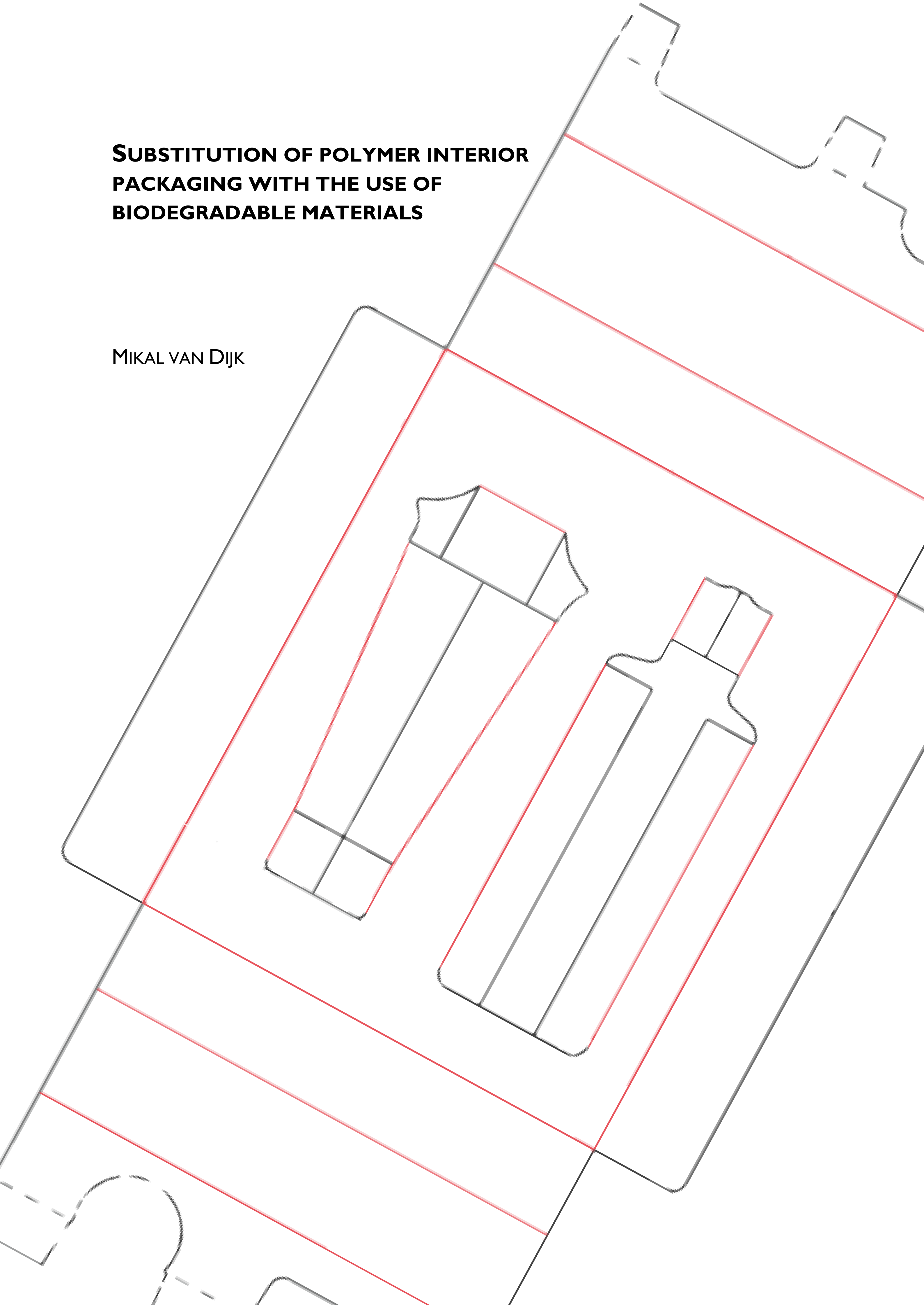
Substitution of polymer interior packaging with the use of biodegradable materials

Mikal van Dijk



MASTER THESIS:

SUBSTITUTION OF POLYMER INTERIOR PACKAGING WITH THE USE OF BIODEGRADABLE MATERIALS

Mikal van Dijk
S1561472

University of Twente
Industrial Design Engineering
Emerging Technology Design
May, 2021

Graduation Committee
prof. dr. ir. E. van der Heide, supervisor
dr.ir. D. Lutters, external member
dr. D.T.A Matthews, internal member

ABSTRACT

The use of plastic in packaging has brought a number of problems into our world and although many people have been working on solutions, the situation calls for more action. The subject of this thesis was the redesign of an interior packaging with the focus of replacing the plastic material. Due to sustainability problems with plastic use, an alternative material was subject of research. The combination of the new material and altered design should lead to a viable packaging. The viability depends on the packaging's ability to protect the contents while also carefully presenting the products.

In order to find a new material for the interior packaging, a material selection process was needed that compares multiple attributes. Also, the relations between material properties were needed in order to score them accordingly. A method that proved feasible was the House of Quality method. With this method, materials can be ranked based on their measurable properties and how they affect the requirements for the interior packaging. As a result of the selection process, paper and board could be contestants for replacing plastics for the interior packaging. Bioplastics may also be a second option.

A case study was executed at Van de Steeg, a printing and packaging company. A specific product-packaging combination was to be designed with computer aided design and rapid prototyping. The case study started from a die-cutting and folding-gluing production process and a large set of packaging materials, which are fiber-based including paper and board. The approach for this part consisted of the following design phases: analysis, idea, concept and detailing. During the design phases, multiple concepts were generated. These concepts were then evaluated on aspects including production, assembly, protection and aesthetics. The concept that scored the highest received more iterations to improve the design in the detailing phase.

In the later stages of the packaging design, a number of tests were conducted to assess the protective performance of the packaging. The assessment of the interior packaging consisted of impact and vibration testing. These tests have been performed with multiple materials and designs. The results showed that thinner materials could not compete with plastics, while the higher grammage materials performed sufficient in these tests.

In conclusion, a viable packaging was designed and tested based on a biodegradable alternative. Although this alternative is currently less protective and more costly than plastic packaging, it will help with countering the plastic waste problem.

It is recommended to carefully select the material thickness for paper and board per product. A flowchart that helps the designer with the material selection supports optimizing the interior packaging. Digital testing may also support the optimization of the interior packaging.

Experimenting with bioplastics is also recommended, since the experimental study did not include them. Finally, extra actions could be taken to further stimulate the use of paper and board and bioplastics by putting more effort into processes that increase the sustainability.

Foreword

My thesis is the last step to completing my master Emerging Technology Design within Industrial Design Engineering at the University of Twente. The completion of this master thesis has been quite a journey for me. During the ideation phase, a lot of interesting insights were gained that could result in a very interesting branch within packaging. Ideally, more of this type of packaging could be included in the assignment. However, the focus remained on making a realistically viable prototype that could be produced. I am very enthusiastic on working with geometrically challenging packaging ideas and concepts and I hope others will continue exploring this path instead.

During the assignment, there were many daunting tasks which felt like enormous obstacles that were in the way of completing my research, but in the end, I have overcome each of these obstacles and as a result, I have been able to bring closure to this chapter in my life.

I want to thank Emile van der Heide for his role of supervisor in this assignment and the many moments of feedback. I would also want to thank Derk-Jan Marsman for giving me the opportunity to execute a large part of the assignment at Van de Steeg and Ramon Westening for being my supervisor at Van de Steeg.

My parents have stood by me to support me throughout the course of the assignment and more importantly, through the tougher moments that I have endured. I want to thank a dear friend of mine, Tim Velthuis, who was very capable in helping me out on multiple aspects of the assignment. Another big help was John Bierlee, who has provided a lot of feedback on many elements.

Mikal van Dijk
20 May, 2021

TABLE OF CONTENTS

Chapter 1:
Introduction

1.1 Background

The last few decades, the world has been more focused on making life more environmentally friendly due to the exponentially increased amount of waste that is produced. Each sector responsible for producing waste is trying to find new methods to lower their negative impact on the environment. Specifically plastic waste is resulting in more problems and more solutions need to be found to keep the situation as sustainable as possible in the future. The annual production of plastic comes down to 280 million ton, of which 18.5 million tons is from just the packaging use in Europe. To put this into perspective, this is 39% of the plastic demand in Europe. It is clear that one of the biggest causes for the packaging waste problem is the packaging sector (B. Luijsterburg et al, 2014).

Because plastic does not biologically degrade thus its cycle does not end when it is not correctly disposed of. A tremendous effort to recycle as much plastic as possible is therefore necessary, but there is more possible than just recycling alone. Due to stricter legislation, packaging producers have to look for alternatives for their plastic packaging as well. This can have consequences for their production methods and therefore their entire packaging (European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste). With many trends focused on the environment, consumers have also shifted their needs towards packaging with fewer plastics since there has been more negativity around plastics and their use because of plastic pollution. Therefore, it should be a careful consideration nowadays to implement it as a material in products such as packaging. Many producers opt to hide the plastic components as to make a consumer not realize that it contains materials that are negative for the environment, which is called greenwashing. This, however, does not solve the plastic waste problem and more actions are necessary to prevent the amount of plastic waste to grow to a higher number. This can be done by working with alternative, more sustainable materials instead of plastics. Thus, a market demand for more sustainable packaging arises.

It is important to examine plastic packaging to determine why it is used in the first place. Plastics are widely used for their beneficial attributes in production, which allows for mass production and plastics offer a much flexibility in the design. Low production and material costs are of extreme importance because packaging production quantities are massive. Any savings in material or production cost per product is therefore highly valued. Plastic has a positive performance to weight ratio. Light plastic structures can still maintain their structure when it undergoes impact for example, which enables savings in transportation. All of these properties make plastics ideal for packaging. The versatility and design flexibility that plastics offer can give a packaging the edge on rivaling packaging materials. The movement towards using plastics has also been driven by these other benefits that they offer to high-end packaging applications, such as:

- Transparency
- Specialized effects with full or partial visibility
- A high variation on visual properties
- Overall good barrier properties, and many options to create the most ideal mix of properties (oxygen and moisture)
- Excellent colouring ability
- Recyclability
- User convenience

Now that the positive aspects of packaging are covered it is time to introduce the negative side. After all, there are reasons to look at replacing more plastic from packaging. The process of plastic pollution has been a rising problem since the last few decades. Cities, shorelines and the countryside have all been affected by a higher amount of plastic waste. The cause of this problem is that plastic biologically degrades very slowly, so waste will remain for a long timeframe. Plastic items such as cosmetic and food containers are among the more common found items in nature for decades. Scott, 1972). Another reason to use fewer standard plastics is because they are not a renewable resource. Plastics will gradually become scarcer and therefore more expensive. Plastics are mostly used when a product needs to be packed in certain conditions, such as food. Plastic barriers make sure that the product holds the right level of humidity and oxygen for example. In many cases, there is no need for these barriers and plastics are only used for their cheap and quick production. The plastic packaging is then overqualified and it could be exchanged more easily than a product that needs those barriers. When transitioning to a lower usage of plastic, the products that do not need certain packaging conditions can be packed in other materials.

Although plastic has its advantages, it is clear that with the current scale of production, too many problems occur. To work towards a more sustainable situation, a part of the current plastic packaging should adapt to alternative materials to prevent a further increase to the amount of waste.

1.2 Scope

The assignment at hand is to determine what the possibilities are from mechanical point of view to replace plastic interior packaging with a biologically degradable (from here on named: biodegradable) version. The main focus of this research is to discover a suitable material and design. The term mechanically means that the packaging will need to protect the product against forces, such as impacts and vibrations. The use of biologically degradable materials is recommended to counter the harmful effects of plastic packaging and its production for the environment. Scientific research on the topics of biodegradable materials, production processes and packaging design has been conducted which shows that there are restrictions when designing such an interior packaging. The sustainability problems with plastic are exchanged for problems concerning the protective properties of the new material. In order to rightfully replace plastics, the new material should offer enough protection to the product in combination with its design.

1.3 The assignment

This assignment started at Van de Steeg, which was a print and packaging company. Van de Steeg provided creative and innovative solutions for their clients in multiple markets such as media, cosmetics and electronic devices. Their packaging could be found in numerous stores within the Netherlands and worldwide.

Figure 1: Van de Steeg packaging example

Van de Steeg encountered a problem concerning the regulations on plastic packaging with one of their clients. This client asked for a replacement of the plastic packaging interior packaging.

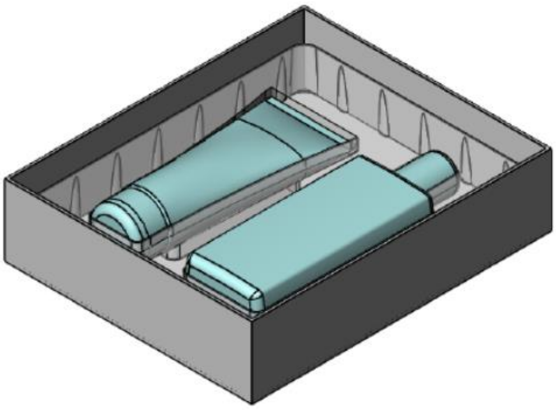


Figure 2: Example of the current interior packaging

The plastic component that can be seen above in Figure 2 is called the interior packaging. Its function is to present and hold the products inside the box. At the start of the assignment, it was unclear for which product(s) the new interior packaging had to be created. One example packaging that would lead to problems when switching the material is the example in Figure 3. Due to the high number of products in this gift set, constructing an interior packaging out of a new material was quite a challenge.

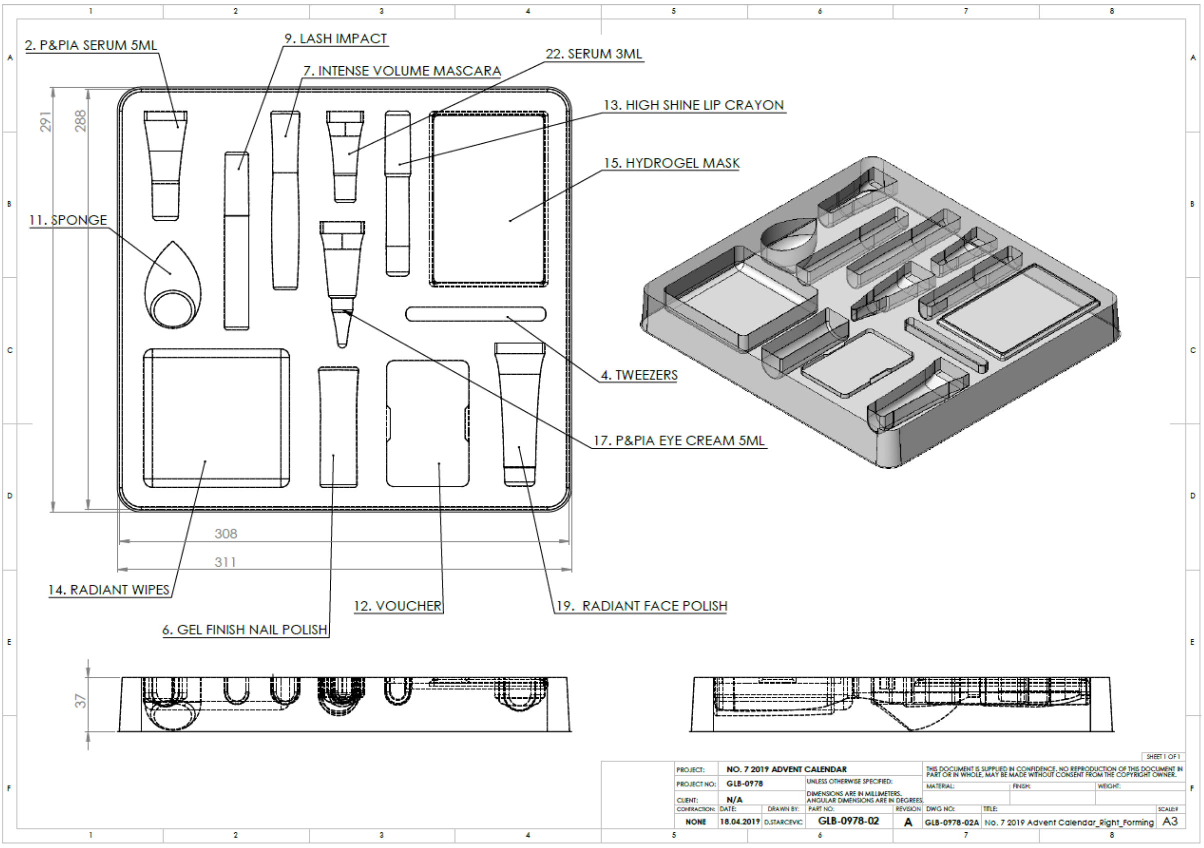


Figure 3: Example interior packaging for multiple products

Throughout the course of the assignment, the focus has shifted from this complex interior packaging with multiple products (Figure 3) to the more common interior packaging with fewer products (Figure 2: example of the current interior packaging). The material choice was the first priority in the new case, which would then become the input for the design and production afterwards.

In the end, the goal is to support the production of biodegradable alternatives to plastic packaging. The available equipment at Van de Steeg is utilized to execute the experimental side of the assignment in the form of a case study. The packaging that is developed during the case study can then be validated with testing afterwards.

1.4 Problem definition

Plastics are used for packaging due to their high strength. Plastic packaging can therefore be lightweight. Its next benefit is its ease in production, such as allowing mass production and difficult geometries. Plastics can also contain products well by offering micro barriers that keep products such as food fresh and sealed off. However, this last property does not find use in mechanically protective packaging. With stricter laws on plastic production due to pollution and the fact that plastic does not biologically degrade, packaging producers are looking for alternatives to create their packaging with. Starting from July 3rd 2021, there will be a ban on single-use plastics within the EU. (KVK, 2021)

Each year, more than 400 million tons of plastic are produced in the world, with a third of that amount coming from packaging. Between 1950 and 2015, 8.3 billion tons of plastic have been produced, which is more than a 1000 kilos per head of the present worldwide population.
Of that 8.3 billion tons, about 30% (2500 million tons) is still in use. In that same timeframe, 6300 million tons of plastic waste has been created. Some 12% (800 million tons) of this rubbish has been burnt, and 9% (600 million tons) has been recycled. Of the recycled plastic, only 10% is again recycled. The remaining 79% of the plastic rubbish ended up on rubbish tips or thrown away in the environment. If production continues at the present rate, there will be approximately 1.2 billion tons of plastic rubbish on rubbish tips or dumped in the environment in 2050 (Plasticsoupfoundation.org, 2019).

Simply put, the plastic waste problem has been around for years and it is time to take drastic measures in order to lower the total amount of plastic waste. The subject already has many working researchers in many different fields, such as recycling. Recycling is only a tool that can help prevent a small amount of this plastic waste and preventing the production could be another.

By using different materials than plastic, other variables change on aspects such as production and design. These materials can be used differently to create new packaging for a more sustainable future.

Figure 4: The starting situation, a box that can be filled with a black box to hold the products.

In the scope of the project, the plastic components that protect the products inside of a box are going to be replaced with a viable alternative. Whether these alternative materials can compete with plastic in terms of production and protection will also be and then compared to the old packaging. The objective is to design a packaging concept that suffices as a viable alternative to plastic.

1.5 RESEARCH QUESTIONS

From the problem definition, the main research questions can be formulated. The interior polymer packaging needs to be replaced with a viable alternative in terms of material. The scope of the project points towards a biologically degradable material. The options for such a material need to be researched. An important question to ask is: When is a material viable? The mechanical properties are the focus in the material replacement. The material choice also has an effect on the production process and therefore the packaging design. What are the encountered constraints? After creating the packaging with this new material, it needs to be compared to the plastic interior packaging to check its viability as a new packaging. Below is a summation of the questions in an overview.

Main research question:
How can polymer interior packaging be mechanically substituted with the use of biologically degradable materials?

The sub-research questions are:

1. What are the viable options for biodegradable materials in packaging?
2. What are the production methods that are fit for creating a biodegradable interior packaging?
3. How can a viable design for a new biodegradable packaging be designed?
4. How well does a biodegradable interior packaging mechanically perform compared to their polymer equivalents?

1.6 Approach

The methodology will be explained in Chapter 2, where the approach for the theoretical side will be generated in order to research the subjects through scientific means. This is followed by the theoretical framework in Chapter 3. Here, the knowledge is gathered on relevant topics in the research. This knowledge can then be used to create an inventory of the possibilities in the fields of materials and production processes. This inventory will then be processed with a method to make a selection of the most viable options. In Chapter 4, the material and production process selection are explained. After the material and production process selection, it is time to work on the packaging design in Chapter 5. Here, the case study that is performed at Van de Steeg that is focused on the use of fiber materials is presented. The prototypes from Chapter 5 will be mechanically tested in the next chapter to determine the viability of the new packaging. The final chapter presents that conclusions, followed by a recommendation.

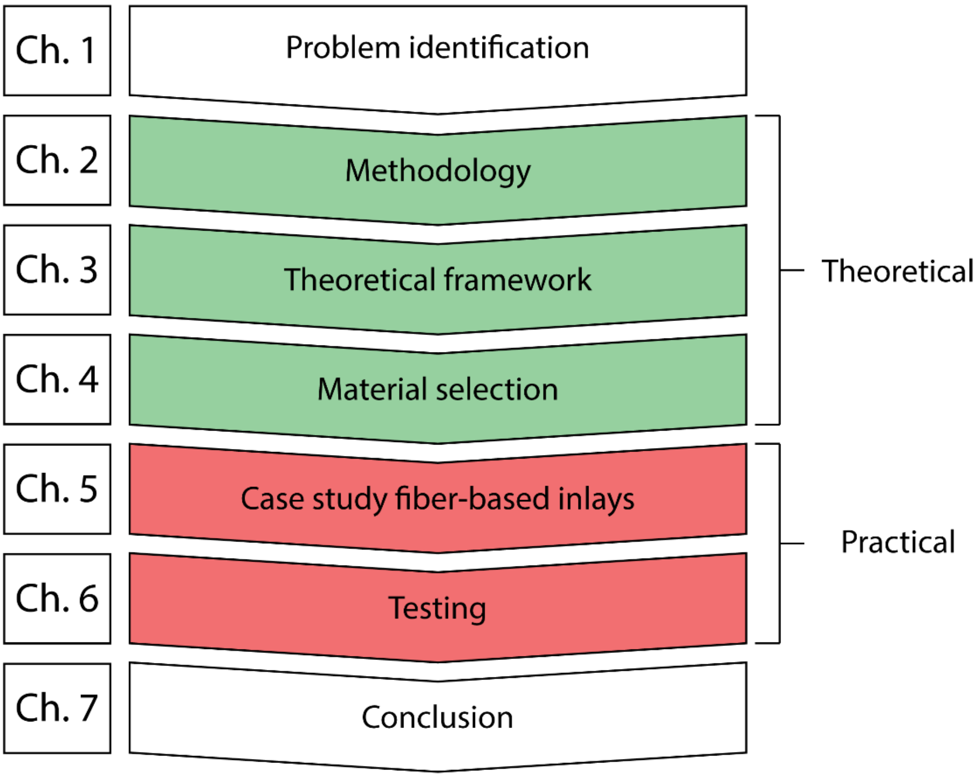
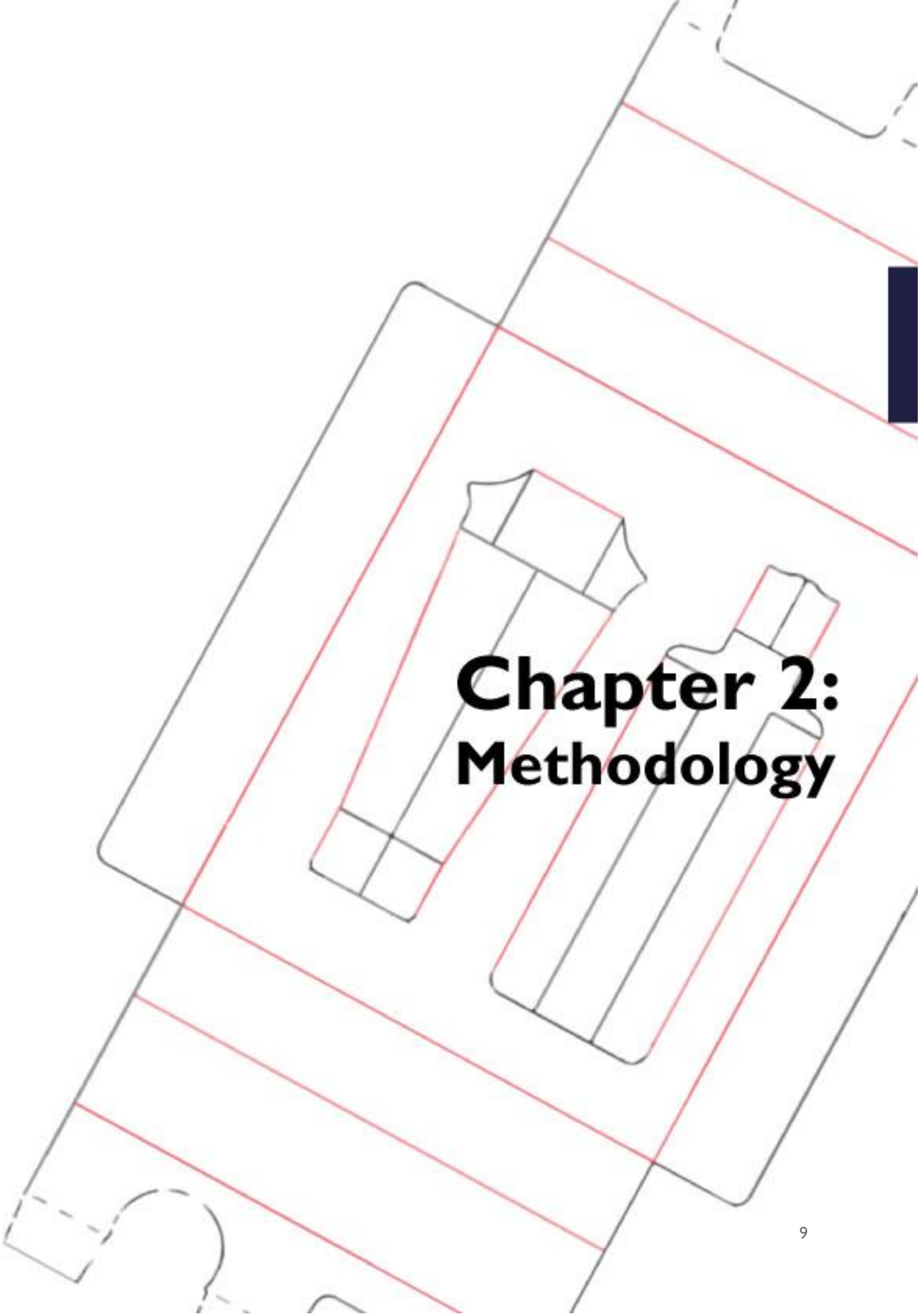


Figure 5: Approach

In the custom Figure above, these steps are visualized. The Figure is inspired and therefore loosely based on an existing approach by Govindan, 2016, but tweaked towards the fulfilment of this assignment.



