects typically involve minor modifications or a request for a special, such as adjusting the dimensions of an existing product. For such projects, using the tool could potentially take more time than it saves. However, the tool is advised for use with any product that is being developed from scratch. The amount of information input can be scaled according to the size of the project, so even for smaller projects, selective use of the tool's functionality can provide valuable structure and insight.

In the case of large and complex projects, the tool is considered valuable but may require more extended pages or double pages. Nevertheless, it is useful in helping to capture and provide insight into this information without missing important steps. The tool could also be applied to specific subsystems or modules within the larger product. However, to avoid suboptimal isolated solutions, it is important to keep the overall product objectives in mind, to avoid optimising only individual components rather than the product as a whole.

The tool could also benefit companies outside Vepa, especially those that do not have a structured approach to managing product development information. For example, start-ups may not yet have a way of working and may not want to invest in expensive software. For other companies, the setup and functionality of the tool may be identical, but the specific subjects addressed, such as those in the requirements and calculations tab, are likely to be different. For companies that already have a way of structuring this information, or have software that already requires them to think about and document this information, the Excel tool may be a step backward rather than forward.

#### *Spreadsheet approach*

Although this is a spreadsheet approach, where high manual data maintenance workload, lack of domain-specific functionality, inconsistencies between simultaneously modified versions, lack of transparency and increased error rates prove to be potential pitfalls [58], this tool has been carefully designed to avoid these pitfalls. It is domain-specific, it takes into account the functionalities that Vepa needs. By making one member the owner of the sheet, simultaneous versions can be avoided. If editing by several people is required, Excel Online can be used. Although there is still a lack of transparency about the information entered, it is better than having it all in someone's head. Additionally, at least it is known what decisions are being made and where to ask for the information. The most error-prone aspect of the tool is considered the automatically calculation of percentages. However, these are all extra functionalities in terms of wishes, the core functionalities, the musts, are considered less error-prone.

### *11.2.3 Part 03. Verification, validation and implementation*

#### *Validation*

The validation process involved conducting semi-structured interviews in an informal setting. While using a comprehensive questionnaire for validation could have been an alternative, it was deemed less suitable for the employees and unlikely to yield more valuable feedback than the open, conversational approach.

#### *Impact*

Why not proceed the product development process without the tool? After all, things are working as they are now. However, with the tool, there is a more solid start, fewer things overlooked, faster and informed decision-making. At the moment, the company does not feel the need to adapt the calculations and comparisons tab. However, by listening, as a critical friend, to product development consultations, it became clear that many decisions involve trade-offs that can be effectively considered and visualised using these tabs. Visualising these trade-offs for quick consultation is expected to add significant value. Additionally, documentation may become more critical in the future, particularly in light of future regulatory requirements. For example, regulations have already become more stringent in medical device design, requiring more technical documentation. For the furniture industry, demonstrating certain criteria may also become essential. If technical information is documented in a structured manner and the employees are already accustomed to consistent documentation, this is potentially highly useful for the company.

## 11.3 Recommendations

### 11.3.1 Product development

*Courage to change*

First of all, it is not surprising that Vepa needs to change the way of working as in today's commercial world, the only constant is change [59]. Or, as the Greek philosopher Heraclitus already stated, "There is nothing permanent except change". Every individual member of the product development team has confirmed the challenges and sees the benefits of utilising the tool. The recommendation for Vepa is to carry out the implementation plan described in Chapter 10 and thus implement the tool. Since not even a financial investment is required, although an Excel course may be beneficial, there is nothing to lose but time. Understandably, employees will feel resistance to implementing the tool, as change is never comfortable, and it will initially seem like much more documentation is asked from them. However, the author of this report is convinced that this time will be regained already in one product development timeframe and especially in the long run. The research has already proven that it does not take a disproportionate amount of time to use the tool and it is expected that this time will be easily regained by reducing consultation time and mistakes that would otherwise be made. Furthermore, the worst-case scenario is that the tool is ineffective, and the 'prototype' has failed.

*Make explicit*

Even if the tool would not be adopted by the company, still the following recommendations remain. First, make the general requirements more specific and measurable so that it can be known whether they are being met or not, according to the SMART principle. Second, developing and testing a prototype provides a wealth of information. Think in advance about what needs to be tested, whether it is possible to test several questions at once and document the most important findings. In this way, the number of tests, and therefore time and money, can be kept to a minimum. As prototyping plays an important role, a model maker in Hoogeveen, as is already the case in Emmen, might be useful to ensure that prototypes can be made easily.

*Company strategy*

It is up to Vepa which company strategy it wants to follow and which perspectives it values most. While defining a clearer company strategy lies outside the scope of this report, being clear about the perspectives that have the most priority aid in making trade-offs and thus speeds up the decision-making process. A clear company strategy can also ensure the same decisions are made across products. Vepa can benefit from defining a clearer strategy regarding what and when decisions should be made and with what level of certainty and support. By utilising the tool, the process of making informed decisions and refining the company strategy is facilitated, as it captures project data and provides greater clarity about what is actually happening within projects.

### 11.3.2 Tool

*Project information tab*

The first tab, project information, of the tool could be redesigned as a project description tab that summarises the project's goal while emphasising the most frequently completed sections, such as the competitor landscape or critical points.

*Calculations and comparison dashboard*

Much information (about processing steps, material, parts and costs) on past projects of Vepa is available in the ERP system. This database can serve as a great starting point for the information input for the product dashboard for a new similar design. The performance indicators of the tool can always be expanded with the preferred indicators. For instance, the subjects of the NPR1813 described in section 5.4.2 could be incorporated as one of the performance indicators to actively apply them in the design process. However, visualising the five performance indicators of manufacturing costs, manufacturability, weight, design value and quality already provides valuable insights. The dashboard can not only be used to compare different products but also individual parts or assemblies, such as the steel frame of the WireWorks mentioned in section 8.2.

*Adjustments*

Although the tool is designed to be comprehensible, many functions are designed and coded into it. Therefore, adjusting the tool template requires some experience with Excel and Excel functions. It is recommended that one person within the company, e.g. who is most proficient with or interested in learning Excel, is chosen to be responsible for making changes to the tool template. The product manager, who has proven not to be the most proficient with Excel, can adjust the template over time together with this person. The ReadMe file already explains the most important adjustments that are most likely to be made in the future. Since someone has recently been hired to implement Lean inside the company, this could also be the person in question. It would be interesting to discuss this tool with this person and maybe he can assist in implementing this tool. Unfortunately, this cannot be done within the timeframe of this thesis assignment. It is recommended to make one person the main responsible for identifying problems on the work floor and for continuously improving the tool accordingly and implementing it in product development.

*Long-term perspective*

Imagine the tool is used for the following years and in for example ten years Vepa decides to develop a new product. By this time, a significant number of products will have been developed, resulting in many Excel files. By employing a large language model (LLM) such as ChatGPT - currently one of the most well-known models - information from past projects can be easily found. This eliminates the need to manually search in each Excel file, enabling quick and efficient retrieval of relevant data [60]. By providing the LLM with these Excel files, it would be possible for the product developers to ask questions such as "Please summarise all the prototyping outcomes that are about welding of the prototyping tab" or "Please return all the critical points (cell X, row X) from the project information tab concerning the hemp material" or "how many weeks did activity X take in project X, X and X?". Naturally, the Excel file should in this case not contain confidential information. Utilising these possibilities aligns with a forward-looking business strategy that anticipates how the tool can enhance efficiency and support data-driven insightful decision-making in product development over time.

*Software*

If the way of working facilitated by this tool has proven to be something Vepa is looking for and if the Excel tool does not support Vepa's needs anymore, it would be worth considering software solutions that offer similar functionalities while addressing the shortcomings of an Excel tool. For example, if data security, collaboration across multiple departments or regulatory compliance are becoming more critical, investing in Product Lifecycle Management (PLM) software could be a strategic choice. PLM systems such as Autodesk Fusion Lifecycle, probably integrate what Vepa needs and enhance data sharing. However, this software will not be specially tailored to the specific requirements of Vepa and come with higher costs. Additionally, integrating PLM software typically requires a significant training investment and change management. Nonetheless, if Vepa's projects or teams continue to grow, these systems provide a scalable, longer-term solution to support Vepa's evolving needs.

### *11.3.3 Hemp panels*

Although these recommendations are mostly accommodated inside the tool, for the hemp product specifically, some recommendations for the product developers at Vepa are listed below.

If even higher sound absorption is preferred for the wall panels, three layers of pre-preg might be used instead of two. This will only add to the material costs, not to the processing costs since the steps stay similar. Material costs can be saved by using one large pre-preg instead of pre-pregs already made the right size.

The panels must be baked in an oven at 160 degrees for at least two hours. The first prototypes were in the oven for one and a half hours and became "soft" again, the unpressed hemp parts allowed more air to react with the material. The minimum of two hours also ensures that pre-pregs that have already absorbed some moisture, because of being in contact with air, are also fully set in the oven. Longer in the oven is always possible, in that case, the panels become darker. The oven rack must be straight to prevent the panels from curving.

Ceiling panels were also well-perceived and are a promising product to explore further. In the case of ceiling panels, the quality of the edge finishing is of less importance, as it is not visible in the system ceiling. Consequently, if the press die is perfectly aligned with a 600×600mm pre-preg, sawing or milling might not be needed anymore, but only sanding may be sufficient. Ceiling panels must measure 595×595 mm to ensure proper installation in the system ceiling.

The manufacturing method of the panel allows for many patterns to be made. For a new wall panel design line, for example, the figures of the Chladni patterns could be used. First of all, most of them can be laser cut, and secondly, it is a subtle reference to sound and nature. Additionally, the pattern of the same frequency octaves is also seamless.

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# Appendix

# A. Nieberding framework

| **Factors influencing the product development life cycle** | | **Values for the various factors for Vepa** |
|---|---|---|
| Organisational Factors | organisational size | medium – 150 employees |
| | organisational structure | Medium, 2 locations<br>Growing from a flat management structure to a more structured management system |
| | organisational type | |
| | purpose | Design and development with series production facilities |
| | production size | Large batches > 20 |
| | stock philosophy | Make-to-order (sometimes engineer-to-order) |
| | selling mechanism | Competing through a tender system |
| | organisational Maturity | Level 2 (documentation & tools individually implemented) |
| | available Design Capacity | depends on project |
| Project factors | project size | Small: 5,000-50,000 man hours |
| | project Complexity | |
| | complicacy | low |
| | dynamics | low |
| | opacity | low |
| | interdependency | low |
| | Multiple objectives | low |
| | project type | Original design/variant design |
| | project constraints | Time, costs, eco-impact |
| | project level of novelty | Low-to-medium to high level of innovation |
| Product factors | product type | Batch production |
| | product complexity | |
| | complicacy | assembly |
| | opacity | low |
| | interdependency | medium |
| | multiple objectives | medium |
| | system hierarchy | Sub-system |
| Personnel factors | team size | Small: 4-20 |
| | level of maturity | Low-high |
| | level of design capability | medium |


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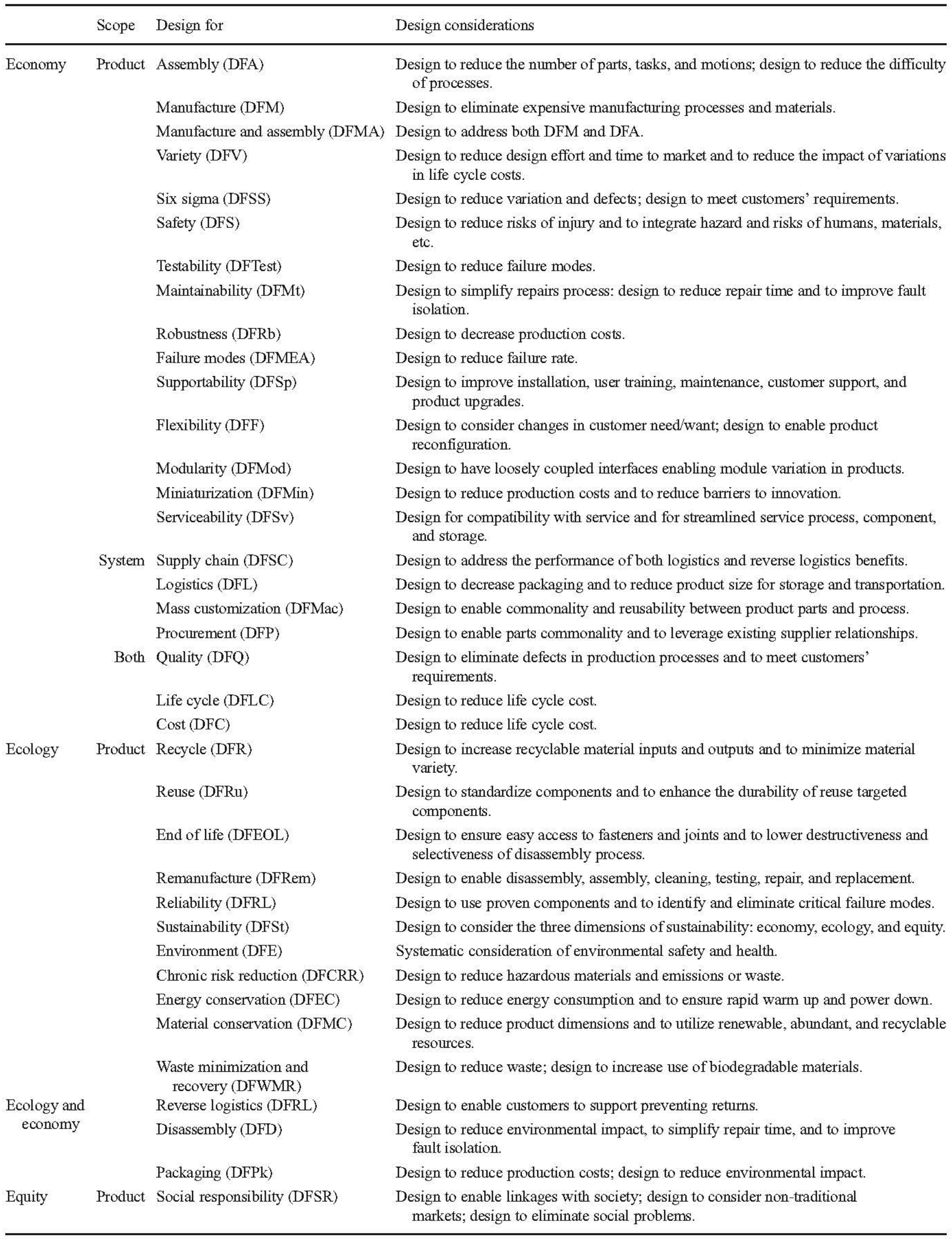
# B. DfX methods



| | Scope | Design for | Design considerations |
|---|---|---|---|
| Economy | Product | Assembly (DFA) | Design to reduce the number of parts, tasks, and motions; design to reduce the difficulty of processes. |
| | | Manufacture (DFM) | Design to eliminate expensive manufacturing processes and materials. |
| | | Manufacture and assembly (DFMA) | Design to address both DFM and DFA. |
| | | Variety (DFV) | Design to reduce design effort and time to market and to reduce the impact of variations in life cycle costs. |
| | | Six sigma (DFSS) | Design to reduce variation and defects; design to meet customers' requirements. |
| | | Safety (DFS) | Design to reduce risks of injury and to integrate hazard and risks of humans, materials, etc. |
| | | Testability (DFTest) | Design to reduce failure modes. |
| | | Maintainability (DFMt) | Design to simplify repairs process: design to reduce repair time and to improve fault isolation. |
| | | Robustness (DFRb) | Design to decrease production costs. |
| | | Failure modes (DFMEA) | Design to reduce failure rate. |
| | | Supportability (DFSp) | Design to improve installation, user training, maintenance, customer support, and product upgrades. |
| | | Flexibility (DFF) | Design to consider changes in customer need/want; design to enable product reconfiguration. |
| | | Modularity (DFMod) | Design to have loosely coupled interfaces enabling module variation in products. |
| | | Miniaturization (DFMin) | Design to reduce production costs and to reduce barriers to innovation. |
| | | Serviceability (DFSv) | Design for compatibility with service and for streamlined service process, component, and storage. |
| | System | Supply chain (DFSC) | Design to address the performance of both logistics and reverse logistics benefits. |
| | | Logistics (DFL) | Design to decrease packaging and to reduce product size for storage and transportation. |
| | | Mass customization (DFMac) | Design to enable commonality and reusability between product parts and process. |
| | | Procurement (DFP) | Design to enable parts commonality and to leverage existing supplier relationships. |
| | Both | Quality (DFQ) | Design to eliminate defects in production processes and to meet customers' requirements. |
| | | Life cycle (DFLC) | Design to reduce life cycle cost. |
| | | Cost (DFC) | Design to reduce life cycle cost. |
| Ecology | Product | Recycle (DFR) | Design to increase recyclable material inputs and outputs and to minimize material variety. |
| | | Reuse (DFRu) | Design to standardize components and to enhance the durability of reuse targeted components. |
| | | End of life (DFEOL) | Design to ensure easy access to fasteners and joints and to lower destructiveness and selectiveness of disassembly process. |
| | | Remanufacture (DFRem) | Design to enable disassembly, assembly, cleaning, testing, repair, and replacement. |
| | | Reliability (DFRL) | Design to use proven components and to identify and eliminate critical failure modes. |
| | | Sustainability (DFSt) | Design to consider the three dimensions of sustainability: economy, ecology, and equity. |
| | | Environment (DFE) | Systematic consideration of environmental safety and health. |
| | | Chronic risk reduction (DFCRR) | Design to reduce hazardous materials and emissions or waste. |
| | | Energy conservation (DFEC) | Design to reduce energy consumption and to ensure rapid warm up and power down. |
| | | Material conservation (DFMC) | Design to reduce product dimensions and to utilize renewable, abundant, and recyclable resources. |
| | | Waste minimization and recovery (DFWMR) | Design to reduce waste; design to increase use of biodegradable materials. |
| Ecology and economy | | Reverse logistics (DFRL) | Design to enable customers to support preventing returns. |
| | | Disassembly (DFD) | Design to reduce environmental impact, to simplify repair time, and to improve fault isolation. |
| | | Packaging (DFPk) | Design to reduce production costs; design to reduce environmental impact. |
| Equity | Product | Social responsibility (DFSR) | Design to enable linkages with society; design to consider non-traditional markets; design to eliminate social problems. |

# C. Extended framework of Hemp Chair

## *C.1. Material*

*What is it?*

The hemp composite consists of hemp fibres and a bio-resin. The hemp fibres come from Hempflax and are created into a uniform fibre web via needling by Polyvlies. Then, the uniform fibre web is pre-impregnated with a bio-resin developed by Plantics. It is a thermoset bio-resin. Thermoset means the polymer becomes irreversibly hardened once it is cured. Once hardened, it cannot be re-melted. The pre-impregnated fibre web is referred to as pre-preg. Curing takes time and is started by heat. Both the resin and hemp fibres are 100% biological.

