Design for Repurposing
Of Composite Products

Master Thesis | Parshva Mehta

ECOBULK

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Author

Parshva Mehta

Msc. Integrated Product Design,
Faculty of Industrial Design Engineering,
Delft University of Technology

Chair

Erik Tempelman

Faculty of Industrial Design Engineering
Delft University of Technology

External Mentor

Irene Fernandez Villegas

Faculty of Aerospace Engineering
Delft University of Technology

Mentor

Jelle Joustra

Faculty of Industrial Design Engineering
Delft University of Technology

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Preface

Here I present you the deliverable of my graduation project from Industrial Design Engineering Masters at the Delft University of Technology. This six-month project was part of the EcoBulk project, granted by the European Union Commission. This project enabled me to look into the different perspectives of design for resource utilization by repurposing and learning from many interesting and inspiring people from different parts of the world with similar goals of design for a sustainable future.

Thank you, Erik, for believing in me and constantly supporting me with your striking enthusiasm and outstanding inspirational talks.

Thank you, Jelle, for always guiding me with your critical designer eye, keeping me on the ground when philosophy took me to the clouds and supporting me with your valuable feedback.

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Thank you, Bart and Safran Cabin, for supporting with the composite aircraft Galley. This project was able to gather all the essential information required to reach the desired goal.

A special thanks to the Eduard (Dassault system), Derk-Jan (AELS), Tanila (Embraer), Mariska (Ampelmann), Mark (Toray), Sarah (Airborne), Mario (Maier), Marcin (Sobczyk), Arun, David for the inspirational interviews and for providing me with insight into the composite market.

I would not have reached here without the constant support and love from my parents. Thank you, mom and dad, for always believing in me.

Maria, Xingyu, Alazne and Nirav, thank you for providing me with endless support and motivational speeches when I needed them the most!

Enjoy the read!

Parshva Mehta

List of Abbreviation

AOM	Aircraft Original Manufacturer
CE	Circular Economy
CFRP	Carbon Fiber Reinforced Plastic
DfD	Design for Disassembly
DfR	Design for Repurposing
EOL	End Of the Life
FRP	Fibre Reinforcement Plastic
LCA	Life Cycle Assessment
OEM	Original Equipment Manufacturer
PLM	Product Life cycle Management

Executive Summary

With the emerging demand for energy-efficient products, the composite material has become a point of attraction for many product manufacturers. Furthermore, with its high strength to weight ratio, long life span, low maintenance and design flexibility, composite materials offer tailored properties by choosing an appropriate combination of reinforcement and matrix material. Being one of the leading users of composite material, the Netherlands is a global player in the field of design, automation, material development and sustainability in the field of high-grade-reinforced plastic.

Recycling of the decommissioned composite material remains underdeveloped research. The current shredding and inefficient recycling result in the loss of material property, struggling to find its scalable application in the market. However, the composite material has a longer life than its entire product, resulting in premature decommissioning of the material due to constant development in the product design. One way around this problem is repurposing. Therefore, there is a need to look for an alternative approach.

Repurposing aims to keep the material alive by utilising its shape and remaining potential in serving an additional product life with a different application. However, the concept of repurposing is undiscovered in the field of composite material.

This graduation thesis aims to create a set of guidelines for industrial designers and companies, guiding them to efficiently utilise the composite material's value with the practice of scalable repurposing.

Further to industrialise and streamline the repurposing practice, there is a need for product lifecycle management, assisting repurposing industrial designers and companies with the set of prerequisite information.

By case study of repurposing an aircraft galley made from the glass fibre reinforced plastic into a bicycle cart for kids, various operations, including disassembly, dismantling and re-manufacturing, were executed to gain a closer look into the repurposing. In addition, different stakeholders' roles in repurposing were identified by conducting interviews with various actors involved in the composite industry. With the help of the theoretical and practical insights gathered during the exploratory phase, the PLM framework and guidelines were formulated focusing on scalable repurposing of the composite material.

A revised set of guidelines was proposed by evaluating the draft guidelines through an interview with the repurposing company and a co-creation session involving various stakeholders, education experts and industrial designers. Based on the evaluation, it can be concluded that the guidelines can serve as a base for implementing the repurposing practice, where the industrial designer can connect the detached stakeholder and guide the implementation of composite repurposing.

However, to make these guidelines well qualified for all the composite products from different sectors, a wide range of case studies should be conducted. Although these guidelines are formulated to support industrial designers to impact repurposing positively, further work is needed to conduct a business model, real case scenario, and policy management to look into the guidelines' pertinency.

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Chapter 0

Introduction

0.1. Initial Problem Statement

With the high strength to weight ratio, low maintenance, and long-lasting life, polymer composite material has found its application in automotive, aerospace, wind energy, and marine industries. However, recycling the polymer composite from manufacturing waste is still under development (Bouw, 2021). In addition, there is still research to be initiated, to recycle the decommissioned products and find suitable market which can consume the recycled grade material.

One way around this problem is repurposing. Many applications of composite material require high-quality standards. When this component is discarded, it has the potential to serve for another product requiring comparatively lower material and mechanical properties.

Some products are made from the sandwich panel containing polymer composite material bonded with honeycomb to improve their mechanical property, This results in deterioration of the composite material when it is separated from the sandwich panel (Leal, 2021). In practice, it is challenging to reshape or re-manufacture the cured polymer thermoset composite material after the decommissioned stage. For an efficient repurposing application, it is propitious to retain the original shape and structure (Ordoñez, 2021).

The discarded composite material must retain the required information for sustainable end-of-life treatment, such as remaining material property and product usage during the decommissioning stage to find the suitable treatment for the old product/ material. As composite material has a long-lasting life span varying from 10-30 years, it is assumed that a material passport can assist the different stakeholders in documenting vital information such as type of material used, manufacturing, service, and maintenance throughout its life (Eijkman, 2021).

With the intense competition and legal issues in many industries, there is a need for an integrated approach where the platform can be designed to improve the inefficiency of the current end of the life process.

Various questions can be raised on what role industrial designers play in the practical and scalable repurposing of composite materials and how can Integrated product designers tackle these problems with a holistic view and creative thinking to add additional life to the composite material's journey before it gets recycled or incinerated.

0.2. EcoBulk Project

ECOBULK project involves multidisciplinary partners coming together to develop new circular technology and strategies applied to the composite products used in the automotive, construction, and furniture sectors (ECOBULK, 2018).

As part of the Horizon 2020 program granted by European Commission, the Ecobulk project was initiated on 1st June 2017 and will be effective till 30th November 2021.

Project partners believe that Composite bulky materials and products are a fast-growing part of the manufacturing industry. Being strong and lightweight composite materials help to reduce weight and material consumption. Although these are notoriously difficult to reuse or recycle, the loss of quality and value makes them economically unattractive. (ECOBULK, 2018)

ECOBULK intends to demonstrate and implementing a new Circular Economy model for bulky composite products in automotive, furniture, and building component industrial sectors, with a high potential of cross-sectoral replicability and transferability to other industrial sectors to promote greater reuse, upgrade, refurbishment, and recycling of these products.

Following are some of the aims of the EcoBulk Project:

1. Design strategies and procedures for the creation of circular designed composite products.

2. Redesigned value and supply chains for the selected sectors to foster upgrade, reuse and recycling of products and parts and material recovery for (re-)manufacturing.

3. New services and business models for the new value chain include collection, maintenance, reuse, tracking and labelling systems. It consists of the integrated Database platform, which can share the value chain data between all stakeholders, including the designers, manufacturers and retailers, waste companies and end-users.

This graduation thesis aims to find a suitable opportunity for the Ecobulk project by creating guidelines and strategies with the concept of repurposing, focusing on polymer composite material. Throughout the project, required information concerning the project were collected through interviews with different partners involved with the Ecobulk project. The result from this graduation project is intended to be shared with the ECOBULK project.

0.3. Research Objective

With the introduction and problem definition, the following primary research questions were formulated:

- How can industrial designers repurpose the polymer composite materials from decommissioned products effectively by utilising the material before recycling or incineration?
- How can we collaborate with different stakeholders from the composite industry to develop the material passport preserving the essential information throughout the service life required for the sustainable end of life (EOL) practice?

Project Objective

- Conduct a case study of repurposing the polymer composite product from its initial life application into a new product, resulting in an extended lifecycle.
- Formulate the list of guidelines for composite product repurposing from the result of the case study to instruct the industrial designers and stakeholders willing to repurpose the decommissioned composite products.
- Design the material passport to provide vital information along the product's journey to industrial designers and EOL solution providers for feasible and viable repurposing.

Academic Relevance

- Implement the Circular economy to improve the EOL of composite products.
- Apply the design for repurposing approach on products utilising the composite material.
- To identify the impediments in repurposing the composite products.
- Discover the need and opportunities for product life cycle management through material passport for sustainable EOL practice.

0.4. Project Approach

The approach for this project was planned (Appendix A.2) considering the 20 weeks, that is equivalent to 100 working days. Considering the limited duration for a big project, the primary objective of the graduation project was to demonstrate the composite product's repurposing with the help of a case study. The double diamond method (British council, 2004) was applied to meet the project objective.

Why the Double diamond model?

To conclude this exploratory research project in a short duration of 20 weeks with the desired result, it is indispensable to have a structured process where the individual stage could provide the required diverging and converging phases. Furthermore, this recognized approach can help understand the nucleus problems and identify the required aspects to solve the problems.

Discover :

The Discover phase aims to understand the composite products and Circular economy in the context of this graduation project. With the existing market research, this phase was utilized to find the suitable sector where the problem will be inevitable in the near future. After selecting the relevant industry for the case study, interviews were conducted with the different stakeholders to recognize the problem and its cause.

Define :

With the insights gathered from the discover stage, the product journey and Stakeholder analysis were conducted to identify the opportunities to introduce sustainable practice in the selected composite product industry. These analyses were also used to formulate the list of essential information required for viable repurposing. The define phase was concluded by selecting the part/product to be repurposed with the help of a product study from the selected industry.

Develop:
The selected product was repurposed during the case study to collect the required insights in order to formulate the repurposing guidelines for composite products, and the case study was concluded with the repurposed prototype. With insights combined from the Define stage and case study, the PLM framework was formulated for feasible repurposing. By the end of the development phase, the draft guideline for repurposing polymer composite material was prepared for evaluation during the co-creation session during the Deliver phase.

Deliver:
The final guidelines were prepared by evaluating the repurposing guideline from the co-creation session and conducting the interview with the repurposing company. The project was

concluded with the recommendation containing the implementation plan for introducing the repurposing in the composite product industry.

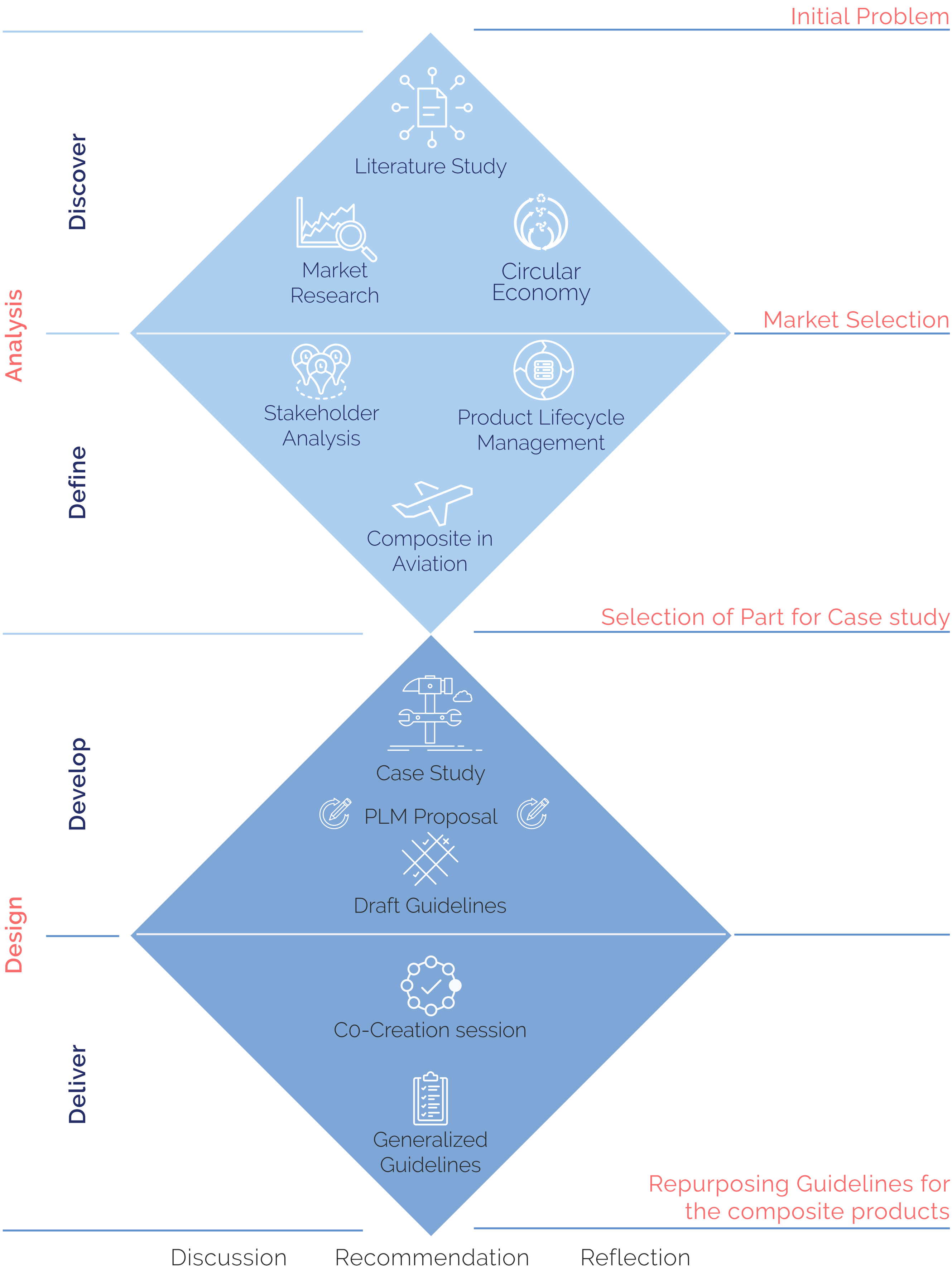


Fig 0.1 Project methodology

DISCOVER

Chapter 1

Discover

With the initial project brief (Appendix A.1), the "Discover" stage aims to collect insights related to the composite industry. Through the literature study, the required information associated with the composite material were gathered. Through market analysis, various industries were analysed to get a closer look into the context. This research facilitated discovering the existing status of the composite market and the scale of the problem to justify the necessary actions. With the literature research and various articles, existing practices to process the end of the life material were discovered. These practices were evaluated with the brief study of circular economy and the value hill model. The evaluation aims to discover the opportunity that has the potential for effective utilisation of the composite material before it is incinerated.

Goal of the Phase:

- Build general and specific knowledge about the composite material and its application.
- Collect the information regarding the current end of the life treatments.
- Identify opportunities by evaluating the present end-of-life treatment with the Value Hill model.
- Select the suitable market for the case study to demonstrate improved EOL practice.

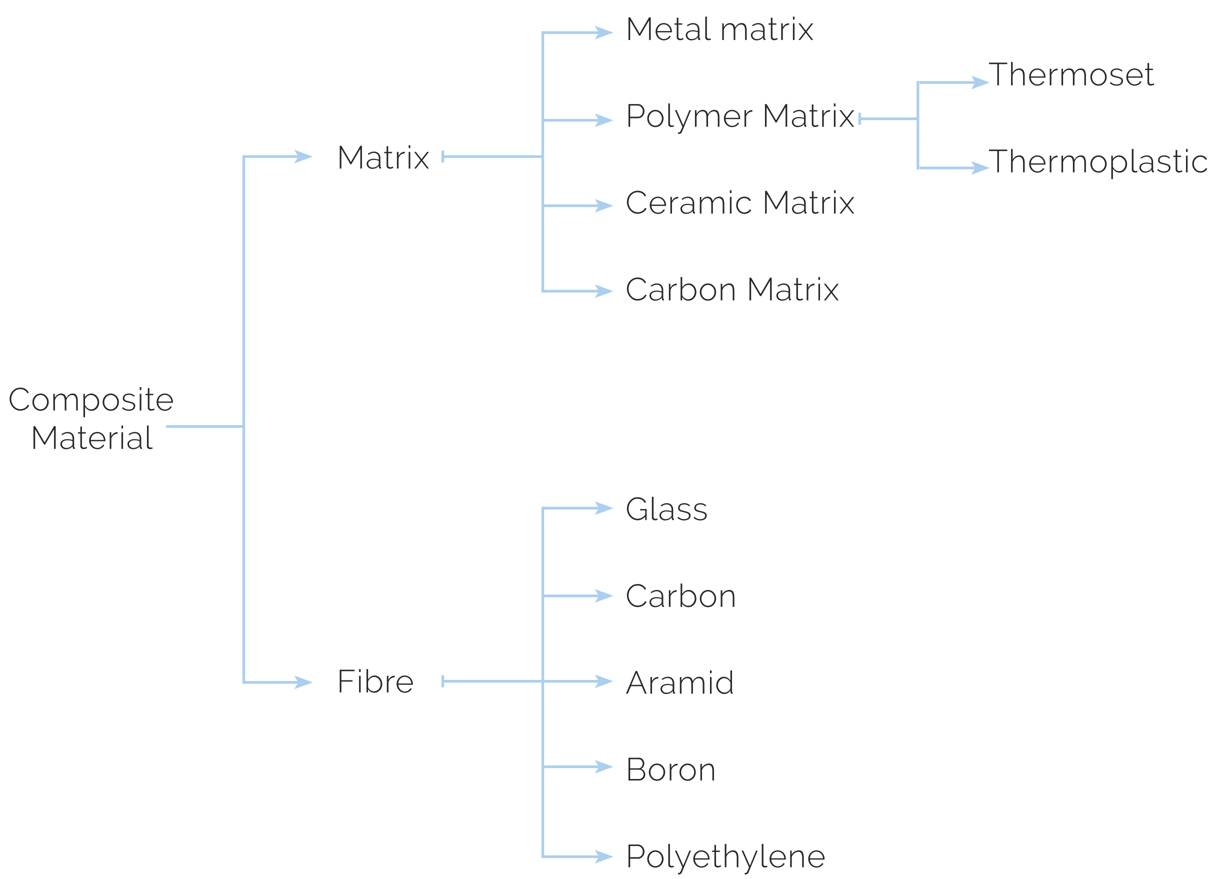


Fig 1.1 Classification of composite material based on material (Aravind et al., 2013; Wanhill, 2017)

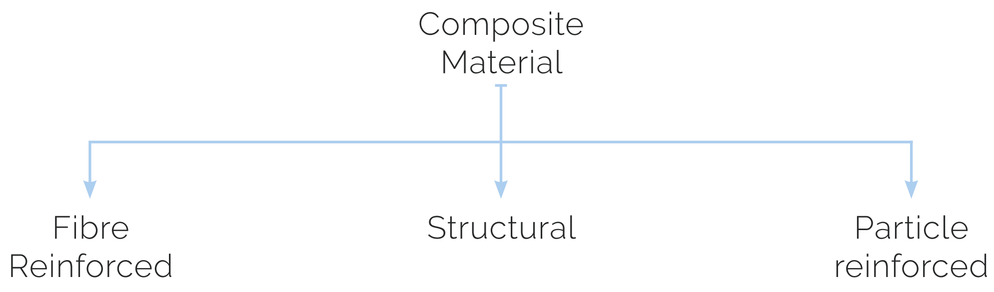


Fig 1.2 Classification of composite material based on structure (Jayaram & Lang, 2013; Park & Seo, 2011)

1.1. Composite Material

This study aimed to gather the basic knowledge required to understand the classification of composite material, its constituents, and primary material properties, which can be used along with the graduation project.

Composite materials can be defined as materials that are constructed of two or more materials to benefit from a combination of material properties. (Royal Society of Chemistry, 2015)

One material acts as a binder, also known as the matrix, which surrounds and binds the other material's fragments, the reinforcement, which can be fibre or particle. (Royal Society of Chemistry, 2015) The matrix phase may be classified as metallic, polymeric, or ceramic materials (Fig 1.1) (fig 1.2). When it is polymeric in nature, it is termed a polymer matrix composite, while a reinforced composite is further classified as a particulate, fibre-reinforced or structural composite (Agarwal et al., 2015).

Classifying composite materials can be done in two ways, namely structure (Fig. 1.1) and material use (Fig. 1.2). The structure describes the way in which a composite is a build-up, whereas the material used describes which materials are used for both the matrix and the fibre (Oudheusden, 2019). Additionally, Fibre reinforcement in thermoplastics has three basic forms: short fibre reinforcement, long fibre reinforcement and continuous fibre reinforcement. (Erden & Ho, 2017).

The report will focus on polymer composite using a thermoset or thermoplastic matrix with glass or carbon fibre reinforcement with the given assignment.

Polymer composites can be altered and provide high strength with low weight, corrosion resistance to most chemicals, and provide highly durable materials under most environmentally severe conditions (Asim et al., 2018). In addition, the composite material can be used to manufacture products having a complex shape and can be bonded with the use of adhesive to eliminate the fasteners, reducing the overall weight of the structure.

Key Insights:

- The composite materials are composed of fibre reinforcement and Matrix.
- Polymer composite material provides a comparatively high strength to weight ratio, resistance to corrosion and long-lasting product life.
- The project will focus on polymer composite materials such as glass fibre reinforced plastic (GFRP) and Carbon fibre reinforcement plastic (CFRP).

1.2. Market Analysis

Market analysis was conducted to investigate the different applications of the composite material. Based on the different insights gathered from the market analysis, a suitable industry was selected for the case study having a series of products, where the end of the life practices needs to be improved in the near future.

In 2018 the estimated global production demand for carbon fibre would increase to 199 Ktonnes by 2022, increasing by more than 40% in 4 years. (Witten and Mathes, 2018). However, With 99% in volume, glass fibre dominates the market size compared to 1% of the carbon fibre market, with the overall composites material market for fibres and resins can be estimated at 3 million tons (Effing, 2018).

Composites provide an opportunity to use the material with high strength, lighter weight and require less maintenance (Yang et al., 2012), making it more attractive for industries such as Aviation, automobile and wind turbines. Additionally, With increasing concern about fuel-efficient use, composite material with high strength to weight ratio is became a point of attraction for material selection (Mangino et al., 2007). With the development in high performances composite, it has found its way into applications of civil engineering, sports equipment, pressure vessel, military and defence and the marine sector. (Fig. 1.3)

Considering the market share of composite by application, aerospace, wind energy, and transportation occupy more than 40% of the market segment. (İşmal & Paul, 2018).

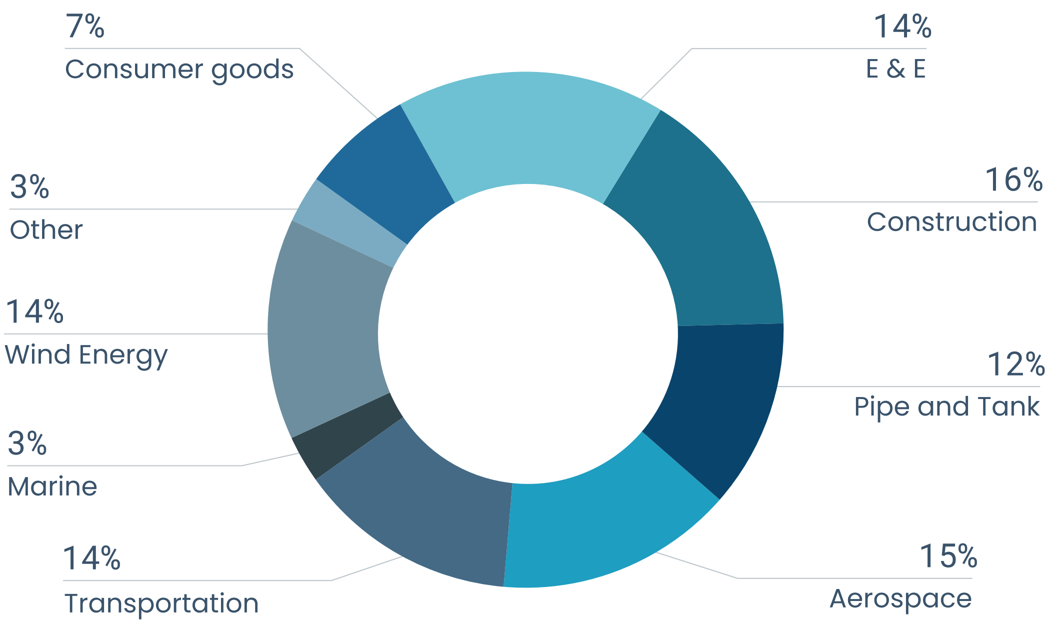


Fig 1.3 Global composite material shipment by market segment (İşmal & Paul, 2018).

E&E= Electrical and Electronics

1.2.1. Automobile

The first application of composite material in production cars goes back to 1953 when the Chevrolet Corvette was manufactured with a fibreglass body. (Mangino et al., 2007). Since those early days, FRP has been used for various automotive applications. Although the Processing time of the composites is relatively long, raw materials(fibres and resins) are relatively expensive, and it can be not easy to achieve high-quality surface finishes. Therefore, more than 50 years on, the application of structural composites in high volume car production is still somewhat limited.

Composite is still a popular choice for the luxurious high-end car model due to its high performance to weight ratio. Some of the examples include the Koenigsegg Regera, the Koenigsegg Jesko, the Koenigsegg Gemera, Alfa Romeo 4C, Corvette C7 and C9 cars. This vehicle involves the entire structural body made of high-performance polymer composite.

With the use of expensive material and high-production time, application of composite is still limited. Due to this, Metal is still a choice of option for mass manufacturers of automobiles. With the Effective use of composite material, automobile manufacturers have again considered the possibility of using it for selected parts. Recent examples involve GMC sierra involving CF pickup bed, Monocoque of BMW i3 (Fig 1.4) and Koenigsegg Regera (Fig 1.5) being produced from thermoplastic composite material.

Fig 1.4 Composite Chassis of BMW i3[1]

Fig 1.5 Koenigsegg Regera carbon fibre body[2]

1.2.2. Energy Production

One of the biggest consumers of composite material can be seen in the wind turbine industry. Wind turbine blades are primarily composed of continuous glass fibre reinforced plastics (GFRP). Technological development has caused a substantial increase in rotor blade size over the past years to increase efficiency. In 1990, 10 meters was a typical size for a wind turbine blade. In 2016, LM Wind Power set the latest record with their 88.4-meter long blade (Breakbulk, 2016).

Recently at Rotterdam port, GE Wind Energy's Haliade-X (Fig 1.6) was installed with a rotor diameter of 220 meters. Each blade weighs around 55 tonnes(Eize de Vries, 2019) and 107 m long (Fig 1.7). Between 2012 and 2021, nearly 1431 new turbines were installed in the United Kingdom, Germany, and the Netherlands. In the U.S. alone, about 8,000 will be removed in each of the next four years from 2020. Europe, which has been dealing with the problem longer, has about 3,800 coming down annually through at least 2022 (Martin, 2020).

Fig 1.6 GE Wind Energy's Haliade-X Rotterdam, The Netherlands[3]

Fig 1.7: 107 meter long composite wind turbine blade[4]

1.2.3. Aerospace

Material science and engineering are an integral part of aerospace engineering, and this sector deals with advanced materials in constructing aerospace structures. The primary needs for all the advanced composites used in aerospace applications remain the same, i.e., lighter weight, higher operating temperatures, greater stiffness, higher reliability, and increased affordability, which can be only achieved with the composites (Giurgiutiu, 2016). With the increasing concern about the sustainability of flight regarding fuel efficiency, passengers aircraft are designed with more and more lightweight composite material (fig 1.8) (Kesarwani, 2017).

In the 21st Century, the use of composites in Aviation has drastically increased. For example, considering the modern passenger aircraft from Boeing 787 Dreamliner and Airbus A350 XWB, using more than 50% of composite by weight and 80 by volume. (Giurgiutiu, 2016). By the end of 2020, more than 1000 787 Dreamliner were sold in the market (Itungu, 2021), each containing approximately 35 tons of CFRP (Onishi, 2012). In addition, more than 16,000 commercial aircraft have been retired worldwide in the past 35 years, and more recently, some 700 aircraft per year are reaching the end of their operational lives (Helping Aircraft Decommissioning, 2021).

The trend is growing over the next ten years. Around 20000 aircraft retirements are expected in the next 20 years (Elsayed & Roetger, 2019).

Key insights:

- The use of polymer composite material in the automotive industry is still under marginal increase.
- The use of composite material in aviation has increased exponentially, whereas the retirement of aircraft is a rising concern.

