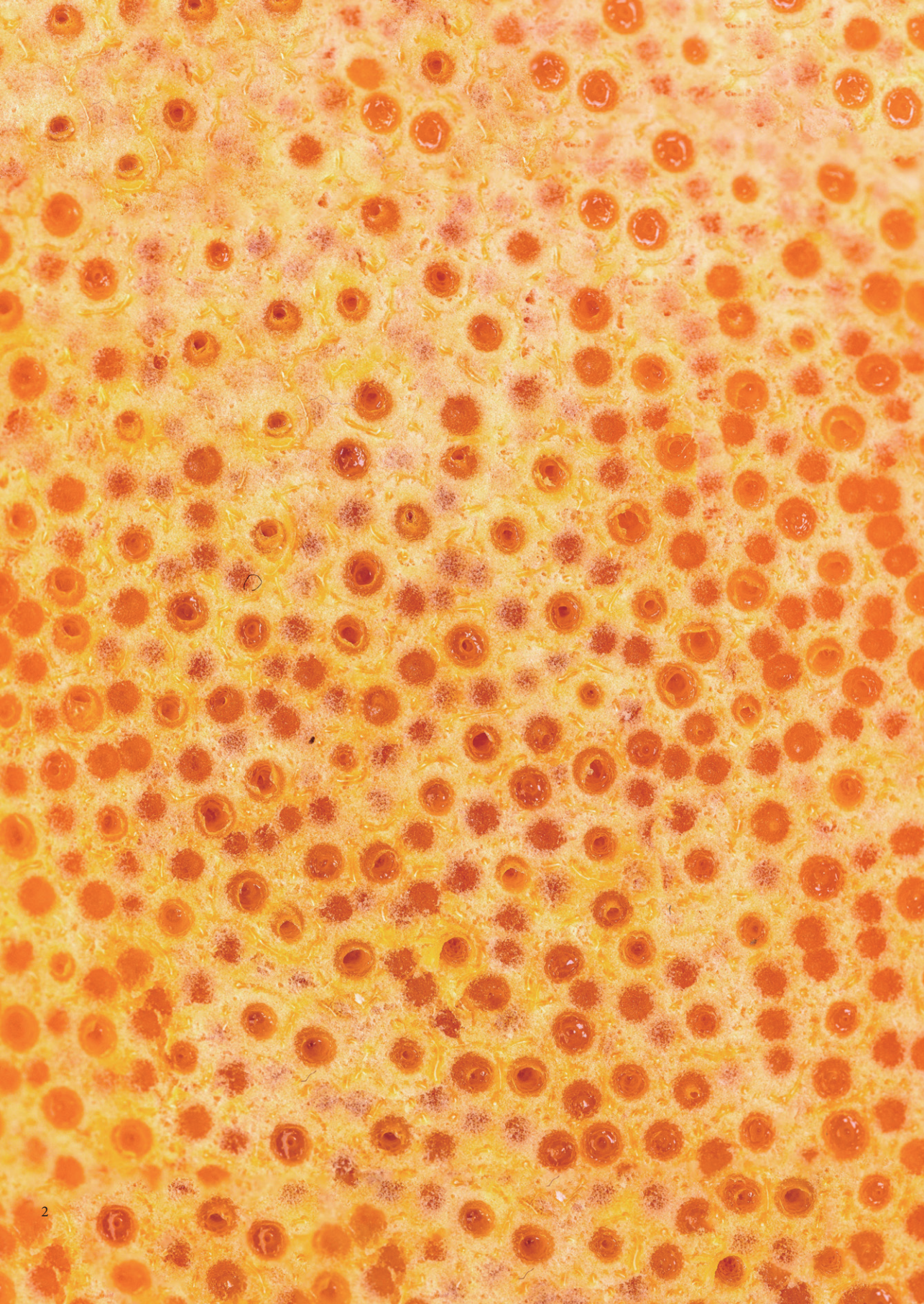


Orange Peel Footwear

-Designing Shoes from Fruit Waste with Aesthetic Attributes of Sustainability-

Shion Ito





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Master Thesis
Design for Interaction
Delft University of Technology

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Summary

This is a thesis of the graduation project for the master's program in Design for Interaction at Delft University of Technology. This project aimed to develop a biodegradable material that communicates its sustainability to consumers through its aesthetic attributes and to apply this material to shoe design.

In the current market, most biodegradable shoes do not express their natural origin through their appearance (tactile and visual properties). For instance, leather-like bioplastic material made from fruit waste, used by some shoe brands, mimics conventional leather with embossed texture, providing no indication to consumers that it is sustainable. While this approach of mimicking conventional materials might be effective for societal acceptance due to its familiar look, I strived to find an alternative approach.

Thus, this project starts with a simple question: What if a pair of biodegradable shoes looked "natural"? Would they communicate their sustainability through their appearance? Would they seem too wild?

To explore these questions, I embarked on the journey of developing biodegradable materials from scratch and constructing shoes with them. Through the research process, a Material Experience Vision was formulated, guiding me through the development of the material and the shoe design: I want people to recognise the material to be biodegradable as well as compostable through visual and tactile properties that people commonly associate with "naturalness" while maintaining their perception of quality. Additionally, I also want people to find the material to be interesting or unique to wear as a shoes with the propeties of natualness.

The research concluded with the evaluation of the proof of concept—a final prototype consisting of a pair of biodegradable shoes made from orange peels and mandarins. This evaluation focused on participants' perceptions of quality and naturalness, involving eight participants in the assessment.



“

Every material possesses its own language of forms, and none may lay claim for itself to the forms of another material.

Adolf Loos

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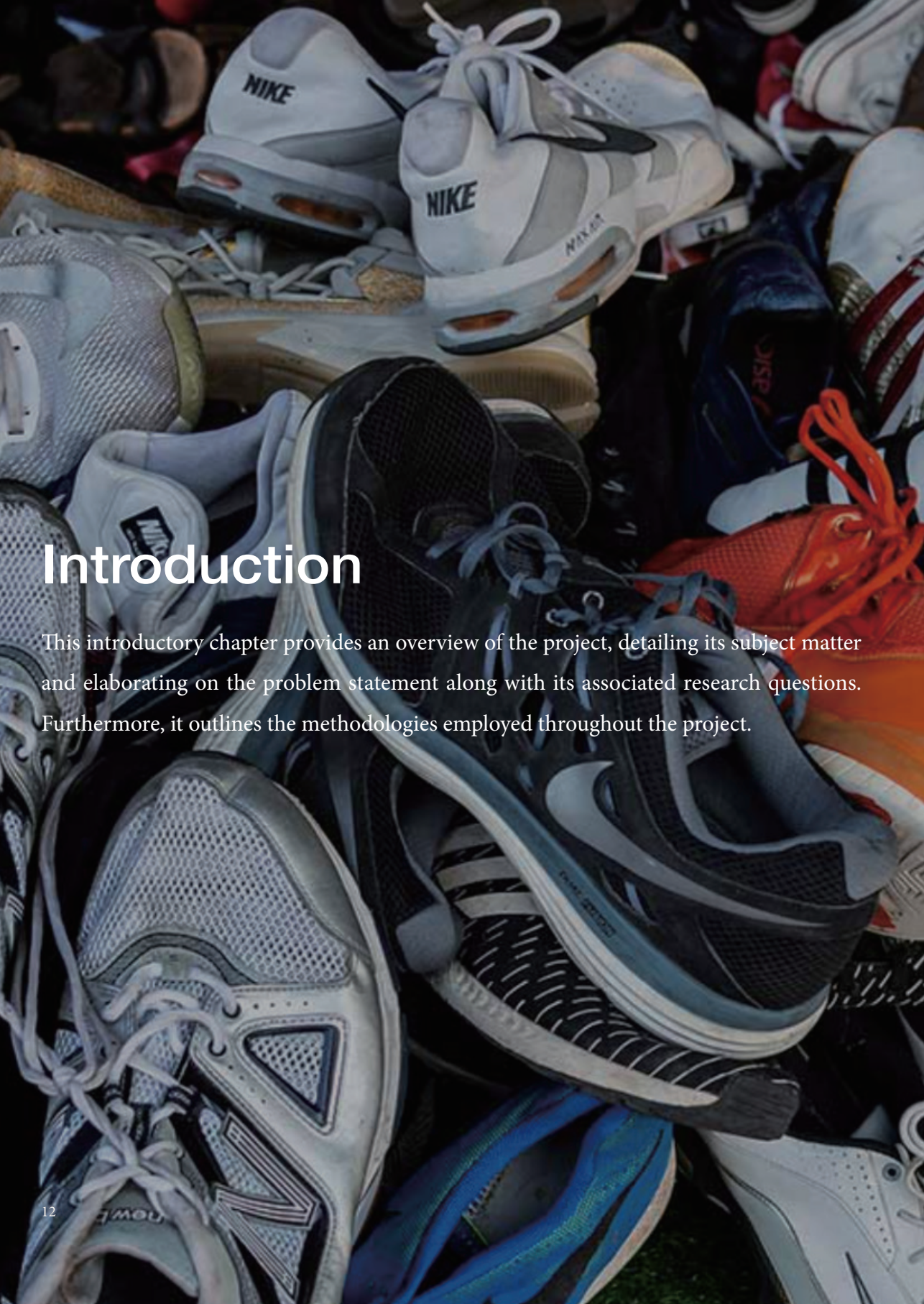
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Introduction

This introductory chapter provides an overview of the project, detailing its subject matter and elaborating on the problem statement along with its associated research questions. Furthermore, it outlines the methodologies employed throughout the project.



0-1 Introduction

According to the World Footwear Yearbook 2019, global footwear production has seen a notable increase of 21.2% since 2010, with an average annual growth rate of 2.2%[1]. As the consumption of footwear rises, it becomes essential to examine environmental concerns[2]. Major environmental concerns regarding footwear have been the hazardous materials used in production. Especially, the tanning process of leather shoes is considered to be a major source of pollution. Wastewater resulting from the tanning process poses a significant environmental threat, contributing to severe issues due to its high chemical oxygen demand (COD), elevated chrome concentration, and intense color content [3].

However, Statikos et al pointed out that the major environmental challenge currently confronting the footwear industry is the immense volume of waste generated during the end-of-life phase[4]. The disposal of old shoes becomes a problem as current materials are not easily decomposed [5]. As illustrated in Table 1, waste items and materials used in footwear manufacturing, such as urethane, synthetic textiles, rubbers, and leather, are slow in complete decomposition when disposed of in landfills[6]. For instance, leather takes approximately 50 years to fully decompose without being recycled or reused. In addition, landfill sites can result in serious environmental pollution of groundwater and rivers due to landfill leachate (the liquid produced from the decomposition of waste within the landfill)[5]. According to the website of Circular Online, a daily news and insights resource on sustainability issues, 23 billion pairs of shoes are produced every year and 22 billion end up discarded in landfills[7].

To approach this problem, researchers suggested the use of biodegradable material for shoe production as one of the viable means of reducing the amount of end-of-life footwear waste [4].



Figure 1. Shoes in landfill. Adopted by <https://rerunnr.com/blogs/news/why-do-300-million-sneakers-go-to-landfill-every-year>

- 1 World Footwear Yearbook 2023 [Online]. Available: <https://www.worldfootwear.com/yearbook/the-world-footwear-2023-Yearbook/231.html>
- 2 Nancy Hernandez. (2022). Evaluation of Sustainability & Materials Among Major Footwear Brands. <http://hdl.handle.net/20.500.12680/8s45qg6k>
- 3 Song, Z., Williams, C., & Edyvean, R. (2000). Sedimentation of tannery wastewater. *Water Research*, 34(7), 2171–2176. [https://doi.org/10.1016/S0043-1354\(99\)00358-9](https://doi.org/10.1016/S0043-1354(99)00358-9)
- 4 Staikos T., Heath R., Haworth B. & Rahimifard S. (2006). End-of-life management of shoes and the role of biodegradable materials. *Proceedings of 13th CirP International Conference on life Cycle Engineering*, pp. 497–502.
- 5 Changhyun, C. (2019). Sustainable shoe design and evaluation using kinematic and kinetic analysis. <https://dr.lib.iastate.edu/handle/20.500.12876/31706>
- 6 Changhyun, C. (2019). Sustainable shoe design and evaluation using kinematic and kinetic analysis. <https://dr.lib.iastate.edu/handle/20.500.12876/31706>
- 7 Shoe waste: how consumption became culture. (2022, December 30). Circular Online. <https://www.circularonline.co.uk/features/circular-trainers-how-consumption-became-culture/>

Items	Life time	Main type of material
plastic bags	10-1000 years	plastic
plastic bottles	450 years or more	plastic
foamed plastic cups	50 years	Plastic
aluminum cans	200-250 years	metal
tin cans	50 years	metal
tinfoil	It does not biodegrade	metal
glass waste	1000000 years	glass
paper waste	2-6 weeks	paper
train tickets	2 weeks	paper
milk cartons	5 years	paper
cardboard	2 months	paper
plywood	1-3 years	wood
painted board	13 years	wood
rubber-boot sole	50-80 years	rubber
leather shoes	25-40 years	fiber
leather	50 years or more	fiber
nylon Fabric	30-40 years	fiber
wool clothing	1-5 years	fiber
cotton Glove	3 months	fiber
canvas products	1 year	fiber
disposable diapers	250-500 years	fiber
ropes	3-14 months	fiber
monofilament fishing line	600 years	fiber
food waste	1-6 months	-
lumber	10-15 years	-
cigarette butts	10-12 years	-
batteries	100 years	-
sanitary pads	500-800 years	-
styrofoam	It does not biodegrade	expanded polystyrene

Table 1 Time Taken by Waste Items to Decompose. Adopted by <https://dr.lib.iastate.edu/entities/publication/81f0dd97-015d-4580-b29a-7dba64fc655c>

0-2 Problem Definition

Raising consumer awareness about biodegradable shoes is paramount to addressing the significant issue of the immense amount of shoe waste accumulating in landfills worldwide. However, in the present market, it's difficult to visually identify most biodegradable shoes as sustainable because they closely resemble conventional leather or synthetic materials as illustrated in Figure 2. The reason for this phenomenon can be attributed to

1. The familiar appearance of conventional materials is readily accepted by consumers, making it easier for these biodegradable shoes to integrate into society.
2. Companies find it challenging to incorporate references in the shoe's design that effectively showcase their sustainable production processes.

While having an appearance that resembles conventional material is an inevitable result or actually an effective approach for products to be accepted by society, it might cause consumer confusion. Researchers are also arguing that sustainable products should express strong, unique aesthetic features, that tell environmental credentials or sustainability[8].

In this project, the expression of 'naturalness' is adopted for shoe design to address the dilemma mentioned above. Naturalness is a visual and tactile property for people to judge whether a material is natural or not[9]. Examples of sustainable products that have naturalness in their designs are Vegetable Parchment Bowls, Solskin Peels, and KUORI(Figure 3). Solskin Peels and Vegetable Parchment Bowls are tableware designed by Ori Sonnenschein and Margaret Dorfman respectively and, both are manufactured in such a way that the original materials are still recognisable. KUORI shoe sole is a biocomposite made from banana peels. It has contingently distributed visible grains with non-reflective textures that give a sense of nature.

However, it's important to acknowledge that this property also has a potential downside: the imperfect texture of the material may lead to negative associations among consumers. The main challenge for this research is to understand and maximise the positive aspect of the material that expresses naturalness while mitigating its downside.

- 8 Rognoli, V., & Karana, E. (2014). Toward a new materials aesthetic based on imperfection and graceful aging. In Elsevier eBooks (pp.145–154). <https://doi.org/10.1016/b978-0-08-099359-1.00011-4>
- 9 Karana, E., & Nijkamp, N. (2014). Fiberness, reflectiveness and roughness in the characterization of natural and high quality materials. *Journal of Cleaner Production*, 68, 252–260. <https://doi.org/10.1016/j.jclepro.2014.01.001>



Figure 2. Biodegradable shoes on the current market.

Top left: Skin Collection by OAT Shoes. Adopted by <https://www.oatshoes.com/skincollection>.

Top right: OLIVE by BLUEVIEW. Adopted by <https://blueviewfootwear.com/>.

Bottom left: Men's Ghost Sneaker by Orba. Adopted by <https://orbashoes.eco/products/mens-ghost-sneaker>

Bottom right: BioCir Slides by balena. Adopted by <https://balena.science/products/biocir-slides2023>



Figure 3 Examples of sustainable products that have naturalness

Left: Solskin Peels. Adopted by <https://designbreakonline.com/student-break-ori-sonnenschein-smell-your-tableware/>

Center: Vegetable Parchment Bowls. Adopted by <https://www.margaretdorfman.com/margaret-dorfman-galleries/vegetable-parchment-bowls/index.htm>

Right: KUORI shoe sole. Adopted by <https://www.yankodesign.com/2021/03/02/using-banana-peels-as-a-sustainable-building-material-you-can-now-make-everything-from-eyeglasses-to-watch-straps/>

0-3 Design Goal

The design goal initially set in this project was to design a pair of biodegradable shoes made from fruit waste that reveals the story of sustainability through its aesthetics. Throughout the research process, the category of shoes targeted for creation was identified as lifestyle shoes, which encompass not only utilitarian aspects but also emotional elements reflecting the wearer's identity. Keeping the idea of creating shoes that communicate its sustainability, the literature review and the understanding of the characteristics of the developed material have guided me to define the experiential and technical aspects of the design goal as follows.

Experiential Design Goal

The life style shoes should communicate biodegradability and compostability through its naturalness. It also should have continuous and regular visual and tactile elements to evoke the meaning of high quality. The patchwork should also evoke the meaning of craftsmanship that evokes the meaning of high quality. At the same time, the ageing properties should be kept intact so that the consumers can enjoy how the material evolves over time. Additionally, the fact that the material manages to hold flexibility and hardness should be communicated through its shapes.

Technical Design Goal

The lifestyle shoes should protect the foot from roughness encountered while walking and standing, while also providing protection for the upper part of the human foot against cold, thorns, and insect bites. Flexibility is also crucial, allowing the shoe to bend naturally at the points where the human foot bends. This necessitates deliberate placement of the stitching lines. Furthermore, the shoe design should allow space for the toes to splay, enhancing wearer comfort. Ankle movement during walking should remain uninhibited by the shoe design.

0-4 Research Question

How can the material that expresses naturalness be used for shoe design to attract consumers while communicating its sustainability?

This main question is divided into smaller parts.

Literature review

1. What advantage does the use of biodegradable materials offer in addressing the issue of the substantial volume of discarded shoes in landfills?
2. What is the challenge sustainable projects are currently facing?
3. What is naturalness?
4. What is the meaning-evoking pattern?
5. What is the meaning-evoking pattern of naturalness?
6. What is the consumers' negative association towards naturalness?
7. How do consumers perceive the quality of material/product?
8. What is the advantage of imperfection in materials?
9. What types of lifestyle the shoes with naturalness can be served?
10. What is the primary purpose of shoes?
11. What are the desired characteristics of shoes?
12. How do conventional shoes achieve those technical requirements?
13. How do biodegradable materials achieve the technical requirements?
And do they express naturalness?
14. What are the structure and function of a human foot?

Material Development

1. How can the property of orange peel be manipulated to retain its water inside so that it maintains its flexibility
2. How can the developed one piece of orange peel material covered with mango pulp be extended to a sheet that can be molded into shoe shape?

Material characterisation

1. How can the property of orange peel be manipulated to retain its water inside so that it maintains its flexibility?
2. How can the developed one piece of orange peel material covered with mango pulp be extended to a sheet that can be moulded into a shoe shape?

Design Conceptualisation and production of the final prototype

1. What are the design strategies to manipulate the meaning of the shoes made from the developed material to make them hold the desired meanings of being natural, interesting, unique, and high-quality?
2. What is the Experiential and Technical Design Goal to achieve in the production of the final prototype?

Evaluation and discussion

1. Does the final prototype prove the design strategy developed in the previous stage?
2. What would be the suggestion for the further development of the material and the shoes?

0-5 Theoretical framework of this project

To conceptualize a design of shoes that convey the meaning of biodegradability solely from its appearance (both visual and tactile properties), it was required to understand how materials and products obtain certain meanings. This understanding is achievable by delving into the meaning-evoking pattern, which constitutes a combination of different material and product qualities that construct specific meanings. Additionally, it was imperative to understand the mechanical properties (tensile strength) of the material for the judgement in the material selection for the final design. To achieve them, I adopted the following methodologies.

Material Driven Design (MDD)

The MDD (Material-Driven Design) method is an approach to materials exploration and design, particularly when a material serves as the starting point for the design process, often because it is novel or not fully developed as depicted in Figure 4. This method starts with the "Understanding the Material" phase where designers are expected to characterise the quality of the material technically and experientially. Building on the insights gained in this phase, the designers formulate a material experience vision. To achieve this vision, in the next phase, "Manifesting Material Experience Pattern", designers seek to identify a distinct pattern that constructs the specific experience of the material. By understanding this pattern, designers can manipulate the properties of the material to realise the desired experience they aim to achieve.

However, within the context of this project, two factors deviate from the fundamental premise this methodology is based on: 1. There was no material to be explored at the starting point of the project. Thus, it was required to develop a new material from scratch by the author. 2. The application of the material was already defined to be shoes.

To integrate the material development phase into the original methodology, a modification was made. The following are steps that I've followed in the modified version of the design research process(Figure 5).

1. MANIFESTING MEANING-EVOKING PATTERN: Meaning-evoking pattern of biodegradable material that expresses Naturalness was formed thorough the literature review

2. CREATING MATERIALS EXPERIENCE VISION: Based on the Meaning-evoking pattern, the Material Experience Vision that should be achieved in this project was formulated
3. Based on the Material Experience Vision, the two different material concepts for the shoe upper and one material concept for the sole part were developed
4. UNDERSTANDING THE MATERIAL: The developed material was characterised experientially and technically. Additionally, tinkering was conducted by the author to get his first-hand experience
5. DESIGNING PRODUCT CONCEPTS: After selecting the material concept for the shoe upper, the design conceptualisation took place.

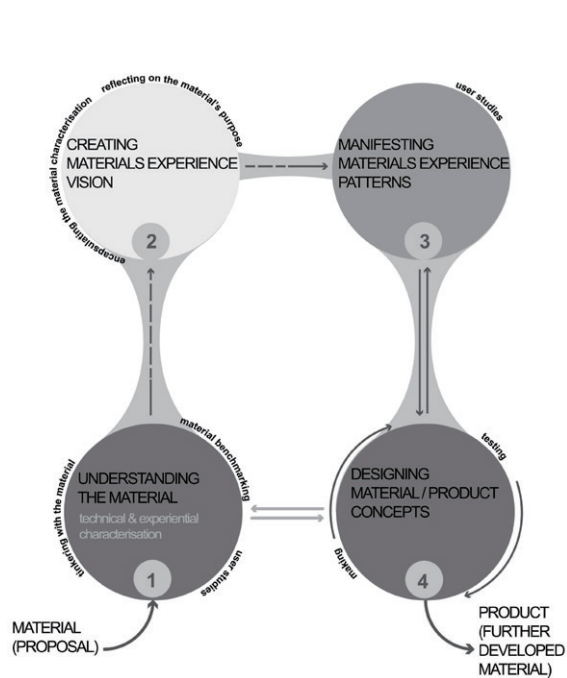


Figure 4. The original Material Driven Design Approach

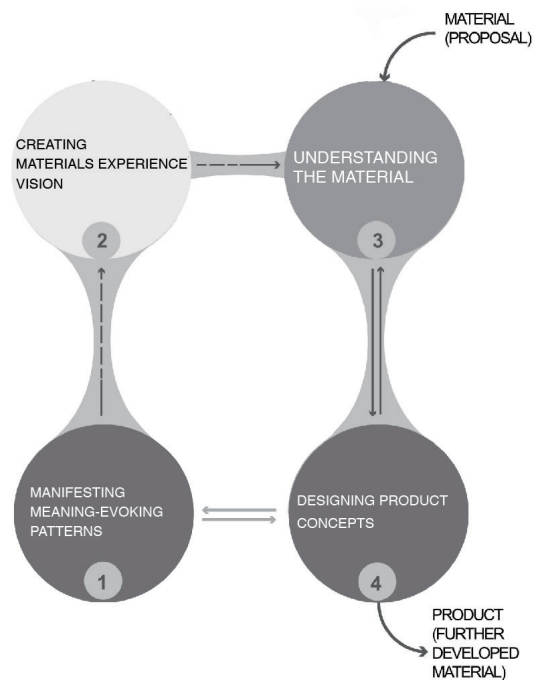


Figure 5. The modified version of Material Driven Design process



1. Literature Review

This chapter covers the biodegradability and compostability of materials, the concept of naturalness, the scope of the problem area, the construction of the shoe, and the structure and function of the human foot. This information provided me with an understanding of both the technical and experiential requirements that the material to be developed later should meet. The chapter concludes with the formulation of the material experience vision, which guides me through material development as well as design conceptualization.



1-1 Biodegradable material

1-1-1 Benefit of biodegradable material

According to BBC Good Food, biodegradability refers to the ability of an item to break down into smaller pieces through the action of bacteria, fungi, or microbes ideally without causing pollution[10]. It also says that everything we use or create can be seen as biodegradable because, ultimately, everything will break down—whether it's organic waste, wooden cutlery, plastic packaging, or steel machinery. On the other hand, there is also a strict definition of the term. European Environment Agency states that it is the ability of a material to break down rapidly by microorganisms under natural conditions (aerobic and/or anaerobic) limiting its examples to substances like food scraps and paper [11]. In this study, I will follow the latter definition, restricting its significance to materials that decompose more rapidly than conventional ones without causing harm to the environment.

As mentioned in the “Introduction”, the problem the footwear industry are facing right now is the enormous amount of waste generated at the end-of-life phase[4].

Thus, equipping shoes with enhanced biodegradability for faster and less harmful decomposition can contribute to addressing the global issue of shoe waste. Although decomposition time can vary depending on the conditions in which the material is surrounded, including humidity and temperature[12], the use of biodegradable materials in footwear is a clear step toward improving the environmental impact of shoe disposal in landfills.

1-1-2 Biobased, biodegradable and compostable

There are three terms that are often used interchangeably in the context of sustainable product design that should be clarified; "biodegradable", "biobased" and "compostable".

The difference between “biobased” and “biodegradable” is that the former refers to the raw material from which a product is made, indicating that it is derived from renewable, natural resources like corn or potatoes, while the latter refers to the final phase of the product's life cycle, signifying its ability to break down over time[13].

The distinction between "biodegradable" and "compostable" lies in the fact that biodegradable products encompass any material capable

10 Ryan, R. (2024, February 7). What 'biodegradable' really means. <https://www.bbcgoodfood.com/howto/guide/what-biodegradable-really-means>

4 Staikos T., Heath R., Haworth B. & Rahimifard S. (2006). End-of-life management of shoes and the role of biodegradable materials. Proceedings of 13th CIrP International Conference on life Cycle Engineering, pp. 497–502.

11 biodegradable. (n.d.). European Environment Agency. <https://www.eea.europa.eu/help/glossary/eea-glossary/biodegradable>

12 Prime. (2022, September 28). Biodegradable materials: what is it, what is it used for and practical examples. Primebiopolymers. <https://primebiopol.com/biodegradable-materials/?lang=en>

13 Koen Pack. (n.d.). <https://koenpack.com/en-gb/biodegradable#:~:text=Biobased%20refers%20to%20the%20raw,such%20as%20corn%20or%20potatoes.>

of breaking down in the environment regardless of whether they leave micro toxic residual, whereas compostable products decompose into beneficial residues that enhance soil health [14]. According to the European standard EN 13432, specific requirements must be met to declare a plastic material compostable, for example, the material must degrade by at least 90% in weight within 6 months in a carbon dioxide-rich environment.[12]. Building upon the discussion regarding the definition of biodegradable products earlier, this project's aim should be to design shoes that are not only biodegradable but specifically compostable. If shoes are equipped with compostability, consumers have more options for disposal. They can not only throw them away in the normal bin with other rubbish but also compost them in soil themselves, which allows for a quicker decomposition process.

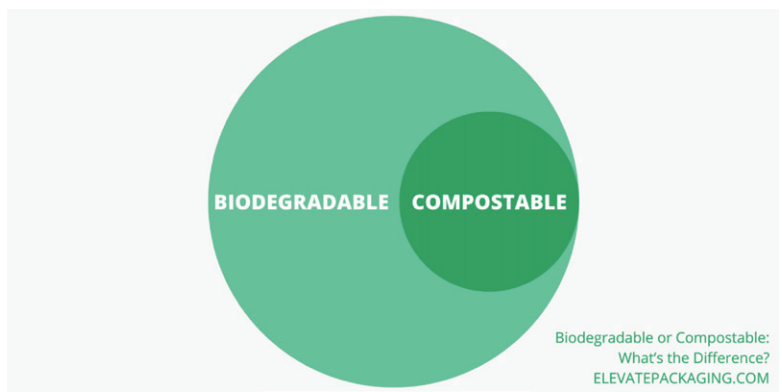


Figure 6. The difference between biodegradable and compostable. Adopted by <https://www.nike.com/nl/en/w/lifestyle-shoes-13jrmzy7ok>

1-1-3 Home compostable and industrially compostable

There are two types of compostable products: home compostable and industrially compostable.

The definition of industrially compostable products is strictly defined by the European Standard while regarding home compostable products, there is currently no harmonized standard to evaluate the compostability of plastic materials in household conditions, although some countries such as Australia, France, and Italy have established national standards for the home compostability of plastic materials [15]. Due to the time constraint of the thesis project, this project aims to design a home compostable product that doesn't have detailed requirements. According

- 14 Watch, O. (2021, January 21). Compostable vs Biodegradable. Oceanwatch Australia. <https://www.oceanwatch.org.au/uncategorized/compostable-vs-biodegradable/>
- 12 Prime. (2022, September 28). Biodegradable materials: what is it, what is it used for and practical examples. Primebiopolymers. <https://primebiopol.com/biodegradable-materials/?lang=en>
- 15 Jögi, K., & Bhat, R. (2020). Valorization of food processing wastes and by-products for bioplastic production. Sustainable Chemistry and Pharmacy, 18, 100326. <https://doi.org/10.1016/j.scp.2020.100326>

to the website of the United States Environmental Protection Agency, fruit and vegetable scraps are categorized as "Nitrogen-Rich Materials," and it is recommended to compost them with dry leaves as shown in Table 2.

Nitrogen-Rich Materials ("Greens")	Carbon-Rich Materials ("Browns")
Fruit and vegetable scraps	Dry leaves
Grass clippings	Plant stalks and twigs
Coffee grounds and paper filters	Shredded paper (non-glossy, uncolored) and shredded brown bags
Paper tea bags (no staples)	Shredded cardboard (no wax coating, tape, or glue)
Eggshells (crushed)	Untreated wood chips

Table 2. The ingredients for composting. Adopted by <https://www.epa.gov/recycle/composting-home>

1-1-4 The challenge sustainable products are facing on the market

As the industry adopts more sustainable practices and consumers become increasingly environmentally conscious, there is a noticeable shift in consumer attitudes towards positively embracing the purchase of eco-friendly footwear, apparel, and recycled products.[4]. However, when it comes to communicating the sustainability of products to customers, two main challenges arise due to consumer unfamiliarity.

The first challenge involves gaining recognition as a sustainable product. Research shows that consumers' awareness and intention regarding biodegradable products play a crucial role in guiding their decisions towards choosing such products [16]. However, if a product on the store shelves does not explicitly convey its sustainability, it becomes challenging for consumers to recognize it. While the most common method to communicate sustainability with consumers is through labelling, such as ones printed on biodegradable packaging [17], some companies and individuals highlight the material's unique properties in their aesthetics, resulting in communicating the origin of the material or their sustainable production process (Figure 7). For example, the backpack brand Freitag incorporates repurposed materials into their products, effectively conveying this aspect through their appearance as recycled materials. According to Karana et al, people often encounter various versions of a particular product crafted from different

16 Nekmahmud, M., Naz, F., Ramkissoon, H., & Fekete-Farkas, M. (2022). Transforming consumers' intention to purchase green products: Role of social media. *Technological Forecasting and Social Change*, 185, 122067. <https://doi.org/10.1016/j.techfore.2022.122067>(2014).

17 Bojanowska, A., & Sulimierska, A. (2023). Consumer awareness of biodegradability of food products packaging. *Sustainability*, 15(18), 13980. <https://doi.org/10.3390/su151813980>

materials or find the same material embodied in diverse products[9]. They pointed out that this reality inevitably leads to a transformation of the meanings attributed to certain materials over time. This manipulation of meaning-attribution of material can be observed in those products that communicate their sustainability through their aesthetics.



Figure 7. Products that express their sustainability

Top left: Messenger bag. Adapted from <https://www.freitag.ch/en/bags/messenger>

Top right: Pilot PetBall. Adapted from <https://www.pilotpen.eu/en/collections/must-have/b2p.html>

Bottom left: Frammento. Adapted from <https://paolostefanogentile.it/project/frammento/>

Bottom right: V'Eco. Adapted from <https://ifdesign.com/en/winner-ranking/project/veco-coffee-machine-made-of-used-ground-coffee/297565>

The second challenge revolves around guiding consumers on proper disposal methods. The widespread unfamiliarity of consumers with concepts of biodegradability has been leading to misguided purchase decisions and disposal practices, as well as possible littering behaviour [18]. For instance, many people misunderstand that paper is compostable because it is often referred to as biodegradable. Thus, it is required to design biodegradable products that give proper guidance for littering. An example of a sustainable footwear company addressing this issue is Johnny Footwear, which has introduced shoes designed to encourage consumers to compost by embedding an apple seed in the sole (Figure

18 Nazareth, M. C., Da Costa Marques, M. R., Pinheiro, L. M., & Castro, I. B. (2022b). Key issues for bio-based, biodegradable and compostable plastics governance. *Journal of Environmental Management*, 322, 116074. <https://doi.org/10.1016/>

8). However, it is hard to say their shoes visually communicate its compostability through its aesthetics.



Figure 8. Johnny Footwear produce a shoes that contains apple seeds to motivate consumer to compost. Adopted by https://www.blogto.com/fashion_style/2021/10/toronto-company-making-shoes-turn-apple-trees/

1-1-5 Insight

The insights found through out the literature review are follwing.

1. There are different types of biodegradability in product design, including those that are biodegradable but not compostable, and those that are both biodegradable and compostable. For instance, leather shoes are natural and biodegradable, but they can take up to 50 years to decompose in a landfill, which is longer than some synthetic materials such as nylon fabric. It suggests the importance of considering the compostability of materials
2. In this project, the fruit waste will be used for developing new materials. Thus, it is expected that the outcome of this project should achieve both biodegradability and compostability.
3. Compostability has also different categories: industrially and home compostable. In the category of home compostable products, fruit waste was recommended to be composted with dried leaves to speed up the decomposition process.
4. There are some products that communicate their sustainability through their aesthetics already on the market whether it was their intention or not. Those products manipulate the aesthetic attributes of the material to evoke the meaning of sustainability. Based on this insight, it is essential to investigate how a material evokes a certain meaning in the context of shoe design.



1-2 Naturalness

1-2-1 What is naturalness?

One particular expression commonly utilised to express sustainability through material aesthetics is called naturalness that involves various visual and tactile properties[7]. Naturalness serves as an aesthetic attribute for individuals to determine whether a material is natural or not. Examples of sustainable products that have naturalness in their designs are Vegetable Parchment Bowls, Solskin Peels and KUORI(Figure 10). Solskin Peels and Vegetable Parchment Bowls are tableware designed by Ori Sonnenschein and Margaret Dorfman respectively and, both are manufactured in such a way that the original materials are still recognisable. KUORI shoe sole is a biocomposite made from banana peels. It has contingently distributed visible grains with non-reflective textures that give a sense of nature. My hypothesis is that integrating "Naturalness" into the aesthetic attributes of shoes has the potential to not only overcome consumers' unfamiliarity with sustainable products but also to create new aesthetic value that motivates people to wear these sustainable products with its unique properties.