*How is it made?*

1. Hemp fibres are extracted from the stalk of the plant by Hempflax.
2. These fibres are delivered to Polyvlies.
3. Homogeneous mixture of hemp fibres becomes a uniform fibre web via needling.
4. This results in a uniform dry fibre web of chopped hemp fibres.
5. This dry mat is delivered to Plantics by Polyvlies.
6. Plantics impregnates the mat with its bio-resin with extra water so that resin is distributed everywhere throughout the mat. The mat is rolled so the resin gets well distributed and excess resin is pressed out.
7. The mat is heated so that all the excess water comes out of the mat (this would cause steam in the hot press later)
8. These pre-pregs, consisting of 50% fibre and 50% resin, are transported to Vepa in an airtight container (to prevent water from entering the mat).

*Critical points?*

- Inconsistency of hemp fibres (also depending on supplier) resulting in strength or colour inconsistency
- Resin should be well absorbed
- One side of pre-preg contains a mesh because of the impregnation process

*Open variables?*

- Colouring possible in the impregnation process
- Different mixes of the resin → resin viscosity
- Different ratios of resin and hemp fibres → more fibres lead to dry composite after curing. Too much resin leads to foaming of the mats once cured.

*Waste*

Only biological waste, cutting edges should remain as small as possible.

*Mechanical properties*
Bio-resin is water-resistant and not flammable. Hemp fibres are flammable. The impregnated hemp mat, pre-preg, is a semi-finished product and will not come in products like this. It should be kept dry, otherwise mat will take up air and become viscous again.

*Physical properties*
Pre-impregnated hemp mats are sticky and flexible.

*Costs*
One hemp mat costs around 13 euros for Vepa. Costs mainly derived from man hours for the impregnating process and cutting in the right shape.

*Energy*
Plants take up $CO_2$ while growing. Harvesting happens once a year. Hemp can grow up to 10 centimetres per day. One square meter of harvested hemp is around 200 grams of fibres. For a 1 $m^2$ non-woven mat of 8 mm thickness 1 kg of fibres is needed, which resembles 400 plants, around 5 square meters of cultivation.

*Dispose*
Fully biological degradable.

*Benchmarking*

The pre-impregnated hemp mats are flexible and can be shaped and put in an oven. When heated, they will retain their shape. This is not seen with other materials.

*(Un)explored opportunities*

- Hemp fibre web thickness (from supplier)
- Colouring after impregnation and before heating
- Different impregnation process so fibres are not completely impregnated by resin leading to less brittleness after curing.

## C.2. Process

*Processes available*
To shape the hemp mats, a hot press mould is used. To cure the hemp mats, an oven is used. For finishing, milling, sanding and drilling can be used, comparable to wood. The material can be coated with linseed oil. Vepa currently investing in cutting machines.

*How is it made?*
1. The mat is pre-heated to make it more flexible before entering the mould.
2. The mat is placed in a hot press mould with the desired shape. Multiple mats can be deposited in the press mould.
3. The press mould is put under pressure of around 100 tons for around 7 minutes at 145 degrees. One dry fibre web mat is pressed to a thickness of 2 mm.
4. The press moulded material is now cooled (with shape support) so that it is not formable before it is placed in the oven.
5. The material is baked off in the oven at around 160 degrees to harden it.
6. The material cools down.
7. The sides are milled by a robot.
8. Sharp edges are being sanded by hand.
9. The material is coated in linseed oil.
10. Drilling holes and joints can now be made, and the product can be assembled.

*Critical points*
- Testing in the lab on a small scale may go well, however on a larger scale still problems may arise (because of the magnification of problems)
- Mat should be preheated, otherwise it will shred.
- Mould is coated with a nonstick coating (in this case Teflon), otherwise it will stick.
- Mould too hot, hemp will burn
- Mould too cold, no homogeneous surface
- Too much resin or water leads to foaming in oven
- Too steep angles in mould → excess material

*Open variables/ Process influence on properties*
- Temperature of oven influences mechanical properties and colour
    - Longer in oven → more hardened, darker, more water resistant
- Less pressure in mould: density will get lower, influences mechanical properties
    - Less pressure → lower density → better acoustical properties
- Shape in mould → imprint, imprint for aesthetically pleasing functioning

*Waste & disposal*
- Sides are cut off but can be shredded and re-used. However, this may take more energy than decomposing in the ground and growing new resources.
- Mould includes layer of Teflon which can release toxic fumes when heated.

*Global shapes/restrictions*
- Mould → Form freedom
- When using a mould, no undercuts, shape should have ability to come out of the mould.
- Mould max 2.30 x1.15 meter
- Organic shapes, draft angles needed, imprint, repetitive shapes/units (because one mould)

*Mechanical properties*
Material is strong but has relatively low impact strength. Further information can be found on data sheet of mechanical properties of hemp composite with density of 1.1 of Plantics.

*Physical properties/user experience*
Brownish colour, evokes natural feeling because of natural materials.

*(Un)explored opportunities for processing*

- Include surface texture in mould
- Colouring in the mould
- Colouring after hot pressing
- Less pressure in mould and test mechanical properties
- Shaping the pre-preg without using a mould, would eliminate processing steps
- Cutting with mould → but probably get blunt edge soon
- Punching → too expensive
- Pressing hemp as a top layer on different materials (like chipboard)
- Bending tests, see what is the max
- Stays watertight if not sanded

*Costs*
High investments for new mould shape, at least ten thousand euros.

*Energy*
Retrieve from LCA.

*Benchmarking*
The hemp composite can both function as structural purpose and aesthetic purpose. The process is labour intensive in comparison to other materials.

## C.3. Market

*End user*
Vepa's end users are people in offices, schools and hospitals.

*Needs*
The market did not request such a chair, since they did not even know this was possible, but rather Vepa created a market need with this design. The design is appealing to customers who want to show off that they care about the environment.

*Trends*
Working from home is becoming more and more frequent.

Offices become more and more a place to meet and with a more homelike atmosphere. Increasing interest in sustainable products.

*Requests*
More colours of hemp → more product variations

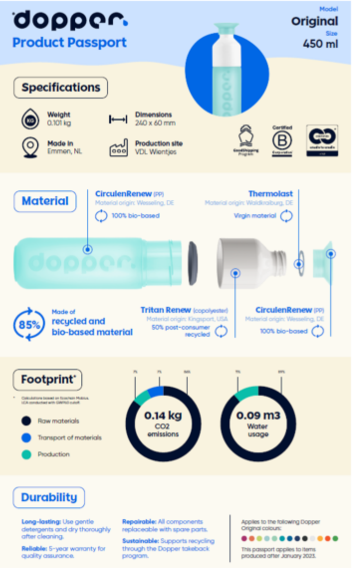
*Competitor landscape*
Numerous four-legged tub chairs exist but there are no fully biological tubs sold in the Netherlands.

## C.4. Company, function and shape

These were not further elaborated as this would not have added value to the development of the case study.

# D. Product sheets

Dopper product passport:



dopper
Product Passport

Model: Original
Size: 450 ml

**Specifications**

Weight: 0.101 kg
Dimensions: 240 x 60 mm
Made in: Emmen, NL
Production site: VDL Wientjes

**Material**

CirculenRenew (PP) – Material origin: Wesseling, DE – 100% bio-based
Thermolast – Material origin: Waldkraiburg, DE – Virgin material
Made of 85% recycled and bio-based material
Tritan Renew (copolyester) – Material origin: Kingsport, USA – 50% post-consumer recycled
CirculenRenew (PP) – Material origin: Wesseling, DE – 100% bio-based

**Footprint***

0.14 kg CO2 emissions
0.09 m3 Water usage

- Raw materials
- Transport of materials
- Production

**Durability**

**Long-lasting:** Use gentle detergents and dry thoroughly after cleaning.

**Reliable:** 5-year warranty for quality assurance.

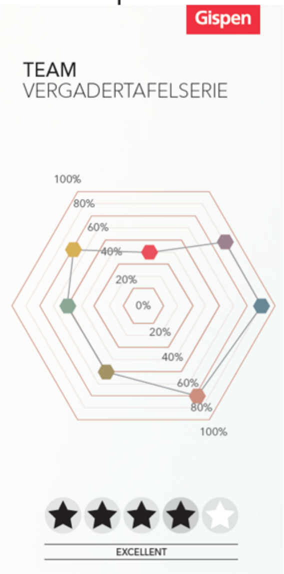
**Repairable:** All components replaceable with spare parts.

**Sustainable:** Supports recycling through the Dopper takeback program.

Applies to the following Dopper Original colours:

This passport applies to items produced after January 2023.

Gispen CE-Label:



Gispen sustainability sheet:

GISPEN UT
PRODUCT SUSTAINABILITY SHEET

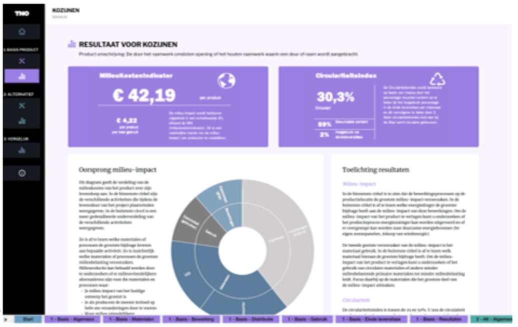
**Duurzame feiten**

**Levensduurverlenging, hergebruik en recycling**

**Productie en verpakking**

SPECIFICATIES
Gewicht: 24,58 KG
73,95% gerecyclede materialen in dit product
93,16% van dit product is recyclebaar
37,94% snel hernieuwbare grondstoffen

TNO Circularity self-assessment tool:



KOZIJNEN

RESULTAAT VOOR KOZIJNEN

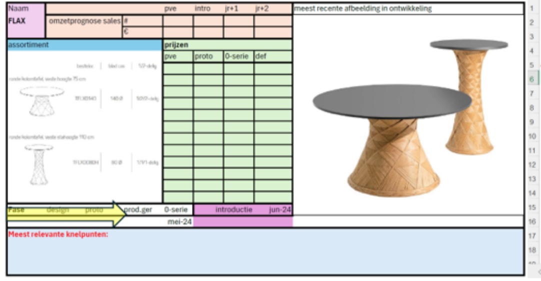
MilieuKostenIndicator: € 42,19 per product
€ 4,22 per product per jaar gebruik

CirculariteitsIndex: 30,3% Circulair
59%
2%

Oorsprong milieu-impact

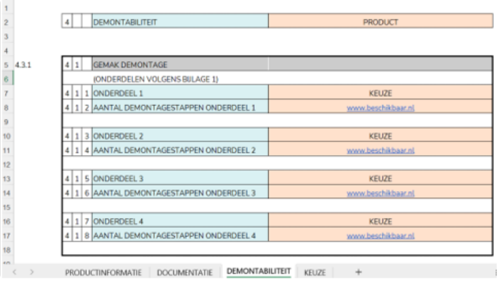
Toelichting resultaten

Vepa product sheet:



Naam: FLAX
omzetprognose sales: # / € – pve | intro | jr+1 | jr+2
meest recente afbeelding in ontwikkeling
assortiment
prijzen: pve | proto | 0-serie | def
Fase: design – proto – prod.ger – 0-serie (mei-24) – introductie (jun-24)
Meest relevante knelpunten:

Vepa NPR:



| | | | | | |
|---|---|---|---|---|---|
| | 4 | | | DEMONTABILITEIT | PRODUCT |
| 4.3.1 | 4 | 1 | | GEMAK DEMONTAGE | |
| | | | | (ONDERDELEN VOLGENS BIJLAGE 1) | |
| | 4 | 1 | 1 | ONDERDEEL 1 | KEUZE |
| | 4 | 1 | 2 | AANTAL DEMONTAGESTAPPEN ONDERDEEL 1 | www.beschikbaar.nl |
| | 4 | 1 | 3 | ONDERDEEL 2 | KEUZE |
| | 4 | 1 | 4 | AANTAL DEMONTAGESTAPPEN ONDERDEEL 2 | www.beschikbaar.nl |
| | 4 | 1 | 5 | ONDERDEEL 3 | KEUZE |
| | 4 | 1 | 6 | AANTAL DEMONTAGESTAPPEN ONDERDEEL 3 | www.beschikbaar.nl |
| | 4 | 1 | 7 | ONDERDEEL 4 | KEUZE |
| | 4 | 1 | 8 | AANTAL DEMONTAGESTAPPEN ONDERDEEL 4 | www.beschikbaar.nl |

# E. Example Vepa's requirements

## E.1. Dutch

**Doel algemeen:** waarom een nieuw product? vergroten van de lockeromzet in de kantooromgeving. Algemeen is het product altijd minimaal op 1 argument beter dan een vergelijkbaar product, en op geen enkel punt slechter. Het product vervult een duidelijke behoefte in de markt waarin Vepa zijn producten aanbiedt.

**Esthetisch:** Vormgeving is gericht op een brede toepassing bij een brede doelgroep. Geen echt niche product, maar mag wel uitgesproken zijn. =Het product is niet sterk trend gevoelig. 'Tijdloos' is het doel.

**Materialen:** Uitgangspunt is duurzame materialen en daarvan zo min mogelijk. Materialen zijn in bij voorkeur gerecycled, recyclebaar, niet uitputtend en komen 'uit de omgeving' en daarmee bedoelen we bij voorkeur Nederland/omringende landen/West Europa.

**Normeringen:** Product mag op geen enkele wijze schade veroorzaken aan mens of dier. Moet voldoen aan gehanteerde normeringen (NEN-ISO-TÜV).

**Montage:** Met alledaags gereedschap te monteren, repareren en de-monteren.

**Prijsstelling:** Betere of gelijkwaardige prijsstelling tov soortgelijke producten.

**Constructie:** Eenvoudige constructie waarbij rekening wordt gehouden met 'after life'. Designed to disassemble. Tevens biedt het product de mogelijkheid om tussentijds te kunnen onderhouden. 'design to maintain' Slimme constructies in materiaal eigen oplossingen. Modulariteit is belangrijk om met zo min mogelijk onderdelen een zo groot mogelijke variëteit te kunnen maken waarbij de kwaliteit gewaarborgd blijft. Constructie is stabiel en geschikt voor de beoogde toepassingen gedurende de volledige levensduur van het product. Geen permanente bevestiging van verschillende soorten materialen t.o.v. elkaar. (verlijmen/lamineren)

**Transport:** Een minimum aan verpakkingsmiddelen. Verpakking herbruikbaar. Klein transportvolume. Onderdelen moeten passen in liften, door deuren en onder plafonds.

**Aantallen:** Inschatting van het aantal producten per jaar op basis van ontwerp en producttype/groep.

**Investeringen:** de grootte van investeringen moeten in verhouding staan met de beoogde aantallen.

**Levensduur:** de technische levensduur is langer dan de economische levensduur. De levensduur van dit product wordt gewaarborgd d.m.v. een garantieperiode.

**Productie:** Het merendeel van het product moet worden vervaardigd door gebruik te maken van bestaande productie middelen van Vepa of FFG bedrijven. Gewichten en afmetingen zijn 'hanteerbaar' en voldoen aan de geldende Arbo normeringen.

**Assemblage:** eenvoudig en snel. Loonkosten per product tot een minimum beperken.

## E.2. Translated to English

**General purpose:** why a new product? increase locker turnover in the office environment. Overall, the product is always better than a comparable product in at least 1 argument, and no worse in any respect. The product fulfils a clear need in the market in which Vepa offers its products.

**Aesthetic:** Design is aimed at a broad application with a broad target group. Not a real niche product, but may be distinct. =The product is not strongly trend-sensitive. 'Timeless' is the goal.

**Materials:** Starting point is sustainable materials and as little of them as possible. Materials are in preferably recycled, recyclable, non-depleting and come 'from the environment' and by this we preferably mean the Netherlands/ surrounding countries/ Western Europe.

**Standards:** Product must not cause harm to humans or animals in any way. Must comply with applicable standards (NEN-ISO-TÜV).

