



Optimistic Futures

Open Access Approach to Digital Product Passports for Boats

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Integrated Product Design
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Abstract

Sailing has long connected people with nature and played a vital role in human progress - enabling exploration, trade, and cultural exchange for centuries. Widely regarded today as a sustainable sport, it induces harmony with wind, water, and the environment. Yet beneath this image lies a growing problem: the materials used to manufacture modern sailing equipment cause significant environmental harm at the end of their life. Most sailing boats, for instance, are produced from glass fibre reinforced polymers - a material which currently cannot be recycled. As a result, many boats are sent to landfill or even abandoned, despite still being structurally sound or usable.

This thesis investigates how boat manufacturing, usage, and end-of-life practices can transition toward a circular economy. The Optimist sailing dinghy serves as the primary case study and a driver for sustainable change. A comparative Life Cycle Assessment (LCA) demonstrates that more sustainable and recyclable material alternatives exist, additionally offering advantages in both weight and durability. However, mapping the life cycle of Optimist dinghies reveals an even greater challenge: for 74% of these boats, essential product related information is lost during their lifespan, rendering recycling efforts highly uncertain.

To address this, the thesis proposes DPP.BOATS, a web-based platform for Digital Product Passports (DPPs) tailored to sailing boats. The system integrates both static technical specifications and dynamic data streams - automatically collected usage data to understand real-world usage patterns and life expectancy, as well as easily submitted maintenance histories, condition reports, and event participation. Crucially, the platform embraces an open access philosophy, designed to minimise friction from authorisation processes and to avoid technological dependencies on subscription services - essential in a sport largely run by volunteers and dedicated parents. By allowing barrier-free access, DPP.BOATS facilitates transparency in second-hand markets, supports preventive maintenance planning, and provides valuable insights for future boat design. It also ensures that final owners know the material composition and correct recycling procedures, enabling true circularity.

Ultimately, this thesis argues for integrating end-of-life considerations into product development and business strategies, emphasizing more conscious material usage and its value preservation - critical steps in addressing the environmental crisis and cultivate optimistic futures.



Content

1. Introduction	12		
1.1 Problem Statement & Research Question	14		
1.2 Research & Design Approach	16		
2. Context	18		
2.1 Transition into a Circular Economy	20		
2.2 The Optimist Sailing Dinghy	22		
2.3 Khulula and the Eco_Optimist	24		
3. Analysis	26		
3.1 Stakeholders and Their Influence	28		
3.2 Optimist Class Rules	30		
3.3 Future Embodiment Opportunities	32		
3.4 LCA Comparison	34		
3.5 Second Hand Market Mapping	36		
3.6 Usage Patterns (at Sailing Schools)	40		
3.7 From Usable to Obsolete	42		
3.8 Marketing and Circular Business	46		
3.9 Life Cycle Summary & Key Findings	48		
4. Concepts & Vision	50		
4.1 Ideation	52		
4.2 Concept 1: Circular Business at Khulula	54		
4.3 Concept 2: Designing the Information Flow	56		
4.4 Concept 3: Eco_Optimist Optimisation	58		
4.5 Concept Choice & Vision	59		
		5.2 Dynamic & Open Access Approach	65
		5.3 Considerations for Usage Data Tracking	68
		5.4 Open Access Intervention Reporting	74
		6. Implementation	76
		6.1 Approach and Requirements	78
		6.2 A New Digital Platform: DPP:BOATS	82
		6.3 blueNode: A LoRa GPS Tracker	86
		6.4 Tracking a Sailing Session	90
		6.5 Cost Calculation	92
		6.6 Business Concept Considerations	94
		6.7 Optimistic Futures	96
		7. Discussion & Conclusion	102
		7.1 Concept Validation	104
		7.2 Discussion	106
		7.3 Conclusions	107
		7.4 Limitations & Recommendations	108
		7.5 Reflection	109
		References & Indexes	110
		References	112
		Indexes	116
		Appendix	118
		A.1 LCA Comparison	120
		A.2 Table Second Hand Market Mapping	136
		A.3 Questionnaire Sailing Schools	140
		A.4 blueNode: Technical Considerations	142
		A.5 Database Architecture	144
		A.6 Graduation Brief	146