Chapter 2: Methodology

This section presents the methodology to get answers to the formulated research questions in Chapter 1.5. This methodology is inspired by Matchett's Fundamental Design Method. The concept of this method can shortly be described *'the extent to which a designer is able to improve further his design ability, is closely allied to the extent to which he can become aware of his mental skills and attitudes employed in designing'* (Matchett and Briggs, 1966)

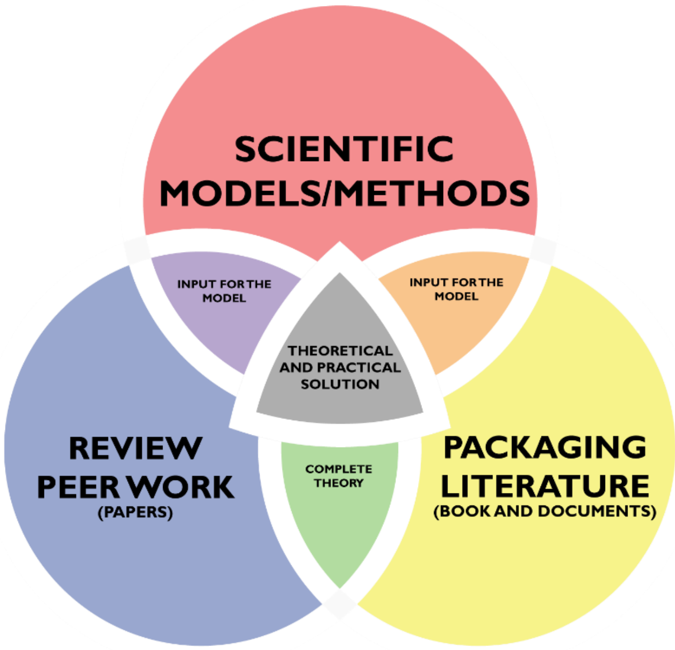


Figure 6: Methodology overview

The Figure above portrays the way of thinking that is used during this assignment. Although the Figure provides a decent overview, some additional information is added to explain it more thoroughly:

- Scientific models/methods: The models/methods that are used to provide answers to the research questions.
- Review peer work: All the papers found on websites such as Scopus and Google Scholar
- Packaging literature: Packaging lectures along with R. ten Klooster et al (2015)

Both reviewing peer work and packaging literature provides information that is necessary for using scientific models. All elements combined lead to a theoretical solution.

2.1 Selection methods

The process to select viable materials needs to follow existing models to provide a scientific insight. It is a task that is difficult to perform due to the vast array of materials that are out there. When selecting materials, there is not always a single right answer. There are multiple selection criteria that make the process even more difficult. Many papers on material selection exist and they help to shape a model that can be used for this specific engineering assignment.

In order to select the best possible materials, a combination of selection methods can be addressed and implemented. 'In choosing the right material, there is not always a single definite criterion of selection and the designers and engineers have to take into account a large number of material selection criteria.' (Rao & Davim, 2006)

Ashby (2014) describes a method that handles the material properties and compares them based on their relative importance. It should result in finding suitable materials for this specific engineering application.

The method for material selection will start with a top-down approach. Secondly, a bottom-up approach can also be used. With some thinking, materials that seem like a logical solution can be pre-selected to see what their properties are and why those materials could be viable for selection. As a third and last addition to the material selection methodology, insights from previous papers on the selection of packaging materials can be used to review how and why certain materials were selected and to check if those materials are viable in this situation as well. The definite selection will be based on how specific materials score based on certain properties. These properties have an order of importance. This importance is based on the needs of the packaging. These needs will be explained later on during the implementation of the material selection process in Chapter 4.

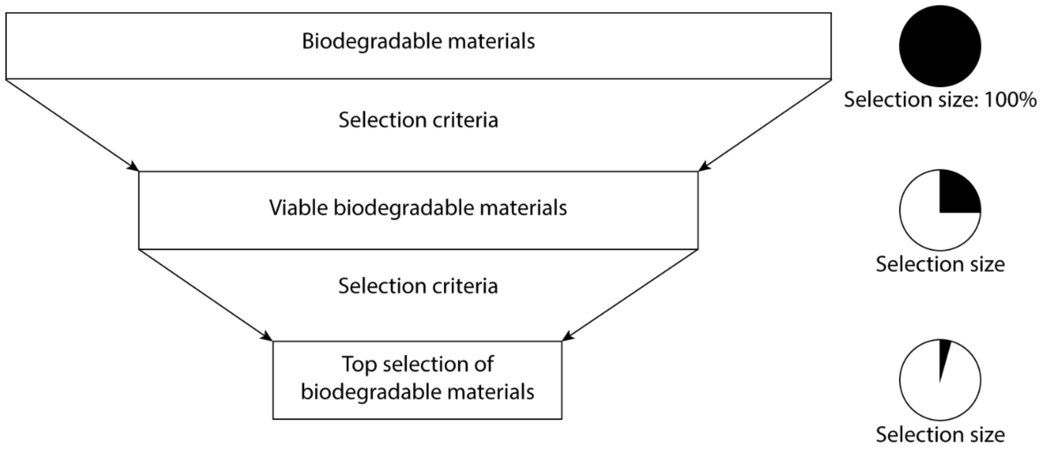


Figure 7: Material selection funnel model

After these steps, a more concrete material selection can be executed with the help of a model. A method that is suitable for selecting materials as well as a production process is the House of Quality method (HoQ)[1]. The method can be classified an analysis tool that shows how requirements relate to methods of fulfilling those requirements. It derives its name from its matrix design, which resembles the outline of a house with a roof, as can be seen below.

Multiple selection methods exist and the correct choice mainly depends on the known constraints of the goal and how well those directly translate to available information about possible materials. As part of the material selection, deciphering what kind of properties are needed for the best packaging is important. Because of this aspect, weighing the desired requirements and finding out which measurable material properties affect those requirements would be ideal.

A few selection methods can only be applied when a most of the required material information is available, such as the TOPSIS method (Shanian and Savadogo, 2005), which operates on matrix mathematics with all the material information as an input. Methods as these are hard to perform when different material groups need to be compared and the materials have different units for their properties.

For packaging design, there's more to think about that just the function, although the outcome based on such a selection method should provide with a better material when talking about its efficiency for its main function, protecting the contents.

Based on the amount of information on materials choosing HoQ over other selection methods seems the right choice. Contrary to the other methods, HoQ does not necessarily need detailed data. Instead, HoQ aims to discover the positive or negative relations between properties and requirements to be able to make the material selection.

[1] https://www.whatissixsigma.net/house-of-quality-qfd/

There is a custom method that closely resembles HoQ because it is also categorized as a quality function deployment method (QFD). It also works with relations between requirements and properties, but it is more detailed on the specific properties.

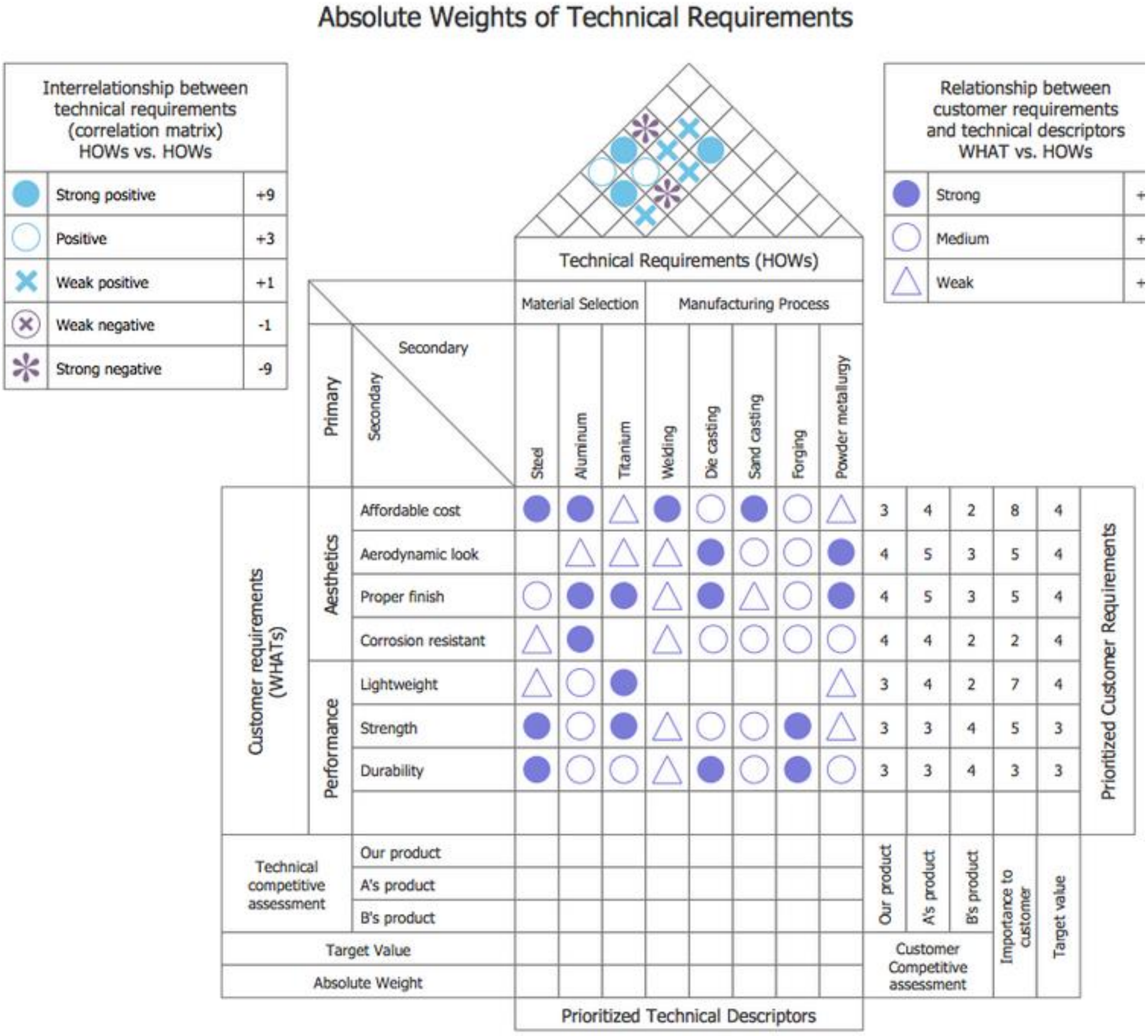


Figure 8: Material selection and manufacturing process in HoQ example

With the help of this method, design requirements can be translated into material specifications. Materials can then be ranked by their ability to meet the required aspects. The HoQ is a broad method and used in many situations around product design. Using it for material selection is viable but not its most common use. The Figure above portrays an example of using HoQ for the use of material and production process selection (Isaac et al, 2015)

2.2 DESIGN FOR PACKAGING

The design for packaging can be done with the help of packaging theories. Sources such as the guide 'Zakboek Verpakkingen' by Ten Klooster et al (2015) give a broad understanding of the topics and how to work with packaging. Many questions that will be encountered during the design process can be answered with the validation of existing packaging theories.

Methodologies for a more sustainable packaging can be used to streamline the approach on the design aspect. Such methodologies focus on specific components of sustainability. With the material switch from plastics to a biodegradable alternative, the focus lies heavily on lowering the amount of waste after use. The user friendliness may also be improved by using an alternative material, partially because of its ease to handle as waste, but also because it will be handled differently by the consumer.

Svanes et al (2010) describes his methodology for sustainable packaging under the following main categories: environmental sustainability, distribution costs, product protection, market acceptance and user friendliness. Its use is also indicated for packaging design and optimisation as well as idea generation. These themes are reoccurring in the 'Zakboek Verpakkingen' and together, they provide a theoretical base to use while conducting the redesign of the interior packaging.

2.3 MECHANICAL TESTING

To provide an answer to the last sub-question and also the main research question, it is important to validate the results. This can be done by mechanically testing the new packaging with existing methods. The testing methods that can be performed depend on the available equipment and the needs of the packaging that need to be tested. The emphasis lies on the mechanical properties of the packaging. There are methods for all kinds of mechanical testing. These tests come from ISTA norms, whereas ISTA stands for the International Safe Transit Association. These tests will be performed for the plastic component as well as the biodegradable version in order to compare them. Testing more than one type of mechanical interaction will provide a better insight in how the packaging will endure forces. At Van de Steeg there is a machine for vibration testing. Also, impact testing can be done without the need of tools. By following ISTA's step-by-step plans on performing these tests, the tests will provide scientific insight and with a passed test, the performance of the packaging is viable to replace the plastic interior packaging. More details on the equipment and how the testing is done can be read in Chapter 6.

Chapter 3:
Literature study

3.1 BIOLOGICAL DEGRADATION

First and foremost: What is biological degradation? The definition of the term ‘biological degradation’ means the following: “Biodegradation is the process by which organic substances are broken down into smaller compounds by the enzymes produced by living microbial organisms. The microbial organisms transform the substance through metabolic or enzymatic processes. Biodegradation processes vary greatly, but frequently the final product of the degradation is carbon dioxide or methane. Organic material can be degraded aerobically, with oxygen, or anaerobically, without oxygen.

Biodegradable matter is generally organic material such as plant and animal matter and other substances originating from living organisms, or artificial materials that are similar enough to plant and animal matter to be put to use by microorganisms.

So, biodegradable materials can be broken down, by microorganisms. These are usually bacteria or fungi. The process is dependent on a number of conditions: Temperature, oxygen, water and the presence of microorganisms.

Why is biodegradable packaging desired? To lower the large quantity of non-biodegradable packaging waste in nature. Materials such as plastics degrade very slowly, with many plastics that take multiple years, up to centuries. All the packaging that is disposed of in nature is removed from the packaging cycle. With more biodegradable packaging, lower amounts of waste will stay in nature for decades.

Biodegradation is an asset to a material even if normally most of the packaging is recycled. If the packaging ends up outside of the recycling cycle after use it will degrade within a short timeframe, unlike conventional plastics. However, not all biodegradable materials degrade quickly. Some materials still take several years and can even leave toxic waste behind. The downside of biodegradation is that the product cycle ends if the packaging degrades. Therefore, the resources need to be gathered again to replace the packaging, which is not necessary when recycling. Packaging producers have to work with a detailed legislation (EUR-Lex, 1994). However, recycling alone is not enough to counter the massive amounts of plastic that already resides in ecosystems as waste. A combination of recycling along with biodegradability could help with tackling the plastic pollution problem.

When working with biodegradable packaging, the designer needs to meet certain requirements as mentioned in the EN13432 standard. This standard lists the requirements for the materials.

- Biodegradability, which is determined by measuring the actual metabolic conversion of the compostable material into carbon dioxide. This property is quantitatively measured using the standard test method, EN 14046 (which is also published as ISO 14855: biodegradability under controlled composting conditions). The acceptance level is 90%, which must be reached in less than 6 months.
- Disintegrability, that is, the fragmentation and loss of visibility in the final compost (absence of visual contamination). This is measured with a composting test (EN 14045). The test material is degraded, together with organic waste, for 3 months. After this time, the compost is sieved with a 2 mm sieve. The residues of test material with dimensions higher than 2 mm are considered as not having disintegrated. This fraction must be less than 10% of the initial mass.
- Absence of negative effects on the composting process. This is checked with a composting test.
- Low levels of heavy metals (below the predefined maximum values), and absence of negative effects on the quality of the compost (e.g. reduction of the agronomic value and presence of eco-toxicological effects on the growth of plants). A plant growth test (OECD test 208, modified) is carried out on compost samples where the degradation of the test material has taken place. There must be no difference from control compost. Other chemical-physical parameters that must not be different from those of the control compost after the degradation are the pH, salinity, volatile solids, N, P, Mg, K.
- Each of these requirements must be met simultaneously for a material to be defined as compostable. For example, a biodegradable material is not necessarily compostable because it must also break up during one composting cycle. On the other hand, a material that breaks up, over one composting cycle, into microscopic pieces that are not totally biodegradable, is not compostable.

Figure 9: EN13432 material requirements

It is important to distinguish to which goal the packaging needs to go. Plastic takes years to degrade, so a shorter degradation timeframe is desired. As short as possible would be ideal, but this time is limited by multiple variables; for example, the type of material(s) and the amount of material that the packaging consists of. The EN13432 regulations for bioplastics require a maximum degradation period of 6 months.

Which materials can be selected based on biodegradability? All biodegradable fiber materials, such as papers and cartons, which generally are biodegradable within a few months. In addition, paper pulp also fits this category.

How is this translated to the design of the packaging? Depending on which material is used, a number of production methods are available that provide limitations to the design. Specific materials require specific structures to be effective as protective packaging.

Creating an interior packaging that functions as a mechanical barrier made from biodegradable material(s). It will have an improved biodegradation time when compared to conventional plastic packaging. This comes at the cost of lower mechanical strengths, although the design is altered to provide as much protection as possible with the new materials.

3.2 BIOPLASTICS

Researchers have opted to work more with bioplastics to replace conventional plastics for multiple decades. Specifically for packaging, studies have been collected and the results have been summarized below.

Bioplastics are often composed of a biomass combined with a biodegradable matrix resin. Biomass is generally cheap, therefore providing cost-effectiveness. Cushioning packaging has already successfully been created with bioplastics (Sohn et al, 2019). Starch is an abundant material that can be used in combination with a plasticizer to create a bioplastic that has a positive rate of biodegradation for example.

Bioplastics can be extracted from a large variety of sources such as: directly from natural materials, like polysaccharides or coming from animal and plant proteins, classically synthesized from bio-derived monomers, and even polymers produced by microorganisms or bacteria (Johansson et al, 2012).

Bioplastics have also been implemented in the food packaging industry, where most of the packaging is single-use and therefore costs are the number one priority. Unfortunately, their use is still limited due to their production costs and functionality. Also, their compatibility with other polymers in recycling streams are currently negatively influenced. However, bioplastics have been successfully implemented as food coatings, plat-based capsules and rigid and flexible food packaging (Teck Kim et al, 2014).

There are quite a few types of bio-based polymers with three main categories: The first being polymers directly extracted from biomass, such as starch and cellulose, as well as proteins like casein and gluten. The second category are polymers that are produced by classical chemical synthesis using renewable biobased monomers, such as polylactic acid. The last category are polymers produced by microorganisms, such as polyhydroxyalkonoates. All materials from these categories have been implemented in packaging (Weber et al, 2002).

The performance of bioplastics is still behind conventional plastics, but the most valuable effect of using bioplastics instead of fiber-based materials or conventional plastics is the low carbon footprint.

The findings above indicate that bioplastics are a feasible alternative to conventional plastics.

3.3 Sustainability

The term sustainability is a broad term. In case of packaging, it points to the following topics:
The property of being durable. This can be further specified in terms such as: resistance, solidity, mechanical wear or decay. The used material should last multiple cycles, before needing replacement. For many user products, this is an important factor for the quality of the product. This has a lesser effect on packaging, especially when the packaging is only used once.

By efficiently using energy and materials for packaging, a higher sustainability can be reached. The impact that packaging has on the environment should be lowered through sustainability. This can be done with multiple methods:

- To use no more natural resources than the amount that is gained in the same timeframe. This is possible by using abundant materials, such as fiber-based materials or biomass. Plastics are a non-renewable resource.

- By recycling as much as possible.
  The recyclability per material group strongly differs, with some groups recycling the majority of its uses. A combination where most of the material is recycled along with being biodegradable guarantees a very low waste. The end-of-life cycle for plastic is different than for paper and cardboard. The average recycling percentage for plastics was 29% in 2007 while paper and cardboard were on 80%. Both incineration and landfill were more commonly used to dispose of plastics. (Guérin, 2011)

- By wasting as few energy and resources as possible.
  For this aspect, optimizing the packaging is the most important. The packaging should use the lowest number of resources by exactly providing the protection that the product needs.

- To produce the least amount of waste as possible.
  By improving its effectiveness per mass: The weight of the packaging contributes to higher transport costs and emissions. It is important to lower the amount of waste. A combination of many methods can be used to do this. By recycling, using less materials, optimizing production processes and by removing waste from the planet. For this last point, biological degradation can help. If more packaging is biodegradable, the cycle ends with natural materials.

  From Seong Sohn et al (2019) environmental improvement charges are becoming stricter, consumer demand for ecofriendly products is increasing. Therefore, research and development related to biomass-based materials are actively performed throughout the world. Because biomass is a carbon dioxide (CO_2) sink, it can contribute to the reduction of greenhouse gases when recycled and can be used as a substitute material for many petroleum plastics, having the advantages of being biodegradable as well as harmless to the human body.

3.4 Protective packaging design

Protective packaging should complement the fragility of the product. More fragile products require more protection than bulkier products. In order to assess the amount of protection needed, the fragility of the product needs to be known.

An integrated framework has been designed by Lye and Yeong (2007) for a polyfoam molded packaging. Even though a different method is used, a part of their approach can also be used during the case study for designing a fiber-based biodegradable interior packaging.

By using CAD modelling in combination with the help of an expert designer, a viable packaging can be designed. In their approach, the viability of the packaging is also determined through testing.

In both Lye and Yeong (2007) and Lye and Ho (1991), the sensitive regions of the packaging are mentioned. The focus of improving the viability of the protective packaging should be to improve the weakest sections of the packaging. The performance of the weakest sections can be determined through testing and with multiple design iterations, the packaging structure can be optimized.

Which material properties help a packaging with protecting a product? Protection against multiple types of damages is necessary based on the product. The assignment focuses on mechanical properties. Protection against compression, impact and vibration are needed. The primary packaging should provide a cushioning function to the product to prevent damage.

The primary packaging consists of the interior packaging as well as the box that encloses the product. Both have the objective to protect the product. There is also a secondary packaging that helps with protecting the product during shipment. The secondary packaging is often a cardboard box that contains multiple primary product-packaging combinations (Kumar, 2012).

Chapter 4: Material selection

4.1 THE PROBLEM IDENTIFICATION

By following the methodology for material selection as described in Chapter 2.1, the first task to perform is the identification of the problem. This is already mentioned in Chapter 1.4. Below is a recap of the problem identification.

"Plastics are a viable material to use for packaging due to its high strength, therefore being lightweight and its ease in production, such as allowing mass production and difficult geometries. Plastics can also contain products well by offering micro barriers that keep products such as food fresh and sealed off. However, this last property does not find use in mechanically protective packaging. With stricter laws on plastic production due to pollution and the fact that plastic does not biologically degrade, packaging producers are looking for alternatives to create their packaging with. By using different materials than plastic, other variables change on aspects such as production and design. These materials can be used to create new packaging for a more sustainable future."

4.2 THE SELECTION OF ALTERNATIVES

In this phase, the selection of alternative materials is made. It involves a large number of materials that could be used for the new packaging. As mentioned in Ashby (2004) there are three selection strategies that can be utilized, even in combination with each other.

The first method is based on quantitative analysis, which is fast and efficient, but needs detailed inputs in an analysable form.

An initial selection of materials needs to be made to fasten the selection process as described in Shanian (2004): 'Also, minimum constraints on the materials under question should be applied to screen a number of candidate materials from all the materials available in a database.' The constraints for this material selection are defined as followed:

- The material is biodegradable
- The material cost is below 20 EUR/kg, a maximum price for the packaging material should make sure that the selected material is viable in terms of cost. The exact price per packaging depends on the price/kg or price/volume and the mass or volume that is needed to protect the product. The materials that have the highest strengths and resistance per cost are the most viable options.

With GRANTA Edupack, a software with a material database and options for material selection, these first constraints can be used as input for the first general selection of materials. Properties such as costs, tensile strength and density will be taken into account for the next part of the material selection.

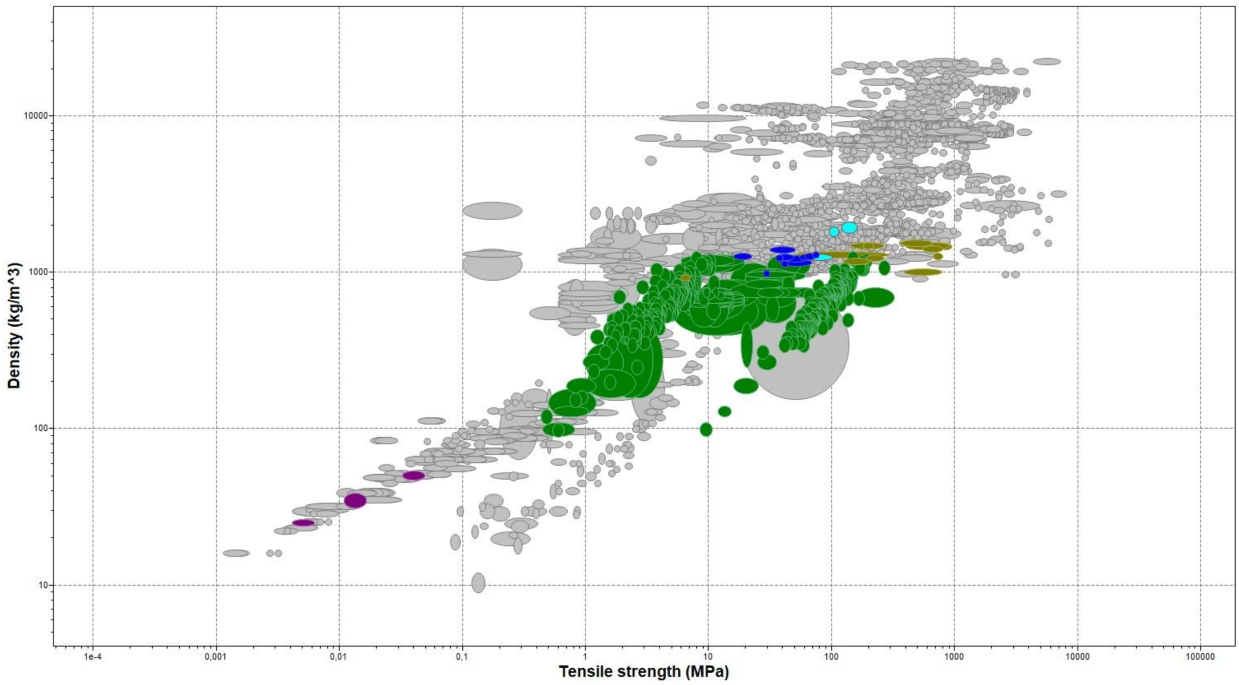


Figure 10: First screening made in GRANTA EduPack based on initial constraints

The highlighted materials are those that passed both the constraint on biodegradability and the cost of 20 EUR/kg.

The materials that are still in the selection are the following:

Fibers
Wood
Bioplastics from starch
Mineralized tissue (e.g. bone)
Resin-impregnated paper
Rejected materials

Figure 11: Legend materials

Although mineralized tissue fits the constraints, it is not a viable material choice.

4.3 The selection of criteria

In order to select viable materials, the selection criteria must be set-up. As mentioned by Ashby (2004) *'to convert a set of inputs—the requirements of the design—into a set of outputs—a selection of material and process.'* In order to find out which material properties are desired it is important to review previous research done on protective packaging.

Protective packaging comes in multiple forms, such as foams, loose filler material such as packaging peanuts, barricades and specifically designed interior packaging. Insights from Lye and Yeong (2007) show that the packaging market desires more than just protection, f.e.: quality conformance, response time, delivery dependability, product variety and volume flexibility. Another aspect is that a designed interior packaging fits better and is more aesthetically pleasing than filler material. From a design perspective it makes more sense to design a fitting interior packaging for the product that needs to packed.

Packaging always needs to be economically viable in terms of costs. A lightweight material is also desired to lower the total waste mass and volume. The efficiency that a material uses to protect a product. The combination of these constraints can be formulated as this: The material that offers the highest protection per mass while having the lowest costs per mass is the most suitable. These constraints may be conflicting so they may need to be factored accordingly on their importance.