**Assembly:** Can be assembled, repaired and disassembled with everyday tools.

**Construction:** Simple construction taking into account 'after life'. Designed to disassemble. The product also offers the possibility of interim maintenance. Design to maintain' Smart constructions in material-specific solutions. Modularity is important in order to be able to make the widest possible variety with as few parts as possible while guaranteeing quality. Construction is stable and suitable for the intended applications throughout the product's lifetime. No permanent attachment of different types of materials to each other (gluing/laminating).

**Transport:** A minimum of packaging. Packaging reusable. Small transport volume. Parts must fit in lifts, through doors and under ceilings.

**Amount:** Estimate number of products per year based on design and product type/ group.

**Investments:** the size of investments should be proportional to the targeted numbers.

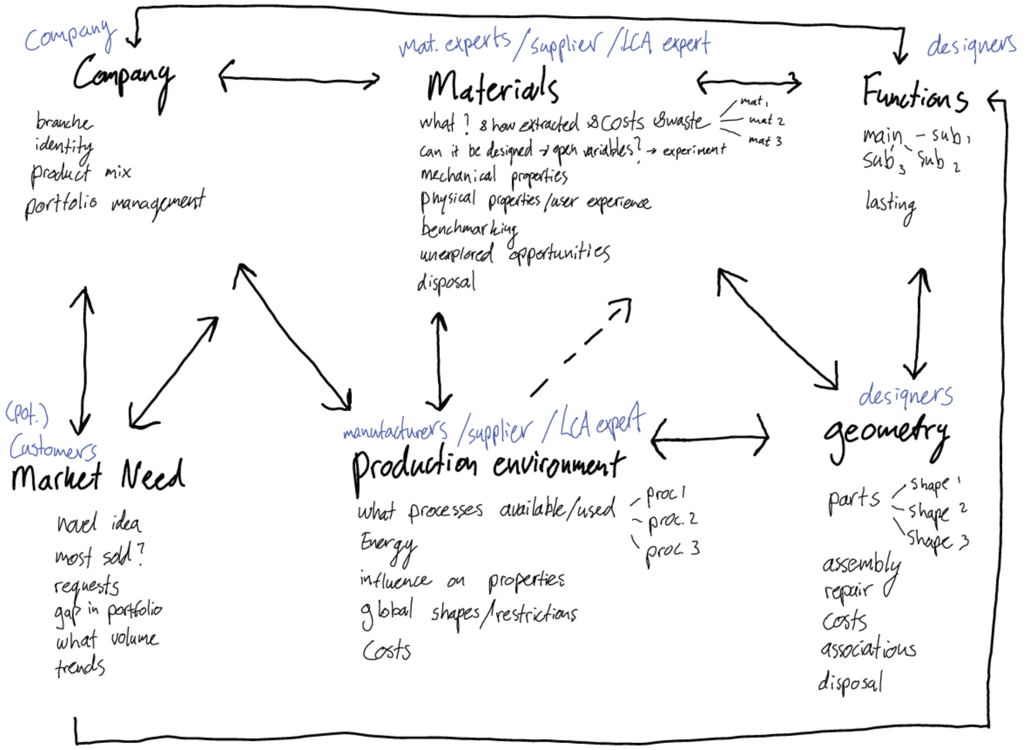
**Lifetime:** technical lifetime is longer than economic lifetime. The lifetime of this product is guaranteed through a warranty period.

**Production:** Most of the product must be manufactured using existing production resources of Vepa or FFG companies. Weights and dimensions are 'manageable' and comply with current working conditions standards.

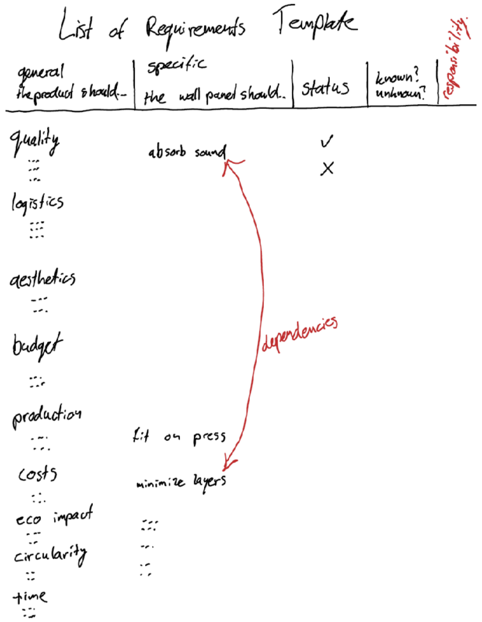
**Assembly:** simple and fast. Keep labour costs per product to a minimum.

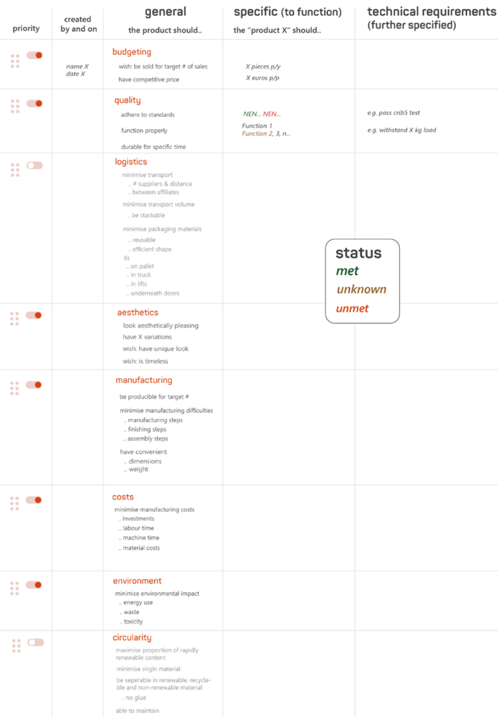
# F. Tool ideation

## F.1. Framework



# F.2. Requirements

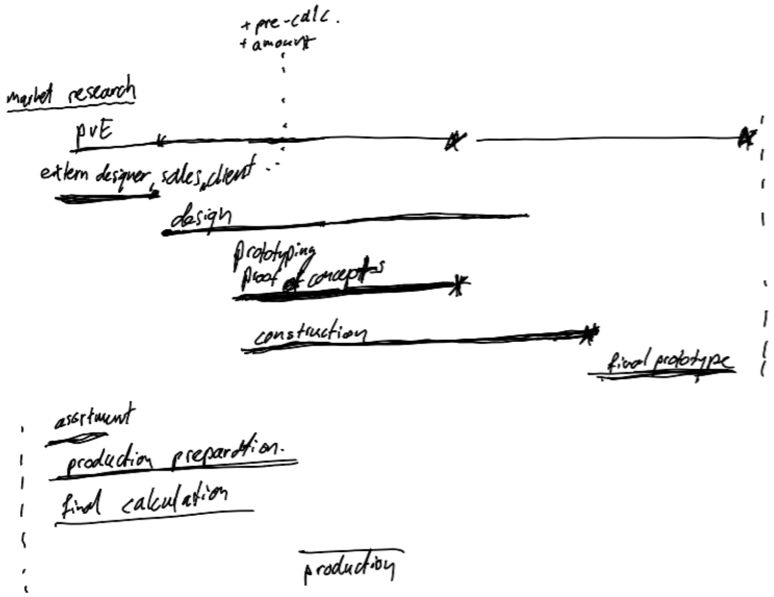


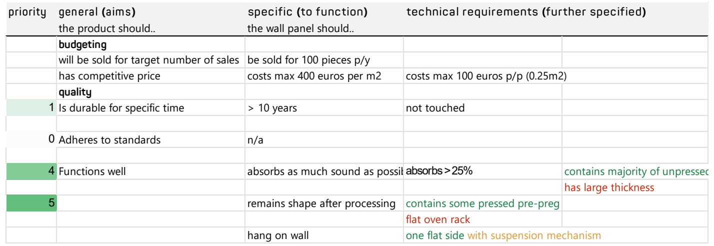


| priority | created by and on | general<br>the product should.. | specific (to function)<br>the "product X" should.. | technical requirements (further specified) |
|---|---|---|---|---|
| ● | name X<br>date X | budgeting<br>wish: be sold for target # of sales<br>have competitive price | X pieces p/y<br>X euros p/p | |
| ● | | quality<br>adhere to standards<br>function properly<br>durable for specific time | NEN... NEN...<br>Function 1<br>Function 2, 3, n... | e.g. pass crib5 test<br>e.g. withstand X kg load |
| ○ | | logistics<br>minimise transport<br>.. # suppliers & distance<br>.. between affiliates<br>minimise transport volume<br>.. be stackable<br>minimise packaging materials<br>.. reusable<br>.. efficient shape<br>fit<br>.. on pallet<br>.. in truck<br>.. in lifts<br>.. underneath doors | | |
| ● | | aesthetics<br>look aesthetically pleasing<br>have X variations<br>wish: have unique look<br>wish: is timeless | | |
| ● | | manufacturing<br>be producible for target #<br>minimise manufacturing difficulties<br>.. manufacturing steps<br>.. finishing steps<br>.. assembly steps<br>have convenient<br>.. dimensions<br>.. weight | | |
| ● | | costs<br>minimise manufacturing costs<br>.. investments<br>.. labour time<br>.. machine time<br>.. material costs | | |
| ● | | environment<br>minimise environmental impact<br>.. energy use<br>.. waste<br>.. toxicity | | |
| ○ | | circularity<br>maximise proportion of rapidly renewable content<br>minimise virgin material<br>be seperable in renewable, recyclable and non-renewable material<br>.. no glue<br>able to maintain | | |

status
met
unknown
unmet

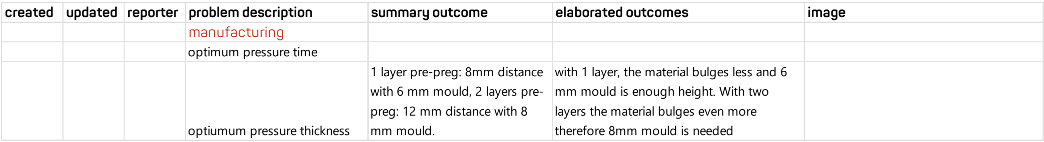
# F.3. Planning





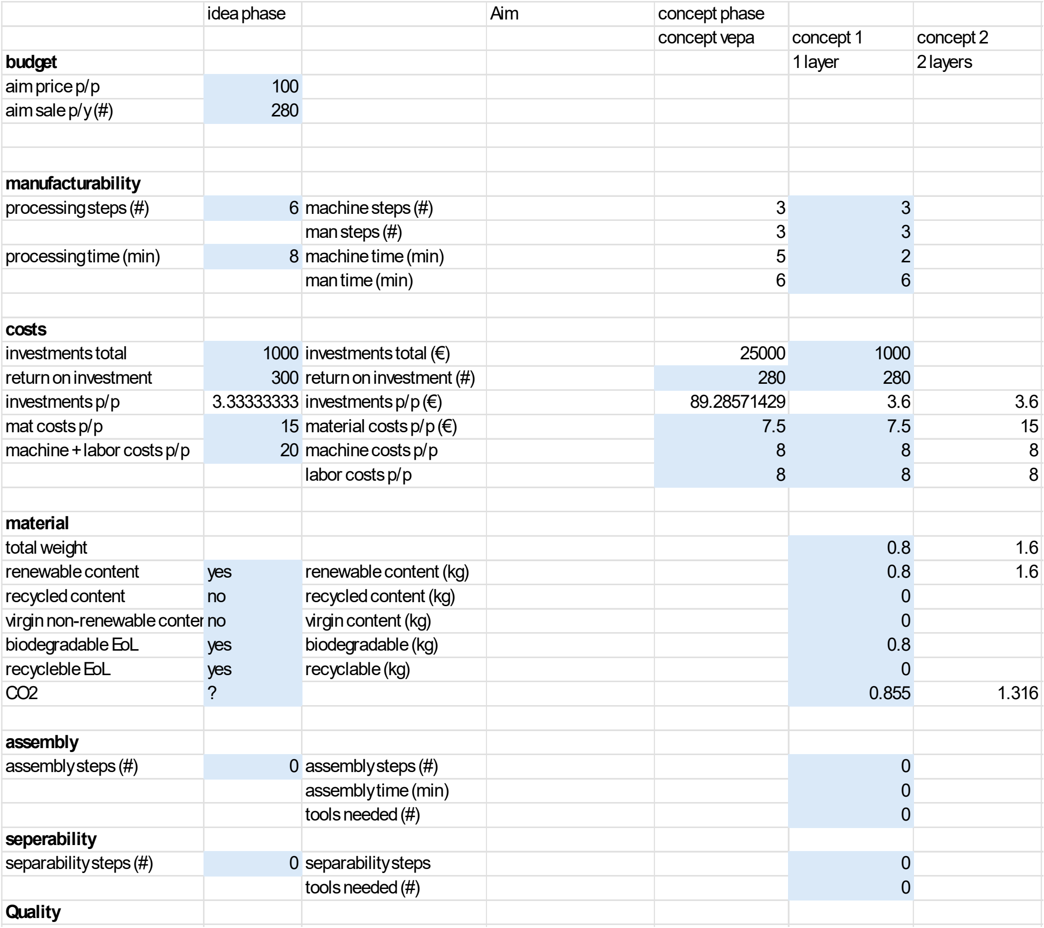
| priority | general (aims)<br>the product should.. | specific (to function)<br>the wall panel should.. | technical requirements (further specified) | |
|---|---|---|---|---|
| | **budgeting** | | | |
| | will be sold for target number of sales | be sold for 100 pieces p/y | | |
| | has competitive price | costs max 400 euros per m2 | costs max 100 euros p/p (0.25m2) | |
| | **quality** | | | |
| 1 | Is durable for specific time | > 10 years | not touched | |
| | | | | |
| 0 | Adheres to standards | n/a | | |
| | | | | |
| 4 | Functions well | absorbs as much sound as possil | absorbs > 25% | contains majority of unpressec |
| | | | | has large thickness |
| 5 | | remains shape after processing | contains some pressed pre-preg | |
| | | | flat oven rack | |
| | | hang on wall | one flat side with suspension mechanism | |

# F.4. Prototyping



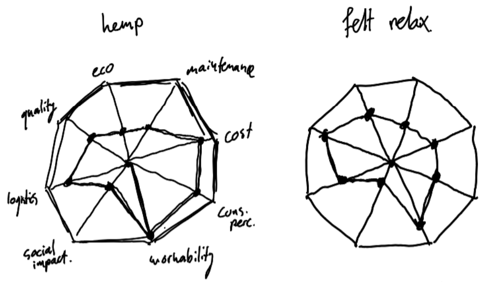
| created | updated | reporter | problem description | summary outcome | elaborated outcomes | image |
|---|---|---|---|---|---|---|
| | | | manufacturing | | | |
| | | | optimum pressure time | | | |
| | | | optiumum pressure thickness | 1 layer pre-preg: 8mm distance with 6 mm mould, 2 layers pre-preg: 12 mm distance with 8 mm mould. | with 1 layer, the material bulges less and 6 mm mould is enough height. With two layers the material bulges even more therefore 8mm mould is needed | |

# F.5. Calculations



| | idea phase | | Aim | concept phase | | |
|---|---|---|---|---|---|---|
| | | | | concept vepa | concept 1 | concept 2 |
| **budget** | | | | | 1 layer | 2 layers |
| aim price p/p | 100 | | | | | |
| aim sale p/y (#) | 280 | | | | | |
| | | | | | | |
| | | | | | | |
| **manufacturability** | | | | | | |
| processing steps (#) | 6 | machine steps (#) | | 3 | 3 | |
| | | man steps (#) | | 3 | 3 | |
| processing time (min) | 8 | machine time (min) | | 5 | 2 | |
| | | man time (min) | | 6 | 6 | |
| | | | | | | |
| **costs** | | | | | | |
| investments total | 1000 | investments total (€) | | 25000 | 1000 | |
| return on investment | 300 | return on investment (#) | | 280 | 280 | |
| investments p/p | 3.33333333 | investments p/p (€) | | 89.28571429 | 3.6 | 3.6 |
| mat costs p/p | 15 | material costs p/p (€) | | 7.5 | 7.5 | 15 |
| machine + labor costs p/p | 20 | machine costs p/p | | 8 | 8 | 8 |
| | | labor costs p/p | | 8 | 8 | 8 |
| | | | | | | |
| **material** | | | | | | |
| total weight | | | | | 0.8 | 1.6 |
| renewable content | yes | renewable content (kg) | | | 0.8 | 1.6 |
| recycled content | no | recycled content (kg) | | | 0 | |
| virgin non-renewable conter | no | virgin content (kg) | | | 0 | |
| biodegradable EoL | yes | biodegradable (kg) | | | 0.8 | |
| recycleble EoL | yes | recyclable (kg) | | | 0 | |
| CO2 | ? | | | | 0.855 | 1.316 |
| | | | | | | |
| **assembly** | | | | | | |
| assembly steps (#) | 0 | assembly steps (#) | | | 0 | |
| | | assembly time (min) | | | 0 | |
| | | tools needed (#) | | | 0 | |
| **seperability** | | | | | | |
| separability steps (#) | 0 | separability steps | | | 0 | |
| | | tools needed (#) | | | 0 | |
| **Quality** | | | | | | |

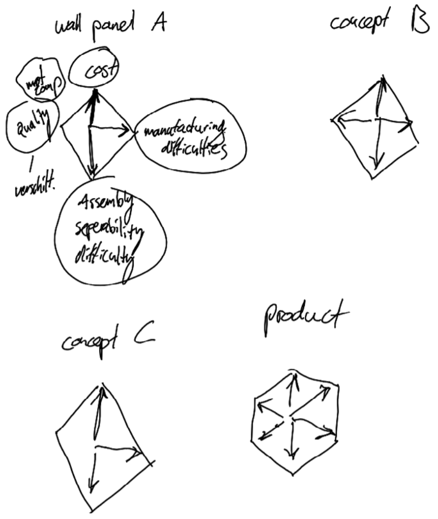
## F.6. Comparison



eco impact → LCA

logistics : transport costs
number of suppliers

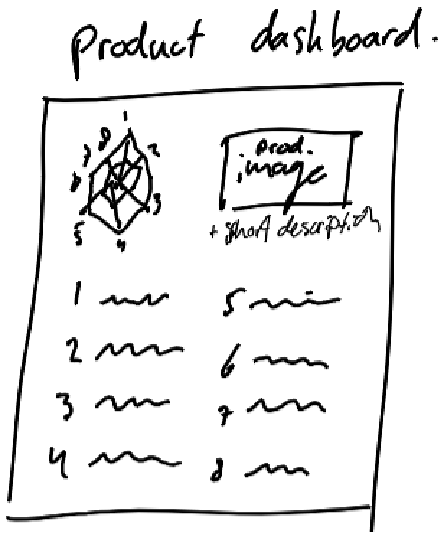
cost → % of sell price.