Abbreviations

AIS	Automatic Identification System (maritime safety and navigation system)
BoM	Bill of Materials
CE	Circular Economy
CEAP	Circular Economy Action Plan
DPP	Digital Product Passport
EoL	End of Life
EU	European Union
ESPR	Ecodesign for Sustainable Product Regulation
GFRP	Glass Fibre Reinforced Polymers
GWP	Global Warming Potential
IoT	Internet of Things
IODA	International Optimist Dinghy Association
LCA	Life Cycle Assessment
LoRa	Long Range Wide Area (wireless communication network)
NB-IoT	NarrowBand-Internet of Things (wireless communication network)
NFC	Near Field Communication (wireless communication network)
SDGs	Sustainable Development Goals
VARTM	Vacuum Assisted Resin Transfer Moulding

Glossary

Class (Boat class)	A grouping of boats based on their length/regulations
Core	Part to be remanufactured
Cradle to Gate	Emissions from raw material extraction up to the point where it leaves the factory
Cradle to Grave	Emissions from raw material extraction to disposal
Cradle to Cradle	Mimicking nature's regenerative processes, closed loop
Dinghy	small sailing boat with removable mast and daggerboard (instead of a weighted keel)
One-design	a form of racing where all boats are virtually identical or similar in design

1. INTRODUCTION



Fig. 1 Abandoned boat causing environmental harm

1.1 Problem Statement & Research Question 14

1.2 Research & Design Approach 16

1.2.1 Scope 16

1.2.2 Research Questions and Methods 16

1.2.3 Research Methods 16

1.2.4 Process 16

1.1 Problem Statement & Research Question

Climate change, resource exploitation and biodiversity loss are accelerated by linear consumption patterns and cradle-to-gate thinking in business concepts (i.e., responsible up to point of sale). The Circular Economy model represents an alternative approach, systematically keeping materials in the loop and managing products to maintain their highest possible value to stay in use for longer. Recreational boats are designed to last in wet and harsh environments. Toxic coatings, integrated assemblies and the use of composite materials obstruct repairability and practically rule out any chance of recycling them. Once no longer fit for use, the boats become a burden to their owner, with proper material separation and waste treatment quickly costing over 5,000 €, sending them to landfill often becomes the last resort. Often enough obsolete boats end up abandoned (orphan-boats) in marinas, shipyards and beaches, causing environmental harm and polluting the playground sailors and outdoor enthusiasts enjoy (see figure 2). H. Ambroselli (2025), an ambassador for more environmental practices in the marine industry goes as far as saying "the only sustainable thing about sailing is the wind", addressing the usage of harmful materials commonly used for boat manufacturing, sailing apparel and other equipment. Things need to change, yet the exhibition halls at „boot“ 2025, a renowned fair for leisure time boating in Düsseldorf (DE), reeks of chemicals - both in a literal and olfactory sense.

The disparity of attitude and actions, highlights the challenges of living sustainably within a consumer-driven society. It has been described as the "surfer's paradox", referring to the contradiction between surfers' strong environmental values and their environmentally harmful behaviours caused by frequent travel and consumption of sport related goods (Langseth *et al.*, 2021). To overcome this cognitive dissonance - where actions do not align with values - and the wasteful material usage, this thesis explores ways to make sailing more sustainable and transition boat manufacturing and usage into a circular future - an optimistic future if you will.

The iconic Optimist sailing dinghy, the go-to schooling boat and entry to the sport for many young sailors, is chosen as the case study and concept carrier.

Main Research Question:

What aspects within a boats life(cycle) need to be addressed, to "shift the winds" and transition manufacturing, usage and end-of-life handling into a circular future?