Another aspect of packaging is that the production quantities are often large. For example, in the UK alone, around five million tons of plastic is produced each year, with nearly half of that amount being used for packaging (Smith, 2021). It is necessary that the material needs to be abundant, while being easy and fast to process to meet the production requirements.

General properties:
- Costs:
    - Material costs: The material costs should be as low as possible, because packaging involves mass production. Therefore, every cost difference has a large impact.
    - Production costs: The production costs of the packaging should be as low as possible, because packaging involves mass production. Therefore, every cost difference has a large impact.
- Density: A lightweight packaging is desired. The material should have a low mass to lower the total amount of packaging waste and to create a light interior packaging for the product. A low mass is obtained when a material has a low density with high protective properties. This needs to be expressed in the right terms to compare it to other materials.

Protective properties:
Protection of the product and maintaining the interior structure are necessities that the interior packaging should provide.
- A high Young's Modulus: A material with a high Young's modulus resists deformation (it is the ratio of tensile stress to tensile strain).
- A high shear modulus: A material with a high shear modulus resists deformation (it is the ratio of shear stress to shear strain).
- A high compressive strength: A material with a high compressive strength withstands a higher compression force before it fails.
- A high tensile strength: This indicates how much stress can be applied to a material before it breaks.
- Elongation: A material that can undergo elastic deformation well is not easily damaged. A material that deforms may help with user friendliness.
- Fracture toughness

A combination of high strengths with the ability to elongate ensures that the packaging material can optimally resist mechanical forces.

A sidenote is that the above-mentioned strengths are not always clearly given with material specifications. In datasheets from fiber-based packaging suppliers, strengths are mostly provided in the form of bending stiffnesses for example. However, stiffness is a geometrical property, whilst the above-mentioned strengths are material properties.

Sustainability properties:
- Carbon footprint: The amount of kg/CO_2 per kg product.

Other properties:

- Material transparency: If the material has options for transparency, it has a higher flexibility in implementation.
- Printability: A material that can easily be printed on has an advantage versus tougher to print materials.

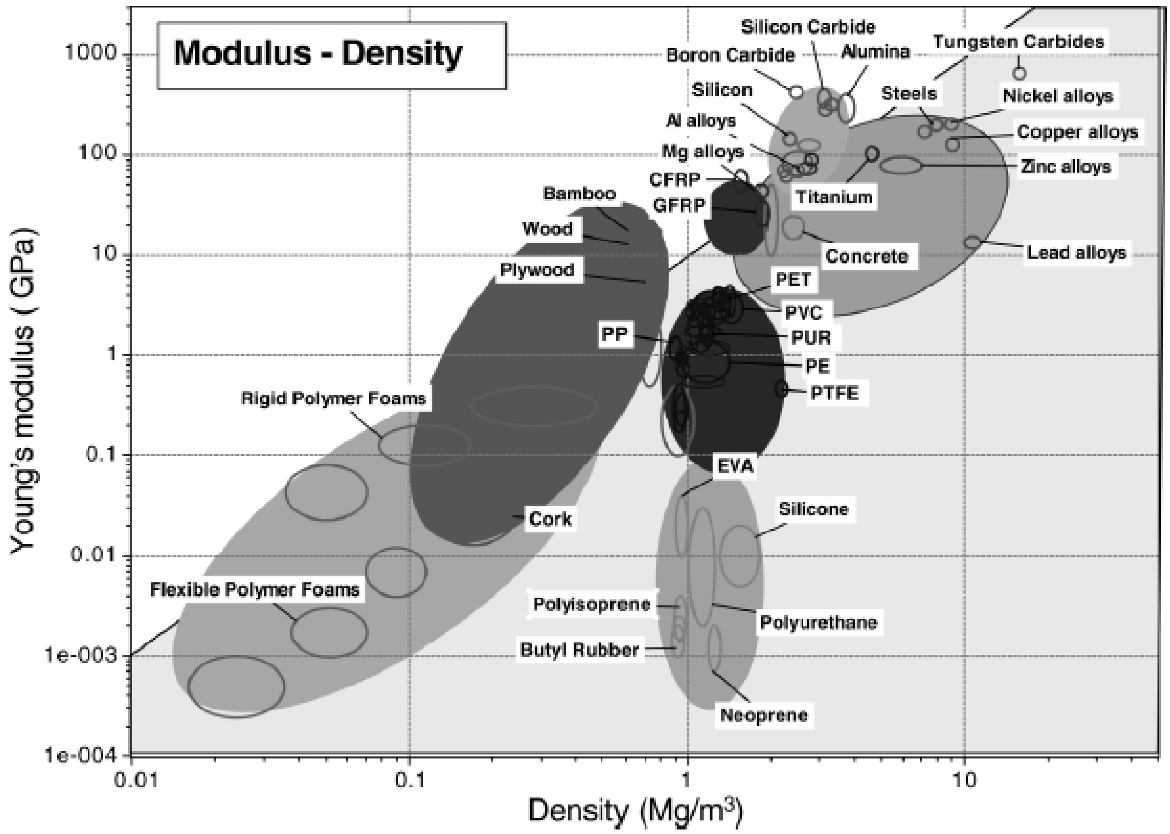


Figure 12: Figure from Ashby et al (2004) on material properties

The Figure above provides a view on how material groups perform based on their Young's modulus versus their density.

4.4 Selection of solution methodology

Each constraint, as well as the wishes for the material, needs to have a factor that depicts its importance. This factor along with heading towards making the right material choices can be done with the help of the House of Quality (HoQ) method. With this method, the importance of specifications can be determined and linked to how each material will score per specification. With all the details in the HoQ model, an overview that shows the score per material can be made. Below is a Figure that shows the layout of a HoQ matrix.

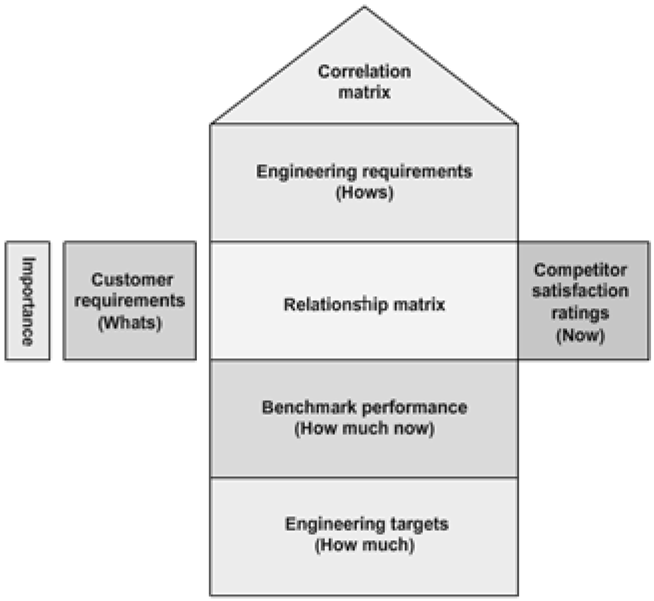


Figure 13: HoQ matrix overview

It consists of a number of blocks that are explained here:
On the left-hand side are the customer requirements, often referred to as 'Whats'. This is the input for the selection process. Each of the 'Whats' has an importance factor linked to it, as these may differ per requirement to make a more detailed analysis.

Moving towards the top is the correlation matrix in combination with the engineering requirements, also referred to as 'Hows'. The big difference between the customer and engineering requirements is that the engineering requirements should be measurable. The correlation matrix shows how each engineering requirement affects the other. This is usually indicated in multiple ranges, from negative to positive correlations. The correlations give more insight for the next step.

By finding the relations between the customer requirements and the engineering requirements, a grid is created that helps with the final choices on how the selected materials will be scored.

Below the relationship matrix is the benchmark performance. After all the details of the matrix are filled in, an overview is calculated that shows the weight of the requirements in combination with the relations.

The bottom block is important if a specific goal needs to be achieved. This is not the case for this assignment

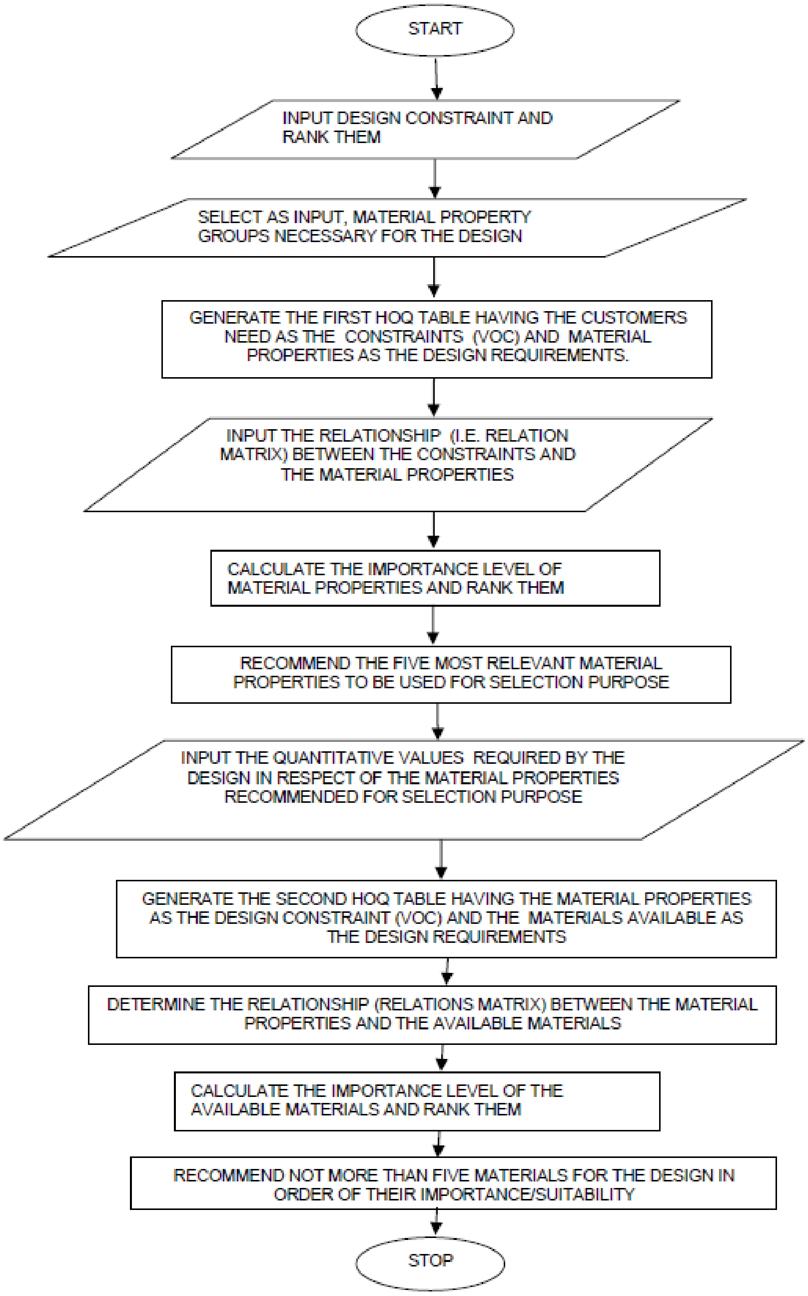


Figure 14: HoQ approach (Isaac et al, 2015)

A number of material attribute selection strategies exist that involve for example calculations in the form of matrices. These methods work exceptionally well when all constraints are perfectly defined, which is not the case here. The exact material properties that are needed are unknown for a design such as this. These are mainly found in literature in the packaging field.

4.5 APPLICATION OF PROPOSED MODEL

It is time to dive into implementing the theories of Govindan's model in this section. The House of Quality model will be filled with input from various sources about all the different material groups.

In the second selection with the HoQ model, further specifications for the sustainability will be included as well as the possible methods for processing the material.

Sustainability properties:

- All materials in this list are confirmed to be 100% biodegradable.
- Sustainability with CO_2: Kg/CO_2 per kg product
- Recyclability: % of recycled amount.

The HoQ matrix is filled with data. However, additional information is required to explain the choices that have been made for each of the requirements that have been included. More information is also required on how the requirements were judged based on the listed characteristics. The correlation between these characteristics is then sought out. These are the relationships that are classified as the purple symbols as can be seen in the legend. This provides the input for creating the relations between the requirements and the characteristics.

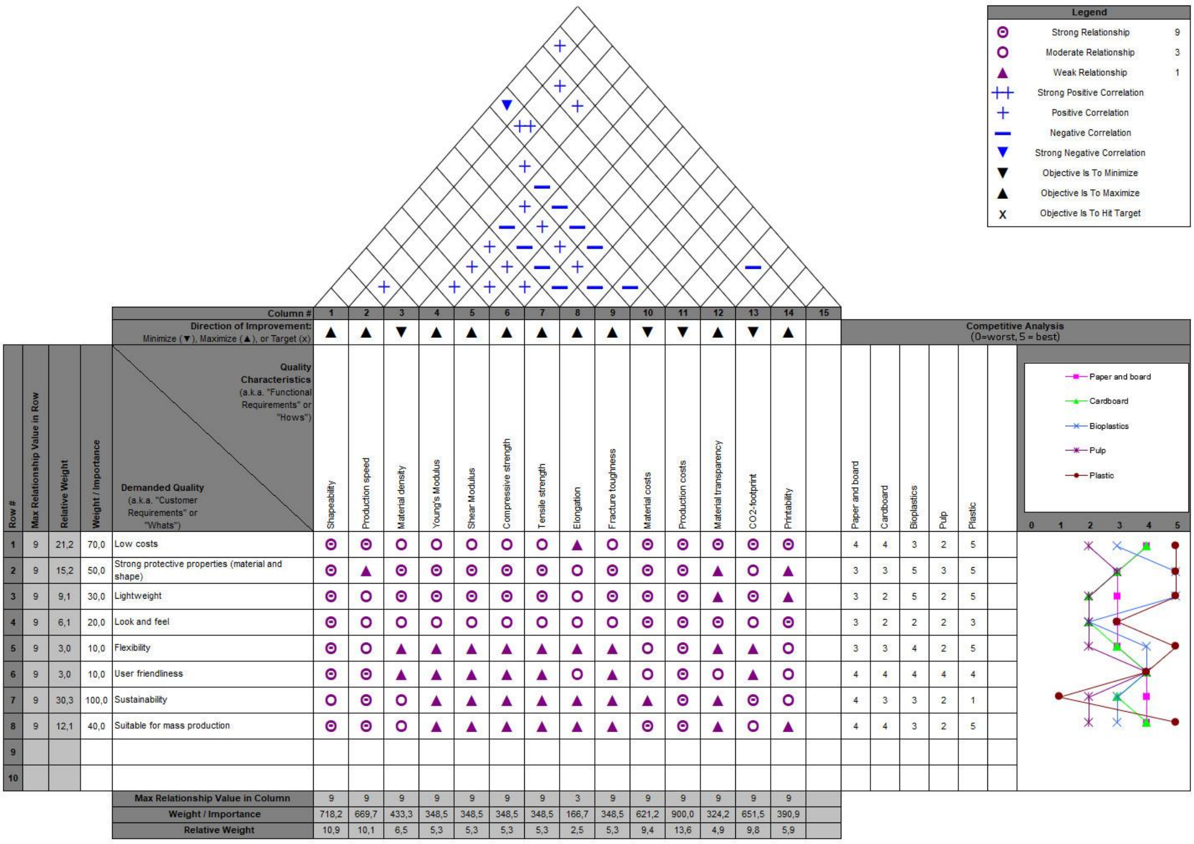


Figure 15: HoQ matrix

In order to get results from the matrix, the weight factor needs to be multiplied to the competitive analysis. This is presented in the next Table.

Quality	Weight	Paper and board	Cardboard	Bioplastics	Pulp	Plastics	Competitive analysis	Paper and board	Cardboard	Bioplastics	Pulp	Plastics
Low costs	70	4	4	3	2	5	1	280	280	210	140	350
Strong protective properties	50	3	3	5	3	5	2	150	150	250	150	250
Lightweight	30	3	2	5	2	5	3	90	60	150	60	150
Look and feel	20	3	2	2	2	3	4	60	40	40	40	60
Flexibility	10	3	3	4	2	5	5	30	30	40	20	50
User friendliness	10	4	4	4	4	4		40	40	40	40	40
Sustainability	100	4	3	3	2	1		400	300	300	200	100
Suitable for mass production	40	4	4	3	2	5		160	160	120	80	200
							Total results	1210	1060	1150	730	1200

Table 1: Relative score results table

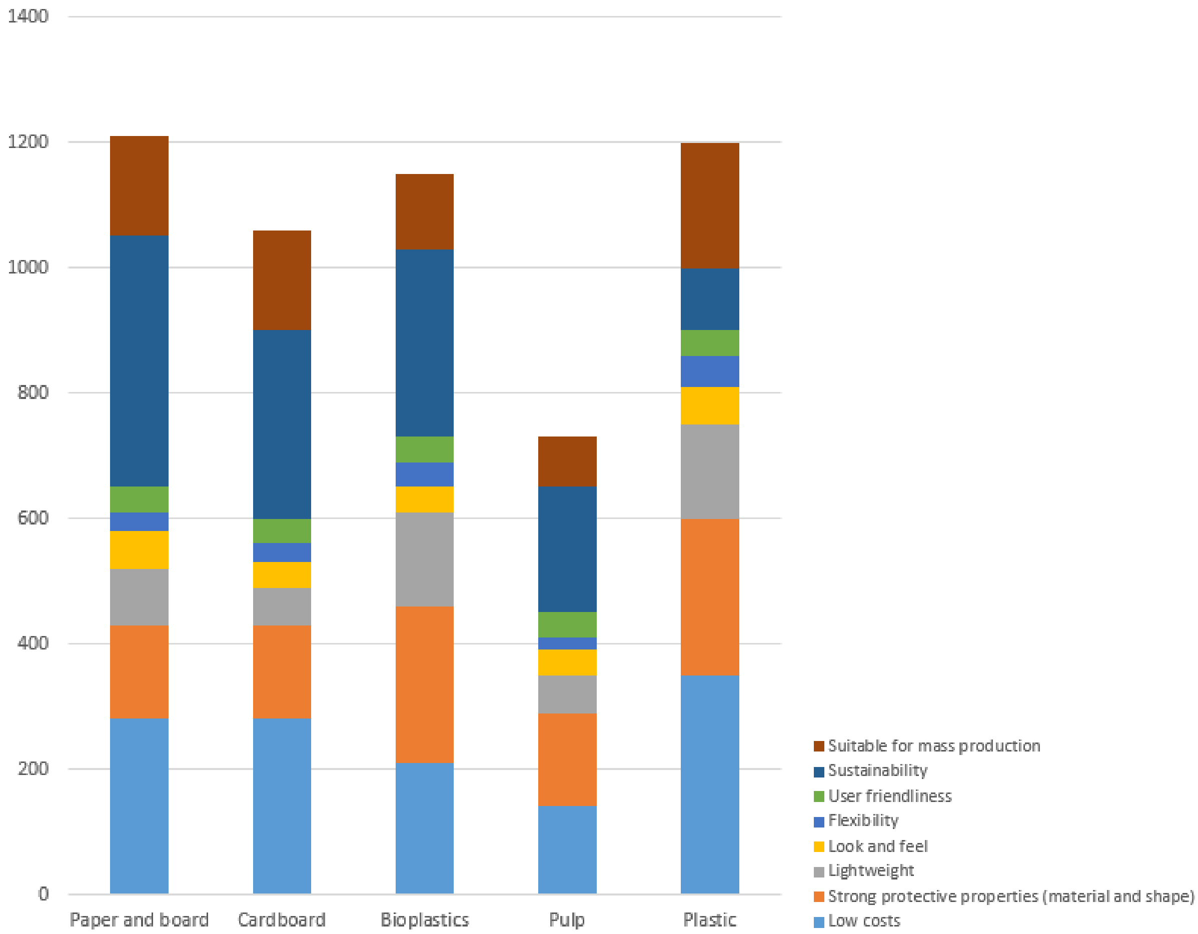


Figure 16: Material selection chart scores

A clarification is needed on the choices for the competitive analysis that have been made, which can be found on the right side of the HoQ matrix in Figure 15. Most of the choices have been determined by Molenveld et al (2014) and Van den Oever et al (2017).

The exact values for each of the requirements are hard to determine, due to the large variations within the material groups and because not every requirement is measured in the same units. Because of this, the choices are largely based on an approximation on the values that have been derived from various sources.

For all materials it is impossible to distinguish the user friendliness based on the material alone because the it is a quality that mostly depends on the design that is made with the material. Therefore, all materials scored the same on this aspect.

Paper and board
Paper and board performs well in most of the requirements. It has generally low costs because it is an abundant material. The combination of its protective properties and their density result in a lower score. Paper and board packaging is generally heavier than plastic packaging, which adds to transport costs. Paper and board is available in a wide range of grammage and with bleached and unbleached variants. There are many surface options, with glossy, smooth textures to coarse, less detailed surfaces. The use of paper and board is limited by the barriers that they can provide for products as well as shaping paper and board has a low flexibility.

The property where paper and board outclasses plastics by far is sustainability as it is a bio-based, biodegradable material with a high recycling rate. The production of paper and board packaging shows low CO_2 -emission rates. Paper and board is already widely used as a packaging material and it is suitable for mass production.

Cardboard
Cardboard provides decent protective properties with a fairly light weight due to the fluting of the material. It is not a material with much flexibility for primary packaging, with big features due to the fluting of the material. Cardboard is quite suitable for mass production with fairly low costs as it is the most used packaging material for secondary and tertiary packaging.

Bioplastics
From the competitive analysis, the position of bioplastics is very clear when compared to plastics. They are slightly behind plastics in the aspects of low costs, strong protective properties, being lightweight, flexibility and being suitable for mass production. However, they make up for that with a better sustainability. Studies show that the CO_2-emission during the production of bioplastics is drastically lower than conventional plastics. In addition, the use of non-renewable energy sources is lower.

Pulp
Pulp packaging offers the possibility to make 3D packaging models. Such structures can be strong, but have a high mass unless very thin-walled structures can be made. The methods for making these models are costlier and slower than flat paper packaging or thin-walled plastic packaging for example. Generally, pulp packaging is coarse, but surface finishes for a better-quality packaging are possible at a higher cost and production time.

Plastics
Plastics score the highest in most of the requirements, as plastics are an ideal material for packaging applications. Plastics fit the requirement of having low costs, strong protective properties, being lightweight, flexible and they are suitable for mass production.

The major downside is of course the sustainability of plastics. As a non-renewable energy source with a high CO_2-emission rate, and a lower recycling rate than paper and board for example, plastics score the lowest.

4.6 SELECTION RESULTS

The ranking of the selection for a group of alternative materials for the interior packaging is the following:

1. Paper and board
2. Bioplastics
3. Cardboard
4. Pulp

Paper and board are already widely used in many packaging applications and due to the sustainability problems that are encountered with the use of plastic packaging, more packaging could make the transition to paper and board.

The choice of paper and board has consequences for the packaging design. An effort needs to be made to optimize the interior packaging design as much as possible to make the strongest structure with the lowest mass in order to be as competitive to the conventional plastic interior packaging as possible.

The next best option is to use bioplastics. Bioplastics scored comparable to conventional plastics except for the costs, flexibility and mass production. The sustainability of bioplastics is the main improvement over conventional plastics, for example because of a better carbon footprint.

At this moment in time, bioplastics are lacking in these requirements, but considering the constant development of bioplastics, it indicates that in the future more plastics could be replaced by a bioplastic. The focus on replacing conventional plastic packaging with paper and board for now, while slowly transitioning to a higher use of bioplastics is the most feasible approach.

Once the development of bioplastics has succeeded in approximating the properties of conventional plastics, there is no longer a reason to use them over bioplastics. The production rate of bioplastics is steadily rising. The production of bioplastics increased from approximately 2 million tons in 2014 to 6,7 million tons in 2018. The most produced bioplastics were starch and polylactic acid (PLA)-based polymers (Onen Cinar et al, 2020).

For a number of polymers, there is a biobased alternative. Polyethylene (PE) foils and bottles can be replaced by Bio-PE, starch blends or hybrids, Polylactic acid blends (PLA blends) and Polyhydroxyalkanoates blends (PHA blends). Polypropylene (PP) foils and bottles can be replaced by Bio-Polybutylene succinate (Bio- PBS), PHA (blends), PLA (blends) and Bio-PP. Polystyrene (PS) thermoformed and foam packaging can be replaced by PLA, cellulose pulp and starch blends. Polyethylene terephthalate (PET) bottles, trays (including interior packaging) and blisters can be replaced by bio-PET, PLA and polyethylene furanoate (PEF). However, this last option has not yet been commercially viable due to price (Van den Oever et al, 2019).

Cardboard and pulp are rejected based on the material selection process result.

Chapter 5:

Case study fiber-based packaging

The contents of Chapter 5 follow a traditional design approach, with a general introduction before it, which results in the following structure:

- An introduction of all generic topics that come before explaining the design phases. packaging amount, company information, goals, design phases.

5.1 INTRODUCTION

The case study at Van de Steeg is an experimental study on creating a packaging that fits the requirements of the assignment. It is important to note that the execution of this case study primarily involves the production methods and materials that are available at Van de Steeg.

However, this does not mean that other methods have to be neglected. Other production methods are also researched in the analysis phase. Extra information on Van de Steeg can be found in Appendix A.

From a design perspective this case study is in order of the design phases below

- **Analysis phase:** This section covers a list of requirements and a summary of production methods along with a conclusion on those production methods. Insights from folding methods are also implemented in the next phase.
- **Ideation phase:** After the initial phase, the approach becomes more specific towards a certain type of design and variations (ideation) on these ideas can be created.
- **Conceptualisation phase:** A more detailed iteration on the interesting ideas from the ideation phase happens in the conceptualisation phase, where the end goal is to have a few viable packaging concepts.
- **Detailing phase:** From the best concepts, one packaging will be selected and further iterations are done to create a final, fully detailed packaging that will also be tested.
- **Final design:** The last iteration on the design is presented and evaluated.

5.2 ANALYSIS PHASE

In this section the situation is explored further than identifying the problem alone. The possible directions for solutions are assessed. A number of tools will be of use to this phase: creating a list of requirements, doing market research on production methods, analysing the current method of production trying to provide improvements through new theories *(in this case, combine origami)*. In order to work towards a clear goal, a program of requirements can be made. The material types that can be processed at Van de Steeg are limited by their production method. It may be worthwhile to check other production methods or producers to work around this limitation.

In the analysis phase the possibilities for the new packaging are explored. In consultancy with the lead designer at Van de Steeg, the options for new geometries that can be made with die-cutting and folding-gluing are explored. This includes researching folding techniques as well.

Below is a list of requirements for when the assignment's goal was to develop a packaging that could contain many products which would involve more complexity. Keep in mind that this list was made during the analysis phase and is no longer fully relevant for how the assignment evolved.

5.2.1 LIST OF REQUIREMENTS

Together with the sales manager and the lead packaging designer the details of the packaging are determined. A number of the requirements below are also based on an earlier packaging line for cosmetics for two packaging companies, Liz Earle and Boots, that were produced by Van de Steeg.

List of requirements:

- The packaging is recyclable.
- The packaging provides enough strength and protection for the products.
    - Confirmation with drop testing.