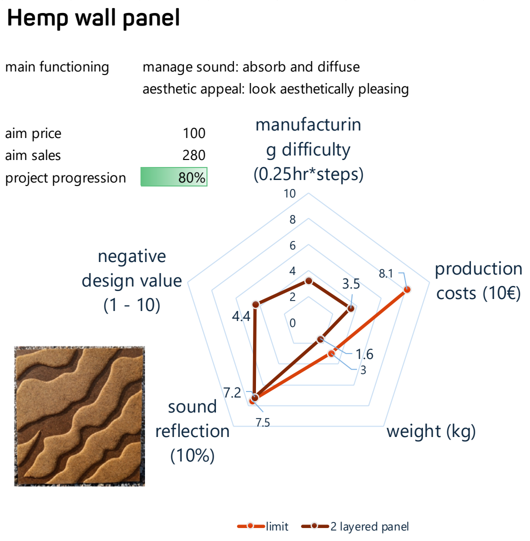


## comparison dashboard

**summmary**
Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tinci-

## F.7. Summary





**Hemp wall panel**

| | |
|---|---|
| main functioning | manage sound: absorb and diffuse<br>aesthetic appeal: look aesthetically pleasing |

| | |
|---|---|
| aim price | 100 |
| aim sales | 280 |
| project progression | 80% |

# G. material samples

The following material samples are being developed at Plantics in Arnhem. A layer refers to one layer of pre-preg. The distance between the top and bottom plate of the press is determined with aluminium spacers of that thickness.

*Varying densities*
- 1 layer to 7 mm
- 2 layers to 7 mm
- 3 layers to 7 mm
- 2 layers pressed to 4 mm +
  1 layer added and pressed to 8 mm
- Top layer of hemp pressed on chipboard

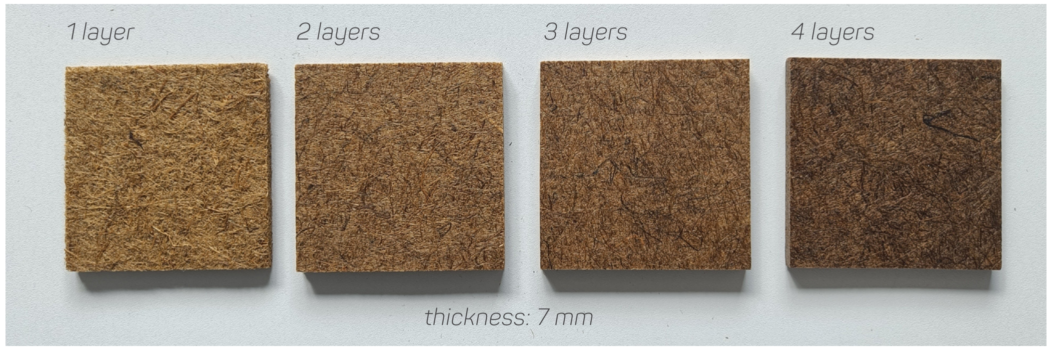
***hot press at Plantics***

*Varying thicknesses*
- 1 layer 2 mm
- 2 layers 4 mm
- 3 layers 6 mm
- 4 layers 8 mm
- 5 layers 10 mm

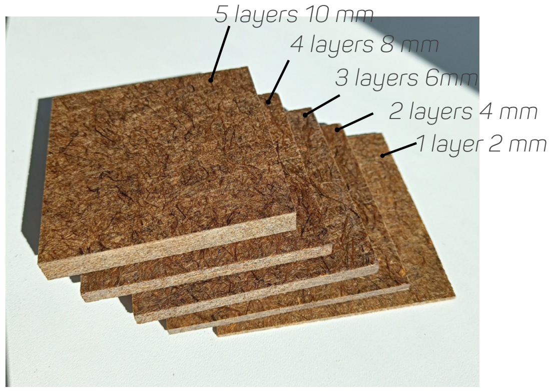
*Varying surface finishings*
- Black with carbon powder after impregnation, before pressing.
- Red with Rubio coating, after curing
- Woven pattern with woven flax fabric
- Pattern by pressing with a negative pattern (of 5 mm thickness) in the mould
    - 1 layer to 8 mm, with and without carbon powder
    - 2 layers to 10 mm

*3d and 2d shapes*
- Chair shape with a press mould and one layer of flax fabric
- Round shape without press mould
- Angular shape without press mould

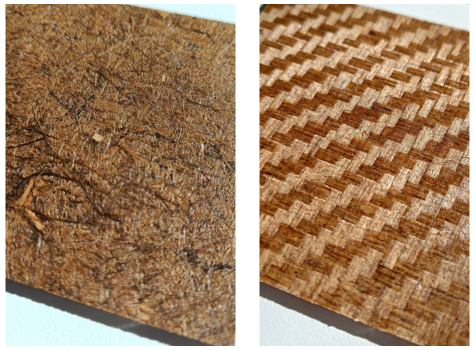
*Multiple layers*
- Partially pressing the layers onto each other
- Partially locating extra pre-preg but pressing to the same thickness



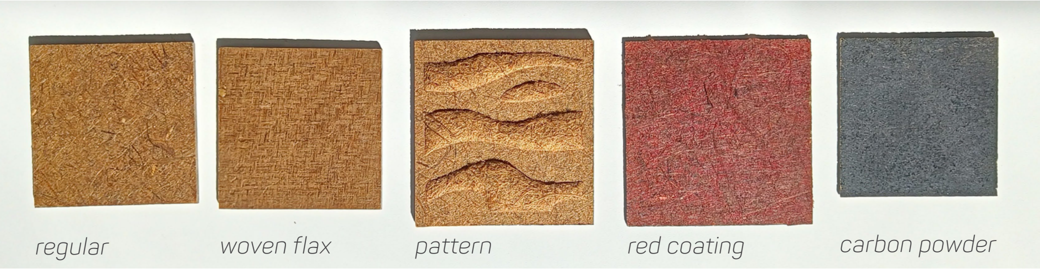
**varying densities**



**varying thicknesses**

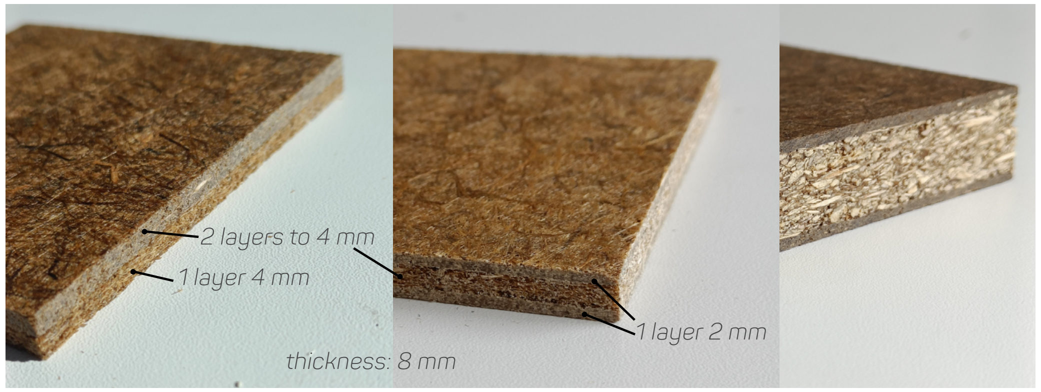

regular
woven flax

**close up**



**varying surface finishes**

**patterned**



**different density layers**

## G.1. 3d shaped

**angled and curved**

**by only putting mass on pre-preg during baking**

**incised, caved-in and twisted**

**seat with one layer of flax**

**mold of seat**

## G.2. multiple layers

*partially pressed layer on hard pressed layer*

*Tabel idea: hard pressed top layer with partially pressed bottom layer. Also one sample was tested with pressing screwthread.*

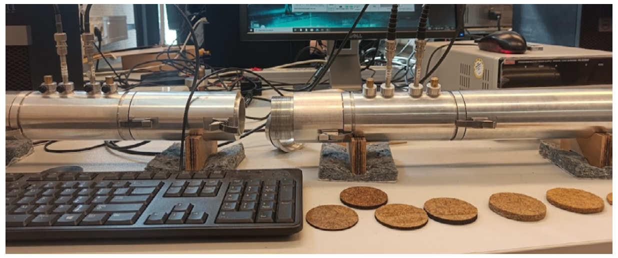
*partially more material located*

*Tabel idea: hard pressed top layer with partially more material located.*

# H. Acoustic measurements

## H.1. Theory

Sound absorbing behaviour is often described by the absorption coefficient (α), defined by: α = 1 - r, with (r) the reflection coefficient. It represents the portion of incident energy absorbed (not reflected) by the material. An absorption coefficient of 1.0 means that sound waves are completely absorbed and an absorption coefficient of 0.0 means that waves are completely reflected. The absorption and coefficient of a material can be measured in a so-called impedance tube with a small sample of the material.



## H.2. Absorption

The following samples have been measured for the absorption of the material at the University of Twente. Pressed refers to a higher-density material sample and unpressed to a lower-density sample.

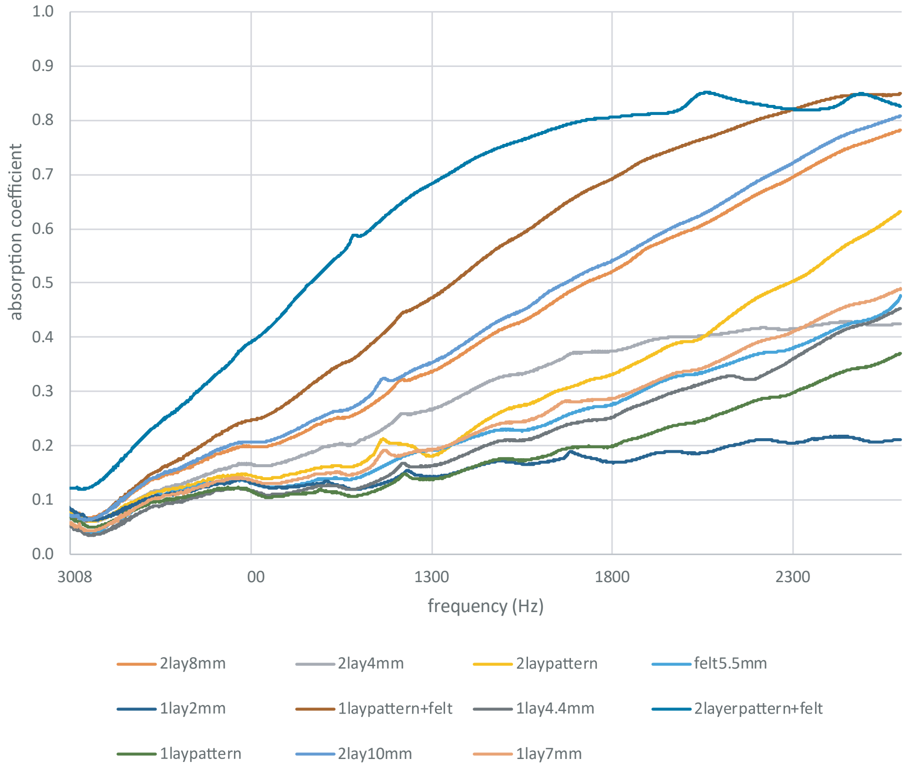
- 1 layer ‘pressed’: 1 layer 2 mm
- 1 layer ‘medium pressed’: 1 layer 4.4 mm
- 1 layer ‘unpressed’: 1 layer 7 mm
- 2 layers ‘pressed’: 2 layers to 4 mm
- 2 layers ‘semi pressed’: 2 layers to 8 mm
- 2 layers ‘unpressed’: 2 layers to 10 mm
- 1 layer pattern
- 2 layers pattern
- 1 layer felt: felt sample of 5.5 mm for reference
- 1 layer pattern + felt
- 2 layers pattern + felt

The results are summarised in the figure below and the image shows the name, thickness, diameter, weight, density and average absorption coefficient of the frequency range 300-2600 Hz. Normally the Sound Absorption Average (SAA) is given for a frequency range of 200-2500 Hz, but for now, the average is taken at 300-2600 Hz due to the impedance tube size and therefore measuring range.

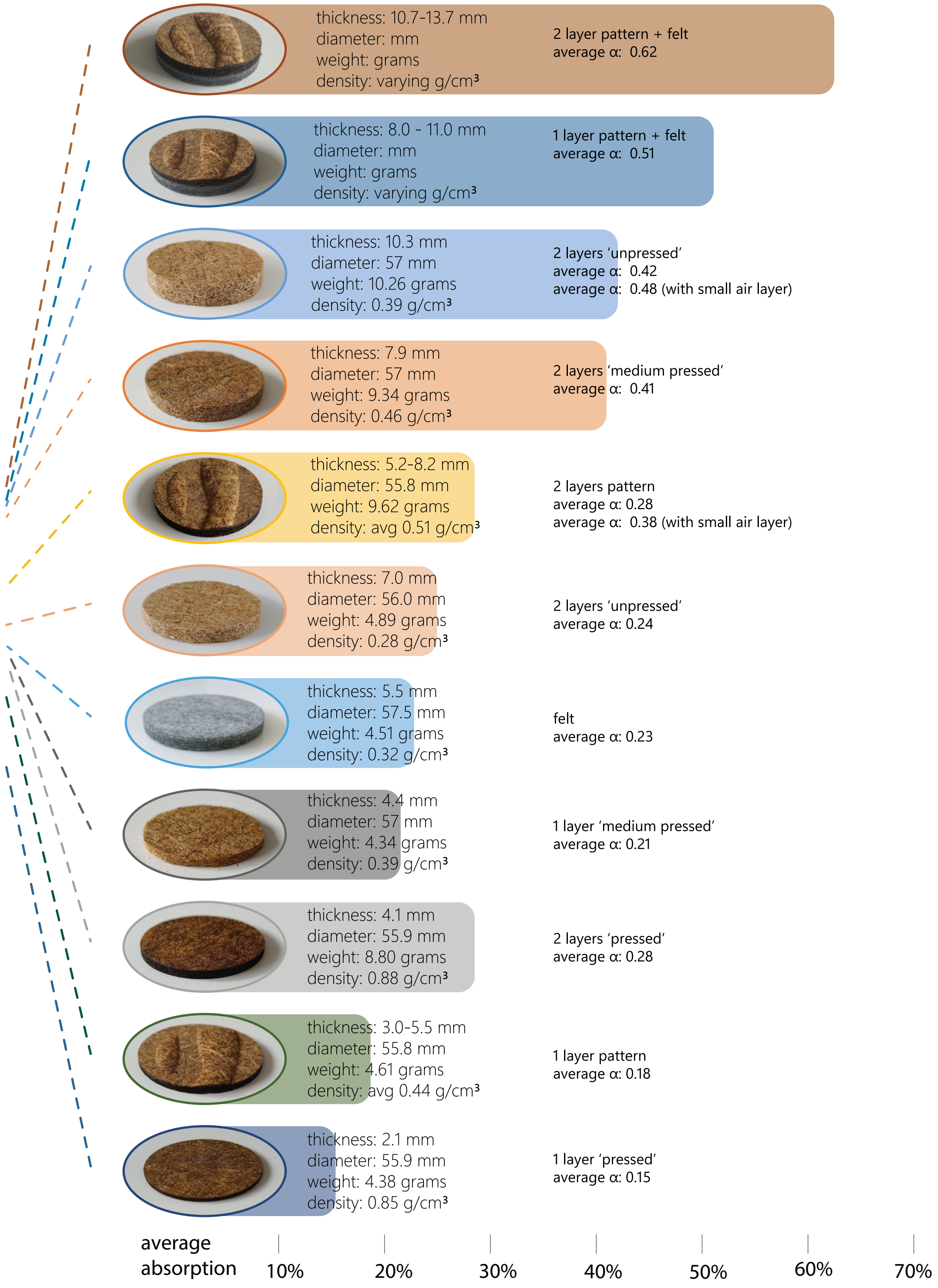
One layer pressed hardly absorbs sound. With a maximum of 20%. One-layer medium pressed absorbs better, but still not much, with a maximum of 45%. One unpressed layer absorbs better, with a maximum of 53%. One layer of patterned hemp (pressed and unpressed) absorbs up to 37%, so between the pressed and unpressed sample.