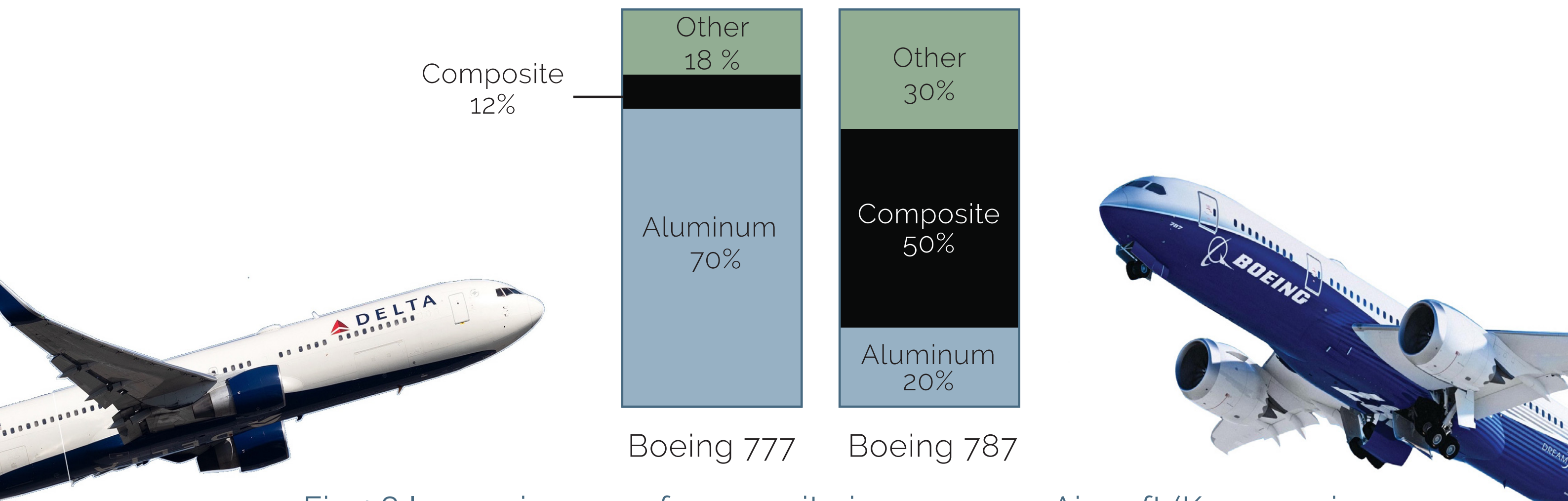


Fig 1.8 Increasing use of composite in passenger Aircraft (Kesarwani, 2017).

Fig 1.9 Wind turbine blades await burial at the Casper Regional Landfill in Wyoming. (Rasmussen, B. 2020)[5].

1.3. End of the life treatment

The FRC industry's growth increased its production and consumption and led to many EoL materials. Currently, the increasing amount and handling of composite waste at their EoL have a negative impact on resources conservation and the environment.

Composite product design is driven by mechanical characteristics improvements, searching for light mechanical structures, and knowing the behaviour during the product life stages (Perry et al., 2012). The inherent heterogeneous nature of the matrix and the reinforcement lead to inferior material recyclability, particularly the thermoset-based composites. Additionally, composite is covered with a protective layer against UV exposure or bonded to additional material such as honeycomb in many applications. This makes post-processing at the end of life much more complex and labour intensive.

There are the monetary and energy costs of recycling the materials compared to creating virgin materials (Oudheusden, 2019). For example, for glass fibre, the price of virgin glass fibres is so low that no process currently available can provide recycled glass fibres with the same characteristics as virgin fibres at a competitive price (Oliveux et al., 2015). Recycled materials are always at a lower value level as they are down-cycled in quality due to the recycling process, lifetime wear, or reduced feedstock element. (Yang et al., 2012) As shown in Fig 1.10, value loss becomes more and more prominent with each backwards step in material recovery (Chawla, 2012).

Efficient recycling of composite (manufacturing waste) is demonstrated at the lab level but many composite products used after 15-20 years of service life are improbable to be recycled back into the industry (Bouw, 2021). As mentioned in Jelle's research (Joustra et al., 2021), most of the composite products find their way back to incineration or Landfilling (Jensen, 2019; Mativenga et al., 2017; Ratner et al., 2020). Although, Landfilling (Fig 1.9) and incineration are undesirable from many perspectives. Landfilling is at the bottom of the Waste Management Hierarchy, banned in an increasing number of countries and prevents further use of the material (Cherrington et al., 2012).

Key insights:

- Recycled material from decommissioned composite products hardly finds its way back into the new life cycle due to the deterioration of material value.
- The most common practice for the decommissioned composite material is incineration and landfilling, where landfilling is prohibited in several countries.

1.4. Circular Economy

It is essential to define the circular economy to locate the composite market in circular business at the initial stage of the project. The circular economy (CE) is a development model that seeks to minimise the negative impact of human activities by applying principles related to the "3 Rs": reduce, reuse, and recycle (Li et al. 2010), to maintain the highest utility and value of products, components, and materials at all times (Ellen MacArthur et al., 2015).

As mentioned in one of the guiding principles of Circular Economy, "Do not repair what is not broken, Do not manufacture something that can be repaired, do not recycle a product that can be re-manufactured. Replace or treat only the smallest possible part to maintain the existing economic value of the technical system." (Stahel, 2010).
The decisive point is to extend the material life and product value for as long as possible, creating an economy that can benefit from products that loop through multiple use cycles (Schild, 2020). The Circular economy action plan 2020 aims to improve how products are designed, promote circular economy processes, encourage sustainable consumption, and ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible (Circular economy action plan, 2020). This initiative focuses on the sectors such as electronics and ICT, batteries and vehicles, packaging, plastics and textiles. However, there are no such policies for polymer composite material.

In a Circular economy, multiple steps can be taken at various product life stages. It is vital to understand the difference and prioritise the action to gain the material's maximum value. From the guidelines provided by PBL

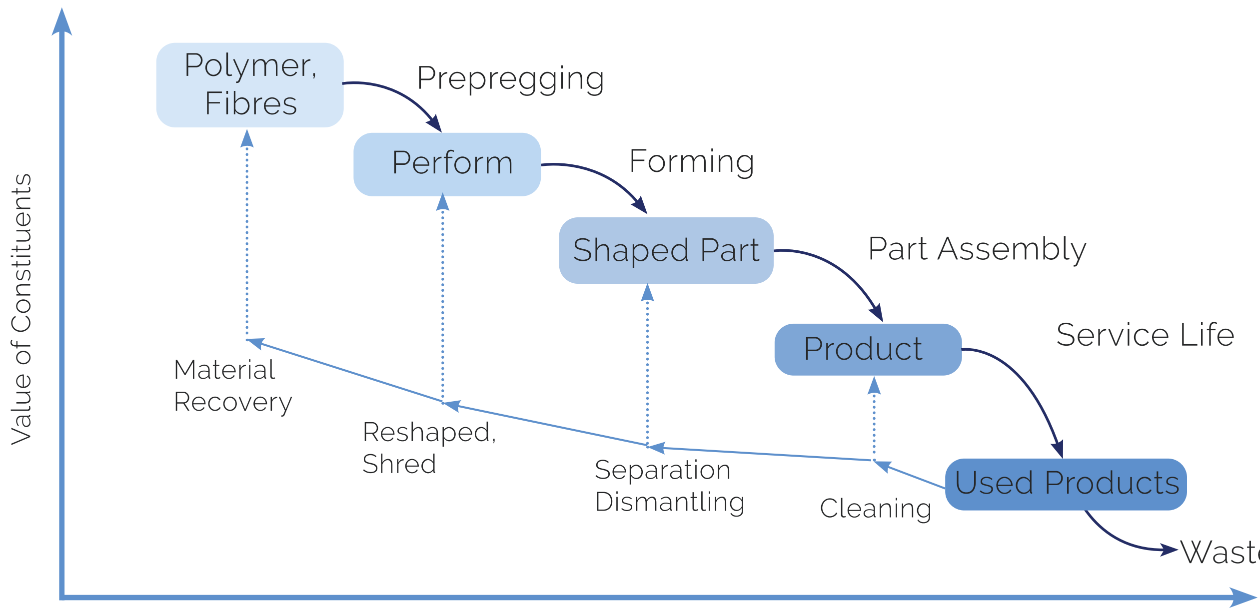


Fig 1.10 decreasing value of material over life (Chawla, 2012).

Netherlands Environmental Assessment Agency, Different steps in the circular economy (Potting et al., 2017) can be categorised as below.

Circular Economy ↑ Efficient use of material value — Linear Economy

Smarter product use and manufacturer	**R0 Refuse**	Preventing the use of raw materials.
	R1 Rethink	Make use more intensive
	R2 Reduce	Reducing the use of raw materials.
Extend lifespan of product and its part	**R3 Reuse**	Product reuse (second-hand, sharing of products).
	R4 Repair	Maintenance and repair
	R5 Refurbish	Refurbishing a product
	R6 Re-manufacture	Creating new products from (parts of) old products;
	R7 Repurpose	Product reuse for a different purpose
Useful application of material	**R8 Recycle**	Processing and reuse of materials.
	R9 Recover	Incineration of residual flow

Table 1.11 CE Guidelines provided by PBL (Potting et al., 2017)

Key Insights

- The material which can be reused must not be recycled or incinerated.
- The circular economy can be introduced by extending the material is utilization.
- There is a need for policy and regulation to introduce a circular economy in composite material.

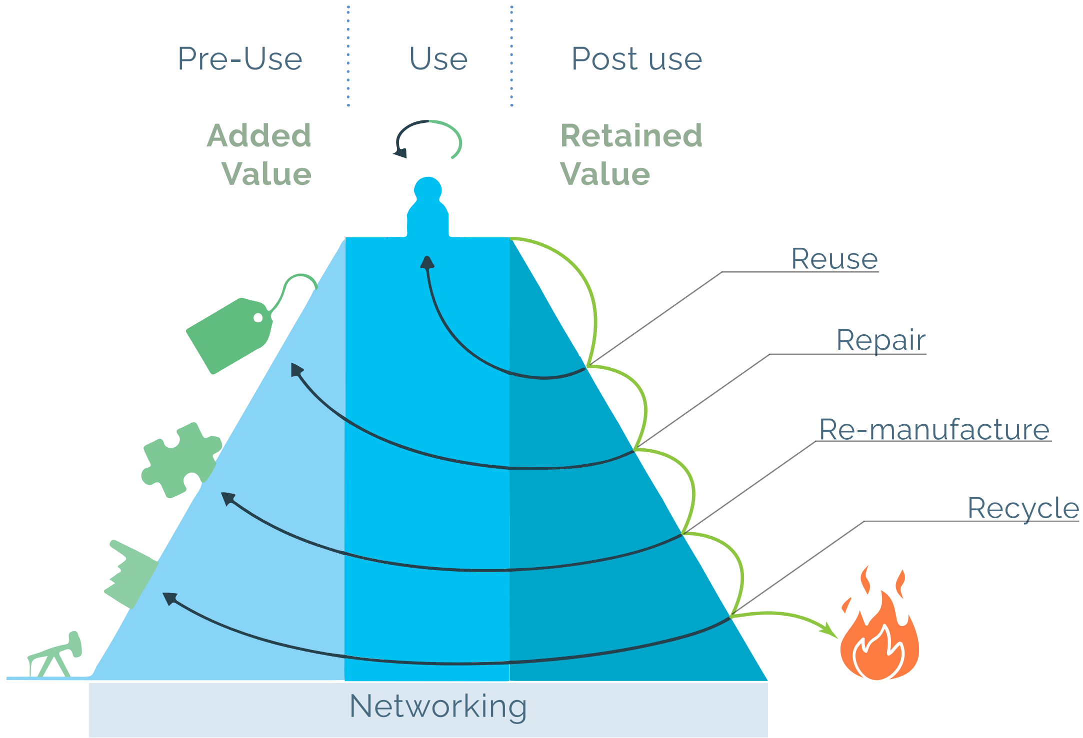


Fig 1.12 Ideal Value Hill (Achterberg, Hinfelaar, & Bocken, 2016)

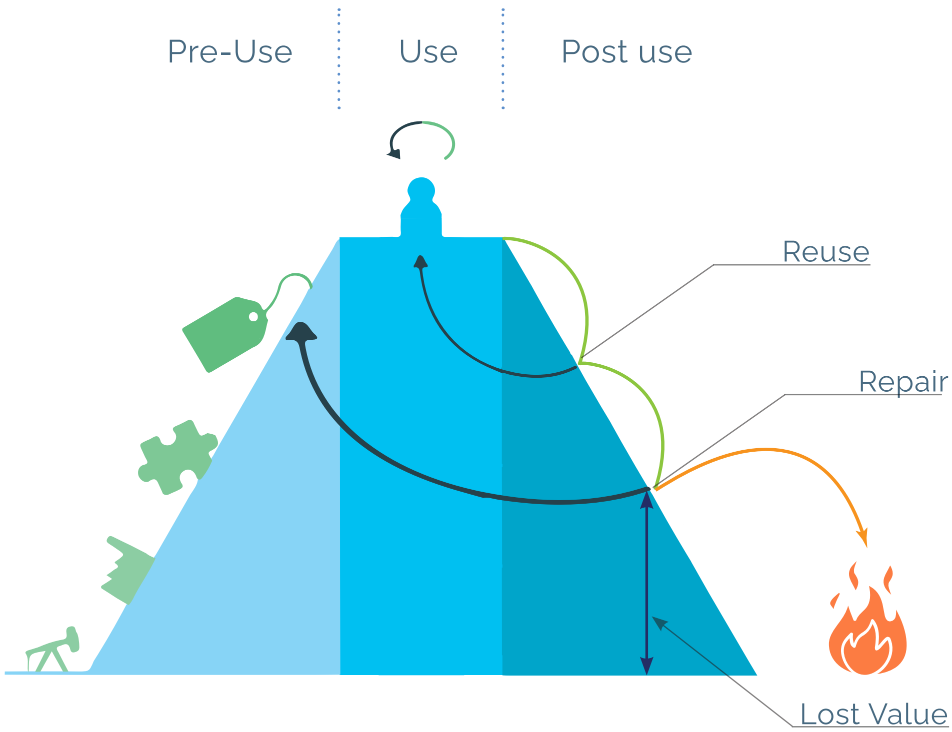


Fig 1.13. Value hill composite products (Achterberg, Hinfelaar, & Bocken, 2016)

1.4.1. Value Hill

By evaluating the composite industry with the Value hill model, the opportunities can be discovered where the end of life of products using polymer composite material can be improved. Looking at the value hill model for an ideal circular product-service system (Achterberg, Hinfelaar, & Bocken, 2016) (Fig. 1.12), It can be seen that the circular Business aims to retain a product's Added Value for as long as possible, if not forever.

Ideal Value Hill (Fig. 1.12) is apportioned into 4 phases: Uphill, top Hill, Down-Hill and Networking. Uphill represent the Pre-use phase, where the value is added to the product during the design, production and distribution phase. The Top hill represents the use phase, where the aim is to keep the product in use as long as possible. At the same time, the downhill illustrates the post-use scenario where the value is lost. Network organisation is the last and overarching category that describes the business activities concerning "the management and coordination of circular value networks". The reader should note that value hill does not represent the loss in value when the material is processed from the Down-hill cycle to the pre-use or use phase, as shown in fig 1.10.

Fig. 1.13 shows the value hill model for the composite industry. When looking at the top hill, composite materials provide long-lasting life compared to other materials. Considering the Down-hill cycle (post use), reuse in aircraft industries is a common and highly preferred practice due to higher economical value in reuse (Heerden, 2021). Decommissioning Aircraft companies resale the used parts to other airline companies. Repairing of composite is often considered as time-consuming and economically expensive.

With the repurposing, efforts have been made at the research level to use the composite for various applications, such as using the wind turbine made from GFRP to use in a low traffic bridge (Speksnijder, 2018) or playground objects at Wikado playgrounds in Rotterdam (Beauson & Brøndsted, 2016).

However, the concept of repurposing in aircraft still requires scalability for further implementation. Most of the composite material is sent to incineration for energy recovery (Interview with AELS, Embraer, Safran), which is considered the least favourable option.

Key insights:

- Products made from composite materials have an extended use phase.
- While considering the post-use phase, material value is lost from the polymer composite products with direct incineration with the missing recycling and repurposing.

1.4.2 Repurposing

Repurposing can be defined as "the reuse of (parts of) obsolete products in a new application, to recapture the value. Whereas design for repurposing can be described as "The circular design (parts) of obsolete products for reuse in a new application, to recapture value." (Schild, 2020).

By implementing the practice of repurposing composite products from its EOL phase, additional life can be awarded to a decommissioned material (or parts). As shown in the repurposing proposal (fig 1.14), rather than directly recycling, incinerating or landfilling, the material (or part) can be used in another application with the relatively less demanding application. In this step, the lost value in direct recycling (Fig 1.12) can be minimised with the extended use of material.

While analysing the various literature defining the guidelines of repurposing (Maas, 2020 and Schild, 2020), repurposed design can have multiple applications, but the goal of a designer is to prioritise the purpose with the feasible, viable and desirable approach. Some of the guidelines relevant to the repurposing of the composite products are as follow.

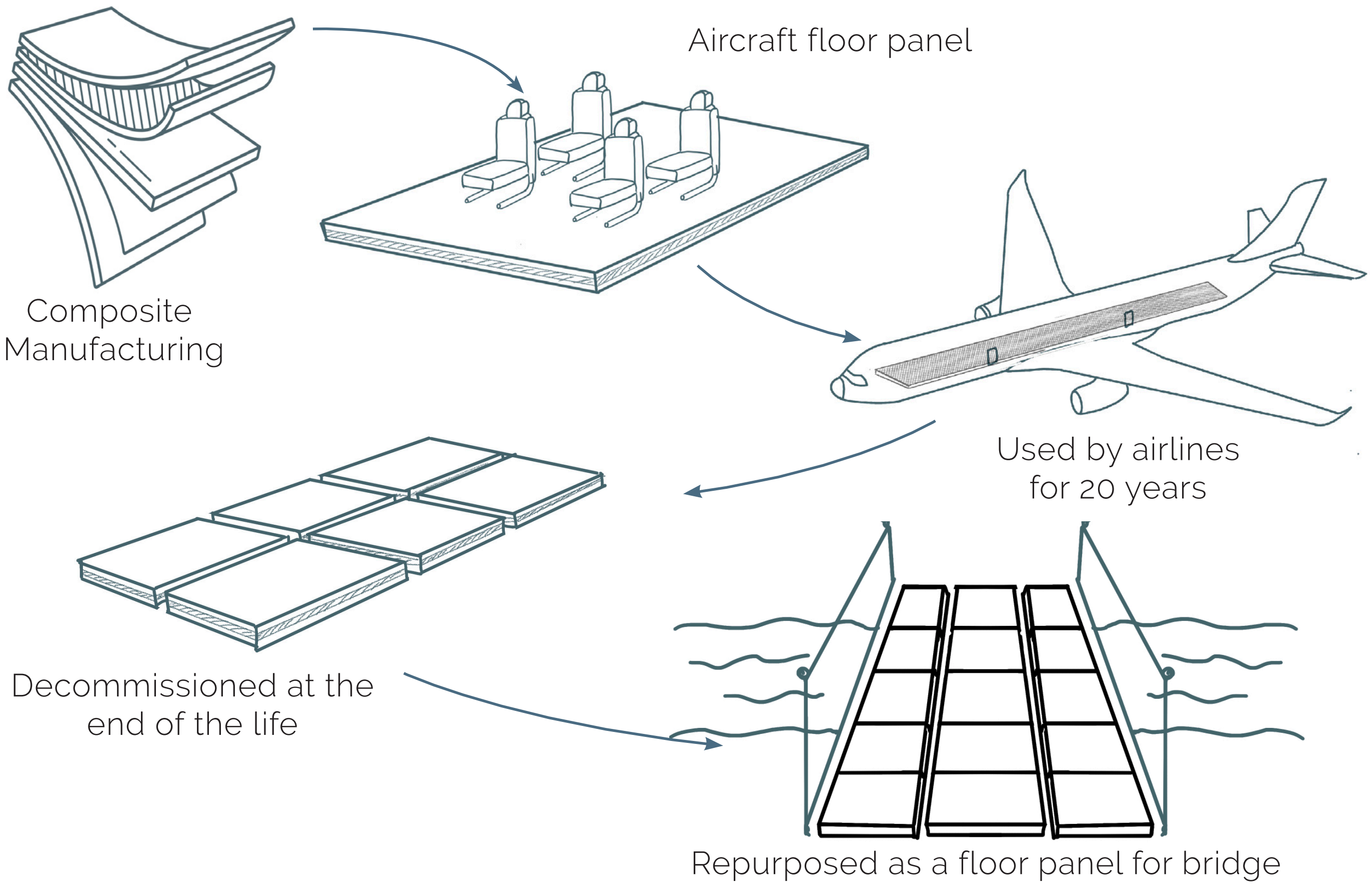
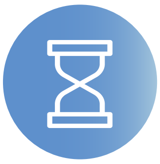
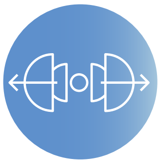


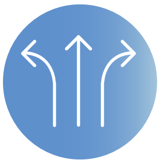
Fig 1.14. Repurposing concept for a composite aircraft floor panel



Time & product:
Finding the moment of obsolescence of an initial product and set the future context



High-Value Function:
Separate the initial product into product/ module/components functions and categorise the highest value products/ modules/ components



Time Bounded feature:
Recognise the context of the initial product that is certain to change over time

Parts and functionality:
Identify the repurposing application which can utilise the maximum value of the initial product's intended function.

Location context/ Need:
Determine the location where the initial product will be decommissioned. Furthermore, the initial product's owner, and one who needs the same material (or product)?

Economical Value:
Minimise the difference in the economic value of decommissioned parts and repurposed parts.

Given that guidelines are formulated for the general repurposing approach for products containing various materials. It is assumed that the composite material requires a distinct approach during the production, sales, use and decommissioning phase. Thus, this graduation thesis will attempt to formulate the guidelines educating the industrial designers and stakeholders focusing on repurposing products made from polymer composite materials.

Scalable Repurposing

The product can be repurposed for another application in two distinct ways: one to one repurposing or scalable repurposing.

- **One to One Repurposing**

In the majority of one to one repurposing at the market level, the waste/ decommissioned product is upcycled into artefacts or limited edition furniture. Artefacts do not take advantage of the material properties, but as part of aircraft, it is used as a showpiece (Fig 1.15). Often it is difficult to sell this product due to its extremely high value and lower demand, and this process is mainly carried out in limed volume.

Fig 1.15. Seat made from engine cowling (Hansen, 2020)[6]

- **Repurposing as mass-produced products**

Mass manufacturing repurposing focuses on producing the products, parts or material in large quantity from the decommissioned product. This strategy requires a solution that can consume a large amount of decommissioned components with its market demands, technology and planning. Additionally, These products/components/materials can be used to replace the products using materials such as plywood, sheet metal, sold in huge quantities. Therefore, we will call it the scalable practice of repurposing.

Why Scalable Repurposing:
The project's primary objective is to involve the repurposing in a circular economy by utilising the material property, which is lost in the incineration. With the predicted number of decommissioned composite material in the coming future, it is crucial to create the process which can utilise a large number of products. Though Artefacts create a high value of the individual product, the amount of decommissioned product it can repurpose is extremely insignificant. Thus in the context of the project, it is necessary to focus only on scalable repurposing.

Key insights:

- By reusing the absolute products/ parts after decommissioning phase, lost value can be recaptured via repurposing.
- There is a need for a list of guidelines focusing on repurposing the products made from composite materials.
- In order to utilize the extensive amount of predicted decommissioned material, it is crucial to focus on scalable repurposing.

1.5. Conclusion

During the discover phase, information regarding the composite material and end of the life treatments related to it were collected and analysed.

While looking at the composite market, it can be seen that the aviation industry is by far one of the leading consumers of it. With the increasing use of high-performance composite in passenger aircraft like Airbus 353 XWB and Boeing 787 Dreamliner, there will be a need for a sustainable approach where efficient practice for decommissioned polymer composite parts will be the centre of focus. Compared to other industries, manufacturing of these parts requires a relatively higher quality of composite materials. At the same time, the recycled material made from the decommissioned composite material is still not a feasible option. Thus, The aerospace sector was selected to demonstrate the process of improving end of life treatment through the case study.

While looking at the different approaches towards the end of life treatments proposed in a previous chapter, repurposing can be considered one the most favoured and unaccounted practices in utilizing the material value before it goes into incineration. Scalable repurposing has the potential to regain the maximum amount of value before this high-performance composite material goes into incineration or landfilling at the end of life.

Guidelines formulated in the existing literature originates from the various repurposing examples that scarcely exemplifies the composite materials. Varying the performance of these composite materials and mode of applications requires modified repurposing guidelines, the different stakeholders in utilizing the life of the polymer composite material via repurposing.

DEFINE

Chapter 2

Define

The collection of the information from the Discover phase gave the project a broad view of the composite products, market, and end-of-life treatment. The Discover phase concluded with extensive research directing toward the improvement of the EOL practice via repurposing.

During the Define stage, multifarious interviews with various stakeholders from the aviation sector were conducted to identify the core problems, which prevents the efficient and sustainable EOL treatment of the products made with composite material. From the insights gathered from the Discover phase and stakeholder interview, a proposal was formulated for a material passport describing the vital information needed for effective repurposing. The Define phase concluded with the selection of composite parts through brief component research for the repurposing case study to be conducted in the development phase.

Goal of the Phase:

- Gather the insights needed for scalable repurposing from Lifecycle analysis and Stakeholder interviews
- Identify the composite part to repurpose for the case study, which is relevant and lies within the scope.
- Formulate the Product Lifecycle Management proposal for efficient repurposing.
- Formulate the problem statement for the development stage.

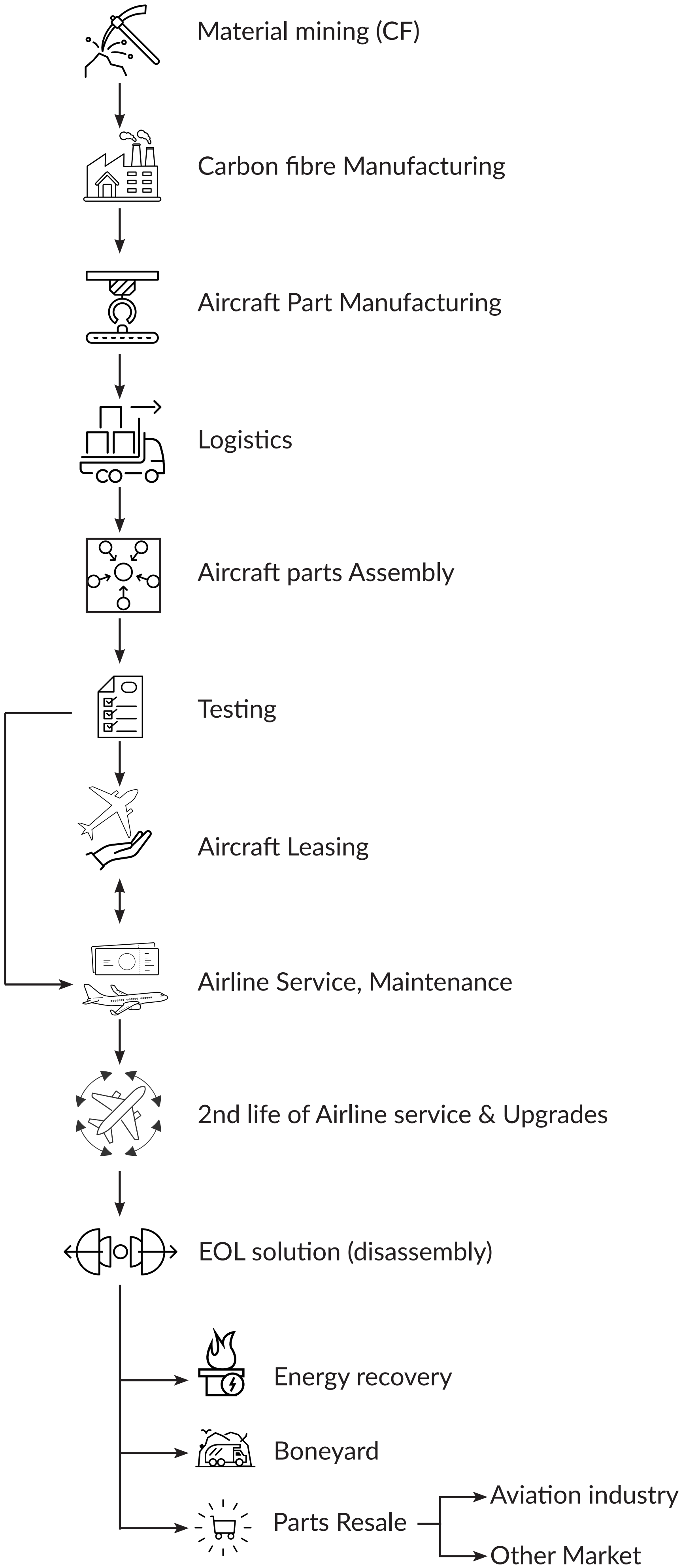


Fig 2.1. Aircraft Life cycle

2.1. Life Cycle Analysis

Product life cycle analysis aims to understand the various phases of a passenger aircraft its entire life, starting from material mining till the incineration phase. These insights were used to understand which type of information from the pre-decommissioning phase is needed for the scalable repurposing of the composite material.

An average passenger aircraft's minimum life expectancy is expected to be around 20 years (Camilleri, 2018). The material used in an aircraft goes through multiple stakeholders during its entire life cycle (Fig 2.1). Thus, it is vital to understand the stakeholders involved to define the core of the problem. This analysis assisted the project in identifying the stakeholders interested in solving the problem and who can be more influential towards the project's outcome.