        - Confirmation with vibration testing
- The costs can be a maximum of: €0,50/product.
    - This partly depends on the extra benefits that the packaging offers over a basic solution. A unique solution that is worth a higher price to the consumer is allowed to cost more, as long as the extra costs are later restored.
- The packaging fits multiple products that may vary in size and shape in specified box sizes and types.
    - Specifications of the maximum box size.
        - Liz Earle:
            - Length: 338 mm.
            - Width: 213 mm.
            - Height: 96 mm.
        - Boots:
            - Length: 310 mm.
            - Width: 300 mm.
            - Height: 70 mm.

    - The differentiation on the amounts of products.
        - Liz Earle.
            - The product amounts will range from 2-7.
        - Boots.
            - The product amounts:
              Star gift +/- 12 products (440k).
              Advent calendar +/- 25 products (130k).
    - Specifications of product combinations.
        - Rectangular shaped boxes.
        - Wedge shaped tubes.
        - Cylindrical containers.
        - Cylindrical cloths.
- The packaging has a tight fit within the gift box and the products: Maximum of 450-500 μ.
    - The packaging cannot move freely within gift box.
    - The products cannot move within the inner packaging.

Wishes:
- The packaging is cost-efficient for small production batches.
    - The smallest production batch for one type of interior packaging is: +/- 1.500 pieces.
    - The largest production batch for one type of interior packaging is: 46.000 pieces.
    - For Boots: 130k and 440k Star Gift production series.
- The packaging should have a luxury look that fits Liz Earle gift boxes.
    - This can be masked when it is black, white or clear.
- The packaging should have a luxury feel that fits Liz Earle gift boxes.
    - This is subjective.
- The packaging has a lower mass than current gift boxes of the same size.
    - Premium gift boxes should have a higher mass, because that gives it a luxury feeling.

This list of requirements was mainly used in the early stage of the case study

5.2.2 Production methods

The production method that Van de Steeg uses and is therefore focused on during this case study is a combination of a die-cutting and a folding-gluing process.

However, many production methods exist that can be used for creating a biodegradable packaging. The possibilities are summarized and explained below.

In order to get more freedom in the production aspect other production methods are explored, since they have an important impact on the design.

5.2.2.1 Paper pulp molding

Paper pulp pressed molding

Another method to create fiber-based packaging is the use of paper pulp molding.
Paper pulp molding is a semi-mass production process that uses paper pulp that gets pressed into a mold, where it is then heated to create 3D shaped objects.

Paper pulp injection molding

Creating 3D interior packaging with paper pulp as a base material is a possibility. A process that molds the material into a modeled shape can be done with paper pulp molding.
The process involves obtaining the right material for the production. A combination of pulp and starch with PVA (Polyvinyl alcohol is kneaded together along with water while heated. This is then placed into the injection machine, where the material is shaped with support of the mold. In this heating and drying process, the water gets drained from the molded material. The final product can then be removed from the mold.
There are multiple companies that create packaging using this method, such as:

Tecnoform

An Italian company called Tecnoform creates 3D packaging that consists of multiple layers. It has a smooth paper-like surface on one side and a rougher sturdy cloth-like surface on the other side. It is a very rigid material that can be created with high detail. It is slightly limited in square angles, since the model is created in one piece[2].

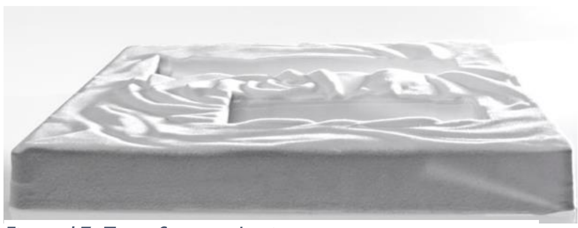


Figure 17: Tecnoform packaging

Paperfoam

Right here in the Netherlands in Barneveld is Paperfoam, a company that creates 3D models out of recyclable and compostable foam. The foam consists of starch, natural fibers water and a premix and is created with injection molding. They can create detailed models with the limitations that the production process brings with it. The model needs to be tapered so it can be removed after finishing. It is a viable alternative if the number of different models is low, due to the production method[3].

Figure 18: Paperfoam packaging

---

[2] https://www.tecnoform.net/en/products/thermoformed-products.html
[3] https://materialdistrict.com/material/paperfoam/paperfoam-paperfoam-ona416-20/

Fibreform

Fibreform is a product created by Billerudkorsnas, a company located in Finland that does paper packaging. Their fibreform is a 3D shaped paper interior packaging. Its main drawback will be the limitation in its shape, because it does not perform well on sharp corners and strong structures. It can make up for this with better looking details as they can create an attractive looking embossed surface[4].

Figure 19: Fibreform packaging

5.2.2.3 3D PRINTING

As an upcoming technology, 3D printing may offer some solutions to the problems at hand. So far, it has been a niche use for the packaging sector. This may change, however, once production speed can handle the high production demand that is often seen in packaging production. More importantly, the mostly used materials for 3D printing are plastics. With constantly updated technologies however, new materials that are viable with 3D printing may be coming in the future.

3D printing with paper

A unique idea that has not been implemented in the direction of packaging design is the use of 3D printing with paper. A specific company, Mcor, has developed 3D printers that are capable of using paper as a base material. This method should be able to create a type of paper packaging that has not been created before. It is therefore an interesting idea for this assignment.

Mcor has unfortunately ceased from production during the assignment and is therefore not an option. In the future however, 3D printing paper packaging may be an interesting direction to pursue. There are more companies that try to work with 3D printed paper and it may become another method of producing plastic-free packaging. For now, it is hard to determine its full viability.

5.2.2.4 DIE-CUTTING AND FOLDING-GLUING PROCESS

A combination of die-cutting and folding-gluing is also a viable option. The design is focused on this production method in the experimental part of the assignment.

Die-cutting process

Flat materials can be shaped with the use of a die-cutting process. A specific design requires a specific cutting die to be made for it. The benefit of using die-cutting is that the same die can be used for mass-production. However, for each unique design, a different cutting die is necessary. A simple overview of this process can be seen in the Figure below.

[4] https://www.linkedin.com/company/fibreform-packaging/

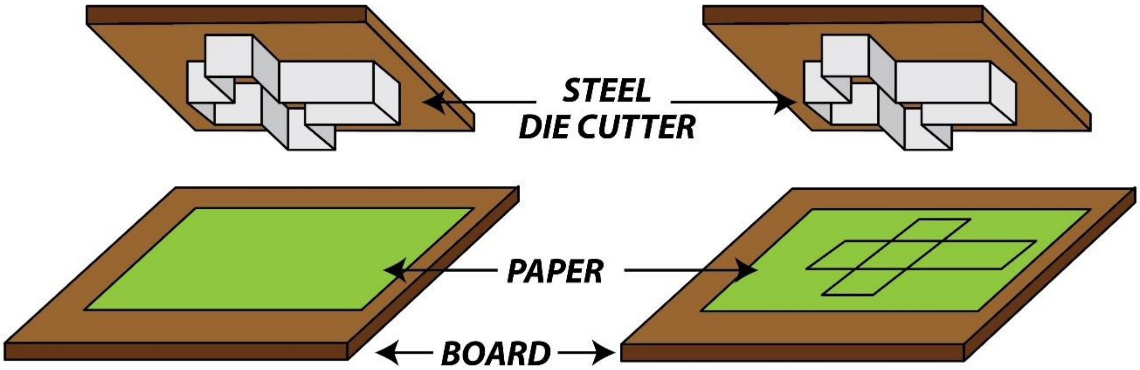


Figure 20: Die-cutting process (retrieved from https://help.tradeprint.co.uk/hc/en-us/articles/360002775234-What-is-die-cutting-)

The die-cutting machines has several options for altering the material:

- Through cutting: through cutting cuts through the packaging material. All the material outside of the center cut is removed after the die-cutting process.
- Scoring: instead of cutting through the material, scoring leaves a partial cut along one line.
- Creasing: creasing is similar to scoring where the die creates a fold line on the packaging material. Unlike scoring, creasing allows for inward bending of the material by having two parallel lines where the packaging is folded along.
- Perforating: perforating involves indenting a line of holes along the design material. The design is not separated from the material itself but can easily detach along the perforated lines.

Folding-gluing

After the die-cutting process, the packaging needs to be folded and assembled. This process happens simultaneously.

In a machine with a constant motor, the packaging is placed. The packaging is then guided by a railing that folds the packaging at the right position and angle, while applying glue to the strip. Another fold overlaps the packaging and compresses the sides onto each other to create the finished, flat packaging. In the Figure below, an overview of the process can be seen.

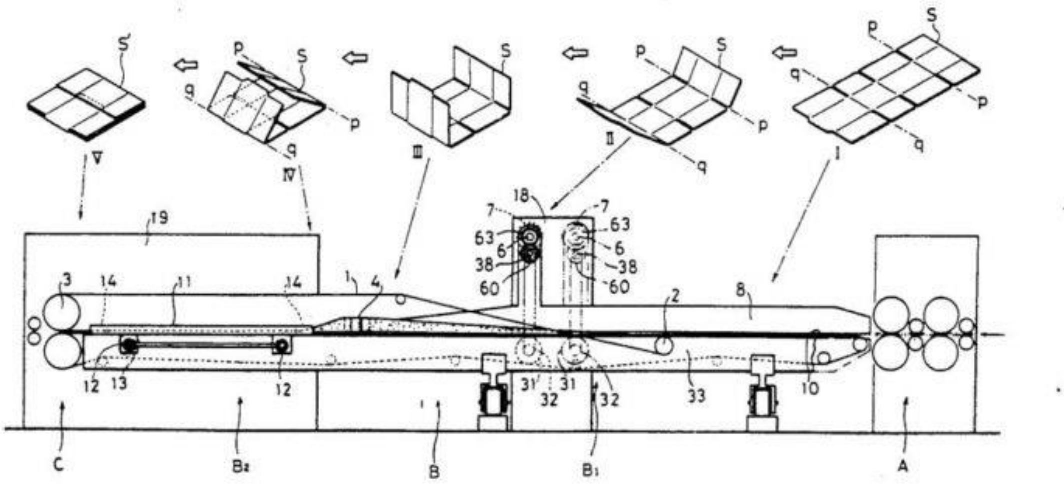


Figure 21: Folding-gluing process (retrieved from http://www.corrugated-line.com/auto-corrugated-carton-box-making-full-line-printer-with-folder-gluer.html)

The remaining process is to assemble the interior packaging by unfolding the flat structure and placing it in the box along with the product(s).

5.2.2.5 Origami and kirigami

Something that cannot be categorized under any of the previously named production methods is the concept of applying more of the art of origami and kirigami in packaging. Origami is the art of paper-folding. Traditionally, this also means that no other technique other than folding is used to sculpt a piece of paper into something else. Kirigami, on the other hand, does involve cutting. Many packaging already involves folding and cutting, so perhaps these crafts can provide more to packaging.

Figure 22: Origami crane example (retrieved from Origami.me, 2019)

The art of paper folding is known as origami, originating from the Japanese words 'ori', which means folding, and 'kami', which means paper. As an art form, it is not necessarily functional. However, the structures that can be folded with flat materials do find a purpose, as a basic version of origami is used in production processes that fold material as well. By researching origami, all structure possibilities can be explored without production limitations. What this artform can give in terms of value can be reviewed afterwards.

A key thing is that all origami structures start with a flat piece of paper. All the necessary creases for a certain structure can be made beforehand. The 'assembly' of the structure can then be done. All creases of a structure are visible when you unfold an origami piece which can be seen in the Figure below.

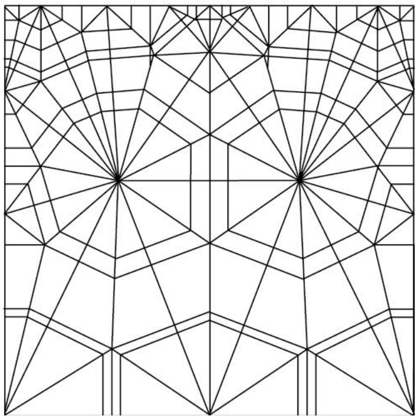


Figure 23: Complexity of a folded model explained in a flat view

The idea is to implement unique folds and structures that are not common in packaging. By experimenting with interesting ideas that are a combination of origami and packaging is one of the initial ideas that could lead to early concepts.

A bit more detail is needed to exactly explain the thought process here. In a number of studies around packaging, it became clear that origami can have association with packaging. The information found in these sources are summed up below, ordered from easy to hard in terms of implementation.

Algorithmic lattice kirigami
The cutting and folding lines that are required to create these shapes are not harder than existing techniques. The shaping of the product afterwards causes more problems, as the geometries need to be put under specific forces in multiple directions in order to create the end shape. Repeatable shapes are common in this style of folding, but the geometries can vary, from smaller basic geometries, to a larger more complex shape that consists of multiple folds. A positive side is that the same patterns can be created in different structures, depending on the folding direction, as can be seen below.

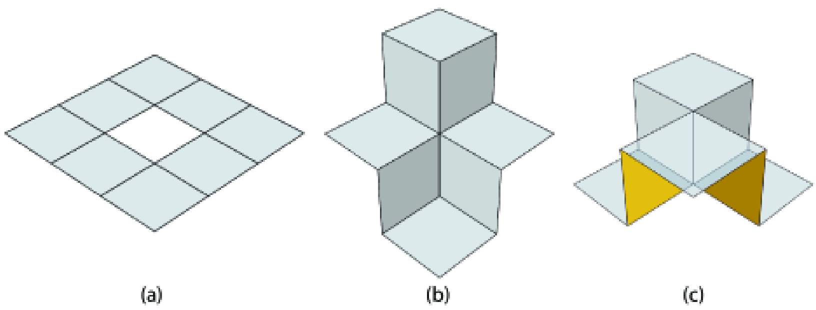


Figure 24: Example of creating a variety of structures with the same template from Sussman (2015)

In the figure below, a number of geometries are explored that give insight to how shapes can be created with a flat material and a cutting and folding process.

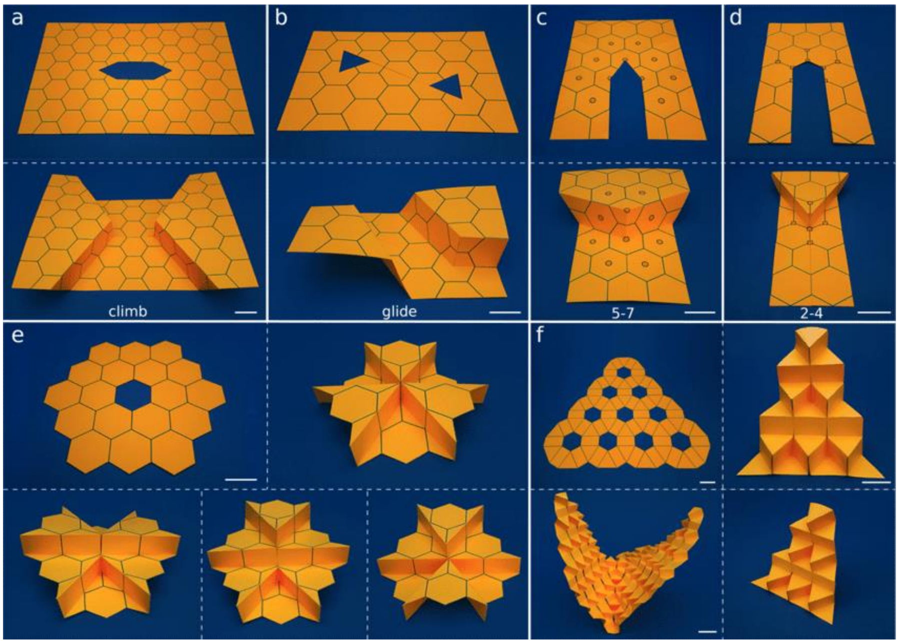


Figure 25: Geometry possibilities from Sussman (2015)

Modular origami
Another interesting sub-category found in origami are art pieces that are created with modular pieces to create more complex shapes. The advantage is that difficult folds can be avoided to make sure the machinery is able to fold the necessary pieces. However, combining all the elements into something that provides a benefit for the design of the packaging is the new challenge.

It is unclear if any advantage can be reached by trying to make a packaging of modular components in this way. Although the general idea of a modular packaging that uses repeating elements in a way was taken into the next design phase, specific solutions and structures that primarily follow this phenomenon were not included.

Rigid origami
Rigid origami specializes in flat, rigid sheets that move through joints. However, it could also be a single sheet. If an origami model can be opened to a completely flat, unfolded state and closed to a folded state in a rigid manner. An example of such a structure can be seen below. All the features of the structure consist of flat, uncurved geometries. For packaging, it is important to know if a structure can be folded without curving before a packaging is taken into production.

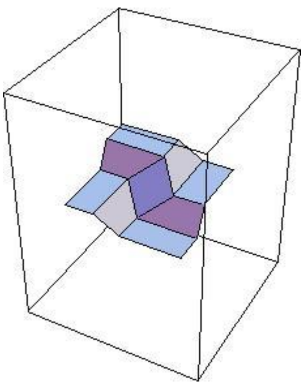


Figure 26: Rigid origami example (retrieved from http://origametry.net/rigid/rigid.html)

Tessellations
Tessellations are repeating patterns of geometric shapes and they may be usable for packaging. Tessellations offer interesting geometric shapes that are not common in packaging and it may therefore provide added value to the packaging.

Tessellations are explored through the art style of origami and it does not yet have a functional purpose. However, from one flat sheet, special 3D structures can be made that could function as a buffer. Some tessellation designs also have cavities that could function as small pockets for products.

Since tessellations have repeating folding patterns, they could be ideal for machine-made packaging. This is also the challenge of implementing tessellations in packaging. The folds are often hard to shape and impossible to assemble in one movement since the folds are not continuous. The smallest single shape that forms the base of the tessellation has folds in multiple directions. In the Figure below, an example of a folded paper tessellation can be seen.

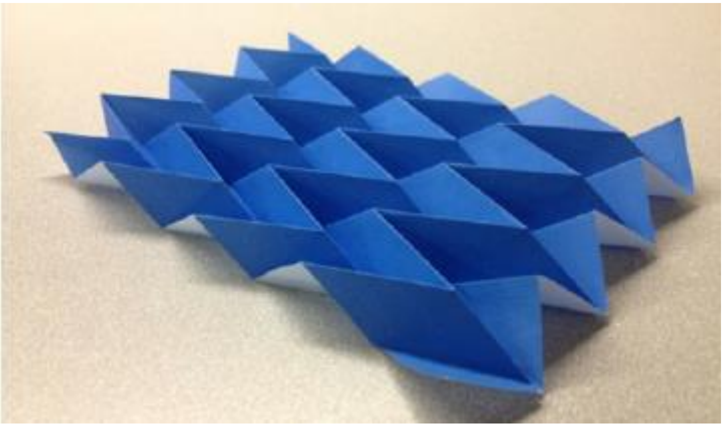


Figure 27: Folded paper tessellation (retrieved from https://www.researchgate.net/figure/Example-of-a-Miura-ori-tessellation-folded-in-paper_fig1_264674700)

5.2.2.6 Options for creating a bioplastic interior packaging
Bioplastics have been successfully converted into food packaging using conventional plastic conversion technologies including extrusion, injection molding, and compression molding (Jariyasakoolroj, P. et al (2018). Below are three Figures that give an overview of the production processes.

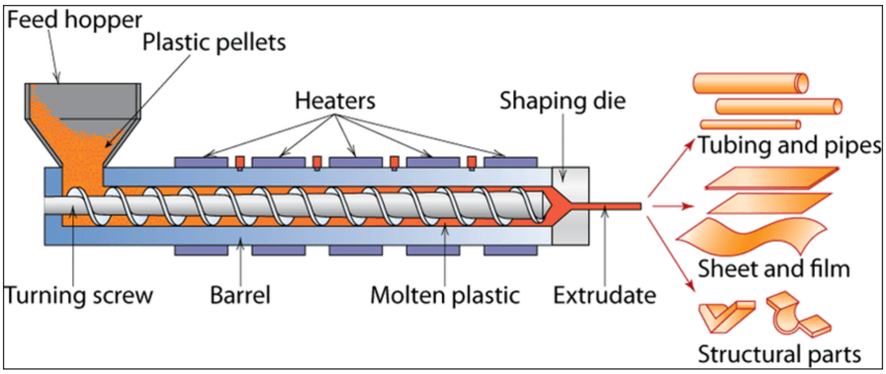


Figure 28: Extrusion overview (retrieved from https://www.researchgate.net/figure/Overview-of-a-plastic-extrusion-machine-with-the-plasticizing-component-in-evidence-The_fig1_321597264)

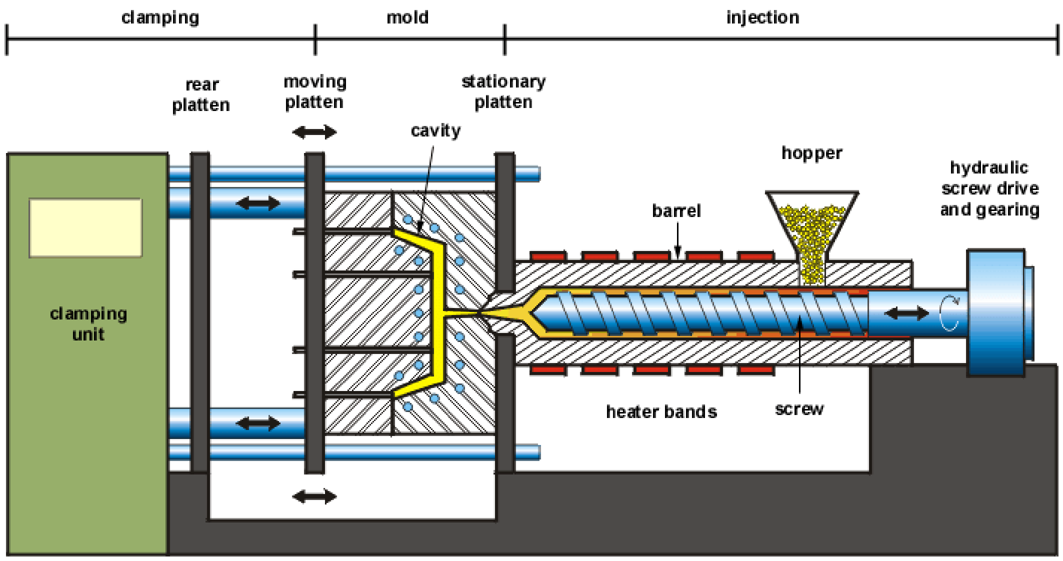


Figure 29: Injection molding overview (retrieved from https://www.researchgate.net/figure/Schematic-of-a-typical-injection-molding-machine-Source_fig1_277126772)

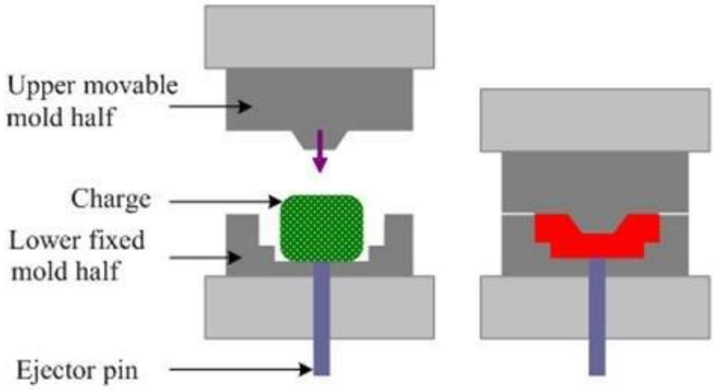


Figure 30: Compression molding overview (retrieved from https://www.researchgate.net/figure/The-schematic-of-the-compression-molding_fig13_305426620)

These are all viable methods that are widely used for conventional plastic packaging. The methods have a high production speed and low cost.

5.2.2.7 Conclusions on production methods

Paper pulp and pulp-injection molding are both viable options for creating a 3D interior packaging. Such a packaging could provide a very viable protective performance when compared to the flat structures that are created in the case study.

3D printing is not yet to be implemented for packaging whilst the process is costly and the production speed is low. The advantages of 3D printing are very viable for packaging but not at this moment in time. Also, the main material use for 3D printing is mostly polymers. Packaging producers are working on implementing different materials such as bioplastics and fibers such as paper, but this has not yet delivered a viable result.

A combination of a die-cutting and folding-gluing process is a common and viable process for creating the interior packaging. It is also the production method that will be designed for in the case study.

Both origami and kirigami could be implemented in the folding-gluing process to discover new viable structures, although the production process offers limitations in the geometry. Specific applications of origami such as logarithmic lattice kirigami, rigid origami and origami tessellations could find use in packaging.

Lastly, a biodegradable interior could also be produced with bioplastics as a material. This has already been successfully implemented with extrusion, injection molding and compression molding.

5.2.3 MATERIALS USED AT VAN DE STEEG

Van de Steeg only produces packaging with fiber-based materials. An overview of the most commonly used materials is given below. More information from the manufacturer as well as specsheets of more detailed material properties can be found per material in Appendix B.

International Paper: Arktika

This is Van de Steeg's most commonly used material. Arktika is a folding boxboard (FBB) GC1 product, with reverse side coating and a high-quality surface. Although a larger subset of grammage for the Arktika range exists, only the 275g, 300g. and 350g. materials were available to use at Van de Steeg.

Invercote: Creato

Invercote Creato is a solid bleached board (SBB) with a high-quality surface finish on both sides. Although a larger subset of grammage for the Invercote Creato range exists, only the 410g. material was available to use at Van de Steeg.

Westrock: Kraftpak

WestRock KraftPak is an unbleached, uncoated virgin paperboard. It is a low density, high-yield product which provides outstanding strength and durability while using less fiber. The unique two-ply design offers a consistent surface with an attractive natural brown appearance and good printability. Although a larger subset of grammage for the WestRock Kraftpak range exists, only the 410g. material was available to use at Van de Steeg.

Invercote: Duo

Invercote Duo is a solid bleached board (SBB) made by back-to-back pasting of triple coated Invercote G with a high-quality surface finish on both sides. Although a larger subset of grammage for the Invercote Duo range exists, only the 610g. material was available to use at Van de Steeg.

Strand Paper & Board: Speypack

Speypack is a board for premium/luxury packaging Although a larger subset of grammage for Speypack exists, only the 655g. material was available to use at Van de Steeg.

5.3 Ideation phase

The ideation phase starts with using the information from the analysis phase in designing the interior packaging. A number of packaging ideas and directions for the packaging were created during this phase which can be found in Chapter 5.3.1.

Rapid prototyping

The ideas and concepts in this paragraph and the rest of the chapter should fit the die-cutting and folding-gluing method. However, since the real machinery cannot be used for this purpose, the process is instead done manually with the help of a plotting machine, which can cut patterns in a 2D area with similar results to what a die-cutting machine can create. ArtiosCAD, is a software that is used for 2D packaging development. In combination, rapid prototyping can be done throughout the course of the entire assignment. The time investment in creating these prototypes is small, so ideas can quickly be tested with real models instead of just digital visualizations. This gives extra insight on the ideas and concepts and it helps with improving models in a later phase as well.