Two layers of pressed hemp behave better than 1 layer of unpressed hemp for frequencies below 2200 Hz. Two layers of medium-pressed hemp behave even better, gradually going from 10% to 78%. Two layers unpressed absorbs gradually from 10% to 81% for frequencies from 400 to 2600 Hz.

absorption comparison



In conclusion, the less compressed the hemp composite, the better it is at absorbing sound. However, with one layer of hemp, a maximum absorption is found that gradually increases from 10% to 50% at a frequency range of 500 to 2600 Hz. A profile with compressed and uncompressed hemp behaves in between the compressed and uncompressed absorbing behaviour. With two (medium) compressed layers, already better absorption is found, namely a gradual absorption from 10% to around 80% in the same frequency range.



thickness: 10.7-13.7 mm
diameter: mm
weight: grams
density: varying g/cm³

2 layer pattern + felt
average α: 0.62

thickness: 8.0 - 11.0 mm
diameter: mm
weight: grams
density: varying g/cm³

1 layer pattern + felt
average α: 0.51

thickness: 10.3 mm
diameter: 57 mm
weight: 10.26 grams
density: 0.39 g/cm³

2 layers ‘unpressed’
average α: 0.42
average α: 0.48 (with small air layer)

thickness: 7.9 mm
diameter: 57 mm
weight: 9.34 grams
density: 0.46 g/cm³

2 layers ‘medium pressed’
average α: 0.41

thickness: 5.2-8.2 mm
diameter: 55.8 mm
weight: 9.62 grams
density: avg 0.51 g/cm³

2 layers pattern
average α: 0.28
average α: 0.38 (with small air layer)

thickness: 7.0 mm
diameter: 56.0 mm
weight: 4.89 grams
density: 0.28 g/cm³

2 layers ‘unpressed’
average α: 0.24

thickness: 5.5 mm
diameter: 57.5 mm
weight: 4.51 grams
density: 0.32 g/cm³

felt
average α: 0.23

thickness: 4.4 mm
diameter: 57 mm
weight: 4.34 grams
density: 0.39 g/cm³

1 layer ‘medium pressed’
average α: 0.21

thickness: 4.1 mm
diameter: 55.9 mm
weight: 8.80 grams
density: 0.88 g/cm³

2 layers ‘pressed’
average α: 0.28

thickness: 3.0-5.5 mm
diameter: 55.8 mm
weight: 4.61 grams
density: avg 0.44 g/cm³

1 layer pattern
average α: 0.18

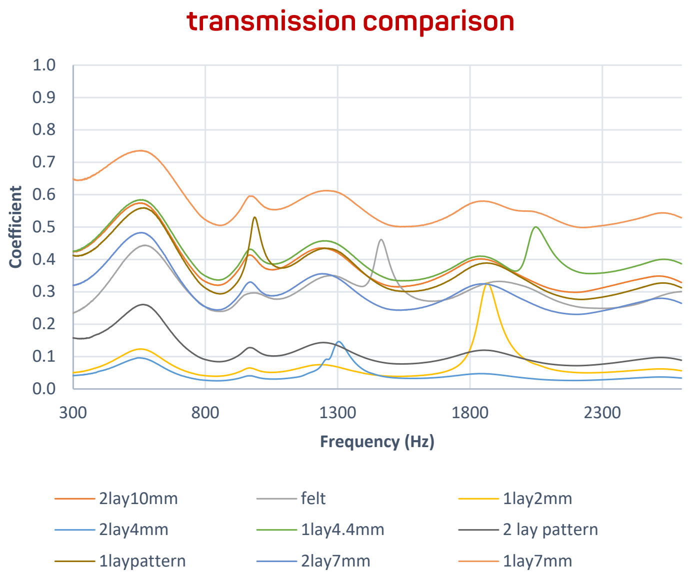
thickness: 2.1 mm
diameter: 55.9 mm
weight: 4.38 grams
density: 0.85 g/cm³

1 layer ‘pressed’
average α: 0.15

## H.3. Transmission

The absorption is different from the transmission of the material. The transmission coefficient (τ) is the ratio of the transmitted sound power Wt to the incident sound power Wi, and ranges from 0 to 1. The following samples have been tested on their transmission.

- 1 layer with pattern
- 2 layer with pattern
- 1 layer 2 mm
- 1 layer 4.4 mm
- 1 layer 7 mm
- 2 layers 4 mm
- 2 layers 7 mm
- 2 layers 10 mm
- Felt



As can be seen in the figure, unpressed hemp transmits sound better than pressed hemp. And one-layer transmits more sound than two layers. Transmission depends on both the layers and the density. One-layer pattern and two-layer pattern transmit a lot of sound.

In terms of transmission, the following can be concluded. The fewer layers and the less compressed the material, the more sound it transmits, which means if there is no hard wall behind the material, not much sound will be reflected.

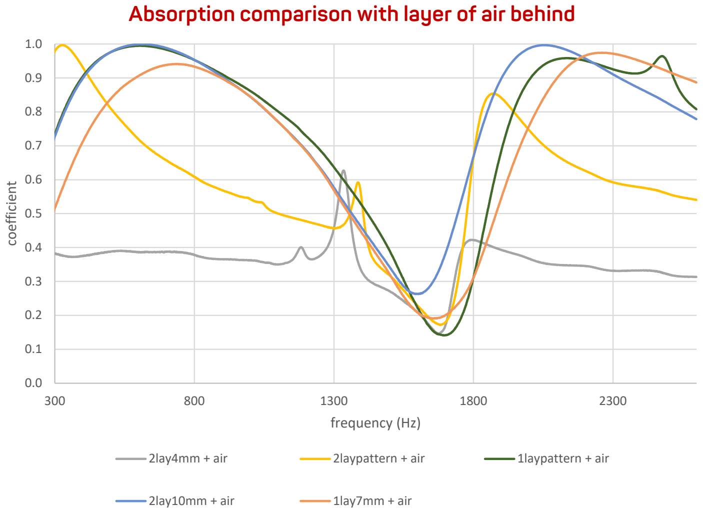
This also means there be a large effect if another material is placed behind the transmitting layer. For example, by combining unpressed hemp with an extra layer of a sound absorber, high absorption values can be reached. As shown in the absorption comparison, one-layer hemp with felt achieves more than 80% absorption from frequencies around 2300. Two layers of patterned hemp with felt achieves more than 80% absorption for frequencies around 1800.

## H.4. Connection to products

For an **acoustic wall panel**, higher absorption is essential. A wall panel hangs on a hard wall. Therefore, the wall panel should either have more than one layer of hemp, or an extra layer of another, even more sound-absorbing material, should be placed behind it. This is effective because the single layer of hemp transmits a lot of sound. For example, 2 layers of unpressed hemp will have an average absorption of 42%.

For a **ceiling panel**, it is mostly important that is it not reflective, since a layer of air is also above the ceiling panel. The perceived absorption is the sum of the dissipation within the material and the sound that is transmitted through the material, or at least, the layer of air above the panel has a large influence on the perceived reflection. The transmission four-microphone measurement showed that especially a single layer indeed transmits a lot of sound. To show the influence of a layer of air behind the material, which is also the case for ceiling panels, 2-microphone sound absorption measurements have been executed with the following samples and 10 cm of air behind it. The figure below shows the results.

- 1 layer pressed
- 2layers pressed
- 1 layer unpressed
- 2 layers unpressed
- 1 layer pattern
- 2 layer pattern



Although being the same samples as those tested on a hard wall, the absorption comparison with a layer of air behind it in the tube shows that high absorption and therefore low reflection is achieved due to a layer of air behind the sample and the hard wall. Therefore, the perceived absorption for a person under the ceiling with a layer of air indeed is high and depends on the layer of air behind it. An air gap behind the panel helps in higher sound absorption (like Helmholtz resonance). Especially for low-frequency sound, the air gap is better. Therefore, for a ceiling panel a single layer of hemp can be used. If necessary, sound-absorbing material can be placed above the ceiling panel.

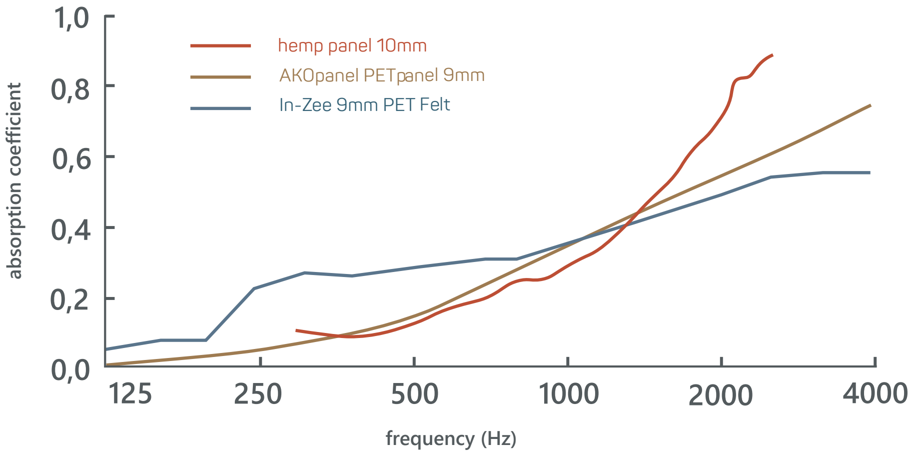
Furthermore, in all the measurements, the effect of diffusion is not taken into account in the impedance tube. An impedance tube works on the principle of normal incidence of sound waves since the dimensions of the tube only allow for horizontal propagation of the sound waves. Therefore, the diffusing effect of the curve in the panels is not taken into account in these measurements. Diffusing means scattering the reflections around the room in different directions which reduces the effect of sound bounces/smoothens out destructing interferences throughout the room. For understanding the effect of diffused sound or for real applications, a reverberation room can be used for testing the acoustic properties of materials.

Furthermore, having a small layer of air, e.g. 2 mm, behind the wall panels also suggest that that would have a positive effect on the perceived absorption of a listener. The air gap enhances the sound dissipation except at certain frequencies where destructive interference occurs.

## *H.5. Product conclusions*

The wall panel will be made of a double layer hemp so that a higher absorption is achieved. A ceiling panel will be made of a single layer since there is also air behind it where the sound can transmit to and therefore the effect of 2 layers instead of one is not necessarily an advantage. The perceived absorption is even higher for a one-layer pattern sample because of the transmission which adds to the perceived absorption.

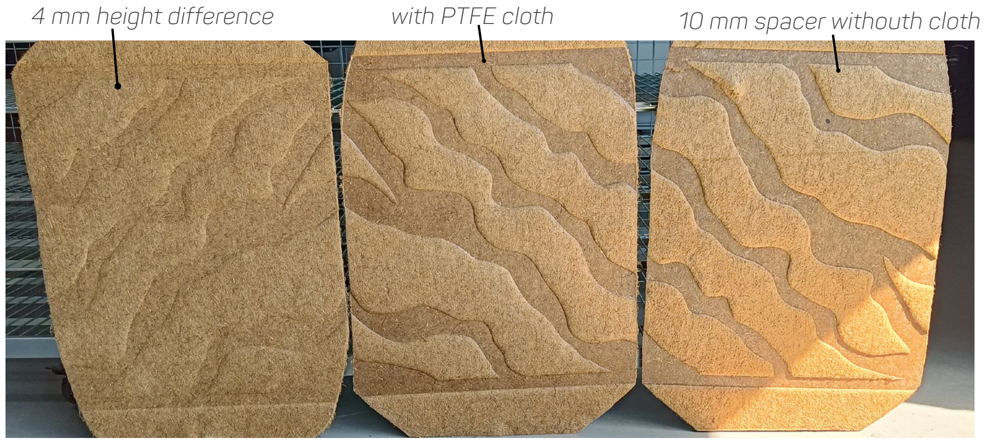
Comparing the hemp panel with its PET felt competitors yields the following results. The hemp panel with 2 layers is comparable in absorption to felt and at frequencies above 1300 Hz is better at absorbing.



## I. Panels prototyping

For the hemp panels, the following should be tested with the prototyping. Therefore, these values were varied during the testing.

- The optimum pressure time
- The optimum pressure thickness
- The easiest way of finishing the edges
- The minimal size for a logo
- The optimum dimensions
- A method for mounting the panel
- Unforeseen findings



***Three slightly different manufacturing techniques***

### *Thickness*

Having a too small spacer the difference between the pressed and unpressed hemp is small, only 4 mm and as can be seen on the left side, the differences become too little.

***Withouth coating or Teflon cloth, sample sticks to steel, with Teflon cloth***

With the Teflon cloth, the unpressed parts still touch the cloth and a small structure is seen on the hemp and the hemp can bulge less. Therefore, the part without the teflon cloth is best, however sticks to the steel. Therefore, a some kind of non-sticking cut-out coating is needed.

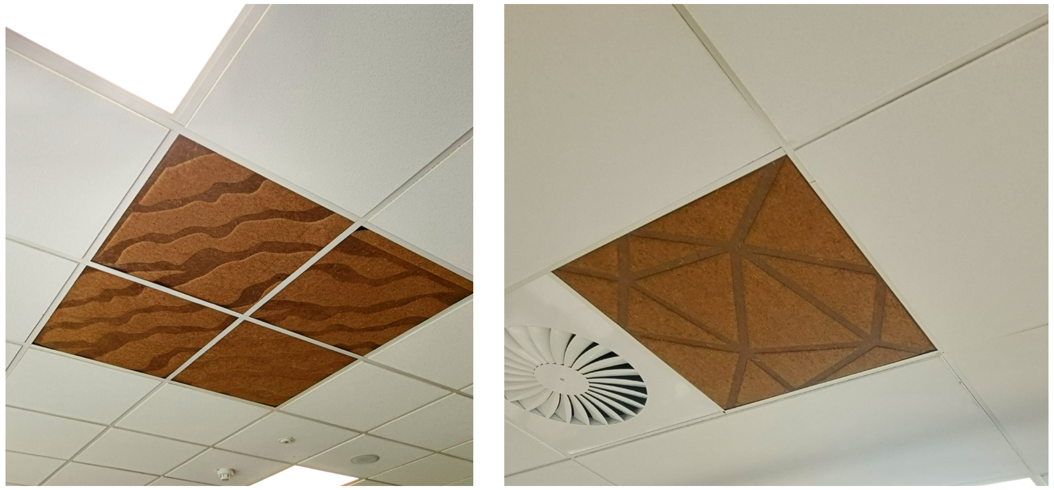
place pre-preg on die

press 2 min 160 degrees

place on rack

oven 2 hours 160 degrees

*Manufacturing operations of panel*



*Ceiling panels*

*Wall panels without flat profile*

## *I.1. Conclusions*

### *Pressure*

The panels are pressed with 500 kN. 1000 kN was also tested but 500 kN is sufficient. The distance of the mould surfaces is achieved by spacers of a certain thickness.

### *Time*

All the pressing times are with one prior minute with little pressure (200 kN). And then the time is at 500 kN. 1000 kN was also tested but 500 kN seems to be sufficient.

### *Single-layered*

- 2 minutes results in little colour difference
- 3 minutes results in better colour difference
- 4 minutes results in high colour difference

### *Double-layered*

- 4 minutes results in little colour difference
- 5 minutes in higher colour difference
- 6 minutes in high colour difference

### *Dimensions*

- Ceiling panel should be 595*595mm to fit in the suspended ceiling
- Ceiling panel should have a flat profile around of 15 mm so that optically a small flat profile of 5 mm is seen.
- Wall panel should have a flat profile around it. So, there are no loose fibres at the sides. This also provides more options for a mounting mechanism.
- Optically, for a wall panel a flat profile of 10 mm around looks best, so that the focus will go to the design on the panel.
- With pre-pregs of 550*550 mm, two panels fit next to each other on the press.

### *Mounting mechanism*

- Pressing a mounting system together with the hemp, this is visible from one side. A layer of hemp should be cut out.
- Coating a piece of steel with the bio-resin and then putting it in the oven does not stick well enough
- Double-sided tape sticks very well to the hemp and in this way a steel plate can be attached to the panel.

### *General*

- Steel sticks to pre-preg after press moulding without a non-sticking layer.
- Teflon cloth should be cut out in the shape, otherwise the hemp cannot bulge properly.
- Pre-preg has one side with a mesh due to the impregnation process at Plantics, therefore there should be carefully looked that that side will become the backside.

## J. Fire test

The Crib5 test was informally conducted. Crib5 is the largest source of ignition. The following conclusions can be drawn from the results: the material is self-extinguishing. It is evident that the pressed sample does not catch fire, and the unpressed sample does scorch to a limited extent but is ultimately self-extinguishing.

Burning time crib: 2:20
Time of flame extinction: 3:00
No smoke visible anymore: around 8 minutes
Post-fire damage: 95x120 mm completely burned out

This meets the Crib5 test because the flames do not escalate and do not bandage the whole specimen and the flames do not touch the extreme edges of the specimen and do not continue to burn for more than 10 minutes and do not carbonise more than 100 mm. Note that in one dimension it was carbonised more than 100mm, but the fire test was executed outside with a lot of wind, the assumption is made that with the formal test procedure inside, no more smoke is visible and the post-fire damage will be lower.

## K. Designs explanation

A four-panel is made referencing the four elements of nature: Wind/Air, Water, Earth & Fire. The earth panel is based on the ridges created in the sand by the wind and refers to the earth. This panel also has a seamless pattern. The wind/air design shows the veins of a leaf. Leaves always hang high in the air and move by the wind. The fire design is based on the shapes seen in flames. The water design is based on the pattern created when a drop falls into water, thus translating the element of water.

