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Design and LCA of a bio-composite skateboard

KTH Thesis Report

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Abstract

This thesis examines the design and life cycle assessment (LCA) of a bio-composite skateboard deck targeting improved sustainability while providing consistent stiffness. Conventional skateboard decks generally consist of 7-ply maple veneer and often use oil or formaldehyde based adhesives which contributes to climate and health problems. This project explores the suitability of bio-composites using wood veneers, flax fibres & bio-resins to create an eco-friendly skateboard deck.

A standard prototype using wood veneer and epoxy was made along with test panels using various combinations of bio-based resin from Orineo with wood veneer and flax fibres. Manufacturing challenges such as excessive resin absorption, dry spots and too soft panels demonstrated how difficult it was. Mechanical testing using 3-point bending and interlaminar shear strength showed lower performance for the bio-composites compared to the standard veneer epoxy model.

To evaluate the environmental impacts of the skateboard models a cradle to gate life cycle assessment was completed. The results showed substantially lower global warming potential but also higher cumulative energy demand for the flax Orineo-based design compared to the veneer epoxy variant, although non-renewables were lower for the flax Orineo design. Sensitivity analysis showed no great fluctuations in the LCA with small changes to input data.

The thesis concludes that while bio-composites have some performance limitations they still offer environmental benefits especially in reduced carbon footprint. Future work should focus on optimising material combinations, improve manufacturing processes to enhance performance and sustainability and lastly examine end of life alternatives.

Abstract

Denna avhandling undersöker designen och livscykelanalysen av en biokomposit skateboard bräda med målet att förbättra hållbarheten samtidigt som styvheten hålls densamma. Traditionellt byggs en skateboard med 7 lager av kanadensik lönnfanér som ofta hålls ihop med olje- eller formaldehydbaserade klister, vilka bidrar till både miljö- och hälsoproblem. Detta projekt utforskar lämpligheten att använda biokompositer för att göra en miljövänlig skateboardbräda.

En standardprototyp byggdes med träfanér och epoxi samtidigt som testpaneler gjordes med flertal olika kombinationer av material såsom linfibrer och träfanér tillsammans med biomatrisen från Orineo. Tillverkningssvårigheter i form av hög matrisabsorption, torrfläckar och för mjuka paneler visade hur svårt det var. Mekanisk provning med 3 punktsböjning och interlaminär skjuvhållfasthet visade lägre prestanda för biokompositerna jämfört med standardmodellen med fanér och epoxi.

För att utvärdera skateboardmodellernas miljöpåverkan genomfördes en vagga-till-grind livscykelanalys. Resultaten visade betydligt lägre global uppvärmingspotential men också högre totalt energibehov för den lin- och Orineo baserade designen jämfört med fanér-epoxivarianten. Dock var energibehovet från icke förnybara källor lägre för lin-Orineo designen. En känslighetsanalys visade inga stora variationer vid små förändringar av indata.

Avhandlingen drar slutsatsen att även om biokompositer har något reducerad mekanisk prestanda erbjuder de ändå miljöfördelar, i synnerhet tack vare minskat koldioxidavtryck.

Framtida arbete bör fokusera på att optimera materialkombinationerna, förbättra tillverkningsprocessen för att ge bättre prestanda och hållbarhet och slutligen undersöka alternativ för återvinning och avfallshantering.

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Chapter 1

Introduction

1.1 Background

Global sustainability demands have risen significantly in recent years, driven by increased awareness of climate change and resource depletion [1]. The Circular economy, which aims to minimise waste and make the most of available resources, is central to these demands [2]. In the spirit of Colin Chapman's design philosophy 'Simplify, then add lightness', light weighting has become a cornerstone of modern engineering, particularly in the automotive [3, 4] and aerospace [5] industries. Composites play a pivotal role in this effort, offering a unique combination of strength and reduced weight. Despite their advantages, composites present challenges due to their multi-phase structure, which complicates recycling and often results in environmentally costly production processes. For example, carbon fibre composites require significant energy during production, with estimates ranging from 670 to 704 MJ per kilogram which is almost 20 times higher than hot-dipped galvanized steel which needs 35 MJ per kilogram [6]. Additionally, the heterogeneity of composite materials makes end-of-life disposal and recycling less efficient compared to single-phase materials [7]. Given these challenges, assessing the environmental impact of composite materials through systematic methodologies like Life Cycle Assessment (LCA) becomes essential.

The total environmental impact of the product can be predicted with tools like LCA, which is a methodology for evaluating the environmental footprint of a product or service. LCA analyzes all stages of a product's life cycle, from raw material

extraction and processing to production, usage and disposal. LCA starts with the goal and scope definition of the product or system. This phase establishes the purpose of the assessment, whether it is *cradle-to-gate* or *cradle-to-grave*, the choice of environmental indicators such as GWP or CED and defines key parameters as the functional unit and system boundaries. GWP measures the product's contribution to climate change in terms of equivalent CO_2 emissions, while CED quantifies the total energy consumption required during all life cycle phases in the scope, highlighting energy intensive stages [8]. With these metrics LCA can provide insight into the trade-off between sustainability and performance.

The functional unit serves as a quantified reference point, ensuring that the assessment compares products or systems on a consistent basis. The system boundary delimits which processes should be included in the analysis of a product system, such as raw material extraction, transportation, and manufacturing. It also considers whether the system produces any co-products that must be accounted for through system expansion or allocation. The system boundary must align with the stated goal of the study to ensure consistency and relevance.

The next step is the Life Cycle Inventory (LCI) where material and energy inputs and outputs are aggregated together with the subsequent emissions. The Life Cycle Impact Assessment (LCIA) follows the LCI, assigning input and output data to selected impact categories. For example, in the GWP category, different greenhouse gases are compiled and weighted by their kg CO_2-equivalent and summed up for a total GWP.

1.2 Purpose

The purpose of this thesis is to assess the potential for incorporating bio-based materials into the manufacturing of skateboard decks, with the primary objective of determining whether these materials can meet performance criteria while lowering the product's environmental footprint. Specifically, this thesis presents an evaluation of the environmental impact of skateboard decks made from a combination of wood veneers, bioresin, and flax fibers. Additionally, it discusses the mechanical properties of these bio-composites, focusing on their ability to achieve comparable stiffness to traditional epoxy-based decks. Finally this thesis attempts to provide actionable insights into the feasibility of transitioning to bio-based materials in composite applications, contributing to the overall goal of reducing the environmental impact of

composite manufacturing.

This investigation will focus on the following key objectives:

1. **Deliverables:**
    - A comprehensive Life Cycle Assessment (LCA) comparing the environmental impacts of bio-based and epoxy-based skateboard decks.
        - Evaluate the potential reduction in Global Warming Potential (GWP) and Cumulative Energy Demand (CED) when using bio-based materials in the skateboard deck compared to traditional skateboard decks with veneer and epoxy.
    - Mechanical testing results for the bio-composite test panels, focusing on stiffness, flexural strength, and interlaminar shear strength.
        - Determine whether the bio-composite materials can achieve the required mechanical performance (specifically, stiffness) for skateboard decks.
2. **Outcomes:**
    - Insights into the viability of using bioresin and natural fibers in sports equipment manufacturing.
    - Recommendations for further research and potential areas of improvement in the bio-composite manufacturing process.

1.3 Benefits, Ethics and Sustainability

Benefit: The obtained results could encourage CEM Composites and other manufacturers toward more sustainable practices by incorporation of feedstocks of bio-based material into their products.

Ethics: The final product would have to be considered for appropriate disposal and recyclability to avoid further waste globally.

Sustainability: The project addresses directly the Global Goals, specifically those related to responsible production and consumption, climate action [1]. First, the

effort to reduce the environmental footprint of composite materials in this project contributes to the trend that increasingly links ongoing efforts to reduce greenhouse gas emissions and energy consumption within manufacturing processes. Besides, this might be performed by the utilization of bioresins and natural fibers, a partial move towards renewable resources in the field of material science.

1.4 Stakeholders

Key stakeholders of this thesis:

- Skateboard manufacturers and consumers, who may benefit from more sustainable and potentially biodegradable alternatives to traditional composite materials.
- Environmental advocates, who wants a reduced carbon footprint of industries like sports equipment manufacturing.
- Researchers and engineers working in the field of composites or plywood who may find the insights from this study applicable to a range of bio-composite applications.
- CEM Composites, which stands to learn from the exploration of bio-based materials.
- Orineo, which sees their bio-resin tested and mentioned.

1.5 Delimitations

This study focuses on the environmental and mechanical performance of bio-based skateboard decks. The research is limited to evaluating stiffness, flexural strength, and interlaminar shear strength as the primary mechanical performance criteria. Other mechanical performance metrics, such as vibration damping, impact resistance, and fatigue behaviour, are not addressed in this study. These metrics, while important for the overall performance and user experience of the skateboard, fall outside the scope of this work. The performance of the skateboard decks is simulated using test data from the respective test panels. The LCA performed has the cradle-to-gate scope which focuses on the production phase (and everything going into the product) and will not

include an exhaustive analysis of the end-of-life disposal or recycling processes for the bioresin.

1.6 Outline

The thesis structure:

Chapter 2: Background - An overview is given about key concepts concerning composite materials, sustainability issues, bio-resins, and natural fibers. Here the importance of LCA in evaluating environmental impacts from different materials is presented and applications of already existing bio-composites in relevant industries is reviewed.

Chapter 3: Methodology - This section explains the methodology to be employed in LCA and mechanical testing. A detailed description of the approaches to quantify environmental and mechanical performances of the skateboard deck is also provided.

Chapter 4: Results - Results of LCA and mechanical tests in terms of stiffness, flexural strength, and interlaminar shear strength are given here. Then, the performance and environmental impact of a bio-composite versus an epoxy-based skateboard deck are compared.

Chapter 5: Discussion - The discussion gives an interpretation of the results by showing the potential of using bio-composites in order to reduce environmental impacts. It also examines the feasibility of replacing epoxy with bio-based resin in skateboard manufacturing, ensuring that mechanical performance is not compromised.

Chapter 6: Conclusion and Future Work - This chapter summarizes the project, quantifying whether the biocomposite material can act as a practical alternative to conventional composites in skateboard decks. Additionally, recommendations on how further research can be carried out and improvements made in the biocomposite technology are given.