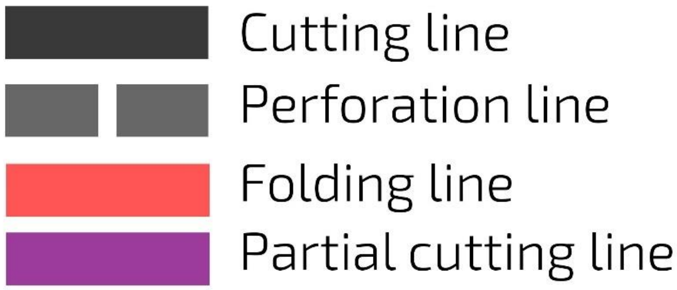


Figure 31: Legend to the line colors for the flat packaging figures

Throughout the ideation phase the directions that were explored and were also discussed with the packaging designer at Van de Steeg to determine the feasibility of production. Although some ideas were innovative, some ideas were a step too innovative for the current machinery and the end goal does demand a working prototype packaging that is fit for production.

5.3.1 Ideas

An interesting direction as a designer to take was to take the artform of origami and try to combine it with packaging. In many ways, packaging already uses simple origami folds but there could definitely be an extension of the packaging world towards more complex and interesting designs.

Although origami is an artform, it definitely is able to offer interesting geometries that are viable for packaging purposes. The difficulty of applying new geometries is the bottleneck for innovations on this part. Either the production process or the geometry needs to be adjusted to reach a sufficient concept.

Rigid origami idea

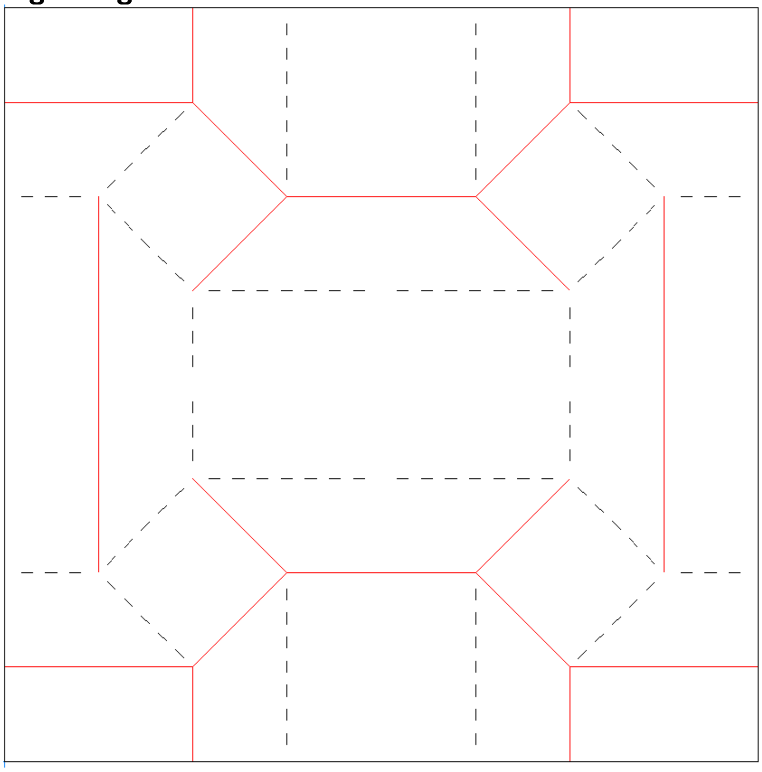


Figure 32: 2D visualization of the rigid origami concept

This idea conveys a buffering structure from one flat sheet. The folds are hard to assemble, but it is an interesting geometry that could be used in packaging. It currently has limitations for holding the products, since only rectangular shapes can fit this idea.

Stretching structure idea

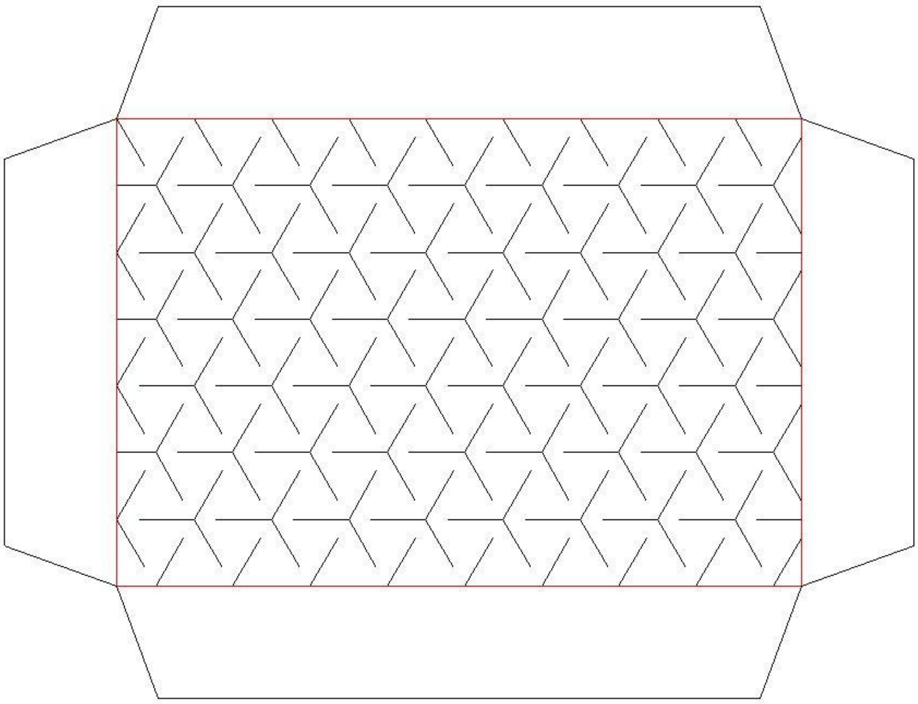


Figure 33: Stretching structure idea

The concept above is a structure that fits a wide arrange of products by clamping them in between two of the concepts in the packaging box. One piece is placed on the bottom of the box, while the other piece is placed in the lid of the box. The product is then contained in the middle of the packaging, in between a buffer. The idea is inspired by converting a tessellation into a flat structure.

However, a similar product has already been made by Iiro Numminen for a packaging design competition by Metsä board as can be seen in the next Figure.

Figure 34: Stretching inner part

Modular tessellation

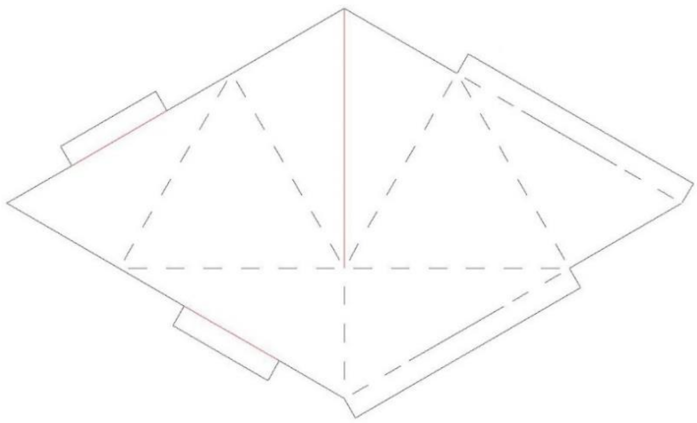


Figure 35: tessellation structure

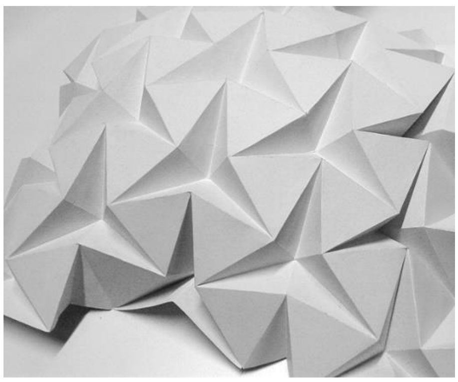


Figure 36: Modular tessellation idea

In the figure above is an idea that would make it possible to produce a paper tessellation as shown in the figure below. Folding a tessellation is complex so in order to simplify the folding, a single piece from the repeated feature is created. Folding one feature is simpler and the number of features can be determined per packaging. However, multiple small models are now required just to pack one product. In addition, the assembly of the modular features turned out to take much time and the connection between the pieces was not optimal, which made the strength of the tessellation substantially weaker.

Folding boxboard idea

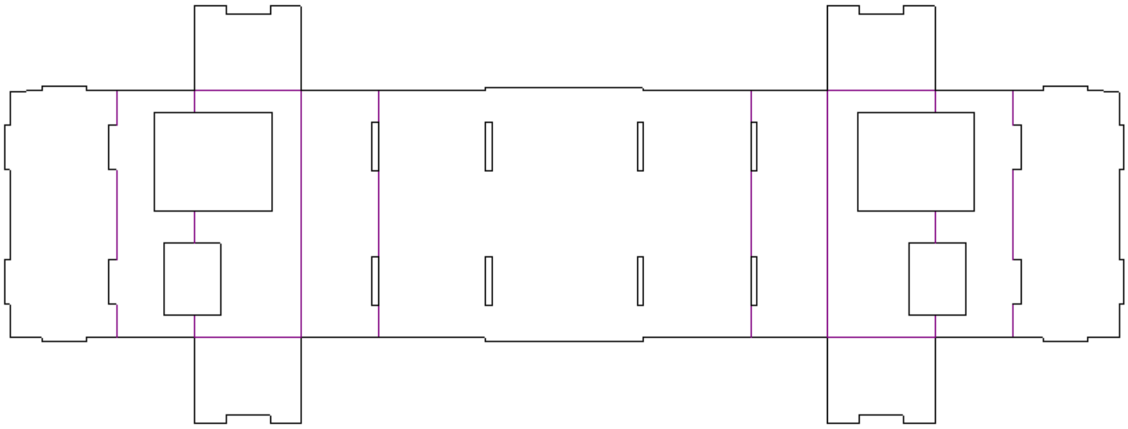


Figure 37: Idea involving folding boxboard

The use of a thicker boxboard has been tested with a simple idea. This is the same material as the box around the interior packaging and it ranges from 1mm to 2.5mm. The sides of the structure are folded inwards to create an interlocking shell. However, further iterations were rejected based on the material.

5.4 Conceptualisation phase

After the ideation phase, farfetched ideas are rejected to focus more on realistically viable concepts. Any technical challenge during production, assembly or fitting the product is a major downside, when simple options would perform better. The packaging needs to be created with a die-cutting and folding-gluing process. This results in limitation to the design. For instance, all folds have to be continuous, because the packaging has to go through the folding-gluing machine in its entirety.

A total of six concepts have been developed in this phase and are explained and illustrated below.

5.4.1 Concept 1: Basic concept

First off is a basic concept. The concept holds the products at the bottom of the box and held at the outer ends of each side. Presentation-wise it could be improved, but it is a simple design that firmly holds the products. The selection of products does not need much protection, but considering that the biodegradable interior packaging should be usable for a large variety of products, such as more fragile products with materials like glass or ceramics, tend to get damaged easier because there is no buffer between the product and the box on the bottom side. The amount of material used is quite small, which is a positive aspect of the concept.

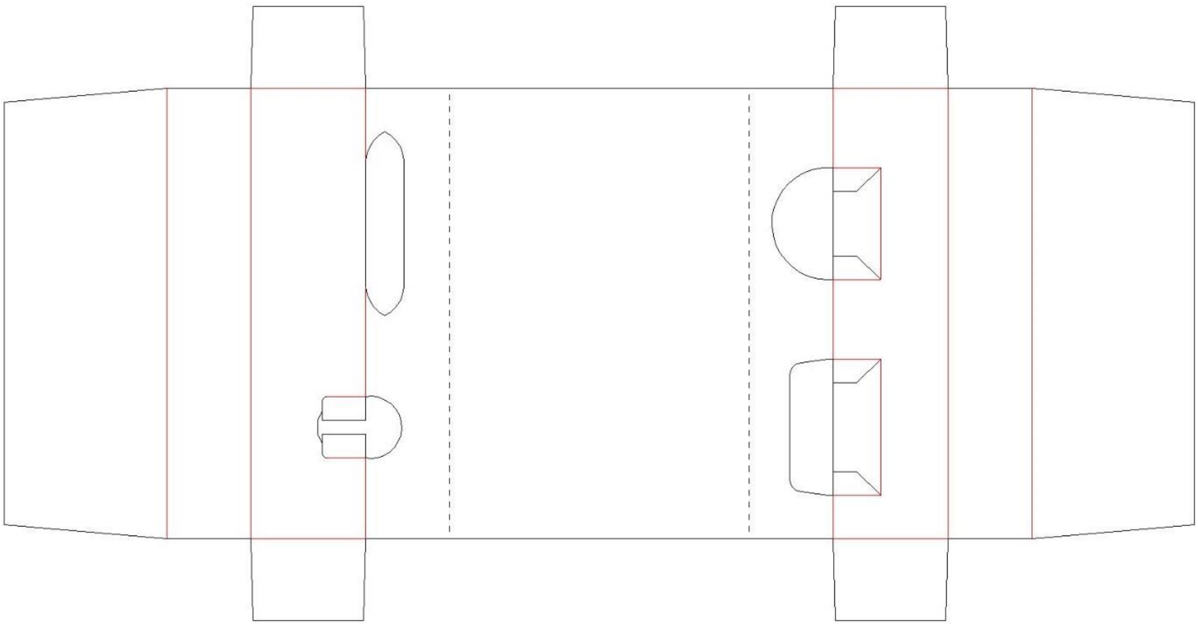


Figure 38: Concept 1 flat view

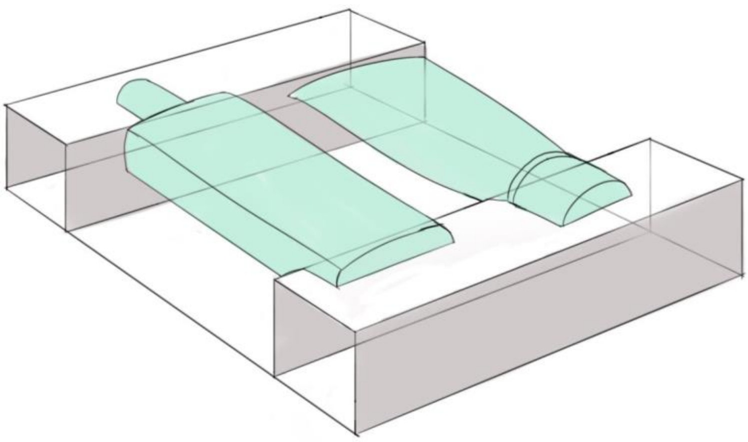


Figure 39: 3D view of concept 1

5.4.2 Concept 2: Cross-fitting concept

The idea behind this concept is that from two directions, the products would be supported. The length side of the packaging would wrap all around the product contours on the bottom side, creating walls in one dimension. The vertical flaps would tuck in between these walls, so the products are fully contained and has a double wall where the vertical and horizontal features overlap.

The packaging is hard to assemble because of the tight fit between the two directions. A substantial amount of material is needed to make the geometry wrap around the contents.

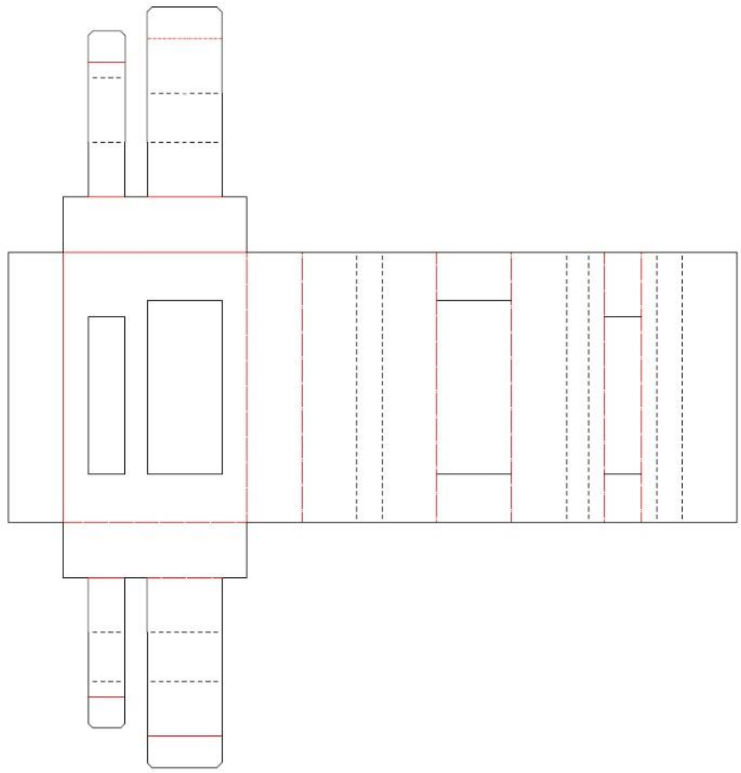


Figure 40: Concept 2 flat view

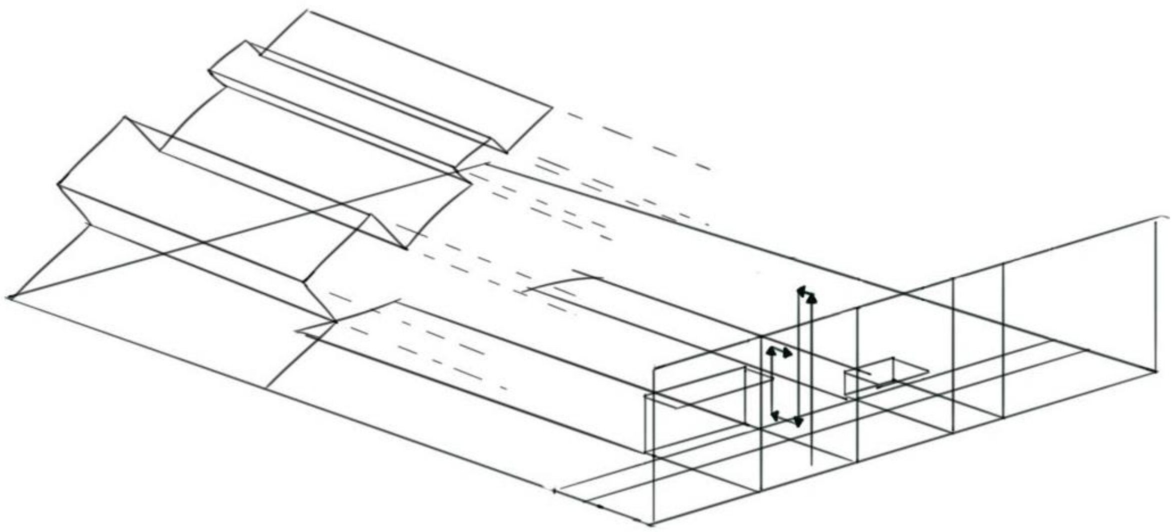


Figure 41: Folding explanation concept 2

5.4.3 Concept 3: Rigid origami

An interesting idea from the previous phase is continued into a concept. The geometry especially is an interesting mechanism that locks the product in place because of its own mass and it also provides a buffer to the product. A top part can be attached to cover the underlying geometry to hide the features of the design, although it is not necessary.

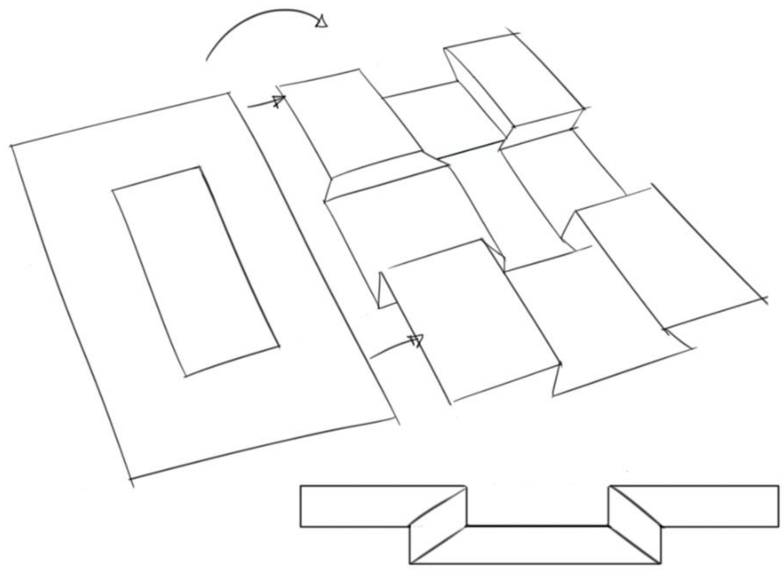


Figure 42: Rigid origami sketch

The downside of the design is that in its current state, the packaging only supports the product in two dimensions. The top cover could have a cut-out of the product dimensions in order to hold the product better, but the concept needs improvement on its flexibility. It is viable for fitting rectangular products, but complex shapes are a bottleneck for the design. More importantly the design does not have continuous folds and the complex folds that are required to assemble the concept cause for problems during the production process.

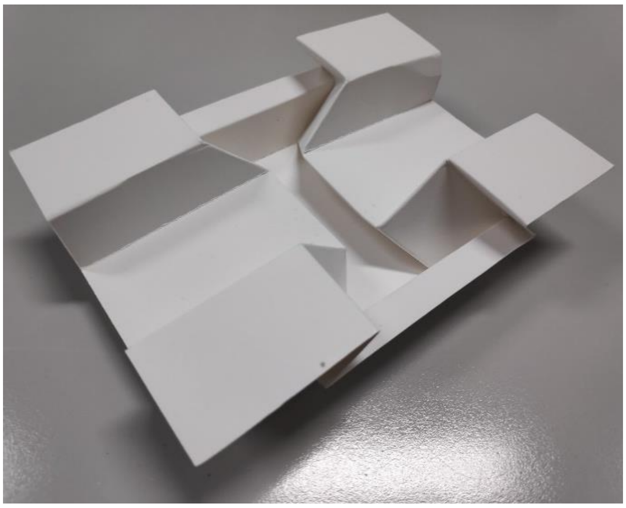


Figure 43: 3D visualization of the rigid origami concept

Figure 44: Example of concept 3 with a cover part

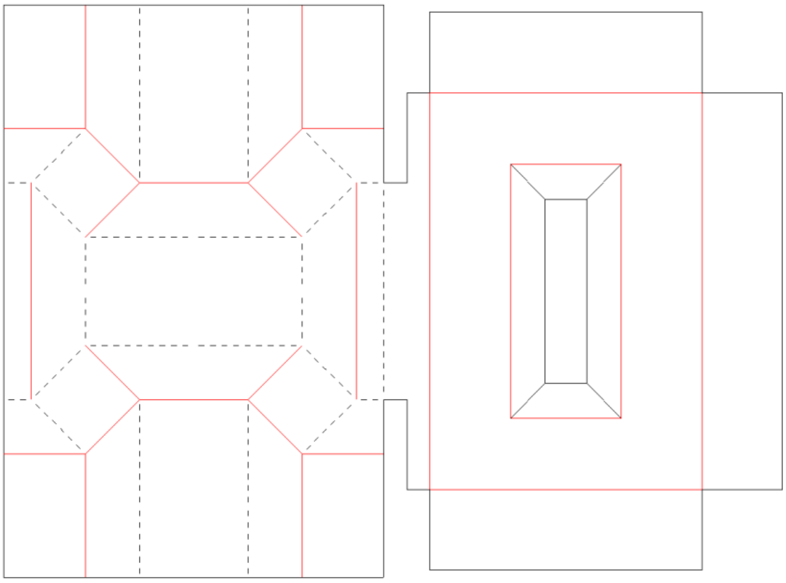


Figure 45: Concept 3 flat view

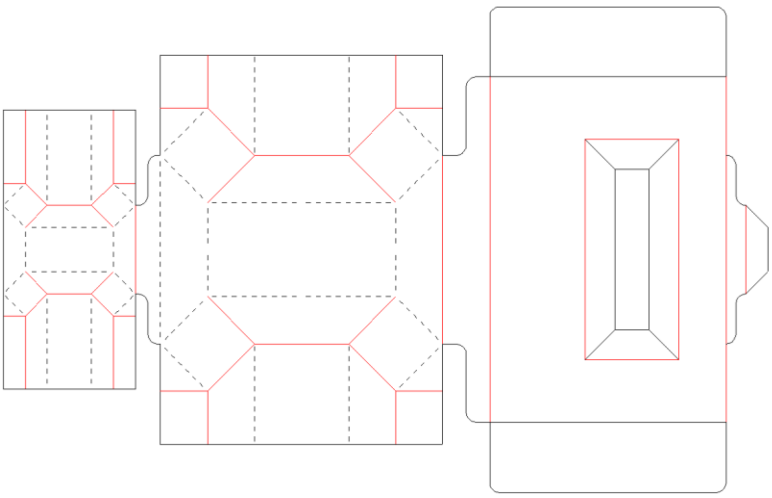


Figure 46: Example of rigid origami concept with two structures

C, combining multiple products into one packaging is not one of the strengths of this design. A single folded support is already complex to make with the folding-gluing process because the folds are discontinuous. Two of these structures next to each other cause even more complexity, which can be seen in Figure 46.

5.4.4 CONCEPT 4: BASIC IMPROVED CONCEPT

The basic improved concept is a different take on a simple concept that has the folded features attached on the vertical sides. This helps with making the lay-out smaller and therefore using less material. It is comparable to concept 1, however, it elevates the products and holds them in a tight-fitting flat top. The top part hides the structure below for a clean presentation.