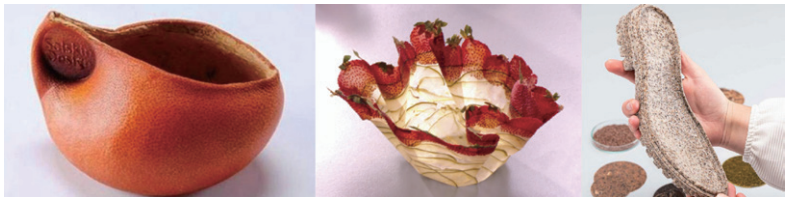


Figure 10 Examples of sustainable products that have naturalness
Left: Solskin Peels. Adopted by <https://designbreakonline.com/student-break-ori-sonnenschein-smell-your-tableware/>
Center: Vegetable Parchment Bowls. Adopted by <https://www.margaretdorfman.com/margaret-dorfman-galleries/vegetable-parchment-bowls/index.htm>
Right: KUORI shoe sole. Adopted by <https://www.yankodesign.com/2021/03/02/using-banana-peels-as-a-sustainable-building-material-you-can-now-make-everything-from-eyeglasses-to-watch-straps/>

1-2-2 Meaning-evoking patterns

Karana et al suggested in the paper, *Characterization of 'natural' and 'high-quality' materials to improve the perception of bio-plastics*, that designers who understand the "meaning-evoking patterns" can more deliberately manipulate the meaning of the product[19]. They mentioned four factors that interact with one another to create the meaning of

products: Material properties, product aspects, context of use and intangible aspects. Following is an explanation of each factor.

- Material properties encompass both technical aspects (such as strength, elasticity, heat conductivity, etc.) and sensory attributes (such as smoothness, transparency, softness, etc.) that differentiate materials from each other.
- Product aspect includes the shape, function and production process specifications of products in which material(s) are used.
- Context of use refers to the consequential experience of how, when and where a material/product interacts with.
- Intangible aspects of materials include associations, meanings and emotions evoked by materials. That can vary depending on individuals' past experiences, mood, culture and values.

In this project, the meaning-evoking pattern of naturalness is explored to understand how the meaning of naturalness is created through the "material properties" and "product aspect". "Context of use" and "intangible aspects of material" are not included in the consideration during the design process and will be investigated in the final on-site evaluation with the final prototype due to the time constraint.

1-2-3 What is the meaning-evoking patterns of naturalness?

Karana(2012) et al identified the surface patterns created through contingently distributed visible grains and fibres, roughness and non-reflexive surface as the three elements that create Naturalness[9]. In addition to them, the aging property of the material evoking the meaning of imperfection that can be associated with natural by viewers[8], in contrast to petroleum-based materials that are produced based on their perfectionist mindset. To summarise, following four properties are factors that create Naturalness(Figure 11, 12).

- **Fiberness:** The degree of fiberish surface. The surfaces that don't expose their fibers are more perceived as unnatural.
- **Roughness:** The degree of rough texture. Smooth surfaces are more seen as unnatural

- Reflectiveness: The degree of reflective surface. Reflective surfaces are more associated with unnatural.
- Agedness: The degree of color and shape-changing in a material. If the material of a product does not undergo changes over time, it may give the impression of being artificial.

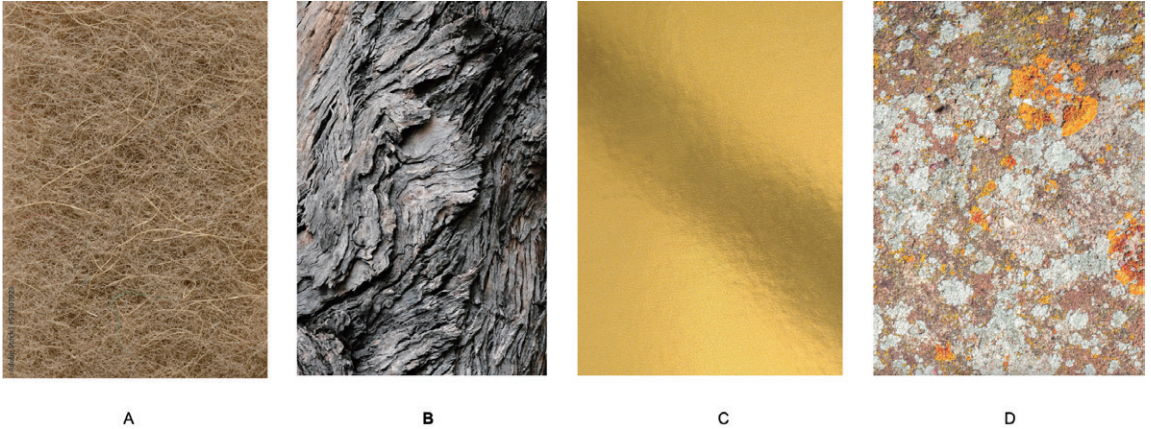


Figure 11. Example image of three different properties.

(A) Fiberness. Adopted by <https://stock.adobe.com/ca/images/beige-coconut-fiber-texture-rough-surface-texture-fibrous-texture-pressed-fibres/532107923>

(B) Roughne. Adopted by <https://unsplash.com/ja/@molnj>

(C) Reflectiveness. Adopted by <https://unsplash.com/ja/@kharp>

(D) Agedness. Adopted by <https://unsplash.com/@slashiophotography>

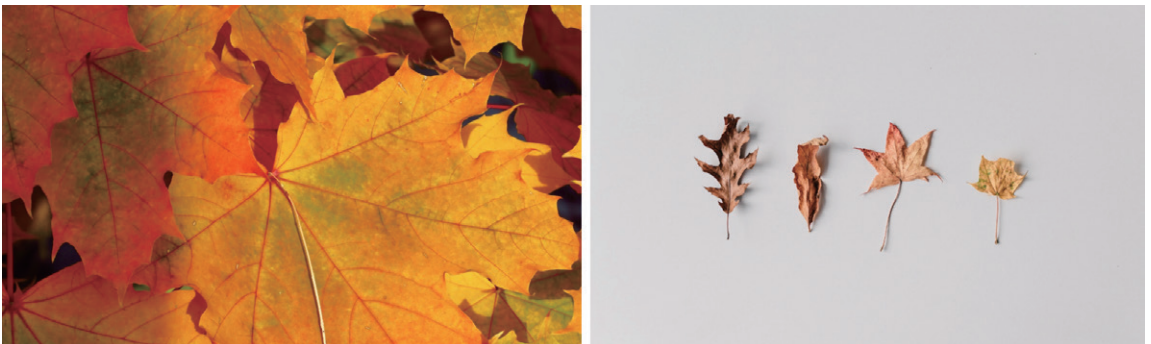


Figure 12. Image of transformative nature of colors and shapes.

Adopted by <https://unsplash.com/ja/@anthonyrossbach> and <https://unsplash.com/ja/@natvalmun>

1-2-4 Consumers' negative association with naturalness

The researcher pointed out that materials that express their natural patterns put a strong emphasis on “green aesthetics”, which may not be always preferred by people[5]. Sijtsma et al pointed out that people have doubts about the durability of products that express naturalness[20]. With the widespread adoption of automation processes and rigorous quality controls which eradicated errors and imperfections in manufacturing[8], consumers now commonly associate quality with flawless production and tend to connect it with a robust aesthetic model [9]. In other words, people often perceive materials or products as high quality when they exhibit characteristics associated with perfectionism. This perception poses a challenge for products that prioritize naturalness, as visible fibres or rough textures, which are inherent to such materials, may be viewed as signs of lower quality. Thus, it is necessary to investigate the meaning-evoking pattern of high quality along with naturalness to complement the consumer's negative association towards naturalness.

1-2-5 The definition of high quality

Now, we need to figure out: What exactly makes something high quality or valuable? To work on this, we first have to understand the concept of "perceived quality". Perceived quality is referred to as the superiority or excellence recognized by the consumer's judgment compared to "objective quality," the actual technical superiority or excellence of products[21]. They explained these differences by citing a story where the manager of General Electric had a completely different view on quality compared to consumer perspectives. While the former emphasized workmanship, performance, and form as critical components, the latter actually focused on different components: appearance, cleanability, and durability. Another study done by Aaker (1991) defined perceived quality as the customer's overall perception of the product or service's excellence and superiority in fulfilling its intended purpose compared to alternatives[22]. From this, it is clear that consumer's perception regarding quality is not necessarily reflected by the actual quality of products or services. The perceived quality regarding sustainable material can be further divided into two different qualities: aesthetic, and functional.

Thundathil et al. conducted a study aimed at identifying characteristics of biocomposite materials perceived by consumers as natural, beautiful, and valuable as shown in Figure 13[23]. From this research, it is clear

- 20 Rozin, P., Spranca, M., Krieger, Z., Neuhaus, R., Surillo, D., Swerdlin, A., & Wood, K. C. (2004b). Preference for natural: instrumental and ideational/ moral motivations, and the contrast between foods and medicines. *Appetite*, 43(2), 147–154. <https://doi.org/10.1016/j.appet.2004.03.005>
- 21 Zeithaml, V. A. (1988). Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of evidence. *Journal of Marketing*, 52(3), 2–22.<https://doi.org/10.1177/002224298805200302>
- 22 Aaker, D. A. (1991). *Managing brand equity: Capitalizing on the value of a brand name*. New York: Free Press. <https://www.semanticscholar.org/paper/Managing-brand-equity%3A-Capitalizing-on-the-value-of-Longwell/e04692fb98caf71988e029616e0a7e04c47235be>
- 23 Thundathil et al. Visual-Tactile Perception of Biobased Composites <https://www.mdpi.com/1996-1944/16/5/1844>

that the material's quality (value) can't be solely defined by only one of them(Aesthetic Value and Functional Value). This research also revealed that the inclusion of visual inconsistencies adds a layer of complexity and improves the perception of beauty although it might indicate defects decreasing the materials' value.

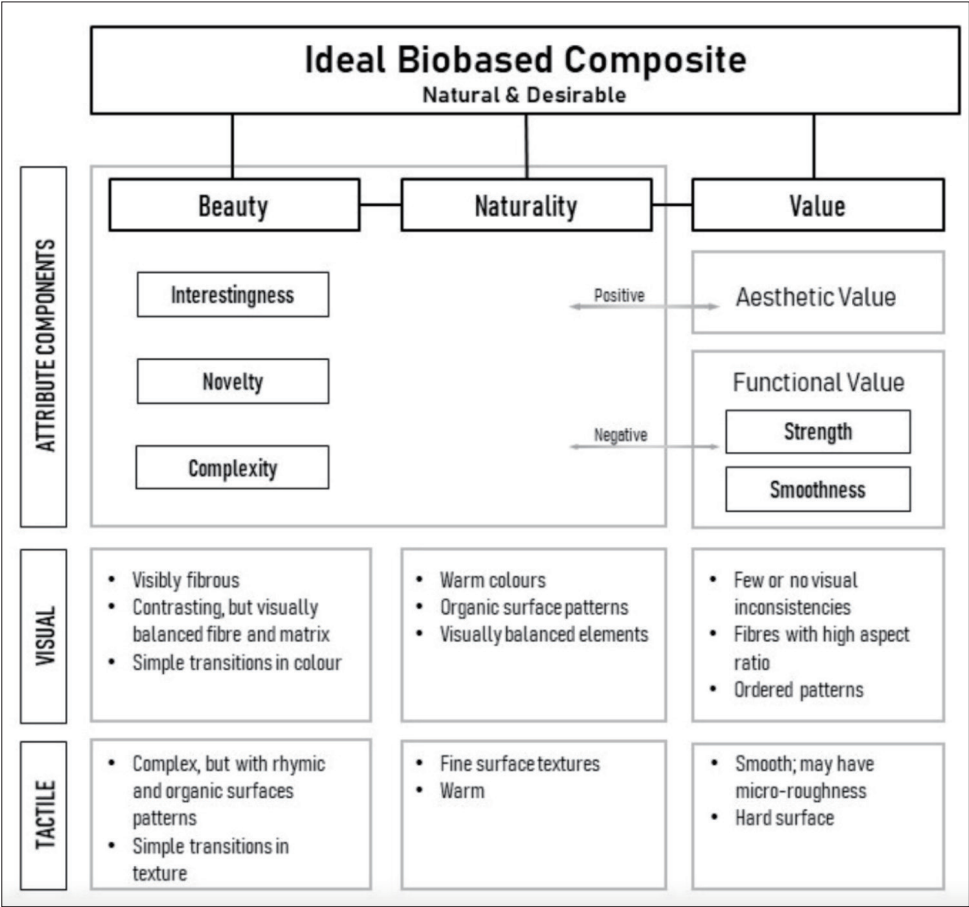


Figure 13. Interrelationship between different properties under the meanings of beauty, natural and value. Adopted by <https://unsplash.com/ja/@anthonyrossbach>, <https://unsplash.com/ja/@natvalmun>

1-2-6 Potential of imperfection

As mentioned earlier, naturalness is sometimes considered to be low quality because of its imperfect surface. However, imperfection of material has also potential to actually contribute to the consumer's perception of high quality. In their paper, Karana et al argue that natural material's uniqueness coming from imperfect surfaces plays an important role in the attribution of the meaning of high quality[8]. Also, as mentioned earlier, in the research done by Thundathil et al, the interestingness evoked by the irregularity is also considered to be a property that contributes to the perception of beauty.

In their paper, Karana et al argue that imperfection creates a uniqueness, and it eventually creates a bond between users and products because of its traces of the owner's personal life[8]. They also stated that the imperfection can create the user's experience richer and more enduring because of its unpredictability of the interaction scenario.

They mentioned that to achieve uniqueness, there are two ways: 1. The use of recycled resources and 2. The product assembly stage where a random mounting of modular pieces by the operator or the user, to obtain high degrees of product variation.

A good example of products that embrace imperfection to evoke the meaning of interesting and unique including Dye It Yourself designed by TAKT PROJECT which expresses the inconsistent patterns that are unique to each furniture, and CRACKS AND SHRINKS produced by Ryota Akiyama that feature intricate cracks in the texture, which invite viewers to look through (Figure 14).

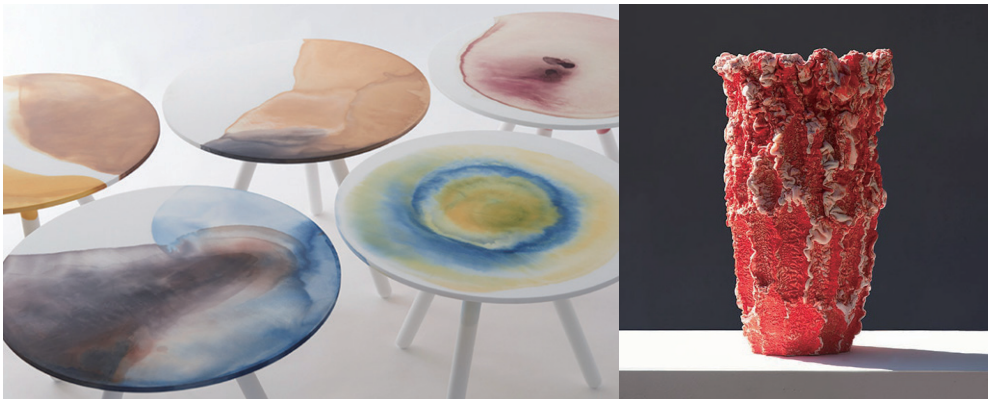


Figure 14.

Left: Dye It Yourself (TAKT PROJECT immerses the porous plastic into paint to create unique color patterns)(left image). Adopted by <https://www.designboom.com/design/takt-project-dye-it-yourself-plastic-table-collection-tdw-12-28-2015/>

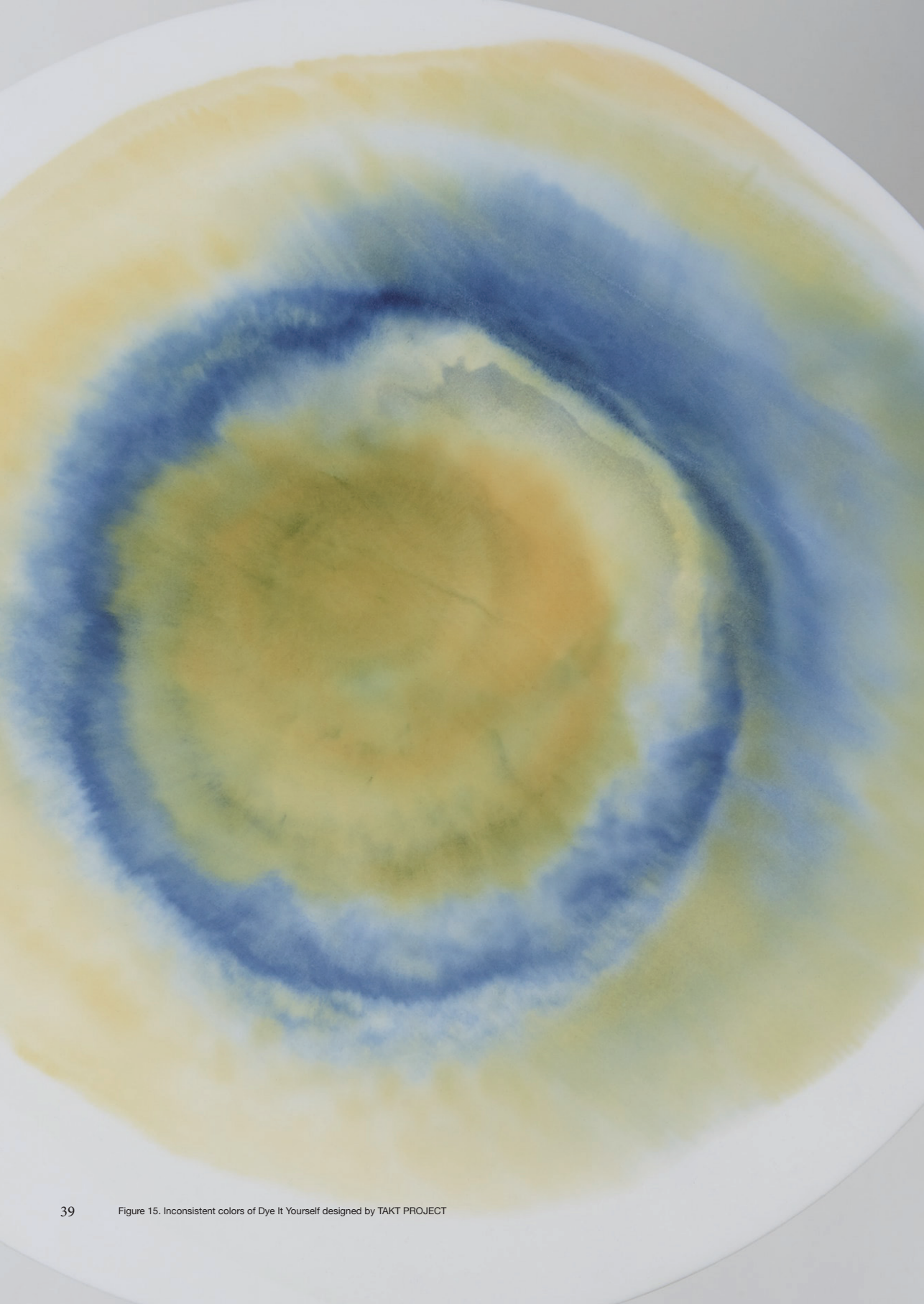
Right: CRACKS AND SHRINKS (Ryota Akiyama paints on the polystyrene and burn them to create unique shrinkage and cracks)(right image) Adopted by https://www.cibone.com/news_exhibition/5681/

1-2-7 Insight

The insights found through out the literature review are follwing.

1. "Function" and "Aesthetic" are two main aspects commonly referred to when evaluating the quality of a material. The functional aspect assesses how well the material properties meet the required or desired functions of the product. In contrast, the aesthetic aspect judges how aesthetically pleasing the material properties are to us.
2. There are gaps between the consumers' perceived quality and the product's objective quality. Thus, it is required to investigate the former one with tangible prototypes
3. Aside from communicating the origin of a natural material, naturalness has the potential to evoke the meaning of interesting or unique through its inconsistent texture
4. This inconsistent texture typically involves complexity in visuals which has the potential to improve the consumer's perceived quality
5. Imperfect surfaces that naturalness typically involves might lead to a consumer's negative association such as suspicion towards its durability. Thus, it is required to find an appropriate balance between expressing naturalness and the consumer's perceived quality.

Regarding insight 3, there is a potential in naturalness to set new aesthetic value that owning sustainable products will allow people to become unique if they wish to. This hypothesis should be investigated in the final evaluation of the shoes that express naturalness.



1-3 Scope of this project

1-3-1 How to catergorise the shoes?

Shoes can be classified into many various ways, depending on the parameters used. Examples include classification by gender (e.g., men’s and women’s shoes) or by the intended use (e.g., sports shoes). Another type of relevant classification is based on the type of material used to produce the upper part of the shoe. Using this classification, shoes can be sorted into leather-based, textile-based, rubber-based, or plastic-based products [5]. In this project, I will use the classification of intended use and use of material to scope the type of shoes I will design as gender classification is not relevant to the aim of this project. Figure 16 shows the 4 quadrants that indicate the type of shoes I will design in this project. The x-axis is the intended use and the Y-axis is the material of the shoes. The scope of this project will be lifestyle biodegradable shoes.

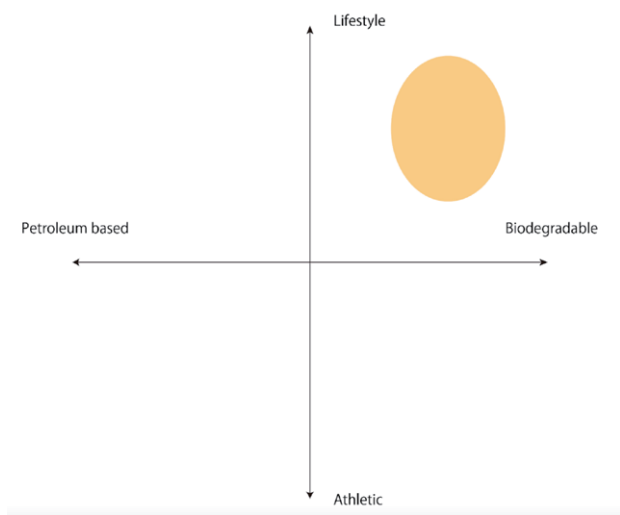


Figure 16. 4quadrants of the types of shoes

1-3-2 Definition of Lifestyle shoes

The term "Lifestyle shoes" refers to a category of footwear specifically designed for daily activities, emphasizing comfort over sports performance. Unlike athletic shoes designed for specific sports, Lifestyle shoes prioritize wearers' daily comfort and aim to integrate seamlessly into their lifestyles.

These shoes go beyond utilitarian aspects, incorporating emotional elements into their design to help individuals express their identities[24]. A good example of this concept is found in popular brands like VANS, whose sneakers are embraced by skateboarders, creating a sense of belonging within the street culture (Figure 17).

You can also find the definition of lifestyle shoes on Nike's website where they feature the "Lifestyle" category separate from athletic shoes such as those designed for football, running, or basketball. Within this category, a diverse range of sneakers, sandals, flip-flops, slip-ons, and boots are showcased, offering various colours, materials, and shapes to attract customers seeking footwear that aligns with their personal identity(Figure 18). From this observation, lifestyle shoes extend beyond the constraints of specific types, such as sneakers and encompass a wide range of footwear types.

While the terms "Lifestyle shoes," "Walking shoes," and "Everyday shoes" share similarities by being excluded from the athletic shoes category, there are nuanced differences. Walking shoes prioritize comfort through optimized shapes and materials, often having a sporty appearance. However, their primary purpose is comfort rather than being a deliberate part of an individual's lifestyle. Everyday shoes, as the name suggests, are intended for daily wear but may not necessarily be designed to reflect a specific lifestyle, differentiating them from Lifestyle shoes with a more explicit focus on personal expression and identity.



Figure 17. VANS sneaker that is often worn by skateboarders

24 Matthews, D., Cryer-Coupet, Q., & Degirmencioglu, N. (2021). I wear, therefore I am: Investigating sneakerhead culture, social identity, and brand preference among men. Fashion and Textiles, 8(1). <https://doi.org/10.1186/s40691-020-00228-3>

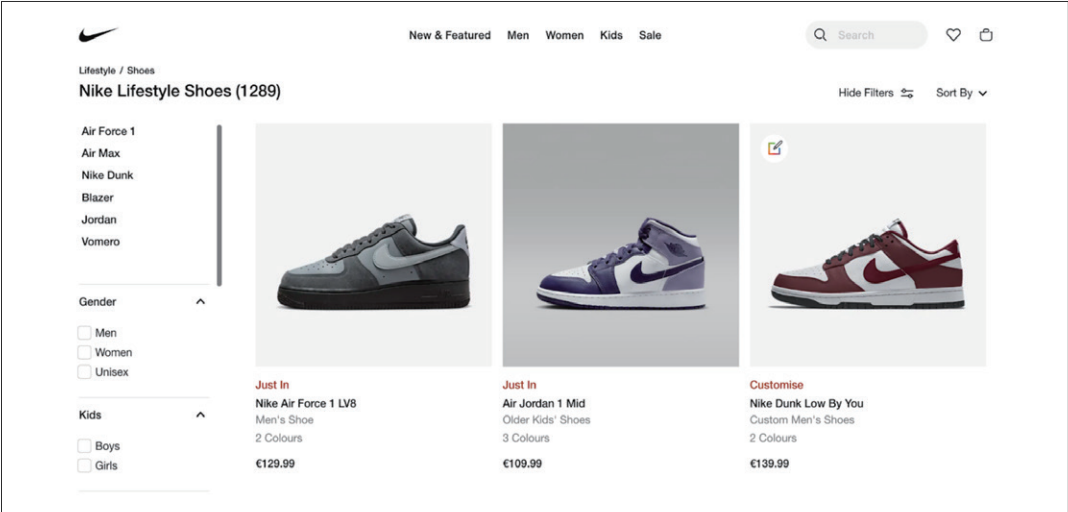


Figure 18. LifeStyle shoes on the Nike website. Adopted by <https://www.nike.com/nl/en/w/lifestyle-shoes-13jrmzy7ok>

1-3-3 Target group of lifestyle shoes

In establishing the design direction for this study, it is crucial to define the desired lifestyle that the shoes should reflect on. Given the emphasis on expressing naturalness, which offers potentially the advantage of uniqueness and interestingness, targeting the lifestyle of fashion-conscious consumers who desire unique and distinctive footwear is suitable (Figure 19, 20). While environmentally-conscious consumers are part of the target demographic, the shoes should primarily cater to the general public who like unique fashion pieces, considering that environmentally-conscious customers constitute a limited portion of the population. If the material that will be developed in the next phase evokes the meaning of interesting or unique, there is a potential for this product to encourage consumers to perceive the sustainable product as not only a responsible choice but also as a trendy and stylish addition to their wardrobe.



Figure 19. Nike sneaker designed by an artist, Tom Sachs. Adopted by https://ilikemudvs.life/product_details/91983203.html



Figure 20. The fashion conscious consumer who likes to adorn them with unique fashion items. Adopted by <https://www.vogue.com/article/street-style-fashion-week-trends-puffer-coat-fashion>

1-3-4 Example of lifestyle

To gain clarity on the exact lifestyle of fashion-conscious customers, I collected images of such consumers from social media(Figure 21). The aim was not to select specific fashion styles but rather to visualize the range of lifestyles the shoes could be integrated into. Despite the diversity of styles, commonalities emerged among the images. Individuals weren't overtly showcasing themselves such as wearing luxurious long dresses; rather, they used everyday fashion items to construct particular images. This is because they don't desire to showcase a totally different personality than their reality in life. However, they also incorporated accent colours or items to prevent their style from becoming mundane. For example, in the upper right image, the person wears a hat as an accent piece. Without the hat, their fashion might have appeared more ordinary.

While it's challenging to define the concept objectively, fashion-conscious customers are a group of people who desire to be unique on some level yet not to distort the image of their real-life overly.



Figure 21.

Image 1, 2, 3: Image of lifestyles. Adopted by Instagram of POPYE Magazine

Image 4: Museum of Milan, Italy. Adopted by Instagram of Wataru Miyashita

1-4 Construction of conventional lifestyle shoes

To understand the functional requirements for the material of lifestyle shoes to be developed, it is necessary to investigate the construction of conventional shoes. This informs how they achieve the desired functionalities with existing materials. This investigation is twofold. Firstly, the required characteristics (functionality) of shoe materials are outlined including the "primary purpose" of conventional shoes as well as "desired characteristics". Secondly, the research delved into the anatomy of conventional shoes to see how each part of the shoes contributes to certain functionalities.

1-4-1 Primary purpose(functions) of conventional shoes

According to J.H. Thornton et al, there are two primary functions for shoes to perform.

1. To protect the sole area of the foot from the heat, cold, dampness, dirt, or roughness of the ground while walking and standing, primitive sandals achieve this task with simplicity. Essentially, they consist of nothing more than a piece of leather, wood, or other material secured under the foot by a strap or alternative means.
2. To protect the upper part of the foot, and potentially the leg, from cold, rain, thorns, and insect or other bites, a simple solution is a bag made of leather or material wrapped around the foot. This type of footwear is commonly referred to as a moccasin [25].

Most shoes in the lifestyle category fulfil both two requirements. With the explanation above, it's clear that shoes can be divided into two separate components, sole and upper, and they achieve two different functions.

In addition, the functions of those components can be even improved by adding new parts. For instance, the upper can incorporate many additional parts, depending on the shoe style, such as laces, and a tongue which protects the top of the foot[26] Those are not necessary but desirable depending on the wearer's demands. In the next section, these "desired characteristics" are explored.

25 Thornton, J. H. (1970). Textbook of footwear manufacture.

26 Maffetone, P. (2021, December 21). A brief history of shoes. Dr. Phil Maffetone. <https://philmaffetone.com/shoe-history/>

1-4-2 Desirable characteristics of conventional shoes

The two main purposes of shoes described earlier are fundamental functionalities required for shoes. However, wearers often desire "additional functionalities" such as flexibility and permeability, which can also be considered characteristics of materials. It's important to note that the functionality of shoes and the characteristics of their materials are interconnected concepts. For example, when designing shoes with flexibility in specific areas, flexible materials would be utilized to achieve this functionality. Throughout this article, I will refer to these attributes as desirable characteristics, not desired functionality, as this exploration is for the material development in the next chapter.

Those desirable characteristics are typically, added to shoes for the purpose of the wearer's comfort or safety. The following lists are some of the common characteristics that are desired in modern shoes. One shoe doesn't necessarily fulfil all of them as they are contradicting from time to time.

Flexibility

Usually, in the context of shoe design, flexibility refers to the bendability of shoes. In regular walking, as the foot bends, the shoe also needs to bend at the same spots as the foot [25]. While running shoes require flex in the midfoot or arch, walking shoes should flex in the forefoot as walkers push off with their toes to generate power and, the shoe needs to bend more in this area [27]. However, in certain scenarios, like when prioritizing stability, there is a preference for stiffer shoes [28]. The flexibility of shoes is dependent on the materials of the sole, shank and fabric.

Elasticity

The term "elasticity" is often mistakenly equated with "flexibility," but there is a distinction. Elasticity refers to "the ability of a stretched material to return to its original shape and size when the forces are released," whereas flexibility is defined as "the ability of a material to bend easily without breaking [29]. The elasticity is mainly important for your shoe sole to get back to its initial shape after the bending. Also, the research indicates that the shoe soles with special rubber bands that maximise energy return (Figure 22)[30].

- 27 Lindsay, M. (2023, December 6). Walking versus running shoes: What's the difference? MyFitnessPal Blog. <https://blog.myfitnesspal.com/walking-versus-running-shoes-whats-the-difference/>
- 28 Subic, J. (2024, January 26). Guide: Flexible vs. Stiff Running Shoes. RunRepeat - Athletic Shoe Reviews. <https://runrepeat.com/guides/flexible-vs-stiff-running-shoes>
- 29 Elasticity and flexibility. (n.d.). FSBPE. <https://www.holcimelevate.com/benelux-en/news/elasticity-and-flexibility#:~:text=Elasticity%20is%20defined%20as%20%E2%80%9Cthe,to%20bend%20easily%20without%20breaking%E2%80%9D.>
- 30 Chen, C., Tu, K., Liu, C., & Shiang, T. (2014b). Effects of forefoot bending elasticity of running shoes on gait and running performance. *Human Movement Science*, 38, 163–172. <https://doi.org/10.1016/j.humov.2014.05.008>

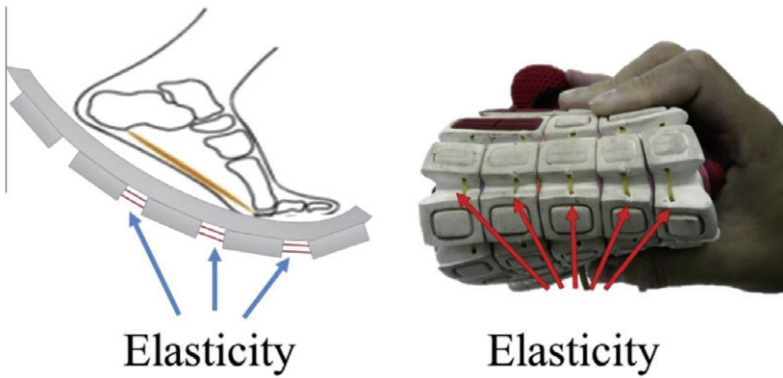


Figure 22. Elastic shoes: The researchers modified the stiffness of the flexible shoes by adding rubber bands into the forefoot part of the shoe sole. Adopted by <https://doi.org/10.1016/j.humov.2014.10.002>

Strength

Generally, in the context of footwear, strength refers to qualities such as tensile strength, resistance to tearing, peeling, puncturing, compression, and shearing. Resistance to tearing is particularly crucial, as materials that tear easily in footwear can lead to significant functional and safety concerns. Moreover, tearing damages can shorten the lifespan of a shoe, thereby posing sustainability issues.[31]

Cushioning

An important role of footwear is to cushion impacts that result from foot-ground contacts[32]. Human movement generally involves repeated loading at the foot-floor interface, resulting in force transmission through the human feet and toward the upper extremities[33]. The midsole of sneakers or running shoes usually has a cushioning function. According to Asics' website, cushioning is determined by the thickness of the midsole, and the level of cushioning directly correlates with the amount of support provided[34]. A study shows that people found footwear with softer midsole materials to be more comfortable [35].

Stability

Footwear, serving as the interface between the body and the supporting surface, has the potential to influence balance and, consequently, the risk of falling[36]. Having footwear that can provide both good cushioning and lateral stability is the best way to prevent both impact peak injury and

- 31 Frank, K. (2024, February 2). Footwear testing methods - Part 1 - framas. Framas. <https://framass.com/en/2023/09/22/footwear-testing-methods1-2/>
- 32 Lafortune, M., & Hennig, E. (1992). Cushioning properties of footwear during walking: accelerometer and force platform measurements. *Clinical Biomechanics*, 7(3), 181–184. [https://doi.org/10.1016/0268-0033\(92\)90034-2](https://doi.org/10.1016/0268-0033(92)90034-2)
- 33 Goonetilleke, R. S. (1999). Footwear cushioning: Relating objective and subjective measurements. *Human Factors*, 41(2), 241–256. <https://doi.org/10.1518/001872099779591231>
- 34 Kinne, W. (2023, April 18). Anatomy of a running shoe: sockliner, heel counter and more - ASICS Runkeeper. ASICS Runkeeper. <https://runkeeper.com/cms/start-running/anatomy-of-a-running-shoe-heres-what-all-those-technical-terms-actually-mean/#:~:text=The%20midsole%20is%20a%20layer,will%20have%20a%20thinner%20midsole.>
- 35 Dinato, R. C., Ribeiro, A. P., Butugan, M. K., Pereira, I. L., Onodera, A. N., & Sacco, I. C. (2015). Biomechanical variables and perception of comfort in running shoes with different cushioning technologies. *Journal of Science and Medicine in Sport*, 18(1), 93–97. <https://doi.org/10.1016/j.jsams.2013.12.003>
- 36 Menant, J. C., Perry, S. D., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2008). Effects of shoe characteristics on dynamic stability when walking on even and uneven surfaces in young and older people. *Archives of Physical Medicine and Rehabilitation*, 89(10), 1970–1976. <https://doi.org/10.1016/j.apmr.2008.02.031>

ankle sprain[37]. The static and dynamic balance can be influenced by the characteristics of shoes, such as the materials used, hardness, thickness and width of the soles, the coefficient of friction of the outsoles, the height of the collar, and heel counters [38][39].

Thermal conductivity

The researchers argue that the thermal management of shoes and their thermal comfort are crucial factors that should be taken into consideration during the design process[40]. Major factors contributing to thermal comfort are air temperature, humidity as well as personal factors such as one's metabolic rate and clothing[41]. The thermal properties of raw materials determine the efficiency of heat and water exchange between the wearer and their environment, influencing the microclimate around the wearer's foot, ultimately shaping the overall comfort of using the footwear[42]

Permeability

The ability of a shoe material to pass air, water and water vapour is one of the most important factors contributing to foot comfort[43].