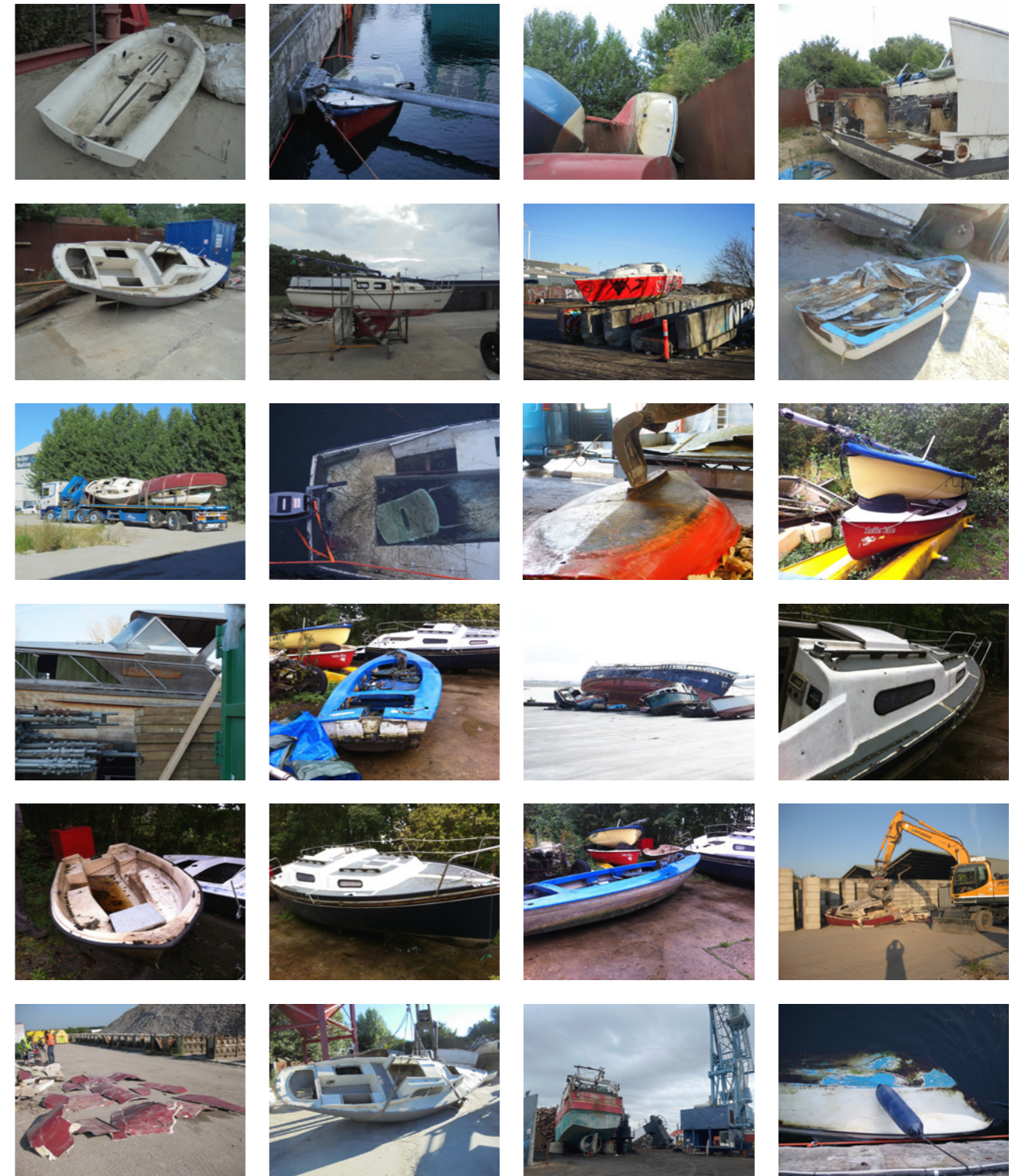


Fig. 2 Selection of images of obsolete and partially abandoned boats (copyright: ten Busschen, Riebesehl)

1.2 Research & Design Approach

1.2.1 Scope

Sustainability in the maritime industry is a broad and multifaceted topic. This thesis narrows the focus to explore the barriers and opportunities for one specific boat class: the iconic Optimist sailing dinghy (see figure 3). The Optimist is widely regarded as the entry point for most sailors, giving it a strong emotional value and making it a suitable case study for investigating sustainable transformations that could potentially influence other boat classes too.

1.2.2 Research Questions and Methods

The following list presents the main research questions explored in this thesis:

Manufacturing

- Which materials and manufacturing process allow for the most environmentally friendly Optimist?

Use-phase

- What is the life expectancy of Optimists?
- How can their lifetime be extended?
- What damages occur most frequently?

End of Life

- When and why does a boat become obsolete?
- How can abandonment be prevented?
- What are drivers and burdens for refurbishment and/or recycling?

1.2.3 Research Methods

A combination of qualitative and quantitative research methods was employed to gain insights into activities across the Optimist's lifecycle. Thirteen semi-structured interviews were conducted with stakeholders from diverse backgrounds, including academic experts in circularity and maritime development, sailing instructors, sailing school representatives, manufacturing specialists, and sailing associations. These interviews provided key qualitative insights. Quantitative research included a comparative Life Cycle Assessment, analysis of questionnaire responses, and a second-hand market mapping exercise. These methods complemented each other, with areas of overlap helping to validate findings. The results are clustered thematically and summarised in dedicated chapters for clarity and ease of reference.