Chapter 2

Theoretical Background

2.1 Composites

Composites are engineered materials made by combining two or more distinct components with different physical or chemical properties. Typically, composites consist of a reinforcement, such as fibres, embedded within a matrix, such as a polymer which is either a thermoset or a thermoplastic. This arrangement enhances properties like strength, stiffness, and durability, often exceeding the capabilities of the individual components [9]. Fibre Reinforced Polymers (FRPs) are a key class of composites, combining high-strength fibers like carbon or glass with a polymer matrix. This results in materials with great strength-to-weight ratios, durability, and versatility, making them ideal for applications in aerospace, automotive, and construction.

Bio-composites are a subcategory of composites where one or more components are derived from renewable biological resources. Common bio-fibres include flax, hemp and jute while bio-resins are derived from plant oils, sugars or even microorganisms. These materials offer an opportunity to reduce reliance on fossil fuels while improving the sustainability of composite production. Bio-composites have been shown to reduce carbon footprint versus traditional composites with up to 87% but cause bigger environmental impacts on especially eutrophication [10].

2.1.1 Production

The production of FRPs involves combining a reinforcement, such as fibres, with a matrix material, like resin. Carbon fibres, in particular, are typically produced from polyacrylonitrile (PAN) precursors, which are derived from petroleum. The production process is energy-intensive, requiring high temperatures for carbonisation in the order of 1200-1600°C and sometimes the fibres are graphitized at up to 3000°C [11]. In FRPs, synthetic fibres like glass or carbon are commonly impregnated with petrochemical-based resins through processes such as hand lay-up, vacuum infusion, or pultrusion. The curing process solidifies the matrix, resulting in a rigid composite material [12].

Thermosets are cured by heat, forming crosslinking between the polymer chains which will keep its shape in high temperature but cannot be melted or reshaped. Thermoplastic resins can be melted and reshaped above it's melting point.

Bio-fibres like flax and hemp follow a similar process but are cultivated and processed through methods such as retting and mechanical separation. Retting involves microbial degradation to separate the fibres from the plant stems, followed by cleaning and weaving into usable reinforcements. Flax fibres, for instance, exhibit an E-modulus of 60-80 GPa and densities of around 1.4 g/cm^3, making them comparable to synthetic fibres like glass in specific applications [13].

Bio-resins are produced through processes involving renewable resources such as vegetable oils (e.g., linseed or castor oil), sugars, or microbial fermentation. For example, oleaginous microorganisms, which can synthesize oils from agricultural waste, provide an alternative source for bio-resins [14].

2.1.2 History of Bio-Composites

The development of bio-composites has it's roots in the earliest known human application of natural fibres. Historically as early as the Neolithic period the wattle and daub technique was used with wooden branches (wattle) and clay, mud or animal dung with straw reinforcements (daub) were combined to make building materials [15], which illustrates the basic concept of reinforcement and matrix. The modern bio-composites, as they are understood today, started emerging in the middle of

20th century with the rise of polymer sciences and the search for more sustainable alternatives to petroleum-based chemicals [10].

During the 1980s and 1990s bio-composites gained renewed attention as environmental sustainability awareness grew with a more rapid increase in the 2000s [16]. Scientists started researching the use of natural fibres like jute, flax and hemp, in combination with synthetic and biobased resins to lower the carbon footprint of the composite. The first application was in automotive interiors where the lightweight and bio degradable materials offered both functional and sustainability benefits[10].

A significant turning point at the start of the 2000s showed advancements with fibre processing techniques and formulations of bio-resins. Mohanty et al highlighted the great potential of bio-fibres to replace synthetic glass fibres with lower energy demand and reduced greenhouse gas emissions [10]. Recently focus has shifted to improve the mechanical properties and the scalability of bio-composites, making them compete with the traditional composites like carbon or glass fibres.

Despite the recent progress of bio-composites several challenges remain. The variability of natural fibres, moisture sensitivity [17] and end of life alternatives continue to limit widespread adoption. Ongoing research and innovation in the field show progress, allowing bio-composites to remain a critical part in the global transition toward more sustainable materials.

2.1.3 Market Demand

Composites have been gaining ground in many different industries [18] and is believed to continue doing so. To achieve the lightweighting benefits of carbon fibre composites while ensuring a more environmentally friendly design, bio-composites can be used as an alternative [19].
Without relying on oil-based source materials the production have potential to be a lot better for the environment and its sustainability. Alternatives such as flax and hemp are gaining ground [20], [21] and oleaginous microorganisms making oil provide an new source for bio-resins [14].

2.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is a systematic methodology used to evaluate the environmental impacts associated with all stages of a product's life cycle, from raw material extraction to production, use and end-of-life disposal [8]. The methodology is widely used in sustainability research and industry to identify hotspots of environmental impact and inform decisions aimed at reducing the environmental footprint.

The LCA process typically involves four key steps:

1. **Goal and Scope Definition:** Establishing the purpose of the assessment and setting boundaries for the study (e.g., cradle-to-gate or cradle-to-grave).
2. **Life Cycle Inventory (LCI):** Collecting data on inputs (materials, energy) and outputs (emissions, waste) for all processes within the system boundary.
3. **Life Cycle Impact Assessment (LCIA):** Evaluating potential environmental impacts using indicators such as Global Warming Potential (GWP) and Cumulative Energy Demand (CED).
4. **Interpretation:** Analyzing the results to draw conclusions and make recommendations.

In this report, the LCA is conducted with a cradle-to-gate scope, which considers the environmental impacts from raw material extraction to the production of the skateboard deck. This scope excludes the use phase and end-of-life disposal but provides valuable insights into the environmental performance of the materials and the manufacturing processes.

2.2.1 Environtmental Indicators

- **Global Warming Potential (GWP):** This study uses the GWP_{100} metric, which evaluates the potential contribution to climate change over a 100-year period. It accounts for greenhouse gas emissions, including CO_2 uptake during material production, and highlights which components have the most significant impact on climate change.
- **Cumulative Energy Demand (CED):** CED quantifies the total energy

required for all life cycle phases of a product included in the scope, for this study that goes from inception to finished product. This indicator identifies energy-intensive stages in the life cycle and takes into account the energy sources (e.g., renewable vs. non-renewable) used at different stages.

2.2.2 LCA in the Literature

LCA has been extensively applied in sustainability research to evaluate the environmental performance of materials and products. For composites, studies such as Das (2011) [6] have demonstrated the high energy demand and greenhouse gas emissions associated with synthetic carbon fibres. However, other studies have shown that the CED over the total life-cycle of composites structures can be similar or significantly lower than a similar component in metal" [6, 22].

2.3 Related Work

The article *The multi-objective optimization framework: A step towards minimizing life-cycle costs and energy consumption of carbon fibre automotive structures* by Kaushik Iyer showed many important aspects of LCA optimization and also displayed the importance that the CED poses [23]. The previous master thesis *Life cycle energy optimization as a tool to compare and evaluate the optimal design in the automotive industry* by Robert Jonsson has also provided great insights into LCA and design [22]. As a general introduction and guidance to LCA Mary Ann Curran's *Life Cycle Assessment Student Handbook* proved a valuble source [8].

Chapter 3

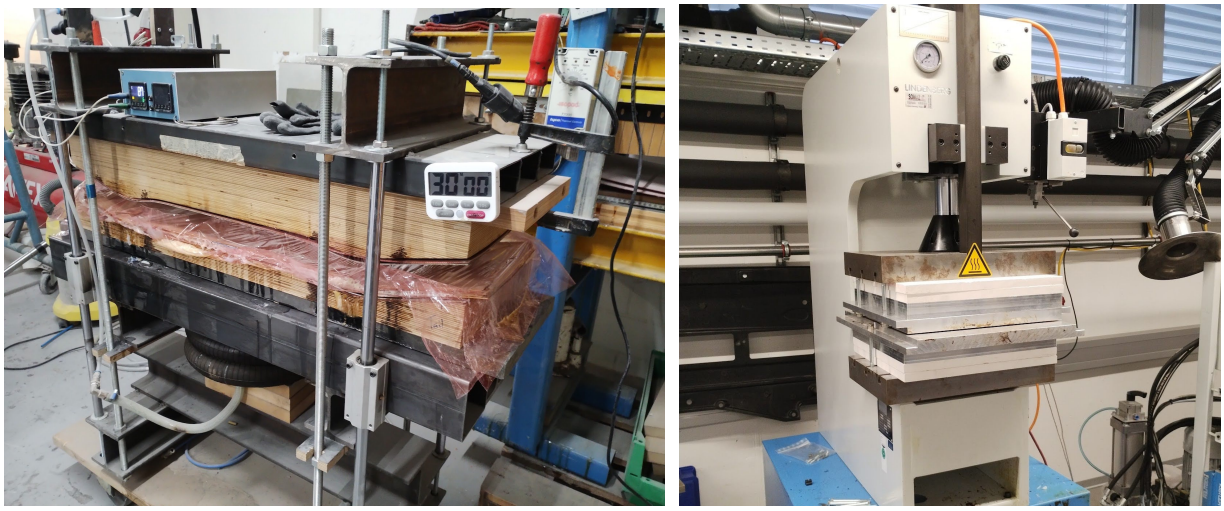
Methodology

3.1 Material Selection and Testing Overview

The initial goal was to evaluate the stiffness of a wood veneer and bio-resin skateboard deck. For this to be feasible, the bonding capabilities must be consistent and sufficiently robust to function effectively in a skateboard deck, in the first tests the protective plastic layer was harder to separate from the wood than the layers of wood veneer against each other. This proved to be a troublesome area as the bio-resin and wood veneer did not in fact create a strong and reliable bond between each other. Due to a lack of available data of the Orineo bio-resin used in this project extensive testing was needed to understand the matrix and investigate the suitability of making a skateboard deck with the resin. For reference, a classical wood veneer epoxy construction was established as the performance benchmark. To compare different concepts, test panels were made and then cut into specific dimensions for 3-Point Bending (length 80mm, width 10mm and height 4mm) and ILSS testing (length 6*height, width 2*height and height 2,5-4,5mm).

Following the selection of materials, the focus shifted to identifying manufacturing processes suitable for both the samples and the final product. This involved analysing and selecting an appropriate technique to ensure compatibility and achieve the desired performance.