Waterproof

Waterproofing is the capability to prevent water from entering[44]. It's crucial to consider the permeability of the shoe material to liquid water, as the material's ability to allow perspiration and facilitate its removal through evaporation or absorption is vital for overall body comfort[25]. It is highly recommended to use waterproof fabrics which incorporate a breathable membrane stitched within the fabric, providing them with both breathability and waterproof[26]

Slip resistance

Slips leading to falls are often attributed to insufficient friction between the flooring and footwear [45]. In order to ensure safety and well-balanced performance, it is crucial that shoes provide effective traction or slip resistance in any slippery situation [26]. The outsole of the shoe is an important factor to be considered as it establishes the contact interface with the floor to create the friction required during stance[46].

- 37 Fong, D. T., Hong, Y., & Li, J. X. (2007). Cushioning and lateral stability functions of cloth sport shoes. *Sports Biomechanics*, 6(3), 407–417. <https://doi.org/10.1080/14763140701491476>
- 38 Kim, M., Kong, B., & Yoo, K. (2017). The effect of shoe type on static and dynamic balance during treadmill walking in young healthy women. *Journal of Physical Therapy*
- 39 Matt Klein PT DPT PhD(c) OCS GCS FAAOMPT. (n.d.-a). Footwear science: Sole flare. *Footwear Science: Sole Flare*. <https://www.doctorsofrunning.com/2017/06/footwear-science-sole-flare.html#:~:text=This%20is%20defined%20as%20the,the%20sole%20of%20the%20shoe>
- 40 Nemati, H., Ardekani, M. M., & Naemi, R. (2021). A mathematical model to investigate heat transfer in footwear during walking and jogging. *Journal of Thermal Biology*, 97, 102778. <https://doi.org/10.1016/j.jtherbio.2020.102778>
- 41 Chrenko, F. A. (1967). Paper 8: Thermal comfort. *Institution of Mechanical Engineers, London, Proceedings*, 182(5), 13–19. https://doi.org/10.1243/pime_conf_1967_182_147_02
- 42 Puskarz, A. K., & Usupov, A. (2019). The study of footwear thermal insulation using thermography and the finite volume method. *International Journal of Thermophysics*, 40(4). <https://doi.org/10.1007/s10765-019-2509-1>
- 43 Ueda, H., & Havenith, G. (2005). The effect of fabric air permeability on clothing ventilation. In *Elsevier eBooks* (pp. 343–346). [https://doi.org/10.1016/S1572-347X\(05\)80054-0](https://doi.org/10.1016/S1572-347X(05)80054-0)
- 44 Chirilă, A., & Iovan-Dragomir, A. (2018). Waterproof process in footwear industry. *The International Conference on Advanced Materials and Systems*. <https://doi.org/10.24264/icams-2018.vi.5>
- 45 James, S. L., Lucchesi, L. R., Bisignano, C., Castle, C. D., Dingels, Z. V., Fox, J. T., Hamilton, E. B., Henry, N. J., Krohn, K. J., Liu, Z., McCracken, D., Nixon, M. R., Roberts, N. L. S., Sylte, D. O., Adsuar, J. C., Arora, A., Briggs, A. M., Collado-Mateo, D., Cooper, C., . . . Murray, C. J. L. (2020). The global burden of falls: global, regional and national estimates of morbidity and mortality from the Global Burden of Disease Study 2017. *Injury Prevention*, 26(Suppl 2), i3–i11. <https://doi.org/10.1136/injuryprev-2019-043286>
- 46 Meehan, E. E., Vidic, N. S., & Beschorner, K. E. (2022). In contrast to slip-resistant shoes, fluid drainage capacity explains friction performance across shoes that are not slip-resistant. *Applied Ergonomics*, 100, 103663. <https://doi.org/10.1016/j.apergo.2021.103663>

1-4-3 Anatomy of conventional footwear

In this section, a review of the construction of conventional shoes took place to examine how conventional footwear accomplishes both the primary function and the desired characteristics outlined earlier. This review included a literature review and an examination of a New Balance sneaker by the author. Figure 23 presents an image of the New Balance sneaker, while Figure 24 details the major shoe components [47].



Figure 23. New Balance Sneaker

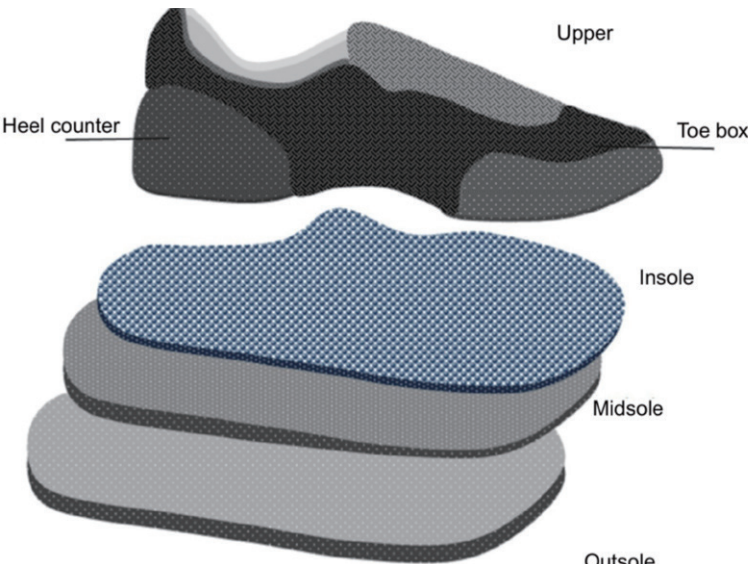


figure 24. Major components of a typical shoe. Adopted by <https://doi.org/10.1016/B978-0-08-101212-3.00017-4>

47 Luximon, A., & Khandual, A. (2018). Footwear. In Elsevier eBooks (pp. 533–558). <https://doi.org/10.1016/b978-0-08-101212-3.00017-4>

A layer of material that is positioned inside the shoe that provides a comfortable layer between the sole and the wearer's foot[48]. Pressure distribution between the plantar surface of the foot and the insole of the shoe can detect the comfort of running shoes for walking movement[49]. The four most common materials of insoles are foam, gel, cork, and leather and, in general, foam is the best for cushioning, support, and pressure relief[50]. Additionally, the desirability of an absorbent insole for comfort is also recognised[25]. In the New Balance sneaker, this part has little resistance that creates a cushioning function.

Midsole

A part located between the insole and the outsole although this part is not always a requirement for shoes[48]. The midsole contributes to determining the thickness, bending stiffness, the cushioning system, and overall mass of the footwear[51]. In general, the midsole longitudinal bending stiffness and the cushioning system have been the primary characteristics that affect the function of footwear. Cushioning is as the name mentions, the characteristics to absorb the force generated from an impact[52]. Midsole longitudinal bending stiffness is the characteristic that resists bending around a mediolateral axis within the shoe[48]. EVA (ethylene vinyl acetate) and polyurethanes are the most commonly used materials for this part[47]. EVA is the standard material for midsoles in running shoes due to its combination of durability and flexibility at low density, while polyurethane is popular in casual footwear for its long-lasting properties[53]. Since the midsole in walking shoes doesn't need to focus exclusively on shock attenuation, certain manufacturers have explored incorporating energy-return characteristics into their designs[54], such as an air midsole which is exemplified by the Nike Air series [55]. This type of midsole features miniature air pockets inside the shoe that offer cushioning and bounce upon impact but promptly reinflate once pressure is released[56]. The firmer the midsole, the stiffer and heavier the shoe becomes, whereas soft midsoles enhance shock absorption at the expense of quicker wear.[57].

Outsole

The exposed part of the sole that is in contact with the ground[48]. A variety of materials, including leather, thermoplastic rubber, and urethanes,

- 48 C. & R. B., says:, S., & says:, R. (2020, June 7). Anatomy of the Shoe. Shoe Guide. https://www.shoeguide.org/shoe_anatomy/
- 49 Che, H., Nigg, B. M., & De Koning, J. J. (1994). Relationship between plantar pressure distribution under the foot and insole comfort. *Clinical Biomechanics*, 9(6), 335–341. [https://doi.org/10.1016/0268-0033\(94\)90062-0](https://doi.org/10.1016/0268-0033(94)90062-0)
- 50 The Insole Store. (n.d.). Insole Guide: How to choose the right insole. <https://theinsolestore.com/pages/insole-guide>
- 51 Agresta, C., Giacomazzi, C., Harrast, M., & Zender, J. (2022b). Running Injury Paradigms and Their Influence on Footwear design features and runner Assessment Methods: A Focused Review to Advance Evidence-Based Practice for Running Medicine Clinicians. *Frontiers in Sports and Active Living*, 4. <https://doi.org/10.3389/fspor.2022.815675>
- 52 What is cushioning in a shoe? (n.d.). SALOMON. <https://www.salomon.com/en-us/running/trail-running-advice/what-cushioning-a-shoe>
- 53 Brückner, K., Odenwald, S., Schwanitz, S., Heidenfelder, J., & Milani, T. (2010). Polyurethane-foam midsoles in running shoes - impact energy and damping. *Procedia Engineering*, 2(2), 2789–2793. <https://doi.org/10.1016/j.proeng.2010.04.067>
- 54 McPail, T. G. (1988). Footwear. *Physical Therapy*, 68(12), 1857–1865. <https://doi.org/10.1093/ptj/68.12.1857>
- 55 Nike Air. Nike.com. (n.d.). <https://www.nike.com/nl/en/air>
- 56 Shoes, V. (2023, May 10). What are midsoles? | Vionic shoes. Healthy Footnotes. <https://www.vionicshoes.com/blog/what-are-midsoles/>
- 57 Sanders, J. (2010, November 6). Understanding the impact of shoe insoles and midsoles. *Podiatry Today*. Retrieved June 10, 2024, from <https://www.hmpgloballearningnetwork.com/site/podiatry/blogged/understanding-impact-shoe-insoles-and-midsoles#:~:text=The%20softer%20the%20insole%2C%20the,provide%20cushioning%20>

have been employed to meet the requirements of durability, flexibility, and slip resistance, yet none have proven to be ideal so far [54]. The study suggests that the selection of outsole materials is dependent on the existing surfaces and contaminants within the given environment[55]. When you compare a rubber sole and a urethane one, the former has better slip resistance and wears less quickly, while the latter has more flexibility and less slip resistance[56]. The outsole plays a crucial role in preventing slipping as well. Having small tread blocks separated by tread channels enhances friction, introduced to Slip-resistant shoes[57]. Hylton B. Menza Stephen R. Lorda Andrew S. McIntoshb et al conducted an experiment where they compared eight shoes with different sole geometries. From this study, the one with a 10° bevel into the rear section of the heel (shape C) was the most slip-resistant on dry surfaces(Figure 25)[58].

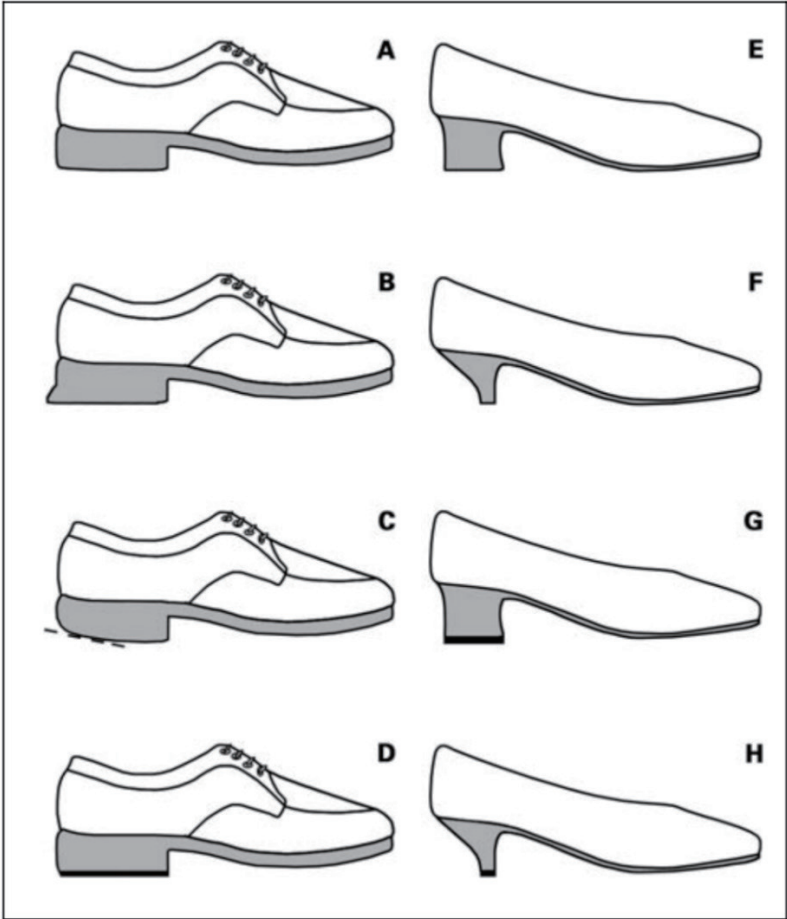


Figure 25. Different type of shoe sole.. Adopted by <https://sci-hub.se/https://doi.org/10.1159/000052788>

54 McPoil, T. G. (1988). Footwear. *Physical Therapy*, 68(12), 1857–1865. <https://doi.org/10.1093/ptj/68.12.1857>

55 Jakobsen, L., Lysdal, F. G., Bagehorn, T., Kersting, U. G., & Sivebæk, I. M. (2022). The effect of footwear outsole material on slip resistance on dry and contaminated surfaces with geometrically controlled outsoles. *Ergonomics*, 66(3), 322–329. <https://doi.org/10.1080/00140139.2022.2081364>

56 Outsole - rubber or PU? (2022, September 23). Belmont Sécurité. <https://belmontsecurite.ca/en/blogs/consells-dexpert/semelle-exterieure-caoutchouc-ou-pu>

57 Hemler, S. L., Sider, J. R., Redfern, M. S., & Beschoner, K. E. (2021). Gait kinetics impact shoe tread wear rate. *Gait & Posture*, 86, 157–161. <https://doi.org/10.1016/j.gaitpost.2021.03.006>

58 Menz, H. B., Lord, S. R., & McIntosh, A. S. (2001). Slip resistance of casual footwear: Implications for falls in older adults. *Gerontology*, 47(3), 145–149. <https://doi.org/10.1159/000052788>

Upper

One of the most prominently visible parts of a shoe that is a large piece of fabric that attaches to the sole of the shoe[59]. This component can be crafted from a variety of materials, including both modern and traditional options such as fabrics, foam leather, original leather, or synthetic materials, such as neoprene foam or polyurethane [47]. In modern footwear, such as sneakers, it is more common to use flexible materials to support the natural gait. As illustrated in Figure 26, the New Balance sneaker exhibits upper deformation in the forefoot region, particularly notable during the toe-off phase of the human gait. Additionally, the material of the upper part of modern footwear uses breathable material to let air and water go inside for comfort. This can be also observed in the New Balance sneaker.



Figure 26. New Balance sneaker exhibited deformation in the forefoot region

Toe box

The front part of your shoe where your toes rest. This part reinforces the shape of the toe part of shoes[47] affording more space for the toe to splay, thereby reducing the friction that could lead to blisters[60]. The study suggested that involving the medial border of the shoe around the 1st metatarsalphalangeal joint and the first toe being designed in a round shape and, the lateral border around the 5th interphalangeal joint having a pointed graduated shape will be ideal for foot health[61]

- 59 Kizik. (2023, May 23). Anatomy of the shoe: 19 parts of the shoe | Kizik. <https://kizik.com/en-nl/blogs/news/parts-of-a-shoe>
- 60 Agresta, C., Giacomazzi, C., Harrast, M., & Zendler, J. (2022c). Running Injury Paradigms and Their Influence on Footwear design features and runner Assessment Methods: A Focused Review to Advance Evidence-Based Practice for Running Medicine Clinicians. *Frontiers in Sports and Active Living*, 4. <https://doi.org/10.3389/fspor.2022.815675>
- 61 Branthwaite, H., Chockalingam, N., & Greenhalgh, A. (2013). The effect of shoe toe box shape and volume on forefoot interdigital and plantar pressures in healthy females. *Journal of Foot and Ankle Research*, 6(1). <https://doi.org/10.1186/1757-1146-6-28>

Heel counters

The piece of material at the back, providing support and rigidity to the heel area[48]. Like the toe box, this part also maintains the shape of the shoe and strengthens the rear structure. Foot stability is achieved through the use of a firm counter with a rear-foot stabilizer in many models[54]. While its primary purpose is to manage overpronation during gait[62], the resulting confinement of the heel (known as the counter effect) has an effect in reducing the severity of external loads acting on the heel[63].



Figure 27. Toe box of New Balance senaker has stiffness to reinforce the shape

- 33 Foot stability is achieved through the use of a firm counter with a rear-foot stabilizer in many models
Branthwaite, H., Chockalingam, N., & Greenhalgh, A. (2013). The effect of shoe toe box shape and volume on forefoot interdigital and plantar pressures in healthy females. *Journal of Foot and Ankle Research*, 6(1). <https://doi.org/10.1186/1757-1146-6-28>
- 62 Spears, I. R., Miller-Young, J., Sharma, J. N., Ker, R. F., & Smith, F. W. (2007). The potential influence of the heel counter on internal stress during static standing: A combined finite element and positional MRI investigation. *Journal of Biomechanics*, 40(12), 2774–2780. <https://doi.org/10.1016/j.jbiomech.2007.01.004>
- 63 Jorgensen, U. G., & Ekstrand, J. (1988). Significance of heel pad confinement for the shock absorption at heel strike. *International Journal of Sports Medicine*, 09(06), 468–473. <https://doi.org/10.1055/s-2007-1025053>
- 64 Nat. (2018, November 22). What is Nike Air Technology? | JD Official. JD UK Blog. <https://blog.jdsports.co.uk/what-is-nike-air-technology/>



1-4-4 Conventional shoes making process

Review of shoe making process took place. The aim of this review is to briefly understand how material characteristics should be aligned with the way shoes are manufactured.

The main source of this is videos on Youtube describing how modern shoes are manufactured in factories (Figure 29) [65]. Although there are diverse types of shoes on the market, it was found that the most shoe making process has commonalities described as follows (Figure 30).

- 1: Measurements & Selection of Style
- 2: Shoe Last Making
- 3: Pattern Cutting & Clicking
- 4: Preform the shape of the upper part with a last
- 5: Combine the upper part with a sole(heel) with glue

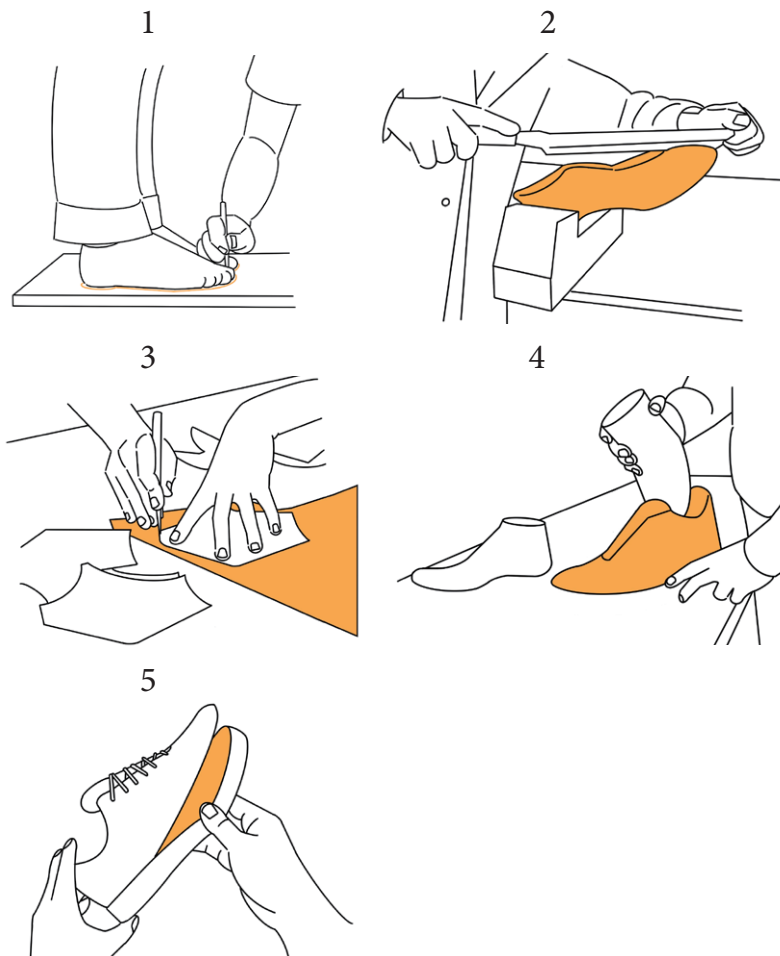


Figure 30 Illustration of the shoe making process depicted by the author based on the review



65 Figure 29. How New Balance Sneakers Are Made by Business Insider. Adopted by <https://youtu.be/>

From this, it is observed that there is a phase where a piece of sheet is moulded into the shape to become the upper part of the shoes. This indicates that it is desirable that the upper material has some plasticity to keep its shape once it's moulded. In the "Textbook of Footwear Manufacture", Thornton pointed out that leather has been a popular material for footwear for a long time because of its characteristics such as its elasticity, plasticity, strength, stretch, and flexibility; especially plasticity is important characteristics as almost all the methods of shoes making involve moulding a flat material to the curved surface of a last[25].

1-4-5 Insight

The insights found through out the literature review are follwing.

1. There are a range of characteristics desired for shoe material depending on their demands. such as flexibility, elasticity, and strength.
2. In sneakers, flexibility is achieved by using polyester meah material in the upper part. It allows the foot to bend easily.
3. In the sneaker, stability is achieved by the heel counter and toe box which reinforce the shape of the shoes. The common material for this part is fabric
4. In terms of the "desired characteristics" of the shoes, it is challenging for one shoe to achieve all of them, as one characteristic can contradict another. For instance, a soft shoe sole can protect your foot from ground reaction force, while a hard shoe sole establishes better stability. Hard soles offer better stability but will lose flexibility and cushioning characteristics. This suggests that priorities should be set based on the design goal. Essentially, achieving the "primary function" of the shoes is most important.
5. The upper part is the most visible component of shoes, significantly influencing how consumers perceive the product. Specifically, when evaluating the material, it might affect both the functional and aesthetic quality of the product. It will be the most important part of the material development as the goal of this project is to communicate the products' sustainability through their aesthetic attributes.
6. Ideally, the material for the upper part of shoes has plasticity to be moulded into the shoes last.

1-5 The existing footwear products that incorporated biodegradable materials

In this section, I will review three footwear that have incorporated biodegradable materials made from plants or fruits in order to understand how the specific types of materials achieve certain functionality. As noted in the previous section, in the conventional shoe design, each parts of the shoe require different characteristics to achieve certain functionality. The aim of this section is to investigate what type of biodegradable materials are utilised for what reason.

ID.EIGHT

The upper part of the shoes consists of leather-like bioplastic materials(pineapple leaves, Grape skin and Apple Skin) and Recycled Polyester (Figure 31). The main component is the white-coloured mesh that is made from recycled polyester that allows for the flexibility of shoes, while red and blue-coloured overlay parts are bioplastic leather made from Apple Skins allowing sturdiness of the shoes[66]. This biocomposite leather has the supporting material made from polyester and polyurethane which means that they are not completely biodegradable for the definition that I set previously.

Explorer V2

The sneaker, Explore V2, designed by 8000 KICKS, utilizes robust cannabis hemp fiber for its upper part and insole(Figure 32). Unlike the previous shoes, bioplastics are not employed in its construction. The upper material made of hemp fibre allowed excellent breathability and flexibility[67].

Glaudio Pavone

The upper part of these shoes is made from white wine leather and mango leather while the sole is made from recycled rubber(Figure 33). Regarding the wine leather, according to the website, A Sustainable Closet, ingredients are bio-oil from grape seeds, grapes and organic cotton fabric[68]. In terms of the production of Mango leather, they use organic cotton for the backing[69]. Thus, the upper part of the shoes is fully biodegradable.

66 The construction of shoes designed by ID.EIGHT. Adopted by <https://www.yankodesign.com/2021/12/01/these-sustainable-sneakers-are-made-from-fruit-waste/>

67 Explorer V2 for Men Beige and green. (n.d.). 8000Kicks. <https://www.8000kicks.com/products/explorer-v2-for-men-beige-and-green>

68 YUNO sneaker. Adopted by <https://claudiopavone.de/>

69 Fruit leather Rotterdam. (2024, January 30). FAQ - Fruit leather Rotterdam. <https://fruitleather.nl/faq/>

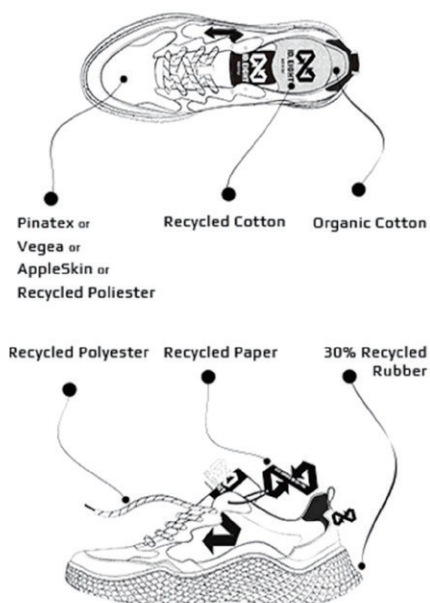


Figure 31. The construction of shoes designed by ID.EIGHT. Adopted by <https://www.yankodesign.com/2021/12/01/these-sustainable-sneakers-are-made-from-fruit-waste/>



Figure 32. Explore V2 sneaker . Adopted by <https://www.8000kicks.com/products/explorer-v2-for-men-beige-and->



Figure 33. YUNO sneaker. Adopted by <https://claudiopavone.de/> and translated into English

From this investigation, it is noticed that bioplastic leather made from fruit waste requires reinforcement material and, this could be biodegradable or non-biodegradable depending on the materials. Also, those materials are usually used for upper material which requires some flexibility and hardness. On the other hand, it wasn't observed that the bioplastic material is used for the sole part of shoes.

When you look at shoes from ID-EIGHT, it is also clear that if you want flexibility in a certain area of shoes upper, recycled mesh is preferred over leather-like material made from fruits.

1-5-1 Insight

The insights found through out the literature review are follwing.

1. Bioplastic leather made from fruit waste requires reinforcement material which can be both biodegradable or non-biodegradable
2. No bioplastic mesh material was found; only leather-like bioplastic materials or canvas materials made from natural fibre were found
3. Thus, for the later material development for the upper part, the realistic option will be either mesh-like material made from fibre or leather-like material made from bioplastic.
4. Most shoe soles are made from recycled rubber. No biodegradable shoes with sole parts made from fruit waste were found. This challenge can be attributed to the difficulty in creating a material that possesses both hardness and elasticity simultaneously.
5. While the upper material made from hemp fibre might have little reference to naturalness, the bioplastic leather material doesn't explicitly express naturalness.
6. Most companies divide shoe components into two parts, the upper and the sole parts and, address the sustainability of each separately. For instance, they use partially biodegradable materials for the upper part and recycled rubber for the sole part.



1-6 Structure and function of the human foot and ankle

In his book, Handbook of Footwear Design and Manufacture, Chan stated that Footwear designed for comfort, protection, and functionality must take into account the anatomy of the foot and accommodate individual variations, such as the position of palpable bony prominences[70]. In this section, the biomechanics of the human foot are briefly reviewed to understand the needs for the design of lifestyle shoes.

1-6-1 Overview of Gait Cycle

The vital functions of the ankle and foot can be observed during walking, commonly referred to as gait. The kinesiological events that take place during walking are typically studied in the context of a gait cycle(Figure 27). The gait cycle is divided into a stance phase, where the foot is in contact with the ground, and a swing phase, during which the foot propels through the air, moving the lower extremity to the next step. The stance phase consists of five key events: (1) heel contact, (2) foot flat, (3) mid stance, (4) heel off, and (5) toe-off. The swing phase comprises (1) early swing, (2) mid swing, and (3) late swing (Figure 35).

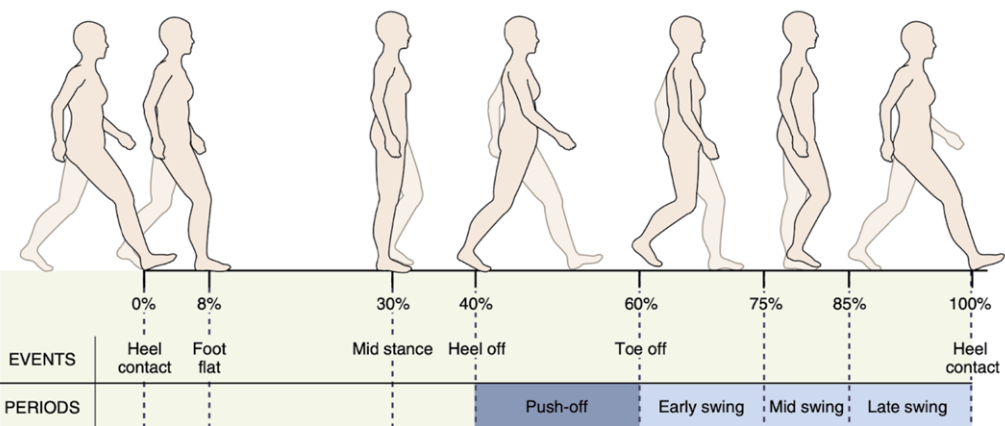


Figure 35 Traditional subdivisions of the gait cycle. Adopted by Neumann DA: Kinesiology of the musculoskeletal system: foundations for physical rehabilitation, ed 2, St Louis, 2010, Mosby, Fig. 15.11.

70 Chan, L. K. (2021). Anatomy of the human foot. Handbook of Footwear Design and Manufacture, 3–28. <https://doi.org/10.1016/b978-0-12-821606-4.00014-4>

1-6-2 Kinematics of the Ankle and Foot

Before diving into the biomechanics of gait, it is necessary to understand the anatomy of the lower extremities. Fundamental movements of the human foot and ankle occur within a conceptual plane(Figure 36) that is perpendicular to the three classic axes of rotation: medial-lateral, anterior-posterior, and vertical. However, these conventional concepts don't fully capture the kinematics across all ankle and foot joints. For instance, joints like the subtalar and transverse tarsal produce a more oblique movement best described using terms like pronation or supination.

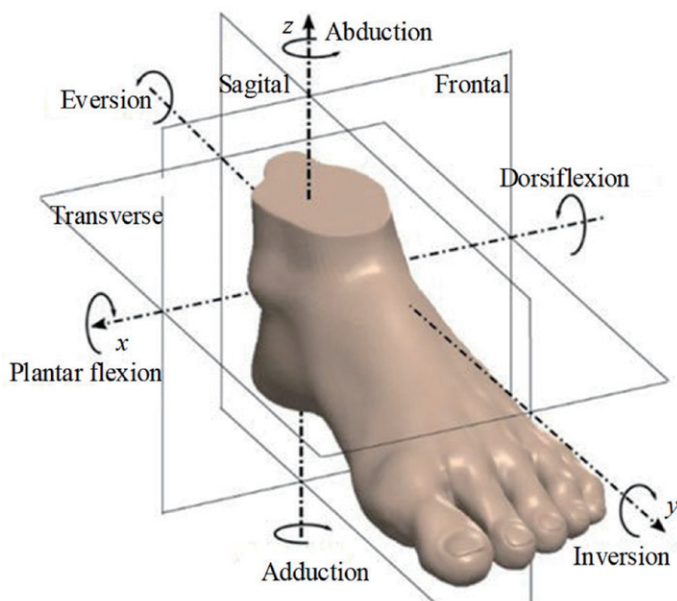


Figure 36. Adopted by <https://www.mdpi.com/2076-3417/13/10/6109>

1-6-3 Kinematics of the Ankle and Foot

Dorsiflexion and Plantar Flexion

Dorsiflexion and plantar flexion occur within the sagittal plane, rotating around a medial-lateral axis(Figure 37). Dorsiflexion is characterized by the motion of elevating the dorsal part (top) of a foot region toward the anterior aspect of the tibia. Plantar flexion, on the other hand, refers to the motion of displacing the dorsal part of the foot region away from the anterior aspect of the tibia.

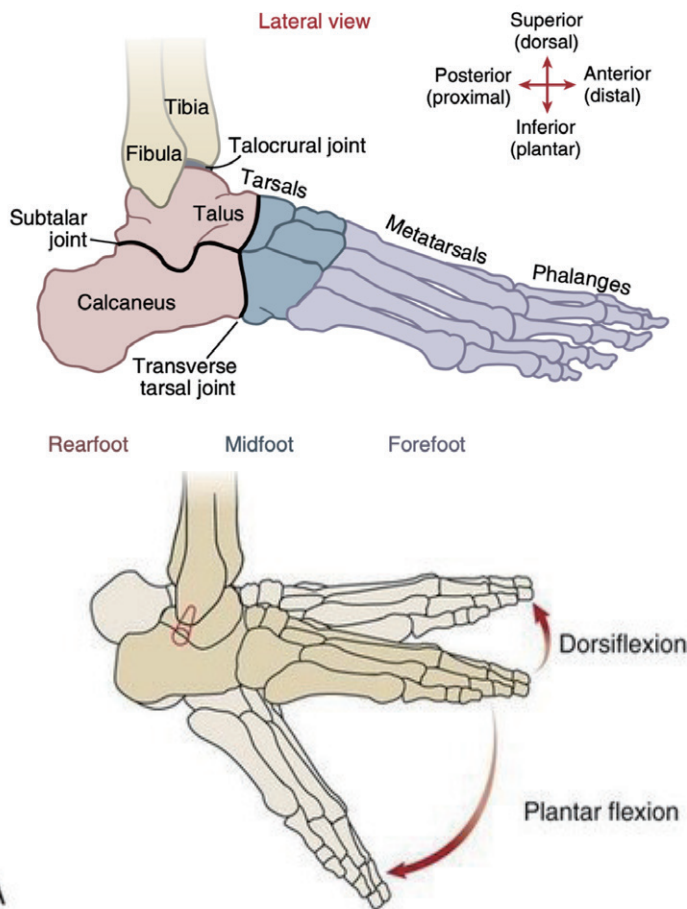


Figure 37
 Upper image: Lateral view of the right ankle and foot. (From Neumann DA: Kinesiology of the musculoskeletal system: foundations for physical rehabilitation, ed 2, St Louis, 2010, Mosby, Fig. 14.1.)
 Bottom image: Dorsiflexion and plantar flexion. Adopted by https://www.researchgate.net/publication/330057169_Structure_and_Function_of_the_Hip

Inversion and Eversion

Inversion and eversion occur within the frontal plane, revolving around an axis oriented in the anterior-posterior direction. Inversion rotates a point on the plantar aspect of the foot toward the midline, while eversion rotates a point on the plantar aspect of the foot laterally, moving it away from the midline (Figure 38).

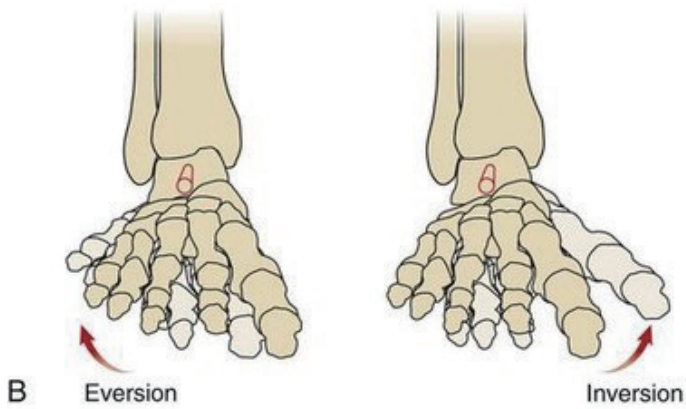


Figure 38 Inversion and Eversion. Adopted by https://www.researchgate.net/publication/330057169_Structure_and_Function_of_the_Hip

Abduction and Adduction

Abduction and Adduction occur within the horizontal plane revolving around a vertical axis of rotation. Adduction is referred to as a horizontal plane rotation of the foot as a point on its anterior surface moves toward the midline. In contrast, Abduction describes the opposite movement, in which a point on its anterior surface rotates away from the midline(Figure 39).