By identifying the problem owners and stakeholders to solve the problem, the project can get the direction towards a more pragmatic solution. This study also directed the project in conducting interviews with potential experts from the aviation industry to verify the previous literature study by comparing it with the present industrial practices. The study focuses on the composite parts used in passenger aircraft.

Design phase:

Composite parts are designed to reduce the aircraft's weight for fuel-efficient and lightweight products during the development phase. This development phase is an extensive and incessant process. At present, the parts are not designed for repurposing or sustainable end of life (Mooij, 2021) (Smet, 2021),

Material mining:

The life cycle starts with the extraction of the raw materials sent to the manufacturing companies producing the fibre resin and matrix.

Composite production:

Matrix and reinforcement are manufactured at this stage and supplied to different manufacturers all around the globe.

Aircraft equipment manufacturing:

Most aircraft's parts are manufactured with outsourcing to original equipment manufacturers (OEM) (Smet, 2021). In contrast, some parts are produced by the parent company itself. The part property defined by the matrix and reinforcement material composition is often guided and governed by the OAM (Heerden, 2021). Some parts are also bonded to Aluminium or Nomex honeycomb structures with the help of adhesive to form a sandwich panel.

Logistics:

Post manufacturing, these parts are sent to the assembly line of the entire aircraft. As some of the vendors are located around the world, parts are shipped with various transportation modes.

Aircraft assembly:

All the individual parts are gathered at the assembly line, assembled in a systematic order. All the parts are registered to the parent aircraft using their part number. Post assembly, some parts are coated with an additional layer for protection against UV light.

Testing and certifications:

For safety precaution, each aircraft goes through testing and certifications before coming into service.

Distribution :

Nearly half of the aircraft's flying at present are leased by airlines from a leasing company for several months to several years. Post use aircraft are returned to the leasing companies defining them as aircraft owners for most of the use phase.

Use phase:

Passenger aircraft spends most of their life span serving in the airlines. During the use phase, an aircraft performs continuous landing and take-off operations. Notably, these conditions play a significant role in defining the life of individual parts (Smet, 2021). Often Interior parts are modified according to the airline demands, such as to suit their brand identity or meet their customer's changing needs (Monterio, 2021).

Maintenance:

The maintenance of aircraft is either performed by the airlines or an external service provider during the use phase. Maintenance contains inspection, repair and replacement of aircraft parts.

Reuse:

After the aircraft's initial use, it is either sold to the EOL solution providers or another airline where it serves its additional life.

End of the life:

Once the aircraft is decommissioned from its service, It is sent to the EOL service provider. Post decommissioning entire aircraft is parked and stored at the facility of an EOL service provider. Usable parts which can be sold again are disassembled and stored in the warehouse (Gastellu, 2021). The use-able parts are again sold to the airlines in case of replacements. When the composite part can not be sold again, it is sent for incineration. Large parts are shredded for ease of transport and processing (Heerden, 2021). EOL service has to ensure that these decommissioned parts do not find their way back into aviation due to safety concerns (Heerden, 2021).

Key Insights

- Based on the current practice, aircraft parts are not designed for repurposing during the design stage of the lifecycle.
- Aircraft spends most of its service with airlines.
- EOL service providers direct the decommissioned aircraft components towards the suitable option of reuse or incineration.

2.2. Stakeholder Analysis

The aim of the stakeholder analysis was to collect insights from the actual industrial practices compared to the literature review. Additionally, this analysis provides the requirement of the different stakeholders to achieve the scalable repurposing practice.

2.2.1. Key Stakeholders

Aircraft Owner

- Aircraft owners are legally obliged to handle the EOL of an aircraft. (Heerden, 2021)
- At different stages of its life cycle, the aircraft owner can be airlines, Leasing companies, second-hand users, private owners, or EOL service providers.

Material providers:

- The material providers give basic information on the raw material used to produce polymer composite products, which is often provided on their website open to public use.
- However, this information does not contain the exact composition of the raw materials, which can be considered helpful in decommissioning stage. (Bouw, 2021)
- For some OAMs and OEMs, the material provided is the government with the restricted use where the material is prohibited from going outside the manufacturing company before it has been cured. (Leal, 2021)

Original Aircraft manufacturer (OAM's):

- OAM owns the material and design data. (Heerden, 2021)
- OAM aims to increase the use of composite material for the cost-effective and fuel-efficient operation of a passenger aircraft.
- The present focus for OAMs and OEMs is to recycle the composite waste generated during manufacturing. (Mooij, 2021) (Smet, 2021)

- With the upcoming regulation regarding producer responsibility in aviation, Aircraft manufacturers have started to look into sustainable aircraft management by collaborating with EOL service providers. (Leal, 2021)

Government:

- The government and political organizations such as the European Union can play a crucial role in the handling of EOL waste from aviation with taxation and various legislative regulations.
- The government's regulations and guidelines highly influence EOL solution providers and aircraft manufacturers' actions and initiatives.
- Subsides and research grants for recycling or repurposing are decided by the government or political organization.

Airlines and Leasing company:

- Airlines and leasing companies operate the aircraft's service phase.
- This stakeholder decides the decommissioning of the aircraft from its service and maintenance.
- The majority of information collected by EOL solution providers are transferred by Airlines and OAM's. (Heerden, 2021)

EOL solution providers or Boneyard owners:

- EOL solution providers are responsible for dismantling and disassembling the aircraft parts as service/own business. (Heerden, 2021)
- Their interest lies in gaining the maximum profit from the aircraft parts(bought at a cheaper cost) (Heerden, 2021)
- These service providers seek to extend material data for a better EOL solution. (Heerden, 2021)

2.2.2. Stakeholder Interview

Following are some of the outcomes from the various interviews undertaken with stakeholders from the aviation sector.

Material Provider:

"Recycling Thermoset Material is yet to be discovered. Companies are still working on recycling the aircraft EOL composite waste, but it is at the initial phase of development. The recycling output is often downgraded, so it very challenging to find its way back into the same application." (Bouw, 2021)

- Technical Service Manager, Toray

Original Equipment Manufacturer:

"During the production of aircraft parts, a major concern is given to the minimisation of the manufacturing waste as it is significant in amount. During manufacturing, the possibility of part rejection is minimal. However, if it occurs, it goes into incineration. The manufactured parts do not have a defined expiry but depend on the service phase and environmental aspects. Due to the demanding conditions and safety concerns, these parts are replaced before they reach the fatigue limits." (Smet, 2021)

- Project Manager, Airborne

Original Aircraft manufacturer :

"During the production of aircraft parts, a major concern is given to the minimisation of the manufacturing waste as it is significant in amount. During manufacturing, the possibility of part rejection is minimal. However, if it occurs, it goes into incineration. The manufactured parts do not have a defined expiry but depend on the service phase and environmental aspects. Due to the demanding conditions and safety concerns, these parts are replaced before they reach the fatigue limits." (Smet, 2021)

- Senior Researcher, Composite R&D, Embraer.

EOL solution provider:

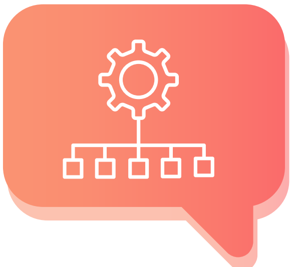
“Priority of the EOL solution providers lies with the maximum profit from the decommissioned parts to sell it for reuse. The material value of the product is negligible but increases over time. Existing repurposing strategies, including upcycling, is yet not feasible and lacks asset management. If there is no demand for the composite material from airlines, they are sent for incineration due to storage costs. For efficient handling and recycling of waste material, some data regarding the material is still restricted to aircraft manufacturers.” (Bouw, 2021)

- CEO, AELS, Netherlands

Offshore Composite gangway manufacturer

“We have started to look into the end of life possibilities to improve our new products’ sustainability from the design phase. The products are leased to the clients giving full control of the management and monitoring of the gangways. Information concerning the life span of the product is monitored throughout its service. The second life application is yet confined within the same industry, but if better repurposing options are available, the team is open to explore new possibilities.” (Rooijakkrs, 2021)

- Project manager, Ameplmann



Product lifecycle management:

“PLM software has the potential to improve the end of the life treatments significantly. The system’s versatile nature can be connected to any software using plug-ins based on the user’s workflow. This software can also act as a material passport to collect and manage the information necessary to transfer from one stakeholder to another. With the life cycle assessment, it can help to improve the footprint of the product.” (Eijkman, 2021)

- Industry Process Consultant, Dassault

2.2.3. Stakeholder analysis conclusion:

Conducting several interviews from the aviation industry helped the project gather insights into present practice and verify the information from literature study. It also provided the information essential for the repurposing and difficulties that may be faced during repurposing.

In the life cycle study, it can be seen that critical stakeholders, before the product go into repurposing, will be OAM's and EOL solution providers. Leading EOL solution provider Tarmac Aerosave have the OAM companies as a stakeholder. With the collaborative plan, these organisations can develop effective repurposing strategies to improve the EOL waste management of composite materials without concern about their products' intellectual property. In contrast, there is still a need for collaboration between the other EOL service providers with OAM. The most influential stakeholder that can be considered here is the government. With the necessary regulations, the government can enforce the Aircraft owners to monitor and improve premature incinerations. While looking into the upcycling companies, there is still a need for scalable plans which can turn the repurposing into desirable solutions.

Key Insights

- OAMs govern the specification defining the material property and the product specification through the intellectual property.
- Within the current practice, recycling is seen as under-development practice at the lab level for the decommissioned composite aircraft components.
- PLM software providers have the potential to create a platform that can be used to collect valuable information required for the repurposing.
- For the repurposing, changing the shape of the existing product seems difficult to achieve, especially for the product made from a thermoset composite material.

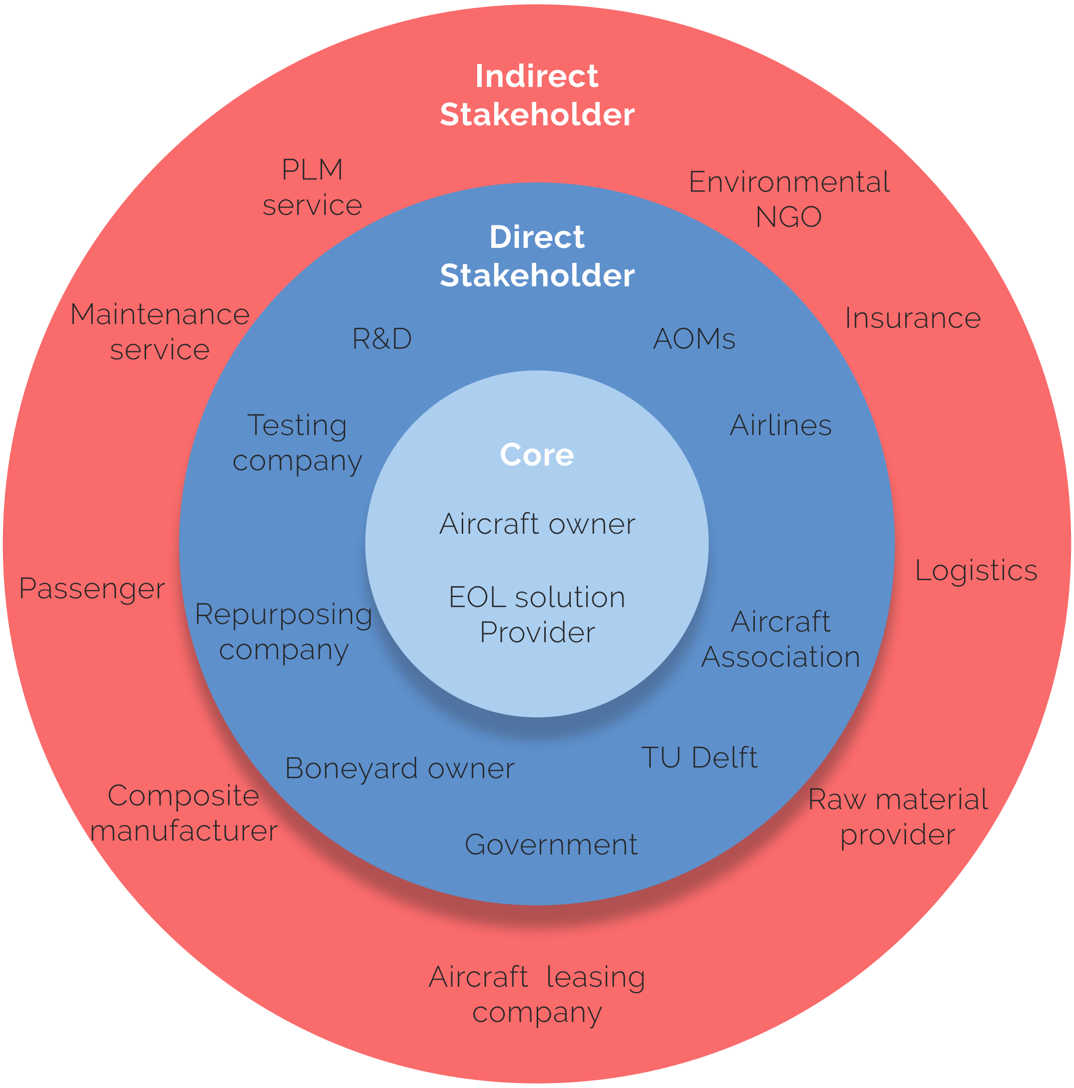


Fig 2.2. Aircraft Stakeholders

2.3. Material Passport

What is Material Passport ?

What is a material passport:
Material passport can be defined as a value tracking tool that brings back residual value to the market. (Hoosain et al., 2020) It is a tool that various stakeholders can use throughout the value chain to document and track the full circular potential of materials, products, and systems by supplying the subsequent stakeholders with accurate information on diverse aspects of the products' circular design. (Luscuere, 2017)

Material passport is getting importance in the different market. A notable example of this can be seen by the Maersk Line (Ellenmacarthur, 2020) and the EU project BAMB (Matthias et al., 2019). This initiative demonstrates the use of the material passport to expedite the recycling and reuse of materials to achieve the circular economy (Jalava et al., 2021).

Why material passport:

For sustainable business, it is necessary to create a viable and feasible repurposing strategy. The material passport can be a vital tool to provide the OAM and repurposing companies with the necessary inputs. For a successful repurposing, a Material passport can provide a digital platform where the product's information can be collected from the initial phase of product life and is passed along from the stakeholder to stakeholder. Once the repurposing product designer has this information, they can effortlessly examine decommissioned composite products, conduct the necessary design evaluation, and repurpose the same product for its second life. Beyond repurposing, this platform can further contribute to the implementation of a circular economy.

With the help of a material passport, the collective data can also help the composite part designer conduct the life cycle assessment by providing the necessary information to OEM and OAM as feedback for design improvement of their composite products. At present, the end-of-life service provider's data from the maintenance is pills of papers (interview AELS). With the digital passport, this knowledge transfer can be more structured and resourceful. The collaborative effort can result in an accelerated circular economy.

Often there are intellectual properties involved in the industry, restricting the vital data are restricted to specific stakeholders. Combining PLM software with a material passport provides the platform where selective access can be given to individual stakeholders and keeping the data safe. OAM's can decide which data needs to be collected or provided to specific stakeholders. With EOL solution providers getting access to the necessary information, the repurposing proce-

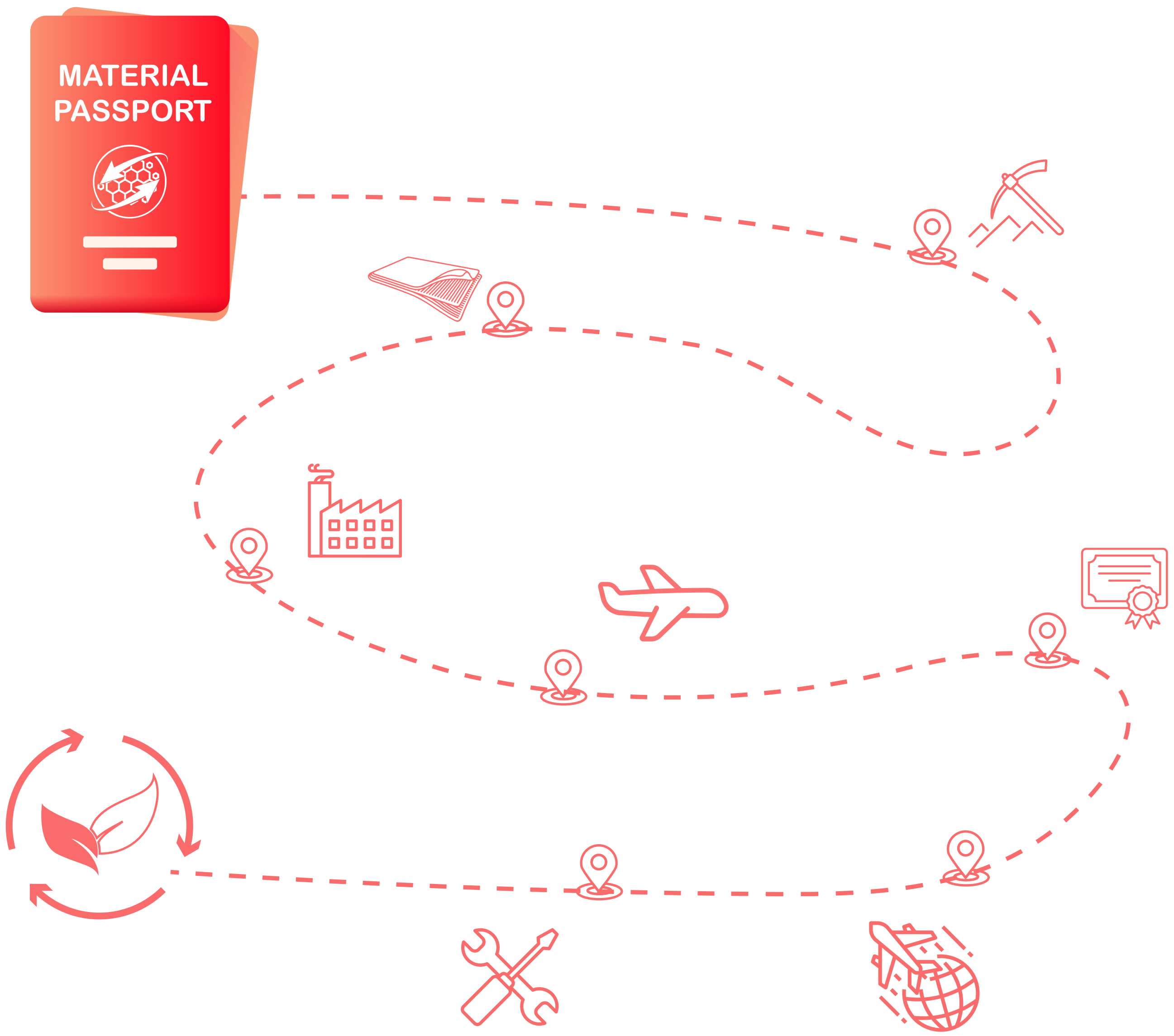


Fig 2.3. Material passport

dure can be accelerated to multiple applications by knowing the provided estimated potential left in the material and preventing premature incineration.

Based on the stakeholder analysis and product life cycle analysis, the following type of data should be provided in material passports from the assigned to individual aircraft parts to enable scalable repurposing.

Material mining:

The origin and compositing of raw material can be collected from material mining companies. This data can assist life cycle assessment in evaluating the overall impact of the material.

Composite material manufacturing: The nature of material composition collected in the material passport can help the EOL solution providers find the best practices for waste management. The material composition can also avoid the hazardous material ending up in repurposed products. The database can also include the bonding strength, property of adhesive and strength of the composite sandwich panel. This information can help in selecting a suitable repurposed solution.

Original equipment manufacturing:

With the OEM providing the manufacturing method, quality certification, and CAD model, the decommissioned part processing can be accelerated.

Logistics:

Throughout life, the logistics of individual aircraft equipment and part can provide a closer look into the environmental impact of each part's overall life cycle. Assessing this data during the LCA study can help to improve the repurposing plan.

Original aircraft manufacturer:

Bill of material and Product data management provided by OAM companies can help the database to locate the individual parts origin, placement in aircraft and present location around the globe.

Airline Service:

The use of aircraft determines the life of the product. By providing the information about the usage, the airlines can help the database and repurposing companies to predict the decommissioning period, resulting in structured resource management.

Maintenance:

The maintenance phase can include the data regarding the repair procedures, testing results, and the aircraft part's replacement.

In the later stage, combining insights gathered from the case study along with the above information, the revised PLM framework will be formulated.

Key Insights

- Combining the Digital Material passport with the PLM system can assist the repurposing designers in effectively repurposing the polymer composite material.
- Not sharing Intellectual property with the repurposing company can create a knowledge among the different stakeholders.
- Material passports can assist the OAMs and OEMs in assessing the entire life cycle of the product and individual components.

2.4. Composite part selection :

In order to conduct the case study, suitable product was to be selected from the various product used in the aviation industry. In brief, several aviation parts were explored with the part study, and various organizations were contacted to obtain the part as a sponsorship. Then During the case study, the selected product would be disassembled and dismantled to collect the insight for the draft repurposing guidelines.

2.4.1 Composite products in aviation

In aviation, composite products are used in structural as well as interior parts. As shown in fig 2.5, the composite product is used to manufacture several components ranging in the Structural members from the fuselage, engine cowlings, wings to interior components such as overhead bins, side-wall panels, aircraft galley and floor panels. Here the goal of the project is to select the component which can satisfy the requirement mentioned above.

Additionally, collecting the aircraft component, one has to make sure that it can not be illegally used back in aviation (Leal, 2021). Thus, the product is given after living minor marks, as shown in fig 2.4. By contacting several companies around the Netherlands and Brazil, different manufacturers suggested conducting fast-track research to determine a product that will be more suitable for repurposing. As indicated in the selection criteria, the product should be an appropriate size.

Additionally, the project's goal was to create a scalable repurposing. Thus, selecting the product that is sold in a more significant quantity creates the possibility of finding the mass manufacturing repurposing solution. Thus, comparing different parts based on their size and quantity, it was concluded to go for interior products. Additionally, getting the product-related specification from the composite interior product is more accessible than structural components.

Fig 2.4. Aircraft seat back with discarding mark donated from Aeroworks

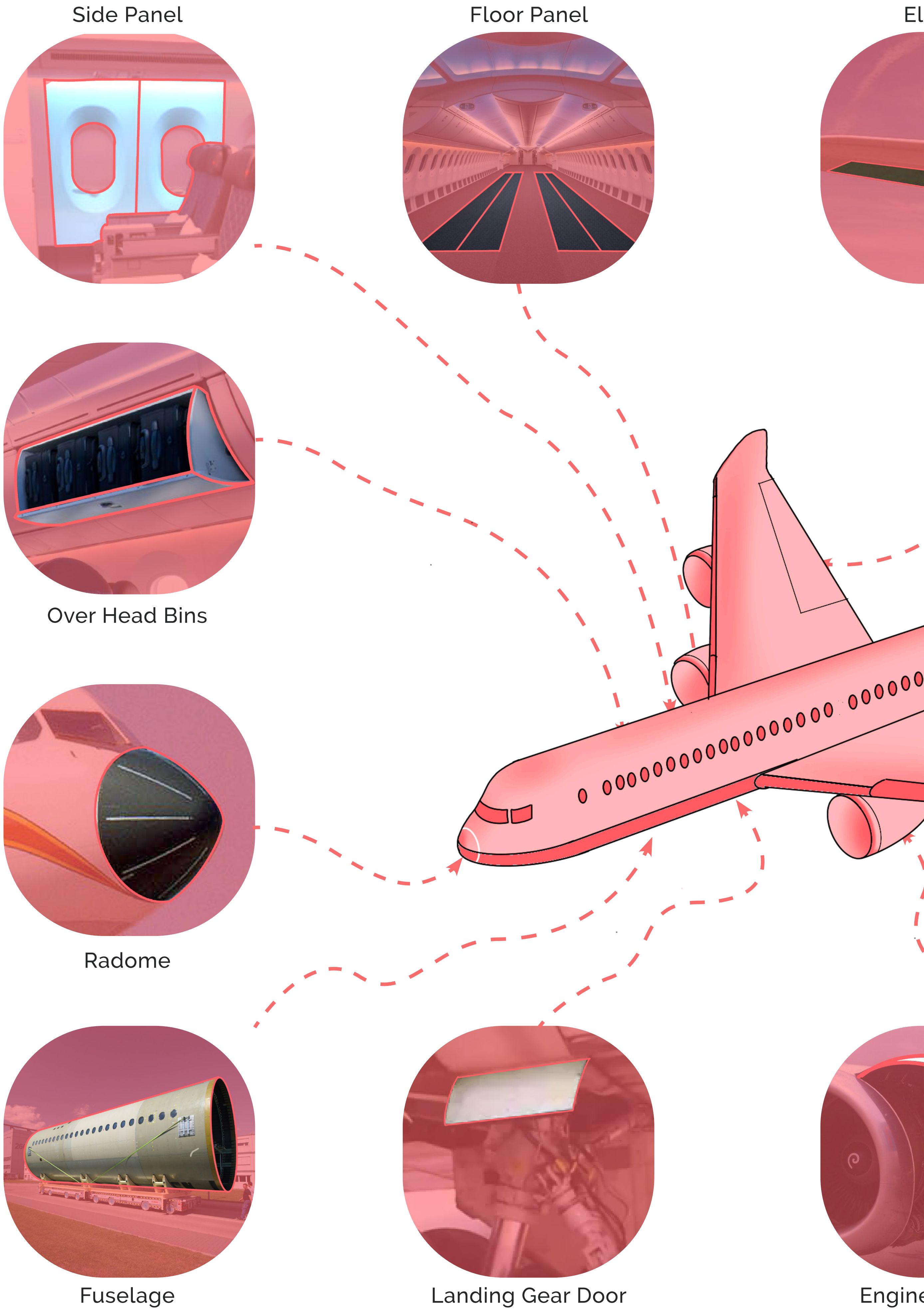
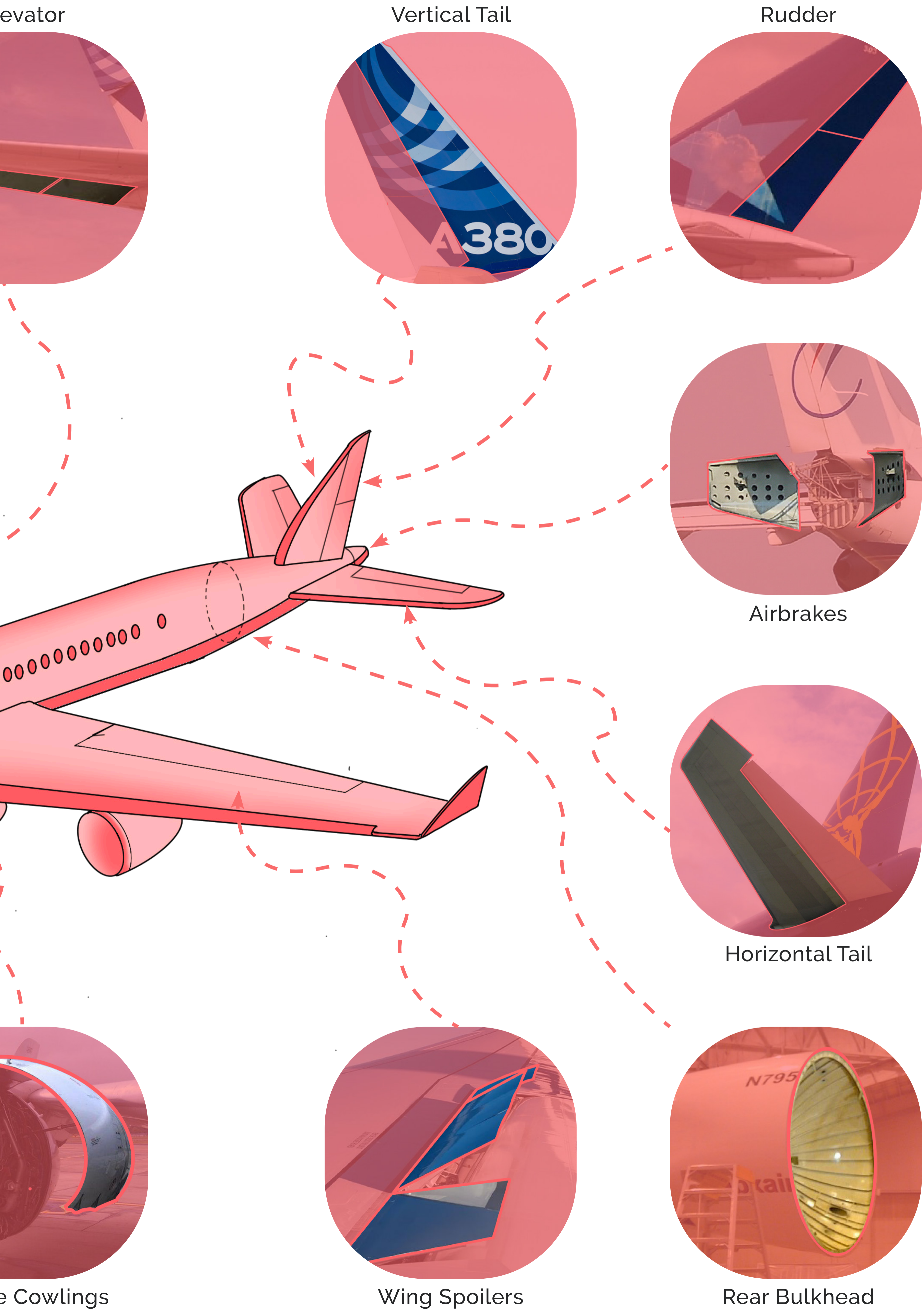


Fig 2.5. Some of the aircraft product

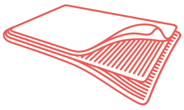


s using polymer composite material

2.4.2 Selection criteria

The selected part must satisfy the following requirement to be acceptance for repurposing

Must have



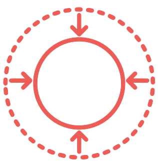
Polymer composite material

The project focuses on generating the repurposing guidelines for polymer composite products. The selected part should be made from polymer composite material.