3.2 Manufacturing Process



(a) Shaped hot press (b) Flat hot press

Figure 3.1: Manufacturing setup

Composite manufacturing is highly shape and resin dependant and both skateboard decks and test panels are very flat objects, making the hot press a great alternative for manufacturing, see figure 3.1. A baseline full-scale skateboard deck was first constructed using seven plies of maple hardwood veneer in a traditional 0/90/0/90/0/90/0 layup. The epoxy resin and hardener were mixed in a 4-to-1 ratio, as recommended by the manufacturer, with a total matrix weight of 500g. The deck was then cured in a hot press at 90 °C for 30 minutes. Few manufacturing defects were observed on the full-scale skateboard deck. In addition to the full-scale deck, a reference wood veneer epoxy test panel was produced with a 0/90/0 layout. This had satisfactory adhesion between layers after the first manufacturing attempt, which was using the same epoxy and hardener mix as the baseline skateboard deck and cured in the hot press the same way as the baseline deck. However the adhesion between the wood veneer and the bio-resin proved insufficient for the first bio-resin test panel see fig 3.2 a, using the same 0/90/0 layout as the epoxy test panel likely due to a greater absorption of the bio-resin. This lead to many iterations of test panels see fig 3.2 b, with some parameters adjusted to try and optimise the bond, see table 3.1.

The absorption of the bio-resin by the wood veneer panels proved to be troublesome and a consistent issue, causing dry spots. Some promise was found using a previously failed test panel as impregnated stock for another test panel, but it was ultimately deemed too inconsistent for production of larger items (such as a skateboard deck).

Manufacturing		Result
Veneer Epoxy		✓
Veneer Orineo	Higher temp + longer	X
	More resin	X
	Extra dried	X
	Preimpregnated	~
	Quartz	X
	Paper	X
Veneer Flax Orineo		X
	Quartz	X
Flax Orineo		~
	Quartz	✓

Table 3.1: Manufacturing iterations

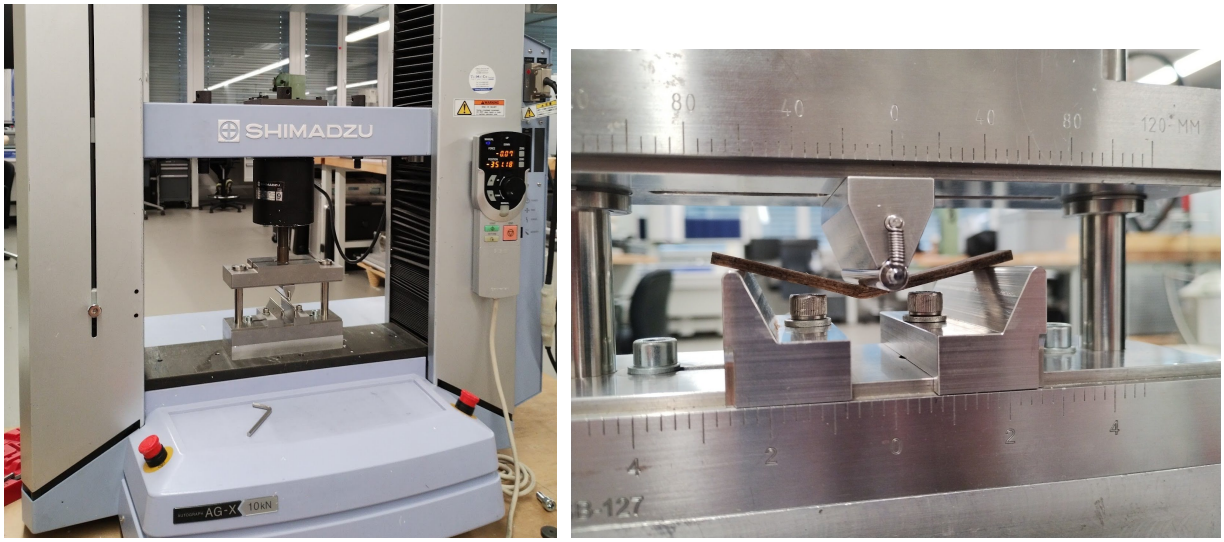
With these absorption bonding issues the idea of a wood veneer bio-resin panel was abandoned. From this point on, other materials and additives were tested until the mix of Flax Orineo Quartz provided consistent and thorough adhesion adequate to advance to testing and simulation.

(a) Bio-resin testpanel (b) Bio-resin paper testpanel

Figure 3.2: Lack of adhesion on certain testpanels

3.3 Testing

The testing was conducted following ASTM standards, more specifically the D7264M for 3-Point Bending (3PB) and the D2344 for the Inter Laminar Shear Strength (ILSS). These were chosen for the stiffness comparison they provide, while also giving information about bending strength and in the case of the ILSS it also provides data on delamination. The test machine and the specific 3PB test setup are shown in figure



(a) Test machine (b) 3PB test in action

Figure 3.3: Testing setup

3.3.

3-Point Bending equation:

$$BendingTension = \frac{\frac{MaxForce * LowerSupport}{4}}{Width * Thickness^2} * 6 \tag{3.1}$$

ILSS equation:

$$ILSS = \frac{3 * MaxForce}{4 * Width * Thickness} \tag{3.2}$$

Testing		Result
Veneer Epoxy		Great
Veneer Orineo	Higher temp + longer	Dry spots
	Preimpregnated	Dry spots
	Quartz	Dry spots
	Paper	Dry spots
Veneer Flax Orineo		Adhesion problems
	Quartz	Adhesion problems
Flax Orineo		Too soft
	Quartz	Soft but OK

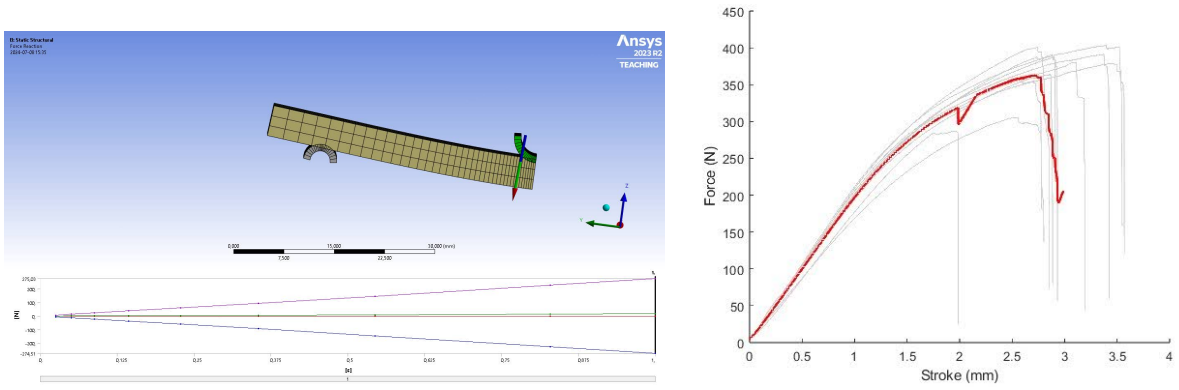
Table 3.2: Testing iterations

3.4 Simulation

To evaluate the mechanical performance of the skateboard deck, simulations were performed using the Finite Element Method (FEM) in Ansys. The goal of the simulation was to match the stiffness of the bio-composite deck to that of the traditional epoxy veneer deck while optimising thickness and material usage. A structured mesh was applied to both the quarter models and the full-scale skateboard deck model. A mesh convergence study was conducted to ensure accurate results, with mesh refinement ceasing when further changes had a negligible effect on the calculated stiffness and stress.

3.4.1 Material Calibration Using Test Panels

Initial simulations were conducted on a quarter model of the test panels, leveraging symmetry to reduce computational demands. The material properties were adjusted iteratively to align the simulation results with the experimental data obtained from the three-point bending (3PB) tests see fig 3.4 for the reference epoxy veneer test panel and see fig 3.5 for the Orineo flax test panel. This calibration ensured that the material models accurately represented the elastic behaviour of the test panels under loading conditions.

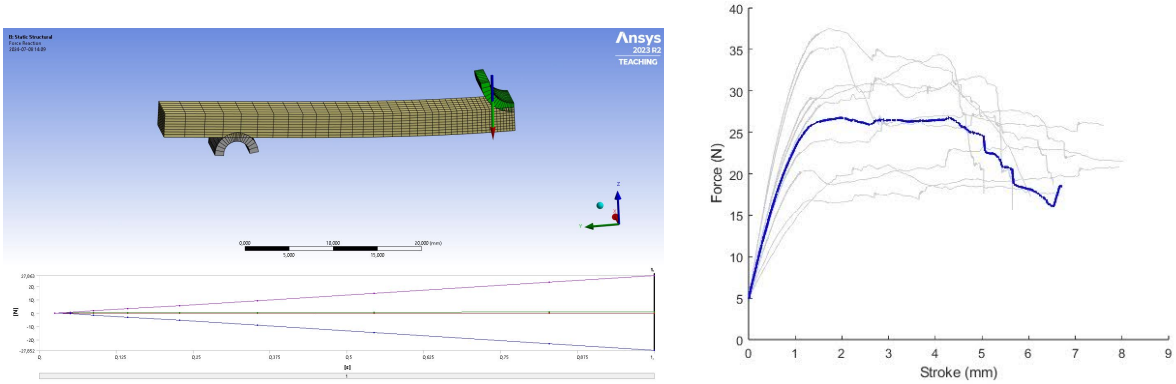


(a) Quarter epoxy veneer panel under 3PB load (b) 3PB test data epoxy veneer panel

Figure 3.4: Simulation of epoxy veneer test panel

3.4.2 Full-Scale Deck Simulation

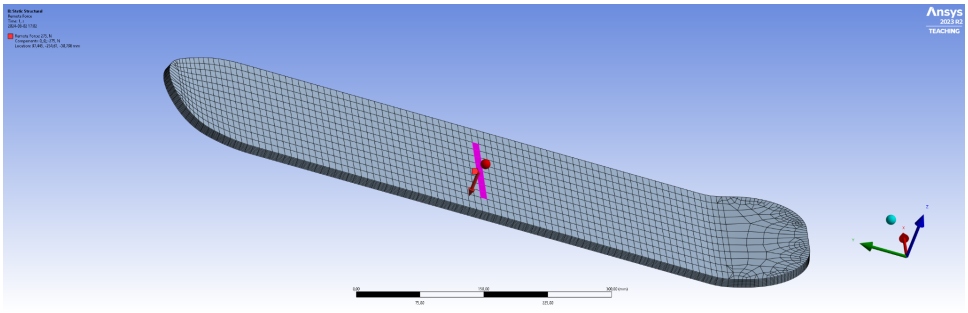
The calibrated material properties were then applied to the full-scale skateboard deck model. A concentrated load was applied at the midpoint of the upper surface of the