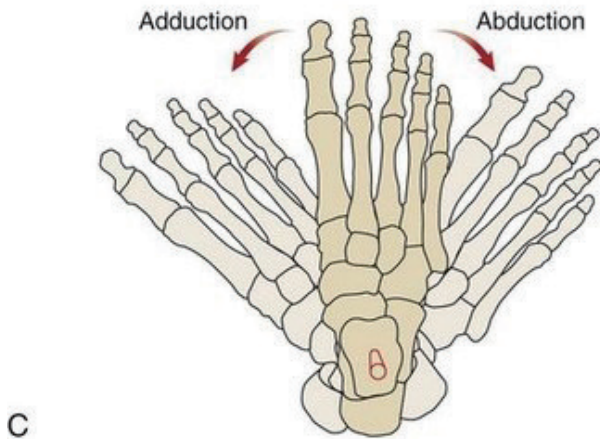


Figure 39 Abduction and Adduction. Adopted by https://www.researchgate.net/publication/330057169_Structure_and_Function_of_the_Hip

Pronation and Supination

Pronation and supination are complex motions that involve a combination of the fundamental movements described earlier. Pronation involves the eversion, abduction, and dorsiflexion of any region of the ankle and foot, while supination, in contrast, involves the inversion, adduction, and plantar flexion of any region of the ankle and foot. These specialized movements can be seen most frequently within the subtalar and transverse tarsal joints(Figure 40).

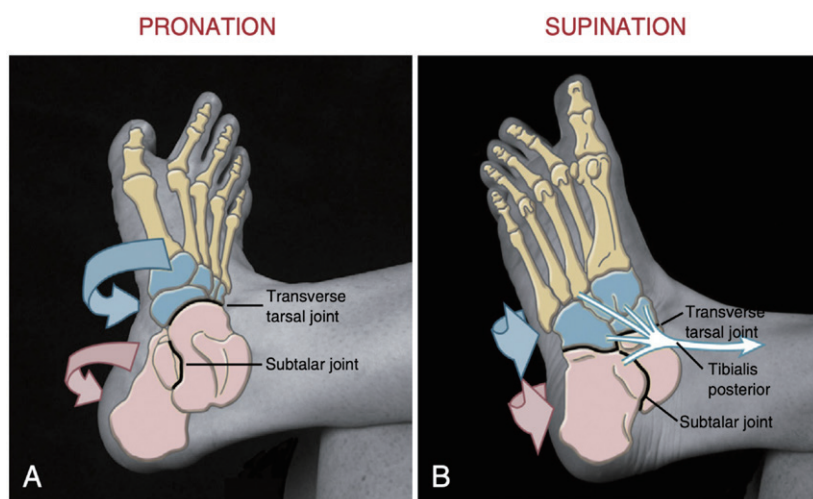


Figure 40 Pronation and Supination. Adopted by https://www.researchgate.net/publication/330057169_Structure_and_Function_of_the_Hip

1-6-4 Overview of gait analysis

The gait analysis conducted by the sports science consultancy, Quintic Consultancy Ltd, revealed that during the six different phases of human gait, the foot utilizes various joint movements to maintain stability and propel forward [71]. Figure 41 illustrates the complex movements in each phase. This indicates that shoes should not disrupt these movements by employing rigid uppers and sole materials.

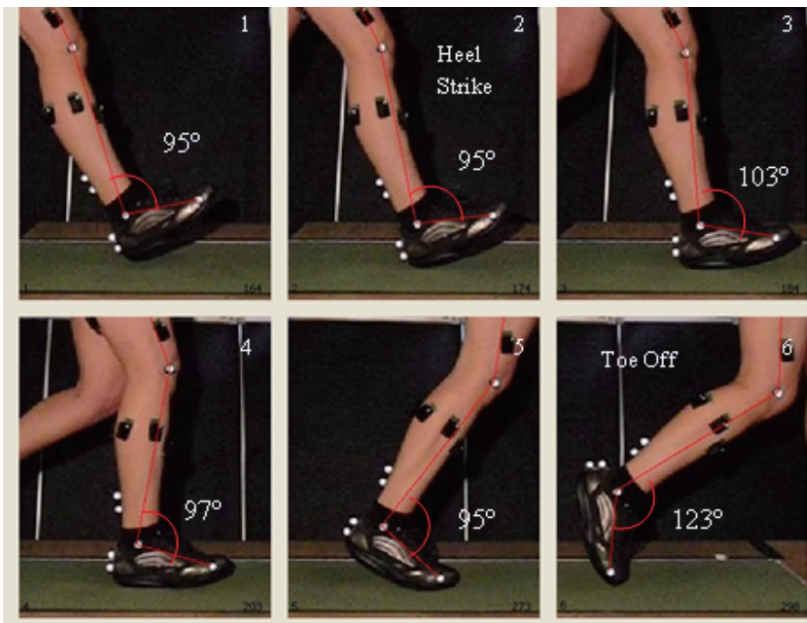


Figure 41

1. 10 frames prior to heel strike – ankle in neutral position ~ 90°
2. Heel strike – ankle in neutral position ~ 90°
3. End of braking phase – ankle plantar-flexes
4. Midstance – ankle returns to neutral position
5. Propulsive phase – Slight dorsi-flexion
6. Toe off – Rapid plantar-flexion helps propel subject forwards

Adopted by: <https://www.quinticsports.com/gait-analysis/>

1-6-5 Insight

The insights found through out the literature review are follwing.

1. The human gait has different phases that utilise different joint movements including Dorsiflexion-Plantar Flexion, Inversion-Eversion, Abduction-Adduction and Pronation-Supination.
2. In the heel-off phase, the weight of weare concentrated in the toe part and, the foot has the movements of Dorsiflexion-Plantar Flexion. The shoes should bend at the same point the foot bends to make the movement smooth.
3. Shoes should allow for a degree of freedom in the ankle joint by providing space to flex during walking. This not only facilitates smooth propulsion but also enhances stability. This suggests that rigid materials are not ideal for the upper part of shoes, despite the traditional use of rigid materials like leather in many classic shoe designs.

1-7 Material Experience Vision

In the Material Driven Design Method (MDD), designers are expected to formulate a vision of the experience they want to achieve with the material. This process typically occurs after the "Understand Material" phase, where the material is characterized technically and experientially. However, since this project involves material development from scratch, it was required to generate a material experience vision as a point of reference before the material development.

1-7-1 Statement of material experience vision

Drawing from the literature review on the various types of biodegradability observed in current sustainable products, along with the effects of naturalness on material: potentially evoking the meaning of not only natural but also low quality, interesting and unique, the material experience vision was formulated as follows.

Material Experience Vision

I want people to recognise the material to be biodegradable as well as compostable through visual and tactile properties including, fiberness, roughness, non-reflectiveness and agedness while maintaining their perception of quality. Additionally, I also want people to find the material to be interesting or unique to wear as a shoe with the properties of naturalness.

With this material experience vision, I have a hope that the product embodying this material will contribute to establishing a new narrative: that owning sustainable products is not just about making responsible choices but also adding trendy and stylish items to one's wardrobe. Achieving this goes beyond designing shoes; it requires product branding and storytelling. However, pursuing this material is certainly the first step towards realizing this dream. In the next sections, technical and non-technical requirements were stated based on the vision.

1-7-2 Technical requirements

The technical requirements for the material to be developed are defined on an ad hoc basis. Based on the literature review regarding biodegradable materials, the construction of conventional shoes, characteristics of shoe materials, existing biodegradable shoes, and biomechanics of the human foot, the technical requirements for the material to be developed in this project are formulated.

Upper part

- The material should have the flexibility to bend in the heel-off during walking
- The material should have plasticity to be moldable in the shoe-making process
- The material should have the strength to resist tearing and ripping
- The material should have hardness to resist impact from outside. It shouldn't easily get holes

Sole part

- The material should possess hardness to shield the sole part of the foot from the roughness of the ground while walking and standing.
- The material should exhibit elasticity to flex during walking and return to its original shape when not bent.

In addition to the characteristics listed above, permeability, waterproofing, stability, and slip resistance are considered to be additional features that are desirable but not necessarily essential.

1-7-3 Non-technical requirements

Based on the literature review on the challenge biodegradable products are facing, the concept of naturalness, and current biodegradable shoes on the market, the non-technical requirement for the material to be developed in this project are also formulated.

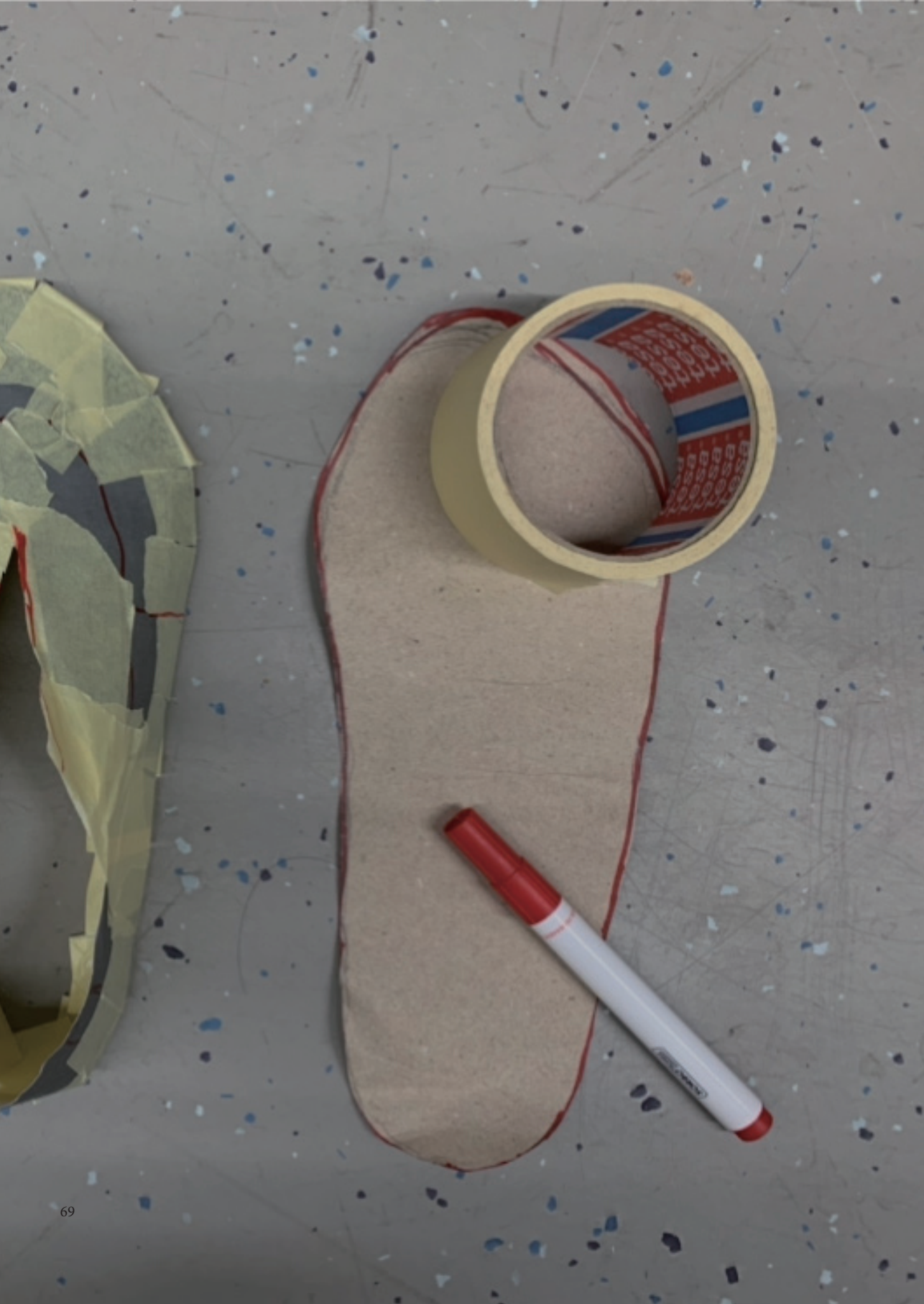
Upper and sole part

- The material should evoke the meaning of naturalness with fibreness, reflectiveness, roughness and agedness
- The material should evoke the meaning of compostability
- The material should evoke the meaning of high quality



2. Material Development

Based on the material experience vision defined in the previous chapter, the material development for the upper part and sole part of the shoes was conducted separately. An orange peel was selected as the starting point for the material development of the upper part, while mandarin was selected for the sole part. Eventually, two material concepts for the upper part were formulated, which will be examined in the material characterization phase.



2-1 Orange Peel

2-1-1 Selection of fruits

As the initial step of this study, the orange peel was chosen as the starting point of exploration, recognizing its potential. Two factors influenced this decision: the technical and sensorial properties of the material.

Regarding technical properties, in an observation, it was found that an orange peel exhibits both hardness and flexibility when it contains a certain amount of water inside. In addition to that, it has the plasticity that allows the material to be moulded into a desired shape.

Regarding sensorial properties, the orange peel maintains relatively its original appearance for a more extended period compared to peels from other fruits (Figure 42). This means that this material can potentially communicate naturalness through its visual and tactile properties.

Although, once the orange peel gets dried, it loses its flexibility and becomes brittle, the potential of this material was recognised by the author because of the advantages mentioned above. This observation led me to hypothesise that if an orange peel is directly applied to the product, it can effectively convey a story of its sustainability to people through its unprocessed-like appearance that is familiar to consumers.



Figure 42 Rotten banana peels that have transformed overtime(left). Adopted by <https://stock.adobe.com/images/banana-peel-rotten-black-peel-on-the-trash-garbage/263383928>

Old orange peels maintain its original appearance (right). Adopted by <https://peels.com/blogs/news/can-you-eat-orange-peels>

2-1-2 Example use of orange peel for biodegradable product

There are two precedent products that utilized orange peel for product design: Solskin Peels and I Peeled an Orange(Figure 43). These products demonstrate the potential of orange peel. Solskin Peels consist of tableware made from moulded orange peel, including cups, plates, and small bottles. Meanwhile, I Peeled an Orange comprises a collection of knitted items like baskets. Both work effectively utilise the technical property of the material,

in the cases of Solskin Peels, they took advantage of moldability to create intended shapes; in the case of the I Peeled Orange, they made interlocking systems that allow the material to become flexible while maintaining its advantage of hardness. Moreover, they successfully communicate their origin through their unprocessed-like visual and tactile aesthetics, more specifically, rough, non-reflective, and fibrous texture as well as ageing features. Although there may be room for discussion regarding whether the products appear high-quality or not, it is observed that the material gives the impression of being hand-crafted, allowing it to avoid direct comparison with conventional industrial products.

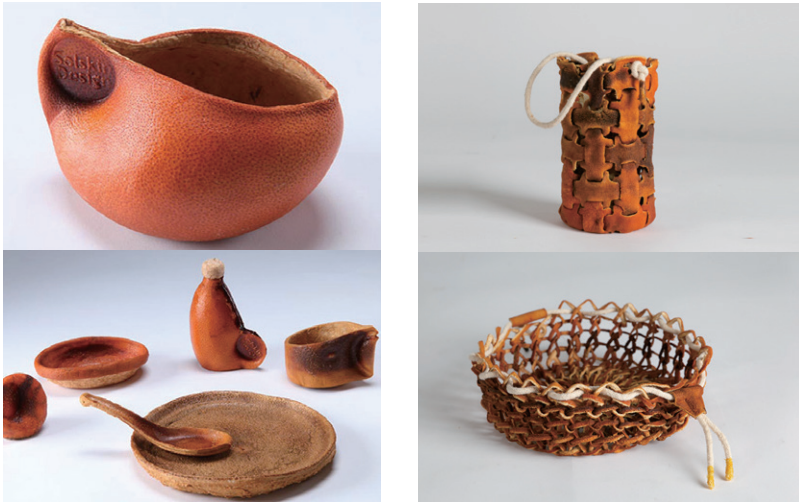


Figure 43
 Right: Solskin Peels Adopted by <https://inhabitat.com/israel-based-solskin-studio-creates-biodegradable-objects-from-orange-skins/solskin-design-biodegradable-orange-peels-objects-2/>
 Left: I Peeled an Orange. Adopted by <https://www.designboom.com/design/yuli-meroz-orange-peel-intricate-crafts-09-07-2020/>

2-1-3 Tinkering with orange peel

The tinkering activity, part of an exercise in the Material Driven Design approach, involved designers playing with a material with their hands to explore its characteristics. In this phase, the raw orange peels were manipulated by the author to understand characteristics that could be both positive and negative attributes as a shoe material. The process of this phase is the following.

1. Buying oranges from super market.
2. Cut the orange into small portation and remove the Carpels (fruits part) and seeds(Figure 44).
3. Interact with the material to understand its characteristics.

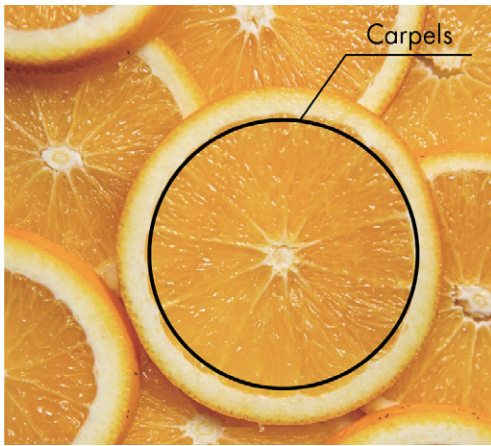


Figure 44 Carpels



Figure 45. Dried orange peel was easy to break

The result: It was found that the raw orange peels exhibited good flexibility and hardness within two to three days after being extracted from the fruits. It also showed waterproof ability. However, after one week, it underwent a transformation and became brittle (figure 45). While this transformative ageing property may be fatal as a shoe material, it was recognised by the author that material possess the potential to convey a sense of naturalness as the upper part of the shoes. This realisation led the author to the next challenge, attempting to retain the water inside the orange peel to maintain its initial hardness and flexibility permanently. The material development for the sole part will be described after the upper.

2-2 Material Development for shoe upper

The goal of this material development was to modify the water retention ability of the orange peel to achieve the desired balance of hardness and flexibility in the material. The development consists of exploratory five trials. The knowledge generated in each trial guided me to the next one, eventually leading to the development of materials that met the minimum requirements of both technical and non-technical.

Trial 1. Covering orange peel with orange pulp

It is clear that the outer surface of the orange peel doesn't lose water easily. From daily observation, it was noted that the orange maintains its shape without deformation for a relatively long time. This is because the orange peel, upon losing water, solidifies quickly, preventing rot. This solidification occurs when the inner surface of the orange peel loses water through its porous surface.

Thus, in this trial, the inner surface of orange peels was covered with orange pulp (figure 46). This orange pulp was fully made from orange distilled by a blender. The intention behind this approach was to block the small hole of orange peel to keep its water.

The result: In one week, the orange peel became brittle again. Not only the orange peel but also the orange pulp itself also became brittle.

Trial 2. Covering orange peel with bee wax

As the material for blocking the hole of the orange peel, bee wax was chosen. Bee wax is known for its use in making winter jackets waterproof. The intention behind this approach was to permeate the bee wax inside the orange peel and block the inner surface.

The result: The bee wax did not permeate the orange peel but solidified on its surface (figure 47). While this approach managed to slow down the process of the orange peel becoming brittle, eventually, both the orange peel and the bee wax exhibited brittleness.



Figure 46. Covering orange peel with orange pulp



Figure 47. Orange peel with bee wax

Trial 3. Leaving the carpel part

Based on the observation in my daily life that dried orange slices in a candy store contain water and keep their flexibility for a long time, it was hypothesised that leaving the carpel part would allow it to keep water inside the orange peel(Figure 48). Thus, a little portion of the carpel part on the orange peel was intentionally kept.

The result: It successfully kept its flexibility. However, after two weeks, it got mouldy (Figure 49). Thus, It was concluded that this approach is not suitable for keeping water inside the orange peel.

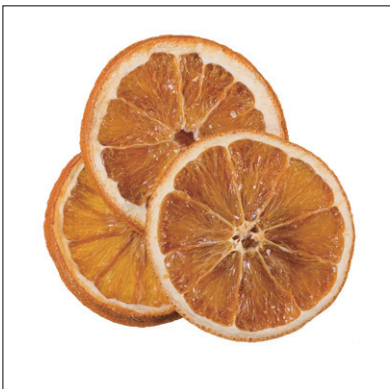


Figure 48. Dried orange slices



Figure 49. Orange peel with remained carpel part got moldy

Trial 4. Removing the mesocarp part from orange peel

After the failures of three trials, it was noticed that mesocarp(albedo) part of orange peel is largely contributing the orange peel to become brittle(Figure 50). The mesocarp of orange peel contains pectine[72]. Pectine is a high-molecular-weight carbohydrate polymer and contributes to the cell structure[73]. Although the pectin performs a firming and water-regulating function, it contributes to brittleness of the orange peel when it dries out.

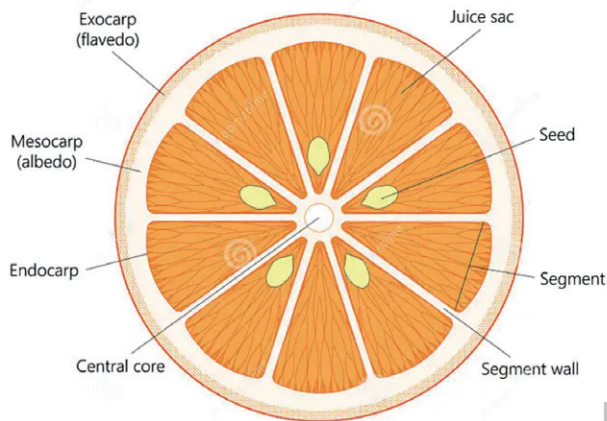


figure 50. Anatomy of orange. Adopted by <https://www.dreamstime.com/orange-fruit-delicious-refreshing-citrus-fruit-known-its-vibrant-color-tangy-flavor-oranges-rich-image281340044>

It was hypothesised that if the mesocarp part was removed from the orange peel, it would retain its flexibility while keeping the iconic appearance of the orange peel to express an unprocessed impression through the exocarp part. To test out the hypothesis, the mesocarp part of the dried orange peel that was already brittle was sanded by the author. The aim was to see if the peel would become flexible again after removing the mesocarp part(Figure 51).

The result: The orange peel had a certain level of flexibility, yet a breaking point was observed in the exocarp region, indicating that this part is also subject to drying and brittleness(Figure 52). When bending reaches a certain level, cracks appear.

With the mesocarp removed, the orange peel became thinner, resulting in reduced brittleness and enhanced flexibility in the material. As you can see in the image below, the original appearance of orange peel could be recognisable. Now it made sense that no matter how the author covered the

- 72 Fishman, M. L., Chau, H. K., Hoagland, P., & Ayyad, K. (1999). Characterization of pectin, flash-extracted from orange albedo by microwave heating, under pressure. *Carbohydrate Research*, 323(1–4), 126–138. [https://doi.org/10.1016/s0008-6215\(99\)00244-x](https://doi.org/10.1016/s0008-6215(99)00244-x)
- 73 Flutto, L. (2003). PECTIN | Properties and Determination. In *Elsevier eBooks* (pp. 4440–4449). <https://doi.org/10.1016/b0-12-227055-x/00901-9>

orange peel from the air in the previous trials, it became brittle eventually with this mesocarp part.

To understand the characteristics of this material further, tinkering of this material was conducted by the author. From this tinkering process, it was found that the advantage of this material is that it has a hardness that is an ideal characteristic of shoe material while having some level of flexibility.



Figure 51. Removing the mesocarp part of orange peel with sand paper



Figure 52. An orange peel became flexible after sanding the mesocarp part

Trial 5. Removing the mesocarp part from orange peel & adding

In Trial 4, it was observed that excluding the mesocarp keeps the flexibility of the orange peel for a longer period, although a breaking point was observed. Initially, prevention of this break had been attempted, but eventually, it occurred to the author that this is inevitable.

This realization shifted the definition of the problem from how not to create breaks to how to keep the material functional while accepting small cracks. This leads to the idea of adding a mango pulp layer to the inner surface of the orange peel. The hypothesis was that mango pulp has good elasticity and resistance to breaking when bent, which will reinforce the orange peel material. It was discovered this characteristic of mango pulp while the author was still exploring different fruit wastes at the beginning of the project. If the mango pulp and orange peel are combined, mango pulp would not only help the orange peel maintain water inside but also hold the orange peel together when they have small cracks. While mango pulp contributes to the water retention and elasticity of the material, the

orange peel provides moderate hardness that reinforces the material. Without the orange peel, the mango pulp is too soft and susceptible to the occurrence of holes.

This new approach involves five steps as follows.

1. Cut orange into four pieces(Figure 53 A, B).
2. Remove the mesocarp part with a knife.
3. Add mango pulp on the back side of the orange peel(Figure 54).
4. Keep them in the oven with 80°C for 20 min to solidify the surface of mango pulp(Figure 55).
5. Allow the combination to dry on a shelf for three to four days until it is completely dried



Figure 53A. Removing mesocarp of orange peel with a knife



Figure 53 B. Orange peel without mesocarp part



Figure 54. Adding mango pulp to exocarp of the orange peel



Figure 55. The orange peel with mango pulp in oven

The result: The orange peel with mango pulp showed a promising outcome(Figure 56, 57). The mango pulp successfully maintains the structural cohesion of the orange peel even when cracks are present. Even if cracks create small holes, the mango pulp can insulate the inside from the outside. Also, mango pulp helps orange peel to keep water inside. The outcome of this trial demonstrated that the material meets the technical requirements of hardness and flexibility and the non-technical requirements of naturalness. it was decided to go further developments with this material.



Figure 56. Top view of the orange peel with mango pulp



Figure 57. Back view of the orange peel with mango pulp

Agedness and scenet of the orange peel material

Through this material development process, the colour change of this newly developed material was observed. There are two factors contributing to this colour transformation. The biggest contributor is the mango pulp itself which darkens within one to two weeks after developed. This mango pulp permeates through the orange peel's exocarp, creating an appearance as if the orange itself has undergone a colour transformation. Additionally, the orange peel itself becomes darker over time, transitioning from bright orange to a darker shade.

Furthermore, the material carries a noticeable fruity scent. While it was difficult to specifically identify whether it's from mango or orange, this aromatic characteristic could be advantageous in conveying the natural essence of the material.

Encouraged by these findings, the author proceeded to the next step, developing two different material concepts utilizing this material.

2-3 Two material concepts for shoe upper part

The next step in the development process is to expand the orange peel into a single sheet that can be moulded to the shoe last. Given the limited surface area of orange peel that can be extracted from a single orange, it was necessary to find a way to connect orange peels to create a continuous sheet. In this process, two different material concepts emerged.

Concept 1: Orange peel material connected with thread (MPT)

This concept involves the sewing method. The intention behind this idea is to add a degree of freedom in the connection between peels. As depicted in Figure 58, the orange peels are connected like patchwork, with each peel cut into random shapes to create an irregular pattern. The intention behind this approach is to evoke a meaning of interestingness through the irregular texture.



The production process of this material is as follows(Figure 59).

1. Extracting orange peels from oranges.
2. Removing the mesocarp part of the orange peels using a knife.
3. Connecting the orange peels without the mesocarp part using cotton thread.
4. Adding mango pulp to the inner surface of the sheet.
5. Putting the sheet in the oven at 80°C for 20 min to solidify the surface of the mango pulp

Becasue this process involves the mango pulp and thread, this concept will be called MPT(mango pulp with thread) in this project.

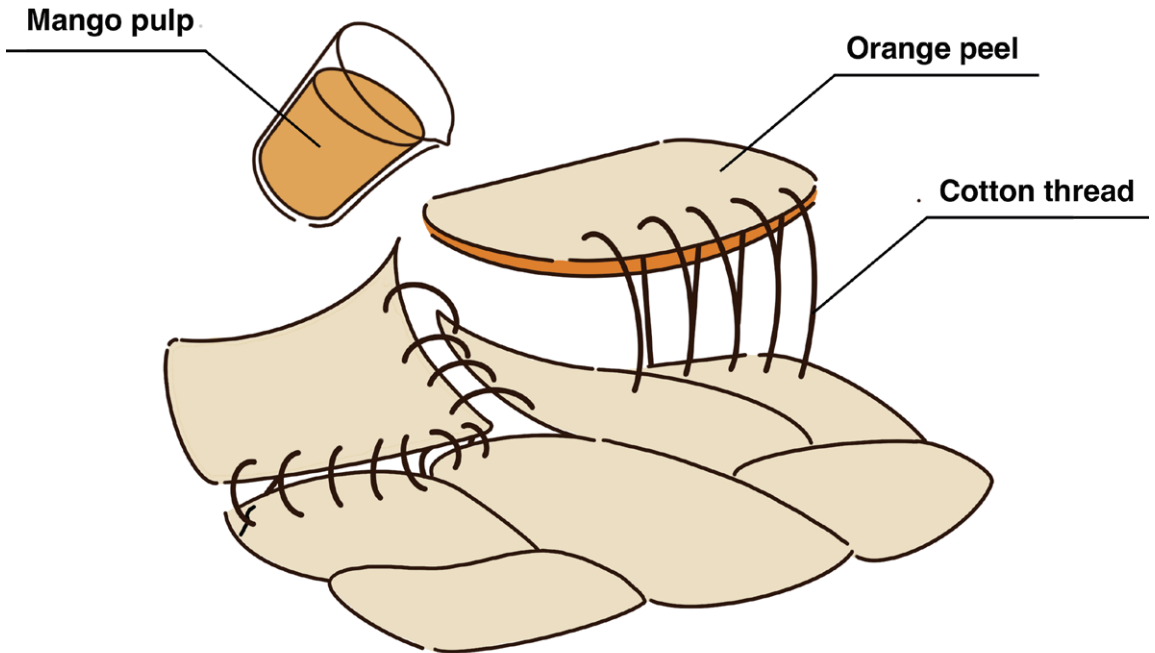


Figure 59. The production process of the orange peel material with thread

Concept 2: Orange peel material connected with banana fiber (MPBT)

This concept involves using a plain-woven banana fibre sheet. The intention of this concept is not only to tie the peels together but also to add reinforcement that would provide more tensile strength. As depicted in Figure 60, the randomly placed orange peels create an irregular texture. Since each peel transforms its colour uniquely, the colour of the sheet also exhibits irregularity. Additionally, as the orange peel is slightly transparent, you can see through the banana fibre on the backside.



Figure 60. Concept 2: Orange peel material connected with banana fiber

The production process of this material is as follows(Figure 61).

1. Extracting orange peels from oranges.
2. Removing the mesocarp part of the orange peels using a knife.
3. Pouring the mango pulp on top of the banana fibre sheet
4. Plotting the orange peels without ther mesocarp part on the banana fiber sheet before the mango pulp becomes solidified
5. Putting the sheet in the oven at 80°C for 20 min to solidify the surface of the mango pulp.

Because this process involves mango pulp and banana fibre, this concept will be called MPBT(mango pulp with banana fibre) in this project.

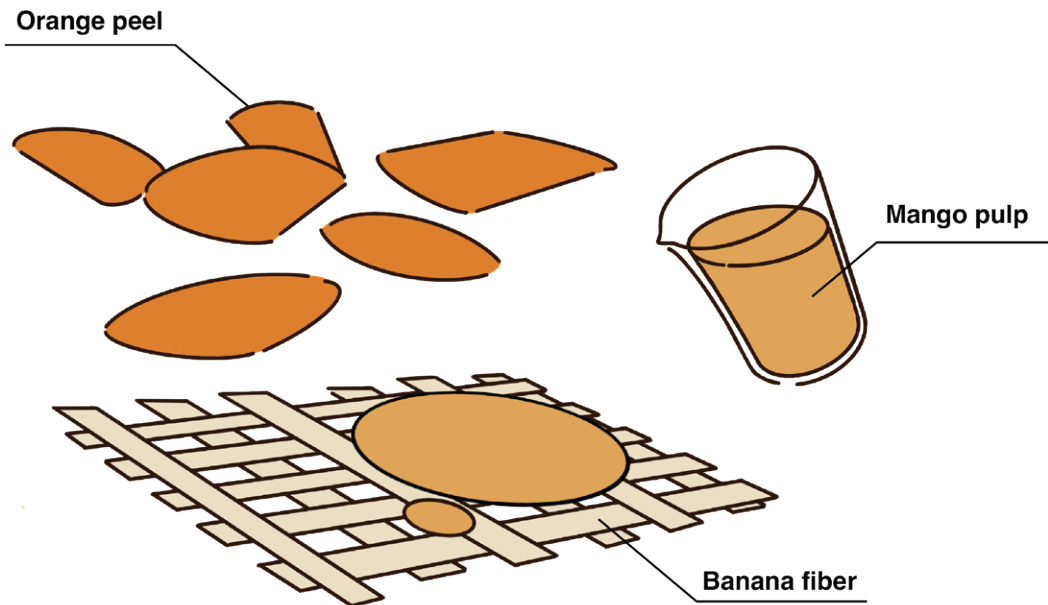


Figure 61. The production process of the orange peel connected with banana fiber

Overall, both material concepts are promising in terms of both the technical and non-technical requirements set in the previous phase, except for evoking the meaning of high quality. At this moment, it is difficult for the author to evaluate if these materials will be perceived as high-quality by consumers. Ultimately, the meaning of high quality doesn't have to be evoked solely by the material but also by its relationship with the function and shape of the product. Therefore, this aspect is left for later consideration, and the two material concepts proceed to the next phase of the material characterisation.

2-4 Material Development for shoe sole

Biocomposite for shoe sole

While the previously developed orange peel materials possess sufficient hardness for the upper part of shoes, there is a desire to create a material for the sole part that offers not only hardness but also thickness to provide insulation between the barefoot and the ground. Therefore, it was decided to formulate a material specifically for the sole part. The necessary characteristics for the sole material are both hardness and elasticity. Three attempts were made to create the sole material that meets the minimum requirements of both technical and non-technical requirements.

Trial 1. Cornstarch with orange pulp

In this trial, the emphasis was placed on achieving hardness. To accomplish this, it was decided to incorporate cornstarch. The production process is as follows.

1. Cutting the orange into small pieces
2. Grinding them (fruit part and peels) with a blender to create a pulp
3. Adding 80g of cornstarch to the orange pulp and mix them
4. Pouring the mixture on a plate
5. Keeping the plate inside the oven at 100° C for five hours

The result: The biocomposite had excessive hardness and brittleness and, did not provide the required flexibility necessary for a sole material. It was found that there were two reasons for this. Firstly, corn starch creates a hard structure on the surface of the biocomposite contributing to its hardness. Secondly, orange contains too much amount of pectine resulting in its excessive hardness. It was also observed that the solidified cornstarch was concentrated on the back surface of the composite, while the front surface mainly consisted of orange pulp. This suggests a challenge in achieving a homogeneous mixture. The side with cornstarch created brittleness, leading to breakage.

Trial 2. Mandarin pulp

From the last trial, it was recognized that both the cornstarch and pectin of the orange contributed to the brittleness of the resultant material. Therefore, this time, it was decided to: 1. not use cornstarch, and 2. instead of using oranges, use mandarins, which contain less pectin. The production process is as follows.

1. Cutting the mandarin into small pieces
2. Grinding them (fruits part and peels) with a blender to create a pulp
3. Pouring the pulp on a plate
4. Keeping the plate inside the oven at 100° C for five hours

The result: The solidified mandarin showed promising properties. It had sufficient hardness to protect the sole part of the foot. It also had the flexibility to bend as you can see in Figure 62. The ideal thickness was around 5mm as it has a good balance of hardened outer surface and soft component inside. Also, it was found that the colour of the outer surface is a good indicator to judge if the material has good properties for shoe soles. If the colour is too dark, the material is probably in the oven too much and will result in brittle characteristics. If the colour is bright brown like the images, it contains both hardness and flexibility.



Figure 62. Mandarin composite for sole part of shoes shows its flexibility

Trial 3. Mandarin pulp + banana fiber

After trial 2, it was desired to further enhance the potential of this mandarin material by adding strength. Thus, the banana fibre that was also used for the upper part of the mandarin pulp was incorporated. The production process is as follows.

1. Cutting the mandarins into small pieces.
2. Grinding them (both the fruit part and peels) with a blender to create pulp.
3. Pouring the mandarin pulp onto the plate.
4. Placing the banana fibre sheet on top of the mandarin pulp that hasn't completely solidified yet.
5. Pouring additional pulp on top of the composite of the banana fibre and mandarin pulp to create a sandwich structure (My hypothesis was that the mandarins would stick together to bond them).
6. Keeping the plate inside the oven at 100°C for five hours.

The result: The resultant material showed the breakage of mandarin surfaces exposing the banana fibre layer as you can see in Figure 63. Despite my hypothesis that the front and back sides of mandarin pulp would bond together, air pockets within the pulp were created between them resulting in the breakage.

While there might be methods to prevent the creation of these air pockets and create even better material for the sole, due to the time constraints of the project, it was decided to proceed with the method from trial 2 for the final design of the shoes.