Aircraft Part

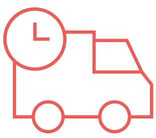
The product should be an aircraft part, preferably decommissioned or used aircraft part. As the decommissioned component will be in used condition and may have degraded mechanical properties compared to a new product, it will be an ideal representative of the intended repurposing case study.

Should have



Product size

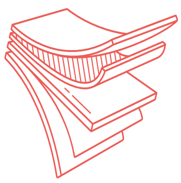
The product will be dismantled and disassembled at the faculty of Industrial design engineering. Thus, the product must be storable in the faculty and manageable for relocating from basement storage to PMB lab. However, it should not be too small not to represent the majority of the components used in the industry.



Transportation

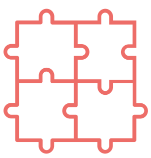
The product should be able to be transported by a medium-sized van and should be able to be lifted by a maximum two-person.

May Have



Sandwich Panel

The selected part may have the elements such as a composite sandwich panel. By selecting such parts, repurposing factors relating to the sandwich panel can be observed noted in guidelines.



Bonded part

By selecting the bonded part for a case study, efforts required to dismantle the bonded structure can be observed during the case study and included in Repurposing guidelines.

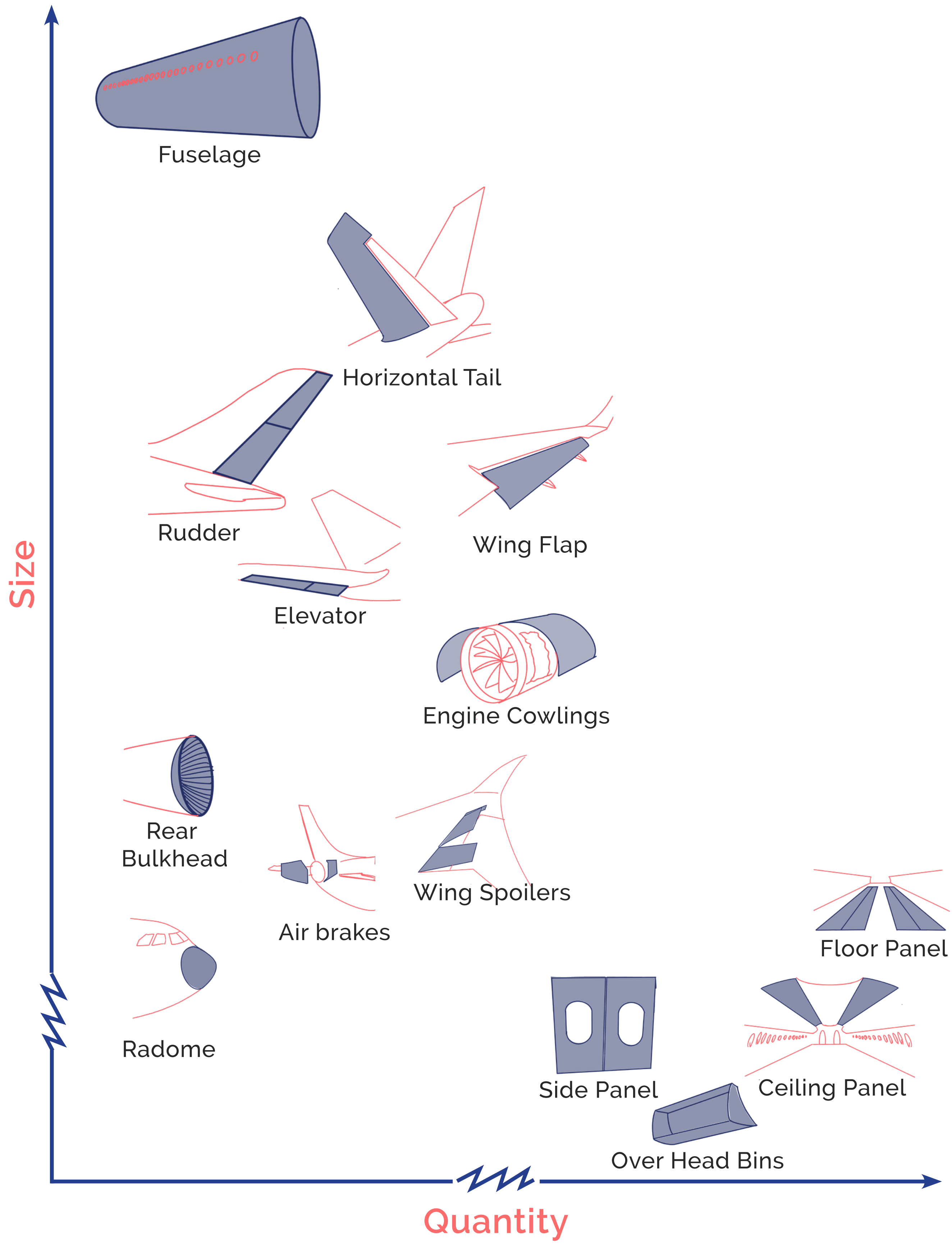


Fig 2.6. Composite Aircraft composite part comparison

Selecting relatively small but available in larger quantities will make repurposing more feasible and viable. Parts with higher quantities will also allow the repurposing to be more scalable solutions.

2.4.3 Selected composite product: Aircraft Galley G5

By contacting several companies regarding the sponsorship of the product, the Aircraft galley was provided for research by Safran Cabin Inc. The aircraft galley G5 was manufactured and designed for Airbus A320. The same galley (fig 2.7) was used for several testing by Safran Cabin. This galley is being produced in a batch of 60 per month (Mooij, 2021), and thousands of the same series of aircraft are currently in service. The design of this galley is altered based on the requirement of buyers (Mooij, 2021)

Additionally, the design of the galley is similar in various aircraft families. The galley is manufactured with a glass fibre-Nomex honeycomb sandwich panel. Thus galley can be considered as the suitable choice for the repurposing case study. Further specifications about the galley will be discussed in the case study.

Fig 2.7. Aircraft Galley G5 (Airbus A320)

Key Insights

- Passenger aircraft contains composite parts ranging from massive wings and fuselage to small composite brackets.
- Used aircraft galley designed for A350 satisfied the list of requirements, and thus was selected for the case study.

2.5. Conclusion

During the define phase, the life cycle relevant for repurposing of composite materials used in the aircraft was analysed in brief. The pre-use phase of the aircraft components contains information that can be considered valuable for the repurposing. However, due to the lack of knowledge transfer and concerning intellectual properties, the decommissioning companies were not able to find an effective and scalable EOL strategy.

Insights gathered through stakeholder interviews identify OAM's, EOL solution providers and government as the key stakeholders who can play a crucial role in repurposing these materials and setting up the Product Life Cycle Management. This will be combined with insights gathered during the case study to propose the final PLM framework.

Furthermore, a brief study was conducted for the composite products used in aircraft ranging from wings to overhead beans. Manufactured in batch production and made from the GF sandwich panel, an Aircraft Galley was selected for the case study.

DEVELOP

Chapter 3

Develop

By collecting the information from the stakeholder interview and life cycle analyses, required insights were employed to generate the draft guidelines. However, an in-hand case study can provide insights relating to the obstacle that repurposing a company might face. By defining the material passport during the define phase and conducting the case study, a framework for the PLM software will be proposed in a development stage to create the base for repurposing. At the end of the phase, draft repurposing guidelines will be formulated for the co-creation session.

Goal of the Phase:

- Conduct the repurposing case study by disassembling and dismantling the aircraft galley to collect the in-hand insights for repurposing.
- Create the framework for PLM software, indicating which data should be provided to repurpose the composite product successfully.
- Create the draft guidelines instructing the repurposing designers and stakeholders on conducting the successful repurposing of the polymer composite products.

3.1. Case Study

This chapter describes the case study conducted to gather the remaining insights for the draft guidelines. The goal of this study was to get the in-hand experience by carrying out the transportation, disassembly, dismantling and repurposing, which are supposed to be carried out by the organization performing repurposing. As these actions are not carried out yet, the case study would reveal the problems or required additional establishment, which will be required to be inaugurated by various stakeholders.

The case study was commenced by acquiring the part from the producer and transporting it to the workshop. It was followed by disassembling the aircraft galley by removing the fasteners and then dismantling it to remove the compatible panels for repurposing. Later, the samples from the composite panel were tested to compare their strength and stiffness with the alternative material.

The study was concluded by collecting valuable information required for the ideation session to discover various repurposing solutions that can use the material recovered during the case study. After observing the functional characteristics, the design of the galley was evaluated with a design for repurposing(Schild, T. 2020) and disassembly guidelines(De Fazio, Francesco, 2019).

3.1.1 Logistics

With the size of aircraft gally, it can be considered as the medium size part. The Galley was transported from Safran Cabin, Alkmaar, to the Faculty of Industrial Design Engineering, TU Delft. A medium-sized Van was used to transport the galley to the university as it can not be transported without dismantling the galley into sub-components. Aircraft Galley was disassembled at the Safran-Cabin workshop and then was placed in the Van. The primary issue was discovered during the storage of the part in the university. With the considerably large size of the galley, it was challenging to find the storage space in the faculty. Processing the similar GF part is also not allowed at many locations in the faculty due to the spread of glass fibre particles.

Key insights:

Large composite products are often bonded. Thus it can not be disassembled into small elemental components. Transporting these components from EOL solution providers to the repurposing factory will require dismantling before transportation.

3.1.2 Characteristics

By interviewing the Safran representative and conducting the product observation following characteristics were noted. Due to the fast-track nature of the case study, the material's properties are not absolute but gives the required information.

Material composition:

The galley is constructed with a sandwich panel made from glass fibre matrix (2 plies of 7781 on each side), Phenolic resign, Nomex honeycomb and covered with PVF Film as shown in the Fig 3.1

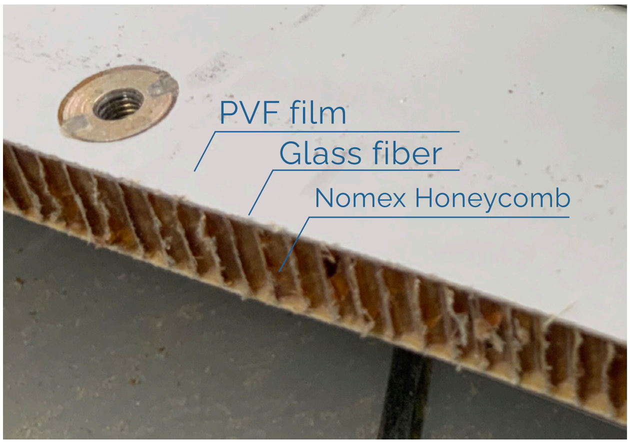


Fig 3.1. Composite panel structure

Use:

The galley is used to store kitchen equipment, food and beverages and contain flight attendant jump seats, emergency equipment storage, and anything else flight attendants may need during the flight.

Assembly:

As shown in fig 3.2, The galley is composed of 3 sub-elements (excluding the trolleys). These sub-components are assembled with 3/8" bolts. All the sub-components contains bonded sandwich panels to form the structure. As these components are custom-made according to the requirement of the airlines, the different galleys will not have similar assembly drawings.

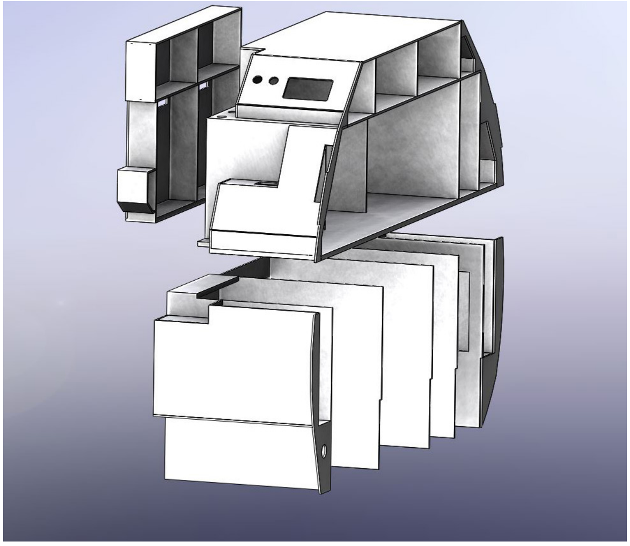


Fig 3.2. Sub component of Galley

Key insights:

It was found that in order to gather the exact information about the material composition, the company representative will have to go through additional information requiring a considerable amount of effort. In addition, for products manufactured in large quantities with different assembly drawings, there needs to be digital documentation of required information along with the assigned product number.

3.1.3 Disassembly:

The galley was initially disassembled into three sub-component at the Safran Cabin to transport it back with a medium-sized van. Further from the bottom component, removable doors and panels were removed with a simple wrench fig 3.3.

Fig 3.3. Galley Door

Initially, the absence of tools with Imperial standards made the processing time consuming and laborious. Further, with the lack of space for the power wrench (fig. 3.4), some fasteners require removal by hand.

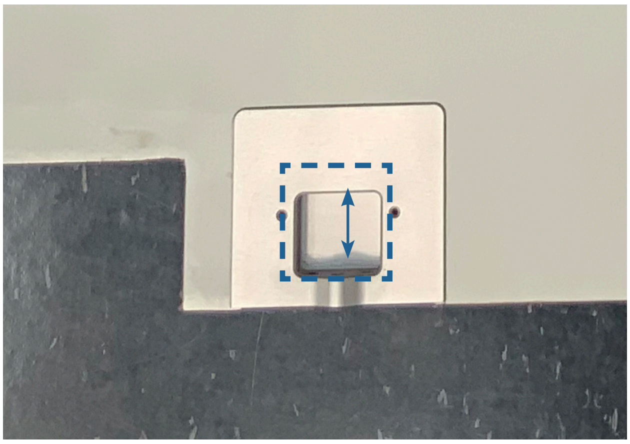


Fig 3.4. Lack of space for power rench

Additionally, the galley contains electronic wiring and several brackets which needs to be disassembled. The bolt head and screw used in the galley were worn out (fig 3.5).

Fig 3.5. Worn out bolts

The only way to remove them was by using the destructive method of drilling into the head. Several panels also contain an aluminium plate connected with aluminium rivets (fig 3.6). As a permanent joint, these rivets can only be removed with destructive drilling on its head.

Fig 3.6. Revets with bonded bracket

Key Insights:

As the product comes with the assembly drawing, the disassembly is according to the judgement of the person performing it. Having the disassembly guide could improve the process. Further, the galley was designed based on imperial units. The repurposing company with the location using Metric units will have to invest in the required sets of tools for disassembly. Decommissioned products after the use of 20-30 years may contain worn-out fasteners and rivets requiring destructive disassembly.

3.1.4 Safety:

Working with composites requires additional safety measures. Using power tools on GF panels spreads the GF particles around the workspace. It is not advisable to conduct this operation with bare hands and eyes. Therefore, during the case study, required safety gears were used, as shown in fig.3.7. Further, breathing the GF particles can cause health issues. Thus it is advisable to wear the Mask with at least a P2 rating. Additionally, the dismantling of the galley had to be carried out in the closed space to avoid the spread of particles around the workspace with the influence of wind flow.

Fig 3.7. Saftey Gears

Key Insights:
These findings show the number of additional safety precautions, to protect the worker, the repurposing company will have to take while setting up the operation in a closed working space. In addition, as industrial safety equipment can be costly, it requires an additional initial investment.

3.1.5 Dismantling:

Disassembling the removable part left the product with a bonded structure that can be dismantled into separate elements, either using the power tools or melting the glue with the heat gun and applying the force to detached the connected panels.

Even though components can be repurposed without dismantling the whole aircraft galley, the dismantling process aimed to discover all the possibilities to repurpose into various products. Thus galley was dismantled entirely.

Dismantling through heating:

Many brackets were attached to the panels using multiple fasteners, even though the bracket was bonded to the panel for equal stress distribution (Fig 3.9).

Fig 3.8. Bonded bolt with bonded bracket

Additionally, the same nut and bolts were locked with the application of additional glue. Thus the only way to remove them is to melt the glue with the help of heat from a heat gun. This process described by the video can be found (Appendix A.3.1). After melting the glue, these brackets can be detached from the panel by a small application of pulling force.

It should be noted that by heating the panel, PVF film is also heated, producing noticeable blisters (Fig 3.9). This process provides maximum material recovery but demands more time to dismantle. The panel with a long bonded edge will need special heating tools to accelerate the material recovery.

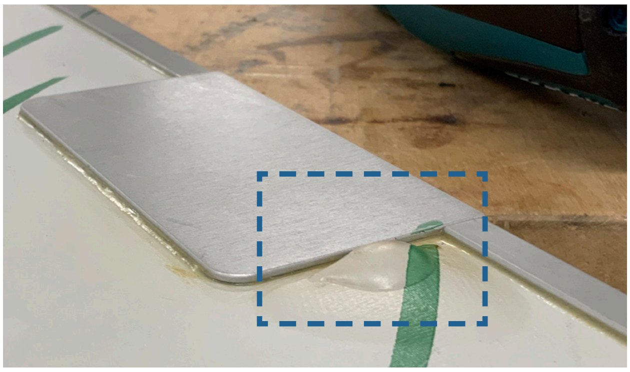


Fig 3.9. PVf film post heating

Dismantling with power tools:

Comparing the dismantling time with the material recovery, later panels were cut into usable elements. Depending on the geometry around the products, it is advisable to use suitable tools. For the case study, a grinding machine (fig 3.10.3) with a cutting wheel, a Jigsaw (fig 3.10.2), and a hand saw (fig 3.10.1) with fine-tooth were used to cut the panels. Jigsaw provided a faster result but can not reach the corner. A hand saw can go through most edges but takes more effort and

Fig 3.10.1 Hand Saw

Fig 3.10.2 jig Saw

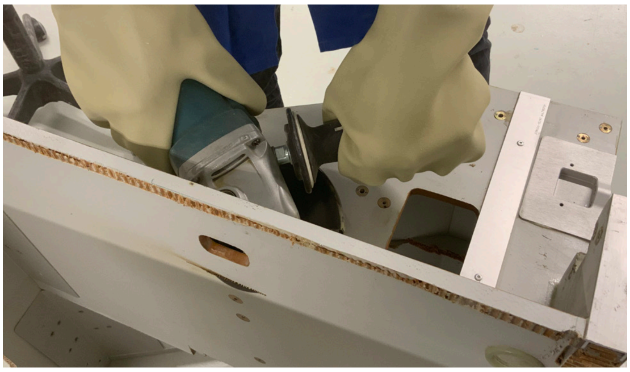


Fig 3.10.3. Cutting machine

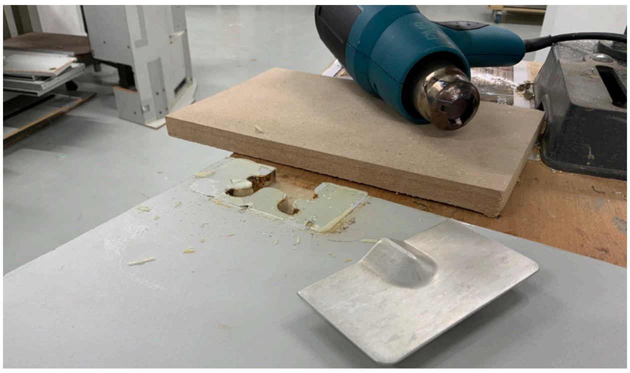


Fig 3.10.4. Heat gun

time than any tool. Both the tools can not be used at some location as there are hidden metal hardened fasteners and brackets installed within the panel

Further, as shown in fig 3.11, the component contains a core plug spread around the panel. The saw can not run over the core plug as they are made of metal.

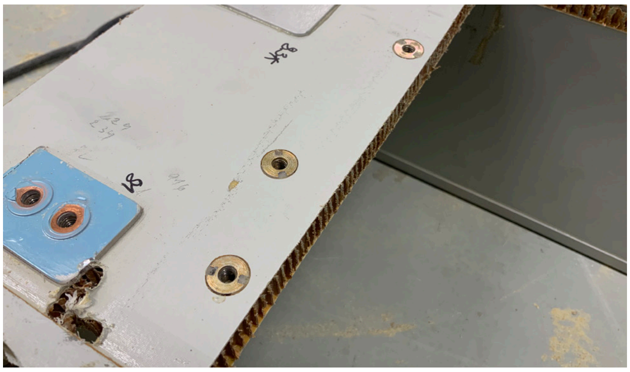


Fig 3.11 Core plug on panel

Key insights:

The dismantling process shows that even with the skilled labour, it will take a considerable amount of time to recover the maximum amount of usable panels for repurposing. Dismantling the galley is necessary, but with descriptive guidelines and automation in dismantling, the repurposing company can accelerate this process and minimise the processing cost.

3.1.6 Extracted Material:

After the case study, Around 52 composite sandwich panels, as shown in Fig 3.12, varying in size and thickness, were extracted from the galley. Then these panels were documented to create a small library in excel. This

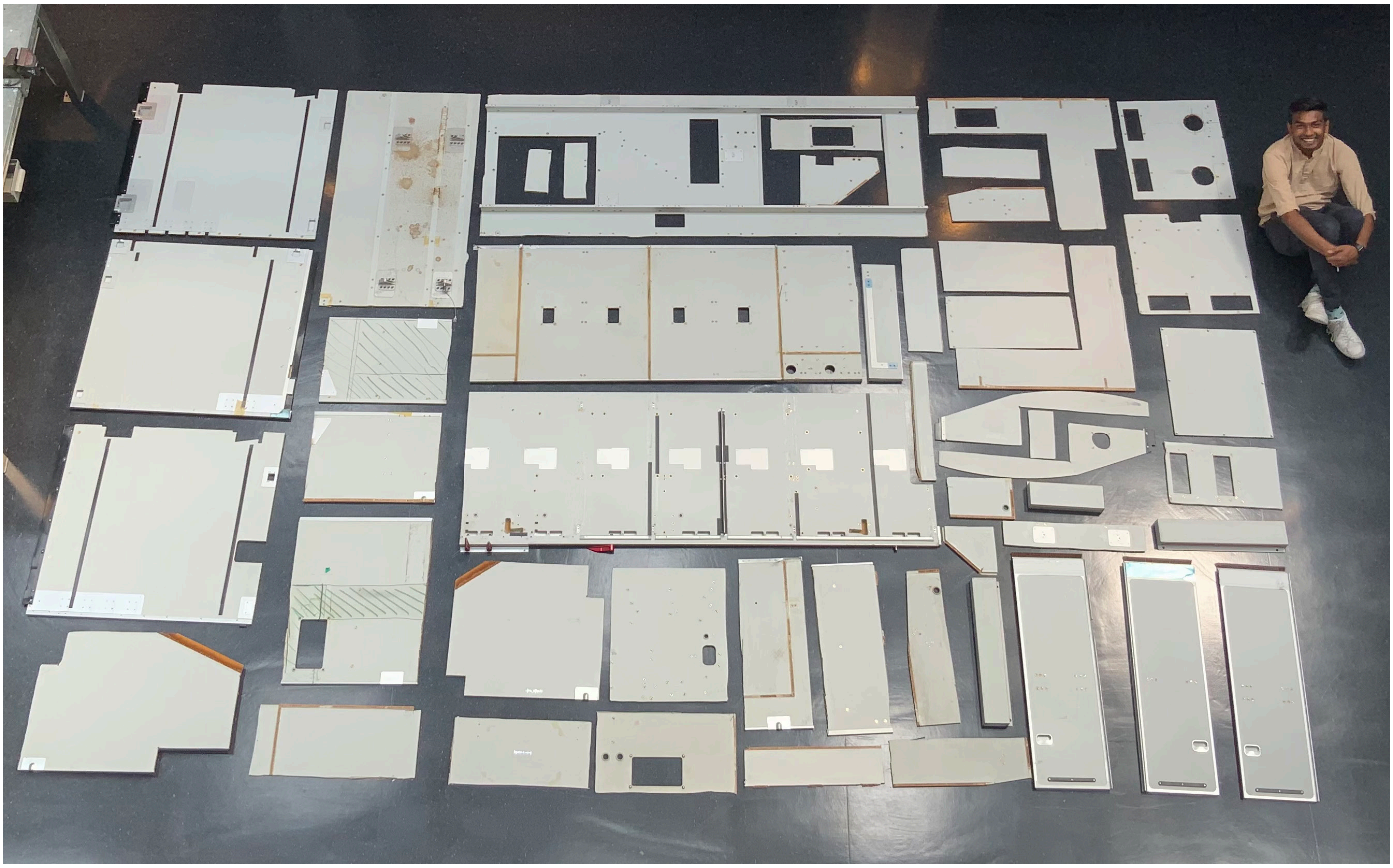


Fig 3.12 Extracted panels through case study

task aimed to discover how a repurposing company can store the information regarding the panels and use it later. Once this project is scaled up, the repurposing company can set up an intelligent system, which can quickly detect the dimension of the material and store it in their database. Thus, the waste of material can be minimised with further work in automation

3.1.7 Material testing:

The goal of this activity was to compare the recovered composite panels with other materials such as plywood. The conducted test during the case study does not compare the material with all the criteria. Composite material has diverse properties such as high torsional stiffness, temperature resistance and high strain to failure. With the available testing facility and limited time, only 3 point bend test was carried out. The test was carried out with several samples of plywood, such as birch plywood (with five plies and seven plies), Hardwood and MDF. The 3 point bend test was carried out with ASTM standard C393. A detailed explanation of the test can be found in (Appendix A3.2).

It can be observed in the graph from fig 3.14 that the recovered panel has a higher strain to failure compared to the wooden samples. The wooden samples show comparatively negligible strain after reaching their yield point but have higher yield strength. At the same time, the composite material shows high strain to failure but lower yield strength. Thus composite material will elongate more before reaching failure compared to plywood. With the results from several tests, the industrial designer can compare the different materials to find a suitable application requiring similar property offered by decommissioned composite material.