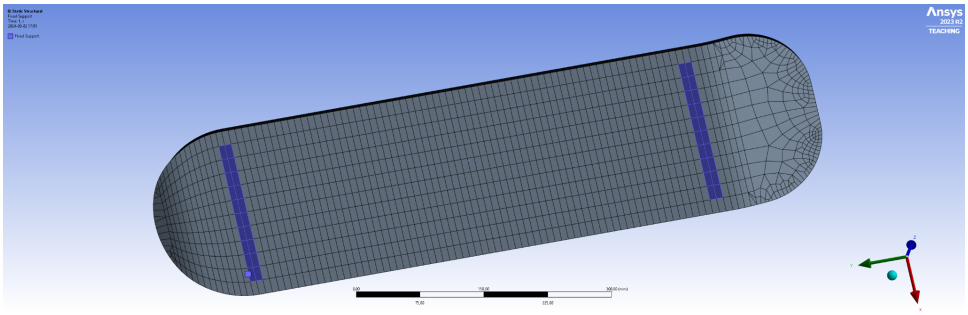
(a) Quarter Orineo flax panel under 3PB load (b) 3PB test data Orineo flax panel

Figure 3.5: Simulation of Orineo flax test panel

deck to replicate a worst case bending scenario, and the edges were modelled as simply supported constraints on the lower surface, similar to where trucks would support a complete skateboard see fig 3.6.



(a) Midpoint loading



(b) Edge supports

Figure 3.6: Simulation of skateboard deck

3.4.3 Simplifications and Assumptions

- The full-scale decks were modelled using Ansys Composite PrepPost (ACP), which allowed for the inclusion of individual layers with distinct material properties. Fibre orientation, ply stacking, and the contribution of each layer

to the overall stiffness were explicitly defined in the model to ensure accurate representation of the mechanical behaviour of the composite.

- ILSS data were not incorporated into the model, because interactions between layers, such as delamination, were not simulated.
- Manufacturing imperfections, such as defects or surface roughness, were not included in the simulations.

3.4.4 Final Design

The simulation results showed that a 30-ply bio-composite deck (flax, Orineo resin, and quartz) with a thickness of 12.75 mm achieved a stiffness of 940 N/mm, closely matching the performance of the 7-ply veneer-epoxy deck (10.5 mm thickness, 920 N/mm). This validated the design's ability to meet performance criteria while informing the LCA by providing precise material masses for both designs.

3.5 LCA

The cradle to gate LCA has been performed using the SimaPro software which use the ecoinvent 3.10, the US LCI and the Agri-footprint-economic databases. These databases provided reliable environmental data for most materials and processes involved. For the epoxy-wood veneer deck, all components were readily available within the databases. However, the Orineo bio-resin, being a new product, was not included. To address this, its base ingredients were modeled individually, and Oribond was substituted with linseed oil as a proxy (see Appendix A for detailed assumptions

The inputs for the epoxy veneer can be seen in table 3.3a and for the Orineo flax in table 3.3b.

The scope of the LCA included raw material extraction, transportation, and production processes, focusing on the cradle-to-gate phase. The use phase and end-of-life disposal were excluded to align with the study's primary goal of comparing production-phase impacts across different concepts. The functional unit is defined as 'one skateboard deck meeting specific performance criteria'.

Two key environmental indicators were selected:

	Epoxy Veneer
Thickness:	10,5mm
Stiffness:	920N/m
Production energy:	1kWh
Wood veneer:	1846g
Epoxy:	500g

(a) Epoxy veneer deck components

	Bio-resin Flax Quartz
Thickness:	12,75mm
Stiffness:	940N/m
Production energy:	1,2kWh
Flax fibre:	1800g
Quartz:	300g (Resin)
Oribond:	310g (Resin)
Water:	181g (Resin)
Organic ester:	61g (Hardener)
Citric acid:	91,5g (Hardener)

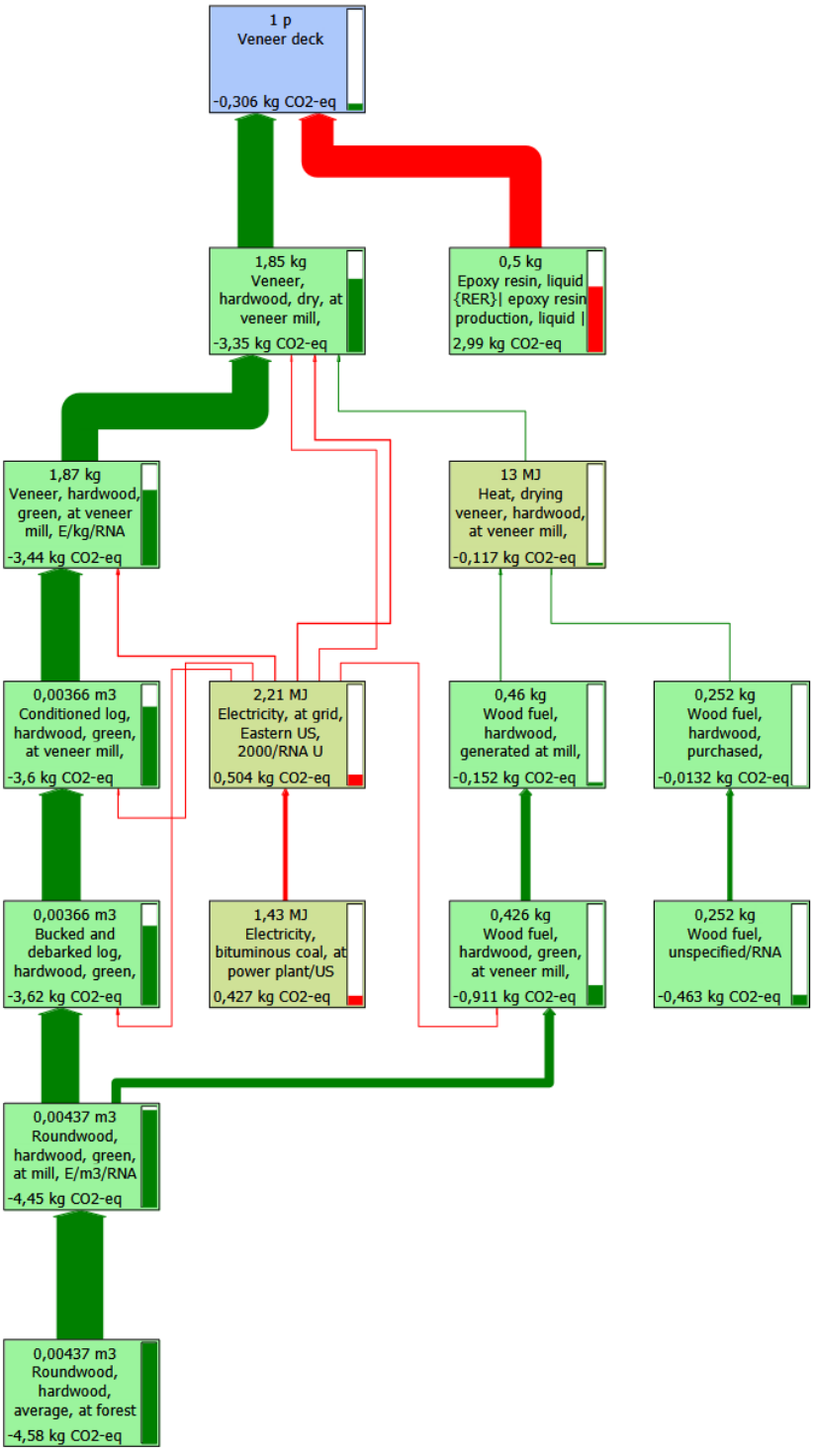
(b) Orineo flax deck components

Table 3.3: Inputs for the LCA

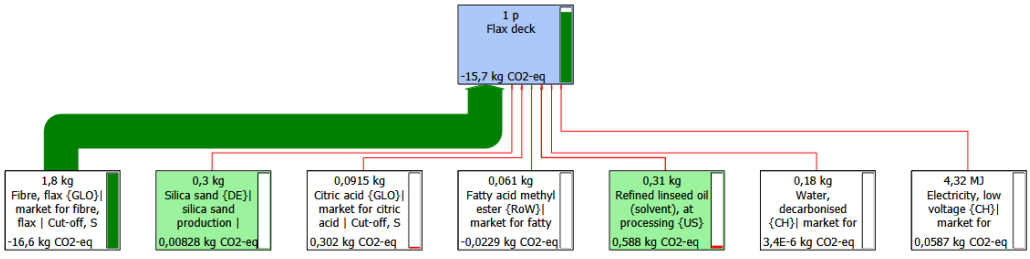
- **GWP_{100}:** This indicator, including CO_2 uptake, was chosen to assess the contributions to climate change over a 100-year time horizon.
- **CED:** CED was used to evaluate the total energy requirements for material production, highlighting energy-intensive stages and renewable versus non-renewable energy sources.

The required material and energy inputs to manufacture the different skateboard decks are shown in figures 3.7 and 3.8

Finally, the ReCiPe 2016 Endpoint method was applied to provide insights into water usage and toxicity, offering a broader perspective on environmental impacts beyond GWP_{100} and CED.