Of course, the interpretation of the designs is still up to the observer. All the designs have an equal level of abstraction, making them fit well together. Furthermore, care has been taken to keep most of the panel with uncompressed hemp, ensuring higher sound absorption values. Also, the panels do not have a pattern that would be optically too busy. The pattern also had to be such that it could be cut from steel, so no loose shapes that would fall out after the cutting.

*zoom.nl/foto/natuur/1467373/de-wind-speelt-met-zand-8*

*www.digifotostarter.nl/tips-waterdruppels-fotograferen*

*pixers.nl/posters/herfst-bladeren-in-de-wind-5437685*

*jufchristel3.webnode.nl/kopie-van-samen-leven-tussen-werkelijkheid-en-droom/*

Majority should stay unpressed

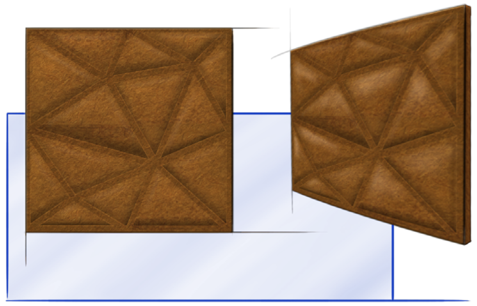
Image should be able to be laser cut

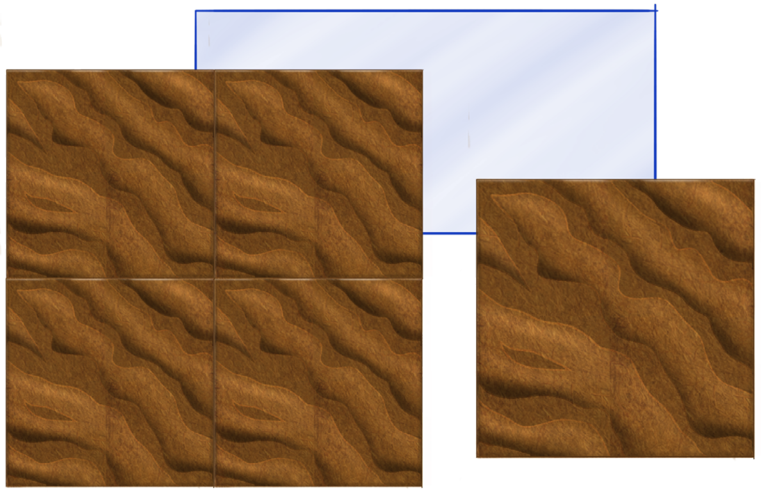
Only pattern from straight lines fits less to the natural character of the material

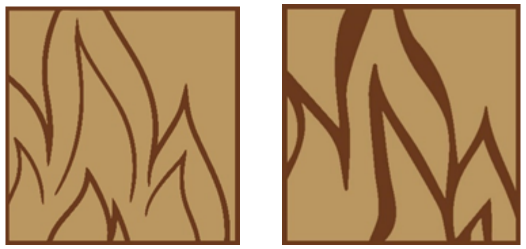
Too thin layers are not working

No varying thickness in lines is less aesthetically pleasing

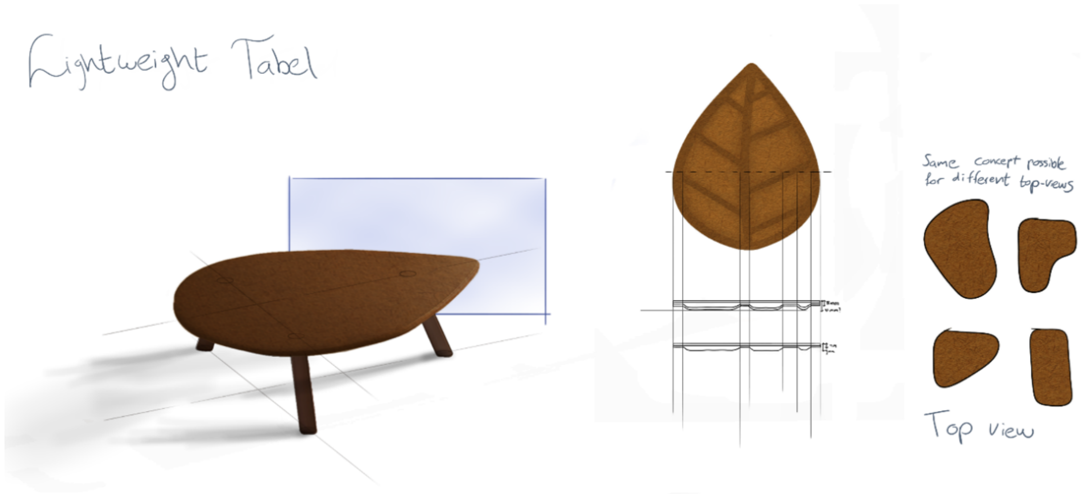
Too many lines are too busy

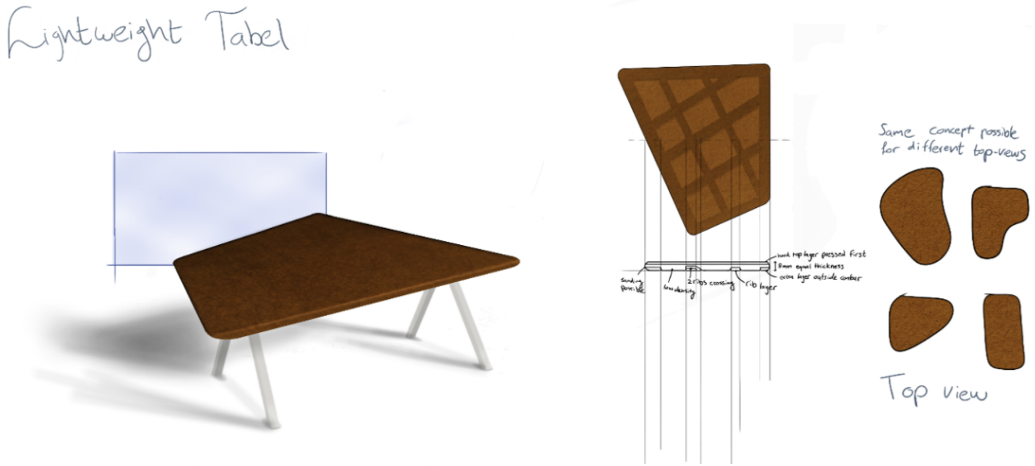






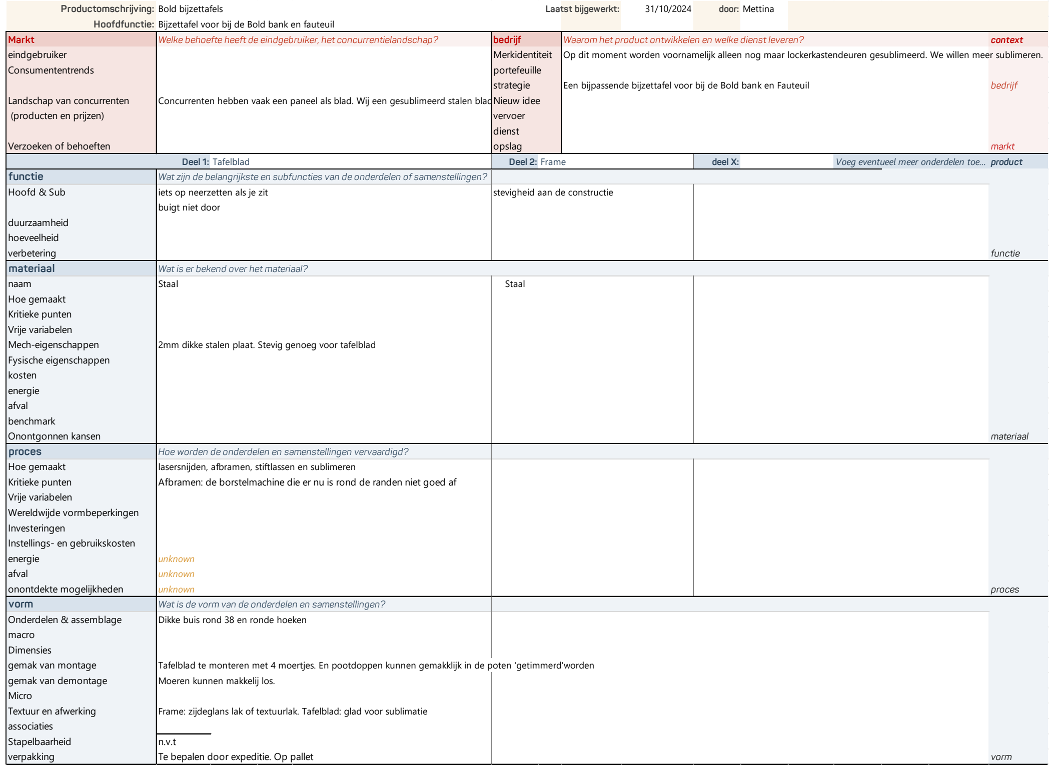
## K.1. Table ideas





# L. Verification

## L.1. Bold project

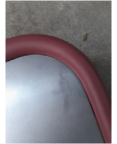
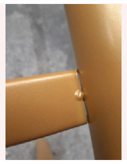


**Productomschrijving:** Bold bijzettafels
**Laatst bijgewerkt:** 31/10/2024 **door:** Mettina
**Hoofdfunctie:** Bijzettafel voor bij de Bold bank en fauteuil

| **Markt** | *Welke behoefte heeft de eindgebruiker, het concurrentielandschap?* | **bedrijf** | *Waarom het product ontwikkelen en welke dienst leveren?* | ***context*** |
|---|---|---|---|---|
| eindgebruiker | | Merkidentiteit | Op dit moment worden voornamelijk alleen nog maar lockerkastendeuren gesublimeerd. We willen meer sublimeren. | |
| Consumententrends | | portefeuille | | |
| | | strategie | Een bijpassende bijzettafel voor bij de Bold bank en Fauteuil | *bedrijf* |
| Landschap van concurrenten | Concurrenten hebben vaak een paneel als blad. Wij een gesublimeerd stalen blac | Nieuw idee | | |
| (producten en prijzen) | | vervoer | | |
| | | dienst | | |
| Verzoeken of behoeften | | opslag | | *markt* |

| | **Deel 1:** Tafelblad | **Deel 2:** Frame | **deel X:** *Voeg eventueel meer onderdelen toe...* | ***product*** |
|---|---|---|---|---|
| **functie** | *Wat zijn de belangrijkste en subfuncties van de onderdelen of samenstellingen?* | | | |
| Hoofd & Sub | iets op neerzetten als je zit | stevigheid aan de constructie | | |
| | buigt niet door | | | |
| duurzaamheid | | | | |
| hoeveelheid | | | | |
| verbetering | | | | *functie* |
| **materiaal** | *Wat is er bekend over het materiaal?* | | | |
| naam | Staal | Staal | | |
| Hoe gemaakt | | | | |
| Kritieke punten | | | | |
| Vrije variabelen | | | | |
| Mech-eigenschappen | 2mm dikke stalen plaat. Stevig genoeg voor tafelblad | | | |
| Fysische eigenschappen | | | | |
| kosten | | | | |
| energie | | | | |
| afval | | | | |
| benchmark | | | | |
| Onontgonnen kansen | | | | *materiaal* |
| **proces** | *Hoe worden de onderdelen en samenstellingen vervaardigd?* | | | |
| Hoe gemaakt | lasersnijden, afbramen, stiftlassen en sublimeren | | | |
| Kritieke punten | Afbramen: de borstelmachine die er nu is rond de randen niet goed af | | | |
| Vrije variabelen | | | | |
| Wereldwijde vormbeperkingen | | | | |
| Investeringen | | | | |
| Instellings- en gebruikskosten | | | | |
| energie | *unknown* | | | |
| afval | *unknown* | | | |
| onontdekte mogelijkheden | *unknown* | | | *proces* |
| **vorm** | *Wat is de vorm van de onderdelen en samenstellingen?* | | | |
| Onderdelen & assemblage | Dikke buis rond 38 en ronde hoeken | | | |
| macro | | | | |
| Dimensies | | | | |
| gemak van montage | Tafelblad te monteren met 4 moertjes. En pootdoppen kunnen gemakklijk in de poten 'getimmerd'worden | | | |
| gemak van demontage | Moeren kunnen makkelij los. | | | |
| Micro | | | | |
| Textuur en afwerking | Frame: zijdeglans lak of textuurlak. Tafelblad: glad voor sublimatie | | | |
| associaties | | | | |
| Stapelbaarheid | n.v.t | | | |
| verpakking | Te bepalen door expeditie. Op pallet | | | *vorm* |

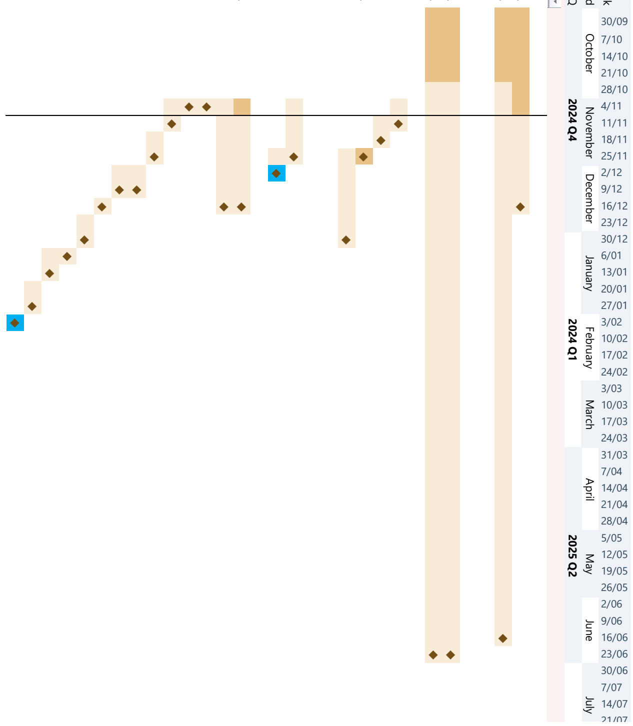
| general (aims)<br>*"het product moet.."* | | **must**<br>*/we* | specific (to function)<br>*Bold bijzettafels moet..* | technical requirements (further specified) | **status all**<br>**0.00%** | **status mus**<br>**0.00%** |
|---|---|---|---|---|---|---|
| **budgettering** | B | | *price and pieces* | | **50%** | **#DIV/0!** |
| **kwaliteit** | Kw | | *durability, standards, functioning* | | **75%** | **75%** |
| duurzaam zijn voor een bepaalde tijd | | | | | | |
| aan normen voldoen | | | | | | |
| goed functioneren | Kwm1 | **m** | Tafel heeft een goede hoogte voor een bijzettafel | tafel is 40 cm hoog | met | |
| | Kwm2 | **m** | Tafelblad buigt niet door | Tussenstrips | met | |
| | Kwm3 | **m** | Tafelblad kan bevestigd worden aan frame | Op tafelblad stiften lassen voor positionering in frame | met | |
| | Kwm4 | **m** | Tafelblad heeft tot het tafelframe overal dezelfde afstand | | in progress | 🟥 |
| **logistiek** | L | | *transport movements, packaging materials, shape* | | **0%** | **#DIV/0!** |
| Beperk het benodigde transport tot een minimum. | | | | | | |
| .. # Leveranciers & Afstand | | | | | | |
| .. tussen filialen | | | | | | |
| Minimaliseer verpakkingsmateriaal. | | | | | | |
| .. Herbruikbaar | | | | | | |
| .. Efficiënte vorm product/flat packing | | | | | | |
| Minimaliseer het transportvolume: stapelbaar | | | | | | |
| passend.. | | | | | | |
| .. op pallet | Lw1 | **w** | Past op europallet | Kleine tafel past op europallett, grote tafel niet | partially met | |
| .. in vrachtwagen | | | | | | |
| .. in liften | | | | | | |
| .. onder deuren | | | | | | |
| **esthetiek** | E | | *aesthetics, variations, logo placement* | | **25%** | **0%** |
| Ziet er esthetisch aangenaam uit | Em1 | **m** | Mooie las | Mooi TIG-las | in progress | 🟥 |
| | | | | | not met | |
| Heeft X variaties | Ew1 | **w** | Verschillende sublimatie afbeeldingen | | in progress | |
| | Ew2 | **w** | verschillende staal kleuren | epoxy kleuren (fijn structuur) en zijdeglans | met | |
| wens: logo Vepa opnemen | | | | | | |
| wens: unieke uitstraling hebben | | | | | | |
| wens: tijdloos zijn | | | | | | |
| **productie** | P | | *manufacturing and assembly steps* | | **0%** | **0%** |
| Massaal produceerbaar zijn voor doel # van de verkoop | | | | | | |
| een handbaar formaat hebben | | | | | | |
| productieproblemen tot een minimum te beperken. | | | | | | |
| .. Productiestappen | Pm1 | **m** | Maten gebogen buizen volgens tekening | Controlemal moet hier oplossing voor bieden | in progress | 🟥 |
| .. Afwerkingsstappen | Pm2 | **m** | Stalen blad randen ontbramen en onscherp maken | | in progress | 🟥 |
| .. Montage stappen | | | | | | |
| **kosten** | Ko | | *machine, labour, material, investment costs* | | **25%** | **33%** |
| Minimaliseer de productiekosten.. | | | | | | |
| .. Investeringen | | | | | | |
| | Kom1 | **m** | Nieuwe borstelmachine voor betere afwerking tafelbladen | | in progress | 🟥 |
| .. arbeidstijd = kosten | Kom2 | **m** | Hand Tig lassen -> duurt lang | | | 🟥 |
| .. Tijd van de machine | Kow1 | **w** | wish: robot lassen ipv handlassen maar vereist investering | | in progress | |
| .. Materiaalkosten | Kom3 | **m** | Sublimatie is duur | | met | |
| | | | | | in progress | |
| **Eco-impact** | E | | *energy use, waste, toxicity* | | **#DIV/0!** | **#DIV/0!** |
| de impact op het milieu tot een minimum te beperken. | | | | | | |
| .. Minimaliseer het energieverbruik | | | | | | |
| .. Minimaliseer toxiciteit | | | | | | |
| .. Minimaliseer afval | | | | | | |
| **Circulariteit** | C | | *material composition, seperability, maintenance* | | **100%** | **100%** |
| Maximaliseer prop snel hernieuwbare inhoud | | | | | | |
| Minimaliseer nieuw materiaal | | | | | | |
| scheidbaar zijn in hernieuwbaar en niet-hernieuwbaar mate | Cm1 | **m** | Pootdoppen zijn goed uit poten te halen | | met | |
| .. geen lijm/mechanisch verbinden | Cm2 | **m** | verbinding door stiftlassen en moeren | | met | |
| in staat zijn om te onderhouden | | | | | | |
| **Modulariteit** | M | | *standaardisatie, configuraties* | | **75%** | **100%** |
| is customisable.. | | | | | | |
| ..gestandaardiseerde componenten gebruiken | Em3 | **m** | Symmetrisch bruikbare buizen | Elke tafelbestaan uit twee dezelfde gebogen buizen | met | |
| ..meerdere configuraties hebben | | | | | | |
| | Em4 | **m** | Twee verschillende maten tafels | Ongeveer 60x60 cm en 60x120cm | met | |
| | Ew1 | **w** | Verschillende afbeeldingen | | not met | |
| makkelijk te.. | | | | | | |
| .. assembleren | Em5 | **m** | moeren, pootdoppen en viltglijders | | met | |
| .. demonteren | | | | | | |