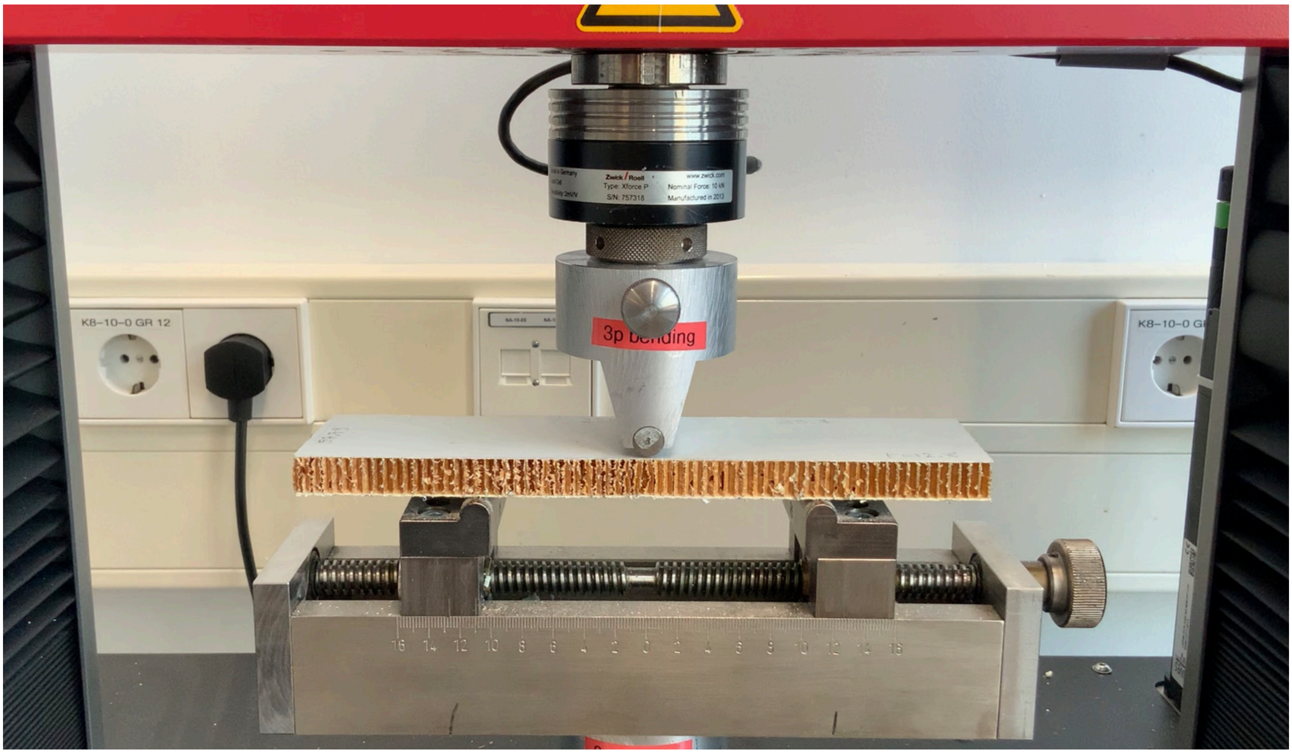


Fig 3.13. Three Point Bend Test

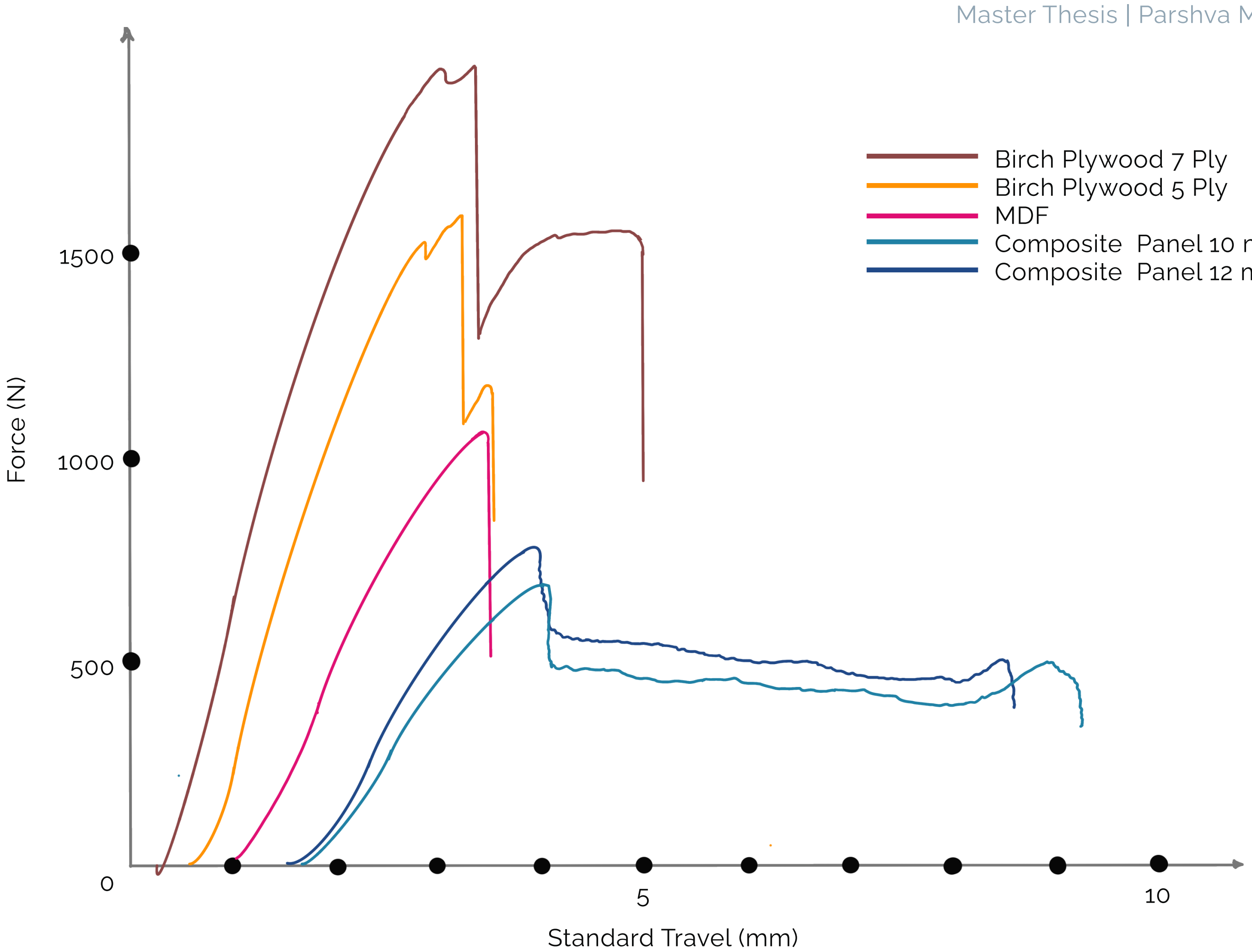


Fig 3.14. Three point bend test result (Force vs standard travel)

Key insights:

While testing this material, repurposing industrial designers should evaluate with a broad range of tests including but not limited to torsional test, flexural test, Impact test and Non-destructive test, with a fair comparison between several materials which the decommissioned material can replace.

This practice will help find out the suitable application for the decommissioned material and detect a probable drastic change in material properties from the products having different use phases.

In addition, material testing data from the design and manufacturing phase can prevent the resources spent by repurposing company in testing.

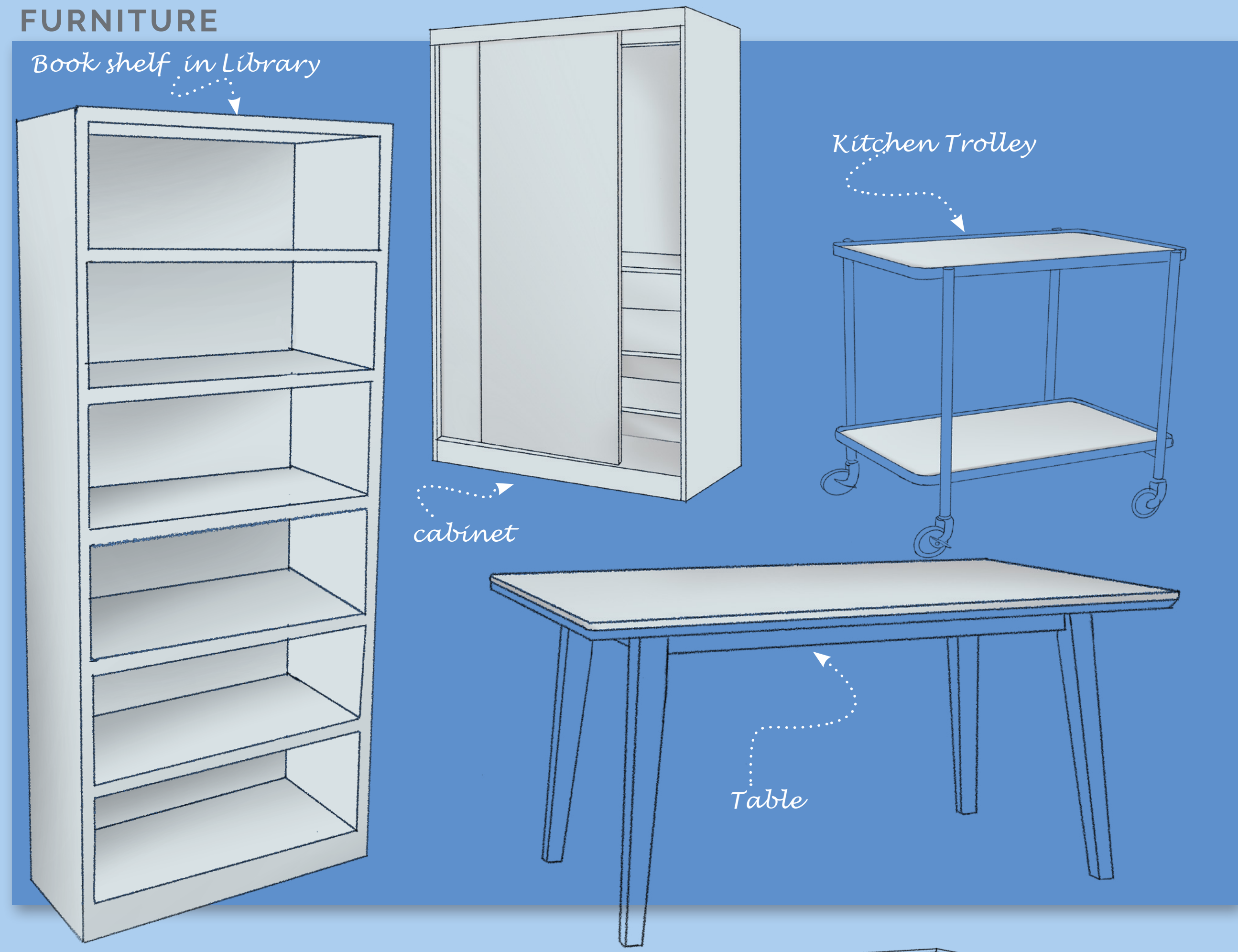
3.1.8 Ideation:

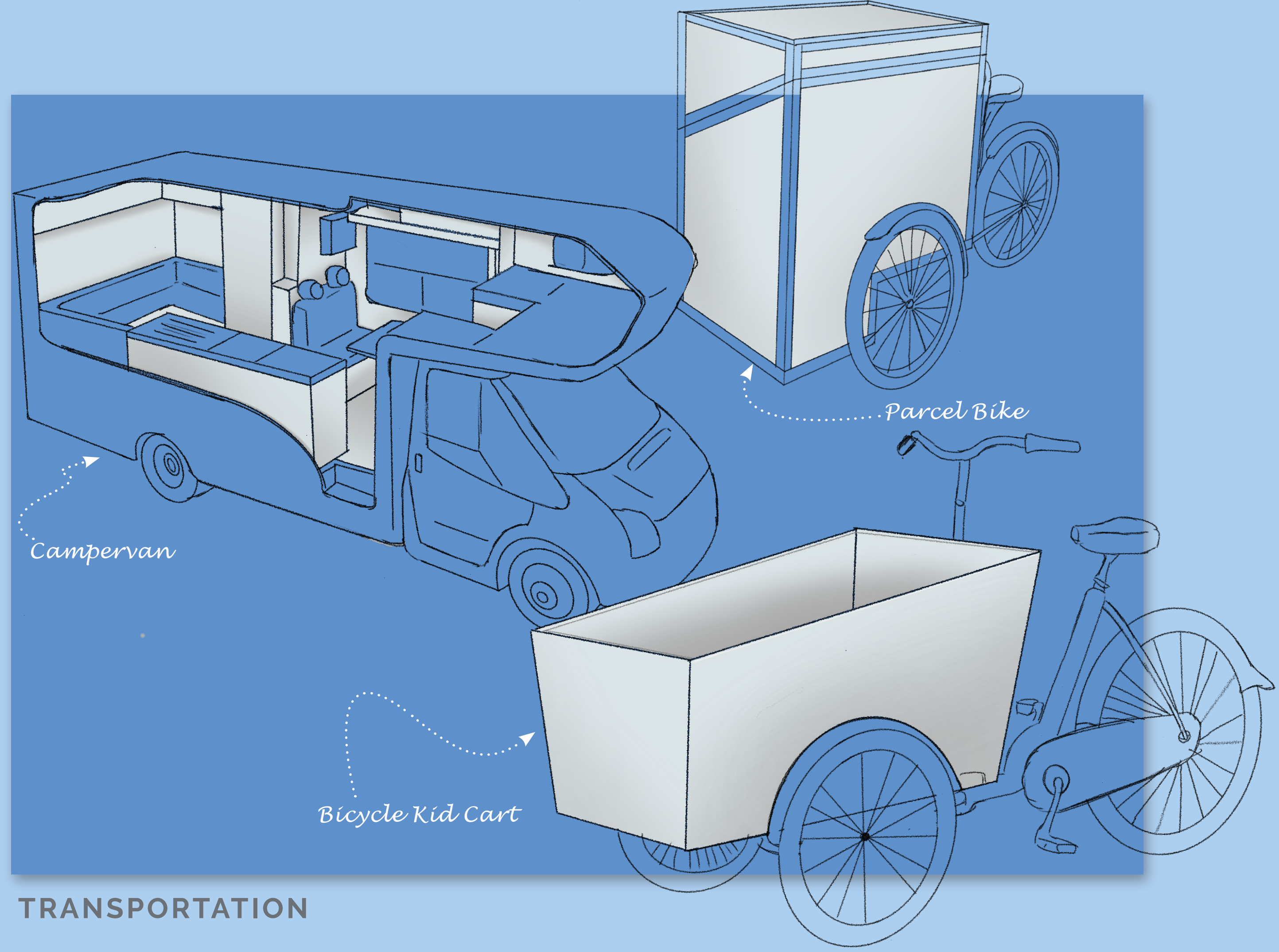
The goal of the ideation (Fig 3.15) was to discover the various possible application of the decommissioned aircraft galley as a repurposed product. The broad ideation phase helped to discover the serval sectors such as home furniture, transportation, automobile and construction industry, where repurposed material from galley can be utilized.

Furniture can create an excellent economical value with the high-performance material and emotional connection with the user.

Using the same repurposing material in a product such as the exhibition stage or storage box for transportation can save the resources spent in trans-

FURNITURE

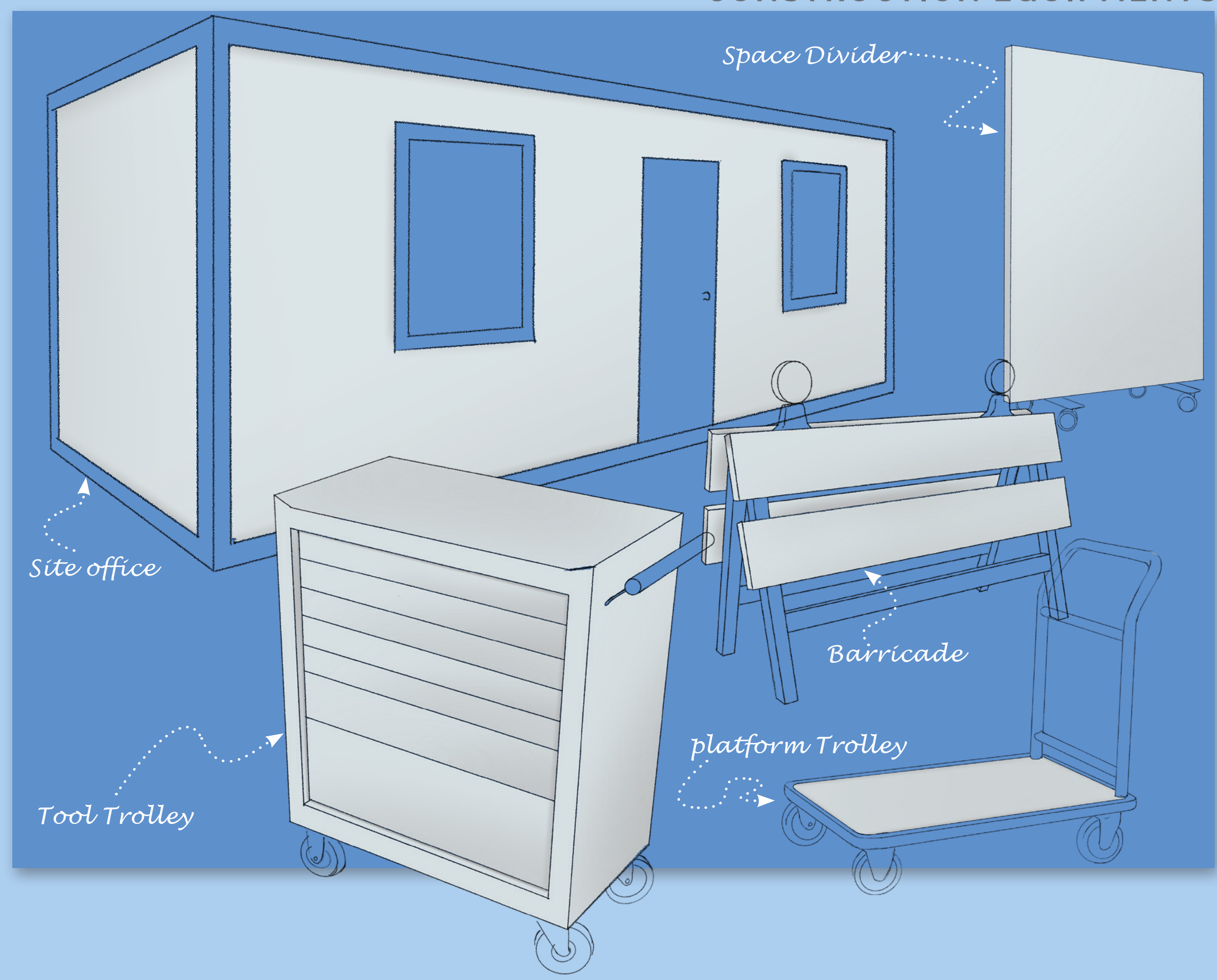


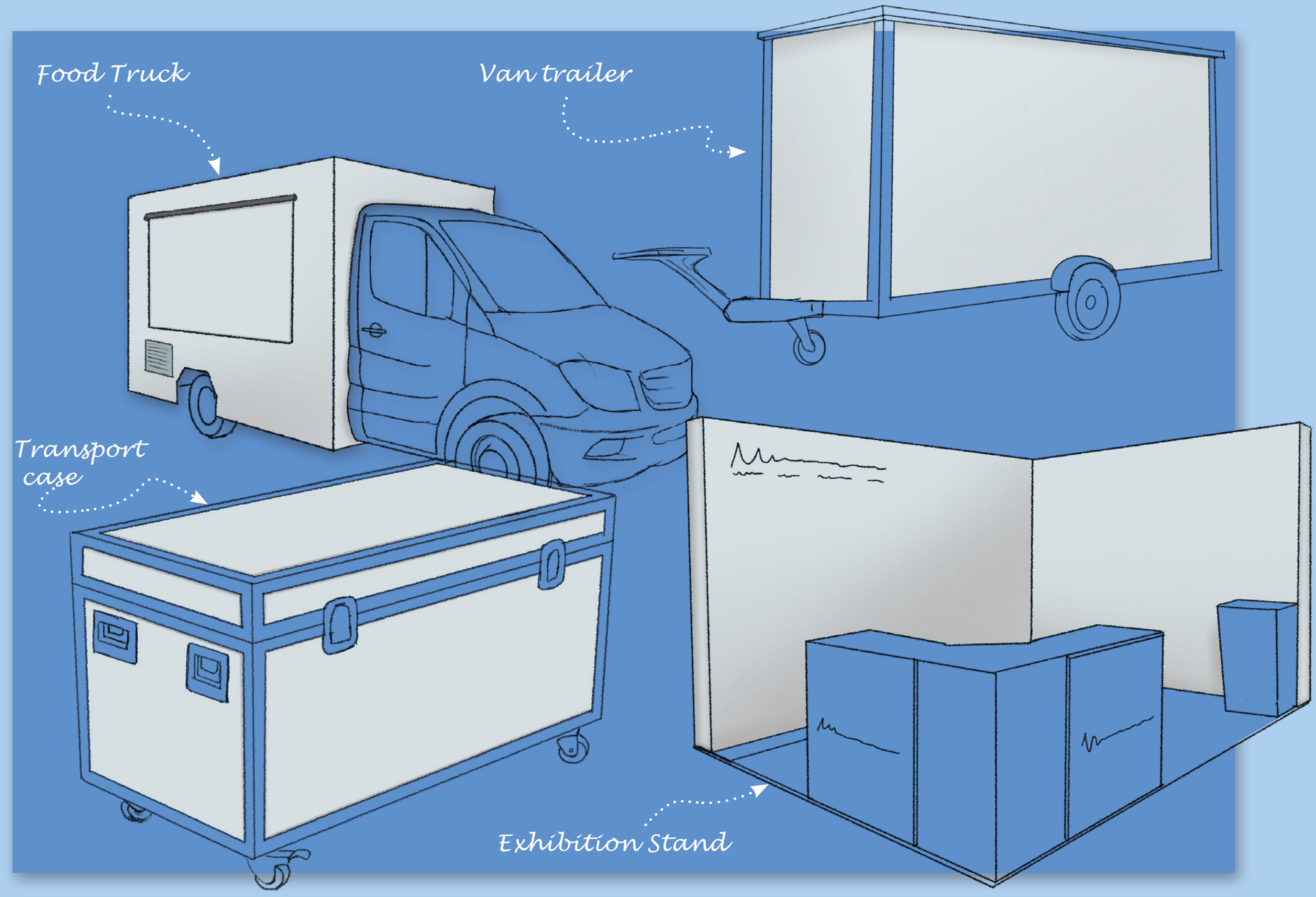


TRANSPORTATION

Fig 3.15. : Repurposing id

CONSTRUCTION EQUIPMENTS





CONSTANTLY MOVING PRODUCTS

eation for aircraft galley

porting the same products made from comparatively heavier material. For example, teams from competitions such as Formula one – Moto GP, where the same products are shipped worldwide, can utilize the lightweight composite material in the same year.

Manufacturers of the construction product can utilize the same repurposed panels where stronger and lighter materials can improve the overall operation.

Using the lightweight panels to construct the bike cart for children can save the amount of effort taken from the parents or the energy consumed by the electrical battery.

One of the most suitable applications for the composite panel repurposed from the aircraft galley can be manufacturing the furniture for the campervan or vanity van. As this type of van is used to drive around the country, repurposed lightweight panels can reduce fuel consumption and also take advantage of fire retardant application in the van's kitchen furniture.

Key insights:

From the wide range of concepts from various sectors, it can be concluded that composite repurposing can be utilized in several repurposing applications.

By knowing the comprehensive list of material properties and functional advantages, industrial designers can find suitable repurposing applications.

3.1.9 Prototyping:

The concept of a bicycle cart for children was chosen to rapidly prototype the repurposed products from the panels recovered from the galley. The goal of the prototyping was to discover the problems which can be faced during the repurposing process. Detailed documentation of prototyping can be found in (Appendix A.3.3)

Initially, a cad model was created with the reference from the actual cart (Fig 3.16). With the dimensions of the individual panels required for the prototype, various panels from the galley were measured to reduce the waste material from re-manufacturing. By marking the dimensions from the design drawing, the panels were cut into the required shape using an available band saw machine at the university (Fig 3.17). Individual panels were connected with the help of a universal, transparent adhesive called " Polymax Crystal express" the transparent adhesive was selected to have an aesthetic appearance (Fig. 3.18). The expected curing time was 2 hours. Panels were held together with the help of tape and heavy blocks kept at the angle. Post curing, the cart was tested with 30 KG of weight compared to the average weight of a 10-year kid's (Fig 3.19). The additional tape was applied at the side and edges to avoid scratching on direct contact. To connect the emotional value with the users, additional illustration indicating "I was an aircraft'' (Fig 3.20). This illustration aimed to connect users so that they can find the cart as a valu-

Fig 3.16: Wooden bicycle Cart

Fig 3.17: Cutting the panel with band-saw

Fig 3.18: Using transparent adhesive to bond the panels

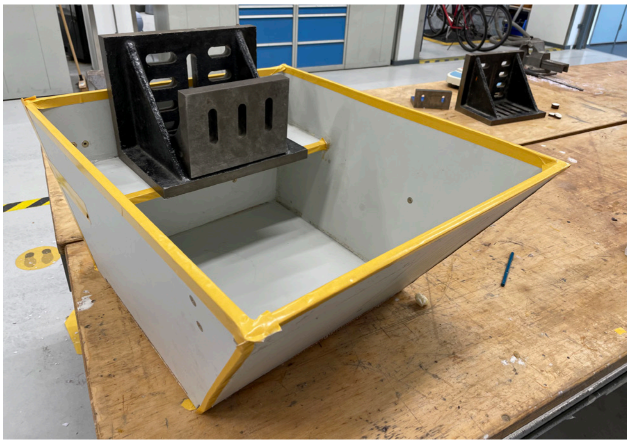


Fig 3.19: Testing the cart with 3 KG load.

Fig 3.20: Final prototype with branding “I was an aircraft“ branding

able part of the aircraft's service and find it as a high-performance material compared to an ordinary wooden cart. The final weight of the prototype was 3.2 kg compared to the wooden cart weighing 6 KG.

Critical discussion on the prototype:

The prototype aimed to see what are the factors which repurposing company can overcome to accelerate the repurposing. Critically looking at the prototype, it should be considered that the composite bicycle cart will be used for the children. Thus it should be tested under different conditions. Further, the repurposing sandwich panels can absorb water. Therefore, all the sides of the panels need to be sealed with the appropriate materials. Further, it should be considered that even GF panels also have a moisture absorbing property. The bicycle cart's material will degrade with constant exposure to rain over time with increased weight.

Key Insights from prototyping:

As found in the prototyping, having an automated system for choosing suitable panels from decommissioned material can reduce the waste in reproduction process.

Compared to manual marking and manufacturing with a band saw, automation with a milling machine can save a reasonable amount of time in repurposing.

From the prototype testing, it can be seen that composite material can take the required loading and with half of the weight.

The critical discussion on the prototype indicates the need for detailed information describing the operating conditions and disadvantages of the material that should be included in the PLM. Suggested properties will help industrial designers to find suitable applications.

3.2. Product Evaluation

3.2.1 Design for Disassembly Guidelines:

One of the most important steps to initiate the repurposing is disassembling the component effortlessly (Schild, T. 2020). While conducting the case study, it can be stated that disassembly of the aircraft galley is a complex process, and the component itself is not entirely designed for disassembly. Therefore, it is imperative to evaluate the galley with disassembly guidelines.

Referring to the work of Francesco De Fazio (De Fazio, Francesco, 2019), focusing on repairability, demonstrates the disassembly guidelines. Considering the guidelines as a reference, Reader should note that evaluating the galley with Dfd guidelines. The goal is not to redesign the part, as the aircraft composite components are designed to avoid the failure involved in the critical condition. However, this will evaluation will demonstrate the resources needed to efficiently dismantle the usable material/component from the composite products when required. Additionally, designers and engineers can resolve these issues if possible when this product is redesigned.

1. It shall be easy to disassemble and assemble the product for repair.

Disassembling the galley into the three sub-component is a simple task, but extracting further usable elements from the galley requires additional processes such as removing a number of fasteners, removing the adhesive by heating, using the power tools and applying the force to remove the glued parts. Thus disassembly process without automation will require a significant amount of resources.

2. The order in which the actions are to be carried out for repair shall be logical and clear.

The design drawing document does not provide the information required for disassembly. Thus it is essential to have clear, logical and documented instruction.

3. No glued parts shall be used that will hamper the opening and closing of the product.

For the design requirement at critical application and need for light weigh product assembly, sandwiched panels are bonded to each other rather than connected with the fasteners. Thus opening and closing of this sandwich panel are time-consuming.

4. It shall be possible to disassemble the product using standard tools.

To disassemble the bracket attached to the panel needs a heating and then unscrewing. Furthermore, as these parts are used with multiple standards following ANSI and Matric system, the Repurposing organisation will have to invest in a wide range of tools.

5. Minimise the number of material types that should be used in an assembly

On a positive note, the material used in the galley is identical. Thus treating the product for disassembly do not require further complexity.

Conclusion:

As a conclusion from the Dfd evaluation, it can be stated that the galley hardly follows the Dfd framework. Thus, when the repurposing company processes this product for repurposing, they will have to collect the necessary information in the form of disassembly and dismantling guidelines from the manufacturers and invest in the required resources to accelerate this process.

3.2.2 Design for Disassembly Guidelines:

After bringing the galley to the faculty, the galley was evaluated with the guidelines proposed by Tom Schild in his Graduation project (Schild, T. 2020). This activity aimed to discover how the existing composite products satisfy the design for the repurposing framework and what are additional resources requires to conduct the successful repurposing. Guidelines relevant to the study, e.g. Embodiment design, are as follows, followed by the evaluation of the component in the context of the project.

1. Conceptualisation:

While interviewing the representative of Safran-Cabin and AELS, it was found that these products are not designed for reuse or repurpose. Thus, this set of guidelines do not apply to the case study.

2. Economic value:
Think of the economic value of both the products. Are they worth the same in economic value?

The price of the component, when used for an aircraft, is exponentially high. After use of 40 years, the value of the material falls on the negative side as end of the life solution providers has to pay around 250 euros per metric ton to incinerate the material(AELS interview). Thus, repurposing the product can create a considerable amount of economical value if the processing cost is kept lower.

3. Efficient Transition:
Make the transition itself as easy as possible (minimal effort). When the moment has arrived to make the product into something new, who will do it, where will he be, and what will he need?

With the discussion with a representative from Safran Cabin, it was found that when the galley gets decommissioned, it can be anywhere around the globe. The part will have the design drawings. However, it does not contain the information regarding the skills required to dismantle the product successfully and stepwise guidelines to disassemble and dismantle the galley.

4. Easy to (dis)assemble
Keep it simple/easy to repurpose the products (reduce time to disassemble & assemble)

Aircraft components are used under extreme loading conditions during their service. Any minor failure can result in a tragic accident. Due to the safety requirements and regulations for aviation industry aviation, aircraft components are designed with high factor safety. In the case of the galley, brackets are bolted to secure them with the composite sandwich panel, and adhesives are applied in-between to distribute the stress equally throughout the surface. Additionally, different panels in the galley were connected with the application of adhesive. To separate the different components requires a considerable amount of time and resources. In addition, this type of product assembly increases the number of resources required during the disassembly.

5. Simple Form - Keep it simple in geometric forms

The galley is constructed with the standard flat glass fibre sandwich panels, varying in thickness. Additionally, even with the customised galley in most aircraft, these panels can be repurposed into applications using products made from a flat object such as sheet metal and plywood.

6. Standardization: Puzzle with standardised shapes, components and sizes that conform to the industry

The galley is made with glass fibre – Nomex sandwich panel having a standard thickness of 3/8", ½", 5/8" and 1" inches.

Conclusion:

From the interview with Safran (Mooij, 2021), the galley was not designed for repurposing. However, it satisfies some of the essential criteria such as economic value, standardisation and simple form. Likewise, it can be assumed that many composite products produced decades ago might not be designed for repurposing, but if it can make the sustainable and desirable business using additional resources can avoid premature incineration.