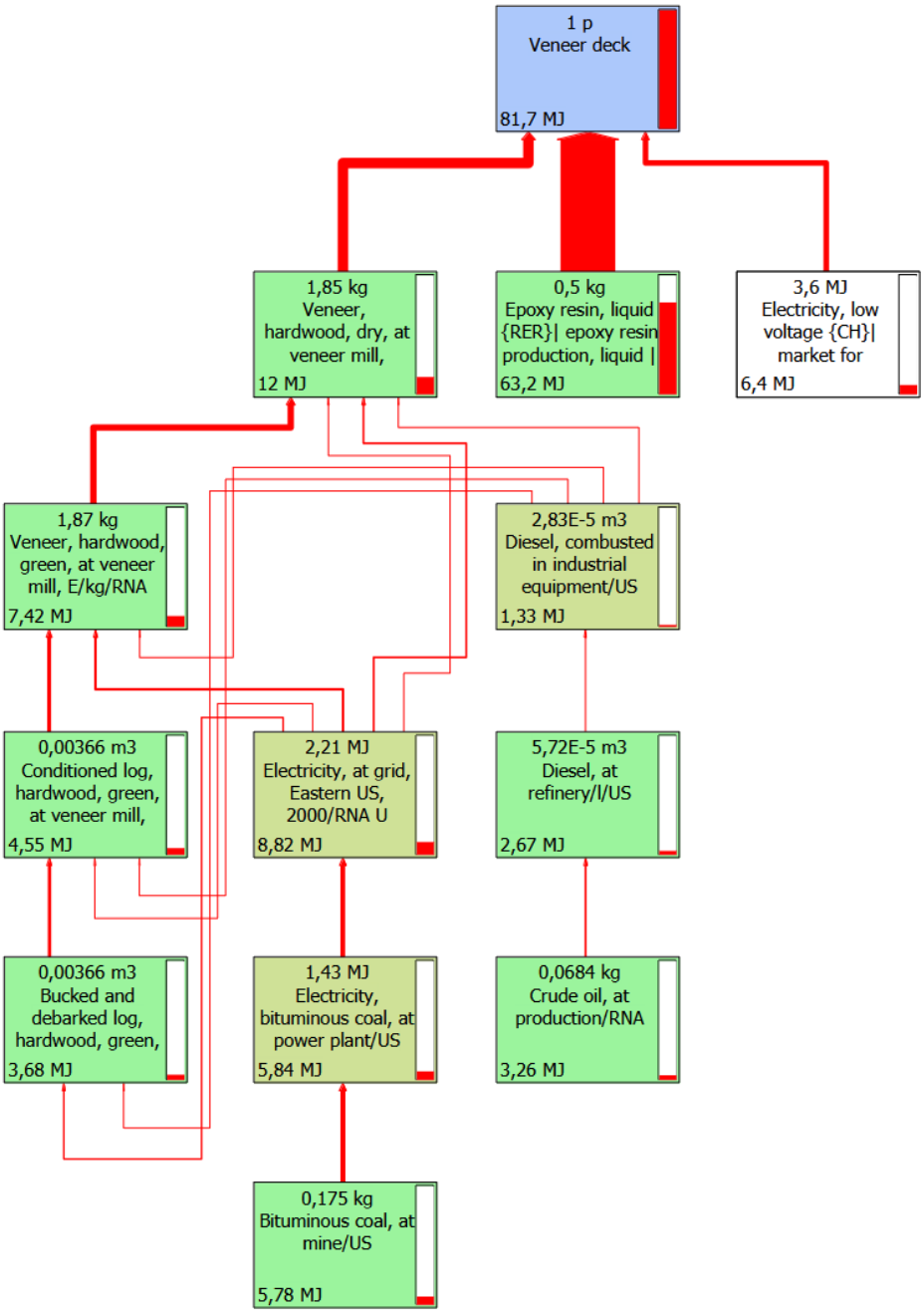


(a) Veneer deck, cutoff: 6,68%

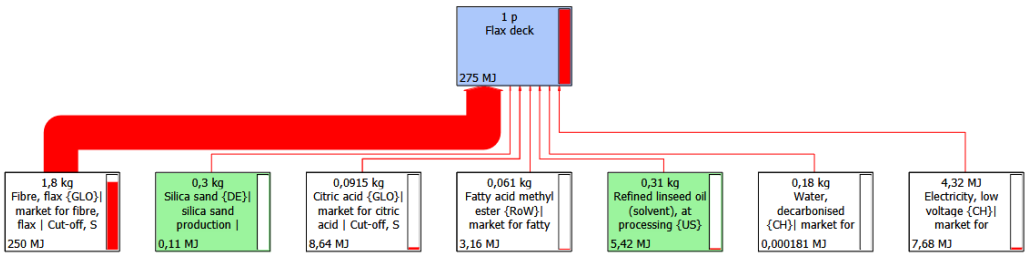


(b) Flax deck, cutoff: 0%

Figure 3.7: Flowchart of the GWP_{100} environmental impact



(a) Veneer deck, cutoff: 3,27%



(b) Flax deck, cutoff: 0%

Figure 3.8: Flowchart of the CED environmental impact

Chapter 4

Results

This chapter presents the results from both the mechanical testing and the LCA. The findings focus on the environmental performance found from the LCA and physical properties found from the testing for the bio-composite and epoxy-based skateboard decks.

4.1 Mechanical Testing Results

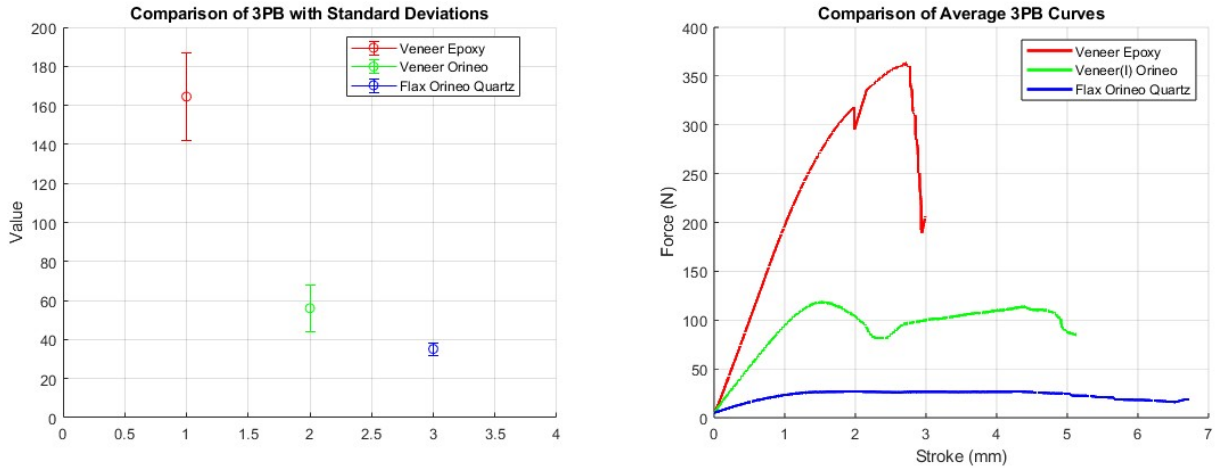
4.1.1 Bending tension

The average curves of the different concepts performance in the 3PB test can be seen in fig 4.1.

The baseline epoxy-wood veneer test panel exhibited an average bending tension of 164,5 MPa with a standard deviation of 22,23. This result establishes a benchmark against which the bio-composite panels can be compared, highlighting the performance gap in stiffness. In contrast, the bio-resin flax composite had a substantially lower average bending tension of 35,2 MPa but with a lower standard deviation of 3,24 indicating consistent performance. And finally the impregnated bio-resin wood veneer panel showed a slight improvement over the bio-resin flax composite with a bending tension average of 56,1 MPa and with a standard deviation of 11,74. However, this panel also exhibited the highest relative standard deviation, suggesting inconsistency in adhesion between the bio-resin and the veneers.

The difference in performance between the three test panels is probably due to the

difficulties in achieving proper bonding with the bio-resin and wood veneer and the soft characteristics of flax fibres and the bio-resin, as discussed in the Methodology section. Despite the lowered performance, the bio-resin and flax combination still provided sufficient stiffness for non-extreme use cases, making a prototype skateboard deck feasible. They also provide a more gradual failure compared to the stiffer and more brittle epoxy-wood veneer, which can be beneficial for a skateboard deck.



(a) Average values with errorbars

(b) Average of the test curves

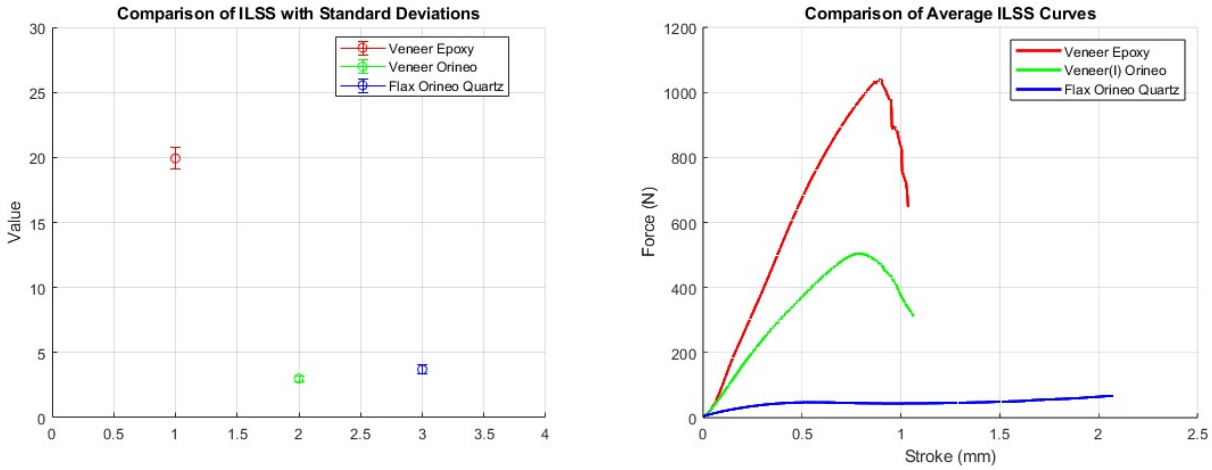
Figure 4.1: Averages from 3PB testing

4.1.2 Interlaminar Shear Strength

The average curves of the different concepts performance in the ILSS test can be seen in fig 4.2.

The ILSS test confirm the high shear strength of the baseline epoxy-wood veneer test panel, which exhibited an average ILSS of 19,9 MPa with a standard deviation of 0,81. Similar to the bending tension the bio-resin flax composite showed a significant reduction in ILSS, with an average of 3,7 MPa and a lower standard deviation of 0,34. The impregnated bio-resin wood veneer panel demonstrated a slightly lower ILSS value compared with the bio-resin flax composite, measuring an average of 3,0 MPa with a standard deviation of 0,22.