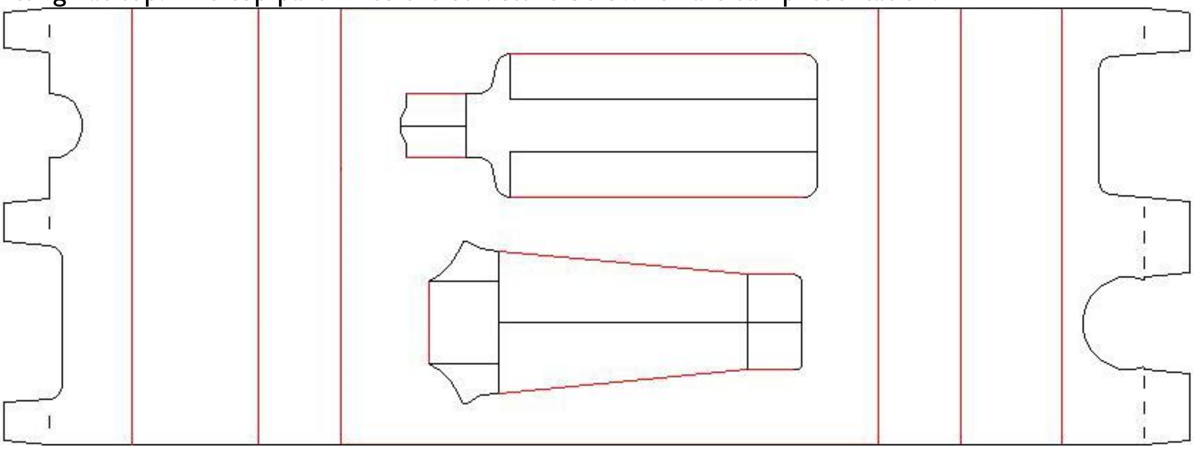


Figure 47: Concept 4 flat view

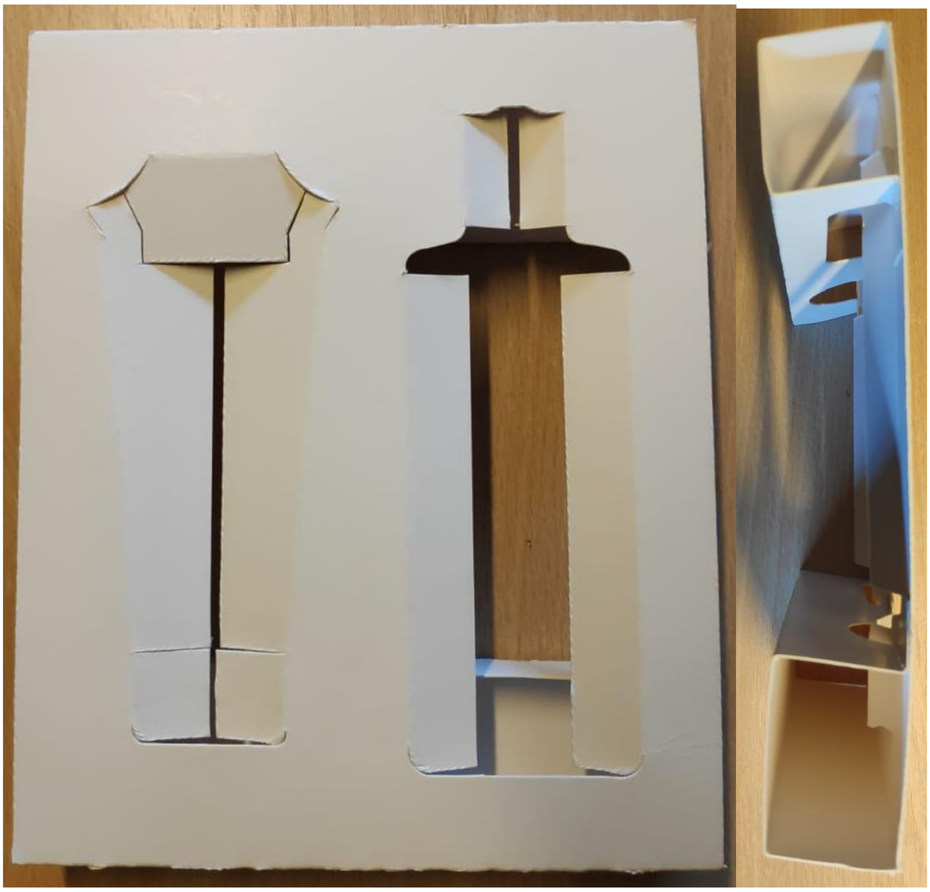


Figure 48: Realization of concept 4

5.4.5 Concept 5: Angled concept

Concept 5 aims to change the positioning and therefore the presentation of the products. On one side, the products will fit into a higher part of the interior packaging, whilst the other side is placed lower. This presents the product at an angle. The design has a different geometry in the sideview. Normally, the sides would be rectangular, but in this concept, it is a skewed rectangle as can be seen in the Figures below.

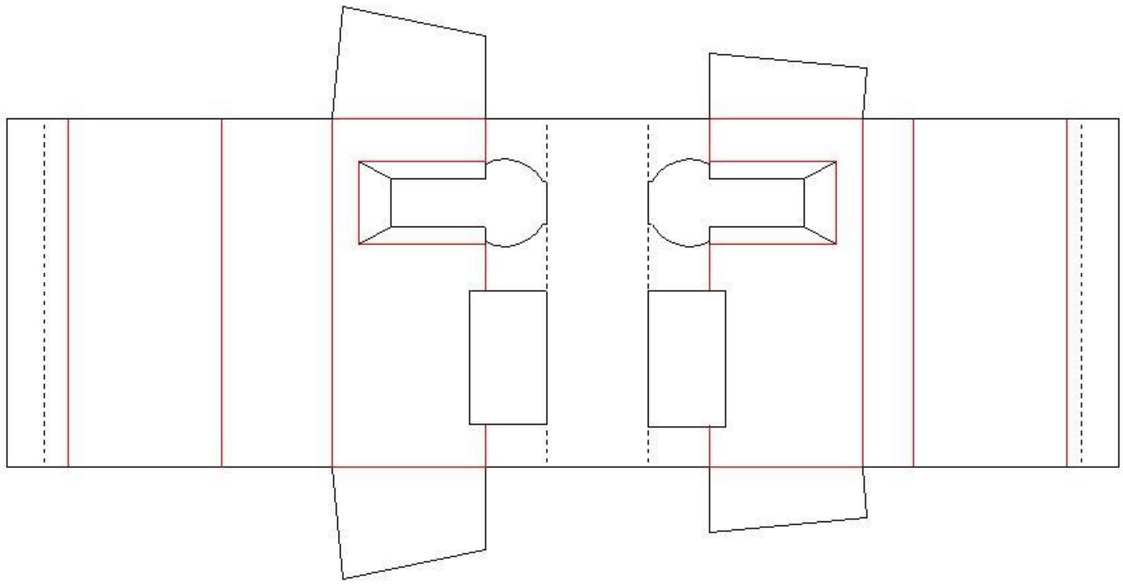


Figure 49: The flat contours of the angled concept

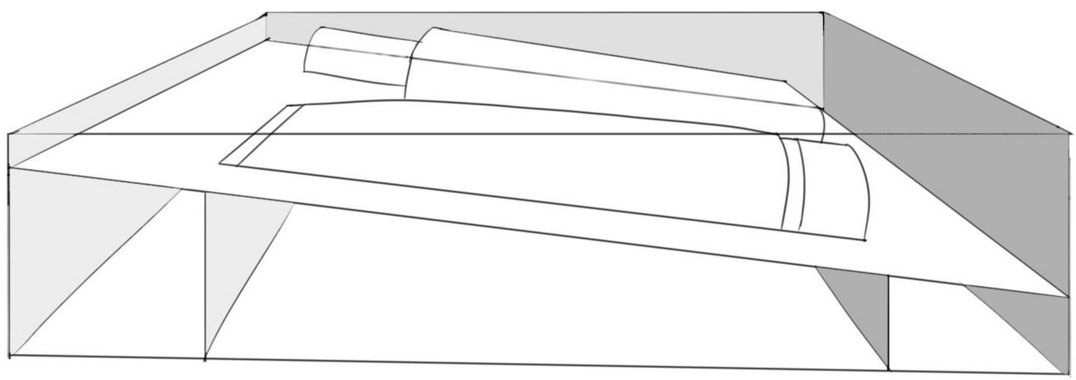


Figure 50: 3D view of the product presentation in concept 5

5.4.6 Concept 6: Arched concept

This concept shows a different take on the presentation, by implementing an arched top layer. An arch could clamp the products differently that a flat top and the presentation of the products is now slightly more interesting. This design made it harder to successfully create a tight fitment with the products because the cut-out shape needs to be slightly larger to compensate for the arch in the top layer. The overall lay-out of the flat design also takes a big amount of space which may need improvement.

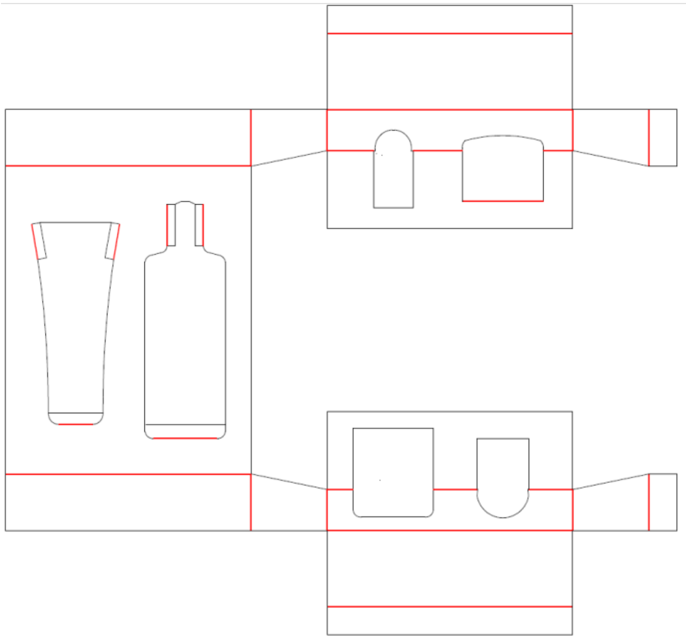


Figure 51: The flat contours of the arched concept

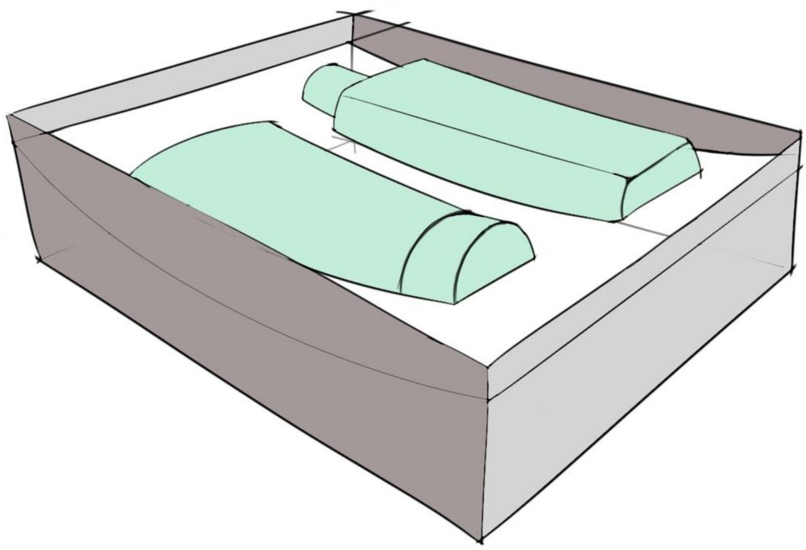


Figure 52: 3D sketch of concept 6

In order to continue to the detailing phase, a choice between the different concepts needs to be made.

5.4.7 Concept choice

The concepts will be compared between multiple properties, as listed below. Each of these properties received a factor that showcases the importance of the property. The property factors range from 1 to 10, with a 10 being the most important.

Property	Explanation	Factor
Production speed	How high is the production speed to create the concept?	9
Handwork	How much extra work is needed to assemble the interior packaging concept?	8
Easy to assemble	How difficult are the actions that are needed to assemble the interior packaging concept?	8
Construction strength	How strong is the structure of the interior packaging concept?	10
Fitment with box	Is the fitment between the interior packaging concept and the box positively influenced?	7
Fitment with products	Is the fitment between the interior packaging concept and the products positively influenced?	8
Buffer	Does the interior packaging concept function like a buffer to protect the product against impact forces?	5
Presentation	Are the products positively displayed inside of the interior packaging concept?	9
Geometry	Is the geometry of the interior packaging concept positively influenced?	5
Innovative	How innovative is the interior packaging concept?	3

Table 2: Explanation of ranked properties

The properties in the Table above have all been factored in order to make a concept selection. The most challenging objective and therefore the most important property is the construction strength of the concept. Following in importance are the production speed as well as the presentation of the concept to showcase the importance of the production process as well as the design. The next in order of importance is the fitment with the products and the handwork. Both of these properties are related to the functionality of the concept as a viable packaging. Slightly less important is the fitment that the packaging has within the box. The buffering function and the geometry of the concepts are assessed as well. Last up, the innovativeness of the concepts are also valued.

The scores for each of the concepts per property can be seen in the following Table.

	Basic	Crossfitting concept	Rigid origami	Basic improved	Angled concept	Arched concept
Concept number	1	2	3	4	5	6
Production and assembly						
Production speed	10	4	4	10	7	7
Handwork	10	4	4	10	8	8
Easy to assemble	10	2	5	10	8	7
Physical properties						
Construction strength	6	7	8	7	4	5
Fitment inside box	10	8	7	9	6	8
Fitment with products	8	8	5	9	8	7
Buffer	2	2	10	6	2	3
Aesthetic properties						
Geometry	4	6	8	8	6	7
Presentation	8	7	9	9	8	7
Innovativeness	1	3	10	2	3	4

Table 3: Concept choice scores

The total scores per concept are then calculated by multiplying the score per concept with the importance factor of the property. The overview can be seen in the next Table.

	Basic	Crossfitting concept	Rigid origami	Basic improved	Angled concept	Arched concept
Concept number	1	2	3	4	5	6
Production and assembly						
Production speed	90	36	36	90	63	63
Handwork	80	32	32	80	64	64
Easy to assemble	80	16	40	80	64	56
Physical properties						
Construction strength	60	70	80	70	40	50
Fitment inside box	70	56	49	63	42	56
Fitment with products	64	64	40	72	64	56
Buffer	10	10	50	30	10	15
Aesthetic properties						
Geometry	36	54	72	72	54	63
Presentation	40	35	45	45	40	35
Innovativeness	3	9	30	6	9	12
Total score:	674	505	616	760	582	605

Table 4: Total scores per concept

The total scores per concept can be seen in the Table above. With the highest score, concept 4 is selected for the next phase. It offers flexibility and a simple but strong design, which is necessary in order for the packaging to pass the tests. It performs better in most of the categories which makes it a solid option for more iterations.

A short clarification why it is logical that the other concepts have not been selected is explained here:

Concept 1: The simple concept scored second overall, due to its simplicity, which was highly valued in the selection process. It offers slightly less in terms of presentation and protection than concept 4.

Concept 2: The structure of the concept proved to present more complications to the production process and

Concept 3: The rigid origami concept is definitely an interesting option, but not at this point in time due to limitation in the production process. Once the concept is viable after developments in the production process, then this type of packaging should be viable.

Concept 5: The angled concept was an experiment with adding angles in the design in order to strengthen the packaging and by presenting the contents of the packaging in a different way. However, the concept did not offer enough extra value compared to the downsides with the assembly and the lay-out of the geometry.

Concept 6: The arched concept was an experiment with adding curves in order to strengthen the design as well as present the packaging slightly different. However, the concept did not offer enough extra value compared to the downsides with the assembly and the lay-out of the geometry.

5.5 DETAILING PHASE

During the detailing phase, the emphasis lies on improving the chosen concept and doing more iterations on the design to improve it. This mostly concerns small edits of the design's features.

Since the final packaging will only receive minor changes, it is also time to start testing the packaging to seek out improvements. The testing details can be read in Chapter 6. In these iterations, the packaging has been evaluated on the following properties:

Fitments

The details of the fitment have changed slightly. In the left Figure below, the fitment does not require the removal of wasted packaging material. Instead, the packaging design does not look as clean as with these features removed. The mass of the small features of these fitments is negligible. A better fitment is more important than trying to fill up the space and including it in the fitment, as done in the right Figure.

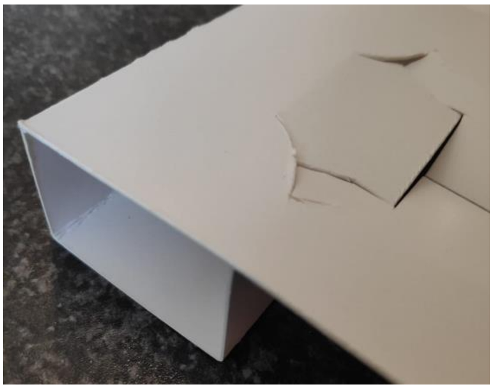


Figure 53: Iteration on filling the fitment

Figure 54: Iteration on removing excess material

Improvement on the fitments would ensure that the products will be clamped in the best possible way with an optimal structure. The term 'fitment' specifies how the products fit in the packaging. A perfect fitment implies that the product is gripped enough by the packaging material to prevent the product from slipping and therefore the packaging is able to protect the product. It should not cost too much effort to remove the product from the fitment either, so there is a tight space where the fitment is the most optimal. Hiding abundant features provides the packaging design with a better presentation.

Structure

An iteration on adding extra support has been conducted. However, the added value is determined not to be high enough, considering that the extra sidewall barely prevented any damage to the interior packaging while increasing the total area and also the mass of the packaging.

Also in the drop tests, the right product caused the most damage to the interior packaging and may need extra support. Two versions of this support have been created.

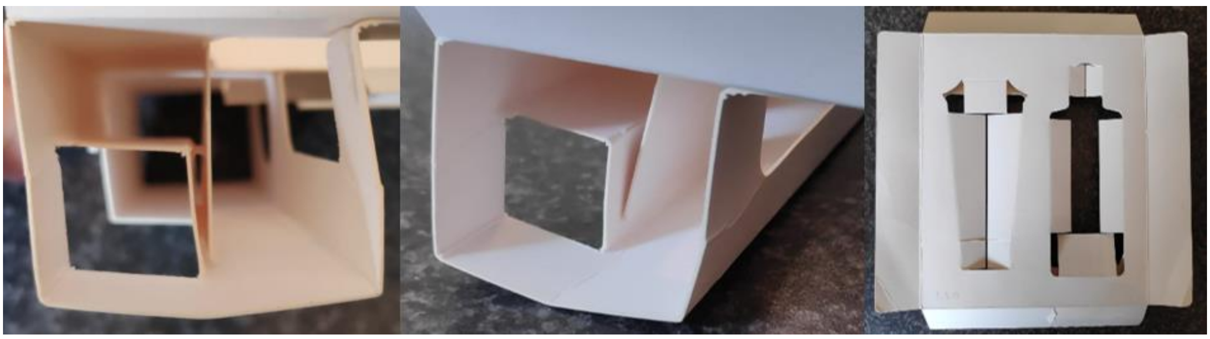


Figure 55: Support version 1

Figure 56: Support version 2

Both options had additional problems during the assembly, because the feature has to be tucked into and therefore the iteration is not an improvement on the interior packaging design.

Gluing edge

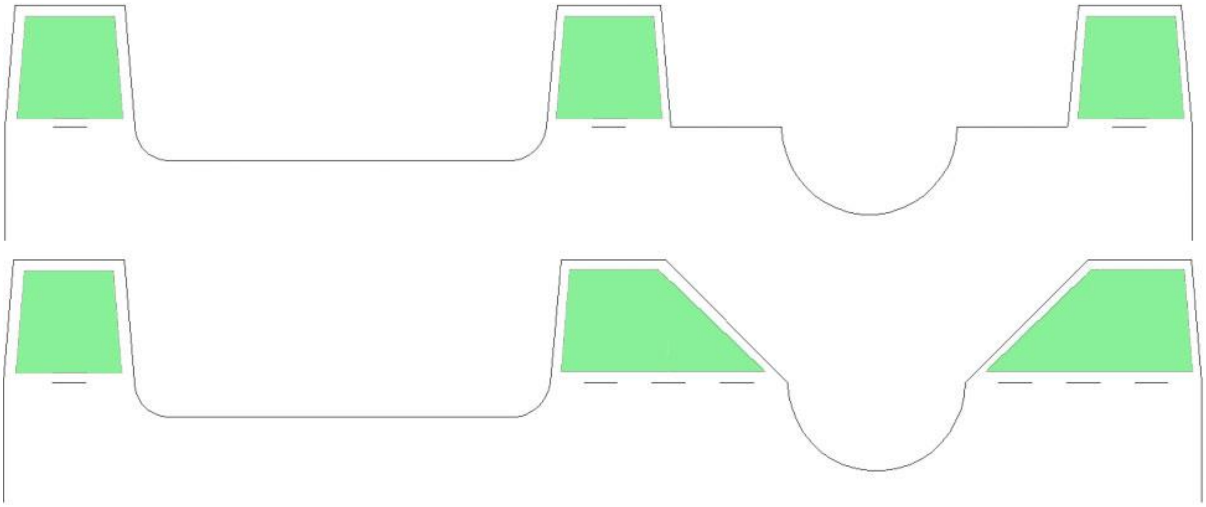


Figure 57: Iteration on the gluing edge of the interior packaging

The gluing edge has been improved by making the contact area larger as can be seen in the Figure above. The gluing edge now follows the contours of the cut-out for the product.

5.6 FINAL DESIGN

Below is a Figure of the final design for the biodegradable packaging. With insights from the tests, the material that has been chosen for the final design is Iggesund Invercote Duo (610 grams), which was the material that performed the best in the tests. More details on the results of these tests can be found in the upcoming chapter.

Iggesund does have more varieties on the grammage for the material available conforming to their website, so more optimizations are available with extra material tests from external sources.

The design itself has a tight fit with the products to hold them firmly even under multiple impacts or after a prolonged time of vibrations.

Figure 58: Final design with products

Figure 59: Final design top view

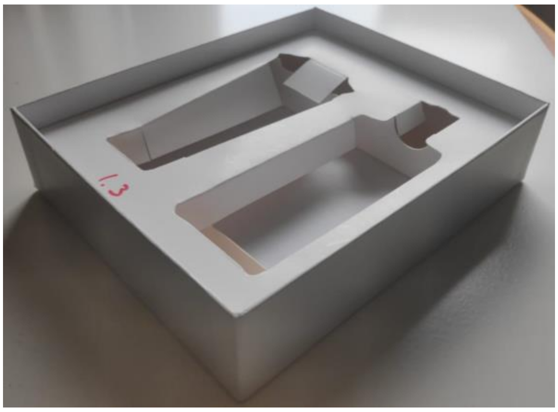


Figure 60: Interior packaging 3D view without products

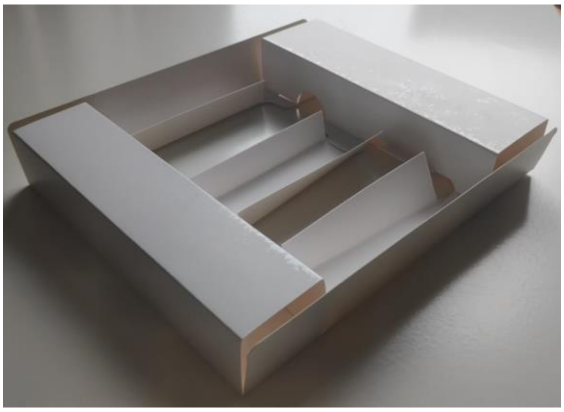


Figure 61: Interior packaging 3D bottom view

Figure 61: Interior packaging top view

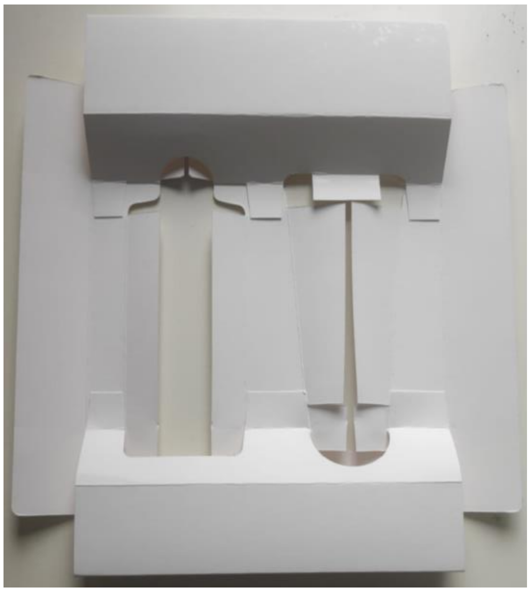
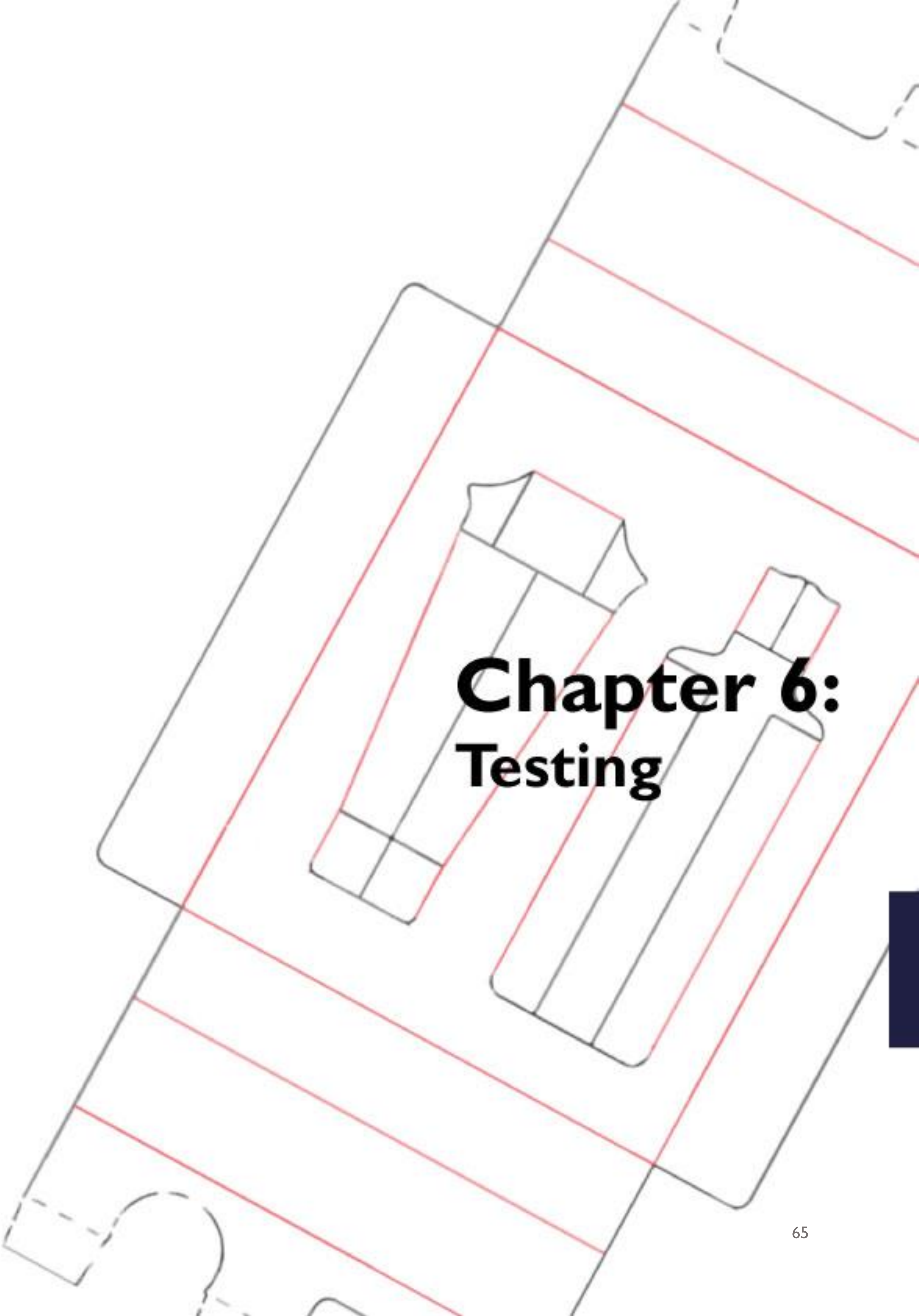


Figure 63: Interior packaging bottom view

In conclusion, a viable biodegradable interior packaging was designed and tested that fits the die-cutting and folding-gluing production process at Van de Steeg.



Chapter 6: Testing

In order to validate whether the new packaging will perform well enough to be able to make the material switch from plastic to a biodegradable alternative, the fiber-based interior packaging has been tested. A vibration testing machine is available to use at Van de Steeg. This machine is able to perform a fixed displacement vibration test. The second part of the testing includes an impact test in the form of a drop test. These tests are performed among ISTA guidelines to determine boundary conditions and to make sure that the tests that are performed are valid among those standards.