1.2.4 Process

This thesis followed the double diamond framework, consisting of two alternating divergent and convergent phases, roughly dividing the project into four phases: discover, define, develop, deliver. The project was carried out over a period of five months. From the outset, a beyond-the-drawing-board approach has been adopted.

Brief:

“Designing the circular future of the iconic Optimist sailing dinghy, focusing on activities and material/information flows during its product life cycle, to enable more environmentally friendly sailing”



Fig. 3 Optimist Regatta Sailing at Lake Constance, Germany, 2013 (author of this project in front of buoy)

2. CONTEXT



Fig. 4 Two Optimist sailing dinghies (Image rights: Khulula)

2.1 Transition into a Circular Economy	20
2.1.1 Circular Design Strategies	21
2.2 The Optimist Sailing Dinghy	22
2.2.1 History of the Optimist	23
2.3 Khulula and the Eco_Optimist	24
2.3.1 Khulula	25
2.3.2 The Eco_Optimist	25
2.3.3 What else can be improved?	25

2.1 Transition into a Circular Economy

In a linear economy, products and materials are destroyed at their end of life (EoL), either being incinerated or sent to landfill. Transitioning into a circular economy (CE) means moving away from the current "Take-make-waste" culture, towards a closed loop system. This approach entails the strategic management of material value, with the objective of preserving its utility and worth for as long as possible. This is done through extending the lifespan of products or by recycling the materials, to be reused for the same application or at the same value level (Stahel, 2019). By definition, wasting materials no longer happens, as they stay in use indefinitely or loop back into it (Hollander *et al.*, 2017).

A recent study by Material Economics (2020), analysing material flows in the EU, highlights the gap of material recirculation and the value loss this is causing. As of today, the EU could supply as much as 64% of all demand for steel, aluminium and plastic with EoL materials, even reaching as high as 86% in 2050 - that is, if loops were closed. The truth however is that after one use cycle, only about 43% of the material value remains, 69% for steel, 70% for aluminium and only 11% for plastics. This represents an economic value loss of €78 billion (Material Economics, 2020). Yet these are the easiest materials to recycle, indicating the true business case CE can become, but also the challenge it presents. Transitioning from the wasteful consumption patterns that society at large has become accustomed to, into a circular future, requires

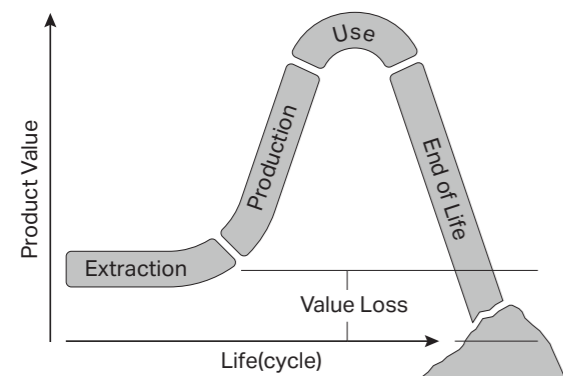


Fig. 5 Value Hill model, outlining a materials/products value development over its life(cycle) in a linear economy

new business models and a systemic shift. Taking responsibility means ensuring "environmental quality, social equity and economic prosperity to the benefit of current and future generations" (Kirchherr *et al.*, 2017).

The value-hill model (see figure 5) outlines the value development of a material throughout one use cycle (euphemistically referred to as a lifecycle in the linear economy as well). First, value is created through material transformation in manufacturing processes. The finished product marks the products/materials highest value level. Once the product becomes obsolete, its value quickly fades, as current EoL practices fail to retain its value. This results in wasteful material utilisation, with a lot of material ending in landfill, being incinerated, or down-cycled at best (Achterberg *et al.*, 2016).

Models such as the "Waste-Hierarchy", or the "10-R-Strategy", outline ways of retaining a product's value: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover, followed by landfill or incinerate as the least favourable options (Achterberg *et al.*, 2016).

With all this in mind, the product's usage turns from lifespan to lifecycle, closing the loop and extending the use phase by managing the product's value to stay as high as possible, visualised in figure 6. This transition towards smarter and more efficient material utilisation brings environmental relief and becomes all the more relevant in times of political uncertainties, climate change and resource scarcities.