The difference in performance between the three test panels is quite similar to those presented with the bending tension above. For some of the bio-resin flax samples the deformation was to much to continue the test despite the layers staying in contact, appearing almost rubbery.



(a) Average values with errorbars

(b) Average of the test curves

Figure 4.2: Averages from ILSS testing

4.2 LCA

The cradle to gate LCA was performed with a focus the Global Warming Potential (GWP) and the Cumulative Energy Demand (CED) of the different material configurations. The results are presented for the epoxy wood veneer deck and the bio-resin flax deck with quartz filler. The ReCiPe 2016 Endpoint method was used to analyse additional environmental impacts, specifically water use and toxicity, seen in fig 4.3. The bio-resin flax design demonstrated higher water usage compared to the epoxy veneer deck, which, in turn, exhibited significantly higher toxicity.

4.2.1 Global Warming Potential (GWP)

Both skateboard deck concepts were found to be carbon sinks, meaning that they take up more carbon dioxide than they emit. This outcome is reasonable, as both designs are primarily composed of biomass materials such as wood or flax, which sequester carbon. The epoxy veneer deck absorbs 0,836kg CO_{2eq}, while the bio-resin flax deck absorbs a significantly higher 15,7kg CO_{2eq}, as visualized in fig 4.4. This increased CO_{2eq} uptake for the bio-resin option is expected, given its greater material mass and higher proportion of bio-based content. Additionally, epoxy resin also has a considerably higher carbon footprint than any of the other components analyzed, further contributing to the differences in overall environmental impact.

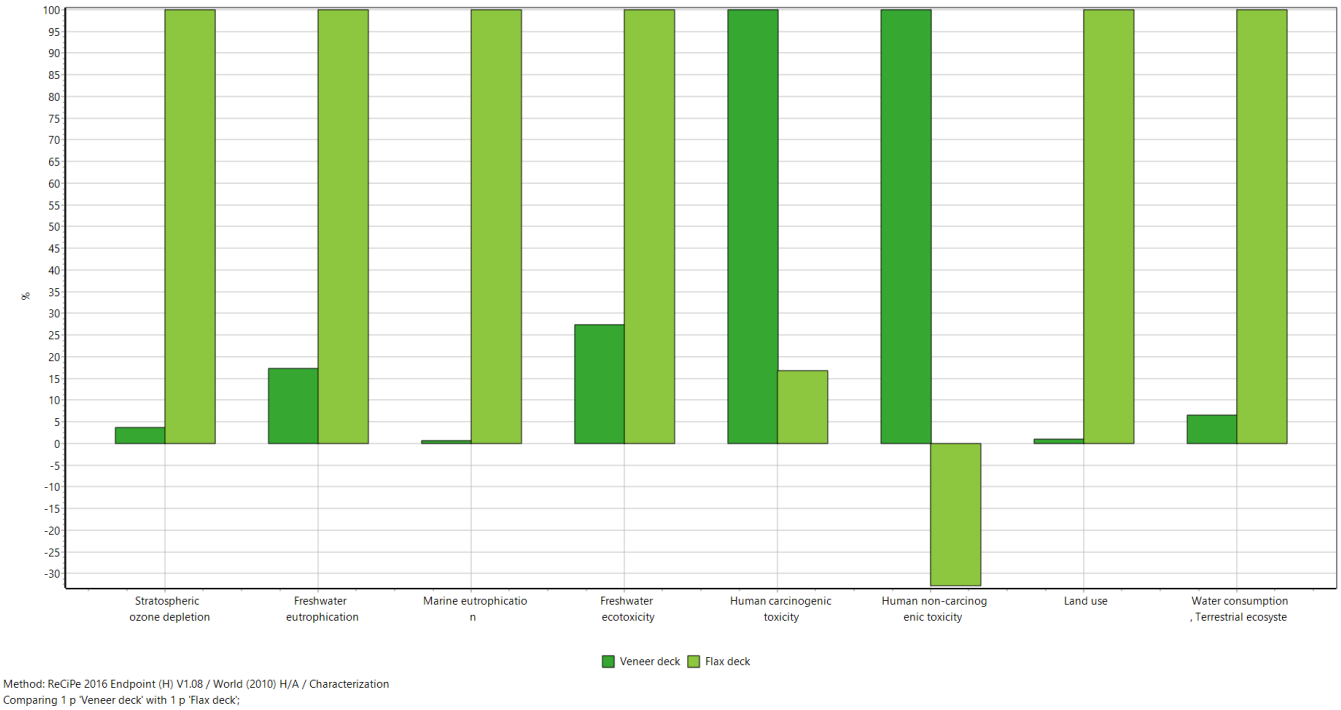


Figure 4.3: ReCiPe 2016 Endpoint

4.2.2 Cumulative Energy Demand (CED)

Interestingly, the bio-resin flax composite design exhibited a higher CED than the epoxy veneer baseline, measuring 281 MJ compared to 77,1 MJ, as shown in fig 4.5. This is likely due to the agricultural processes involved in producing both the bio-resin and flax fibers, as a significant portion of the CED comes from renewable biomass. However, when considering only non-renewable energy use, the results shift: the bio-resin flax deck only requires 46,1 MJ of non-renewable energy whereas the epoxy veneer deck still demands 73,2 MJ.

4.2.3 Sensitivity Analysis

A sensitivity analysis was conducted by increasing every individual component of each design by 10% and observing differences the resulting changes in environmental impact.

For the epoxy veneer deck, increasing the epoxy content 10% led to a 30% decreased CO_{2eq} uptake, while increasing the mass of veneer by the same percentage raised carbon sequestration by 40% see fig 4.6. In terms of CED, the epoxy had the most significant effect, though it only resulted in a 7% increase in total energy demand seen in fig 4.7. The bio-resin deck showed an 11% increase in CO_{2eq} uptake when the total mass of flax

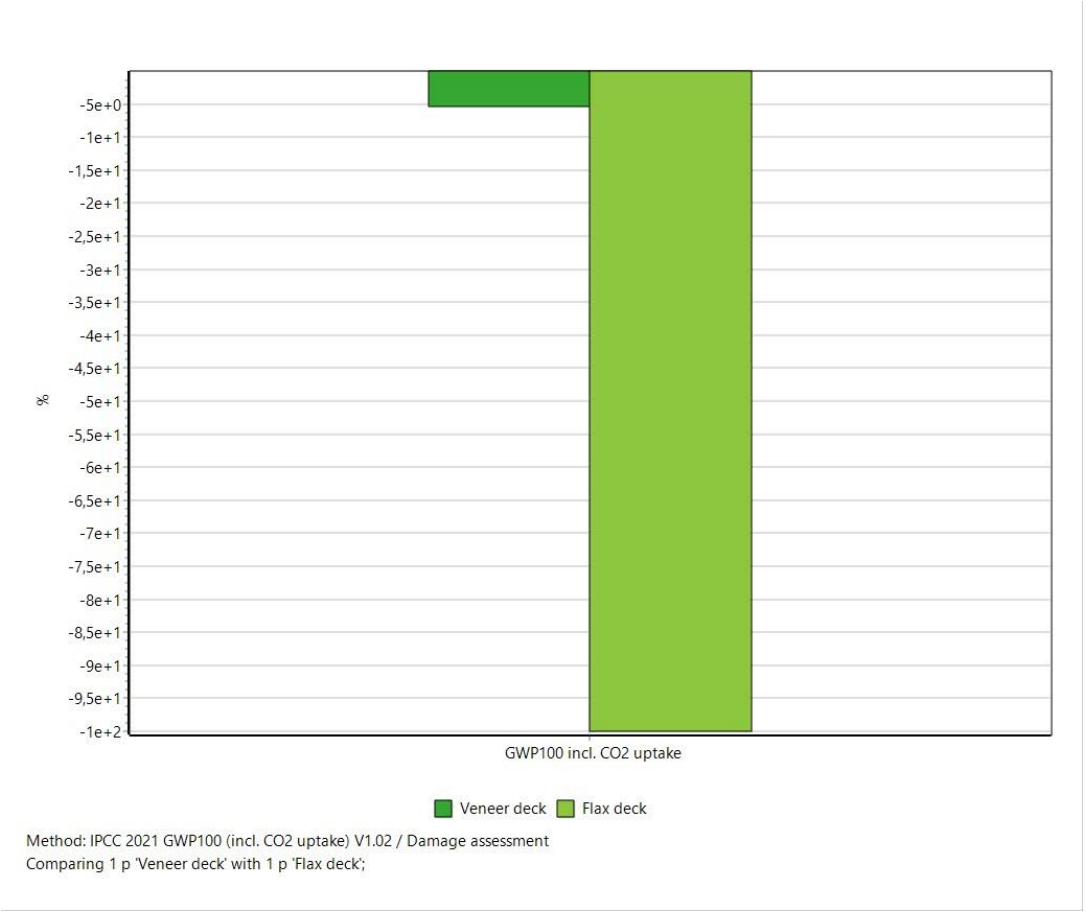


Figure 4.4: GWP_{100}

was increased by 10% shown in fig 4.8. Similarly the only notable difference in CED was an increase by 9% after the flax increase which can be seen in fig 4.9.