Figure 63. Uneven thickness of mandarin pulp after adding banana fiber structure

After developing two material concepts for the upper part and one for the sole part, the connecting method of upper and sole part were explored. After consideration, the sewing method was selected(Figure 64). This approach was inspired by observations of some conventional shoes found during research.



Figure 64. The connecting method for the upper and sole part was explored



3. Material Characterisation of the upper part material

This chapter describes the material characterization of the two material concepts that have been conducted over the span of one month. The characterization activities include both technical and experiential assessments, as well as tinkering by the author.

As noted earlier, after the material development, it was found that the newly developed orange peel materials have ageing properties. Thus, the objective of the activities was to achieve a comprehensive understanding of how the materials evolve over time, both technically and experientially. This understanding enabled the selection of one of the materials to proceed to the final design conceptualization.



3-1 Set up of assessment

3-1-1 Understand the Material

The Material Driven Design approach (MDD) facilitates designers in identifying applications for newly developed materials, beginning with understanding the material in hand and characterise it both technically and experientially.

For this project, this phase was adopted to achieve the following objectives:

1. Finding the meaning-evoking pattern of the two different material concepts for the upper part of shoes (Experimental characterisation)
2. Finding the mechanical strength of the two different material concepts for the upper part of shoes (Technical characterisation)

Previously, the meaning-evoking pattern was identified to shape the material experience vision. Now, the focus is on understanding how the newly developed material triggers specific meanings. This understanding will guide me in the conceptualization phase. Additionally, because of the time constraints of the project, the mandarin material for the sole part of the shoe is excluded from this phase.

3-1-2 Capturing the materials' transformation within one month

During the previous material development phase, it was observed that the newly developed orange peel material demonstrated ageing properties(Figure 65). Over time, both its mechanical and experiential properties underwent changes. Despite possessing water retention ability, the material tended to dry out over time, resulting in alterations in colour and increased brittleness. These observations prompted concerns regarding the material's mechanical strength and overall consumer experience.

There was speculation that as time progressed, the material's mechanical strength may decline, potentially affecting its perceived quality. Therefore, it was crucial to understand how the meaning-evoking pattern and mechanical strength of the material would evolve over time. Do consumers judge the quality of the material based on the functional aspect or aesthetic aspect? Is there any advantage for the material in ageing? To answer these questions, technical and experiential characterization were conducted three times within the span of one month to capture any changes in those aspects.



MPBF Day 1



MPT Day 1



MPBF Day 15



MPT Day 15



MPBF Day 30



MPT Day 30

3-1-3 Structure of the tests

Within the span of one month, both technical and experiential characterizations were conducted three times with a 15-day interval. For the technical characterization, which will be detailed later in this chapter, a tensile testing machine was utilized to measure the tensile strength of the material. However, since the machine measures the strength of the material until it breaks, the tested pieces couldn't be retested. Thus, it was necessary to create a total of three pieces of each material for the entire test at the same period. After each test, new materials were prepared for subsequent evaluations. Each step of the test process was depicted as follows(Figure 66).

1. Three pieces of each material, mango pulp with thread(MPT) and mango pulp with banana fibre (MPBF) were created during the same period.
2. On Day 1, experiential characterizations were conducted first for one of the three pieces of each material. Subsequently, technical characterizations of the same pieces were performed.
3. 15 days after the test, the second round of experiential and technical characterisations took place with another piece.
4. After 30 days from the first date of the material creation, the last pieces of each material were tested.

This way, although the pieces of each test are not identical, they are under the same conditions and expected to have the same characteristics technically and experientially.

Day 0

(Material
creation)

Day 1

Day 15

Day 30

Figure 66. The testing pro

(MPT)



1

2

3

Tested



1

2

3

Tested



2

3

Tested



(MPBF)



4



5



6

Tested



4



5



6

Tested



5



6

Tested



3-2 Experiential characterisation

The initial non-technical requirements for the material to be developed included evoking the meanings of naturalness, compostability, high quality, uniqueness, and interestingness. The main interest of this experiential characterisation phase was whether and how those meanings can be generated by consumers. Having understood this meaning-evoking pattern, I will be able to create the desired material experience by manipulating the visual and tactile properties of the material.

3-2-1 Material Experience

"Material experience" is a term coined by Karana et al. and further developed in a recent framework by Giaccardi and Karana[74]. In another paper, Karana et al. noted that the materials used in artefacts often serve as a means to initially attract people's attention. They highlighted that individuals can experience a range of emotions in response to materials, from captivation and excitement to indifference[75]. Giaccardi and Karana introduced four layers of information that shape how people experience material: sensorial, interpretive, affective and performative[74] as outlined below.

- Sensorial level: The technical characteristics of the material are experienced with the senses through touch, vision, smell, sound and taste.
- Interpretive level: How we interpret and judge materials. The meanings we ascribe after the initial sensorial encounter; for example modern, traditional, elegant.
- Affective level: How we feel about the qualities of the material on an emotional level; for example fascinated, surprised, disgusted.
- Performative level: How the material elicits our actions; for example touching, picking, stroking.

Those four different levels are influencing one another. To understand this complex interrelationship, Karana et al introduced the toolkit, Ma2E4 (Materials-to-Experiences at four levels) [76] with which people can express their experience with materials in each layer. In this project, this toolkit is adopted and modified to understand the interrelationship between these four different experiential levels.

- 74 Giaccardi, E., & Karana, E. (2015). Foundations of Materials Experience. CHI 2015. <https://doi.org/10.1145/2702123.2702337>
- 75 Karana, E., Pedgley, O., & Rognoli, V. (2015). On Materials Experience. *Design Issues*, 31(3), 16–27. <http://www.jstor.org/stable/43829331>
- 76 Camere, S., & Karana, E. (2018). Experiential Characterization of Materials: toward a toolkit. *Design Research Society (DRS) 2018*. <https://doi.org/10.21606/dma.2017.508>

3-2-2 Ma2E4(Materials-to-Experiences at four levels)

The toolkit proposed by Karna et al consists of an experiential characterisation map for recording the participants' answers, two sets of words (i.e. the affective and the interpretive vocabulary) and a collection of images (i.e. the interpretive picture sets) to be used for refining the interpretive descriptions.

- Performative level: The participants are encouraged to play around with the material to discover characteristics to understand what action the material makes them do
- Sensorial level: The participants are asked to fill out a sensorial scale printed on a form to express how they perceive the material's sensorial properties.
- Affective level: The participants are asked to choose three emotional words and position them within the axis of pleasance and intensity to express their emotional responses to the material (Figure 67).
- Interpretive level: Participants are prompted to select three interpretive words, such as "luxurious" or "high-quality," and then choose images that closely align with their associations for each word. These images help to articulate their interpretive understanding of the material.

After completing the experiential characterization map by filling out all the information across the performative, sensorial, affective, and interpretive levels, all the gathered data are compiled and plotted onto a single form or chart(Figure 68). This comprehensive visualization provides an overview of participants' experiences and perceptions regarding the material, allowing for a holistic understanding of its various dimensions.

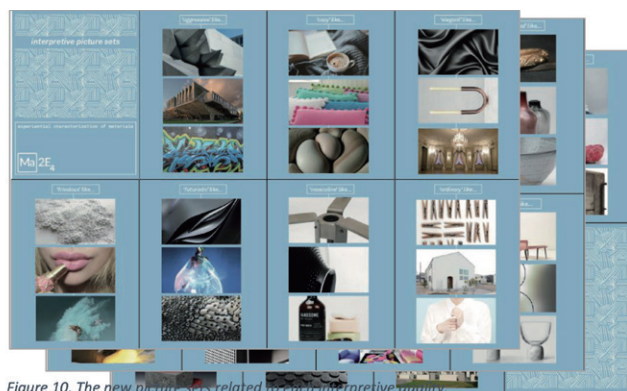


Figure 10. The new picture sets related to each interpretive quality.

Figure 67. The affective vocabulary and the map to record participants' answers at the affective level(the right image). The set of interpretive images and words(the left image). Adopted by <https://www.sciencedirect.com/science/article/pii/S0264127520300769>

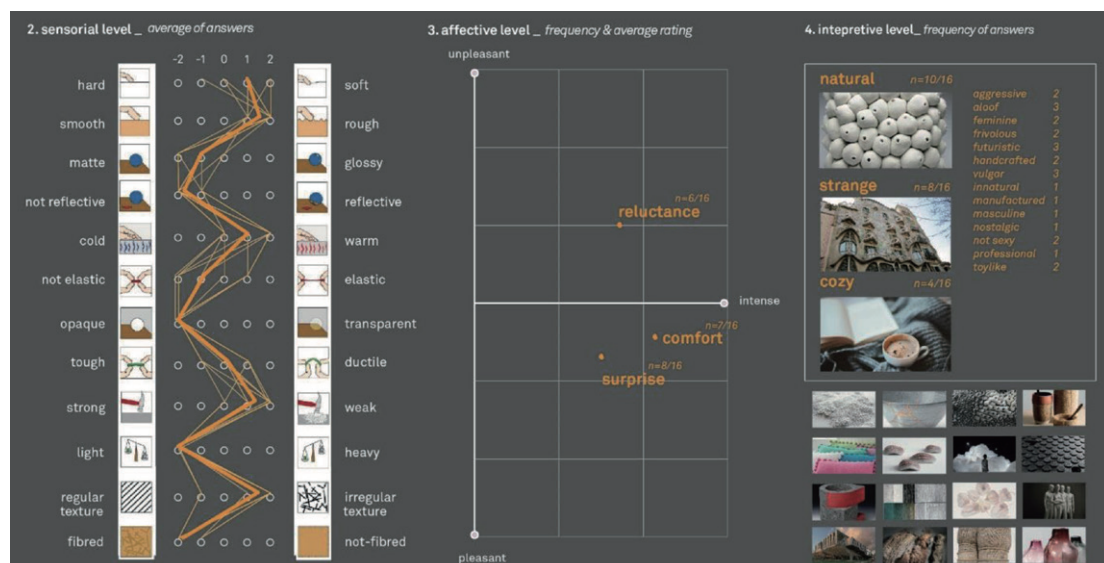


Figure 68. examples of how Ma2E4 data (for one material) can be analyzed and represented through systematic methods. Adopted by <https://www.sciencedirect.com/science/article/pii/S0264127520300769>

3-2-3 Modification of the Ma2E4 toolkit

The main concern of this project is how specific properties like, reflectiveness and agedness shape the material experience as well as how the material that has undergone transformation will affect their perception. The following are the parts that are modified.

- The sensorial scale was adopted from the one developed by Jiwei Zhou in their master thesis research[77]. This scale includes, irregular texture and fiberness in addition to the original sensorial characteristics developed by Karanaet al.
- The new scaling area was added. This section concerns the what extent the participants think the materials are "high quality", "aged", "artificial", "biodegradable", "compostable" and "processed". In the origianl method, those meanings were suppoed to be included in the section regarding interpretive level. However, given the critical importance of understanding the participants' perceptions regarding these specific attributes, they were independently included in the separated area. By independently asking participants to evaluate and provide input on these aspects, the project sought to obtain comprehensive insights into their perspectives on the material across all relevant dimensions.

77 Zhou, J. (2019). Interwoven: Designing Biodigital Objects with Plant Roots: Exploring Material Structure and Experience. <http://resolver.tudelft.nl/uuid:ffdcf947-06df-4941-a587-bdf008f87783>

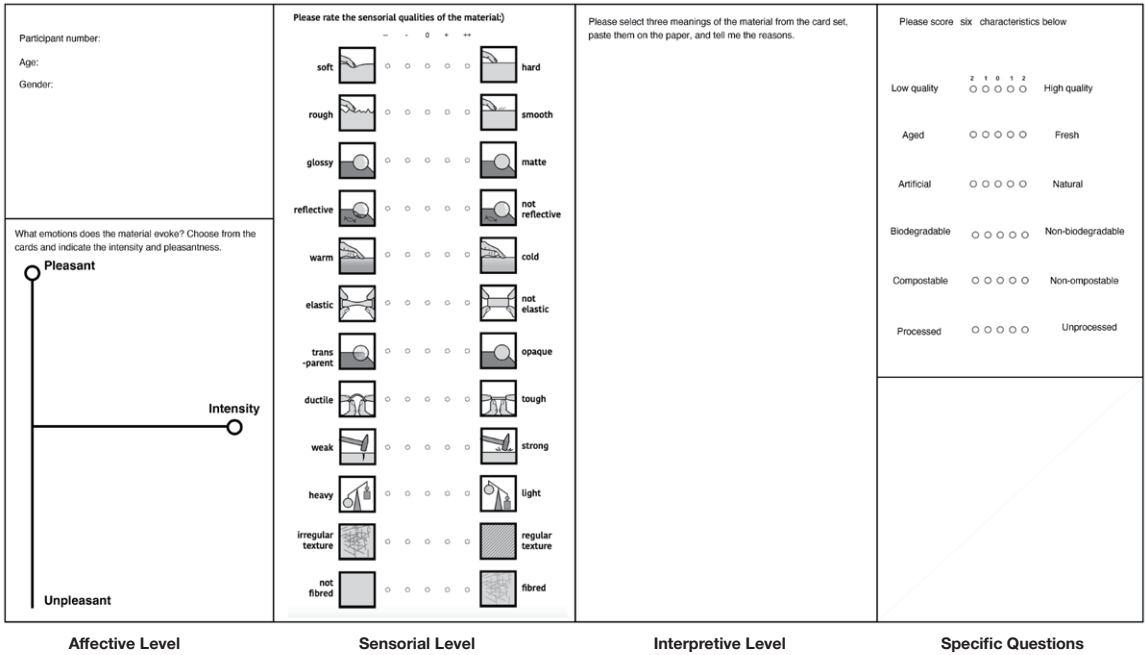


Figure 69. Modified version of experiential characterisation map. In the sensorial scale, fiberness is added to the original version developed by Karana et al. Next to the interpretive level, there is a area for the specifically interested meanings to be scaled by participants

3-2-4 Method after the modification

Following the modifications made to the toolkit, the procedure of the test was outlined as follows. The tests involved 11 participants, including students from industrial design, architecture, and mechanical engineering, as well as part-time a worker from a restaurant. Additionally, the participants were not limited to those who have the targeted lifestyle of this project, as the aim of this study is to gain consumers' general perception towards the materials.

1. First contact with the material

Each participant will be invited for an individual one-hour session. They will be presented with the material and informed that it will be used for shoes.

2. Playing with material

They will be asked to manipulate the material in their hands while vocalizing their thoughts and associations(Figure 70). This will be observed to understand their interaction with the material at the performative level. It will be emphasized that there are no right or wrong opinions. The entire process will be recorded with a camera.

3. Evaluate the two different materials

Afterwards, participants will be asked to complete the characterization tool(Figure 71). In the tool, there are questions regarding affective, Sensorial and interpretive levels. For the interpretive level, they are also asked to cut out pictures that are associated with the three meanings they chose. Additionally, the “Specific question” section was added to understand the interrelationship between participants’ perception of “quality” and “naturalness” and materials’ “Agedness”. By adding those questions, it will be possible to understand, for instance, how sensorial level would have a relationship with high quality (e.g. Hard material could be associated with high quality).

4. Follow-up question

The primary purpose of this step is to understand the interrelationship between different levels and “Naturalness”, “Agedness” and “Quality”. For instance, the author ask participants why they found it to be low quality and if they state because this has a rough texture, you can see the meaning attribution pattern.

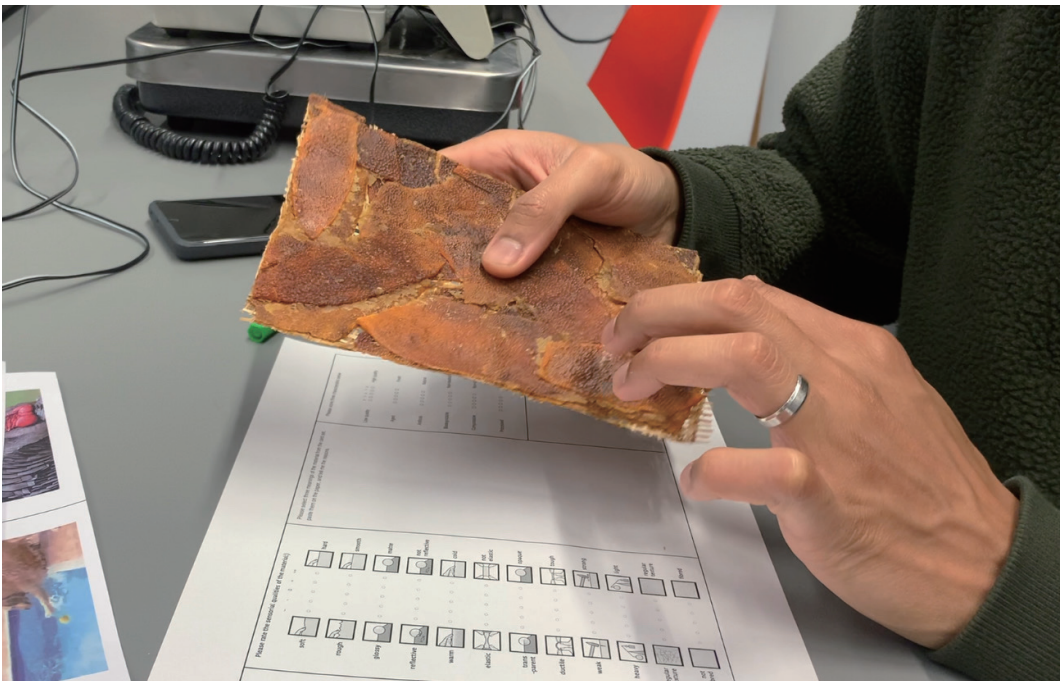


Figure 70. A participant playing with the mango pulp with banana fiber(MPBF)



Figure 71. A participant choosing an image that suits the meaning they chose.

3-2-5 Result

Day 1

Mango pulp with thread

Performative level: The interactions are: pressing, rubbing, looking through, bending gently and smelling.

Sensorial level: The material is considered to be mostly matte, rough, not reflective, ductile, irregular texture and slightly fibered and rough. Additionally, warmth is polarized, with some participants perceiving it as emotionally warm.

Affective level: Overall, the material evoked positive emotions including comfort, fascination, surprise and curiosity except for disgust which is positioned in the unpleasant area.

Interpretive level: Imperfect, wild, interesting and manufactured(handmade) were the most frequently chosen meanings(Figure 72)

Specific Questions: The rate of quality is positioned in the middle, biodegradable and compostable are evoked strongly.

Mango pulp with banana fiber

Performative level: The interactions are: pressing, rubbing, looking through, bending gently and smelling.

Sensorial level: The material is considered to be mostly matte, not reflective, ductile, strong, irregular texture and fibered. Additionally, hardness, is polarized, with some participants mixing up the meaning of hardness with ductility.

Affective level: The material evoked overall positive emotions including surprise, fascination, curiosity, and confidence while negative emotions were also evoked: disgust and doubt.

Interpretive level: Imperfect, interesting, lab-created and manufactured(handmade) were the most frequently selected meanings (Figure 73).

Specific Questions: The rate of quality is positioned in the middle, biodegradable and compostable are evoked strongly. The rate of Agedness is not as strong as MPT because of its bright color

MPT 1

Specific Questions

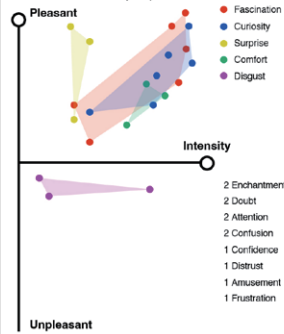
Participant number:

Age: 24-31

Gender: F, M - 5, 6

Background: Design for Interaction, Strategic Product Design, Integrated Product Design, Architecture, Mechanical Engineering, restaurant Part-time worker

What emotions does the material evoke? Choose from the cards and indicate the intensity and pleasantness.

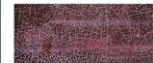


Please rate the sensorial qualities of the material(s)

soft	☐	☐	☐	☐	☐	hard
rough	☐	☐	☐	☐	☐	smooth
glossy	☐	☐	☐	☐	☐	matte
reflective	☐	☐	☐	☐	☐	not reflective
warm	☐	☐	☐	☐	☐	cold
elastic	☐	☐	☐	☐	☐	not elastic
trans-parent	☐	☐	☐	☐	☐	opaque
ductile	☐	☐	☐	☐	☐	tough
weak	☐	☐	☐	☐	☐	strong
heavy	☐	☐	☐	☐	☐	light
irregular texture	☐	☐	☐	☐	☐	regular texture
not fibred	☐	☐	☐	☐	☐	fibred

Please select three meanings of the material from the card set, paste them on the paper, and tell me the reasons.

Imperfect N=8/11



Wild N=4/11



Interesting N=3/11



Manufactured N=2/11



Friendly, Intimate, Vernacular, Non-toxic, Continuous, Approachable, Fashionable, Provocative, Inflammable, Cozy, Reliable, Unpredictable

Please score three characteristics below

Low quality	☐	☐	☐	☐	High quality
Aged	☐	☐	☐	☐	Fresh
Artificial	☐	☐	☐	☐	Natural
Biodegradable	☐	☐	☐	☐	Non-biodegradable
Compostable	☐	☐	☐	☐	Non-compostable
Processed	☐	☐	☐	☐	Unprocessed



Affective Level

Sensorial Level

Interpretive Level

Figure 72. The test result of experiential characterisation of the mango pulp with thread (MPT) on teh Day 1

MPBF 1

Specific Questions

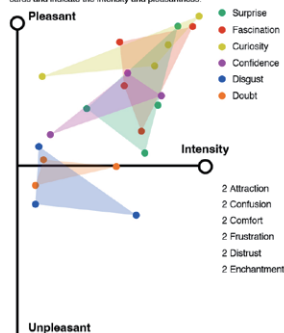
Participant number:

Age: 24-31

Gender: F, M - 5, 6

Background: Design for Interaction, Strategic Product Design, Integrated Product Design, Architecture, Mechanical Engineering, restaurant Part-time worker

What emotions does the material evoke? Choose from the cards and indicate the intensity and pleasantness.



Please rate the sensorial qualities of the material(s)

soft	☐	☐	☐	☐	☐	hard
rough	☐	☐	☐	☐	☐	smooth
glossy	☐	☐	☐	☐	☐	matte
reflective	☐	☐	☐	☐	☐	not reflective
warm	☐	☐	☐	☐	☐	cold
elastic	☐	☐	☐	☐	☐	not elastic
trans-parent	☐	☐	☐	☐	☐	opaque
ductile	☐	☐	☐	☐	☐	tough
weak	☐	☐	☐	☐	☐	strong
heavy	☐	☐	☐	☐	☐	light
irregular texture	☐	☐	☐	☐	☐	regular texture
not fibred	☐	☐	☐	☐	☐	fibred

Please select three meanings of the material from the card set, paste them on the paper, and tell me the reasons.

Imperfect N=7/11



Interesting N=5/11



Lab-created N=3/11



Manufactured N=4/11



Wild, Friendly, Provocative, Wabi-sabi, Vernacular, Cheerful, Reliable, Basic, Fashionable, Non-toxic, Peaceful, Approachable

Please score three characteristics below

Low quality	☐	☐	☐	☐	High quality
Aged	☐	☐	☐	☐	Fresh
Artificial	☐	☐	☐	☐	Natural
Biodegradable	☐	☐	☐	☐	Non-biodegradable
Compostable	☐	☐	☐	☐	Non-compostable
Processed	☐	☐	☐	☐	Unprocessed



Affective Level

Sensorial Level

Interpretive Level

Figure 73. The test result of experiential characterisation of the mango pulp with thread (MPBF) on teh Day 1

Interrelationship of the four experiential levels

Overall, both materials evoked positive emotions such as fascination, surprise and curiosity. They found the material to be interesting because of the fibres and the irregular texture of the materials. They were interacting with the materials with excitement discovering their properties. On the other hand, irregular texture also evoked negative emotions such as disgust and doubt. The sheets consisted of orange peels with varying textures and colours, creating irregularity. Some were darker than others. One participant mentioned, "If the materials had coherent colours, it would look high quality".

In the case of the mango pulp with thread, participants frequently chose the image of a frog at the interpretive level due to the resemblance of their irregular textures, which also evoked slight disgust(Figure 74). The stitching on the material was perceived as a sign of high quality, because of their association with elaborate handcraft works.

As for the mango pulp with banana fibre, participants admired the regular pattern of the banana fibre, associating it with professionalism(Figure 75). They often selected images of lab-created items at the interpretive level. Additionally, confidence was frequently chosen at the affective level due to the presence of the fibre. However, some participants expressed doubt on the affective scale because they were uncertain about the manufacturing process. One participant mentioned feeling hesitant because they didn't understand how the fibre and orange peel were connected, indicating that despite the explicit expression of naturalness, some participants may still perceive the material as mysterious.

From this assessment, it became clear that the fibres play a significant role in evoking the meaning of interesting. On the other hand, it also evoked negative emotions such as disgust.

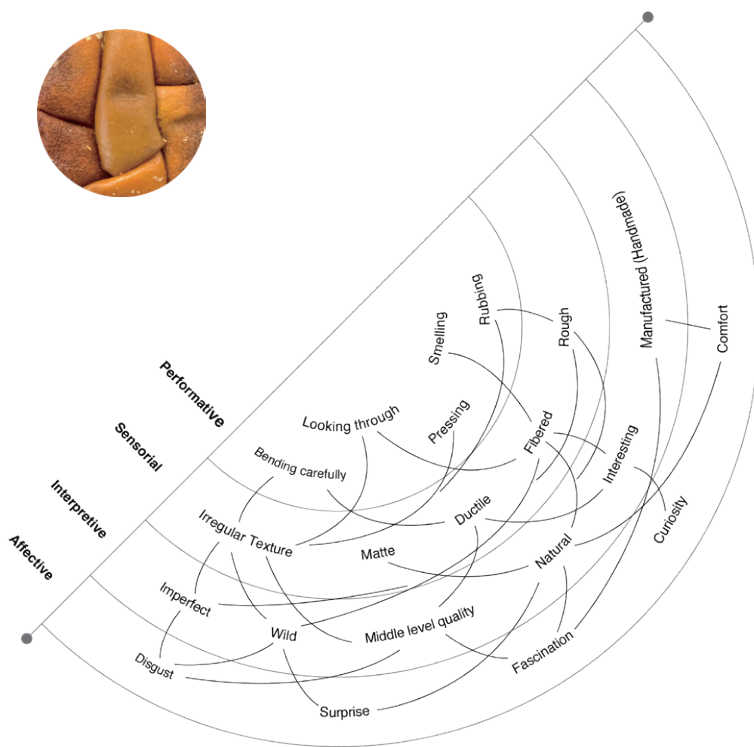


Figure 74. The interrelationship between the four experiential levels of the mango pulp with thread(MPT) on the Day 1

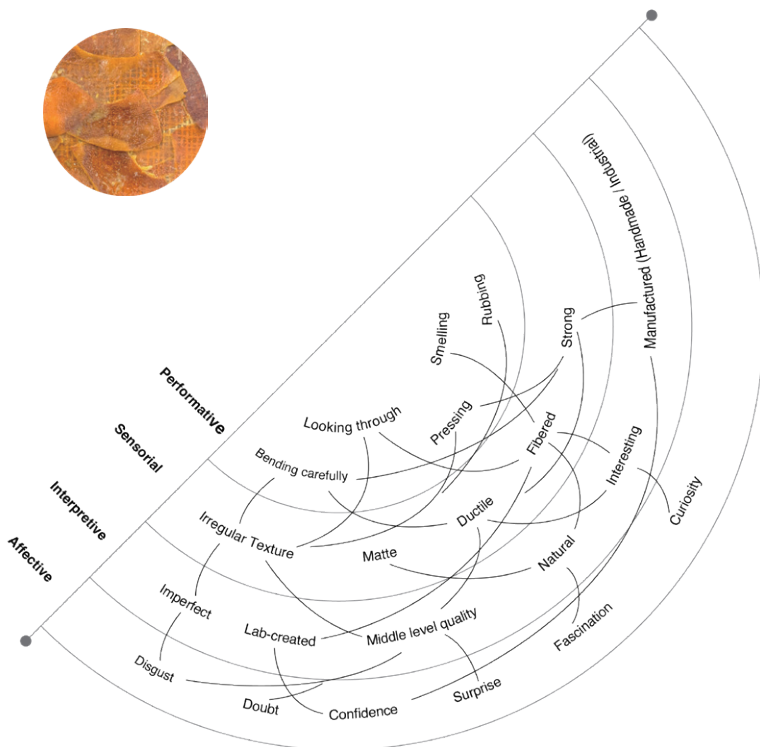


Figure 75. The interrelationship between the four experiential levels of the mango pulp with thread(MPBF) on the Day 1

Day 15

Mango Pulp with thread

Performative level: The interactions are: pressing, rubbing, looking through, bending gently and smelling.

Sensorial level: The material is primarily perceived as rough, matte, non-reflective, ductile, and possessing an irregular texture. Interestingly, the fibred quality, which was frequently noted in the previous session(Day 1), was not as prominent this time.

Affective level: Overall, the material evoked positive emotions including surprise, curiosity, fascination and comfort while there were a few unpleasant emotions evoked such as Doubt and disgust.

Interpretive level: The most frequently selected meanings for the material were "imperfect," "unpredictable," "interesting," and "manufactured." (Figure 76)

Specific Questions: The rate about quality is positioned in the middle. The meanings of biodegradable and compostable stay strongly high. The rate of agedness has increased.

Performative level: The interactions are: pressing, rubbing, looking through, bending gently and smelling.

Sensorial level: The material is considered to be mostly hard, rough, matte, not reflective, ductile, irregular texture and fibred. The Strong, which was frequently mentioned by participants in the previous session(Day 1) was polarized because of the material's ageing.

Affective level: the emotions evoked by the material are predominantly situated within the unpleasant zone on the scale, indicating a substantial increase in negative emotions compared to the previous assessment.

Interpretive level: Imperfect, interesting, unpredictable and wabi-sabi were the most frequently chosen meanings (Figure 77).

Specific Questions: The results are similar to the MPT although the rate of quality leaned towards low.

MPT 2

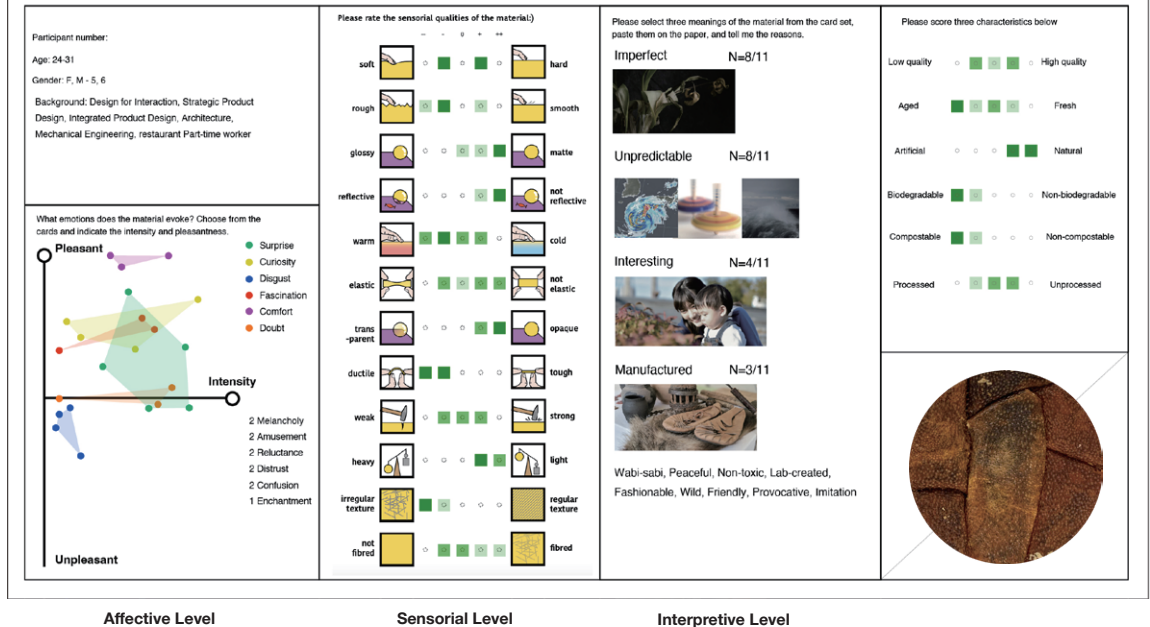


Figure 76. The test result of experiential characterisation of the mango pulp with thread (MPT) on teh Day 15

MPBF 2

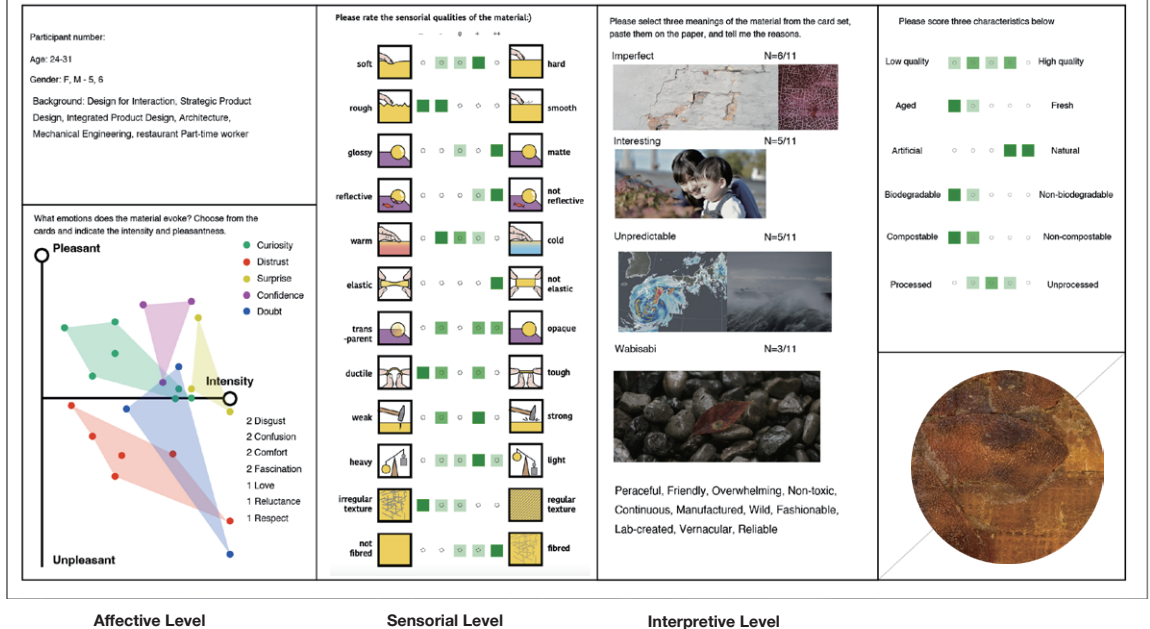


Figure 77. The test result of experiential characterisation of the mango pulp with banana fiber (MPBF) on teh Day 15

Interrelationship of the four experiential levels

The participants' reactions to both materials underwent a significant shift. In the updated version of maps on the right page, newly emerged words and disappeared words are highlighted in red. For both materials, "unpredictable" and "aged" have emerged at the interpretive level. Many participants commented that based on the observation of the transformation of colours and irregular patterns compared to the previous assessment, they now perceive the unpredictability of the materials' ageing properties. The meanings of unpredictability and age were associated with both positive and negative meanings.

Regarding the mango pulp with thread, the aged properties were perceived as disgust and fascination in the affective level (Figure 78). Most people interacted with the material with a positive surprise while there were 2 participants concerned about the strength of the material. One of them mentioned that they are now afraid of the material breaking down while wearing as a shoe. This suggests that the reference to biodegradability is not always perceived as positive. In addition to these findings, at the interpretive level, the image of a dried flower was frequently selected. One participant highlighted that this shouldn't be interpreted as a negative sign. They perceived the material as becoming more stable due to its matured colours. In contrast, during the previous assessment, the material had immature colours, leading participants to anticipate future changes.

Regarding the mango pulp with banana fibre, many participants interacted with the material with negative emotions such as doubt and distrust, although some retained a positive perception (Figure 79). Those who maintained a positive appreciation chose "wabi-sabi" at the interpretive level, embodying an attitude rooted in Japanese culture that embraces the natural changes and imperfections inherent in materials. It's noteworthy that despite the prevalence of negative reactions at the affective level, the material maintained a middle level quality. This is because of the existence of the fibre that reinsure to tie the orange peels together.

From this assessment, it became evident that the evolving features of the materials evoke the meaning of unpredictability, eliciting both fascination and disgust among participants.