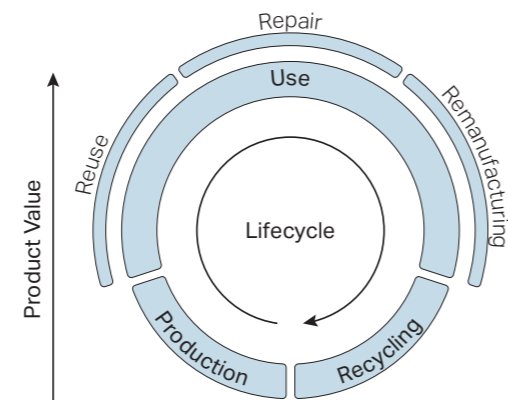


Fig. 6 Value development of a material/product in a closed loop system

2.1.1 Circular Design Strategies

In order to project a product into a circular economy, three key aspects must be addressed: the product embodiment itself, the operational processes the product goes through, throughout its lifespan and the marketing strategies that drive its adoption. These aspects often influence one another and for this reason they all need to harmonise for a successful transition into a circular future.

The list below further details these opportunities/barriers:

Designing a circular-ready product:

- Standardisation, compatibility, modularity
- Durability
- Ease of reuse, repair, refurbishment (Design for Disassembly)
- Upgradability & adaptability of product
- Closed loop material choice, material purity
- Low global warming potential of materials and manufacturing processes

Operational processes and infrastructure:

- Lifecycle extension through reuse, repair, remanufacturing
- Information pass-along between all stakeholders
- Condition assessment
- Choosing R-strategy at End of Life
- Resources: material, people, time, finances
- Systemic considerations: labour prices
- Product service systems
- Improving collection systems for EoL products
- Organising reverse logistics

Marketing with circular value propositions:

- Communicating value propositions (value added)
- Consumer acceptance of circular models (behavioural barriers)
- Business model innovation
- Strengthening customer trust
- Fostering emotional attachment to products

List sources: (Bakker *et al.*, 2019; Bocken *et al.*, Boorsma *et al.*, 2022, 2016; Flipsen, 2020; Material Economics, 2020; Stahel, 2019).

The often intertwined aspects outlined in this list (which by no means gives an exhaustive overview) indicate that a successful transition into a circular future, is highly complex. Overcoming these challenges, as well as systemic and behavioural barriers will be critical for realising the full potential of circular business. For this to happen, an interdisciplinary effort, requiring participation from all stakeholders, is needed (Stahel, 2019).

2.2 The Optimist Sailing Dinghy

The Optimist is a beginner sailing dinghy for children aged eight to fifteen. It is the most widely used boat class in youth sailing, thus most sailors are introduced to the sport with their first few “tacks and turns” on the Optimist. Given the large number of Optimists out there (400,000+), its durable design and emotional value to sailors, the Optimist offers a suitable platform for the promotion of sustainable change. Hence it was chosen as the focus point of this project. Besides that, it is small and simple enough to try out things without major investment costs.