| reporter | bijpassende eis | onderwerp | status | samenvatting prototyping uitkomst | afbeelding |
|---|---|---|---|---|---|
| Gertjan/ Mettina | kwm1 | **Hoogte Bold tafels** | satisfied | Hoogte was eerst 400 mm zonder pootdoppen. Bij nieuw prototype is hoogte 400mm inclusief pootdoppen. Ook moeten de tafelpoten wat schuiner komen te staan. |  |
| Mettina | Kwm4 | **Aansluiting blad op frame** | satisfied but action needed | Het blad had niet overal een gelijke afstand met het tafelframe. |  |
| Mettina | Em1 | **Laskwaliteit** | satisfied | Eerste protoype is gemaakt met CO2 lassen. Dit is een vrij dikke las. Het volgende prototype wordt TIG-gelast. |  |
| Mettina |  | **Buigkwaliteit** | unsatisfied | Er is een verdikking te zien aan het einde van de bocht. Volgens Wijchen kan dit niet verbeterd worden. |  |
| Mettina | Em1 | **Laskwaliteit/ Stalen u-profiel** | satisfied | Op de plek waar het u profiel is gelast is een 'druppel' en een gleuf te zien. Het u-profiel moet beter op het frame aansluiten |  |
|  | Pm1 | **Buigkwaliteit** | satisfied but action needed | De gebogen buizen voldoen nog niet helemaal aan de maat. Een controlemal moet dit oplossen. |  |
|  |  | **Hoogte tafelblad ten opzichte van het midden van de buis** | satisfied but action needed | Nu nog in het midden maar moet hoger. Dit in verband met de verdikking aan het einde van de bocht. Hierdoor lijkt de afstand tussen het tafelblad en het frame niet mooi. Dit wordt getest |  |
|  |  | **Sublimeren tafelblad** | satisfied but action needed | De scherpe randen van het tafelblad kunnen nog beter afgerond worden. Doordat het tafelblad gesublimeerd wordt lijkt het nu 'beschadigd' |  |

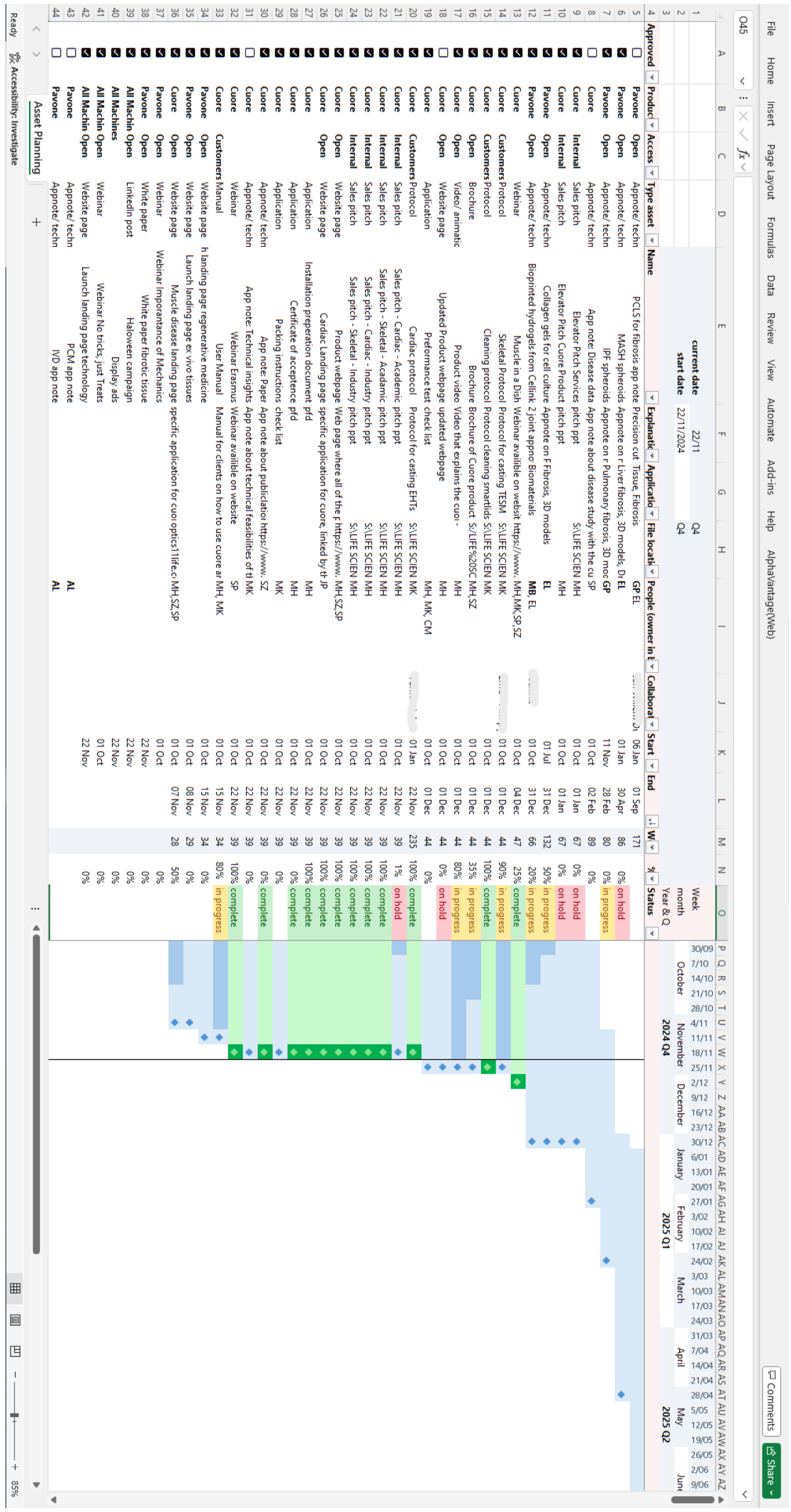
# L.2. Inline project

|  | huidige datum | 06/11/24 | Q4 |
|---|---|---|---|
|  | start datum project | 01 October 2024 | Q4 |

| activiteit | evt. Uitleg | toegewezen aan | start | eind | weken | % | status |
|---|---|---|---|---|---|---|---|
| **Ketterer** |  |  |  |  |  |  |  |
| Design freeze |  | Ketterer | 01 Oct | 16 Dec | 11 | 50% | in progress |
| Start massa productie |  | Ketterer | 01 Oct | 19 Jun | 38 | 10% | in progress |
|  |  |  |  |  |  |  |  |
| **Vepa Inkoop** |  |  |  |  |  |  |  |
| Uitloop huidige verstel systeem |  | Henk H | 01 Oct | 26 Jun | 39 | 10% | in progress |
| Uitloop huidige buizenset |  | Henk H | 01 Oct | 26 Jun | 39 | 10% | in progress |
|  |  |  |  |  |  |  |  |
| Definitieve doorsnede buizen bepalen | *Contact met Wupperman* | Henk H / Allard | 04 Nov | 15 Nov | 2 | 0% | not started |
| Definitieve specs buis bepalen |  | Henk H / Allard | 11 Nov | 22 Nov | 2 | 0% | not started |
| Proef serie buizenset bestellen |  | Henk H | 25 Nov | 29 Nov | 1 | 10% | in progress |
| Levering proefserie buizenset |  | Henk H | 25 Nov | 30 Dec | 5 | 0% | not started |
|  |  |  |  |  |  |  |  |
| **Product ontwikkeling** |  |  |  |  |  |  |  |
| Scope in kaart brengen |  | HDW | 04 Nov | 29 Nov | 4 | 0% | not started |
| Definitieve scope bepalen Milestone 1 --> Aftikken in CMT 2 december |  | HDW | 25 Nov | 06 Dec | 2 | 0% | not started |
|  |  |  |  |  |  |  |  |
| Principe middenbuis meenemer evalueren + testen |  | Allard/HDW | 04 Nov | 20 Dec | 7 | 10% | in progress |
| Maakbaarheid middenbuismeenemer bespreken met producent (BEWET) |  | Allard/HDW | 04 Nov | 20 Dec | 7 | 0% | not started |
| Concept ontwerp Presto T-poot (Presto-R) uitwerken in CAD |  | Allard | 04 Nov | 08 Nov | 1 | 0% | not started |
| Concept ontwerp Presto H-poot (Presto-R DUO) uitwerken in CAD |  | Allard | 04 Nov | 08 Nov | 1 | 0% | not started |
| Concept ontwerp Presto Wang (Presto RW) uitwerken in CAD |  | Allard | 04 Nov | 15 Nov | 2 | 0% | not started |
| Voorstel nieuwe voetbuis + Einddop uitwerken in CAD |  | Allard | 18 Nov | 29 Nov | 2 | 0% | not started |
| Voorstel nieuwe voetbuis Proto 1 --> Proof of concept |  | Andre/Bertram | 02 Dec | 13 Dec | 2 | 0% | not started |
| Voorstel nieuwe rechthoekige wang in CAD |  | Allard | 02 Dec | 13 Dec | 2 | 0% | not started |
| Voorstel nieuwe rechthoekige wang Proto 1 --> Proof of concept |  | Andre/Bertram | 16 Dec | 20 Dec | 1 | 0% | not started |
| Kerstvakantie |  |  | 23 Dec | 03 Jan | 2 | 0% | not started |
| Proto's Presto R, R Duo en RW bespreken met productie/spuiterij/montage |  | Allard/HDW | 06 Jan | 10 Jan | 1 | 0% | not started |
| Verwerken Input productie/spuiterij/montage |  | Allard/HDW | 06 Jan | 17 Jan | 2 | 0% | not started |
| Afronden concept fase |  | Allard/HDW | 20 Jan | 31 Jan |  | 0% | not started |
| Einde Concept fase Milestone 2 --> Aftikken in CMT Februari |  | HDW | 03 Feb | 07 Feb | 1 | 0% | not started |

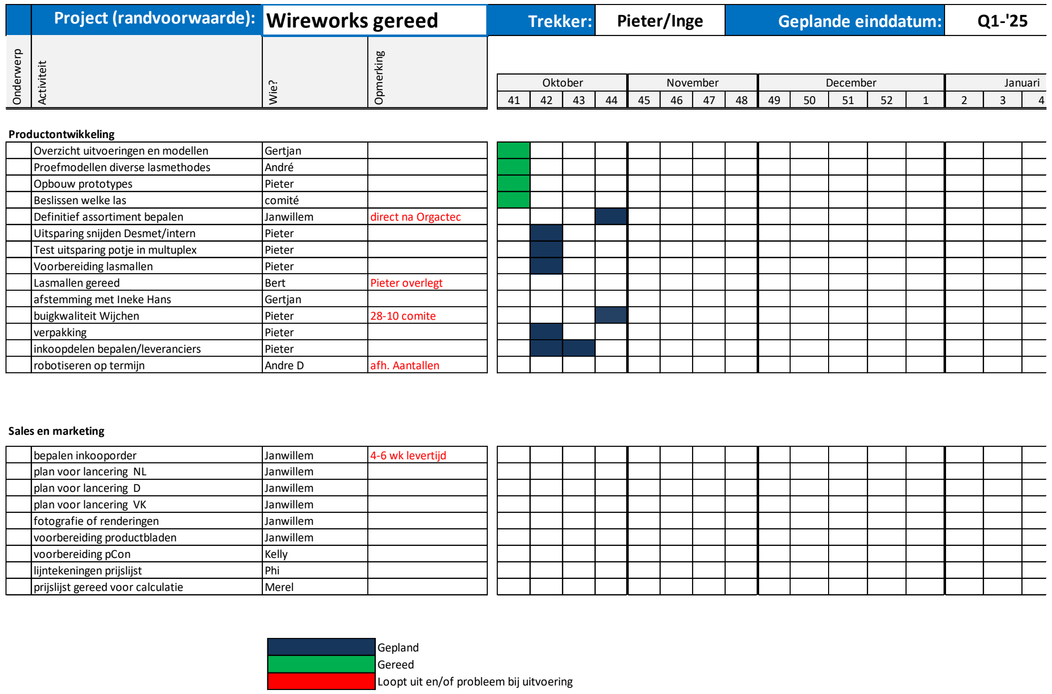


## L.3. Different company



# M. Lean implementation

## M.1. Planning tab

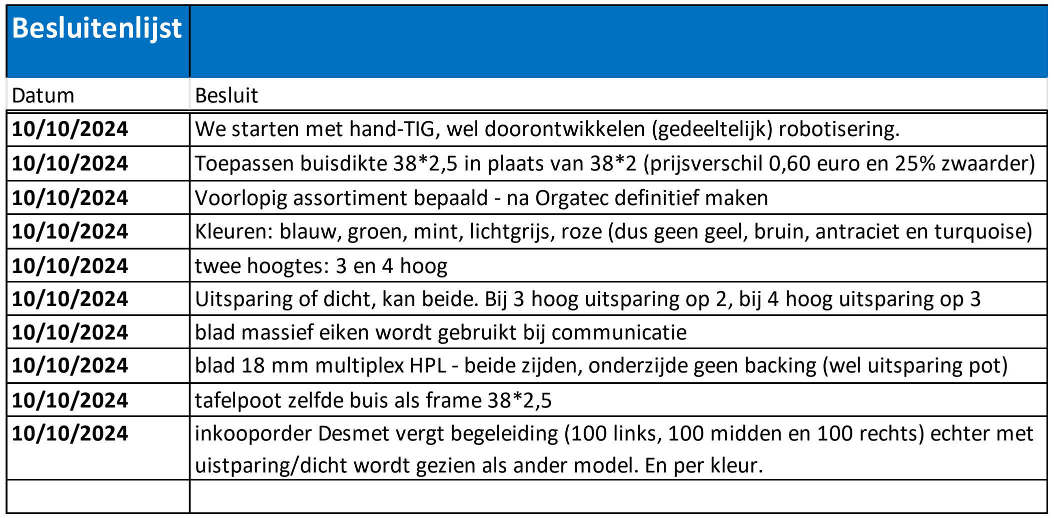


**Project (randvoorwaarde):** Wireworks gereed **Trekker:** Pieter/Inge **Geplande einddatum:** Q1-'25

| Onderwerp | Activiteit | Wie? | Opmerking | Oktober 41 | 42 | 43 | 44 | November 45 | 46 | 47 | 48 | December 49 | 50 | 51 | 52 | 1 | Januari 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Productontwikkeling** | | | | | | | | | | | | | | | | | | | |
| | Overzicht uitvoeringen en modellen | Gertjan | | 🟩 | | | | | | | | | | | | | | | |
| | Proefmodellen diverse lasmethodes | André | | 🟩 | | | | | | | | | | | | | | | |
| | Opbouw prototypes | Pieter | | 🟩 | | | | | | | | | | | | | | | |
| | Beslissen welke las | comité | | 🟩 | | | | | | | | | | | | | | | |
| | Definitief assortiment bepalen | Janwillem | direct na Orgactec | | | | 🟦 | | | | | | | | | | | | |
| | Uitsparing snijden Desmet/intern | Pieter | | | 🟦 | | | | | | | | | | | | | | |
| | Test uitsparing potje in multuplex | Pieter | | | 🟦 | | | | | | | | | | | | | | |
| | Voorbereiding lasmallen | Pieter | | | 🟦 | | | | | | | | | | | | | | |
| | Lasmallen gereed | Bert | Pieter overlegt | | | | | | | | | | | | | | | | |
| | afstemming met Ineke Hans | Gertjan | | | | | | | | | | | | | | | | | |
| | buigkwaliteit Wijchen | Pieter | 28-10 comite | | | | 🟦 | | | | | | | | | | | | |
| | verpakking | Pieter | | | 🟦 | | | | | | | | | | | | | | |
| | inkoopdelen bepalen/leveranciers | Pieter | | | 🟦 | 🟦 | | | | | | | | | | | | | |
| | robotiseren op termijn | Andre D | afh. Aantallen | | | | | | | | | | | | | | | | |
| **Sales en marketing** | | | | | | | | | | | | | | | | | | | |
| | bepalen inkooporder | Janwillem | 4-6 wk levertijd | | | | | | | | | | | | | | | | |
| | plan voor lancering NL | Janwillem | | | | | | | | | | | | | | | | | |
| | plan voor lancering D | Janwillem | | | | | | | | | | | | | | | | | |
| | plan voor lancering VK | Janwillem | | | | | | | | | | | | | | | | | |
| | fotografie of renderingen | Janwillem | | | | | | | | | | | | | | | | | |
| | voorbereiding productbladen | Janwillem | | | | | | | | | | | | | | | | | |
| | voorbereiding pCon | Kelly | | | | | | | | | | | | | | | | | |
| | lijntekeningen prijslijst | Phi | | | | | | | | | | | | | | | | | |
| | prijslijst gereed voor calculatie | Merel | | | | | | | | | | | | | | | | | |