3.2.3 The conclusion from the case study:

Lack of knowledge transfer:

During the case study, it could be observed that the lack of vital information extended the duration of the case study. Information such as the material composition of composite sandwich panel used, List of hazardous material, disassembly & dismantling guidelines, list of mechanical property, product certification and primary knowledge about the suitable application for the repurposing was unavailable. As a repurposing industrial designer, one has to find all the essential information to conduct a successful repurposing operation.

When the product collected for repurposing is different in design or comes from a distinct sector, frequently conducting time-consuming tasks will be not be economical for repurposing and may increase the overall cost of the repurposed product. Thus it is necessary to document the existing data during the initial life cycle of the composite product. From the literature study, it can be assumed that a digital material passport with a PLM system containing such information can facilitate the required service.

Guiding the industrial designer

The case study also suggests that existing guidelines for repurposing do not support the repurposing of composite in a structured manner. For example, generalize "Design for Repurposing guidelines'' discussed during the literature study do not instruct the industrial designers and various stakeholders on steps that need to be carried out at different stages of the product lifecycle for successful repurposing. The absence of this literature makes the process of repurposing amorphous and relies on the experience of industrial designers executing the repurposing operation. It infers the need for repurposing guidelines specifically formulated for products made from polymer composite material.

3.3. Personas

As concluded from product lifecycle analysis and stakeholder analysis, defining the different personas involved in the repurposing strategy is necessary. By defining different personas, For the reader, the role of different stakeholders in solving the problems will be clear.

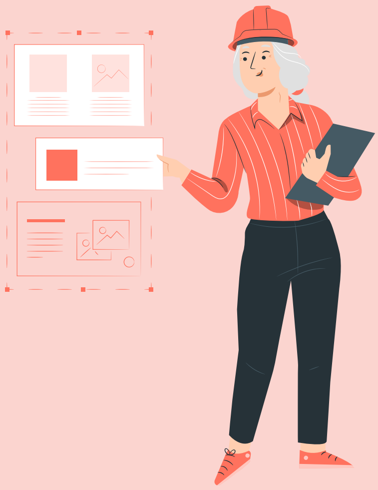
As discussed in the conclusion of stakeholder analysis, the key stakeholders from the initial life cycle are the product manufacturer and end of the life solution provider. With the graduation project context, the third stakeholder who will play an essential role in the repurposing phase will be Industrial design engineers working to develop the repurposed products. Description of the individual roles, interests and frustration can be seen in fig 3.21.

Collaboration

While zooming out from the aviation industry, the individual personas might be working in the different organisational structures. The connection and relationship between each key player define the ease of implementation. As seen from fig 3.22, different organizations can be divided into three scenarios.

Scenario 1:
In this scenario, individual key players are not working under the same organization. As an example, It describes the aviation industry. Composite product is sold from one stakeholder to stakeholder without any producer responsibility. Here, the interests and priorities of individual stakeholders can be different. As there is no parent organization instructing individual personas, Implementing the new strategy can be difficult and might face resistance from the product manufacturer or EOL solution providers. To implement the repurposing, all the stakeholders will have to collaborate with each other to come up with a feasible plan. The governmental policy can play an essential role in initiating the collaboration.

Scenario 2:
In this scenario, the composite product might be sold as a service or used within the organization. After the initial use phase, the product will be returned to the producer. The producer will handle the decommissioning. Here at all stages of product life before decommissioning, the Producer will be the owner of the composite product. It represents the Ampelmann organization where the product is leased to their customer, but Ampelmann carries out the monitoring, maintenance and decommissioning of the gangways. Later the product is given to the repurposing companies with the required information to repurpose into new products. By collaboration between the repurposing company and the initial product, the owner is comparatively hassle-free as the responsibility of sustainable end of life practice



	Product manufacturer	EOL solution provider	Industrial designer
Role	Produces the polymer composite products. Governs the intellectual property.	Obtains the composite products from the end users in the initial life-cycle. Redirect the product to the next stages, such as Reuse, repurpose or incinerate.	Design the products with maximum material utilization Re-purpose the existing scalable products.
Interest	Develop lightweight composite product with cost-effective production. Maintain the confidentiality of its products	Maximum profit from the resale. Minimize the processing cost of decommissioning from storage, disassembly, dismantling, etc.	Finding the suitable repurposing application with maximum recovery and sustainable business plans. Minimize the impact on the environment from repurposing.
Frustration	Unsustainable end of life practice of their composite products.	Incomplete information from the product manufacturer.	Lack of information in accelerating the repurposing.

Fig 3.21: Key personas in composite repurposing

will be on the initial product owner.

Scenario 3:
Scenario 3 represent the ideal situation where all the key stakeholders will be working under the same parent organization. The parent organization's goal of sustainable end of life practice will direct the different key stakeholders in the same direction. The issue of intellectual properties will be irrelevant as the product will stay within the organization. Here, the repurposing operation will be carried out within the company, and repurposed products could be used within the organization.

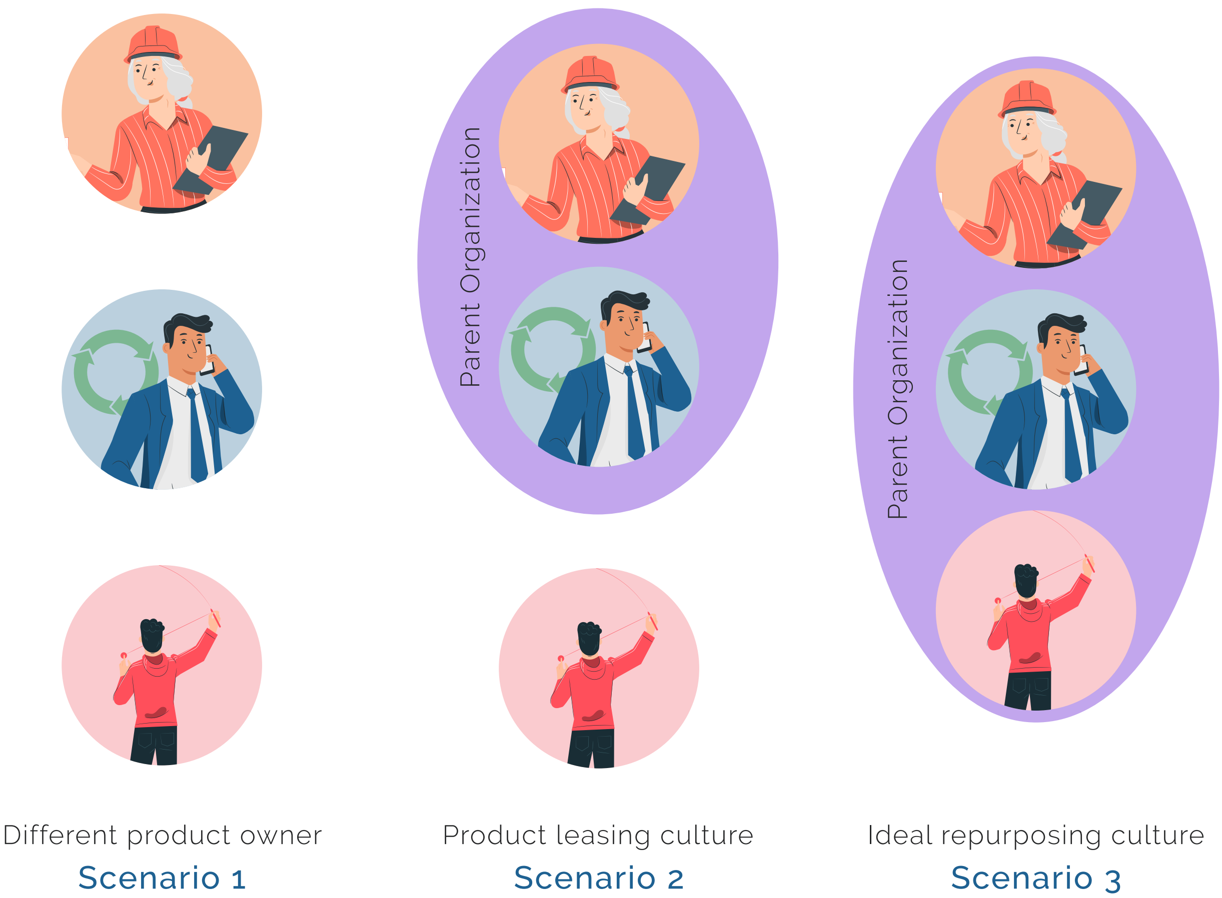


Fig 3.22: Collaboration scenarios between key personas.

Key insights:

- The critical personas for the repurposing operation are the Aircraft manufacturer, the EOL solution provider and Repurposing industrial designers.
- With the different organizational structures, the relationship between different stakeholders will change, directly influencing the implementation of the repurposing in a scalable manner.
- The most suitable scenario for implementing repurposing is when the composite product manufacturer, EOL solution provider, and repurposing company works under the same parent organization.

3.4. Product Life Cycle Management

Through the literature study and conclusion from the case study, it can be seen that knowledge transfer can play a crucial role in carrying out the repurposing. Without needed information, every repurposing company will have to create their own data directory. Eventually, repurposing companies will have to invest a considerable amount of time and energy in collecting the information which is spread around the stakeholders.

In an industry like aerospace, most of the information is documented on paper (Heerden, 2021), and with millions of individual parts in a single aircraft, it is practically impossible at the end of the product life to keep the documentation of the essential information associated with the individual part. The project aims to create the Material passport framework for repurposing companies and industries such as automobiles, marine, and wind turbines where such practices barely exist. Thus further suggestions are applicable for general composite products not restricted to passenger aircraft.

3.4.1 How to use the PLM system

As a letter needs the location for delivery, to store the information, each part needs to have a unique identification number. This identification number or parts will be assigned for the entire life cycle of the composite component. The practise of assigning a part number is widespread in aircraft components but should also be implemented for the products used in other industries.

As the product begins its journey from material mining and ends with decommissioning, it goes from stakeholders to stakeholders. All the information (Fig 3.23) needed for the product's life cycle must be stored in a single PLM platform from all the stages of the product journey. If the individual stakeholders use different software, the software should support the various plug-ins to streamline all the information needed in one place.

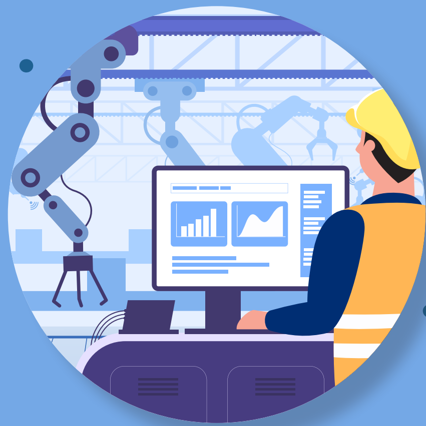
Further, this system provides selective data transfer. If a stakeholder wants to provide the information to specific companies, software should be able to protect its data and intellectual property with data protection features. Many composite parts are used for decades. Companies can also input their information without sharing it at the earlier stage, and once it reaches the repurposing phase, it can be made available.

Material

- Material composition
- Hazardous material

Design

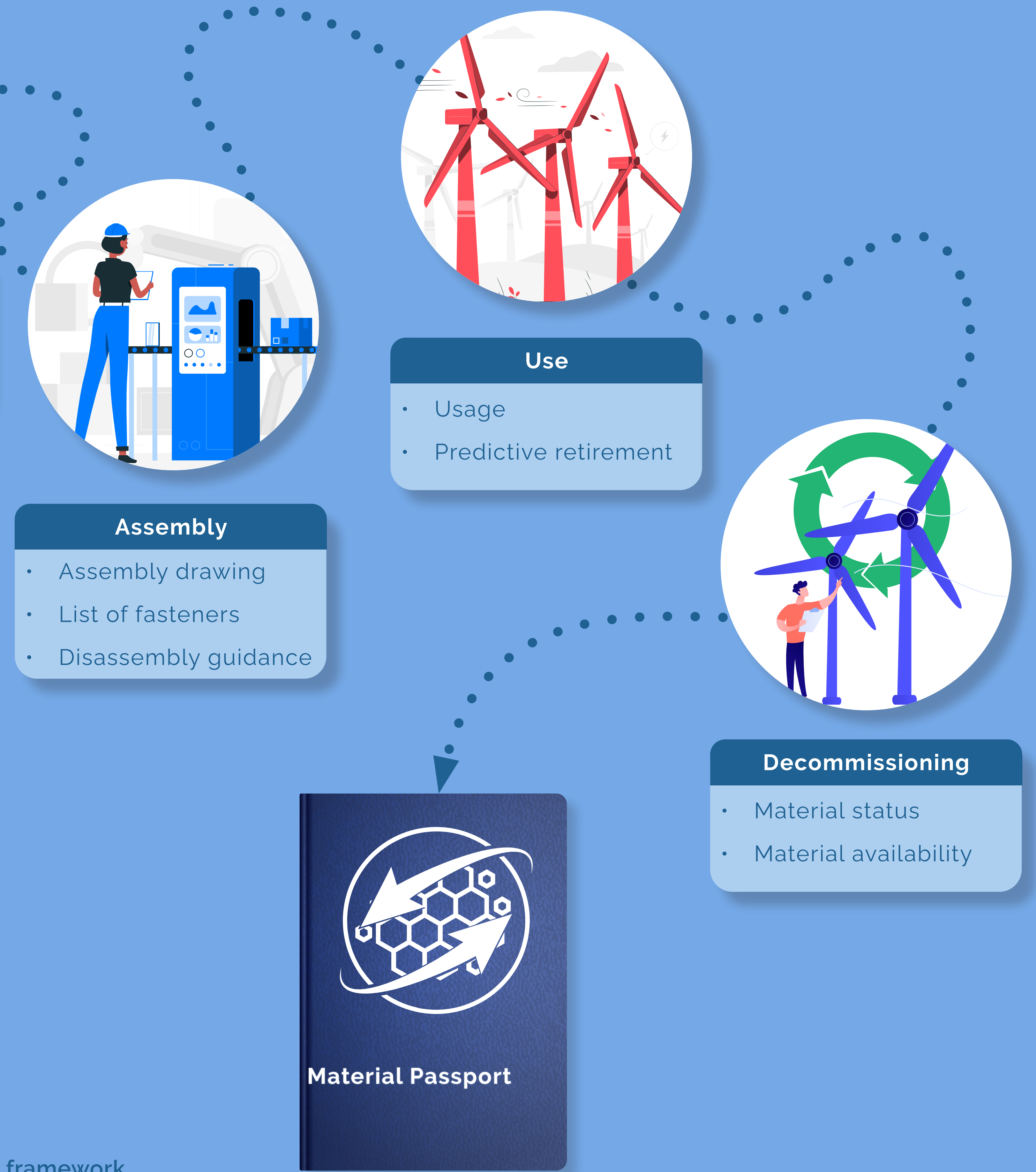
- Design drawing
- Primary functionality
- Design drawback
- Life expectancy
- Part number



Manufacturing

- Manufacturing technique
- Used adhesive

Fig 3.23. PLM


Use
Usage
Predictive retirement
Assembly
Assembly drawing
List of fasteners
Disassembly guidance
Decommissioning
Material status
Material availability
Material Passport

framework

3.4.2 PLM framework for repurposing

This section provides information about the primary inputs which can be included into the PLM system from the entire life of the composite products to assist the repurposing after it has been decommissioned. Some of the data will not be feasible for specific sectors, but the complete information aims to provide a holistic approach.

Material:

The raw material and composite manufacturer can provide the following information in the material passport.

Material Composition :

By knowing the precise and comprehensive information relating to the used material in decommissioned products with its chemical and mechanical properties, the repurposing company can find a suitable application and conduct the exact simulation if needed during the repurposing phase. In addition, this information will provide ease in determining the composite material, matrix and resin used, and other metal or critical materials which are used along with the product. This information has the potential to assist in keep track of critical materials used for the products. During the case study, it was found that knowing the exact material composition can be time-consuming once a composite part goes out of the factory (Mooij, 2021). Thus keeping the digital data of this material will make this process simplified and effortless.

Hazardous Material:

While making the polymer composite material, additives are often added to the mixture, enhancing the material properties. For some repurposing applications such as food packaging or product for children, the decommissioned composite material will not be a suitable repurposing material. By keeping documentation of this material from the design phase, the repurposing company can avoid design errors. This also provides the opportunity for the EOL service provider to treat the material with the required waste management strategy (Heerden, 2021).

Design :

Component manufacturer and product manufacturer can provide the following information focusing on the design aspect of the initial product in the material passport.

Design drawing:

In some industries, composite products such as an aircraft or yacht interior are often custom-designed based on buyers' requirements. Having the dictionary of design drawings or CAD models, repurposing companies can also predict the usable elements and amount of resources they will require to process the product in advance. This will help the repurposing organisation to prepare the business plan and look for the market opportunity based on extractable material.

Primary Functionality:

Knowing the primary functionality of the material from the PLM software can help the industrial designer find a suitable repurposing application. The same information will also help them match the new products requirement with the supplied decommissioned material's functionality.

Design drawback:

Not all industrial designers are aware of complete composite specifications. By assigning the information regarding the advantage and disadvantages of the composite element or entire products in PLM software with each component, it becomes easier to conduct the risk assessment for the repurposing designer. As an example from the case study, the composite panel extracted from the galley is not suitable for a point load. With this information, the industrial designer can assume that elements can not use as floorboards where someone wearing the hills can walk on.

Life expectancy:

Predicting the life of the composite product is a complex process. However, if the endurance strength of these materials is provided along with the PLM database, an industrial designer can find the remaining potential by knowing the service life span.

Part Number:
As mentioned in the literature study, every part after the design phase should be assigned with a unique identification number where all the information added in the PLM can be designated.

Manufacturing:

The component manufacturer can provide the following information regarding manufacturing the initial product in the material passport.

Manufacturing Techniques:

Often property of the composite panel is defined by the manufacturing techniques used. Type of layup, number of composite plies, the direction of matrix fibre, type curing process, and other relevant factors also define the component's property. Thus adding the information, the industrial designer can get an overview of the decommissioned product to find the suitable repurposing.

Adhesive:

As seen during the case study, in an aircraft, galley composite panels are often bonded together. By knowing the bonding agent, designers and engineers can find the correct melting temperature of this adhesive. This can provide information regarding how to accelerate the de-bonding process during the dismantling.

Assembly:

The stakeholder managing the entire assembly of products can provide the following information regarding manufacturing the initial product in the material passport. Single part composite products might not have to add some of the mentioned information, such as assembly drawings or a list of fasteners.

Assembly drawings:

The digital design drawing attached in the PLM software should contain a comprehensive list of components used in the structure. Additionally by indicating how things are assembled can indicate the number of usable elements that can be extracted. Additionally, composite structures contain additional elements such as aluminium brackets and inserts inside the sandwich panels to improve the strength of the structure. By indicating such information in design drawings, the repurposing company can plan the dismantling process without damaging the tool or panel itself. Additionally, by mentioning the other non-composite parts, the repurposing company or EOL service provider can keep track of additional unwanted parts and create a waste management system for them. For example, compared with the case study, the galley comes with several aircraft-grade aluminium brackets, wiring and hundreds of fasteners, which might need to be discarded with suitable waste streams.

List of fasteners:

As mentioned in the case study, composite products are often built around the world and may contain different fasteners with different measuring standards such as Metric or Imperial systems. Using the incorrect tools can damage the fastener with unnecessary time added in disassembly and repurposing. By involving the separate list of fasteners can prepare the repurposing operation to be facilitated with required tools in advance.

Dismantling Guidance:

Like a bill-of-material and assembly guidelines, a composite structure containing several elements can come with the dismantling guidelines. Like design for disassembly, instruction for dismantling can be provided with a PLM system. To assist the industrial designers and engineer, instructions can be provided with the list of tools which should be used to remove the usable components and instruction on step-by-step actions which should be carried out to dismantle the entire assembly with a minimum time. This guideline will give the estimation of the required time and processing cost for dismantling.

Use:

The user can provide the following information regarding product use in the material passport. If individuals use the product, the following information might not be applicable.

Usage:

The life of the composite structure can be defined by the usage (loading cycle) rather than the time duration. So to predict the remaining potential of a composite structure, it is necessary to know the loading conditions. As an example for aviation composite structure, it can be predicted with a number of take-off and landing operations. Thus by registering the usage in PLM software, the users of these products can assist the design engineers in estimating the remaining material life before procuring the material. Once the required information is feed into the system, Repurposing companies can estimate when certain parts will be retired from their service. Using this information a few years in advance, the repurposing company can predict the waste supply and start the development of the repurposed product, which can consume the amount of waste over the estimated timeline.

Disassembly :

If the retired product is operated by the end of life solution provider or similar organization, they can assign the following information in the PLM software.

Material status:

Once the usable element is extracted from the decommissioned products, the sample's material property should be verified. Using this information, the repurposing designer can identify the suitable repurposing application for the elements.

Availability:

The EOL solution provider can keep the directory of the composite products available online to sell the material to the repurposing company.

Repurposing:

The repurposing company can provide the following data to the different stakeholders associated with the product by means of a material passport to close the loop.

LCA

With all accessible information, the repurposing company can conduct the LCA of the product at its EOL. By doing so, the material utilisation of this product can be evaluated with the new repurposed application. The repurposing company can decide if the repurposing will provide a positive impact or incineration and recycling is feasible to avoid the negative impact.

Feedback:

Repurposing companies can provide feedback to the OEM companies regarding the material properties post decommissioning and design modification to make the repurposing more feasible. Further, this information can provide the OEM companies to evaluate the life cycle assessment of their own parts to modify their products or services.

Followed by the evaluation through the co-creation session and interviews with repurposing companies, the framework will be finalized in the Deliver phase of the graduation project.

Key insights:

The Material passport intends to assist the industrial designers and repurposing companies with the essential information gathered from the various stakeholders involved from the different stages of the product life cycle.

Based on the lifecycle of the individual composite products, the content of the Material passport will vary.

3.5. Draft Repurposing Guidelines

3.5.1 The goal of the Repurposing guidelines

Following draft guidelines were formulated from the interview conducted with various stakeholders and insights gained from the case study. These guidelines were later evaluated during the co-creation session and interview with repurposing companies to create the modified and generalised repurposing guidelines which can be implemented for the various composite products from various sectors.

Repurposing guidelines for composite material aims to :

1. Regain the value of the composite product, which are overlooked after the first use cycle.
2. Make the transition from decommissioning to repurposing more efficient.
3. Guiding industrial designers in selecting the suitable repurposing application

Who can use these guidelines:

These guidelines are suited for composite product designers and manufacturers looking to introduce circularity to their products by means of repurposing. The repurposing guideline can be used as a tool to assist the industrial designers and other stakeholders involved in the composite industry to extend the use of the material by means of repurposing. Compared to the guidelines made for generalised design for repurposing (Schild, T. 2020), this set of guidelines only focuses on composite products which are already designed or an existing design using polymer composite material that requires the modification to introduce the repurposing in the product's life cycle.

The guidelines can be divided into 4 phases of repurposing, as shown in figure 3.16. In addition, guidelines can be subdivided into meta-level and product level. Guidelines in Meta level focuses on the entire life cycle and involves the multiple composite product lines. At the same time, guidelines at the product level are applicable to the individual phase of the repurposing.

Note: These guidelines should be applied when they create a positive impact on the product life and circular economy. As these guidelines provide the holistic overview of introducing repurposing to composite products, designers should use their own judgment to select the sets of guidelines applicable to their products coming from diverse sectors.

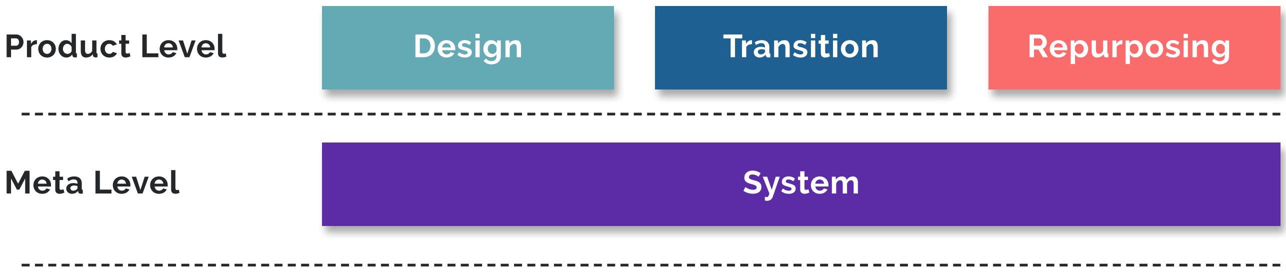


Fig 3.24 Structure of repurposing guidelines

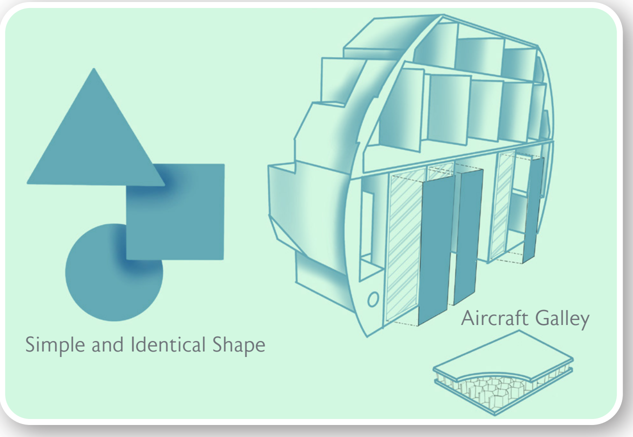
3.5.2 Develope

Phase 1: Development Phase

This phase is applicable when the design engineer or industrial designer from the initial product lifecycle wants to modify the design for an existing or new product to support the repurposing. One should note that these guidelines should be applied without compromising the design requirements such as safety and functionality to keep the positive impact without involving complexity in existing practice.

1. Keep it standard!

When possible, use standard geometry and material to construct the composite structure, for example, using an identical composite panel with a similar sandwich structure. It will help to scale up the repurposing of decommissioned products and accelerate the sorting and disassembly process.

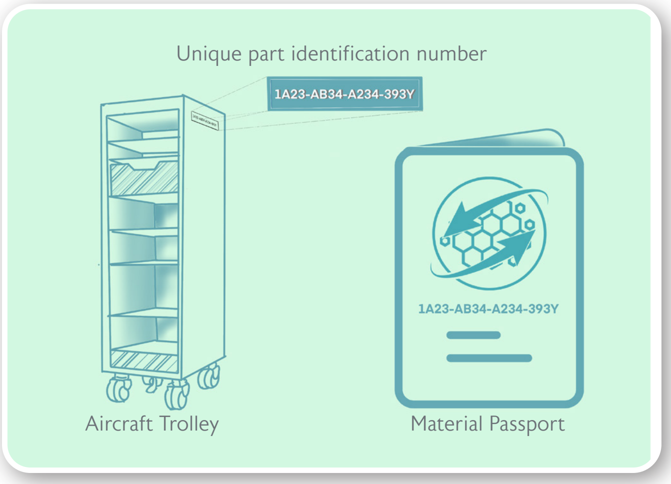


Explanation:

Design guideline applies to the products in their development stage. Here, standardisation stands for the geometry and material used. With this practice, the designer should note that it is necessary to prioritise the safety and functional requirement over this guideline. Repurposing can substitute existing products that use the same geometry in the second life using the standard composite material and shape in the first product life. With standardisation in shape and geometry, composite waste from multiple products can be streamlined into a repurposing solution with higher demand. As an example, carbon fibre reinforced floorboards used in various applications can be used for the same repurposing application.

2. Identify the Part

Like the Aviation industry, Composite manufacturers should provide a unique identification code/ number to each composite part, which stays with the component throughout its life. Unique identification will assign the required documentation for the entire product life to a single address and streamline the component's processing at the end of life.



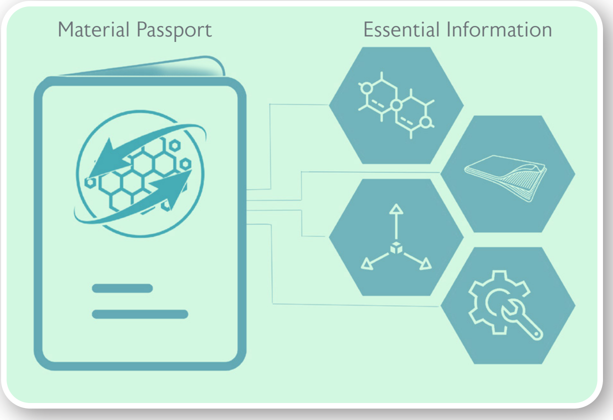
Explanation:

With the case study and inspiration from products which has their own identification, It can be found that the process of storing the required information becomes desirable. Furthermore, with this number assigned from the manufacturing company, when a part moves from stakeholder to stakeholder, information can be assigned to the respective parts using the same identification number. Thus, even if there is no standard registry of PLM, including all the stakeholders, the repurposing designer can obtain the data from individual stakeholders as a last resource during the repurposing stage. Practice to assign the part identification number is widespread in the aviation industry but should be extended to all composite products.

3. Document Everything

From the beginning of the product life, keep a digital registry of the primary function of products, material composition, list of hazardous materials used, design drawings, manufacturing methods, product use, instruction for disassembly, list of modification or repair and other essential information.

Later, a repurposing designer can use this information to assess the remaining material value at the end of the life without wasting their time and effort in looking for the required information from a number of stakeholders.