Figure 78. The interrelationship between the four experiential levels of the mango pulp with thread(MPT) on the Day 15.

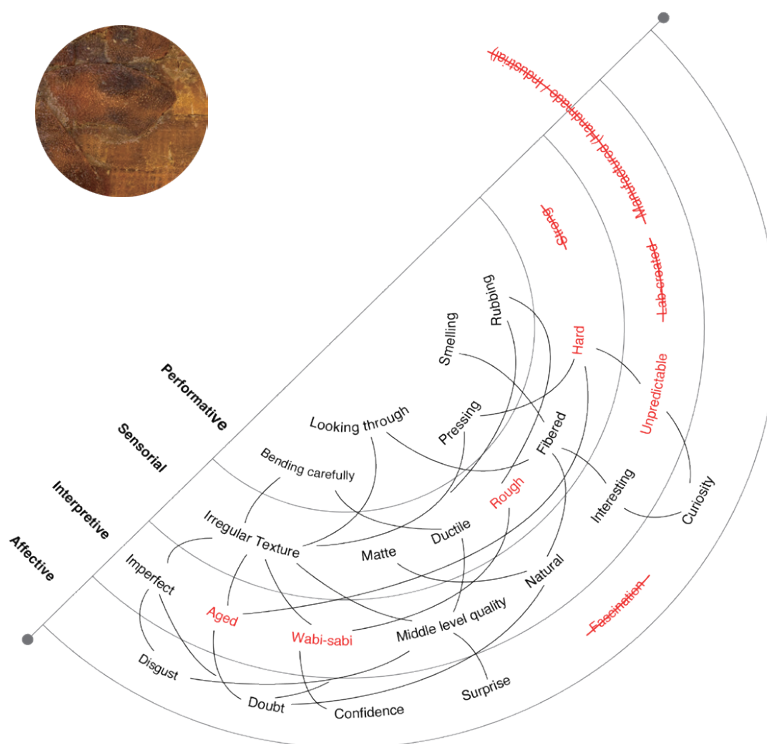


Figure 79. The interrelationship between the four experiential levels of the mango pulp with banana fiber (MPBF) on the Day 15.

Day 30

Mango Pulp with thread

Performative level: The interactions are: pressing, rubbing, folding, lifting and looking through, bending gently and smelling.

Sensorial level: The material is considered to be mostly hard, rough, matte, not reflective, ductile, irregular texture and fibered.

Affective level: Both pleasant and unpleasant emotions are almost evenly positioned on the scale of affective level. The word, amusement has newly emerged.

Interpretive level: Imperfect, wild, unpredictable and imitation were the most frequently chosen meanings (Figure 80).

Specific Questions: Agedness, Natural, biodegradable, compostable are strongly high. The quality and processed are slightly high

Mango Pulp with thread

Performative level: The interactions are: pressing, rubbing, folding, lifting and looking through, bending gently and smelling.

Sensorial level: The material is considered to be mostly hard, rough, matte, not reflective, ductile, strong, irregular texture and fibered. Additionally, hardness, is polarized, with some participants mixing up the ductility and softness.

Affective level: Both pleasant and unpleasant emotions are almost evenly positioned on the scale of affective level. The word, amusement newly emerged.

Interpretive level: Imperfect, wild, interesting and overwhelming were the most frequently chosen meanings (Figure 81).

Specific Questions: The rate of quality is low. Agedness, Naturalness, biodegradable., compostable are strongly high while processed are slightly leaning towards unprocessed.

MPT 3

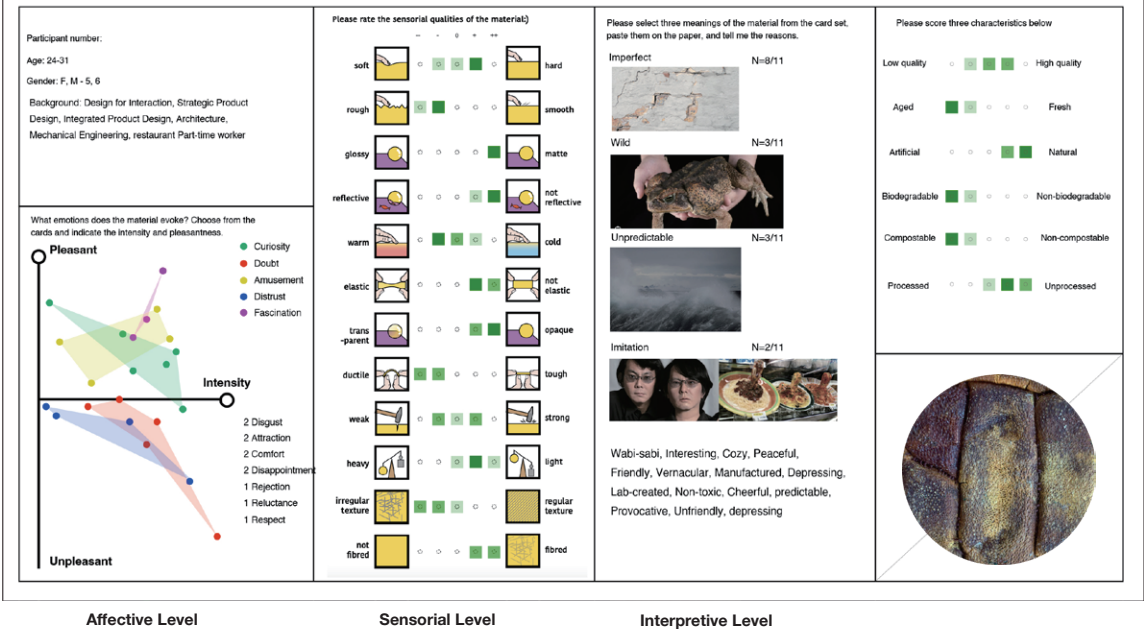


Figure 80. The test result of experiential characterisation of the mango pulp with thread (MPT) on teh Day 30

MPBF 3

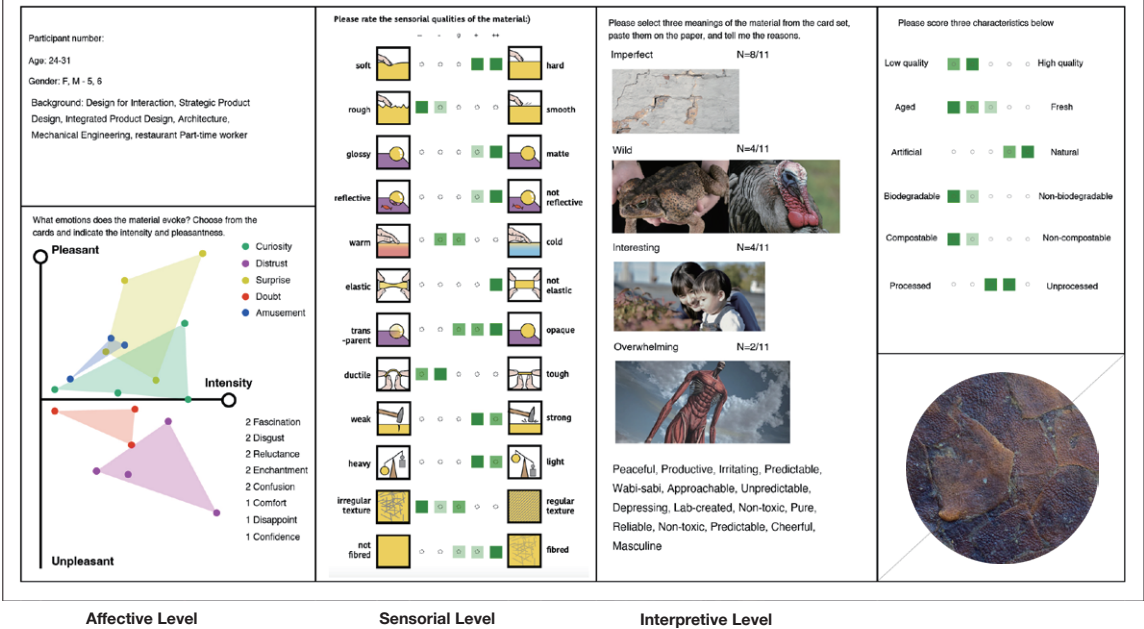


Figure 81. The test result of experiential characterisation of the mango pulp with banana fiber (MPBF) on the Day 30

Interrelationship of the four experiential levels

Overall, both materials triggered pleasant and unpleasant emotions almost evenly at the affective level with the newly emerged word, amusement. One participant found it amusing to uncover new features in the aged materials, particularly impressed by their ability to maintain flexibility and strength despite ageing. The biggest difference between the two materials in this assessment was that while the mango pulp with thread maintained middle-level quality, the mango pulp with banana fibre was perceived as low quality. This was attributed to the orange peel becoming less flexible with ageing, resulting in its peeling off when participants attempted to bend the material.

In the case of the mango pulp with thread, participants experienced a significant shift from pleasant to unpleasant emotions, including feelings of distrust and doubt (Figure 82). This shift was attributed to the irregular texture of the material, with participants noting the occurrence of yellow-coloured spots. The appearance of these bright yellow spots was counterintuitive for participants, as they had observed the material's colour darkening over time in the previous assessment. It is noteworthy that the ageing process elicited both positive and negative emotions. While the irregular texture was perceived negatively, the material's increased hardness instilled trust among participants regarding its strength. Interestingly, the emotion of trust was not included in the affective scale, but some participants commented on it during the session. Furthermore, at the interpretive level, the word "imitation" has newly emerged. Participants selected the image of an uncanny human-robot and noted that the material, once resembling leather, has now transformed into something else. The chosen image captures this transformation well.

Regarding the mango pulp with banana fibre, the negative emotions elicited have remained consistent since the last assessment: distrust and doubt (Figure 83). However, there has been a shift in pleasant emotions, with the emergence of the word "amusement." At the interpretive level, the word "overwhelming" has newly emerged, indicating that the peeling off of the orange peels overwhelmed participants (Appendix C). "Wild" was also selected at the interpretive level. One participant chose the image of a bird because the material resembled feathers. Finally, the material was considered to be low quality. Many participants mentioned that their perception of quality was based on both aesthetic and functional perspectives.

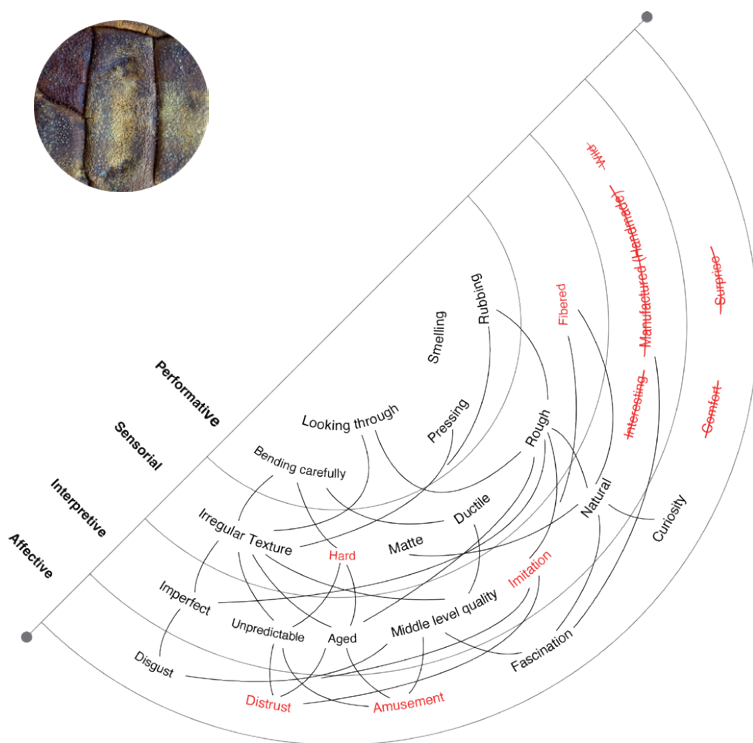


Figure 82. The interrelationship between the four experiential levels of the mango pulp with thread(MPT) on the Day 30.

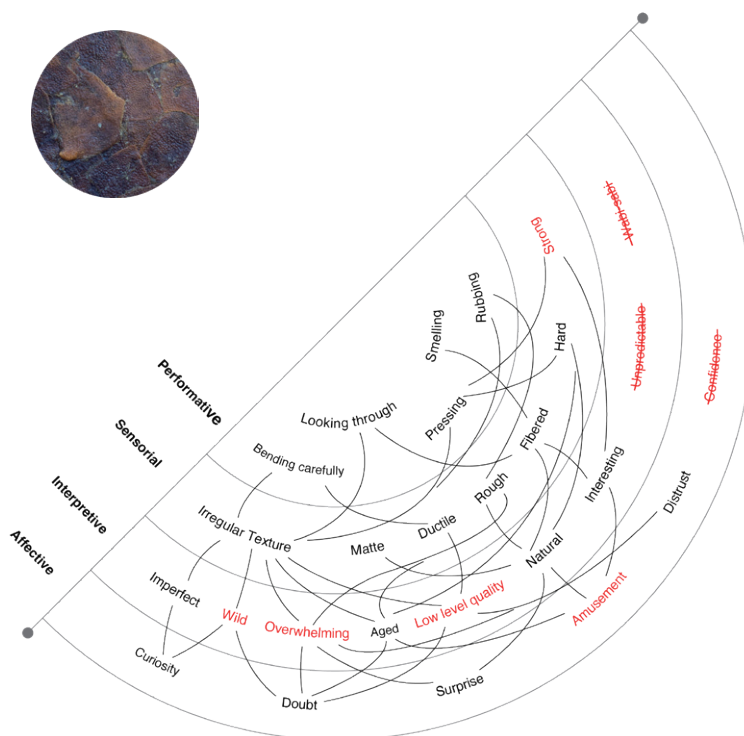


Figure 83. The interrelationship between the four experiential levels of the mango pulp with banana fiber (MPBF) on the Day 30.

3-2-6 Insight from the experiential characterisation

Throughout the three times of experiential characterisation involving 11 participants within the period of one month, some meaning-evoking patterns were recognised as follows.

1. The visual and tactile properties of naturalness including, fiberness and irregular texture play an important role in creating the meaning of interesting. This interestingness in general positively affects their emotions. On the other hand, the properties of naturalness evoked negative emotions such as doubt. This was especially prominent in the second assessment (Day 15) when they noticed the evolving nature of the materials.
2. Both materials successfully evoked the meaning of biodegradable and compostable. However, the explicit expression of biodegradability was negatively perceived by a few participants, especially after noticing the change in the visual and tactile properties in the second round (Day 15). They mentioned that they are afraid of the material breaking down while using the shoes.
3. Across the three assessments, the meaning "imperfect" was consistently selected for both materials. This suggests that imperfection may be a predominant characteristic associated with the materials.
4. The ageing feature of the materials appears to have a dual impact on participants' perceptions of quality, both positively and negatively. While the emergence of irregular patterns over time was not regarded positively from an aesthetic standpoint, the increase in hardness was viewed positively from a functional perspective.
5. The correlation between reflectiveness and naturalness was not prominent from the participants' comments although both are rated to be high across the three times of the test in both materials. From the observation in the tests, it can be concluded that they are not strongly related.
6. Participants assessed the quality of the materials based on both functional and aesthetic perspectives, which varied depending on individual preferences and the timing of the assessments. As a result, no clear patterns were extracted from the data.
7. Although their preference for two different materials has been varying throughout the period of one month, in the final assessment (Day 30), 9 participants preferred the mango pulp with thread over the one with banana fibre.
8. Despite the initial expectation that participants' perception towards the materials would be primarily determined by their aesthetic and functional qualities, it became evident that craftsmanship also played a significant role

in influencing their perception of quality. Many participants noted that the mango pulp with thread was perceived as higher quality due to the elaborate handmade stitch works, in contrast to the other material, which appeared to have randomly laid out fibres on the banana fibre.

3-3 Techcnal characterisation

One of the technical requirements during the material development phase was to ensure strength to resist tearing and ripping. However, as mentioned earlier, there was a concern regarding the mechanical strength of the material potentially evolving over time. Thus, tensile tests were conducted three times within the span of one month. This approach allowed for a comprehensive understanding of the strength of the material and facilitated comparison between the two different material concepts.

3-3-1 Tensile test

A tensile test, a widely used mechanical testing method, involves applying tensile (pulling) force to a material specimen and observing its response to stress(Figure 85).

Yield strength is the stress level at which a material begins to deform plastically(Figure 85). This is the point where non-uniform deformation initiates during a tensile test. Below the yield strength, materials adhere to Hooke's law, returning to their original shape once the stress is removed, and remaining within the elastic region, also known as elastic stiffness. However, when stress surpasses the yield strength, plastic deformation occurs. In such cases, materials cannot revert to their original shape once the load is removed. Plastic deformation preceding fracture is known as ductility. In this study, the ultimate strength and elongation are the most important factors to measure as they are relevant to the ripping.

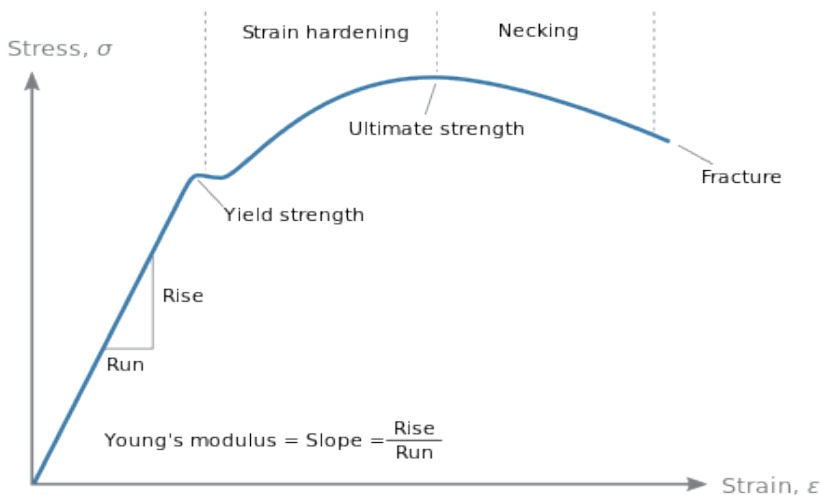


Figure 84. Stress-Strain curve. Adopted by https://en.wikipedia.org/wiki/Stress%E2%80%93strain_curve

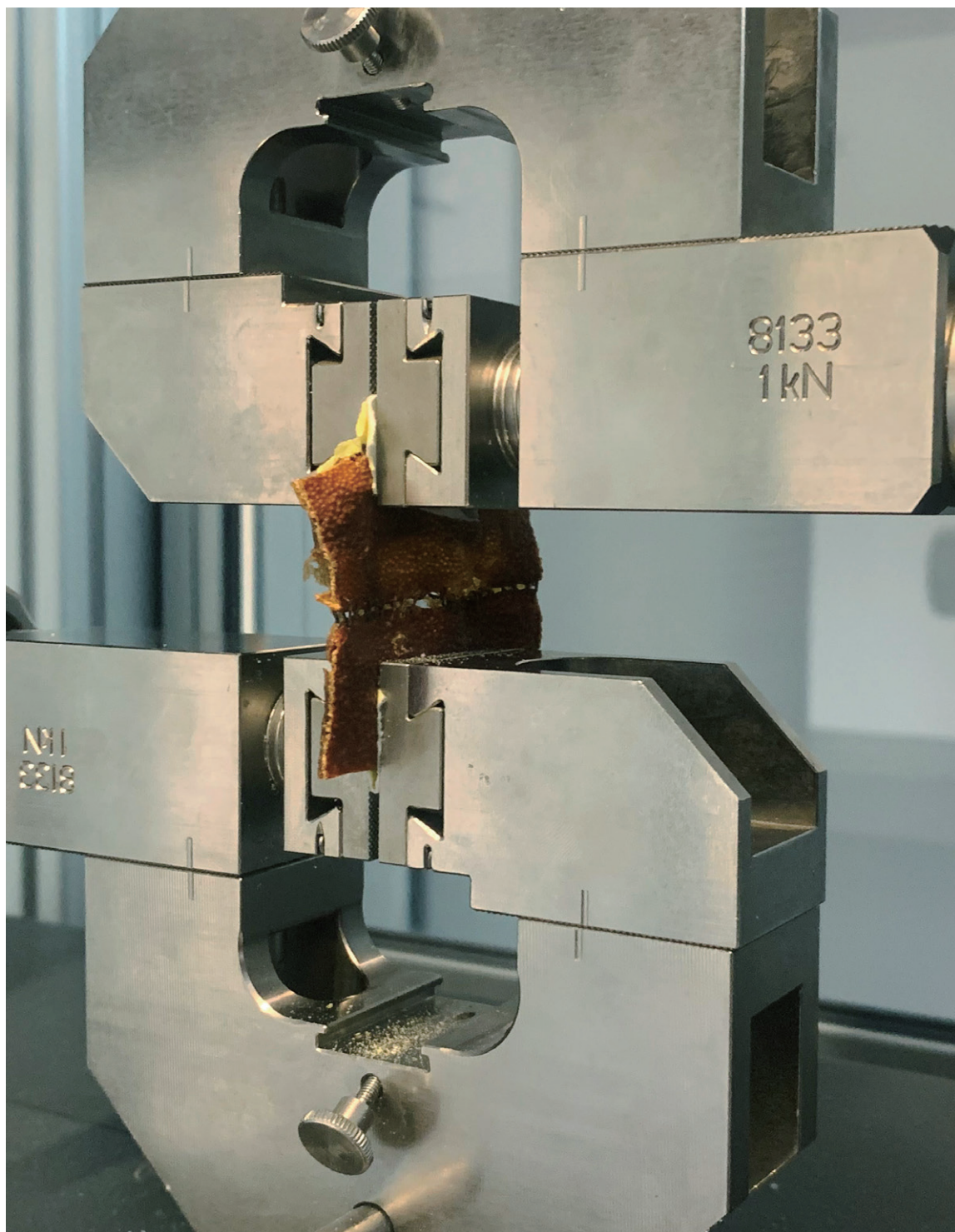


Figure 85. The itensile testing machine messuaring the mango pulp with thread (MPT)

3-3-2 Method

The test follows the ASTM D5034-09 Standard (Standard Test Method for Breaking Strength and Elongation of Textile Fabrics). The dimensions of the test specimen are adjusted to 20mm wide by 100mm long for mango pulp with banana fibre and, to 20mm wide by 60mm long for the mango pulp with thread. The crosshead speed is set at 1mm/min to ensure a slower change in load.

To observe the evolution of the tensile strength of both materials over the course of three tests conducted within one month, three sheets of each material were prepared simultaneously. This allowed for the measurement of the materials at ages 15 days and 30 days, enabling the examination of their ageing properties over time.

3-3-3 Samples

The tensile test was carried out with a total of two types of materials: Orange peel with mango pulp connected with banana fibre(MPBF), and orange peel with mongo pulp connected with threads(MPT). For the MPBF, 4 samples were cut in rectangular shape with a surface of 20 x 100mm(Figure 86). For the MPT, 4 samples were cut in rectangular shape with a surface of 20 x 60 mm. It should be noted that while the four samples within the same material group are not identical due to the inherent randomness in the arrangement of orange peels, they, however, had similar patterns of the orange peel placement.

	Construction	Number of samples	Dimensions (W, L, T)
(MPBF1-4)	Orange peel with mango pulp connected with banana fiber	4 samples	20mm x 100mm x 2mm
(MPT1-4)	Orange peel with mongo pulp connected with threads	4 samples	20mm x 60mm x 2mm

Table 3. 4 smaples for the each specimines of mango pulp with banana fiber(MPBF) and thread(MPT)



MPBF 1



MPBF 2



MPBF 3



MPBF 4



MPT 1



MPT 2



MPT 3



MPT 4

3-3-4 Result

Day 1

The tested specimens of the orange peel material connected with thread (MPT) and the orange peel material with banana fibre (MPBF) exhibited varied tensile strength in the Day 1 test (see Appendix A). The average stress-strain curves of the four samples for each material and tables of ultimate tensile strength and elongation are on the right page (Table 3, 4, Figure 87). The average ultimate tensile strength on Day 1 was 0.16 MPa for MPT, while for MPBF, it was 2.98 MPa. Compared to the recommended tensile strength of animal-based leather material for shoe uppers: 15MPa, both materials showed significantly weak properties.

Day 15

The tensile test conducted on Day 15 revealed a dramatic shift in the tensile strength of the orange peel connected with banana fibre, which measured 4.41 MPa. This phenomenon can be attributed to the ageing of the material, which results in an increase in its hardness. It was also observed that there was a dramatic decrease in the elastic region, indicating that the material was becoming more fragile. On the other hand, the orange peel material connected with thread exhibited an average tensile strength of 0.18 MPa, which is almost identical to the strength measured on Day 1, with a slight increase.

Day 30

To my surprise, the average ultimate strength of the orange peel material connected with banana fibre showed 1.84 MPa, which is even lower than on Day 1. This can be attributed to the separation of the orange peel layer and the banana fibre layer due to ageing. With respect to the orange peel connected with thread, the elongation area has doubly increased.

With respect to the orange peel connected with thread, the average ultimate strength is 0.26 MPa and the elongation area has doubled. This increase can be attributed to one of the four specimens having a shorter length but wider width, resulting in exceptional strength compared to the others (Appendix A).

	Day 1	Day 15	Day 30
Ultimate tensile strength (MPa)	2.98	4.41	1.84
elongation rate (%)	27.11	17.53	17.93

Table 3 . Average of ultimate tensile strength and elongation rate of MPBF across one month

	Day 1	Day 15	Day 30
Ultimate tensile strength (MPa)	0.16	0.18	0.26
elongation rate (%)	5.92	18.12	55.85

Table 4 . Average of ultimate tensile strength and elongation rate of MPT across one month

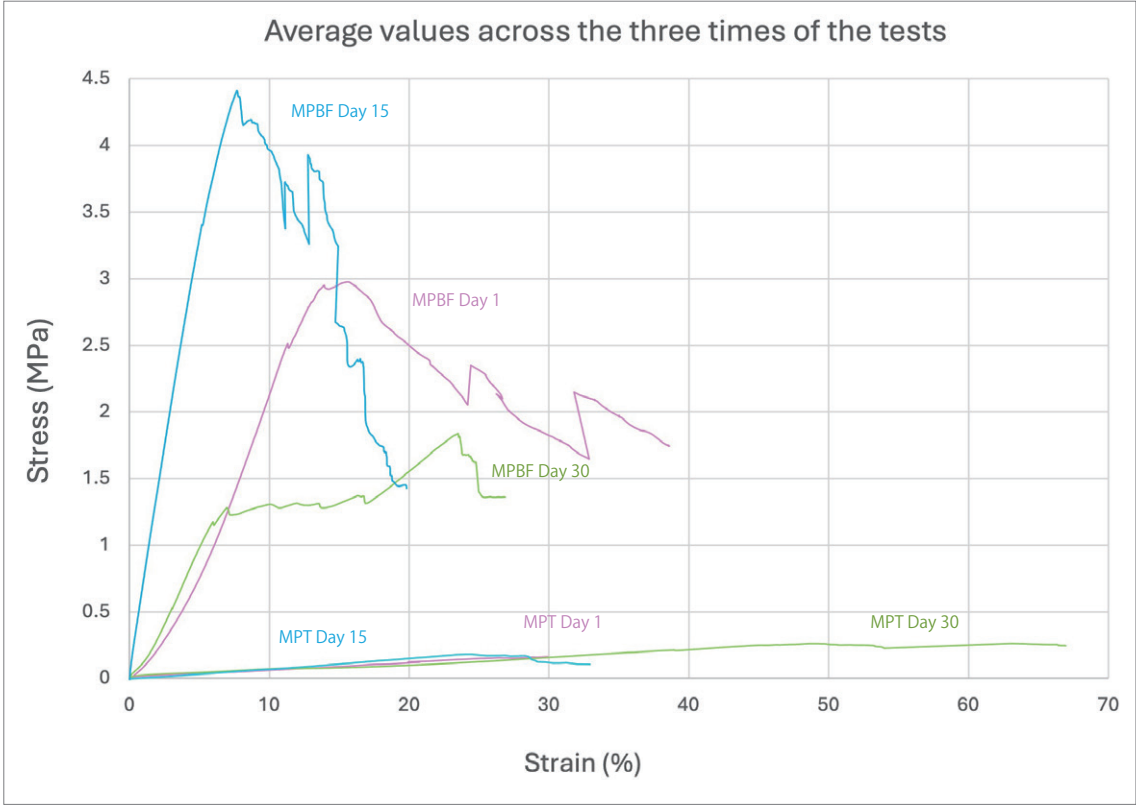


Figure 87. Average of stress strain curve across three times of the tests.

3-3-5 Deformation characteristics

For the mango pulp with thread (MPT), the break happens around the stitching area (Figure 88). Despite my expectation that the thread would tear first, it resisted the ripping. Instead, the orange peel surrounding the stitching exhibited breakage first. It can be attributed to the fact that the rim of the orange peel had become brittle and lost its elasticity(Figure 91). From the observation in the material development phase, it was noticed that the rim part of the materials is usually susceptible to dring out in both the orange peel upper material and mandarin sole material(Figure 91).

In the case of the mango pulp with banana fibre, the fibre orientation was aligned with the direction of the pulling force. Consequently, the fibre was pulled out first, followed by the breakage of the orange peel layer(Figure 89). However, it was incidentally discovered that the material exhibited higher resistance when the fibre was arranged in an angle-ply configuration as MPBF4 in figure 90(Figurte 90).

In the analysis of both materials, an occasional separation between the orange peel layer and the mango pulp layer was observed during breakage. This observation suggests a limited bonding ability between the layers.



Figure 88. Stress and strain curve on the Day 15



Figure 89. Stress and strain curve on the Day 15

Stress Strain Curve (MPBF4)

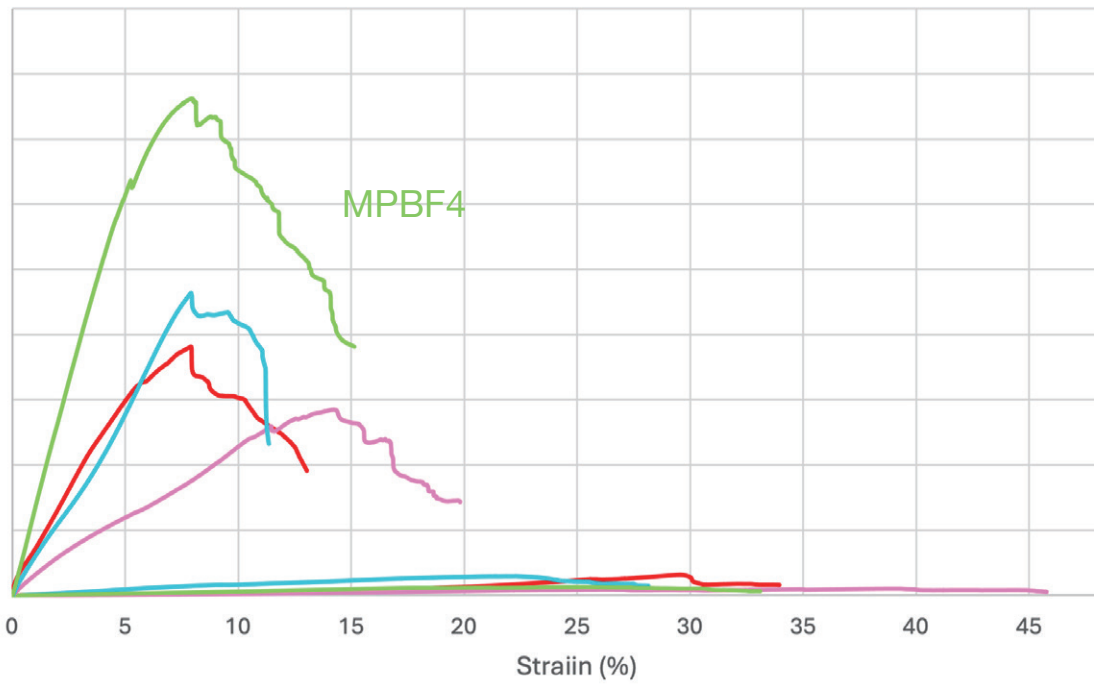


Figure 90. Stress and strain curve on the Day 15



Figure 91. The rim part becomes brittle leading the decrease of tensile strength

3-3-6 Insight of technical characterisation

Throughout the three tests, it is evident that the orange peel material with banana fibre exhibits a significant superiority in tensile strength (see Figures 92 and 93). On Day 1, its tensile strength is 19 times greater; on Day 15, it is 30 times greater; and on Day 30, it is 8 times greater. However, the material also displays unpredictability in its evolving features. The strength increased in the second round but decreased to even lower levels than the first round in the third round. This fluctuation is attributed to its susceptibility to drying out when exposed to air.

On the contrary, the orange peel material connected with thread has the ability to retain water inside, making it less prone to becoming brittle. This ultimately contributed to more stability in the strength compared to mango pulp with banana fibre. This phenomenon is also reflected in the elongation results. As depicted in Figure 94, the materials exhibited an increase in elongation while the counterpart decreased. It can be attributed to that the orange peel material connected with thread absorbs water in the air of the room. This was recognised in the observation by the author.

3-3-7 Correlation between the materials' mechanical strength and the participants' perceived quality

From the experiential characterisation on Day 15, it was found that the materials becoming harder because of ageing was considered to be an improvement in strength by participants. In fact, on Day 15, the ultimate tensile strength of the material increased dramatically. Although there needs to be a further experiment, there might be a correlation between the mechanical strength of the material and their perception of quality. However, throughout three times of the experiential characterisation, the participants explicitly mentioned that flexibility is the biggest factor contributing to their perception of quality. On Day 30, they rated the mango pulp with banana fiber to be of low quality, and its elongation had indeed decreased compared to Day 1 and 15 (Figure 94). Thus, the correlation between the material's flexibility and consumers' perceived quality seems possible.

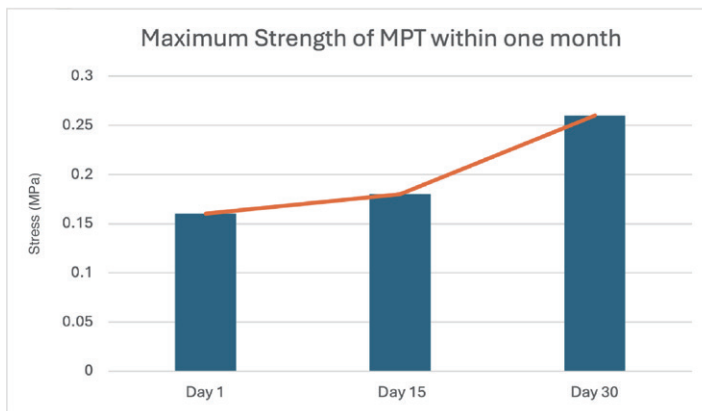


Figure 92 Maximum Strength of the average value of mango pulp with thread across one month

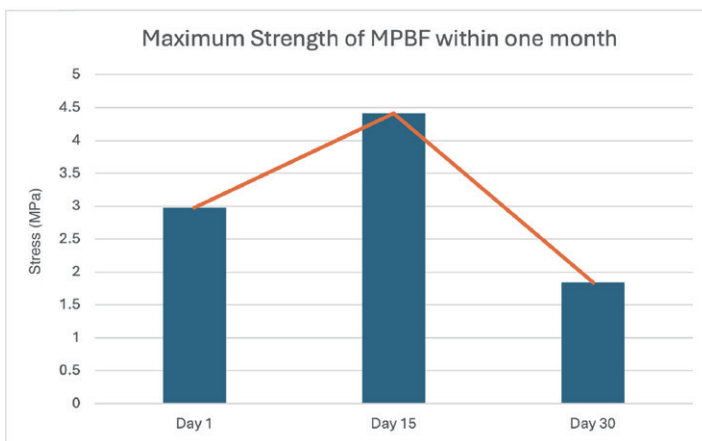


Figure 93 Maximum Strength of the average value of mango pulp with banana fiber across one month

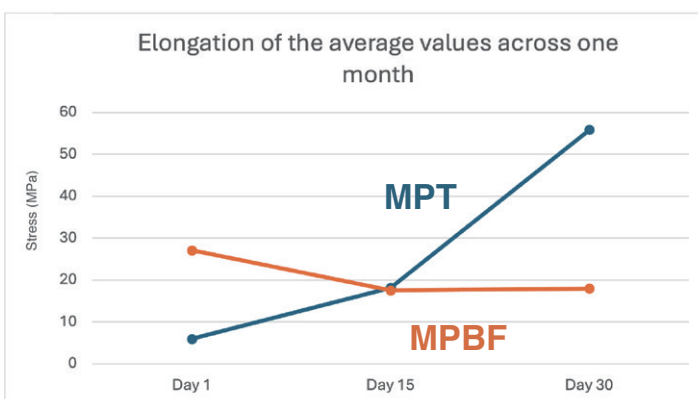


Figure 94 Maximum Strength of the average value of mango pulp with banana fiber across one month

3-4 Tinkering

Tinkering with the developed material was conducted by the author to get a first-hand experience of the material. The main objective of this activity is to discover the points that should be considered in the next design phase. The findings of this activity are as follows.