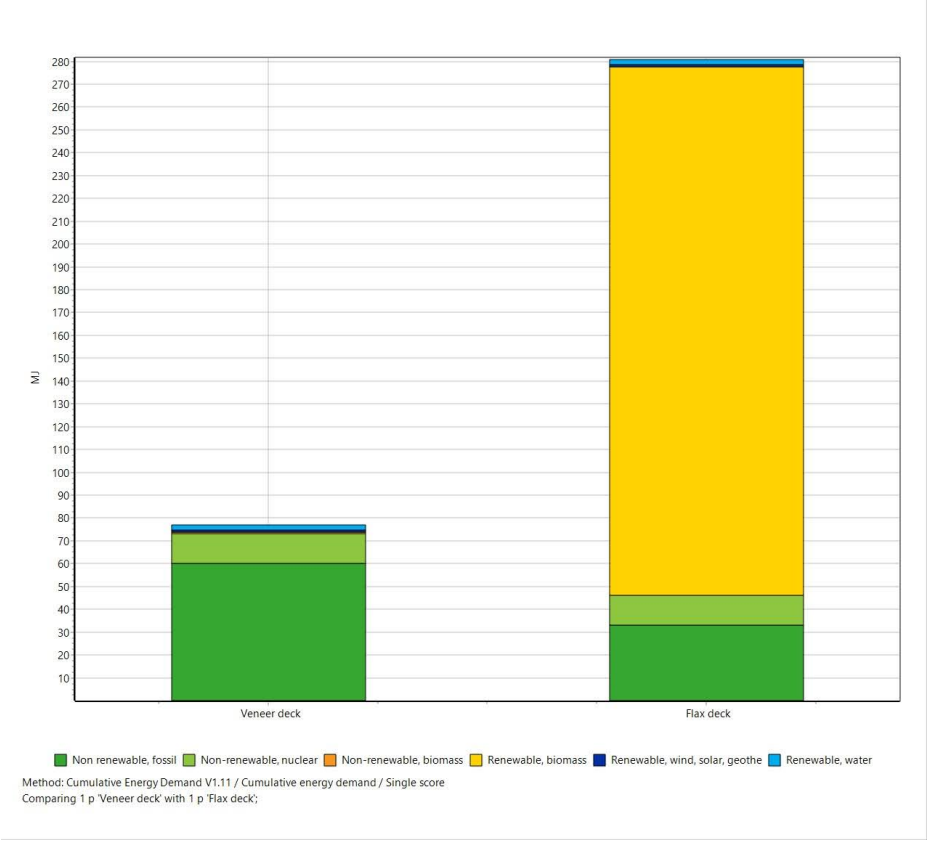


Figure 4.5: CED

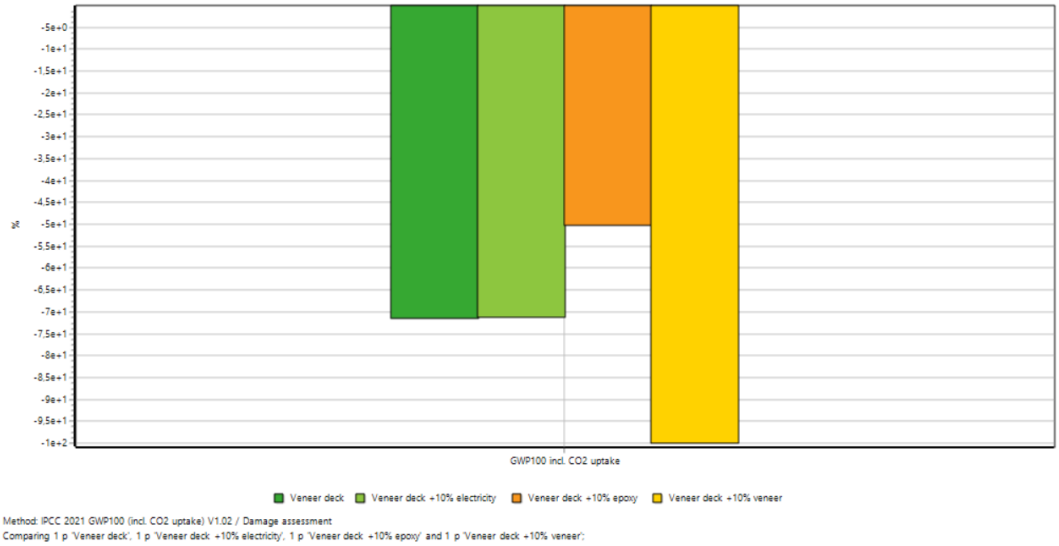


Figure 4.6: GWP sensitivity analysis of epoxy veneer deck

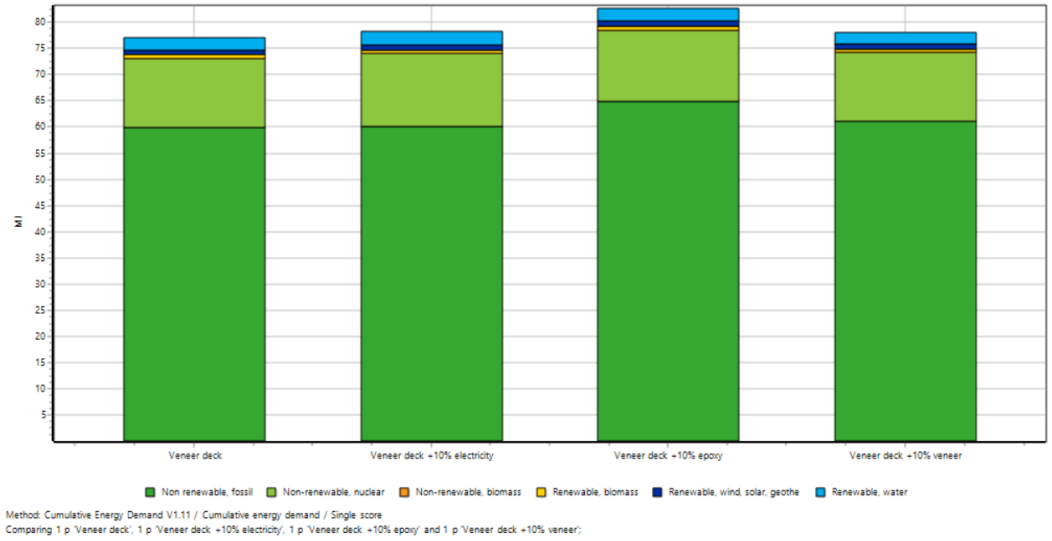


Figure 4.7: CED sensitivity analysis of epoxy veneer deck

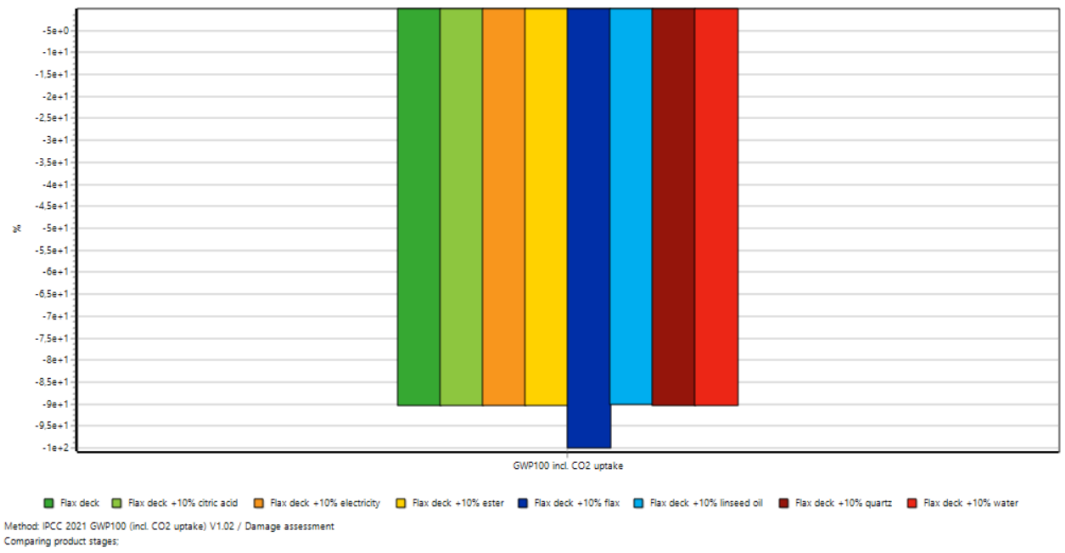


Figure 4.8: GWP sensitivity analysis of bio-resin flax deck

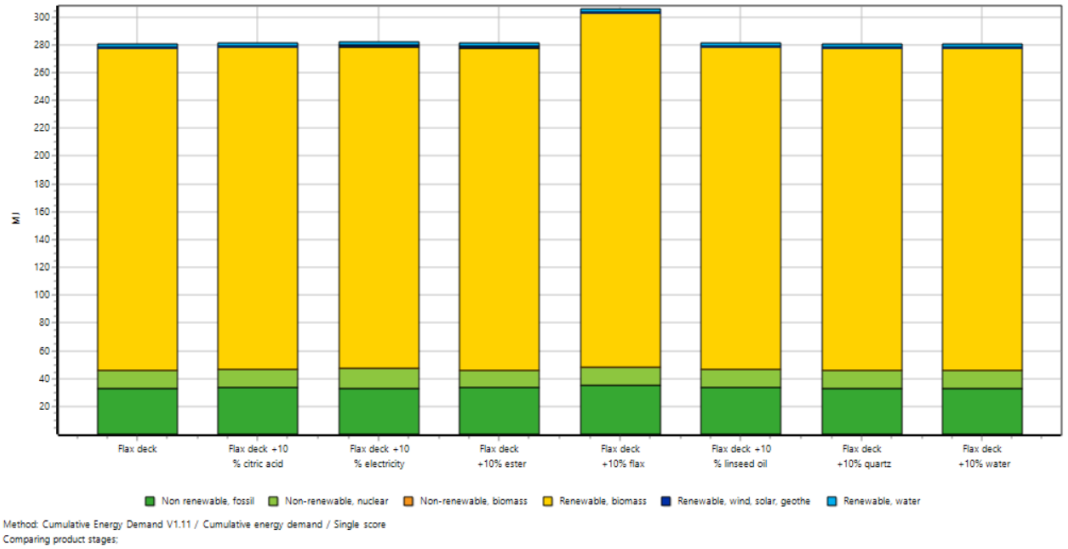


Figure 4.9: CED sensitivity analysis of bio-resin flax deck

Chapter 5

Discussion

5.1 Results

From the testing it is clear that the bio-resin alternatives all had lower performance than the epoxy baseline. Although some reduction in performance was anticipated at the outset of the project, the challenges associated with manufacturing a test panel that maintained structural integrity proved significantly more difficult than expected. Weight is generally not a limiting factor for skateboards, but stiffness remains critical for performance. This suggests that a thicker and heavier bio-resin skateboard with comparable stiffness could be feasible. Yet, when environmental impacts such as increased material usage and energy demand are incorporated as design considerations, the trade-offs between weight, stiffness, and sustainability must be carefully evaluated. For instance, the higher mass of bio-resin-based designs could offset their environmental benefits if production and transport emissions increase significantly.