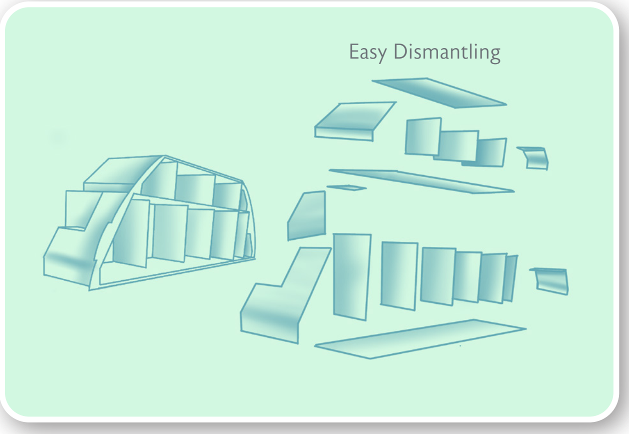
Explanation:

The aim of this documentation is to keep track of necessary data over the prolonged use phase. By assigning the required information to the product, the job of repurposing designers and engineers becomes easier in analysing the decommissioned product and treating it with the application process. By following this guideline, a designer might face resistance from stakeholders in sharing the sensitive design data, an additional task for the software operator and the number of resources spent in processing the information. Thus, the repurposing designer should indicate to the company why this information is vital and how it can help in effective repurposing.

4. Make it Modular

With a modular design, the original product can be easily split into modules, which can be effortlessly disassembled for repurposing for a second life.

Additionally, While bonding the composite component or additional parts, apply the adhesive that can be de-bonded with a simple process without compromising the part's functionality. It will reduce the processing time and labour cost of dismantling.

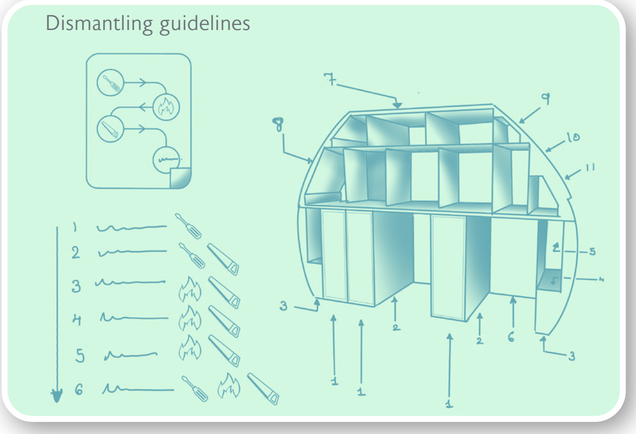


Explanation:

Here, modularity refers to ease in disassembly. By creating a modular part, the product designer can save time in disassembly during the maintenance and dismantling, resulting in lower processing costs during the transition phase of repurposing. This is in contrast to increasing the weight due to the addition of fasteners for joining. Thus the evaluation should be made to compare the bonded structure and modular design, and priority should be given based on the nature of the design requirement.

5 . Prepare the Dismantling guidelines

By providing the dismantling instruction, the repurposing organisation will estimate the time and resources required to recover the usable material. Additionally, these instructions will accelerate the process regardless of the custom-designed products (Ex. aircraft and yacht interior).



Explanation:

Here Dismantling refers to taking out or stripping out all the usable composite components utilizing external tools involving disassembling with tools like a spanner or removing the bonded panels with the use of power tools and heating.

With this document, the repurposing company can already prepare itself with the required tools and facilities. With design drawings, the dismantling worker needs to understand the design and then prepare the manual plan to remove the usable components. The quality and accuracy of dismantling and recovered parts will be dependent on individual judgment. With the customed designed product, dismantling will have to be prepared each time a new design is brought for repurposing.

3.5.3 Transition

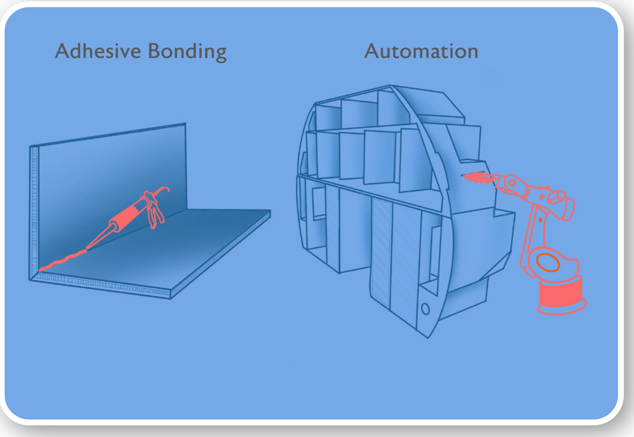
Phase 2: Preparation phase

Repurposing guidelines for the transition phase focuses on making the transition from decommissioning stage to the repurposing stage feasible and viable. This set of guidelines focuses on the existing products and relates the company conducting repurposing.

1. Accelerating the Dismantling

For the bonded composite products, separating the individuals component can be a complex and time-consuming task.

With the Dismantling guideline, the repurposing company should recover the maximum amount of usable material without damaging the component and be equipped with the required tools and facilities. As this process can be labour intensive, using automation can accelerate the transition phase.

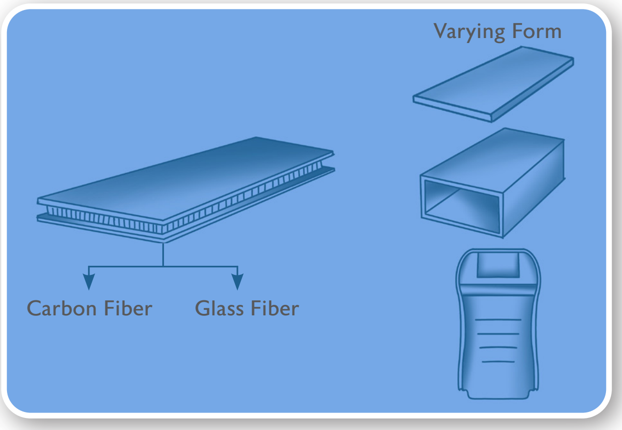


Explanation:

This guideline applies to the product having multiple parts, which are time-consuming in disassembly or dismantling but is not critical for simple shaped products such as floorboard or overhead bins. To accelerate this process, industrial designers can take the help of automation, where manual work can be replaced or assisted by automation or innovative technology. The priority should be given to reduce the cost of processing to make the repurposing product more desirable with a lower cost.

2. Material Sorting

Along with the composite material, other valuable materials gets decommissioned at the end of life. Some products contain more than thousands of parts varying in shape and materials.



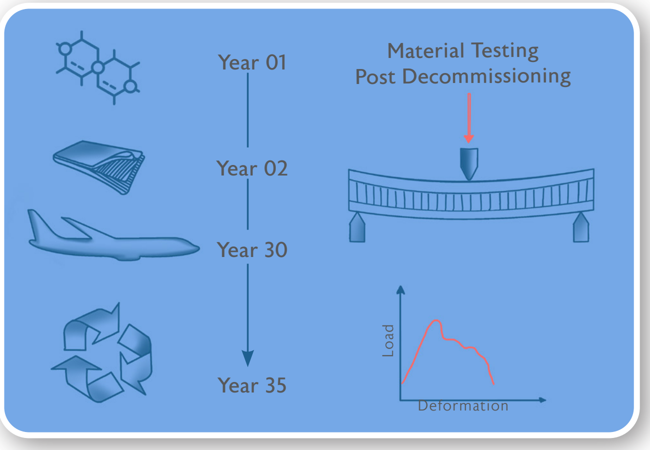
While decommissioning, these products should be strategically sorted to avoid inefficient waste management and loss of valuable materials. In addition, sorting these parts will assist the designers in planning the repurposing based on the available directory of components.

Explanation:

This guideline applies to the product having multiple parts, which are time-consuming in disassembly or dismantling but is not critical for simple shaped products such as floorboard or overhead bins. To accelerate this process, industrial designers can take the help of automation, where manual work can be replaced or assisted by automation or innovative technology. The priority should be given to reduce the cost of processing to make the repurposing product more desirable with a lower cost.

3. Material Status

Periodically, the repurposing company should test the decommissioned material according to the requirement of a selected repurposing solution. As some products are in service for more than a few decades, the strength and stiffness of these materials are difficult to predict after prolonged life.



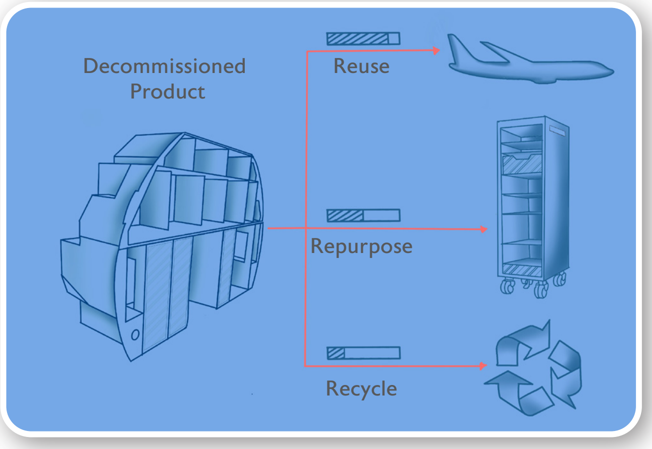
Decommissioned composite elements can be tested with different methods to estimate the remaining properties and can be compared with other materials to find a suitable second life application.

Explanation:

It is not possible to predict how the material property of the composite material varies with the use. Thus to find a suitable application for the used material, the repurposing designer should verify the material property and find the suitable application.

4. Should we Reuse, Repurpose or Recycle?

After determining the status of the component and its remaining strength, the decommissioning company should evaluate the market demand in multiple scenarios to choose the viable option to recover the maximum material and economical value from the products.

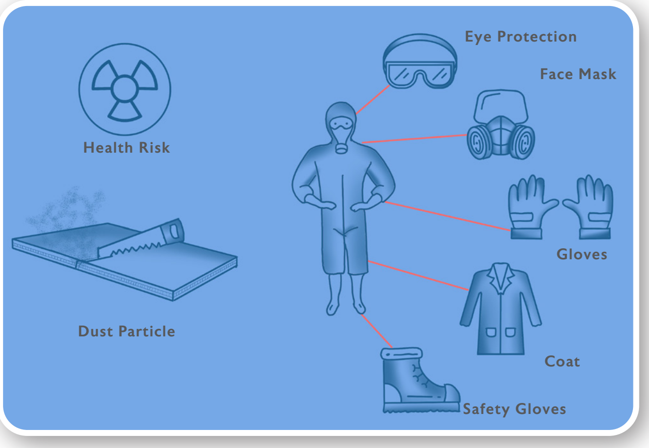


Explanation:

A designer should note that repurposing all the composite product may not feasible and viable due to the varying cost and complexity. Thus, based on the available choice, the repurposing designer

5. Take the necessary precautions

Some composite products may contain the materials and chemical which are not suitable for particular repurposing applications. These parts should be separated and treated carefully.



When modifying the original component made from glass fibre or Carbon fibre, use the appropriate equipment and safety gears to avoid injury and health issues. In addition, as this process spreads the composite dust around the workplace, the factory worker should avoid direct contact by wearing the necessary safety gear use the closed room to avoid spreading dust around the workspace.

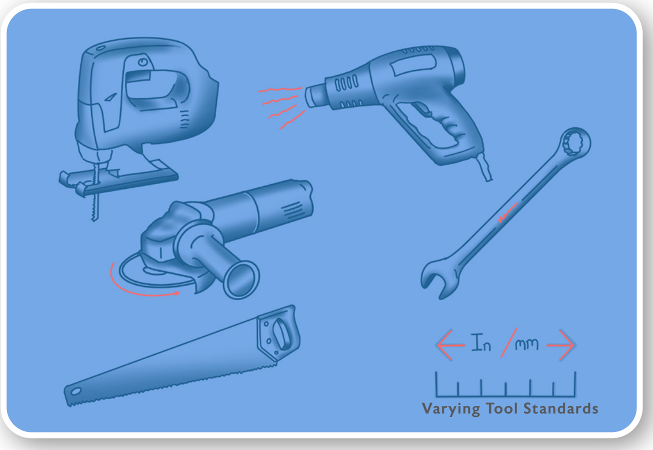
Explanation:

The safety measure can be devised by creating a list of measurements formulated to guide the industrial designer on avoiding the application where specific composite material is prohibited. This practice can be extended by formulating a regulation on health precautions that the workers should follow to avoid injuries and health issues. This practice can use the information which will be provided in PLM software by specifying the material properties.

5. Use the right Tools

Use appropriate tools to process the composite material to avoid damage to the composite layer. By examining the design document of the decommissioned part, the repurposing company should capitalize on the required tools and facilities.

Parts being old and manufactured around the globe requires a wide range of tools, working with different standards such as matrices and inches.



Explanation:

This guideline aims to prepare the repurposing company with the required facilities and evaluate the cost of processing.

3.5.4 Repurposing

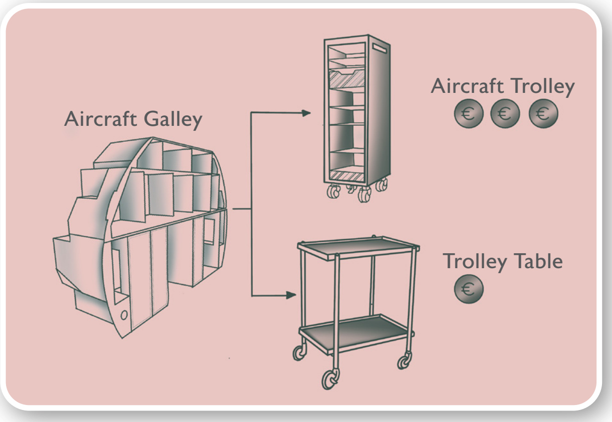
Phase 3: Repurposing phase

The repurposing phase involves the guidelines which assist the industrial designers in evaluating their design choice. The aim of these guidelines is to select the repurposing application which can utilise the maximum value of the original composite product.

1. Maintain the Economical Value

Most of the products made from composite materials are expensive. With the complex assembly and disassembly of the existing products, processing this component for repurposing can be expensive.

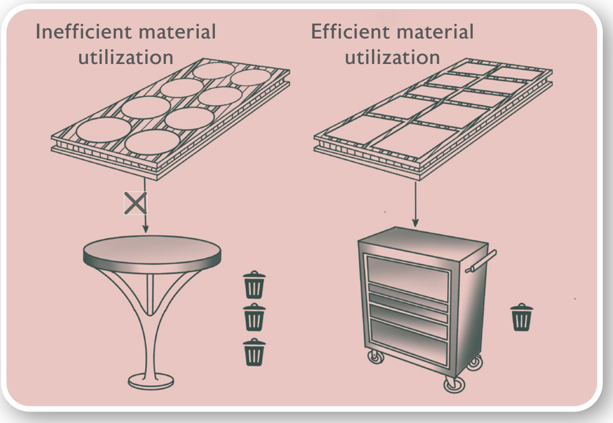
For successful repurposing, finding a suitable application that can create nearly equal economical value is crucial.



Explanation:
With processing costs involved in repurposing, industrial designers can only create successful repurposed products by selecting profitable and marketable choices. For example, repurposing the aircraft galley into the table will create less profit than using it in transportation or construction as a lightweight product.

2. Maximise the Material Recovery

While processing the part, the design should prioritise which has minimum waste in repurposing from the original material while utilising the maximum amount of the material from initial products.



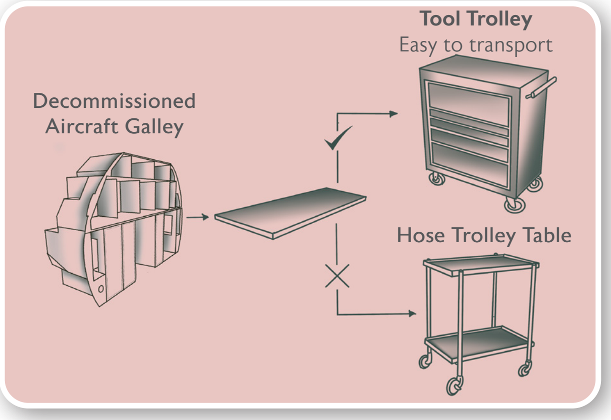
Explanation:

This guideline served as one of the criteria to evaluate the different design options.

3. Maintain the Functional Value

The repurposed solution should match the functionality of the original product, retaining the functional value of the original product.

For example, by taking advantage of the composite material's high strength to weight properties, the repurposed product can be used in the transportation or construction sector.



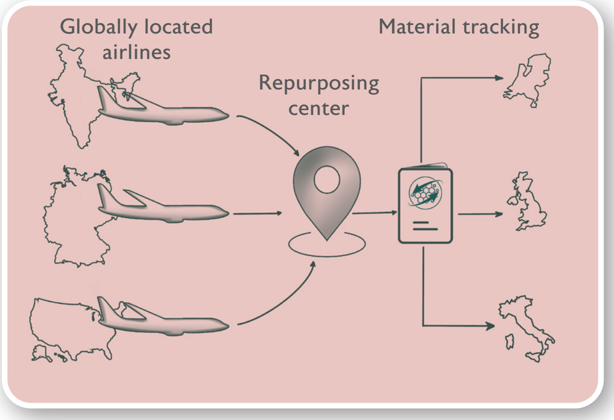
Explanation:

To increase the value of the repurposed product, the Industrial designer can refer to the functional value mentioned in the PLM software. For example, composite panels extracted from the galley serve as a lightweight and strong material, superior in resistance against fire. The same panel can be used as a table for the house but can also be used in a vanity van where material can reduce fuel consumption.

4. Effective Waste Management

During the decommissioning of the original product, the material is already collected at one location. However, After repurposing, there is a possibility that composite material will be again distributed around the globe.

Maintaining the material passport for repurposed products can retain the waste management structure organised. Additionally, finding the repurposing application around the location can create a possibility to recollect the part to recycle or incinerate successfully after it has been decommissioned from repurposing life.



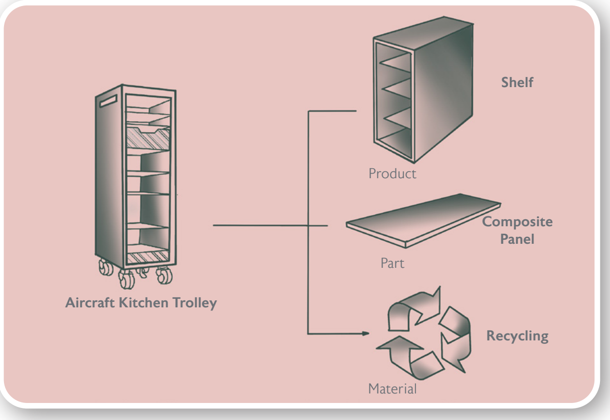
Explanation:

Once the product is repurposed, the composite waste material is transferred from a location where all the waste was collected and sold around the country, disturbing the existing waste management system. One way to overcome this problem is by creating a repurposed product for local buyers. A neighbouring industry will use the product near the repurposing company, and once it is decommissioned again, it will be returned to the repurposing company.

5. Product vs Part vs Material

When composite products are dismantled into smaller segments, it comes with the processing cost. At the same time, the dismantled part will occupy less space and cost less in transportation.

By evaluating the labour cost, the economical value of repurposed product and market demand, the repurposing company should select the favourable option.



Explanation:

As shown in the figure above, with the remanufacturing, the galley can be repurposed as a cabinet with minimum work. It can also be split into panels which can be used to make the furniture, and further, it can be shredded for recycling. The industrial designer's job is to discover a suitable product based on repurposed solutions with more economical value and material utilisation.

3.5.4 System

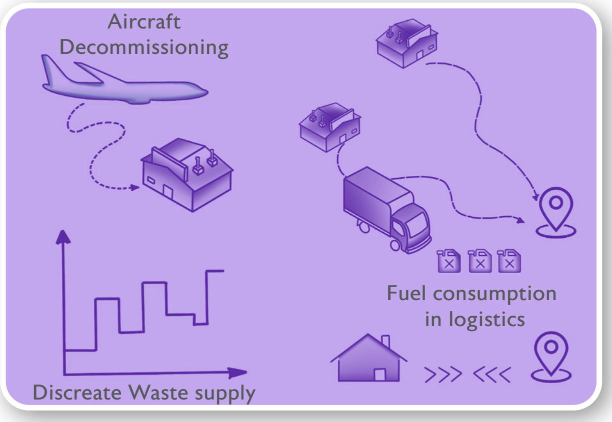
Phase 3: Meta Level

The system phase aims to focus on a meta-level and is applicable when designing the entire product life to support the repurposing with multiple life cycles and industries in consideration.

1. Minimise the Logistics

When composite components are decommissioned, they will be located around the globe. Moving from decommissioning location to repurposing factory will burn the unnecessary fossil fuel.

It is essential to locate the repurposing factory at the centre of various decommissioning locations.



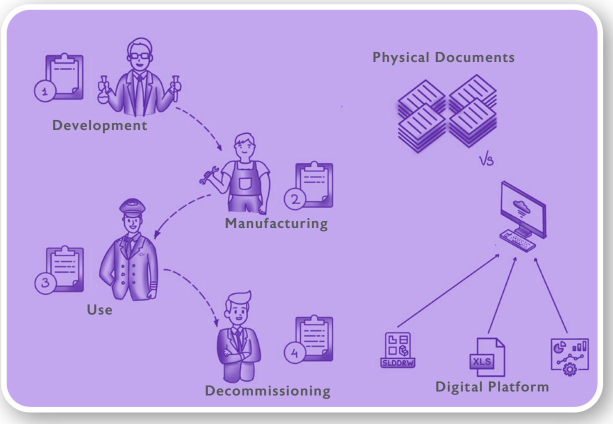
Explanation:

The guideline aims to conduct the repurposing with as minimal environmental impact as possible. One way to reduce the impact is minimising the logistics. By locating the repurposing factory near the EOL service provider, transportation of waste material can be reduced. Further finding the repurposed application around the company can reduce the transportation in distribution.

2. Knowledge Transfer

Often, composite parts advance from stakeholders to stakeholders during their first life. It is essential to keep the relevant information flowing along with the original product such that the repurposing company can use this information to process into new products.

Additionally, using a single platform in a digital form can save a massive amount of effort to process the data than traditional paper-based entries. Using a digital tool supporting the existing and varying platforms used by the different stakeholders will simplify this process.

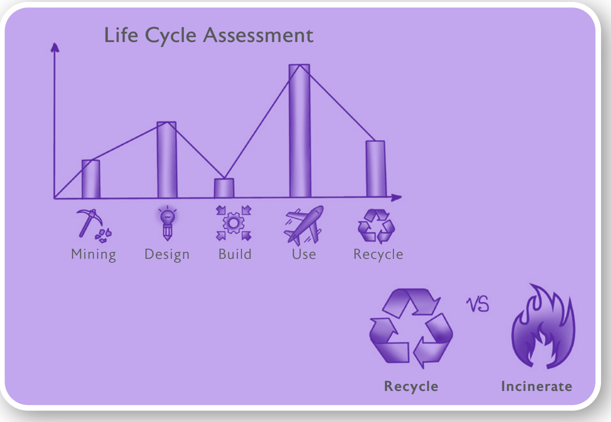


Explanation:

The knowledge transfer has the potential to accelerate the repurposing by providing the necessary knowledge to the industrial designer. Setting this platform has an initial cost that will reduce over time.

3. Creating the base for a circular economy

The repurposing aims to efficiently utilise the material value of the composite product before going into incineration. Therefore, it is necessary to conduct the LCA of the entire life cycle to avoid creating a negative impact by repurposing. Furthermore, manufacturers can use the information collected for the repurposing to modify the design or its entire life cycle.



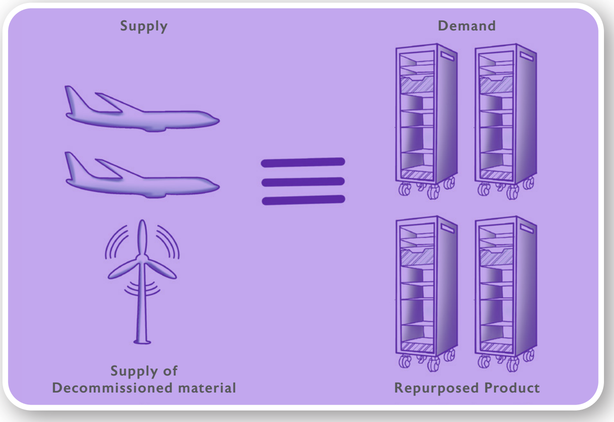
Explanation:

LCA can be used to evaluate the impact of a product on the environment during the different stages of the Life cycle. By evaluating the various options, the designer can make sure if the repurposing is desirable or creates a negative impact on the circular economy. The designer should verify the authenticity of the data used for LCA and use the result responsibly

4. Match the supply and demand

It is necessary to match the supply of composite waste from decommissioned products to the demand for repurposing solutions to run the repurposing program successfully.

Additionally, the repurposing designer can streamline decommissioned composite products with similar functions and form multiple industries to match the repurposing product's demand.

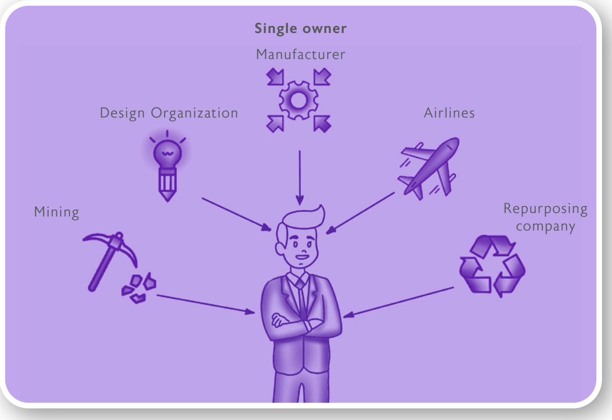


Explanation:

The supply of composite waste material can be discrete and varying in quantity for various products. If the supply is greater than the demand, the repurposing company will have to deal with the remaining waste. In contrast, if the repurposing product is chosen whose demand is larger than the supply of composite waste material, the repurposing company will have to depend on other material or add the virgin material in addition to the decommissioned elements from the initial product life.

5. Part Owner and Business

Often the end of the product's life is ignored during the design phase as there are no producer responsibilities in decommissioning the composite products. By appointing the single product owner with producer responsibility throughout the product life, repurposing can be made more viable.



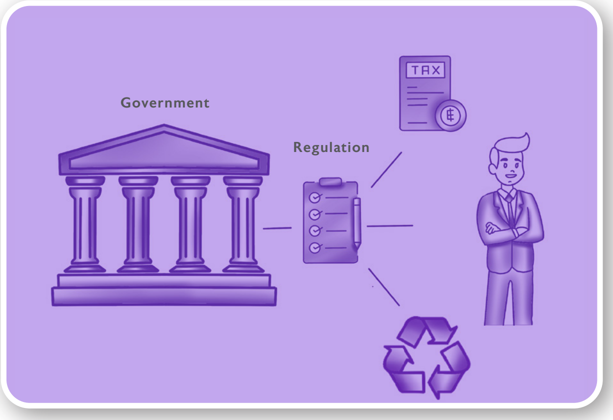
Explanation:

With multi-stakeholder involved in the product life cycle, the goal of individual stakeholders is different. Often the control over the product ownership is transferred to the stakeholder with a different goal. As seen during the case study, products are not designed for decommissioning stage. When products are leased, the manufacturer's responsibility is to look over all the stages of product life. Thus by having a single product owner and leasing models, more control is given to the company. They can regulate the flow of information without any concern about its confidentiality and prepare the product for the desired end of life.

6. Legislation

Without regulation, all the processes are monitory. To implement a sustainable solution in the composite industry, it is crucial to formulate legislation. Legislations will compel the industry to use the resource with necessary research and development towards the sustainable end of life.

Regulation such as
+ Extended producer responsibility
+ Tax including decommissioning
+ Material Utilization



Explanation:

The European Union, extended producer responsibility is mandatory regulation within the context of the WEEE, Batteries, and ELV Directives, which put the responsibility for the financing of collection, recycling and responsible end-of-life disposal of WEEE, batteries, accumulators and vehicles on producers. Implementing a similar approach for the composite waste material can be enforced for the sustainable end of life practice. Looking at the cost structure of any product, often cost of handling the material for recycling or Reuse at EOL is not included in the tax (Environmental taxes, 2016). Thus, it becomes a monitory job for repurposing company and is partially responsible for direct incineration over material utilization. Therefore legislation is a crucial part of the implementation of efficient material utilization for composite products.

3.6. Conclusion

Collecting the insights from the discover and define stage, and case study conducted during the development stage helped gather a number of insights. These insights were later used to create the draft guidelines that can assist the industrial designers to successfully repurpose composite products after they are decommissioned from their life cycle. Also, the framework for PLM was formulated that can prepare the list of information that can make the repurposing more feasible and viable.

As the repurposing guidelines are formulated based on the interviews and case study, it needs to be evaluated by several experts, including a representative from the composite industry, researchers, industrial designers, and repurposing experts. Further, the guidelines can be difficult to be a entirely applicable for an individual sectors, as these guidelines are not tailored to specific sectors. When compared with passenger aircraft, some of the given development guidelines are not feasible. For example, most of the products are already designed and are in service. In addition, making the product modular will increase the weight and result in more fuel consumption during the flight. Therefore, the industrial designers need to select the sets of guideline that applies to the selected composite products.