1. The rim area of an orange peel is susceptible to drying out and becoming brittle, even if it's covered by mango pulp to prevent water from escaping. This is the reason why usually the cracks occur in the rim area of dried orange peel. This brittleness of the rim area affects the flexibility of both materials. While the rim area of the mango pulp with thread (MPT) is hidden between the connection gaps, resulting in less brittleness, the rim part of the mango pulp with banana fibre exposes some areas to the air, leading to brittleness(Figure 95). From first-hand experience, it was clear that the mango pulp with thread has significant superiority in flexibility.
2. The stitching line of the mango pulp with thread (MPT) sometimes contributes to the occurrence of cracks. This is because the presence of a stitching line allows the material to bend more easily along a certain axis, while other parts of the orange peel lack stitching lines in that direction. Consequently, the bending force becomes concentrated in areas without stitching lines, leading to the occurrence of cracks(Figure 95). The positive aspect of this finding is that even when cracks occur, the inner layer of solidified mango pulp holds the orange peel together and blocks the holes.

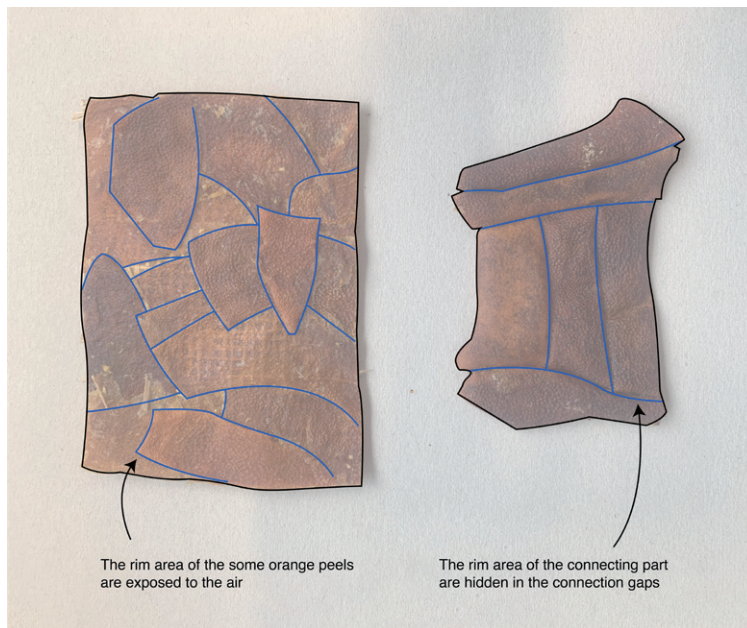


Figure 95 The rim of some orange peel are exposed in the mango pulp with banana fiber (MPBF) while the rim

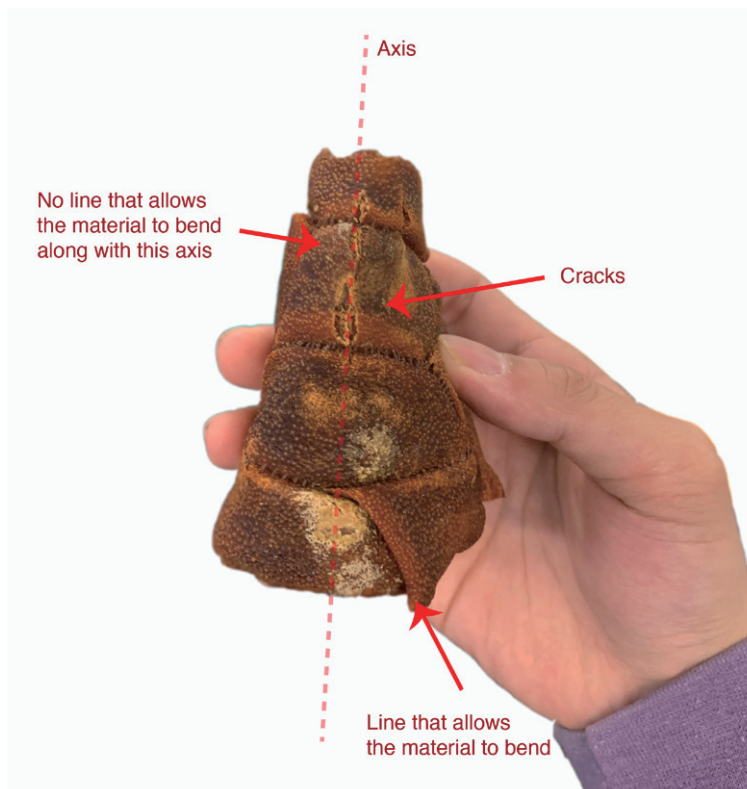


Figure 96 The absence of the bending axis cause unwanted cracks

3-5 Selection of the material for the upper part

The two material concepts were compared based on their technical and experiential characteristics to determine which one is more desirable for the final prototype. This evaluation is regarding the unique qualities of each material as well as how they have evolved over time.

For the experiential qualities, overall they have a number of commonalities: evoking the meaning of natural, biodegradability, and compostability. This is triggered by their sensorial properties including roughness, irregularity. In terms of the experiential characterisation of Day 1, they didn't have explicit superiority. However, as time passed, the differences between the two materials became prominent. While both materials evoked positive surprise by their flexibility, the mango pulp with banana fibre exhibited the peeling off of orange peel which dramatically decreased the participants' perceived quality. This was reflected in their selection of "Overwhelming" in the interpretive level of their experiences. In the end, on Day 30, the mango pulp with thread maintained its middle-level quality in their perception, the mango pulp with banana fibre was rated as low quality.

Regarding the technical quality, the mango pulp with banana fibre showed significant superiority in tensile strength thanks to the banana fibre. However, its strength fluctuated over time showing its unpredictability. Compared to it, the mango pulp with thread has more stability.

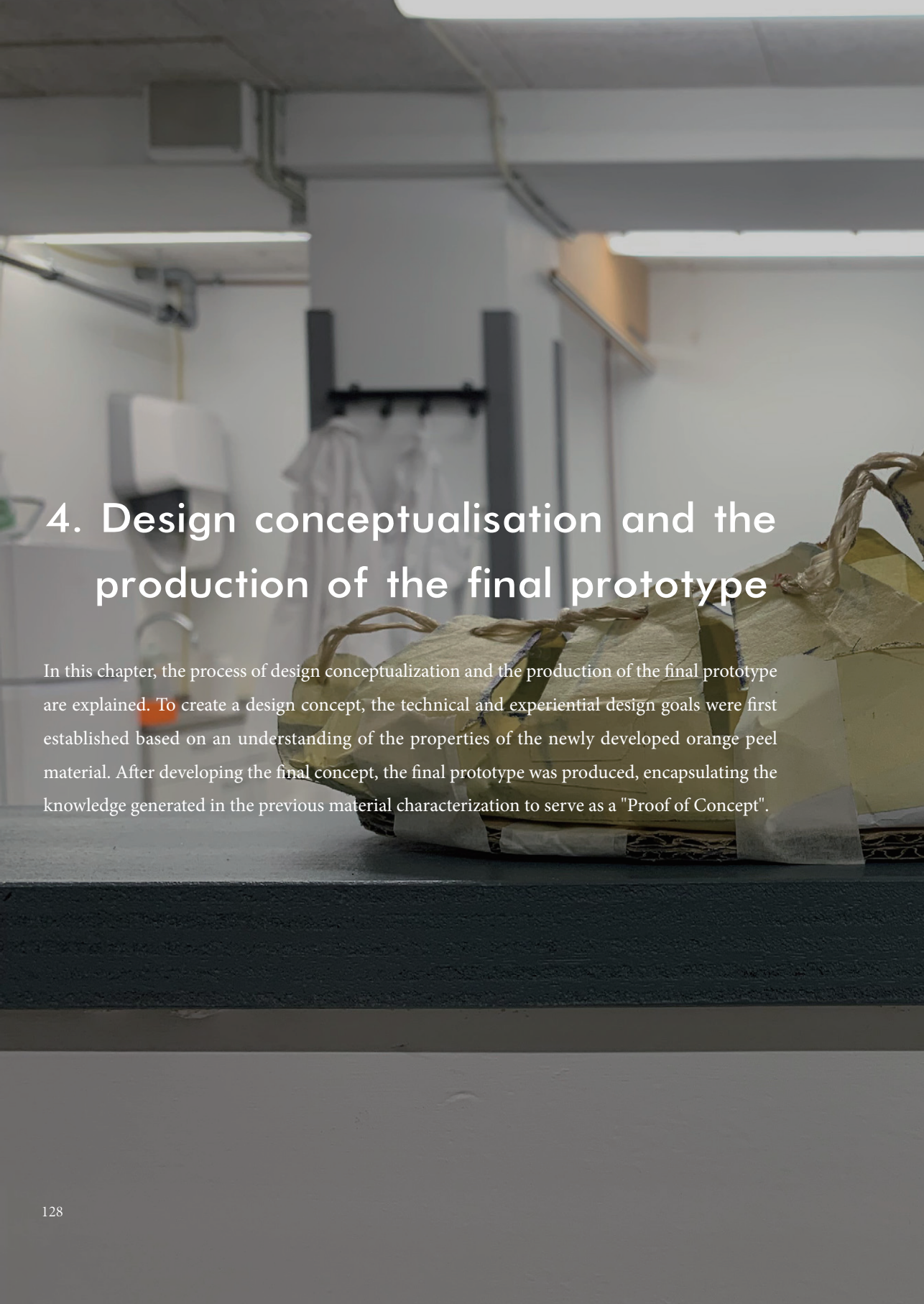
It is interesting to note that although objectively, the quality of the mango pulp with banana fibre is higher quality in the sense of its tensile strength, because of the peeling off of orange peels, it was not considered to be higher quality in the end.

Based on the findings above, it is evident that the mango pulp with banana fibre has considerable drawbacks in experiential quality, making it too problematic to ignore. Although it has better tensile strength, the negative experiential aspects are too significant to justify favouring this material based solely on strength. Therefore, for the further development of the final prototype, the mango pulp with thread was chosen as the upper material.

3-6 Meaning-evoking pattern of the mango pulp with thread(MPD)

In this chapter, a comprehensive assessment of the two material concepts was conducted through technical and experiential characterizations, as well as tinkering, over the course of one month. To conclude this chapter, the insights gained from this phase are integrated into the meaning-evoking pattern of the mango pulp with thread as follows.

1. The material's connecting method of stitching creates an image of craftsmanship that contributes to people's perceived quality
2. The irregular colour caused by the ageing evoked negative emotions such as distrust and disgust. It also evoked the meaning of unpredictability. This unpredictability is perceived as both positive and negative depending on the person. While some people found it to be exciting, other people commented that this is worrisome.
3. The aged material results in hardening the material which is positively perceived by people because they think it improves the overall strength of the material. However, inflexibility resulting from too much hardness evoked the meaning of low quality. This indicated that when exceeding a certain point of hardness, this turns out to be negative.
4. Having the balance of hardness and flexibility not only evoked the meaning of high quality but was also interesting. This is due to the comparison with normal orange peel that gets dried and becomes hard. This indicates the "processed yet unprocessed" intrigues viewers
5. Although the irregularity of patchwork evoked the meaning of interesting, the regularity and continuity were desired to make the material look high quality
6. Biodegradability was recognised by people yet there is concern about the shoes breaking down during their use of shoes.
7. Positive surprise was one of the frequently answered affective quality across three times of the tests. It is attributed to its sensorial properties. including irregular and rough texture, strength, ductility.



4. Design conceptualisation and the production of the final prototype

In this chapter, the process of design conceptualization and the production of the final prototype are explained. To create a design concept, the technical and experiential design goals were first established based on an understanding of the properties of the newly developed orange peel material. After developing the final concept, the final prototype was produced, encapsulating the knowledge generated in the previous material characterization to serve as a "Proof of Concept".



4-1 Design goal

Before diving into the design conceptualisation, the experiential and technical design goal were set separately.

For the experiential one, the focus was to connect the meaning-evoking pattern of the material with the shape of shoes. As mentioned previously, the meaning of material/product is generated not only through the material properties but also the relationship between the material and the product including its shape and function. By manipulating the shape of the shoes in such a way that the material's advantage in its experiential properties is fully expressed, it is possible to achieve the experiential vision of communicating its biodegradability while maintaining its perceived quality. If potential downsides of the experiential properties of the material, such as evoking a perception of low quality, are recognized, the shape of the shoes can be manipulated to compensate. For instance, if the material's irregularity evokes a perception of low quality, creating regularity in the shape of the shoes can help mitigate this perception.

For the technical design goal, the knowledge gathered in the literature review and material characterisation were integrated. By considering the desired characteristics of shoes and the technical constraints the newly developed material has, the realistically achievable technical goal was generated.

4-1-1 Mapping meaning-evoking pattern

The meaning-evoking pattern gained in the material characterisation was mapped in order to grasp their interrelations as follows.

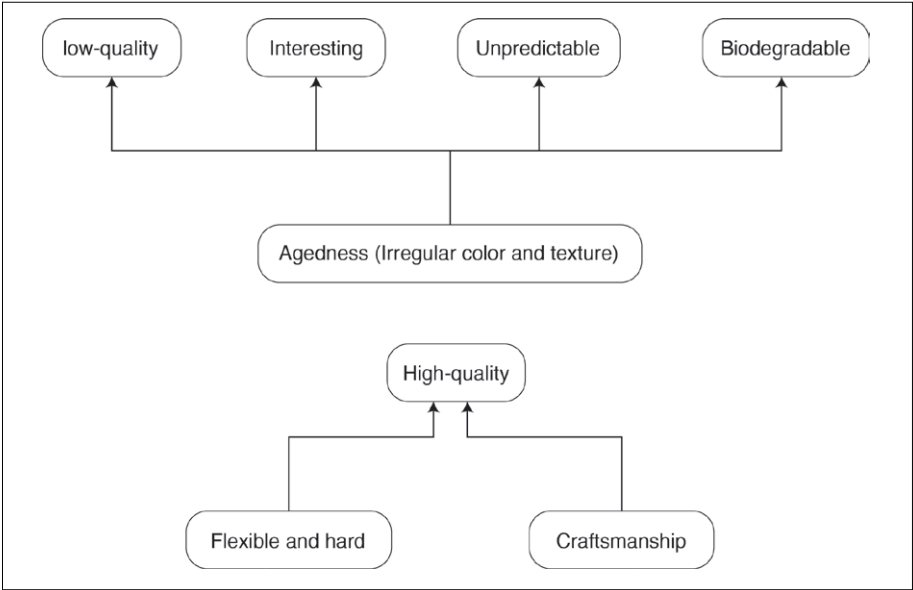


Figure 97. Map of meaning-evoking pattern

As you can see in Figure 97, the irregularity of the material evokes the meaning of interesting and biodegradable which the material experience vision required to achieve. However, it also evoked a negative meaning, low quality which had been expected to occur from the literature review. On the other hand, the meaning of high-quality was also evoked by the material's flexibility and hardness as well as the craftsmanship of the patchwork.

4-1-2 Design strategy for better experience

Based on the mapping, the author conducted the ideation of the strategy. The objective of this phase is to develop a strategy that minimises the negative meanings evoked by the material while maximising the positive ones through design. The outlined strategy is as follows.

1. Regularity: The irregularity of colours and textures evoked the meaning of low quality. Thus, the design should add regularity in the design to decrease the generation of the negative meaning.
2. Processed yet unprocessed: People find the material to be interesting when recognising that the material looks unprocessed visually yet the tactile property shows it was modified artificially to meet specific function. Thus, the design should add artificial elements to make the material more interesting.
3. Flexible and hard: The material showed its flexibility and hardness at the same time which evoked the meaning of high-quality because it functions as a shoe material. Thus, the design should represent its flexibility with its shape.
4. Craftsmanship: The patchwork of the material was found to be high-quality because it was associated with craftsmanship. Thus, the design should evoke the meaning of a hand-made production process.

Based on the design strategy outlined above as well as the material experience vision formulated in chapter 1, the experiential design goal of the shoe was generated as follows.

Experiential Design Goal

The life style shoes should communicate biodegradability and compostability through its naturalness. It also should have continuous and regular visual and tactile elements to evoke the meaning of high quality. The patchwork should also evoke the meaning of craftsmanship that evokes the meaning of high quality. At the same time, the ageing properties should be kept intact so that the consumers can enjoy how the material evolves over time. Additionally, the fact that the material manages to hold flexibility and hardness should be communicated through its shapes.

4-1-3 The constraint of the mango pulp with thread

In order to define the technical design goal of the final shoe design, the technical constraints are reviewed as follows.

1. Based on the tinkering with the material, it was observed that unintended cracks are likely to occur when the stitching lines are not aligned with the same bending axis. Therefore, deliberate placement of the stitching lines is necessary to ensure the intended bending direction.
2. Based on the tinkering, the material can bend easily in one direction. However, when attempting to bend it simultaneously in two directions, its rigidity became apparent. Thus, the shape of shoes should be designed to accommodate this unidirectional bending characteristic while minimizing stresses associated with bending in multiple directions.

Based on the design strategy outlined above, the literature review on human foot, as well as the technical constraints of the developed material, the technical design goal of the shoe was generated as follows.

Technical Design Goal

The lifestyle shoes should protect the foot from roughness encountered while walking and standing, while also providing protection for the upper part of the human foot against cold, thorns, and insect bites. Flexibility is also crucial, allowing the shoe to bend naturally at the points where the human foot bends. This necessitates deliberate placement of the stitching lines. Furthermore, the shoe design should allow space for the toes to splay, enhancing wearer comfort. Ankle movement during walking should remain uninhibited by the shoe design.

4-2 Image exploration of shape of shoes

After setting the design goals, an image exploration of shoes took place. The aim of this exploration was to investigate shoe shapes that exist on the market or have been proposed by artists, which align with the design strategy defined by the author earlier, such as "processed yet unprocessed" and "craftsmanship."

This exploration consisted of two phases. The first phase was diverging, where different possibilities of shoe shapes were reviewed. In the second phase, footwear that incorporated structural elements of Carbatina was explored.

4-2-1 Diving possible shoe designs

The plant-based sculptures by Christopher Guinet



Figure 98 The plant-based sculptures by Christopher Guinet.
The left image. Adopted by <https://www.designboom.com/art/christophe-guinet-grow-nike-sneakers-plants-flowers-11-02-2014/>
The right image. Adopted by <https://www.designboom.com/art/monsieur-plant-sneakerium-10-22-2019/>

The images above are the sculptures of Nike shoes that are composed of natural elements that grow themselves (Figure 98). Although these shoes are not functional, they illustrate an intriguing concept: the fusion of natural properties with artificial elements, resulting in visually appealing and high-quality designs. For example, the combination of wood textures with vibrant red shoelaces, or the juxtaposition of soil textures with the iconic Nike swoosh logo, creates a captivating contrast. This phenomenon resonates with the findings from the experiential characterization of the orange peel material, where participants perceived the material as high quality when it evoked the concept of "processed yet unprocessed."

SYNERGY MULE - White by Peterson Stoop



Figure 99 SYNERGY MULE - White by Peterson Stoop. Adopted by <https://petersonstoop.com/products/patchwork-mule>

These shoes are crafted from upcycled materials primarily sourced from Nike Air Force and Stan Smith shoes (Figure 99). This design showcases the fusion of regular and irregular elements, contributing to its overall appeal. Despite the seemingly random placement of upcycled materials, the dominant white colour scheme creates a sense of cohesion in the design, ultimately evoking the perception of high quality.

NOACA-one-piece-Slippers by Naoko Hirota



Figure 100NOACA-one-piece-slippers by Naoko Hirota. Adopted by https://www.biennale2010.citedudesign.com/GB_expo_international.php

This slipper is crafted from a single piece of sheet, showcasing both flexibility and hardness simultaneously(Figure 100). The design highlights the material's ability to create shape itself, emphasizing its hardness characteristics. Furthermore, the visual of one continuous surface increases the perception of high quality.

CARBATINAE - SHOES OF THE ROMANS by Romer Shop



Figure 101 CARBATINAE - SHOES OF THE ROMANS by Romer Shop. Adopted by <https://www.der-roemer-shop.de/Carbatinae-Shoes-of-the-Romans>

According to the Romer Shop website, the company that produces these shoes, this footwear belongs to a shoe type known as "carbatina" (plural: carbatinae)[78]. They explained that carbatinae are characterized by a one-piece construction of leather and were prevalent in the Roman Empire, continuing to be used until the first millennium AD(Figure 101). This shoe communicates the fact that the shoes consist of one piece of leather expressing the flexibility of leather. Additionally, the shape of the shoes accommodates the leather material to bend in the direction it naturally can. This design feature allows the material to cover the upper part of the human foot while avoiding the breakage of the material caused by the concentration of force in a specific area.

78 Carbatinae - Shoes of the Romans - The Romans. (n.d.). Carbatinae - Shoes of the Romans - the Romans. <https://www.der-roemer-shop.de/Carbatinae-Shoes-of-the-Romans>

4-2-2 Reflection

From this exploration, it was observed that certain shape-material relationships can be manipulated to evoke specific meanings or emphasize specific material properties. These patterns align with the findings of the literature review as well as the experiential characterization of the orange peel material.

For the upcoming design conceptualisation, the shape of the carbatina was chosen as a base model to be explored. The idea was to get inspiration from the structural elements of the Carbatina and come up with a new design that would fit with modern lifestyle.

4-2-3 Converging possible shoe designs (Carbatina)

From the last image exploration, the Carbatinae was chosen as a base model for the further design conceptualisation. The purpose of the second image exploration was to understand how modern shoes can incorporate elements from ancient footwear. By gathering images of modern shoes that use similar designs—material wrapping around the sole and extending over the upper part with laces—we can create designs tailored to modern lifestyles.



Figure 102 NIB Coach Laceup Ballerina Sneakers. Adopted by <https://poshmark.com/listing/NIB-Coach-Laceup-Ballerina-Sneakers-6432d0d317e49c01f8f74658of-the-Romans>



Figure 103 THE LILT by ISSEY MIYAKE X UNITED NUDE . Adopted by https://milled.com/united-nude/issey-miyake-x-united-nude-the-lilt_xATPNkfil-xL53A



Figure 104 Mens Slip On Sport Shoe by Brand FOGGY. Adopted by <https://www.limeroad.com/grey-mesh-foggy-p19335093>



Figure 105 KI ecobe footwear by G.D. Kim. Adopted by <https://www.designboom.com/design/ki-ecobe-footwear-shoe-06-20-2017/>



Figure 106 Shoes with an Expiration Date by Laura Muth. Adopted by <https://www.yankodesign.com/2021/03/25/constructed-like-lego-these-modular-shoes-are-made-entirely-from-compostable-materials/>

4-2-4 Insight from the image exploration of Carbatina type of footwear

1. Through this additional image exploration, it was observed that the parts extending over the upper part of human foot doesn't entirely cover the whole foot (Human foot, specially upper parts are exposed to the air). This design feature offers the advantage of enabling easy bending of the foot during walking.
2. However, a potential drawback is that it may not provide complete insulation for the upper part of the foot. It's clear that while the shoe's shape appears simple and primitive, incorporating geometric shapes into the design could add a modern aesthetic to the footwear.
3. Some shoe designs have incorporated consistent rhythmic geometric shapes to the upper covering part (the part that extends over the upper part of the foot) such as KI ecobe footwear by G.D. Kim (Figure 105). It gives a modern impression in contrast to the spontaneous organic shapes that are often considered to be hand-crafted.

4-3 Sketching and mock-up-making for the final concept

Based on the insight from the previous image exploration about the shoes that have incorporated a similar structure to the Carbatina, three shoe design ideas were developed. This process involved sketching and creating paper mock-ups. While sketching is an effective way to visualise the overall impression of what I've conceived, it lacks technical feasibility. Thus, mock-up-making was conducted to define the design details. Kraft paper was chosen as the mock-up material due to its flexibility, similar to the orange peel material connected with thread (MPT).

4-3-1 Ideation

Idea 1

This design idea incorporated regular geometric shapes into the upper covering part to give a modern impression(Figure 107). Among the three ideas, this looks the most modern because of this.



Figure 107. Paper mock-up and sketch of Idea 1

Idea 2

This design idea incorporates 11 slits in the upper covering parts, minimizing the gaps between them and enhancing insulation compared to Idea 1(Figure 108). However, a drawback of this concept is that the shoe loses its flexibility while walking due to increased rigidity in the upper part.



Figure 108. Paper mock-up and sktch of Idea 2

Idea 3

This design idea draws inspiration from the shape of the ancient Carbatina, featuring a wide opening in the upper part(Figure 109). While it lacks insulation for the upper part, it allows for easy bending during walking, making it the most flexible among the three ideas. Also, the shape accentuate the impression of hand-crafted. However, the shape seemed too detached from modern lifestyle to the author. It was concerned that the combination of this shape with the orange peel material might evoke a meaning of low quality beyond just historical references to ancient footwear.



Figure 109. Paper mock-up and sketch of Idea 3

4-3-2 Selection of the design idea

Each idea was evaluated based on the technical and experiential design goals defined previously. For the technical design goal, a wear test with the paper mock-ups was conducted by the author(Figure 110). From the evaluation, the following findings were obtained.

1. While the Idea 2 has the best insularity, it offered the worst bendability
2. While the Idea 3 has the best bendability in walking, the opening of the upper part exposed the human foot to the air completely
3. In terms of the balance between the insularity and the bendability, Idea 1 shows the best performance.
4. Idea 1 gives the impression of being modern the most, followed by Idea 2 and 3.

Based on the findings, Idea 1 was selected as the final design. Considering that the orange peel material connected with thread (MPT) already evokes the meaning of craftsmanship, which contributes to the perception of high quality, it was decided that there is no need to choose a shape that may be associated with hand-crafting. Thus, the shape of Idea 3 was excluded from the option. In accordance with the design strategy defined earlier: "Regularity" and "Processed yet unprocessed", by combining the geometric shape of Idea 1 with the orange peel material, it is possible to evoke the meaning of high-quality as well as interesting.



Figure 110. The sole part made of card board was attached to the paper mock-ups and worn by the author

4-4 Desinging the patchwork pattern of shoes

The goal of this phase is to conceptualise the patchwork pattern that improves the consumer's negative perception towards the orange peel material while creating the meaning of interesting. To achieve this, the design strategy defined earlier, "Regularity" and "Processed yet unprocessed" were followed. Regarding "Regularity", a consistent geometric patchwork pattern compensates for the meaning of low quality caused by the irregular colour and texture. In terms of the "Processed yet unprocessed", the contrast between the naturalness and artificial element of impression creates the meaning of interesting.

In the end, the regular patchwork pattern in Figure 111 was conceived. Although this pattern was intended to give an impression of consistency, it turned out that it is also optimal for the material to bend along with the shape of the human foot.

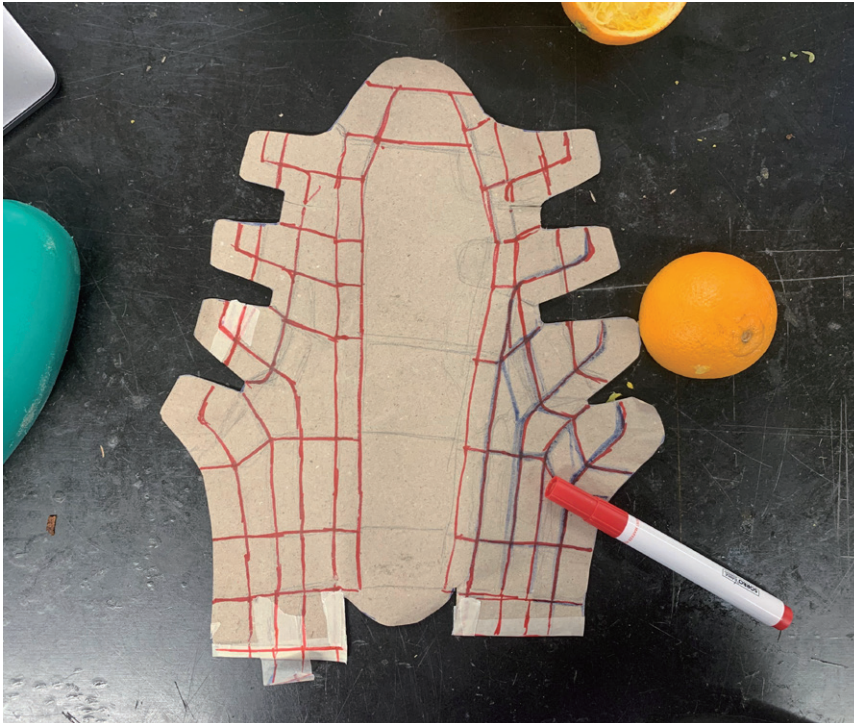


Figure 111 Ideation of patchwork pattern

4-5 Production of the final prototype (proof of concept)

The final prototype of the upper part was produced based on the sketch, paper prototype, and patchwork sketch(Figure 112). To achieve the two-sided orange peel texture, two finished orange peel sheets in the same shape were overlaid in such a way that the inner sides of the materials hide each other. The sole part was also created with the mould (Figure 113).

Figure 114 shows the lateral view of the final prototype. The design expresses the naturalness of the newly developed orange peel material through its irregular colour and texture while maintaining regularity with consistent patchwork which was intended to evoke a message of high-quality. This combination of the naturalness of the material and the regularity of the shape of the product creates interestingness. Additionally, the shape, which references the carbatina, communicates the functionality of wrapping around your foot, showcasing the flexibility of the material. This further enhances the perception of the material as interesting.

When wearing the shoes, despite the rigidity of the material, you can feel the flexibility thanks to the upper part opening. It allows the shoe to bend at the same point the foot does when walking. Additionally, since the shoe is essentially one piece of material wrapping around your foot, wearers can adjust how tightly they want it to fit, allowing them to create space for their toes to spread according to their preferences.



Figure 112 Production of the shoe upper



Figure 113 The production of shoe sole



Figure 114. Lateral view of the final prototype





5 Evaluation and Conclusion

In this chapter, the result of the final evaluation and conclusion of this project are presented. To understand how well the prototype functions as shoes and how consumers perceive its aesthetics, the on-site evaluation was conducted with 8 participants. The participants were asked to wear the prototype and walk on three different surfaces: flat floor, rough ground and staircase. The finding from this evaluation lead the discussion and final conclusion of this project.



5-1 Evaluation of the shoes

The on-site evaluation of the shoes was conducted with 8 participants (male: 2, female 6). The aim of this evaluation was to assess how well the final prototype achieved both experiential and technical design goals. Each evaluation session lasted 40 minutes. The evaluation process was as follows:

1. Participants wore the shoes and walked on three different surfaces: flat floor, uneven ground, and stairs, to simulate different environments and usage scenarios.
2. Participants completed a questionnaire focusing on the comfort, functionality, and aesthetics of the shoes (Appendix D).

As described in the previous chapters, the prototype was designed based on the knowledge generated from the literature review and material characterization. The newly developed orange peel material was expected to evoke a sense of naturalness and interest due to its inconsistent visual and tactile properties. The shoe design was conceived to maximize these advantages. This evaluation aimed to determine whether people could understand the sustainability aspect of the shoes appreciate the natural pattern, and, if so, explore the reasons behind their perceptions. Additionally, in this evaluation, the context in which they want to wear the shoes was investigated. Through the research and design conceptualisation phase in this study, the material and product aspects of the material experience were explored while the contextual aspect was left untouched. Therefore, the contextual aspect was investigated in the test to gain a comprehensive understanding of how and where participants envisioned using the shoes.



Figure 115. The participants walk on the test surface with the shoes

5-2 The result of the evaluation

Overall, the participants' reactions to the prototype were positive, with many expressing their appreciation for its fidelity. One participant noted that the shoes' fidelity exceeded their expectations. The test results for each theme—comfort, functionality, aesthetics and the context of use—are described in the three tables that follow.

Comfort

	Very Poor	Poor	Normal	Good	Very Good
How comfortable are the shoes while walking on flat ground?	☐	☐	☒	☒	☒
How comfortable are the shoes while walking on rough ground?	☐	☐	☐	☒	☒
How comfortable are the shoes while ascending and descending stairs?	☐	☐	☐	☒	☒

Overall, the participants' perceptions of comfort were positive, though their reasons varied. One participant mentioned that the opening of the upper part contributed to breathability, while another remarked that the hardness of the sole provided stability while walking. The most common response, however, was that the structure of the shoe, which wraps around the foot from the sole, resulted in a good fit that conformed to the shape of the foot. This indicates that the wrapping structure of the shoe accommodates individual variations in foot shape, improving the functional aspect of perceived quality.

On the other hand, negative concern was also brought up. As the sole is thin, when they climb up the stairs, they find the distance between the shoes and stairs to be longer than their expectations. This suggests that they might need some time to adjust to the design of the shoe.

Functionality

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Do you feel the durability of the shoes should be improved?	☐	☐	☒	☐	☐
Do the shoes have enough space for your toe to spread out?	☐	☐	☐	☒	☒
Is the shoes easy to put on and take off?	☐	☒	☐	☐	☐
Do you feel the protection of sole part of your foot should be improved?	☐	☒	☐	☐	☐
Do you feel the protection of upper part of your foot should be improved?	☒	☒	☐	☐	☐
Overall, functionality of the shoes should be improved	☐	☒	☐	☐	☐

Overall, the functionality of the shoe was also perceived positively. The most frequent remark was that it takes time to put them on and take them off. Putting on the shoes requires tightening the lace hole by hole, which requires some level of concentration. As the material looks natural, they are afraid of breaking it and can't tighten the lace with one pulling. Additionally, one participant commented that the lace holes should be positioned deeper, as they were concerned about the potential breakage of the holes.

Regarding the overall functionality of the shoes, participants did not have any particular thoughts. However, one participant mentioned that they would like to wear the shoes barefoot but were concerned that their feet would get sweaty.

Aesthetic

	Strongly disagree	Disagreeee	Neutral	Agree	Strongly agree
Can you imagine you wearing the shoes in your daily life?	☐	☐	☐	☒	☒
Do you feel the shoes are biodegradable?	☐	☐	☐	☒	☒
Do you feel the shoes are compostable?	☐	☐	☐	☒	☒
Do you want to convey your self-image as environmentally conscious with the shoes?	☐	☐	☐	☒	☒
Do the shoes makes you look unique or interesting	☐	☐	☐	☒	☒
The material of the shoes has potential to transform its colors and texture over time. Will you be able to enjoy it?	☐	☐	☐	☒	☒
Do you feel shoes are high quality?	☐	☐	☐	☒	☒

The perception of aesthetics was surprisingly positive. All participants answered that the shoes look biodegradable and compostable. They also answered that they feel the shoes are high quality. One participant mentioned that the geometric patchwork of the orange peel material feels industrial and professional hence high quality. This proves that geometric consistent patchwork contributes to consumer's perception of high quality.

Regarding the question about the ageing properties of the shoe material, participants had positive views. Their reasons were mostly rooted in curiosity, although three participants mentioned that the ageing properties added a storytelling aspect that attracted them. One participant noted that this feature made the shoes a good conversation starter.

In terms of their motivation to purchase the shoes, the most common answer was the unique appearance, followed by environmental friendliness.

Context of use

The contexts in which participants wanted to wear the product varied from inside the house to outdoor activities. The most common responses included outdoor settings such as the beach, city, nature, parties, and gardening. Many participants associated the appearance of the shoe with sandals and envisioned using them during the summer. None mentioned wanting to use the shoes during winter.

This indicates two things. First, the aesthetic attributes have a strong connection with warm environments where participants engage in various activities, including but not limited to walking on both flat and rough ground. Secondly, participants have some level of trust in the durability of the shoes, as the contexts they mentioned are not limited to environments where they have to be careful about shoe breaking.

Aside from the general answers above, one participant noted that they wanted to use the shoes when giving a presentation to their manager. This participant is engaged in the sustainability transformation of the company they currently work for. They remarked that they always wear sustainable fashion items when trying to convince their managers to direct the company towards sustainable business practices despite the possibility that the manager doesn't notice. This participant mentioned that they want to wear the shoe to express and share the value they have about a sustainable lifestyle.

5-3 The final assessment based on the design goal

In this section, assessment of how well the final prototype achieved both the experiential and technical design goals set in the previous chapter takes place. To do so, each of them is broken down into small elements to be discussed.