Fig. 7 Optimist class logo

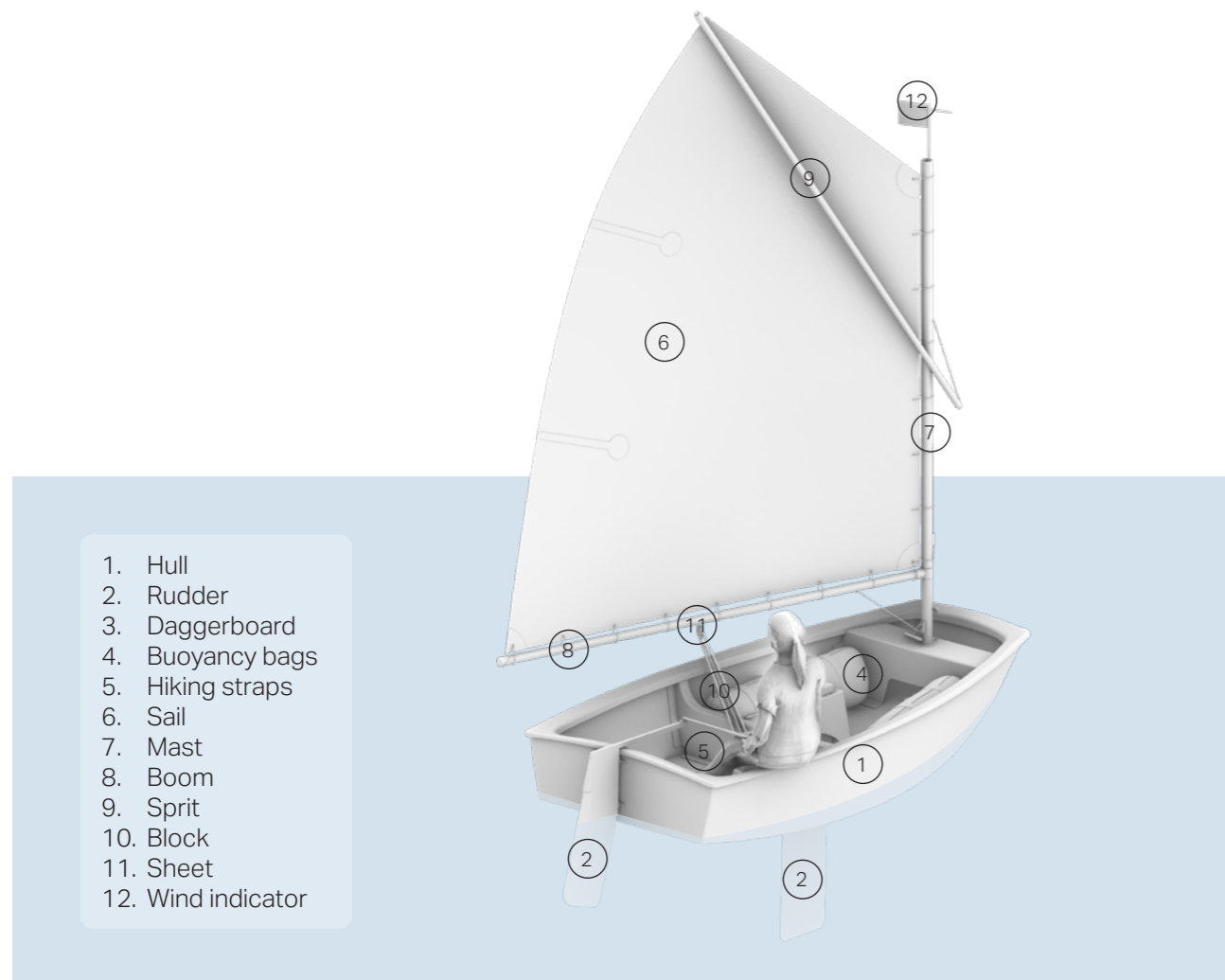


Fig. 8 Parts and components of the optimist

2.2.1 History of the Optimist

Conception:

The Optimist was conceived in 1947 in Clearwater, Florida, USA. Inspired by a soap-box race for children with sponsored carts by local merchants, major Clifford A. McKay a member of the “Optimist Club”, an organisation committed to youth education, set out to introduce children to sailing. With the brief to design a boat for 50 \$, made out of two sheets of 4 x 8 ft plywood and a bed sheet for a sail, Clark Mills, a local designer and craftsman, started drafting some plans. To stay within budget, the bow was eventually designed to be flat. Soon enough, the decision was made to build a fleet and a first regatta was staged, later followed by state and country wide events (Wilkes, 2013).

Status Quo:

As popularity and adoption of the Optimist dinghy grew, it was consolidated to be a one-design boat in 1995, meaning each Optimist has to comply with strict rules regarding the shape, construction, weight and so on (more on that in Chapter 3.2). With that, most Optimists today are made out of GFRP to be more durable. The International Optimist Dinghy Association (IODA) updates these rules in a yearly interval. Today there are approximately 150,000 Optimists registered at the IODA in over 120 countries. The total number is estimated to be 400,000, when including training Optimists, which are not complying with the one-design class rules, as well (IODA, 2025).

Future:

Sailors, in particular children should not be the ones punished for environmental emissions, however as they are closely connected to nature, they are a suitable target group for sustainable transformations.

This master thesis project therefore sets out to project the Optimist into a circular future.