DELIVER

Chapter 4

Deliver

The Deliver phase is the final part of the Double Diamond method. In the Deliver phase, the draft guidelines will be evaluated to deliver the final proposal. By inviting various stake-holders involved in the composite industry together in the same meeting, the draft guidelines will be presented. Furthermore, by means of evaluation through creative facilitation workshop, the guidelines will be made more concrete and applicable to various products. In the end, these guidelines for the composite repurposing will be reviewed by one-on-one expert inter-views to propose the final guidelines as a deliverable

Goal of the Phase:

- Conduct the Cocreation sessions with various stakeholders and industrial dersigners to evaluate the composite repurposing guidelines.
- Review the modified guidelines with repurposing exrperts and deliver the final list of guidelines.
- Formulate the finalized guidelines and PLM framework

4.1. Co-creation Session

As seen in the previous chapter, draft guidelines were formulated based on the literature review, individual stakeholder interview and case study. Further, a co-creation session can provide an opportunity to engage all the stakeholders, including composite researchers, product manufacturers, service providers, academic experts, and industrial designers, to discuss the composite material's repurposing. The primary aim of this session was to assess what industrial designers and stakeholders think about the repurposing of composite products and repurposing guidelines that can assist them. Further, this discussion was used to evaluate the draft guidelines for repurposing and obtain participants' opinions concerning PLM and acceleration in the transition phase of repurposing.

4.1.1 Attendiees

The co-creation session aimed to get as many of the stakeholders involved in the composite industry along with the industrial designers to have a constructive discussion on repurposing. During the individual stakeholder interviews, they were asked about their interest in the topic and their willingness to involve in the co-creation workshop. Participants with the following profession (Fig 4.1) and experiences were invited to the workshop. The detailed information about the participants can be found in (Appendix A4.1)

Fig 4.1 Background of attendees' from the co-creation session

4.1.2 Setup

With restriction due to Covid-19, the workshop was conducted online. To organize the online meeting, Zoom platform was used for video conferencing and having a discussion among different participants. Activities for the entire workshop was conducted on the Miro board (Appendix A4.2). Invite for the workshop was sent with a brief manual describing all the activities. The online website was prepared with guidelines and was sent to individual participants along with an invitation. The author facilitated the co-creation session with the help of another co-facilitator by keeping track of time and guiding the participant through different activities.

Activities:

The entire workshop was planned for 90 min with sprints of activities (Fig. 4.2) as follows. Activity in detail can be found in (Appendix 4.3).

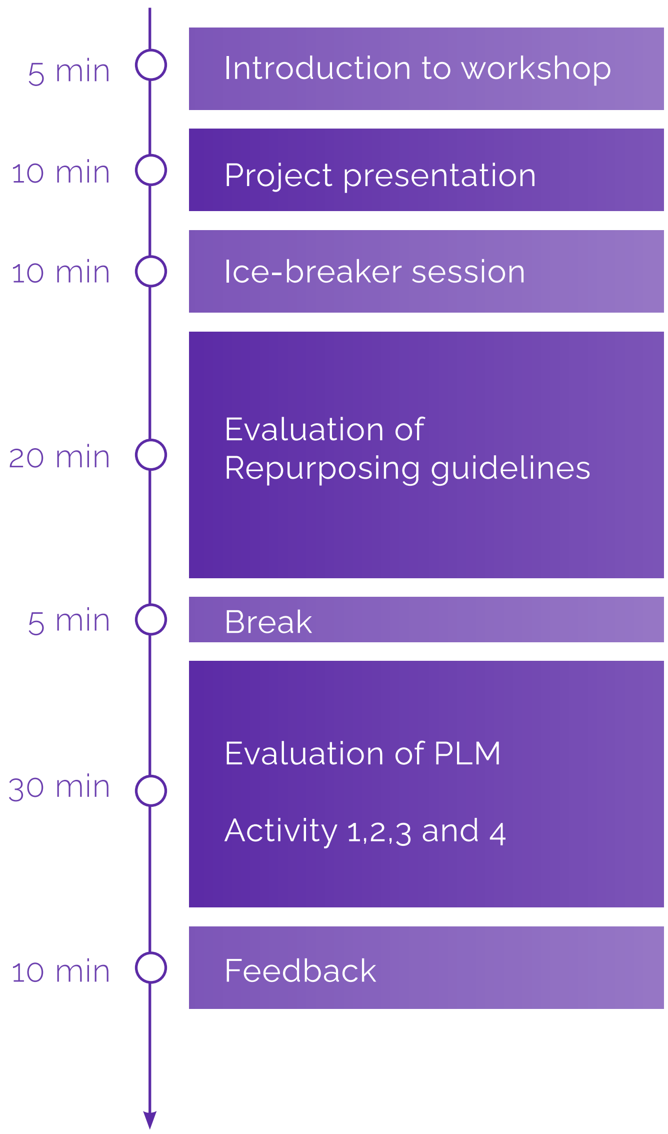


Fig 4.2: Co-creation workshop activities

Activity 1: Evaluate the repurposing guidelines with all the participating stakeholders

Participants were asked to go through the guidelines considering themselves as a stakeholder, and writing the feedback on Miro board or opening the discussion. The activity was aimed to get a review from the potential user of these guidelines. Later, Industrial designers were asked to give their opinion on guidelines after the workshop.

Evaluation of guidelines:

Concerns:

Concerns were raised about the impact of standardization and modularity on high-performance composite products in aircraft having a complex shape, and negative impact due to the addition of weight.

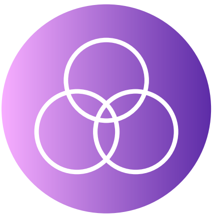
Some of the participants indicated their concerns regarding the economical investment required for the additional steps.

Suggestion:

The part identification was related to block-chain and NFT. One of the positive impact mentioned in identification guidelines were making the process more transparent and accessible with PLM software. However, the problems of intellectual rights and excessive data that might need to be handled were highlighted.

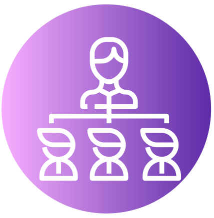
Feedback from participants indicated the need for personas to understand each key actor's role, such as Industrial designers, user and EOL solution providers.

In addition to existing guidelines, new guidelines were suggested focusing on the consumer perspective, such as aesthetics and the expectation of consumers.



Agreement :

The similarity between the economical value, material recovery and functional value was pointed.



The participant indicated their agreement over the single part-owner, solving the issue of missing responsibility for material utilization. At the same time, some participants believed that assigning responsibility can also solve the same issue.

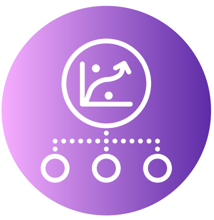
Activity 2: Evaluate the PLM framework

Group of participants were given a case study of repurposing the original galley into a trolley. The original PLM framework was not presented to them in order to obtain creative suggestions discovering overseen information in the draft framework. Initially, stakeholders were asked to suggest the required information for repurposing to understand their expectations on PLM data. Later, they were asked to indicate the obstacles they see in following the PLM frameworks.

Suggestions:

In addition to the required information mentioned in the PLM chapter, participants suggested including the list of skills required from workers to dismantle the entire composite product after decommissioning.

The other important element discussed during this activity was the inclusion of product weight which can provide information concerning sustainability at a different stage.



The participant also suggested building the PLM system, which can indicate the repurposing organization about forecasting the retirement of a different material.

Indication of obstacle in PLM framework :

As indicated by a participant, legislation can be an obstacle in implementing the PLM framework.

Some participants find the incentive and time required to run the PLM framework as an obstacle.

Activity 3: Evaluate the repurposing process from the industrial designers perspective

3rd Activity consists of a group of tasks given to industrial designers in order to evaluate the concept of repurposing the composite material. The goal of the activity was to understand the expectations from the designers and test if they could come up with a suitable application after going through the guidelines from the previous activity. The result of this activity could improve the repurposing guidelines and PLM framework to assist the industrial designers. (Appendix A.3.3)

Task 1: Listing out the required information to repurpose the product as an industrial designer.

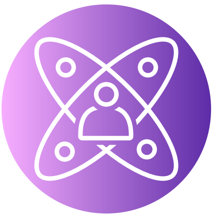
Outcome:
The result of the discussion shows that most of the designers would like to know the quality of the decommissioned material and the material composition to repurpose the product.

Further, some of the suggestions include providing the information describing the possible use, behaviour in second life, and manufacturing process suitable for repurposing the decommissioned product.

Task 2: Listing out the possible application from the decommissioned products from the case study.

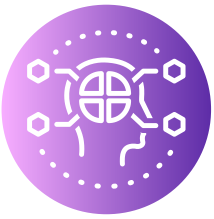
Outcome:
The suggestion given by participating industrial designers were repurposing applications from the

automobile, transportation and temporary film sets where such products are continuously moved from location to location.



This shows that, by keeping the guidelines, designers can find the application which will take advantage of very well known high strength to weigh the property of composite material. It can be assumed that by providing more properties of the decommissioned composite material, industrial designers can come up with the more feasible and desirable solution

Task 3: Listing out the strategy to create more economical value from the decommissioned products.



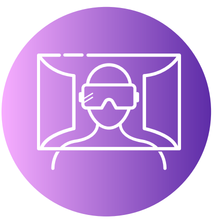
Outcome:
Some of the suggested strategies were as followed

- Provide carbon credits for the manufacturing industry, promoting repurposing of their products.
- Find the application with exceptionally long life to utilize the maximum potential by repurposing.
- Create an emotional value to market the repurposing product.

The suggestion shows that participating industrial designers can come up with an economically feasible solution at the product level and at the strategic level. With the productive ideation phase and correct policy, the repurposing products can have a sustainable business opportunity.

Task 4: This activity aimed to discover if participants can predict the existing technology to accelerate the process of dismantling and reduce the overall time.

Outcome:
With the positive discussion, a few of the suggestions were as followed.



- Give AR headset or projecting on a composite part where dismantling worker needs to work. This will eliminate the manual hassle of deciding.

- Use an adhesive that can be easily removed.

- Find the repurposing application which does not require entire disassembly.

- Use CAD assembly from PLM software to plan the dismantling.

The outcome shows that stakeholders can predict the technology which can accelerate the dismantling process. Thus, the guideline on accelerating the process can be still fulfilled with the viable process planning.

4.1.3 Conclusion form co-creation session:

The co-creation session provided an excellent opportunity to evaluate the repurposing guidelines from the various stakeholders, and industrial designers present on a single stage together. It was concluded that the guidelines need additional explanation with the distinct role of different players. Further guidelines should be made more generalized, supporting the majority of the sectors. The concern among the different stakeholders regarding the business model indicates that further works need to be carried to create a set of holistic guidelines suggesting various steps to make the repurposing more economically feasible. Further disagreement over the possible support over the transparency in knowledge transfer indicated the need for regulation that can support the material utilization with mandatory data sharing.

Finally, the concern regarding the management of possible enormous data from PLM shows that there is a need for collaboration between different stakeholders and repurposing organizations in mutually deciding the selective data supporting the repurposing operation and circular economy. This can also result in lowering the investment needed for the implementation and execution of PLM software.

Further, various co-creation activities show that repurposing guidelines can support different industrial designers in ideating feasible and desirable solutions. Suggestions provided by the industrial designer should be added in the final guidelines that can support them with the required information. The co-creation session also revealed certain aspects, such as convincing the stakeholders in collaborating for repurposing and making the repurposing business economically feasible. As this project aims to create the base for repurposing practice, there is a need for a development plan indicating steps that should be carried out to execute the repurposing practice in the nearest future successfully. The plan of action will be recommended at the end of the project to develop the new practice of scalable repurposing with stepwise future development.

4.2. Evaluation with experts

Along with the co-creation session, it was crucial to interview a composite repurposing expert. One of the core users of these guidelines will be an industrial designer from the repurposing company. Getting the opinion of industrial designers from the repurposing company on these guidelines can provide the required insights. However, there are very few repurposing companies in Europe that produced repurposed parts from discarded composite products. One of the companies in Europe is ANMET.

About ANMET:

ANMET is engaged in recycling wind turbine blades and is looking for new solutions that enable the reuse of wind turbine blades designated for dismantlement (ANMET Andrzej Adamcio, 2021). ANMET has recently repurposed several furniture and other products from segments of wind turbine blades. Currently, the company is working on producing the footbridge from the decommissioned wind turbine blades with ongoing prototype testing (Sobczyk,2021). With the closely related work and one of the users of guidelines, the repurposing industrial designer from the ANMET was interviewed to evaluate the guidelines and PLM framework.

4.2.1 The result of the interview is as followed

"It is imperative to understand the composition of the material while repurposing any product after decommissioning. However, the existing production companies do not close the loop with the issue of intellectual property."

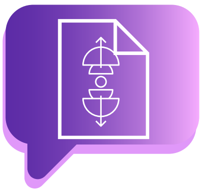
"By collaborating the product owner, the repurposing company can scale up the process."

"If the documentation is created to support the repurposing as mentioned in the guidelines from the initial product lifecycle, the process of repurposing becomes more viable."

"With the experience of making the furniture, repurposing the wind turbine blades does not make the wind turbine blade entirely sustainable, but the goal is to extend the life of material and delay the premature incineration."

"As mentioned in 'product, part or material' guideline, We, for example, use best quality blades as a bridge frame (product), with small damages we use as a piece of furniture(part), and completely damaged are sent for milling and incineration (Material)."

"Wind turbine blades are used for 30-40 years. However, we test the material during the decommissioning to predict the remaining use, which indicates that blades can be used for repurposing application for more than a few decades."



"To dismantle the wind turbine, ANMET developed its own process and equipment to accelerate the dismantling. However, as mentioned in repurposing guidelines, if document of the dismantling guidelines are provided from the manufacturers, the repurposing can attract more companies and people.''

"To repurpose into more valuable products like a bridge, we need comprehensive information. Unfortunately, wind turbine manufacturers do not share this information. To execute the project, ANMET had to voluntarily reproduce the design drawings, collaborate with the third party service provider and get financial support from the EU project for expensive testing. This takes a considerable amount of time and resources."

"Current Guidelines and information available for repurposing are minimal and do not provide elaborated information. The proposed guidelines in this project are much more informative but should be made suitable for more sectors."

4.1.2 Conclusion form interview:

The feedback gathered from the interview turned out to supportive rather than positive-feed-forward feedback. The interview concluded that the draft guidelines closely reflect the existing practice of the composite repurposing company, ANMET. However, through the interview, it was stated that the existing guidelines in the market do not have a clear vision and elaborated information attracting existing companies.

Although, if the proposed guidelines for composite repurposing from the project are made more holistic, supporting various industries can provide the desired base to expand the repurposing practice. Existing practice from the initial product manufacturers does not provide the required information to support the repurposing companies, making the process of repurposing time-consuming and economically undesirable. Therefore, there is a need for an initiative from product manufactures and the government to create a policy to support the material utilization via repurposing.

4.3. Revised Product Lifecycle Framework for Repurposing

From the combined evaluation from the co-creation session and interview, the draft proposal for the PLM framework was modified. Part of the final proposal from the graduation project is described as follow:

The PLM framework for repurposing is the list of required information that should be documented in the form of a digital passport to facilitate the industrial designer engineer designing a repurposed product from the decommissioned composite products. By sharing the material passport with the repurposing designer, the system will save the time and resources spent re-discovering the information required to repurpose the decommissioned composite product efficiently.

Who will use the PLM framework ?

Various stakeholders must use the PLM framework to input the required information created by the product manufacturer. After the decommissioning of the composite product, essential information should be shared with the repurposing company. The industrial designer can use this information to successfully and efficiently develop scalable repurposing products. In addition, the repurposing company can return essential feedback to the various stakeholders to modify the design or product lifecycle to reduce the impact on the environment through repurposing.

How to use the PLM framework ?

Initially, composite product manufacturers should collaborate with the repurposing company and experts from the relevant field to decide the set of desirable and feasible data to be included in the PLM system. Then, by allocating the unique identification code to individual products, required information for repurposing can be documented in the PLM system. In order to effortlessly running this practice, users should implement the PLM system in the form of a digital material passport. This practice will accelerate the documentation process for a large assembly product and enable selective data sharing to protect sensitive intellectual properties.

The following set of information should be included in the material passport from the different phases of a composite product's lifecycle.

Material Passport

1

Raw Material production

Material Composition

A complete list of materials and additives used for the manufacturing of the raw composite material.

Hazardous Material

List of harmful constitutes present in the material. must be added in the material passport from the different phases of the composite product lifecycle.

Material Passport

2

Product design phase

Design drawing

Information containing design drawings and cad model.

Product specification

The primary function of the material and product, including the advantage in various conditions.

Product Design phase

Material Passport

2

Design drawbacks:

Drawbacks of product and material in the various condition that should be avoided during the repurposing phase.

Life expectancy:

The expected life of the product and material in terms of time or loading cycle.

Manufacturing

Material Passport

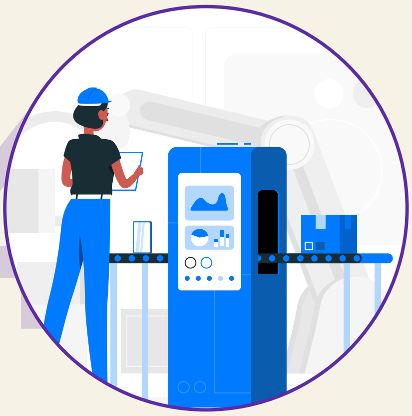
3

Manufacturing technique:

Manufacturing specification, including the list of information required to assess the decommissioned product successfully.

Material Passport

Product Assembly



Assembly drawing:

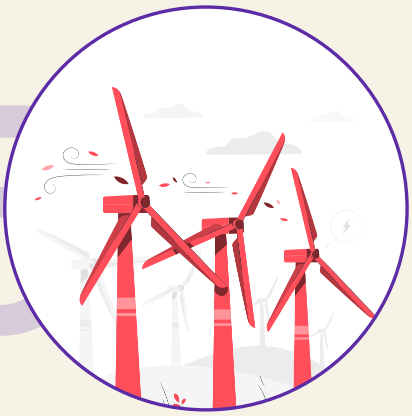
Set of information describing the product assembly, hidden elements, extractable parts and material through disassembly and dismantling.

Disassembly guidelines

Set of instructions including stepwise disassembly instruction, list of fasteners and required tools.

Material Passport

Use



Critical Usage:

Quantified information of critical usage to predict the remaining product life.

Maintenance:

The primary function of the material and product, including the advantage in various conditions.

Material Passport

6

Decommissioning

Material status:

Functional property of the material after the decommissioning.

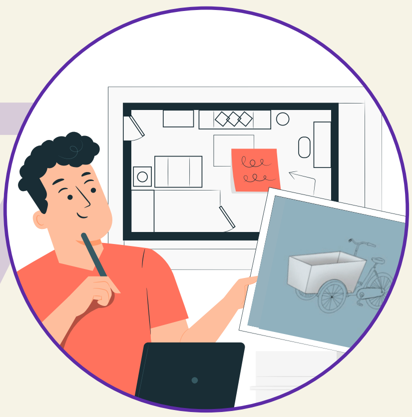
Material Availability

Forecasted availability of the decommissioned composite product.

Material Passport

7

Repurposing



Feedback:

Feedback to improve the lifecycle, supporting repurposing and environmental impact.

4.4. Revised Guidelines for Repurposing a Composite Product

The draft guidelines for repurposing a composite product was revised with collective evaluation from the co-creation session and interview. The final proposal from the graduation project is de-scribed as follow:

Repurposing guidelines for composite material aims to :

1. Regain the value of the composite product, which are overlooked after the first use cycle.
2. Make the transition from decommissioning to repurposing more efficient.
3. Guiding industrial designers in selecting the suitable repurposing application

Who can use these guidelines:

These guidelines are suited for composite product designers and manufacturers looking to introduce circularity to their products by means of repurposing. In combination with material passport, the repurposing guideline can be used as a tool to assist the industrial designers and other stakeholders involved in the composite industry to extend the use of the composite material by means of repurposing. This set of guidelines focuses on composite products which are already designed or an existing design using polymer composite material that requires modification to introduce the repurposing in the product's life cycle.

How to use it:

The guidelines can be divided into 4 phases: Develop, Transition, Repurpose and System phase. In addition, guidelines can be subdivided into meta-level (System phase) and product level (Develop, Transition, Repurpose). Guidelines in Meta level focuses on the entire life cycle and involves the multiple composite product lines. At the same time, guidelines at the product level are applicable to the individual phase of the repurposing.

Note:

These guidelines should be applied when they create a positive impact on the product life and circular economy. As these guidelines provide the holistic overview of introducing repurposing to composite products, designers should use their own judgment to select the sets of guidelines applicable to their products coming from diverse composite sectors.

Guidelines for Repurposing A Composite Product

Develop: Prepare the product

Set of guidelines that must be followed before decommissioning stage to develop a base for scalable repurposing practice. This set of guidelines are primarily applicable to the product manufacturer willing to introduce a circular economy through repurposing.

Document the prerequisite information for repurposing:

Consulting the repurposing expert, the Product manufacturer should create the digital directory as described in the material passport. Then, using the material passport, different stakeholders involved in the initial product lifecycle should support the repurposing designer with the list of prerequisite information to develop a scalable repurposing product.

Provide a unique identification number to each part:

Provide a unique identification number to each composite part, linked with the material passport and assigned for the entire life cycle.

Prepare for dismantling:

Develop dismantling and disassembly guidelines for multi-part products to educate the repurposing industrial designers with the stepwise instruction in material extraction, required tools and essential labour skills.

Transition: Prepare for repurposing.

This set of guidelines applies after retiring a product from its initial phase and is applicable to EOL service providers and repurposing companies to prepare the product for repurposing.

Analyse the decommissioned product:

Periodically test the decommissioned composite material to evaluate the remaining material potential in part. Choose the appropriate test providing the material comparison relevant to the requirement of repurposed solution.

Reuse, repurpose or incinerate:

Based on the result of the material test and part status, and market demand, select the viable option to recover maximum material and economic value from the product

Creating the storage free strategy:

Based on the composite waste supply forecast, select the product development strategy to minimize the storage cost and tackle the intermittent waste supply.

Develop accelerated dismantling practice:

Choose the dismantling process and technology which can accelerate the process for bonded composite products at a minimal cost.

Economic dismantling plan:

Use the dismantling guidelines to evaluate the capital need to invest in a suitable dismantling process, required tools and essential safety requirements. Then, choose the decommissioned product which cost the least in dismantling to create a profitable business.

Repurpose: Choose the right repurposing application.

This set of guidelines applies in choosing the correct repurposing strategy and applies to Repurposing industrial designers.

Economical repurposing:

Think of the solutions which can create positive economic value from the repurposing cost. To achieve this, take advantage of decommissioned parts' functional properties and upgrade the existing product that can enhance its functionality by replacing the existing material with the composite repurposed part. Further, developing a system reduce the material waste in repurposing.

Use the emotional value:

Utilize the emotional value which user has from the initial product's lifecycle and sustainable initiative to create the market demand for repurposing. By creating the marketing and branding strategies, connect the user's emotional value with repurposed product.

Effective waste management

Avoid the spread of accumulated composite waste through repurposing and to reduce the transportation cost, develop the repurposed product for local users around the repurposing company.

Product vs part vs material

Choose the dismantling of decommissioned components between a product, part or material, after evaluating the storage cost, labour cost, economical value and market demand of each repurposing strategy.

System: Taking a holistic approach towards circularity

This set of guidelines applies to all the stakeholders involved in the composite industry. Here the role of an industrial designer is to take the initiative in leading the different stakeholders to implement the scalable repurposing practice.

Transparent business

Create the practice of maintaining transparency in composite repurposing business where the required information and resources are provided to implement the repurposing with minimum expenditure.

Evaluate the circularity

Evaluate repurposing with tools such as life cycle assessment to avoid the negative impact by redesigning the lifecycle of the existing composite product.

Support with pre-determined responsibility and legislation

Prevent the repurposing from becoming a voluntary job by promoting the product leasing culture, producer responsibility, value chained collaboration and regulation supporting the material utilization.

Project Conclusion

The destination of the thesis has been to discover an alternative approach to solve the composite waste issue through repurposing.

The result was achieved by using the double diamond method, split into two converging and two diverging phases. During the discovery phases, literature research was conducted to gather knowledge in composite material, its product market, and the existing end-of-life practice. Further, exploratory research was extended by evaluating the present repurposing practice and selecting the composite in the aviation industry for the case study.

By conducting the life cycle assessment and stakeholder analysis during the define stage, key actors were identified who can implement the repurposing of composite products in the aviation industry. With the brief analysis of composite parts in passenger aircraft, composite galley used in A320 aircraft was selected to conduct the further case study.

By performing a repurposing case study of aircraft galley through observation, disassembly, dismantling and prototyping a bicycle children cart, practical acquaintances focusing on the scalable repurposing were collected during the development stage. Furthermore, combining insights from an executed repurposing case study with outcomes from Discover and Define stage draft guidelines and PLM framework for repurposing were formulated.

Draft proposals were revised with evaluation from the co-creation workshop with different stakeholders from the aviation industry, and interviewing an industrial designer from the composite repurposing firm and evaluating from the co-creation session, a revised proposal was formulated.
By referring to the primary research question.

The thesis has been concluded with the set of guidelines for repurposing a composite product. From the evaluation, it can be concluded that the proposed guidelines provide the set of recommendations that has the potential to assist the industrial designers and stakeholders in creating the base for introducing the repurposing. Furthermore, guidelines aim to implement the repurposing practice at the scalable level to utilize the massive amount of composite waste forecasted in future.

Referring to the second research question, A framework for product life cycle management was formulated for solving the issue of missing knowledge transfer and lack of transparency for repurposing in the composite industry. Implementing the material passport in practice, stakeholders from the initial product life of a composite product can provide the set of prerequisite information to the repurposing industrial designers. This information has the potential to accelerate the repurposing by saving them time and resources spent manually discovering the missing information from the product manufacturer.

However, the guidelines need to be evaluated with the diverse set of composite products from various sectors. Further, to implement the guidelines in the market, various experts should be consulter to improve the economical side of composite repurposing practice.

Discussion

Case study

The goal of the project was to create the guidelines for scalable repurposing practice. However, the case study was conducted at the faculty of industrial design engineering. The faculty is not equipped with the necessary workspace to work with the composite material. Therefore, the case study might not have provided all the critical aspects relating to scalable repurposing. Further, due to the fast-track nature of the case study, some valuable information might have been lost. The entire case study was performed with a GFRP sandwich panel. However, many products are made from CFRP or GFRP panels. Considering the size of the galley, many composite products such as aircraft wings or wind turbine blades are extremely large. Insights might not have been included covering such products.

Aviation

In order to implement the material passport, there is a need for data transparency. However, considering the competitive industries such as aviation, it is not desirable for aircraft manufacturers to provide third party repurposing company data. Further, each aircraft carrying millions of parts and missing material passport for an existing composite product is a high possibility of failure in PLM implementation.

Interview

The core users of the proposed guidelines are composite repurposing companies. However, with the limited number of companies, only a single interview was conducted to evaluate the proposal. Thus evaluation lacks the number of user tests to be more comprehensive.

Scope of the repurposing in compos-ite:

Being a new concept at the scalable stage, repurposing of the composite products has been hardly discovered. Further dismantling and re-manufacturing of the composite product were found an expensive process. To create a sustainable business out of composite repurposing, there needs to be considerable demand for repurposed composite products among the user. However, There were no case studies supporting the desirability of the repurposing.

Recommendation

Regarding the case study:

More case studies should be collected to gather the required insights as composite products are produced in a wide range of sectors with varying properties and sizes.

More research should be conducted to find the list of suitable manufacturing techniques required to accelerate the repurposing by conducting elaborated research.

Material Passport

To avoid excessive data management, product manufacture and repurposing experts should collaborate to find the list of data allocated in the material passport. By Conducting the pilot test with simple composite products, the system can be upgraded for the complex product having a larger assembly

More research and interview should be conducted to solve the problem of intellectual property. Then, the trial should be carried out with lesser risk by consulting with the policy management experts and product owner. With the example from such a trial, more product owners can be approached for implementation.

Regarding guideline:

Test the usability

Conduct small educational repurposing projects with the industrial designers to verify the usability of the guidelines. Then, more repurposing companies can be reached to gather the required information.

Broaden the application:
Starting from the aviation sector, apply the guidelines to wind turbines, construction, and automobiles to get a holistic overview. Combining this insight can create generalized guidelines.

User test:
Test the users with repurposed composite products to evaluate their emotional value with repurposed composite products. This will help to improve the market demand for the repurposed products made from composite products.

Business plan:
Create an accurate business plan for repurposing to investigate the viability of composite repurposing. Ideate the different strategies to increase the demand that consume the decommissioned products.

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1 Fig 1.4 [The carbon fiber chassis of the BMW i3] (n.d.). https://3dprint.com/261294/state-of-the-art-carbon-fiber-3d-printing-part-one/

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3 Fig. 1.6 [GE Wind Energy's Haliade-X at Rotterdam, The Netherlands] (GE Renewable Energy). https://topgear.com.my/news/stop-everything-this-is-a-naked-carbon-koenigsegg-regera

4 Fig 1.7: [107 meter long wind turbine blade] (LM wind power) https://www.instagram.com/p/Bwow_XqnBGy/?utm_source=ig_web_copy_link

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