The Orineo bio-resin is a relatively new product still branching out into more and more products and industries, the given data on Orineo (shown in Appendix A) is focused on it's environmental performance and gives little guidance on how to extract the best adhesion when using the bio-resin. As demonstrated in this report, there are opportunities to optimize the application of the Orineo bio-resin. Both the manufacturing and the mechanical testing highlighted challenges with achieving strong adhesion between the bio-resin and wood veneers, see chapter 3 and respective sections. Addressing these bonding issues, possibly through improved surface

treatments or alternative formulations, could unlock the full potential of the bio-resin by enhancing both performance and consistency. Andreas Trunz also performed tests with different additives and treatments that showed some promise, see fig 5.1.

Figure 5.1: Different treatments tested by Andreas Trunz

Although the bio-resin concept drastically reduces the carbon footprint (GWP_{100}) of the skateboard compared with the epoxy baseline, the higher CED makes the choice less clear cut. Improvements in the manufacturing process, such as reduced curing time and temperatures, would lower energy consumption, directly reducing greenhouse gas emissions associated with production. Additionally, optimised resin usage would minimize material waste, decreasing both the environmental impact of raw material production and waste disposal. Compared to Orineo, epoxy is a more mature product which provides great performance but at a higher carbon footprint. The flax fibres are a significant part of the CED for the bio-resin flax deck, improving and optimizing flax cultivation could show great improvements in reducing the energy consumption of flax fibres.

5.1.1 Key Findings

The bio-composite's lower mechanical properties necessitate a thicker, more material-intensive bio-resin flax skateboard. The GWP part of the LCA shows that the while both concepts are carbon sinks the bio-resin flax deck sequester significantly more carbon. For the CED the energy demand is substantially higher for the bio-resin flax deck, although looking solely on non-renewable energy shows a higher energy demand from the epoxy veneer deck.

Sustainability assessment depends heavily on the chosen environmental indicators. While the bio-resin flax deck showed clear advantages in terms of reduced carbon footprint it's higher CED value reflects trade-offs in other environmental aspects. These findings highlight the importance of selecting appropriate indicators when evaluating the sustainability of materials, asthey can lead to different interpretations and design choices. Even regional variations in analysis can influence outcomes [24]. The original idea of using bio-resin with wood veneers proved unsuccessful due to bonding issues.

5.2 Challenges

The initial idea was to build a full size skateboard deck with alternative materials. Due to prolonged manufacturing difficulties, project time became limited, necessitating a shift to simulating the bio-resin skateboard deck. This lack of a physical prototype and real-world testing data represents a significant limitation. Consequently, practical performance characteristics, such as vibration dampening, perceived deck stiffness, and weight perception, remain uncertain.

From discussions with Cem Koeylueer @ CEM Composites, Andreas Trunz @ Auftriib and Philippe Willems @ Orineo it is apparent that the Orineo bio-resin can work great with wood but that the maple hardwood veneer traditionally used for skateboard construction is too absorbent for a good bond to develop.

5.3 Limitations

One aspect not measured is vibration dampening, an area where flax fibres are hailed for being a great alternative compared to regular carbon fibres, see [25] and even

for a Formula 1 seat see [26]. The current bio-composite concept, primarily using flax fibres, likely already exhibits good vibration-dampening properties due to flax's inherent ability to dissipate energy. However, if vibration dampening were a critical design criterion for a high-performance skateboard used in extreme or competitive environments, the design might need to incorporate a hybrid approach. For instance, carbon fibres or wood veneers could be supplemented with flax fibres to achieve a balance between stiffness and vibration dampening.

An issue with the FEM analysis and the simulation is that the ILSS values are disregarded. This may change characteristics of the simulated skateboard decks. Specifically, neglecting ILSS could lead to an overestimation of the deck's stiffness and strength, particularly in bending and torsional loading scenarios. In reality, lower ILSS values would make the deck more susceptible to delamination under stress, potentially affecting its flex, durability, and ultimate failure load. This simplification means that the simulation results represent a simplified model of the deck's real-world behaviour.

The energy required to make wood veneers can vary greatly depending on the level of moisture accepted as seen here [27] [28], veneer production in the USA requires 6790 MJ per m^3, almost double the 3811MJ per m^3 required in Ghana. It's also worth noting that wood veneer are a quite highly processed form of wood that need a significant amount of energy [29]. This variability in energy requirements introduces significant uncertainty into LCA results. Specifically, variations in energy consumption, as seen in the USA and Ghana examples, can substantially alter environmental impact assessments. Global sensitivity analysis (GSA) [30] can address this input variability by accounting for the range of possible input values. Beyond input variability, the chosen LCA time horizon (e.g., 20 years, 100 years, or infinite) can also significantly influence outcomes [31]. Such uncertainties can affect the comparability of results across studies and regions, potentially leading to misguided conclusions or decisions.

Chapter 6

Conclusions

6.1 Summary of Findings

This study investigated the mechanical and environmental performance of bio-resin and flax fibre composite skateboard decks as a potential sustainable alternative to conventional epoxy and wood veneer decks. From the mechanical testing it was clear that the bio-resin and flax composites fell short in terms of stiffness and shear strength compared with the conventional epoxy veneer deck.

Specifically, the epoxy veneer deck exhibited significantly superior mechanical properties, with an average 3-point bending tension of 164.5 MPa, compared to 35.2 MPa for the bio-resin flax composite and 56.1 MPa for the impregnated bio-resin wood veneer panel. The epoxy veneer deck also exhibited the highest ILSS, with an average of 19.9 MPa, compared to 3.7 MPa for the bio-resin flax composite and 3.0 MPa for the impregnated bio-resin wood veneer panel. These results highlight the superior bonding of epoxy with wood veneers and the challenges in achieving strong interfacial adhesion with the bio-resin alternatives.

The environmental assessment of the skateboard designs using LCA and SimaPro showed that the carbon footprint (GWP_{100}) is significantly lower for the bio-resin option although the CED is higher unless only the non-renewables are counted. Both the epoxy veneer and the bio-resin flax decks are carbon sinks but the flax deck have captured 15,7kg CO_{2eq} compared to 0,836kg CO_{2eq} of the epoxy deck. The CED shows a more nuanced story where the total energy is far greater for the flax deck at 281 MJ compared to the epoxy decks 77,1 MJ. However, a significant portion of the

energy consumption of the flax fibre skateboard deck is derived using renewable energy 234,9MJ, while the epoxy deck consumes a larger portion of the non-renewable energy 73,2MJ as compared to the flax deck.

6.2 Key Takeaway

This study illustrates the trade-offs inherent in sustainable material design. While bio-based composites offer substantial environmental benefits, such as a lower carbon footprint, their mechanical performance falls short of conventional materials. This highlights the importance of balancing sustainability with functionality in product design. By addressing these challenges through innovative designs and optimized manufacturing processes, bio-composites have the potential to become viable alternatives in applications like skateboard decks. Further research focusing on improved bio-resin formulations, surface treatments, and composite layup techniques could bridge the gap in mechanical performance and unlock the full potential of these sustainable materials.

6.3 Future Work

- **More different prototype designs explored:** A sandwich design with a bio-based foam core could be a great alternative. Further examination of different material combinations, not necessarily only using bio-based resins.
- **Testing full scale prototypes:** Simulations rarely give the whole answer and testing of full scale prototypes can give a clearer image of pros and cons of a bio-resin skateboard deck.
- **Manufacturing optimization:** How would scale production look? Would different wood qualities allow easier use of the bio-resin? Would work intensive layering of flax fibre mats need to be automated? Would vacuum infusion allow better control of resin absorption and possibilites of more intricate shapes?
- **End of life alternatives explored:** Would the scenarios be very different using a cradle to grave LCA? Would the bio-based alternatives give better results from a different recycling process than epoxy based composites or could composting be a viable alternative?

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Appendix - Contents

A First Appendix **40**

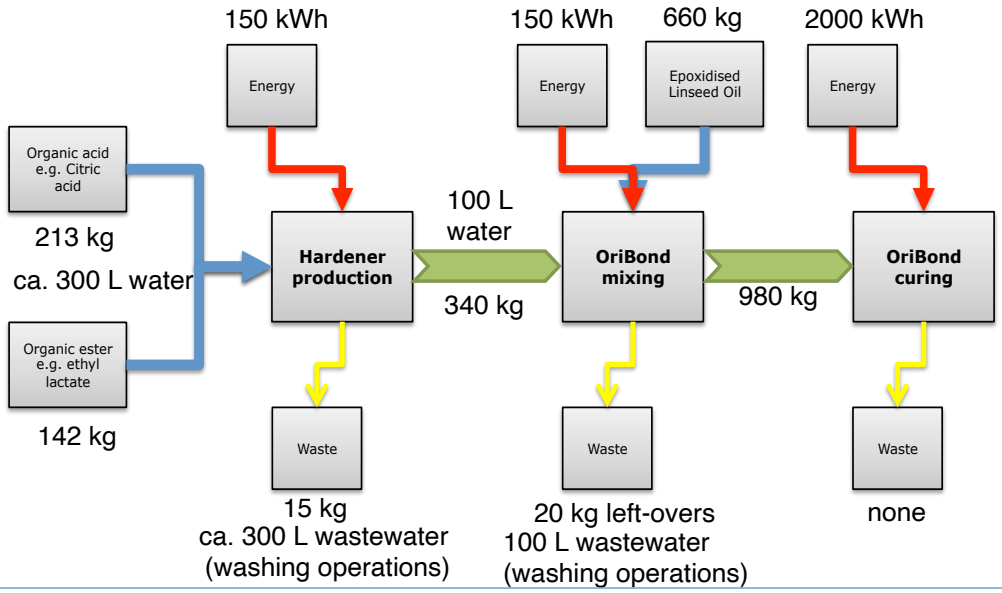
Appendix A

First Appendix

This gives information on the ingredients to Orineo's Oribound

LCA of Oribond: system boundaries

Cradle-to-gate system



- Production of materials in Europe considered
- EU energy mix (baseline) and wind energy (scenario II)
- Infrastructure and labour activities excluded
- Transportation not included
- Apart from gaseous emissions to the air it is assumed that all emissions are controlled as solid waste and effluents will go to wastewater treatment
- Foreground process: primary data
- Background processes: Ecoinvent v3.6 + Literature