A relevant sidenote is that the available equipment at Van de Steeg has not been used for over a decade. It was calibrated in 2005. On the manufacturer's website, the following information has been found: L.A.B. equipment should be calibrated at least once a year. Annual calibrations maintain the integrity of test equipment and ensure the most reliable and accurate test results for your customers or products. Since this is not the case, the outcome of the tests may not be fully accurate.

6.1 ISTA NORMS FOR TESTING

Testing in packaging is a broad subject and it is important to set the right objective. These tests will be in conformity with ISTA norms (ISTA, 2020). The International Safe Transit Association (ISTA) is a global alliance of shippers, carriers, suppliers, testing laboratories, and educational and research institutions focused on the specific concerns of transport packaging. This test objective can be categorized as either a screening or prediction test, as found on the website of ISTA.

6.1.1 TESTING OBJECTIVES

A screening test is a test that is used to avoid serious problems during shipment, such as damaged products. It is the most common type of testing because it mostly fulfills the user's needs. Characteristics of this type of test include the terms: Simple, inexpensive, available.
The second testing objective is called prediction testing. It is generally more difficult, because prediction tests are focusing more on the differences between damage ranges. It allows the user to fine-tune costs and environmental.

A starting point is to perform a screening test as a basic test and to include features from prediction testing in addition to the screening test. Because prediction testing seems to offer more details on the tests, the goal is to perform a test with prediction testing as the objective. However, next to testing objectives, ISTA also has a category for their tests as explained below:

- Performance tests that result in a pass or fail assessment and are used to determine the viability of a packaged product to survive normal shipment.
- Development tests which compare relative performance of two or more designs or the same design from different suppliers.

Since getting a pass is necessary as well as comparing the performance between variations on the interior designs, both types of tests are needed.

Minimum use of packaging
ISTA tests establish lower limits for packaged-product performance, but in general do not set upper limits. Therefore, used in their most straightforward pass/fail fashion, ISTA tests do little to detect over-packaging (where a packaging is overqualified and could be optimized) situations. However, with the addition of a "reduce to damage" or "pass with minimum margin" approach, ISTA testing can be used for the demonstration of minimum use of packaging. "Reduce to damage" means that if a packaged product passes the test, it must be redesigned with less packaging and tested again until an optimum level is reached. The "Reduce to Damage" approach is an essential component of an effort to make packaging more sustainable (as described in the Responsible Packaging by Design process guideline. "Pass with minimum margin" might involve subjecting a packaged-product which has passed the test to increased severity levels, determining when damage does occur, and then verifying that those levels are not overly excessive.

A "reduce to damage" or "pass with minimum margin" protocol employing screening tests should be used with extreme caution. Since screening tests may not well represent actual field exposure in either intensity or type, the tests cannot be readily shown or proven to have a positive relationship to the field damage. Using *screening tests can perhaps be effective if coupled with a program of field monitoring and feedback after package redesign. But the far better approach is to use tests which provide an actual simulation of the distribution hazards.*

A large part of the project is the testing of the packaging to determine how well it handles hazards. There are four categories of hazards that exist in distribution: shock, vibration, compression and atmospheric.

The first categories, shock and vibration will be tested in this project. The two other types will not be tested due to the lack of equipment. Also, the type of products that are used in for the type of packaging have no additional atmospheric needs.

To conclude, the testing goals are to detect improvements for the packaging and implement them and to determine if the packaging has passed the tests and is therefore feasible to use as a replacement for the plastic packaging.

6.1.2 ISTA TEST STANDARDS

There are a number of ISTA testing standards that all specify a different range of packaging that can be tested. Below is a general overview of the available tests as found on ISTA's website.

Normally, ISTA will be contacted when doing a test following their procedures to receive an "ISTA-certified" mark on the packaging after verification of the test results. Due to Van de Steeg's bankruptcy, ISTA was not contacted. Since only a vibration testing machine is available to use for tests and a drop test can be performed without the need of equipment, ISTA 2A can be used to guide the process. An overview of the testing procedures can be found in Appendix C.

6.2 VIBRATION TEST:

There are ISTA test regulations for single packaging as well as multiple packaging and both can be performed. The test is not designed to simulate environmental occurrences and it is mainly used as a screening test, particularly when used as a consistent benchmark over time.

The machine has two settings that need to be determined. A specific number of G-forces should be tested, namely 1.15. This number corresponds to a specific RPM number of 275 as can be concluded from the Figure below.

The second setting is the testing time. It is standard that the tested packaging needs to be tested for 14,200 vibrations. With the setting of 275 RPM, the testing time will be 52 minutes. Halfway through the test the packaging needs to be rotated by 90°.

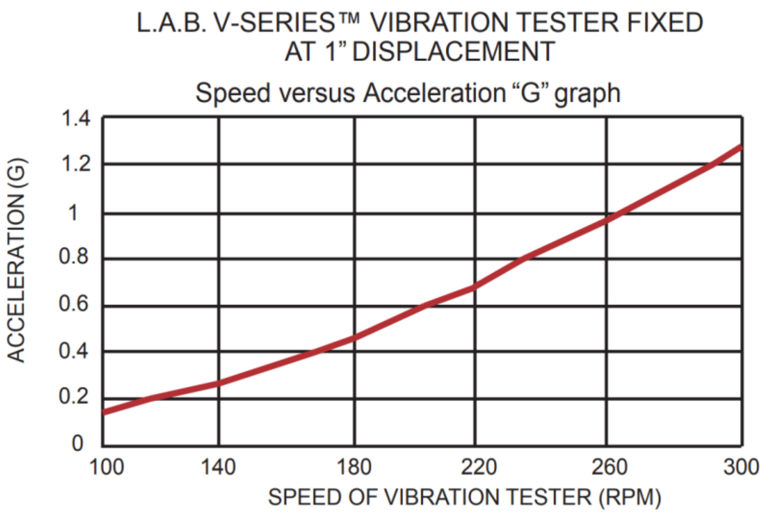


Figure 62: Graph on accelerations versus RPM of the vibration tester

With the graph that shows the vibration table settings, which is provided by the company, the correct RPM value can be retrieved with an input of G as 1.1.5. Van de Steeg's vibration testing machine can be categorized as a fixed displacement vibration tester. It complies with Method A1 or A2 of the apparatus section of ASTM D 999. The machine has a fixed displacement of 25 mm.

6.2.1 Vibration test results:

Single packaging vibration test results

	Material	Testing time	RPM	Test # 1	Test # 2	Test # 3
	Plastic	52	275			
	Arktika 350g.	52	275			
Tested again	Arktika 350g.	52	275			
	Arktika 300g.	52	275			
	Arktika 275g.	52	275			
	Creato 400g.	52	275			
	Kraftpak 410g.	52	275			
	Duo 610g.	52	275			
	Speypack 655g.	52	275			

Legend

Pass
Product displacement
Fail

Table 5: Single packaging vibration test results

Multiple packaging vibration test results

Material	Testing time	RPM	Test # 1	Test # 2	Test # 3
Plastic	52	275	Pass	Pass	Pass
Arktika 275g.	52	275	Pass	Pass	Pass
Arktika 275g.	76	185	Pass	Pass	Pass
Arktika 275g.	52	310	Pass	Pass	Pass
Arktika 275g.	52	275	Pass	Pass	Pass
Arktika 275g.	52	275	Pass	Product displacement	Pass
Arktika 275g.	52	275	Pass	Pass	Pass
Arktika 300g.	52	275	Pass	Pass	Pass
Arktika 350g.	52	275	Pass	Pass	Pass
Creato 400g.	52	275	Pass	Pass	Pass
Kraftpak 410g.	52	275	Pass	Pass	Pass
Duo 610g.	52	275	Pass	Pass	Pass
Speypack 655g.	52	275	Pass	Pass	Pass

Legend

- Pass
- Product displacement
- Fail

Table 6: Multiple packaging vibration test results

In the Tables above, the vibration test results are summarized. As can be seen, most tests went successfully, with the exception of a few occasions where the product slipped out of the fitment of the packaging, presumably late in the testing cycle, before any damage could be done. The vibration tests provided more insight in how well the current fitment was working and if it needed improvements. A few tests have been conducted with different settings to check if damage would occur, while still following the guideline of a testing time of 14,200 vibrations. Even with a higher RPM or a longer testing time, no damage to the packaging occurred.

Surprisingly, no damage occurred when the product slipped out of the fitment. This is surprising because once the product is no longer held down, the vibrations make the product create impacts against the interior packaging as well as the box around the interior packaging. It is likely that the product slipped out of the fitment near the end of the testing cycle before it could cause damage.

It can be concluded that fiber-based materials are viable to use as packaging when transporting products. The main focus point should be for the designer to use this type of test to iterate on the packaging fitment. Also, more vibration testing methods exist, such as a random displacement test. More tests will give more insight in the behavior of the packaging and these can be conducted if needed.

6.3 Drop testing

ISTA has a guideline on how to perform a drop test for a product-packaging combination. Earlier in the assignment, the product-packaging combination had not been set. Packaging for seven different gift sets have been created for the first drop test. In this first drop test, only the same material was used. Because of this, more insight on the impact of the product mass and packaging design was gained. Some general information on the product-packaging combination can be seen in the table below.

Also, the old vacuum formed plastic interior packaging will be tested first to see how it performs.

6.3.1 Drop test preparation

Before the drop tests, some preparations need to be met. For instance, the testing regulations state that the damage allowance should be determined by the shipper. Because the tests are targeted at this assignment, this is instead determined in consultation with the lead designer at Van de Steeg.

Damage scale for drop testing

	Number scale	
Indentation	0	No indentations in the material
	1	Minor indentation, not bigger than 30 mm
	2	Indentation that is up to 50 mm. There can be multiple minor indentations
	3	Indentation that creases the surface or edge and distorts the structure
Tears	0	No tears in the material
	1	A tear that is up to 10 mm long
	2	A tear (max. 10 mm²) that is up to 20 mm long
	3	A tear that is up to 40 mm long
Broken connection	4	A broken connection can be a normal or major tear and it has broken a part of the structure

Table 7: Damage scale for drop testing

In the Table above there is a scale for the damage. If a packaging gets a score of 3 or higher, then the packaging has failed the test. If a packaging receives a score of 2 or lower then it will have passed the test.

A list of the tested materials is summarized below:

International paper Arktika (275g, 300g, 350g)
Invercote Creato (400g)
Kapstone Kraftpak (410g)
Invercote Duo (610g)
Westrock Speypack (655g)

6.3.2 Drop test results

6.3.2.1 First test

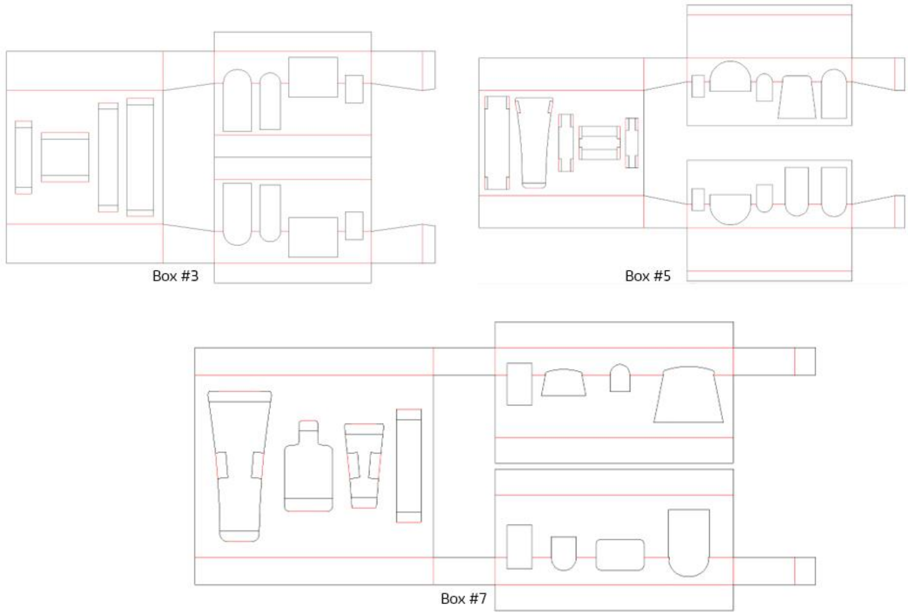


Figure 63: Drop test flat packaging examples

Figure 64: Droptest boxes

The first drop test was done before the detailing phase. Seven different product-packaging combinations were tested to evaluate the effects that the product mass had on the damage to the packaging. The product-packaging combinations that have been tested can be seen in the Figure above. The first droptest involved a benchmark test with the plastic packaging as well. The results of these tests can be seen in the Table below. No damage was detected during these tests and as a conclusion, the plastic interior packaging passed the test.

Droptest November 6th

Box #	Description of interior packaging damage	Indentation	Tears
1	No tears, no indentations	0	0
2	No tears, no indentations	0	0
3	No tears, no indentations	0	0
4	No tears, no indentations	0	0
5	No tears, no indentations	0	0
6	No tears, no indentations	0	0
7	No tears, no indentations	0	0

Pass	Fail
0-2	3-4

Table 8: First droptest plastic packaging results (November 6th)

The chosen material for this test was Arktika 275 g., which is the thinnest material from the selection at Van de Steeg. Most product-packaging combinations resulted in a failed test with this material. The drop test results are visible in the Table below. Only the box that consisted of four light products passed the test with near to no damage, as can be seen in the Table below. It can be concluded that this material can only be used under circumstances with very light products.

Droptest November 6th

Box #	Description of interior packaging damage	Indentation	Tears
1	Cover part: Minor damage on upper side, multiple indentations and major tears on bottom side Support structure: Partly damaged and partly dented on upper side, nearly entirely damaged on bottom side	3	4
2	Cover part: Minor damage on upper side, more bends and major tears on bottom side Support structure: Partly damaged and partly bend on upper side, nearly entirely damaged on bottom side	3	4
3	Cover part: Connection teared open, small tears on most edges Support structure: Multiple connections teared open, major indentations and many major and small tears	3	4
4	Cover part: Connection teared open, small tears on most edges Support structure: Major indentations and many major and small tears, partly intact	3	4
5	Cover part: Nearly every connection is teared open, a few indentations Support structure: Mostly collapsed and major and minor tears, indentations in all other locations	3	4
6	Cover part: Nearly every connection is teared open, a few indentations Support structure: Mostly collapsed and major and minor tears, indendations in all other locations	3	4
7	Cover part: One light indentation, no tears Support structure: Small indentation on the left side, with minor tears	0	1

Pass	Fail
0-2	3-4

Table 9: First droptest Arktika results (November 6th)

6.3.2.2 SECOND TEST

Droptest November 11th

Box #	Description of interior packaging damage	Indentation	Tears
1	Cover part: Only tears and minor indentations on the upper sides Support structure: Some small tears with indentations on the upper side, major damage on the bottom side, with multiple tears and indentations	2	3
2	Cover part: One small indentation Support structure: Minor indentations, one tear	1	1
3	Cover part: Connection teared open, few minor tears and indentations Support structure: Multiple connections teared open, major indentations and many major and small tears	3	4
4	Cover part: One small indentation, minor tears Support structure: Minor indentation	1	1

Pass	Fail
0-2	3-4

Table 10: Second droptest Arktika results (November 11th)

The second drop test has been conducted during the start of the detailing phase. Four different product-packaging combinations were tested to evaluate the effects that the product mass had on the damage to the packaging. The chosen material for this test was Arktika 350 g. The heavier product-packaging combinations resulted in a failed test while the two lighter product-packaging combinations resulted in a passed test. The difference in product mass can be detected quite easily by the damage that was caused to the products, which can be seen in the Table above.

6.3.2.3 Third test

Droptest January 7th

Box #	Material	Description of interior packaging damage	Indentation	Tears
1	Arktika 275g.	Cover part: Massive damage to, multiple big tears and some indentations Support structure: Massive damage, multiple big tears and some indentations	3	3
2	Arktika 300g.	Cover part: Massive damage, multiple big tears and some indentations Support structure: Massive damage, multiple big tears and some indentations	3	3
3	Arktika 350g.	Cover part: Massive damage to insert, multiple big tears and some indentations Support structure: Massive damage to insert, multiple big tears and some indentations	3	3
4	Creato 400g.	Cover part: A few minor indentations and minor tears, no damage on the upper side Support structure: One major indentation and two tears at the bottom of the right product	1	3
5	Kraftpak 410g.	Cover part: A few minor indentations and minor tears, no damage on the upper side Support structure: One major indentation and two tears at the bottom of the right product	1	3
6	Duo 610g.	Cover part: Small indentation, no tears Support structure: Small indentation, no tears	0	0
7	Speypack 655g.	Cover part: Small indentation at the bottom side, minor tear Support structure: Small indentation at the bottom side, minor tear	1	1

Pass	Fail
0-2	3-4

Table 11: Third droptest results (January 7th)

From the Table above can be concluded that for this final test using the final concept from Chapter 5.6, the tests partially succeeded because a few packaging failed the test while others passed. The packaging made from the Arktika boards in 275g, 300g and 350g as well as the 400g Invercote Creato and 410g Kraftpaper did not succeed the tests. The damage on the prototype made from the Creato and Kraftpaper mainly failed the test because the fitment with the product stretched too much.

The packaging that used the Invercote Duo 610g and Speypack 655g both passed the test. The Invercote Duo 610g has almost no visible damage and is therefore the most viable material from the selection. The Invercote Duo 610g prototype received no tears from the tests, but only a minor indentation. Below are the pictures of the packaging after the final test that provide more insight on the damage in addition to the results above. The results column refers to the earlier Figure in Chapter 6.1.3. All the prototypes can be made with a die-cutting and folding-gluing process and therefore it is a viable method to create a biodegradable interior packaging.

Figure 65: Packaging after drop test

6.4 Testing conclusion

The vibration tests only had positive results. No damage occurred. In three separate occurrences, the products got out of the fitment, so an iteration on the fitment was needed to solve the problem. The interior packaging was tested again after such an occurrence. All materials passed the vibration test.

The drop tests were harder to pass. The first drop tests had mostly failed results except for a very product-packaging combination. After using the higher grammage materials, the results were more positive. The final drop test used all available materials. Only two materials of the selection passed the final drop test with the final design from Chapter 5.6. These materials were Invercote Duo 610g and Speypack 655g.

Chapter 7:
Conclusion

The answer to the research question: How can polymer interior packaging be mechanically substituted with the use of biologically degradable materials? Can be explained with the conclusions on the sub-research questions.

What are the viable options for biodegradable materials in packaging?
The goal of this research was to determine the viability of replacing plastic interior packaging with an alternative, biodegradable material. By conducting a material selection process, two material groups were found as a viable candidate. This should improve the sustainability while keeping the mechanical performance as close to the original as possible. Studies indicate the feasibility of bioplastics in replacing conventional plastics.

Furthermore, it showed that paper and board are viable options as well. The latter requires a redesign due to the different geometrical possibilities that come with changing the production process. It is noticeable that with the varying thicknesses of this fiber material, the protective performance was negatively influenced by the thickness. By using the thicker (600 grams and higher) boards, the protective performance increased sufficiently.

What are the production methods that are fit for creating a biodegradable interior packaging?
There are many different methods that all result in different designs. The currently used die-cutting and folding-gluing process proved suitable, however only flat structures can be produced.

With methods such as 3D printing and molding with for example paper pulp, 3D structures are possible that offer more protection, yet at the cost of a heavier interior packaging.

How can a viable design for a new biodegradable packaging be designed?
At the start of the design process, many packaging ideas were quickly made with fast prototyping to assess the viability of an idea. With fast prototyping, the translation from digital to a real model was possible. Multiple ideas were developed into concepts. With a selection process, the concept that scored highest was selected for a more detailed iteration.

How well does biodegradable interior packaging mechanically perform compared to their polymer equivalents?
The overall results showed both failed and passed interior packaging tests. The vibration tests were mostly successful, considering that there was no damage. However, in a few occasions, the product slipped out of the packaging's fitment. Surprisingly, this did not result in any damage. By optimising the fitment, the fiber-based materials passed the test.

The impact testing showed that using paper and board could be promising, although there were failed tests as well. Different product combinations were tested that varied in volume and mass. There were tests with very light products where even the thinnest paper passed the test. The thicker boards held up to the impact tests with heavier products, with only a minor indentation as the only visible damage.

To conclude: How can polymer interior packaging be mechanically substituted with the use of biologically degradable materials? A viable packaging was designed based on a biodegradable alternative.

7.2 Recommendation

To correctly implement paper and board for interior packaging, the right material needs to be linked to products that need packaging. Smaller, lighter products need less protection and thin (350g. or lower) fiber-based materials can be used. Bigger, heavier products require additional protection and thus, thicker fiber-based materials can be used instead.

Ideally, a flowchart could be created that guides the designer into the right material choice based on the volume and mass of the product. Digital testing could provide more insight to further optimize the design and therefore being able to create such a flowchart.

The challenge with paper and board is to create optimal structures to ensure that the lowest packaging mass can be obtained in order to make the packaging more sustainable with transportation. Digital testing may also be of help in creating the optimal packaging structure.

Bioplastics were not included in the experimental side of this assignment because Van de Steeg only used fiber-based materials and a die-cutting and folding-gluing process. Bioplastics are concluded as a viable option for the redesign of a biodegradable interior packaging.

A sidenote is that the abundant use of plastic packaging was a cause for trying to improve the recycling percentage. Also, people have to separate plastic at home to make an effort into making its use more sustainable. The fact that people have to pay a deposit to use plastic bottles in order to convince people to recycle those bottles means that much extra effort is put into making plastic packaging more sustainable. The same can be done for materials such as paper and board and bioplastics to improve their implementation.

REFERENCES

Ashby, M. F., Bréchet, Y. J. M., Cebon, D., & Salvo, L. (2004). Selection strategies for materials and processes. Materials & Design, 25(1), 51–67. https://doi.org/10.1016/s0261-3069(03)00159-6

Ban on single-use plastics from 2021. (2021). retrieved May 19, 2021 from https://www.kvk.nl/english/ban-on-single-use-plastics/

Onen Cinar, S., Chong, Z. K., Kucuker, M. A., Wieczorek, N., Cengiz, U., & Kuchta, K. (2020). Bioplastic Production from Microalgae: A Review. International Journal of Environmental Research and Public Health, 17(11), 3842. https://doi.org/10.3390/ijerph17113842

EUR-Lex. (1994, December). European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31994L0062

Govindan, K., Madan Shankar, K., & Kannan, D. (2016). Sustainable material selection for construction industry – A hybrid multi criteria decision making approach. Renewable and Sustainable Energy Reviews, 55, 1274–1288. https://doi.org/10.1016/j.rser.2015.07.100

Guérin, D. (2011) Design and development of an innovative ecoefficient low-substrate flexible paper packaging from renewable resources to replace petroleum based barrier films

Guidelines for Selecting and Using ISTA® Test Procedures and Projects retrieved February 17, 2020 from https://ista.org/testing_guidelines.php

Jariyasakoolroj, P. et al (2018) Advances in research and development of bioplastic for food packaging

Johansson, C. et al (2012) Renewable fibers and bio-based materials

Teck Kim, Y., Min, B., & Won Kim, K. (2014). General Characteristics of Packaging Materials for Food System. Innovations in Food Packaging, 13–35. https://doi.org/10.1016/b978-0-12-394601-0.00002-3

Kumar, S. (2012) Applications of biodegradable pharmaceutical packaging materials: A review

Luijsterburg, B., & Goossens, H. (2014). Assessment of plastic packaging waste: Material origin, methods, properties. Resources, Conservation and Recycling, 85, 88–97. https://doi.org/10.1016/j.resconrec.2013.10.010

Lye, S. W., & Yeong, H. Y. (1994). An integrated framework for protective packaging design and manufacture. International Journal of Production Research, 32(8), 1837–1856. https://doi.org/10.1080/00207549408957045

Lye, S. W., & Ho, H. K. (1991). Knowledge-based CAD system for protective packaging design. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 5(2), 125–134. https://doi.org/10.1017/s0890060400002614

Matchett E., Briggs A.H. (1966) Practical Design Based on Method (Fundamental Design Method). In: Gregory S.A. (eds) The Design Method. Springer, Boston, MA. https://doi.org/10.1007/978-1-4899-6331-4_21

Molenveld, K., et al (2014) Catalogus biobased verpakkingen retrieved March 9, 2021from https://www.wur.nl/nl/artikel/Download-Catalogus-Biobased-Verpakkingen.htm

Isaac, O., Olumide, O., & Rasaki, O. (2015). Application of House of Quality Matrix to Material Selection for Engineering Designs. British Journal of Applied Science & Technology, 10(4), 1–11. https://doi.org/10.9734/bjast/2015/19105

Origami crane example. Retrieved July 7, 2019 from https://origami.me/crane/

Plastic facts and figures retrieved September 19, 2019 from https://www.plasticsoupfoundation.org/en/plastic-problem/plastic-pollution-facts/plastic-facts-Figures/

Rao, R. V., and Davim, J. P. (2006). A decision-making framework model for material selection using a combined multiple attribute decision-making method. The International Journal of Advanced Manufacturing Technology, 35(7–8), 751–760. https://doi.org/10.1007/s00170-006-0752-7

Scott, P. G. (1972). Plastics packaging and coastal pollution. International Journal of Environmental Studies, 3(1–4), 35–36. https://doi.org/10.1080/00207237208709489

Sohn, J., Kim, H., Kim, S., Ryu, Y., & Cha, S. (2019). Biodegradable Foam Cushions as Ecofriendly Packaging Materials. Sustainability, 11(6), 1731. https://doi.org/10.3390/su11061731

Smith, L. (2021). Plastic waste (No. 08515). (2021, April). https://commonslibrary.parliament.uk/research-briefings/cbp-8515/

Stretching inner part retrieved January 2020 from: https://www.metsaboard.com/Media/Product-news/Pages/Better-with-Less-Design-Challenge-winning-design-introduces-an-ingenious-alternative-to-bubble-wrap.aspx

Svanes, E., Vold, M., Møller, H., Pettersen, M. K., Larsen, H., & Hanssen, O. J. (2010). Sustainable packaging design: a holistic methodology for packaging design. Packaging Technology and Science, 23(3), 161–175. https://doi.org/10.1002/pts.887

Tessellation structure retrieved May 19, 2021 from http://www.designcoding.net/design-geometry-final-works

Van den Oever, M., Molenveld, K, Van der Zee, M and Bos, H. (2017) Bio-based and biodegradable plastics – Facts and Figures retrieved March 9, 2021 from https://edepot.wur.nl/408350

Weber, C. J., Haugaard, V., Festersen, R., & Bertelsen, G. (2002). Production and applications of biobased packaging materials for the food industry. Food Additives & Contaminants, 19(sup1), 172–177. https://doi.org/10.1080/02652030110087483.

Appendix

Appendix A: Van de Steeg information

Figure 66: Packaging example[5]

In August 2020, Van de Steeg had to close its doors due to financial problems. The problems got worse due to the Brexit, because Van de Steeg had most of their clients in the United Kingdom. The coronavirus also had a negative impact on Van de Steeg. (https://www.tubantia.nl/enschede/drukker-agi-van-de-steeg-enschede-sluit-95-banen-weg~af6b3ec0/)

Van de Steeg uses printing, punching and folding gluing processes on flat base materials to create packaging. Their machinery input is only fiber-based, such as paper and cardboard.

The printing process is a large component within the process for Van de Steeg, but it is not one of the main concerns for the assignment. The printing process is for visual results, while the assignment is focused on the physical properties.