🟦 Gepland
🟩 Gereed
🟥 Loopt uit en/of probleem bij uitvoering

## M.2. Decisions tab



| **Besluitenlijst** | |
|---|---|
| Datum | Besluit |
| **10/10/2024** | We starten met hand-TIG, wel doorontwikkelen (gedeeltelijk) robotisering. |
| **10/10/2024** | Toepassen buisdikte 38*2,5 in plaats van 38*2 (prijsverschil 0,60 euro en 25% zwaarder) |
| **10/10/2024** | Voorlopig assortiment bepaald - na Orgatec definitief maken |
| **10/10/2024** | Kleuren: blauw, groen, mint, lichtgrijs, roze (dus geen geel, bruin, antraciet en turquoise) |
| **10/10/2024** | twee hoogtes: 3 en 4 hoog |
| **10/10/2024** | Uitsparing of dicht, kan beide. Bij 3 hoog uitsparing op 2, bij 4 hoog uitsparing op 3 |
| **10/10/2024** | blad massief eiken wordt gebruikt bij communicatie |
| **10/10/2024** | blad 18 mm multiplex HPL - beide zijden, onderzijde geen backing (wel uitsparing pot) |
| **10/10/2024** | tafelpoot zelfde buis als frame 38*2,5 |
| **10/10/2024** | inkooporder Desmet vergt begeleiding (100 links, 100 midden en 100 rechts) echter met uistparing/dicht wordt gezien als ander model. En per kleur. |
| | |

# N. Findings of product development consultation

*Information sharing and decision making:* Information is often exchanged during consultations with everyone, but this should rather happen at the own department. We want to keep each other more informed during the process, so the department consultation is more about making decisions instead of updating each other. This way, decisions can be made faster.

*Commercial versus product development aim:* There is a misalignment between the commercial goals and the development aims. The production team often does not have a clear visibility of what the priorities of product development are.

*Consultation within the FFG:* Once in the time there is also consultation with the other companies of the FFG. The other companies within the FFG approaches their consultation in a different way than Vepa.

*Investment decisions:* New investments are not always clearly communicated in terms of why they are needed and how they will impact the product development process.

*Project list:* There is a desire to do the consultation with a project list to ensure everyone is aligned and aware of the project progress and priorities.

*Communication problem:* A significant challenge is to effectively bring all stakeholders of the product development process together in communication. “How do we get everyone together?”

# O. Findings of discussions with product developers

## O.1. Product developer 1

*Identified problems:* Eight years ago, we had a team of four people in product development, and now around eleven at two locations, which is why coordination is now challenging. And indeed, things like the environment are never treated as a trade-off but rather seen as a consequence.

*Tool feedback:* Very nice document, especially the list of requirements a sort of checklist is really helpful. Currently, there is not much documentation for prototyping, primarily because we have everything in-house, so we can directly walk to the production department. However, some kind of documentation would be beneficial. For smaller projects we normally don’t use a list of requirements, but this can still be a valuable addition to formulate some kind of requirements. I am not sure whether the calculations and chart tab will be used.

*Recommendations:* Sometimes projects have to go fast because of commercial pressure, and I think filling in everything would take too much time. Halfway extra requirements must be able to be added. Maybe a smaller version of this tool would be helpful for smaller projects. I am not sure everyone would like to fill in this sheet. When external designers are involved, aesthetics might be prioritised over costs, it would be helpful if the tool could allow these types of priorities to be indicated, ensuring alignment of objectives across the team.

## O.2. Product developer 2

*Identified problems:* Responsibilities within the product development process are not clearly defined, and much of the relevant information is mainly in people’s heads. There are often many meanings and information is not documented in a structured manner. Currently, SolidWorks drawings serve as the only formal documentation. Prototyping is an important factor in designing and often this is not acknowledged by production employees but rather seen as a waste of time. This might be because the directors are primarily concerned with generating profits.

*Excel tool feedback:* The tool appears clear to me, this would help in providing insight. This can be very useful, especially because there is not one way of working. This is okay, but some kind of consistency across projects be really helpful and the tool can help with that. Currently, I manage tasks by putting emails in my agenda which I have to provide feedback on. The first sheet is more about the project description I think is the responsibility of the person initiating the job. The list of requirements is especially helpful, as it includes the relevant subjects and applies to multiple products. It would be great if extra documents can be linked directly in this sheet. Overall, this tool is the reason behind why you come to certain CAD drawings. Knowing the status of prototyping would be an advantage as well.

*Excel Tool recommendations:* There is one project leader per product, the leader can manage this tool, and the other employees should report to this project leader. The project leader can then at the end of the day spend for example 10 minutes on updating this sheet. Maybe this Excel can be linked to the project in the ERP system, AS400, to centralise this information. Probably this tool only works for larger projects, smaller projects just go quickly. I wonder how to make sure that not two people are editing at the same time.

## O.3. Product manager

*Identified problems:* Currently as employees leave, there is a lack of accessible project information from the past. The only documentation available consists of technical drawings, which often do not clarify the rationale behind design choices. Additionally, sometimes even different versions of the same drawing exist, leading to further confusion. Although stated in the planning of Vepa, often this formal go/no-go moment does not take place, therefore, the decision-making process is often without these clear assessment points.

*Excel Tool feedback:* Indeed things go wrong right now, which in my opinion can be prevented with this tool. The tool is really something that would help, it is is in fact one document that contains all the project information. Also, in a few years being able to look back at projects is indeed valuable. I wonder what this filled-in tool looks like for a completely different project and when do you use this and when don't you use this? I think the requirements checklist is particularly useful. The tool is well put together, and I plan to use it for an upcoming project! I agree with putting more effort into the early stages when setting up a project to prevent problems from arising at later stages.

*Excel Tool recommendations:* Maybe this tool is already a step to far. Currently, there is nothing, so every step extra is an improvement. It is hard to measure the project progression on the requirements, therefore I would rather measure it on the phase you're in. For future projects, I see the tool being useful in the planning stages, including proof of concept, developing an 80% version, and preparing for the zero-series production phase.

## O.4. Product developer 4

*Identified problems:* There is indeed a noticeable lack of structure and clear guidance within the team. I have never seen any form of planning or documentations since I am working here. Based on my educational background, I know that documenting processes and decisions is essential, however this is not something I have to do here. While many tasks also happen naturally and go well the way they go, the absence of a standardised way of documenting leaves room for improvement.

*Tool feedback:* The tool is well-constructed, and I would be interested in using it! At this point, I don't feel anything is missing from it. The tool appears functional and comprehensive.

*Tool recommendations:* I think it may take some time for team members to fully understand how to use this tool. Some form of training may help overcome this problem. However, I believe this is doable.

## O.5. Director assistant

*Identified problems:* Something has to change structurally in the product development team. Decision-making processes are often prolonged, and even after a decision has been made, they are revised by others who are not responsible for that topic. Indeed, responsibilities are unclear. We want to move towards a way of working with a more standardised approach and taking decisions faster.

*Tool feedback:* The Excel tool contains everything in my opinion, it is very complete. It aligns with the way of working we want to move towards. It includes the necessary information for the continuous monitoring of product progression and ensuring that decisions, outcomes, and constraints are well-documented.

*Tool recommendations:* The tool could be a valuable addition to the product development team, however, a simplified version may be more practical at this stage, especially compared to the way of working right now. Although the process sounds straightforward in theory, integrating it into the current workflow could present challenges. As a preliminary step, it is essential to foster a cultural shift in how the team communicates and collaborates.

## O.6. Product developer 5

*Identified problems:* During the years I have worked here, 2,5 years, I have rarely seen clear measurable requirements that can be checked off as completed. It's also common for everyone to involve themselves in every part of the process, which can lead to confusion and lack of ownership.

*Tool feedback:* "We really need something like this" I can clearly see the added value of this tool. It provides valuable insights into projects. I wonder how much training or learning is needed for using the tool.

*Tool recommendations:* Adding a pre-set list of steps to the planning section would save time and ensure that steps are not missed. This would help avoid situations where essential steps, such as making an assembly instruction, are overlooked. The tool looks somewhat overwhelming to me right now. To make it more approachable for the team, maybe not use everything at once but gradually adopt more features.

# P. ReadMe file of tool

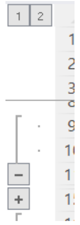
## Read Me van *The Excelerate tool*

In principe heeft de tool niet veel bewerking nodig en hoeven alleen de vlakken met de witte vlakken worden ingevuld, de rest is een template of wordt automatisch ingevuld. Maar de voglende aspecten zijn handig om te weten voor het gebruik of later eventuele aanpassingen te maken. Wil je iets bereiken in een cell maar je weet niet hoe dit te bereiken? Raadpleeg internet, chatGPT of microsoft support.

### Groeperen van rijen of kolommen

Items kunnen worden gegroepeerd om secties van gegevens in te klappen of uit te vouwen. Groepen in groepen kunnen ook worden gemaakt.

1. Selecteer de rijen of kolommen die je wilt groeperen.
2. Ga naar **Data** en klik op **Group**
3. Je ziet nu een + of – symbool waarmee je de groep kunt in- en uitklappen.
4. met het 1 of 2'tje klapt alles in een keer in of uit.

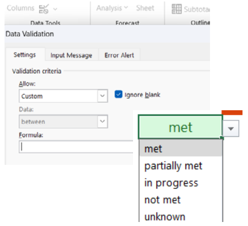


### Gegevens validatie

Data → Data validation → list → typ opties onder 'source'.

Met gegevensvalidatie kun je een lijst met opties maken waaruit de gebruiker kan kiezen. Dit voorkomt ongeldige invoer en zorgt ervoor dat je minder zelf hoeft te typen.

1. Selecteer de cel of reeks cellen waarin je een keuzelijst wilt maken.
2. Ga naar de tab **Data** en klik op **Data Validation**.
3. Kies in het menu bij **Allow** voor **List**.
4. Voer de opties voor de keuzelijst in, gescheiden door komma's, of selecteer een reeks cellen die de opties bevat.
5. Met het rechter pijltje bij de kolom kan je de opties voortaan kiezen.



### Rij of kolom toevoegen

1. Rechtermuisklik onder de rij of rechts van de kolom
2. Kies **invoegen**
3. Een rij of kolom wordt nu boven de rij of links van de kolom toegevoegd.

### Eigen formule toevoegen

Een formule kan worden toegevoegd door in de cell te beginnen met "="

Bijvoorbeeld: =A1*A2.

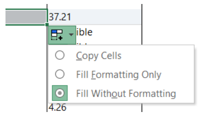
Als je wilt dat de cell leeg blijft wanneer in A1 en A2 niks staat, kan een IF statement worden toegevoegd: =IF(COUNTBLANK(A1:A2)=ROWS(A1:A2), "", A1*A2))

Deze formule geeft lege tekst terug wanneer A1 en A2 leeg zijn, en als dat niet waar is geeft die A1*A2 terug.

### Formules doortrekken

Formules kunnen worden doorgetrokken naar andere cellen.

1. Selecteer de cellen
2. Klik rechtsonder en trek door naar de gewenste richting
3. Als je wel de formule wilt nemen, maar niet de formatting, klik het icoon rechtsonder en **fill without formatting**



### Voorwaardelijke opmaak

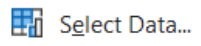
Met voorwaardelijke opmaak is ook veel mogelijk. Cellen kunnen een opmaak krijgen op basis van hun waarde in de cel, of op basis van een formule.

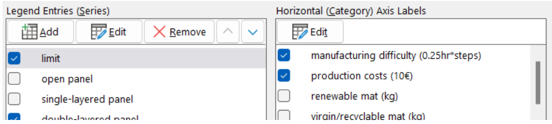
1. Conditional formatting
2. Klik **new rule**

### Selecteren van gegevens in het radar diagram

In de diagrammen kan het zijn dat je verschillende concepten of performance indexes wilt weergeven. Gegevens selecteren werkt op dezelfde manier voor ieder ander diagram.

1. Klik met de rechter muisknop op het radar diagram
2. Klik **gegevens selecteren**.
3. Selecteer de concepten en performance indexes naar keuze





Legend Entries (Series):

☑ limit
☐ open panel
☐ single-layered panel
☑ double-layered panel

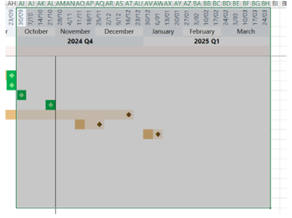
Horizontal (Category) Axis Labels:

☑ manufacturing difficulty (0.25hr*steps)
☑ production costs (10€)
☐ renewable mat (kg)
☐ virgin/recyclable mat (kg)

### Planning uitbreiden

De planning kan gemakkelijk worden uitgebreid door de kolommen door te trekken. Als je het per half jaar doet dan gaat de invulling van de kleuren ook gelijk goed. Je kan altijd daarna weer een deel van de planning verwijderen.

1. Selecteer voor een half jaar de planning, ook de onderste rijen, zodat de voorwaardelijke opmaak van de planning eronder ook mee wordt genomen.
2. Klik op het vierkantje rechtsonder
3. Sleep het gebied naar rechts

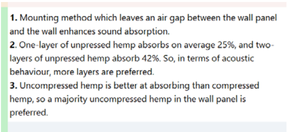


Optioneel kunnen er extra ruiten worden toegevoegd op de planning door een "u" in het schema te typen.

### Nieuwe regel in een cel invoegen

In sommige gevallen wil je meerdere regels tekst in één cel invoeren. Dit kan eenvoudig worden gedaan door een regelovergang in te voegen.

1. Klik in de cel waarin je tekst wilt invoeren.
2. Druk op **Alt + Enter** om naar de volgende regel te gaan binnen dezelfde cel.



**1.** Mounting method which leaves an air gap between the wall panel and the wall enhances sound absorption.
**2**. One-layer of unpressed hemp absorbs on average 25%, and two-layers of unpressed hemp absorb 42%. So, in terms of acoustic behaviour, more layers are preferred.
**3.** Uncompressed hemp is better at absorbing than compressed hemp, so a majority uncompressed hemp in the wall panel is preferred.

### Lock cells

Door cellen te vergrendelen, kun je voorkomen dat anderen per ongeluk belangrijke gegevens wijzigen. Dit is nuttig wanneer je een werkblad wilt delen, maar bepaalde informatie beschermd wilt houden.

1. Selecteer de cellen die je wilt vergrendelen.
2. Klik met de rechtermuisknop en kies **Format Cells**.
3. Ga naar het tabblad **Protection** en vink het vakje **Locked** aan.
4. Om de vergrendeling daadwerkelijk in te schakelen, moet je de werkmap beveiligen:
   - Ga naar de tab **Review** en klik op **Protect Sheet**.
   - Je kunt optioneel een wachtwoord invoeren om extra beveiliging toe te voegen.

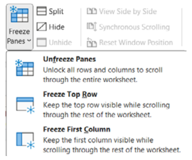
Protect Sheet

Nu zijn de geselecteerde cellen vergrendeld en kunnen ze niet worden bewerkt tenzij de bescherming wordt opgeheven.

### Freeze panes

Met de functie **Freeze Panes** kun je bepaalde rijen of kolommen vastzetten zodat ze zichtbaar blijven wanneer je door de rest van het werkblad scrolt. Dit is vooral handig voor lange tabellen met kopteksten.

1. Selecteer de cel onder de rij en rechts van de kolom die je wilt vastzetten.
   - Als je bijvoorbeeld de bovenste rij wilt bevriezen, klik dan op cel A2.
2. Ga naar de tab **View** en klik op **Freeze Panes**.
3. Selecteer een van de volgende opties:
   - **Freeze Panes**: Bevries rijen en kolommen boven en links van de geselecteerde cel.
   - **Freeze Top Row**: Bevries alleen de bovenste rij.
   - **Freeze First Column**: Bevries alleen de eerste kolom.



Je kunt de vensters ontgrendelen door naar **Freeze Panes** te gaan en op **Unfreeze Panes** te klikken.