5-3-1 Experiential Design Goal

1. Evoking the meaning of biodegradable and compostable

All participants agreed that the prototype look biodegradable and compostable.

2. Evoking the meaning of high-quality by continuous and regular visual and tactile elements

The consistent geometric patchwork were associated with professionalism and industrial manufacturing that evokes the meaning of high-quality

3. Evoking the meaning of craftsmanship that eventually evokes the meaning of high-quality

By adopting the consistent geometric patchwork, the shoes appear less hand-made. Although participants were amazed by the prototype's high fidelity, this was because they acknowledged that the prototype was made by the author, not necessarily because the design conveyed an impression of craftsmanship. It became clear that adding consistent elements to the material while holding craftsmanship was a difficult goal to achieve.

4. Keeping aging property for consumers to enjoy the transition

Participants enjoy the ageing property of the material such as inconsistent colors throughout the material. They also expressed positive views towards these properties, showing curiosity about how the material would change over time.

5. Communicating flexibility and hardness of the material through its shape

During the test, it was frequently observed that participants were amazed by the flexibility of the material. One participant even noted that the material is more flexible than conventional leather. Regarding hardness, participants felt that the upper part of their foot was well-protected. While it is difficult to say if this result solely came from the material itself or the shape of the product, my observation suggests that their perceptions of flexibility and hardness were more influenced by the material itself, as they did not clearly attribute these feelings to the product's shape.

5-3-2 Technical Design Goal

1. Protecting the foot from roughness while walking and standing

Participants clearly mentioned that the sole part of the shoes is hard enough to walk on rough ground.

2. Protecting the upper part of the human foot against cold, thorns and insects bites

In the questionnaire, participants answered that they feel upper part of their foot is protected. Also, one participant mentioned that the material has good insulation. On the other hand, five participants brought up their concerns about the opening part. Because of this opening, participants noted that the shoes are not durable for winter use. Thus, the goal of protecting against cold wasn't achieved.

3. Bending naturally at the points where the human foot bends

It was observed that the shoes are bent at the same point the human foot does. The participants also mentioned that the shoes achieved flexibility that allowed them to climb up stairs without being worried about falling.

4. Allowing a space for toe to splay

For this goal, participants' answers in the questionnaire ranged from strong agreement to neutral. Overall, they confirmed this goal. One participant noted that the wrapping structure of the shoes allows them to adjust to different foot sizes, enabling them to create a preferred amount of space between the shoes and their foot.

5. Uninhibit ankle movement during waking

For the Dorsiflexion-plantar flexion and Abduction-Adduction, the shoes perfectly support their movements without causing any disturbance. However, as the shoe has a narrow shape compared to the sneaker, participants felt that the Inversion-Eversion movement wouldn't be as smooth. If the wearer has to run with shoes, stability might be compromised.

5-4 Discussion

In this section, the experience of wearing the shoes, the functionality of the shoes, and the material properties are discussed based on the findings from the final evaluation and the author's observation of the prototype. This discussion will illuminate the positive and negative points of the material and shoes, as well as possibilities for improvement.

Experience of wearing shoes

Overall, the participants' perception towards the prototype was as it was intended. The prototype was successfully perceived as biodegradable and compostable while holding the meaning of high quality. In the Experiential Characterization phase, the newly developed orange peel material raised concerns that it would break down while being worn on the foot. However, this concern wasn't raised in this final test, proving that the negative association towards the naturalness of the material was compensated by the shape of the shoes. They also reacted positively to the fact that the material has ageing properties. This was not the case in the Experiential Characterisation. This can be attributed to the fact that the prototype of the shoes is crafted professionally, and participants are reassured about the durability of the shoes. Overall, the shoes were perceived as high-quality based on both functional and aesthetic aspects.

Their positive reaction was not only about the upper part of the orange peel material. It was observed frequently that participants were impressed by the flexibility and hardness of the sole. They mentioned they felt the soles of their foot were protected and insulated from temperature of ground.

Functionality of shoes

Although the design of the shoes was not intended for running, it was seen that the shoe didn't support their ankle movements fully because of the narrow shape. Many participants were trying to be careful and walk gently so as not to break the prototype even though they didn't mention it. That indicates there is a need to improve the durability of the shoe and communicate it through its shape.

In this project, cushioning was not included in the primary design goals. However, after the final evaluation, it was found that the low height of the outsole, which lacks cushioning, requires some adjustment time for those who usually wear sneakers. Thus, adding a midsole layer can be considered. One way to achieve this is by adding a new layer of orange peel material. As the orange peel can retain flexibility and softness when it is not directly exposed to air, it is possible to pile orange peels between the upper and outsole parts to create cushioning ability.

After the creation of the final prototype, it was also found that the shoe had water-repellent ability (Figure 116). The orange peel material itself is waterproof, but due to the stitching areas that contain some gaps, describing the shoe as water-repellent is more accurate.



Figure 116. The shoes showed the water-repellent ability

Material property

Regarding the strength of the material, overall, the upper material showed sufficient durability, although breakage of a hole for the shoelace was observed. This was due to the tensile stress that occurred when bending the foot during walking. However, aside from this issue, no other breakages, such as ripping, were observed. The breakage of the hole can be addressed by increasing the margin around the hole or adding another layer of orange peel material around the rim. As described in the technical characterization, the strength of the material was measured as 0.16 MPa on Day 1, 0.18 MPa on Day 15, and 0.26 MPa on Day 30, which is significantly weaker compared to the tensile strength of animal-based leather used for shoe uppers, which is around 15 MPa. However, since the material consists of two sheets of orange peels tied together, it is expected that load bearing capacity is doubled not the strength. To improve the tensile strength of the material even further, adding banana fibre can be considered. By sandwiching a banana fibre layer between two layers of orange peel material, the tensile strength can reach 2 to 4 MPa based on the results of the MPBF (orange peel material combined with banana fibre) in the technical characterisation.

During the test, it was found that a small crack occurred in the toe part of the shoes. The tensile stress during walking tends to concentrate in this area. Additionally, the material is flexible in one direction but not in two directions simultaneously. However, the shape of the toe part requires the material to bend three-dimensionally, which also contributes to the cracking. To address this issue, adding more connecting areas can be considered. As mentioned in the chapter of material characterization, the stitching part provides a degree of freedom. Therefore, adding a new stitching line will allow the material to be more flexible, avoiding the concentration of tensile stress in the orange peel part.

5-5 Final Conclusion

In this project, the aim was to design a pair of biodegradable shoes that reveals the story of sustainability through its aesthetics. To achieve this goal, materials with aesthetic attributes of naturalness were developed, and their ageing properties were characterized both technically and experientially.

Regarding the technical aspect, the tensile strength of the materials was investigated over one month. From this study, it was found that on Day 1, the orange peel connected with banana fibre (MPBF) showed 19 times greater strength than the orange peel connected with thread (MPT): 2.98 MPa and 0.16 MPa respectively (See Table 5 and 6). By Day 15, the strength of each material had increased by factors of 1.5 and 1.1 respectively. At this point, the ageing property of the materials seemed positive as it indicated they were becoming stronger over time. However, on Day 30, this optimistic view was completely shattered. The orange peel connected with banana fibre showed a decrease by a factor of 2.3. This fluctuation can be attributed to its brittleness. On the other hand, the orange peel connected with the thread increased by a factor of 1.4. Yield strength of the material. Additionally, the changes in yield strength in the two different materials were also recognised. On Day 1, the Yield Strength of the orange peel connected with banana fibre (MPBF) was 0.12 MPa whereas the counterpart was 0.04 MPa. This indicates that orange peel connected with thread is easier to deform permanently. It can be attributed to the property of the thread that doesn't go back to the same position once it's pulled. From Day 15, the Yield strength of the orange peel connected with banana fibre is increased by a factor of 27 while the orange peel connected with thread is decreased by a factor of 2. On Day 30, however, the orange peel connected with banana fibre was decreased by a factor of 22, going back to the almost same number as Day 1. For the orange peel connected with thread, the Yield strength was the same as on Day 15.

Regarding the experiential aspect of the material, in the material characterisation phase, it was found that both materials successfully communicate their biodegradability and compostability in exchange of their perception of quality. The meaning of agedness was evoked through the sensorial properties of both materials: irregular colour and texture. To mitigate the association of low quality caused by the agedness, in the final design concept, the geometric consistent patchwork was adopted. In the final evaluation, this patchwork design increased the participants' perceived quality as well as evoked the meaning of interesting and unique.

Overall, the design goals and the material experience vision defined in this project were achieved except for two points: protecting the upper part of the human foot and uninhibited ankle movement during walking(partially achieved). Those two aspects are related to the design of the shoe shape. The first issue can be addressed by adding shoe tongue in such a way that it maintains the flexibility of shoes. For the second point, adding a wider shape to the shoe sole can solve the problem.

	Day 1	Day 15	Day 30
Ultimate tensile strength (MPa)	2.98	4.41	1.84
elongation rate (%)	27.11	17.53	17.93
Yield strength (MPa)	0.12	3.25	0.15

Table 5 . Average of ultimate tensile strength, elongation rate and Yield strength of MPBF across one month

	Day 1	Day 15	Day 30
Ultimate tensile strength (MPa)	0.16	0.18	0.26
elongation rate (%)	5.92	18.12	55.85
Yield strength (MPa)	0.04	0.02	0.02

Table 6. Average of ultimate tensile strength, elongation rate and Yield strength of MPT across one month

5-6 Limitation of this study

The limitations of this study are the following.

-The span of the material characterisation-

In this project, the material characterisation was conducted within one month see how the mechanical and experiential properties of the material evolve over time. However, it is ideal to take a longer period for a thorough investigation.

-Author's shoe-making technique-

As the author has not been trained as a professional shoemaker, the possibility of designing the final prototype was dependent on his limited handcraft technique. There should be a better shape to represent the newly developed material

-Manufacturability-

The final design of the shoes and its production method requires handcrafting skills. Although this study emphasizes the naturalness of the shoes, it does not provide insights into how they can be manufactured industrially.

-Demographics of the participants in the final evaluation-

Due to the time constraint of the project, only one pair of shoes was produced. Consequently, the participants in the final evaluation were limited to those who could fit the size of the prototype including six female participants and two male participants.

5-7 Recommendation

-Investigating feasibility and viability of the product -

The next step of this project involves investigating the viability and feasibility of the product as a business owner. For viability, several questions arise: How can orange peels be sourced? What are the costs associated with transporting orange peels to the factory? What brand strategy can be implemented to create the narrative that wearing sustainable fashion items is equal to being fashionable?

As for feasibility, considerations include: How can the orange peel material be produced using industrial automated machines? Is there a way to improve the water retention ability of the material?

-Improving the design of shoe shape-

The final evaluation revealed that the shoe lacks support for the Inversion-Eversion movement fully. To address this, a wider shape of shoe soles can be considered.

-Investigating further material experience-

The ageing property of the material leads to colour transformation, characterized by sudden dark and white dots. Typically, these aspects evoke negative associations among consumers. How can we mitigate these effects? I'd like to delve deeper into the causes of these transformations."

-Investigating the correlation between the experiential and mechanical properties of the material-

During this study, the correlation between the tensile strength of the material and the consumer's perceived quality was recognised in the orange peel connected with banana fibre. It is ideal to further investigate correlations in both two material concepts.

-Improving the mechanical strength of the orange peel material-

It goes without saying but the strength of the developed material needs to be improved. The current method to connect orange peels with thread is quite susceptible to ripping. It is necessary to find a way to increase the strength.

6-1 Reflection

In this section, I'd like to briefly reflect on my thesis project.

The goal of creating a biodegradable material that can communicate its sustainability was the foremost important objective for me personally, and I am quite pleased with the outcome of the material development. It requires non-linear thinking in which you have to understand the situation moment by moment with your intuition based on the observation of consequences you make through the creations. It is safe to say that it was also quite challenging as there is no reassurance of when you can finish it and move on to the next step of material characterisation. However, this experience reinforced my belief that you should never give up till you achieve the goal you want to see.

Regarding the technical and experiential characterisation, I found those activities quite useful for gaining a comprehensive understanding of the material. However, I've also learned that you have to be purposeful in choosing those activities. Without specific motivation or reason, there is a possibility of blindly following the approaches for the sake of being systematic. In the case of my thesis project, ripping and breakage were the concerns for the shoe material and I adopted a tensile test for investigation. Although I still believe that was the best possible option for me at the time, I wish I could spend more time considering other options.

Given that the project spanned from material development to the creation of shoes, which is quite broad for a thesis project from my understanding, it was challenging to spend too much time on specific aspects. As a designer who emphasizes aesthetics, I wish I could have had more time to refine the final design of the prototype.

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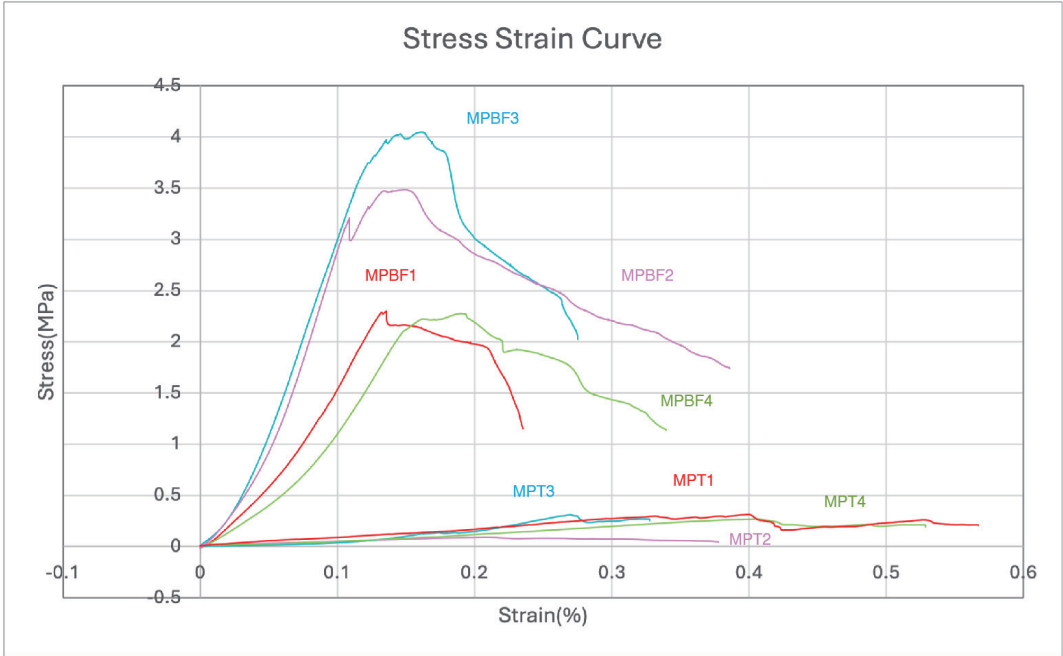
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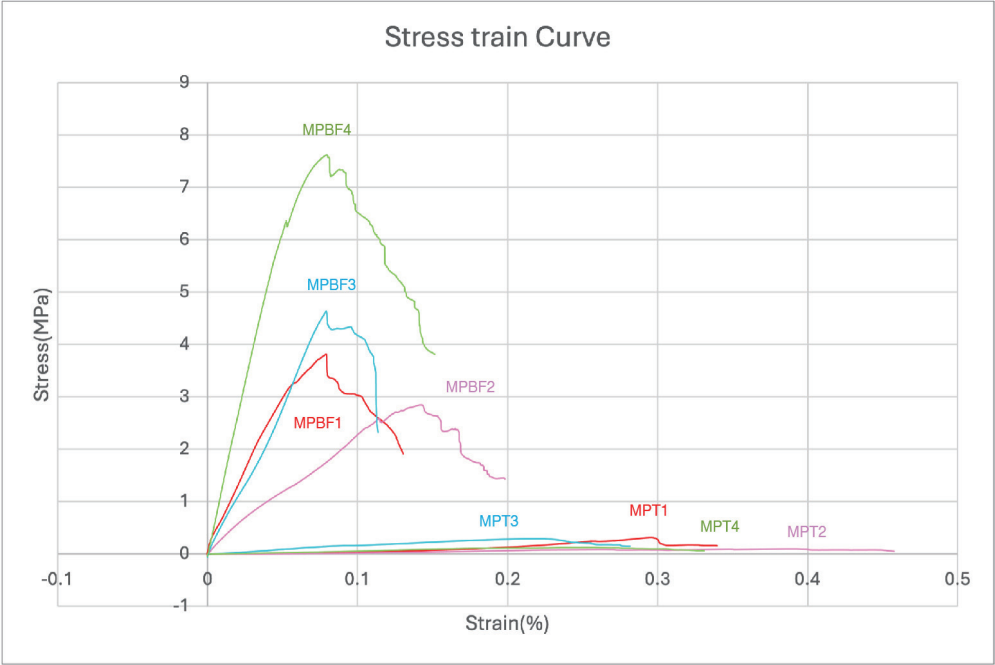
Appendix A

Day 1



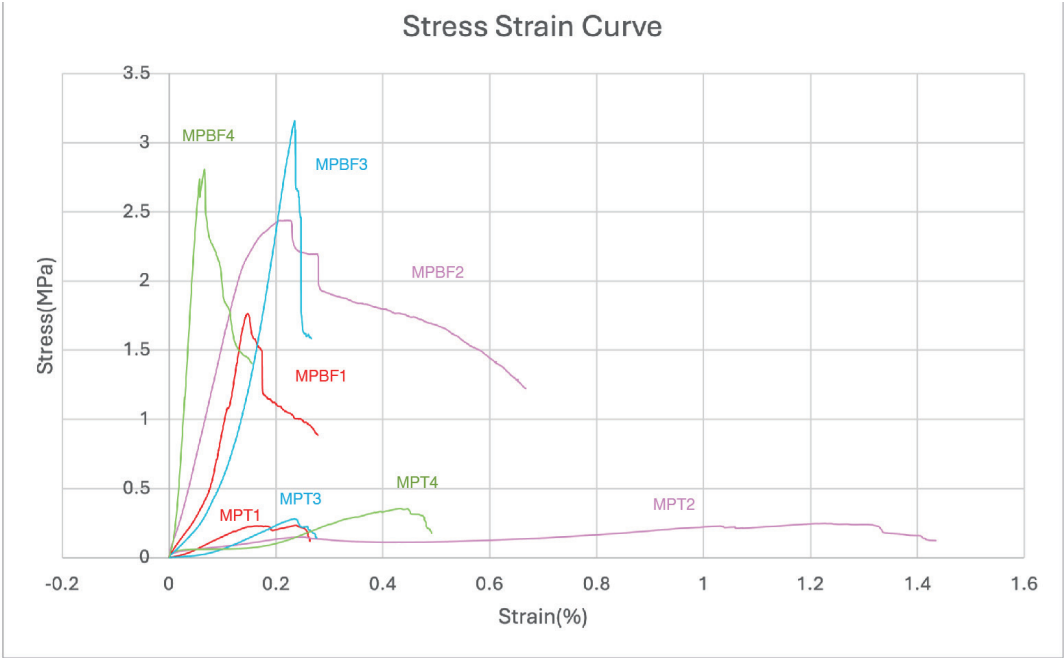
	Young Modulus (MPa)	Yield Strength(MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
MPBF1	12.33	0.66	2.30	13.92
MPBF2	15.57	0.40	3.48	27.55
MPBF3	13.21	0.18	4.05	11.62
MPBF4	8.52	0.51	2.28	20.41
Average value of MPBF	12.41±2.93	0.44±0.20	3.03±0.88	18.35±7.18
MPT1	0.90	0.09	0.31	35.02
MPT2	0.54	0.25	0.09	29.53
MPT3	0.28	0.02	0.31	8.56
MPT4	0.62	0.02	0.27	13.52
Average value of MPT	0.59±0.26	0.10±0.11	0.25±0.11	21.66±12.63

Day 15



	Young Modulus (MPa)	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
MPBF1	100.56	0.57	3.82	11.23
MPBF2	29.09	0.74	2.85	14.84
MPBF3	53.17	1.21	4.64	7.36
MPBF4	132.97	5.48	7.63	20.52
Average value of MPBF	78.95±46.68	2.00±2.34	4.74±2.06	13.49±5.60
MPT1	0.23	0.01	0.31	8.55
MPT2	0.22	0.02	0.10	21.13
MPT3	1.76	0.02	0.29	20.28
MPT4	0.54	0.01	0.12	12.24
Average value of MPT	0.69±0.73	0.02±0.01	0.21±0.11	15.55±6.15

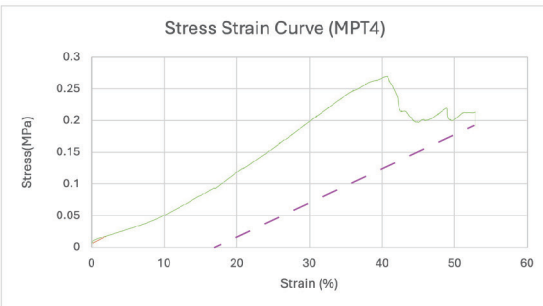
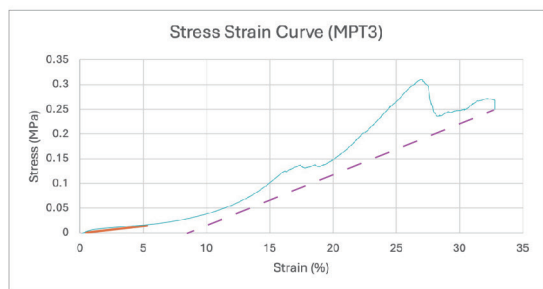
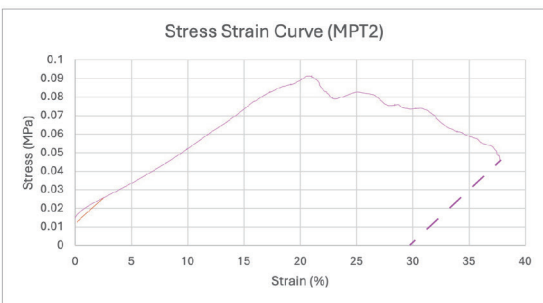
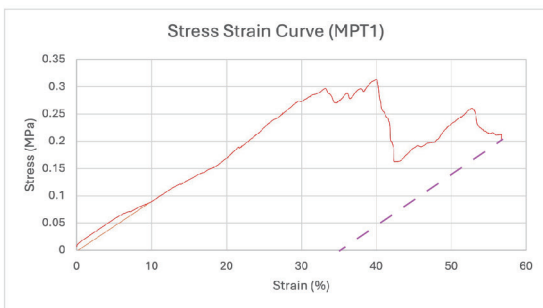
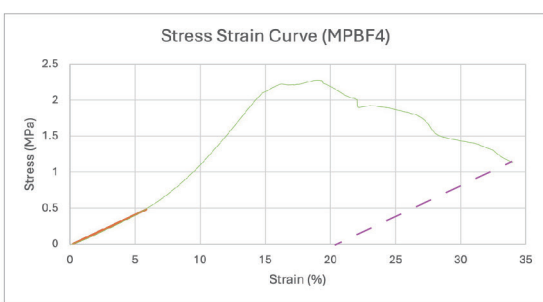
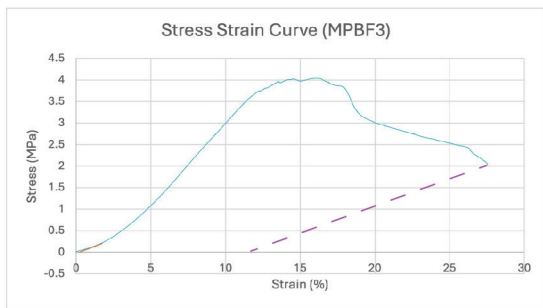
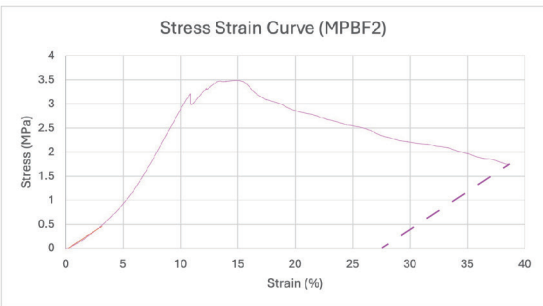
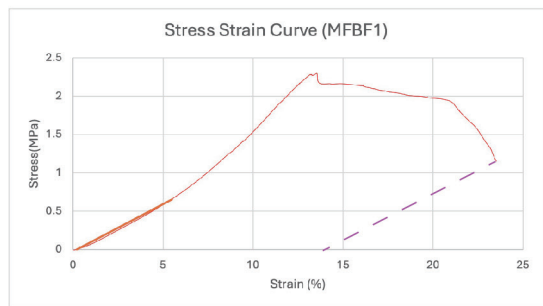
Day 30



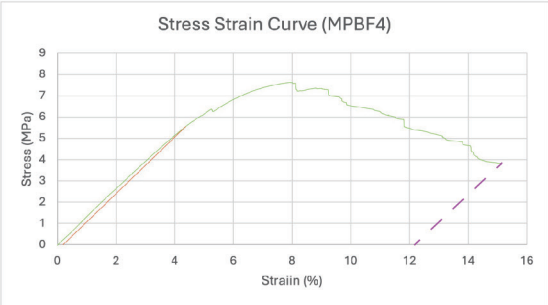
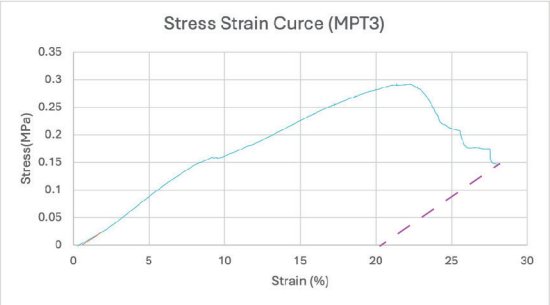
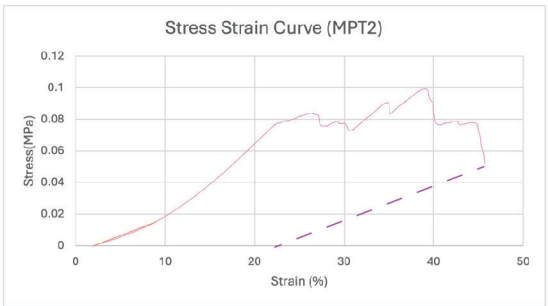
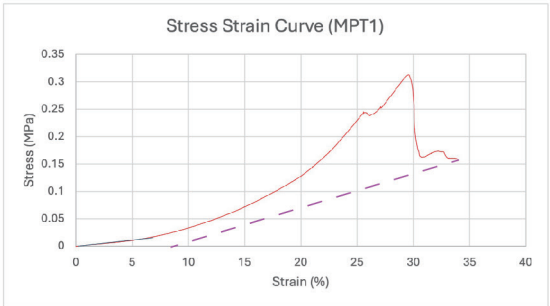
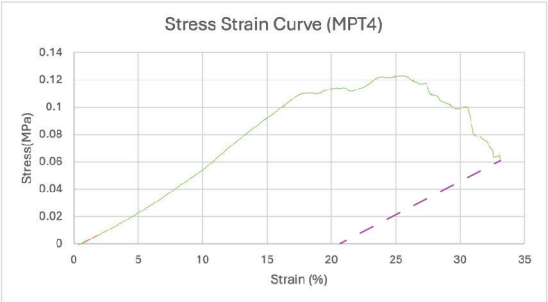
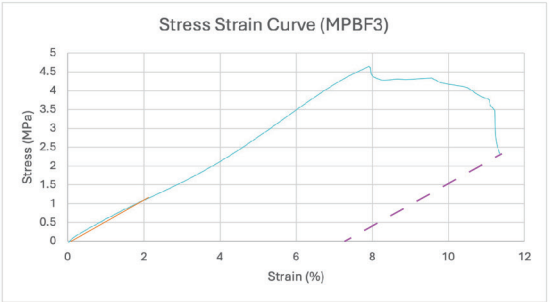
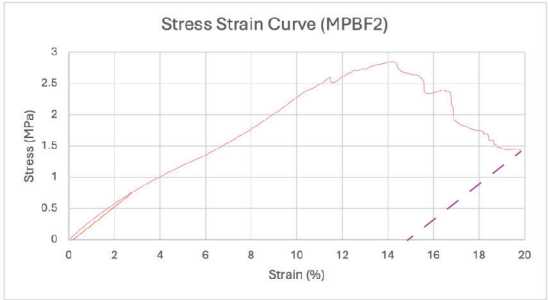
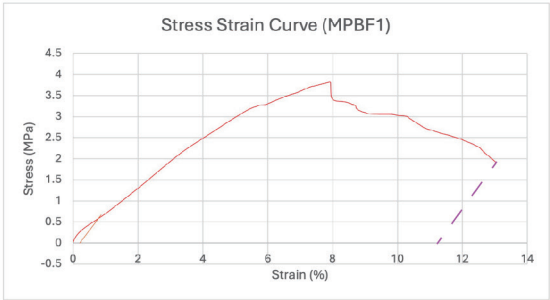
	Young Modulus (MPa)	Yield Strength(MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
MPBF1	5.92	0.22	1.77	11.62
MPBF2	12.79	2.38	2,44	57.24
MPBF3	4.17	0.08	3.16	10.06
MPBF4	25.57	0.20	2.81	10.43
Average value of MPBF	12.11±9.71	0.72±1.11	2.55±0.59	22.38±23.28
MPT1	0.87	0.01	0.23	7.51
MPT2	1.15	0.06	0.25	132.52
MPT3	0.27	0.01	0.28	10.06
MPT4	2.76	0.05	0.35	42.63
Average value of MPT	1.26±1.06	0.03±0.03	0.28±0.05	48.18±58.46

Appendix B

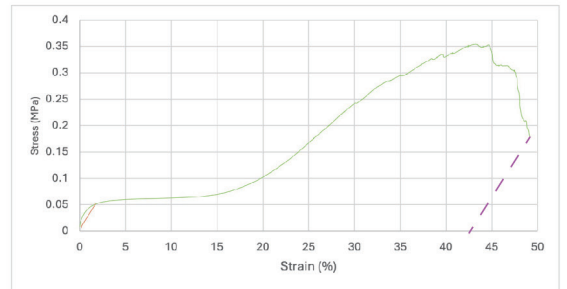
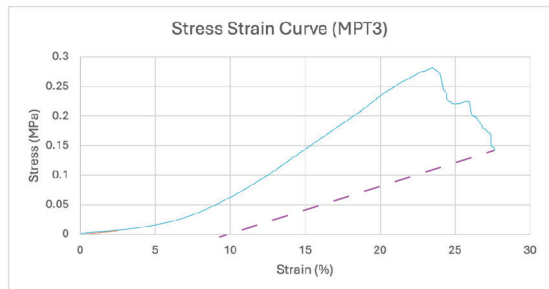
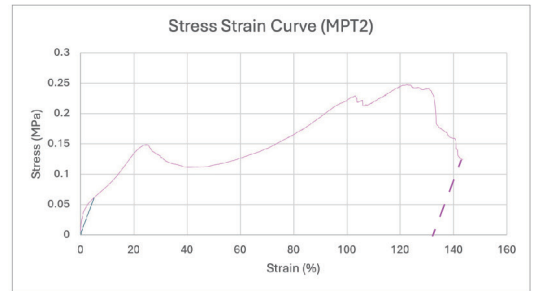
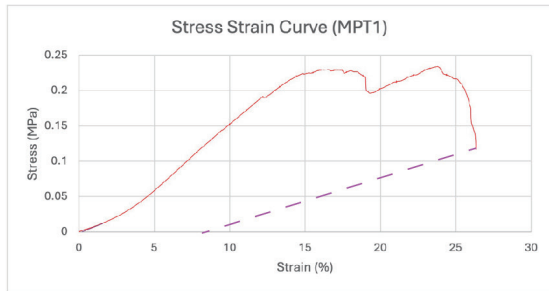
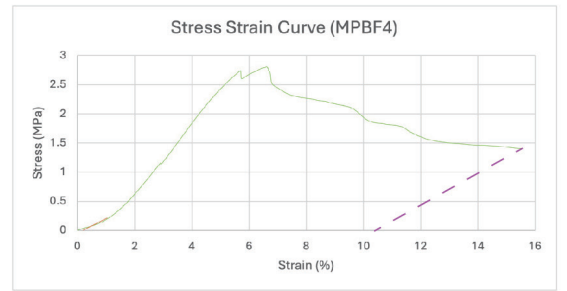
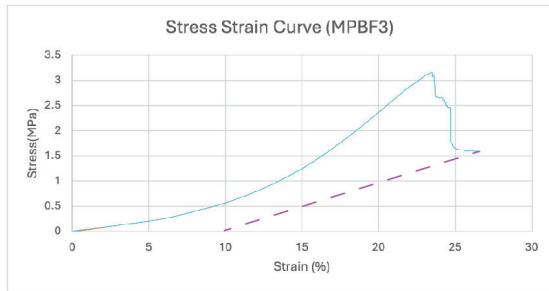
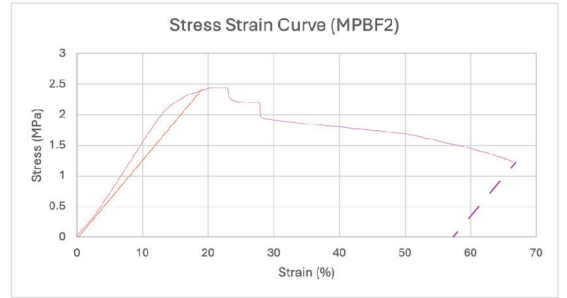
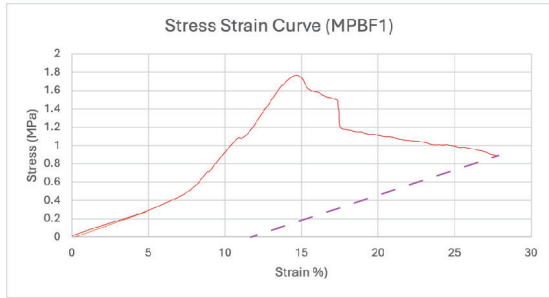
Day 1



Day 15



Day 30



Appendix C



These two images above show the the orange peel's peerling off in the mango pulp with banana fiebr (MPBF)

Appendix D

Questionnaire

The following statements address your perception about the shoes' comfort, functionality and its aesthitics. Please answer the each question, using 5-point likert scale below and free description.

	Very poor	poor	normal	good	Very good
Q1. How comfortable are the shoes while walking on flat ground?	☐	☐	☐	☐	☐

Q2. Please explain the reason for your answer in Q1

Q3. How comfortable are the shoes while walking on rough ground?	☐	☐	☐	☐	☐
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Q4. Please explain the reason for your answer in Q3

Q5. How comfortable are the shoes while ascending and descending stairs?	☐	☐	☐	☐	☐
--	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

Q7. Please explain the reason for your answer in Q5

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Q8. Do you feel the durability of the shoes should be improved?	☐	☐	☐	☐	☐
Q9. Do the shoes have enough space for your toe to spread out?	☐	☐	☐	☐	☐
Q10. Is the shoes easy to put on and take off?	☐	☐	☐	☐	☐
Q11. Do you feel the protection of sole part of your foot should be improved?	☐	☐	☐	☐	☐
Q12. Do you feel the protection of upper part of your foot should be improved?	☐	☐	☐	☐	☐
Q13. Overall, functionality of the shoes should be improved	☐	☐	☐	☐	☐

Q14. Tell me if you find critical functional problems while you ware wearing the shoes and the reasons

Q15. Can you imagine you wearing the shoes in your daily life?

☐
☐
☐
☐
☐

Q16. Please explain the reason for your answer in the Q15

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Q17. Do you feel the shoes are biodegradable?	☐	☐	☐	☐	☐
Q18. Do you feel the shoes are compostable?	☐	☐	☐	☐	☐
Q19. Do you want to convey your self-image as environmentally conscious with the shoes?	☐	☐	☐	☐	☐
Q20. Do the shoes makes you look unique or interesting	☐	☐	☐	☐	☐
Q21. The material of the shoes has potential to transform its colors and texture over time. Will you be able to enjoy it?	☐	☐	☐	☐	☐
Q22. Please explain the reason for your answer in the Q21					
Q23. If you purchase this shoes, what would be the motivation ? Intersting or unique appealance? Or environmental credential?					
Q24. What context do you want to weare the shose? Write down as much as you can think of					

Strongly
disagree

Disagree

Neutral

Agree

Strongly
agree

Q25. Do you feel shoes are high quality?

☐☐☐☐☐

Q26. Please explain the reason for your
answer in the Q25