Printing process
For their printing process, Van de Steeg uses a press that can make detailed, multicolour prints with the option to offset prints, as well as using special foils. The exact model is a Heidelberg 106 XL. The machine is specifically for packaging, label and commercial printing. The printer at Van de Steeg is customized to a specific set-up with six colour presses, with additional 'towers' for lacquering and drying. The set-up is also capable of UV-printing, which has a few advantages such as faster curing time and making materials attach better.

[5] *https://www.vandesteeg.com/beauty-personal-care/*

Figure 67: Heidelberg printer (retrieved from https://www.heidelberg.com/global/en/products/offset_printing/format_70_x_100/speedmaster_xl_106/product_information_12/product_information_20.jsp)

Die-cutting process

The die-cutting process comes after the printing process and prepares the material for the next step. The flat shape of the packaging is created here. Van de Steeg uses die-cutting machines from WPM. The abbreviation stands for Woschnik Partner Maschinenbau Gmbh. The machine covers the whole range of the materials used at Van de Steeg, such as paper, cardboard, flute materials and PET foils, in a size of up to 72 x 102 cm. Next to die-cutting, the machine can also do embossing and creasing. The Figure below shows the machine, although it is quite hard to explain its features. From the right side, a stack of flat materials is inserted in the machine. One by one, the machine will take one of the sheets and drag it onto the die-cutter in the middle to cut the edges of the packaging from the sheet in one movement. The entire sheet will then be placed on a stack. This type of die-cutting machine is called a flatbed die-cutter. Rotary version and more modern laser die-cutters also exist.

Figure 68: Die-cutting machine (retrieved from https://www.maschinensucher.de/mss/wupa)

This specific production process comes with some restrictions. The most important aspect is that the process requires a flat material that cannot overlap itself.

Folding gluing process


Figure 69: Bobst folder gluing machine retrieved from https://www.pressxchange.com/en/folding-gluing-bobst-media-100-ii-year-2004/machine-id/73566/

A folding gluing machine folds the packaging shape while gluing it simultaneously to keep it in place. Folds are applied through the entire packaging because of how the packaging has to go through the machine. The order and layout of folds, shapes and adhesive strips are important considerations to validate the production side of a design. This causes more design limitations that need creative solutions.

Url: https://www.bobst.com/usen/products/folding-gluing/folder-gluers/
About the process: https://www.bobst.com/usen/products/folding-gluing/process/

Packaging design and prototyping
At Van de Steeg the packaging designs are created with the help of ArtiosCAD, which is a structural design software for packaging. These prototypes can be created very fast. Once a 2D model is ready, the file can be sent to the plotter close to the workspace. A number of common materials are readily available there to use for prototyping. After configuring the settings, the machine is able to cut the model out of the material at high speed. By manually folding (and frequently, taping) the model, the prototype is ready.

Appendix B: Fiber-based material specsheets of materials used at Van de Steeg

International paper: Arktika range

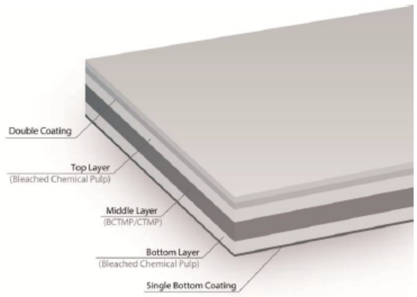
From the website of the manufacturer, the following information is gathered:

Features & benefits

- Outstanding printing quality and high surface smoothness
- Excellent printability on the backside producing homogenous reverse-side print results
- FBB (Folding Boxboard) GC1 product, with reverse side coating
- Available in basis weights 200-350 gsm
- Produced at the International Paper Kwidzyn mill in Poland
- Produced from 100% virgin fibers

(Retrieved from http://www.internationalpaper.com/products/europe-middle-east-africa/coated-paperboard/folding-boxboard/product-detail/arktika)

INTERNATIONAL PAPER



ARKTIKA

COATED FOLDING BOXBOARD GC1

Specifications:

Property (Unit)	Tolerance	Value								Standard
Basis Weight (g/m²)	+/- 4%	200	215	230	250	275	300	325	350	PN-ISO 536:1996
Thickness (µm)	+/- 4% max. 20 µm	282	308	336	378	428	474	520	568	PN-EN 20534:2005
Stiffness DIN 53 121 (5°) MD (mNm)	+/- 15%	11.8	15.7	19.1	26.1	35.7	46.1	58.3	76.6	PN-ISO 2493:1995
Stiffness DIN 53 121 (5°) CD (mNm)		5.9	7.8	9.6	12.6	17.4	21.8	27.4	34.8	
Stiffness Taber (15°) MD (mNm)		6.6	8.7	10.6	14.5	19.8	25.6	32.4	42.5	
Stiffness Taber (15°) CD (mNm)		3.3	4.3	5.3	7.0	9.7	12.1	15.2	19.3	
Stiffness L&W (15°) MD (mN)		136	180	220	300	410	530	670	880	
Stiffness L&W (15°) CD (mN)		68	90	110	145	200	250	315	400	
Moisture Content (%)	+/- 1.0	7.2	7.2	7.2	7.2	7.2	7.5	7.5	7.5	*PN-ISO 287:2009
Brightness Top with UV D65 (%)	+/- 1.0	92								ISO 2470-2:2008
Brightness Bottom with UV D65 (%)	+/- 1.0	91								
Gloss 75° Gardner (%)		> 45								TAPPI 480 om - 99
Roughness PPS S10 (µm)		< 1.3								PN-ISO 8791-4:1997
Internal Bond Strength Scott (J/m2)		> 110								TAPPI 833 pm - 94
Surface Strength (medium viscosity IGT oil) (m/s)		≥ 1.0								ISO 3783:2006
Water Absorption Top $COBB_{60}$ (g/m2)		< 55								PN-E 20535:1996
Water Absorption Bottom $COBB_{60}$ (g/m2)		< 60								

*Computerized measurement and adjustment. Calibration of measuring heads and parameter control according to standard.

Issued on 6th February 2013

International Paper Kwidzyn Sp. z.o.o. (LLC) operates in compliance with the following standards: **PN-EN ISO 9001, PN-EN ISO 14001, OHSAS 18001, ISEGA** Certificate of Conformity (approved for food packaging and safety of toys), **FSC®** Mix Credit System (SGS COC 002560) and **PTS/FFPI** certification for inkjet coding on pharmaceutical packaging.

Visit us at: http://www.internationalpaper.com/EMEA/EN/Products/CoatedBoard/index.html

FSC

Arktika

Iggesund: Invercote Creato range
From the website of the manufacturer, the following information is gathered:

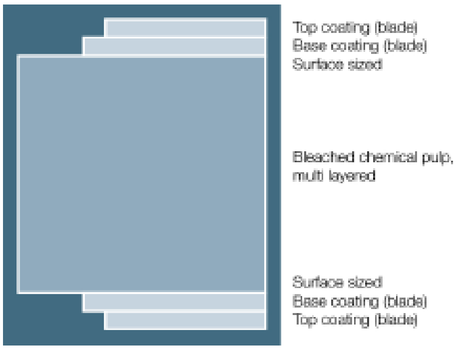
Invercote Creato is a solid bleached board (SBB) designed for graphical products, and offers equal, outstanding aesthetic printing properties on both sides. Both sides are fully coated and have a matt finish. Invercote Creato has a smooth surface that is tailored to faithfully reproduce the most sophisticated printed images. This surface, combined with Invercote Creato's excellent structural, design and embossing characteristics, make it ideal for demanding graphical applications. The whiteness level is tailored to ensure the best print contrast and colour reproduction properties required for high-end print productions. A patented coating formula provides outstanding lightfastness, giving the end products a longer life.

Thanks to its composition of multiple layers of solid bleached primary fibres, Invercote Creato has a superior strength and toughness compared to board grades that contain mechanical or recycled fibres or single-ply bleached primary fibre board. This strength gives several advantages in designing and producing brochures, covers and cards of various kinds. In addition to traditional printing techniques, Invercote is qualified and certified for most digital printing presses on the market today and suitable for digital finishing technology.

Due to the excellent consistency of Invercote Creato's performance is predictable and dependable, making repeat print runs with the same machine settings and excellent print results possible.

(Retrieved from: https://www.iggesund.com/products/solid-bleached-board/invercote-creato/)

Solid Bleached Board, GZ



Product description

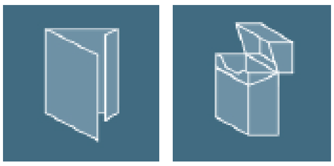
Invercote Creato is designed for graphical products, and offers equal, outstanding aesthetic printing properties on both sides. Both sides are fully coated and have a matt finish.

Invercote Creato has a smooth surface that is tailored to faithfully reproduce the most sophisticated printed images. This surface, combined with Invercote Creato's excellent structural, design and embossing characteristics, make it ideal for demanding graphical applications.

The whiteness level is tailored to ensure the best print contrast and colour reproduction properties required for high-end print productions. A patented coating formula provides outstanding lightfastness, giving the end products a longer life. In addition to traditional printing techniques, Invercote Creato works well in most digital colour copiers and digital printing presses today.

Thanks to its composition of solid bleached primary fibres, Invercote has a superior strength and toughness compared to board grades that contain mechanical or recycled fibres or single-ply bleached primary fibre board. This strength gives several advantages in designing and producing of brochures, covers and cards of various kinds.

Due to the excellent consistency of Invercote Creato its performance is predictable and dependable, making repeat print runs with the same machine settings and excellent print results possible.



Covers
Cards
Folders
Tags
Point of sales
Tobacco

Grammage (g/m^2)	200	220	240	260	280	300	350	400
Thickness (µm)	200	230	260	290	315	345	415	485
Caliper (pt)	7.9	9.1	10.2	11.4	12.4	13.6	16.3	19.1
Tolerances: Grammage ± 5% (ISO 536) Thickness ± 5% (ISO 534)								

The range is further extended by Invercote Duo, available in grammages 370 - 770 g/m². See specification sheet in the *Board Laminates*-section.

Invercote Creato

									Tolerances	Methods/Remarks[1])
Grammage (g/m²)	200	220	240	260	280	300	350	400	± 5%	ISO 536
Thickness (µm)	200	230	260	290	315	345	415	485	± 5%	ISO 534
Opacity	96.0	96.5	97.5	98.0	98.3	98.5	99.0	99.5	-	ISO 2471
Printing side properties - both sides identical										
Colour										
L* (%)	96.5	96.5	96.5	96.5	96.5	96.5	96.5	96.5	±0.8	ISO 5631-2
a*	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	±0.6	ISO 5631-2
b*	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	±1.1	ISO 5631-2
Whiteness (%)	127	127	127	127	127	127	127	127	±5	ISO 11475
ISO brightness (%)	94	94	94	94	94	94	94	94	±2	ISO 2470
Surface roughness PPS (µm)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	≤ 1.6	ISO 8791-4
Board gloss 75° (%)	40	40	40	40	40	40	40	40	±10	ISO 8254-1
Surface pH	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	+1/-1.5	1
Ink absorption (%)	35	35	35	35	35	35	35	35	-	1
Surface strength IGT (m/s)										
blister	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	≥ 0.5	ISO 3783
pick	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	≥ 0.8	ISO 3783
Board properties										
Ply Bond (J/m²)	160	160	160	160	160	160	160	160	≥ 120	TAPPI 569
Cobb (g/m² 60 s)										
both sides identical	30	30	30	30	30	30	30	30	-	ISO 535
Moisture content (%)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	±1.0	ISO 287
Bending stiffness L&W 5° (mNm)										
MD	6.9	10.1	13.5	18.7	24.3	30.1	47.8	72.4	-	ISO 5628
CD	3.3	4.8	6.4	8.9	11.6	14.4	22.8	33.6	-	ISO 5628
Bending resistance L&W 15° (mN)										
MD	74	108	150	204	265	300	520	820	-15%	ISO 2493
CD	34	49	70	95	122	151	250	375	-15%	ISO 2493
Bending moment Taber 15° (mNm)										
MD	3.6	5.2	7.2	9.8	12.8	14.5	25.1	39.6	-15%	ISO 2493
CD	1.6	2.4	3.4	4.6	5.9	7.3	12.1	18.1	-15%	ISO 2493
Tensile strength (kN/m)										
MD	20.0	21.0	22.0	23.5	24.0	25.0	28.0	31.5	-	ISO 1924-2
CD	9.5	10.5	11.0	11.5	12.0	13.0	14.0	15.0	-	ISO 1924-2
Tearing resistance (mN)										
MD	1800	2050	2400	2800	3100	3200	4200	5600	-	ISO 1974
CD	1900	2300	2600	3100	3500	3700	4500	6000	-	ISO 1974

1) See section *General Technical Information*

PC 2013E ICC

WestRock: Kraftpak range

From the website of the manufacturer, the following information is gathered:
WestRock KraftPak sets the standard for unbleached, uncoated virgin paperboard. It is a low density, high-yield product which provides outstanding strength and durability while using less fiber. The unique two-ply design offers a consistent surface with an attractive natural brown appearance and good printability. KraftPak is highly versatile and ideal for a wide variety of packaging applications.

Features & Benefits

What you can expect from us:

- Exceptional Strength: Excellent stiffness, tear and internal strength properties make for extremely durable packaging.
- Low-Density, High-Yield: Using less fiber for a given caliper and an output that generates more cartons per ton provides the customer with an efficient and cost-effective packaging option.
- Product Uniformity: Caliper, basis weight and moisture uniformity promote excellent performance and optimize productivity. Controlled curl and coefficient of friction ensure consistent handling on automated equipment.
- Clean, Consistent Appearance: State-of-the-art stock preparation systems yields a clean, uniform, natural appearance.

Best used with:

- Health & Beauty
- Food Service, Carry-out
- Sporting Goods
- Wines & Spirits
- Dry & Prepared Food
- Automotive
- Gift Boxes
- Filter Frames
- Slip Sheets, Partitions

(Retrieved from: https://www.westrock.com/products/paperboard/kraftpak)

WestRock

KraftPak®

WestRock KraftPak® sets the standard for unbleached, uncoated virgin paperboard. It is a low density, high-yield product which provides outstanding strength and durability while using less fiber. The unique two-ply design offers a consistent surface with an attractive natural brown appearance and good printability. KraftPak is highly versatile and ideal for a wide variety of packaging applications.

Best Used With

Health & Beauty

Food Service, Carry-out

Sporting Goods

Wines & Spirits

Dry & Prepared Food

Automotive

Gift Boxes

Beverage Carriers

Filter Frames

Slip Sheets, Partitions

Product Classification

Uncoated Unbleached

Kraft

UUK Paperboard

What You Can Expect from Us

Exceptional Strength	Excellent stiffness, tear and internal stength properties make for extremely durable packaging. This translates into enhanced product protection and reduced damage.
Low Density, High-Yield	Using less fiber for a given caliper and an output that generates more cartons per ton provides our customer with a very efficient and cost-effective packaging option.
Product Uniformity	Caliper, basis weight and moisture uniformity promote excellent performance and optimize productivity. Controlled curl and coefficient of friction ensure consistent handling on automated equipment.
Moisture Resistance	Outstanding moisture resistance and wet durability make KraftPak the ideal substrate for many challenging packaging applications.
Clean, Consistent Appearance	State-of-the-art stock preparation system yields a clean uniform natural appearance. KraftPak top surface (L*a*b) targets (60.0, 7.0, 18.0).

Additional Product Information

Sustainability	Recyclable. BPI® certified for industrial composting. Compostable documentation available (EN 13432), up to 22 pt. All WestRock North American paperboard mills are certified to the SFI®, PEFC™, FSC™ Chain of Custody Standards. Contact your WestRock sales representative for certified fiber availability for this product.
Food Contact	Meets multiple national requirements for food contact packaging, e.g., US and Canada. Contact your sales representative for information on specific markets and end uses. ISEGA Certificate available.
Environmental and Safety	Notices under US California Proposition 65 and the EU REACH regulation are not required. Meets heavy metal limits of the US Model Toxics in Packaging rules and Article 11 of the EU Directive 94/62/EC.

WestRock

*Not transferrable to converted product. Restrictions may apply.

Grade Availability & Typical Properties (U.S.)

KraftPak®

Grade Availability by Caliper												Units	Method
Caliper (in)		0.013	0.015	.0.17	0.018	0.020	0.022	0.024	0.026	0.028	0.030	inches	T-411
Base Weight		46	46	50	53	58	63	68	73	79	84	lbs/1000 sq ft	T-410
Moisture		6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	percent	T-412
Gurley Porosity		20	16	16	16	16	16	18	20	22	24	sec	T-460
Stiffness													
Taber 15°	**MD**	80	100	150	180	230	300	375	475	590	705	g-cm	T-489
	CD	32	45	60	75	95	125	160	195	250	300	g-cm	T-489
	GM	51	70	95	116	148	194	248	308	389	458	g-cm	T-489
Receptivity													
Cobb	**Top, 2 min**	45	45	45	45	45	45	45	45	45	50	g/m2	T-538
	Bottom, 2 min									-0.3	-0.3	L-a-b	T-524
Scott Internal Bond		100	100	100	100	100	100	100	100	100	100	ft.lb/1000 sq in	T-569
Coefficient of Friction (COF)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		T-815
Smoothness													
Side	**Felt**	300	355	355	355	365	370	375	380	380	385	mL/min	T-538
	Wire	385	420	420	420	420	420	420	420	420	420	mL/min	T-538
Elmendorf Tear, MD		315	325	370	390	435	505	555	590	620	655	gf	T-414
Strength													
Tensile	**MD**	70	80	90	95	102	110	115	118	122	125	lb/in	T-494
	CD	40	42	45	47	50	55	58	60	63	68	lb/in	T-494

Grade Availability & Typical Properties (Metric)

Grade Availability by Caliper												Units	Method
Caliper (in)		330	381	432	457	508	559	610	660	711	762	microns	T-411
Base Weight		225	225	244	259	283	307	332	356	386	410	gsm	T-410
Moisture		6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	percent	T-412
Gurley Porosity		20	16	16	16	16	16	18	20	22	24	sec	T-460
Stiffness													
Taber 15 (Metric)	**MD**	7.6	10.5	14.3	17.2	22.0	28.7	35.8	45.0	56.4	67.4	mN.m	T-489
	CD	3.1	4.3	5.7	7.2	9.1	12.0	15.3	18.6	23.9	28.7	mN.m	T-489
	GM	4.8	6.7	9.1	11.1	14.1	18.5	23.7	29.4	37.0	44.0	mN.m	T-489
Receptivity													
Cobb	**Top, 2 min**	45	45	45	45	45	45	45	45	45	50	g/m²	T-538
	Bottom, 2 min	50	50	50	50	50	50	50	50	50	50	g/m²	T-524
Scott Internal Bond		210	210	210	210	210	210	210	210	210	210	J/m²	T-569
Coefficient of Friction (COF)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3		T-815
Smoothness													
Side	**Felt**	300	355	355	355	365	370	375	380	380	385	mL/min	T-538
	Wire	385	420	420	420	420	420	420	420	420	420	mL/Min	T-538
Elmendorf Tear, MD		3.09	3.19	3.63	3.83	4.27	4.95	5.44	5.79	6.08	6.43	N	T-414
Strength													
Tensile	**MD**	12.3	14.0	15.8	16.6	17.9	19.3	20.1	20.7	21.4	21.9	kN/m	T-494
	CD	7.0	7.4	7.9	8.2	8.8	9.6	10.2	10.5	11.0	11.9	kN/m	T-494

For more information, please contact your WestRock representative or visit our website at westrock.com.

WestRock

SUSTAINABLE FORESTRY INITIATIVE
SFI-00095
Good for you. Good for our forests.

PEFC
PEFC/29-31-137

westrock.com

Iggesund: Invercote Duo range

From the website of the manufacturer, the following information is gathered:

Invercote Duo is a solid bleached board (SBB) made by back-to-back pasting of triple coated Invercote G.

This standard version has identical printing surfaces front and back. Alternative versions are available, with e.g. front-to-back pasting to achieve special properties or appearances. An Iggesund representative would be happy to discuss further and give advice.

Invercote Duo's printing surfaces has the ability to faithfully reproduce the most sophisticated printing images. A patented coating formula provides outstanding lightfastness, giving the end products a longer life. Due to its strength, toughness and thickness, it is especially suitable for various display purposes and different types of rigid, exclusive packaging.

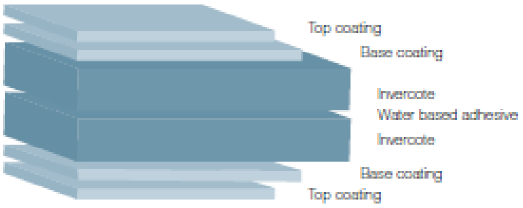
Invercote Duo is particularly recommended for packaging of aroma and flavour sensitive products.

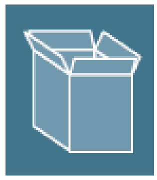
The pasting glue is taint and odour neutral. Invercote Duo can be extrusion coated to add the barrier functions necessary under extreme conditions, e.g. outdoor displays or foil or film laminated for added sales appeal.

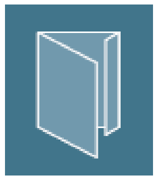
(Retrieved from: https://www.iggesund.com/products/solid-bleached-board/invercote-duo/)

Invercote Duo

Solid Bleached Board, GZ







Product description

Invercote Duo is made by back-to-back pasting of double coated Invercote. This standard version has identical printing surfaces front and back. Alternative versions are available, with e.g. front-to-back pasting to achieve special properties or appearances. An Iggesund representative would be happy to discuss further and give advice.

Due to its strength, toughness and thickness, it is especially suitable for various display purposes and different types of rigid, exclusive packs.

Invercote Duo is particularly recommended for packaging of aroma and flavour sensitive products. The pasting glue is taint and odour neutral. Invercote Duo can be extrusion coated to add the barrier functions necessary under extreme conditions, e.g. outdoor displays.

Grammage (g/m²)	430	470	510	550	610	670	710
Thickness (µm)	550	610	660	720	800	880	940
Caliper points	21.7	24.0	26.0	28.4	31.5	34.7	37.0
Tolerances: Grammage ± 6% (ISO 536) Thickness ± 6% (ISO 534)							

Invercote Duo is available in gramages up to 1430 g/m² with a thickness up to 1880 µm, (Caliper 74).

Certifications						
Product related	ECF	PEFC credit material	FSC® Mix FSC-C110018	Food contact	Toy safety	Archiving
		2778 PEFC	TUEV-COC-000232	EC 1935/2004, EC 2023/2006[1], American FDA, German BfR	EN 71 Part 3 ISO 8124-3:2010	ISO 9706
	All fibres from sustainable and controlled sources in compliance with the EU Timber Regulation EC 995/2010.					
Mill related	ISO 14001	ISO 9001	FSC® C. o. C.	PEFC C. o. C.		
	EcoVadis Platinum Standard					
[1] the GMP regulation, extended with CEPI GMP						

More information, application examples as well as environmental declarations and other certificates can be found at www.iggesund.com.

Product properties

Properties	Printing side – both sides identical[2]	Tolerances	Methods/Remarks[1]
Grammage (g/m²)	430–1430 g	± 6%	ISO 536
Colour			
L*(%)	96.7		ISO 5631-2
a*	2.5		ISO 5631-2
b*	-7.3		ISO 5631-2
Whiteness (%)	124		ISO 11475
ISO brightness	94		ISO 2470
Surface roughness (µm)	1.5	≤ 2.0	ISO 8791-4
Board gloss 75° (%)	30	+20/-10	ISO 8254-1
Cobb (g/m² 60 s) (both sides)	30	≤ 40	ISO 535
Moisture content (%)	6.5	±1.0	ISO 287
Robinson taint	Below the detection limit of 0.6	-	EN 1230, DIN 10955

[1] See section *General Technical Information*

[2] Using the reverse side OUT will give other surface properties

Grammage dependent properties								Tolerances	Methods/Remarks[1]
Grammage	**430**	**470**	**510**	**550**	**610**	**670**	**710**		
Thickness (µm)	550	610	660	720	800	880	940	± 6%	ISO 534
Bending resistance L&W 15° (mN)[2]									
MD	1014	1345	1738	2131	2566	3373	3932	-	ISO 5628
CD	517	683	869	1097	1262	1718	2028	-	ISO 5628
Bending stiffness L&W 5° (mNm)[2]									
MD	99	131	170	209	252	331	386	-	ISO 2493
CD	50	66	84	107	123	168	199	-	ISO 2493
Bending moment Taber 15° (mNm)[2]									
MD	49	65	84	103	124	163	190	-	ISO 2493
CD	25	33	42	53	61	83	98	-	ISO 2493

[1] See section *General Technical Information*

[2] Typical values

Issued: 2021.02

All properties are measured in test climate 23°C/50% RH at Iggesund mill. Tolerances and max/min levels, when stated, are based upon 95% confidence interval within each production run.

Strand paper & board: Speypack range

From the website of the manufacturer, the following information is gathered:

We specialise in combining the highest quality liners and boards from the world's leading mills to create bespoke "Duo" or "multi-layered" rigid boards, unavailable direct from the mill, which allow for challenging print and foil applications to be applied to meet the demands of the luxury carton market.

Whisky, Gin, Sparkling Wine and Champagne boxes are markets where SPEYPACK® products meet the demanding requirements, providing a premium/luxury box.

The speed achieved on laminator means that for runs of 10 tonnes and up, we achieve greater economies of scale for our printing partners than using their own in-house sheet to sheet laminator.

DATASHEET

Quality; SPEYPACK® ECO

Origin; Europe

SPEYPACK ECO 655g/770um		DATA	TOLERANCE
Grammage	g/m²	655	±5%
Caliper	µm	770	±7.5%
Moisture	%	8.0	±0.5%
Smoothness µm	ISO8791-4	-	<2.0 µm
Stiffness CD	(50mm/5° - DIN53121)	900	-15%
Stiffness MD	(50mm/5° - DIN53121)	450	-15%
ISO brightness +UV	ISO2470	95%	±3%

Tolerances, when specified, are based on 95% confidence limits on single mill measurements of random samples measured in manufacturing conditions. Indicative technical values (23°C RH 50%).

Issued 01.04.2017.

APPENDIX C: ISTA TESTS OVERVIEW

Non-Simulation Tests

1A, 1B, 1C, 1D, 1E, 1G, 1H

Challenge the integrity of the product and package combination. Useful as screening tests but not designed to simulate environmental occurrences.

Learn more >

Partial Simulation Tests

2A, 2B, 2C

More thorough screening test useful for refining preliminary designs. Not intended to be predictive of shipping performance.

Learn more >

General Simulation Tests

3A, 3B, 3E, 3F, 3H, 3K

Provide a simulation of the damage-producing motions, forces, conditions, and sequences of transport environments. Useful as a predictive tool to understand risk of damage.

Learn more >

Enhanced Simulation Tests

4AB

Customizing test plans that closely tie the tests and sequence to a user-defined pattern of distribution environment hazards.

Learn more >

Member Performance Tests

6-AMAZON.com, 6-SAMSCLUB, 6-FEDEX

Created by an ISTA member or in cooperation with ISTA to establish unique requirements or to reflect their particular conditions of distribution. Useful in evaluating the effectiveness of packaging against hazards represented in their supply chain.

Learn more >

Development Tests

7D, 7E

Used in the development of transport packages by comparing the relative performance of two or more container designs but are not intended to evaluate the protection afforded packaged-products.

Learn more >

https://ista.org/test_procedures.php