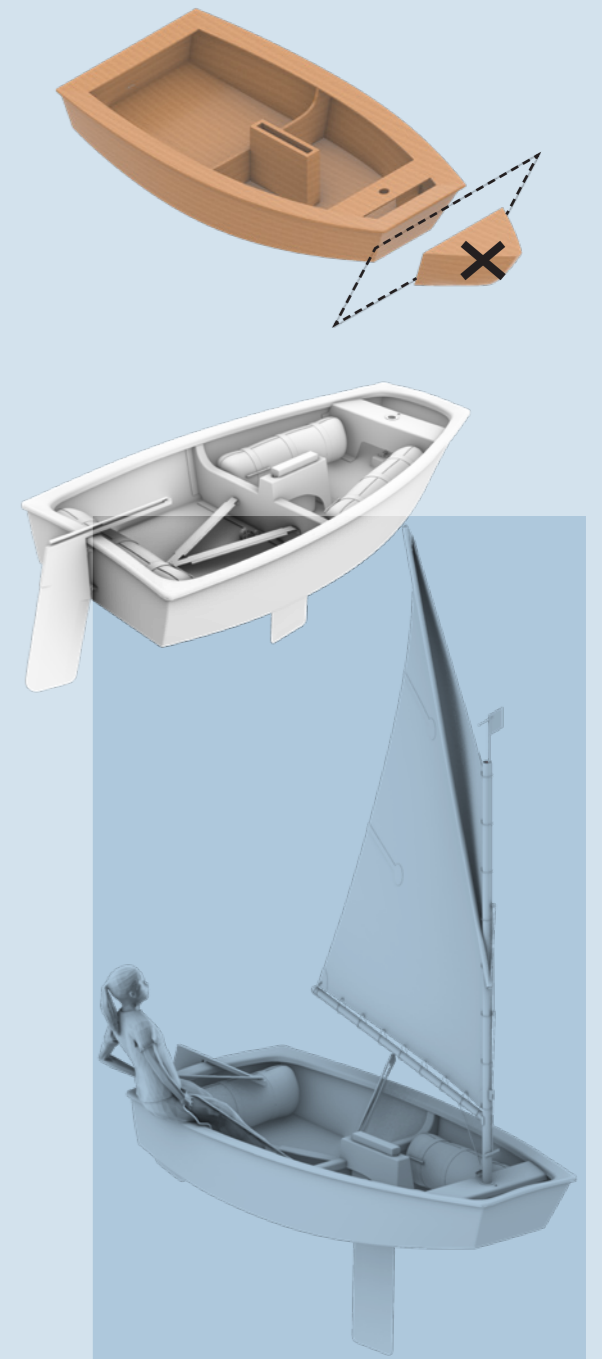


Fig. 9 Illustration of historic development of the Optimist

2.3 Khulula and the Eco_Optimist



Fig. 10 Photos of the Eco_Optimist (image rights: Khulula)

2.3.1 Khulula

This project is developed in collaboration with Khulula, a brand by Ecologgii.eco, providing sustainability consultancy services in the water-sports sector with a growing portfolio of sustainable products. It was born out of the idea of facilitating outdoor enthusiasts to enjoy their hobby in a more environmentally friendly way. Khulula understands themselves as a platform, joining forces with other collaborators to achieve common goals.

2.3.2 The Eco_Optimist

One of Khulula's products is the Eco_Optimist, depicted in figure 10. The hull, daggerboard and rudder is produced in close collaboration with Jade Yachting, a shipyard in Wilhelmshaven, Germany. The Eco_Optimist's weight and shape conform to the one-design class rules, the material choice however differentiates it from other Optimists, making it a more sustainable option for sailors.

The upfront carbon emissions of the hull itself are reduced due to the following material substitutions:

- Flax-fibres instead of glass-fibres
- Bio-based resin instead of petrol based resin
- Recycled PET foam core instead of virgin foam.

The daggerboard and rudder are made from hard-corc and biobased-resin. While these material substitutions reduce the dinghy's environmental footprint, these material substitutions make it nonconforming with the Optimist class rules, which since the consolidation of the Optimist in 1995 prescribe the use of glass-fibre-reinforced-polymer (GFRP) or wood (IODA, 2025). This currently disqualifies the Eco_Optimist from competitive sailing, ultimately making it a training dinghy with the performance of a competition dinghy (see figure 11).

2.3.3 What else can be improved?

While the upfront carbon emissions are already reduced, recycling for instance remains just as challenging. So what does it take to make sailing more environmentally friendly? This is what this project is all about!

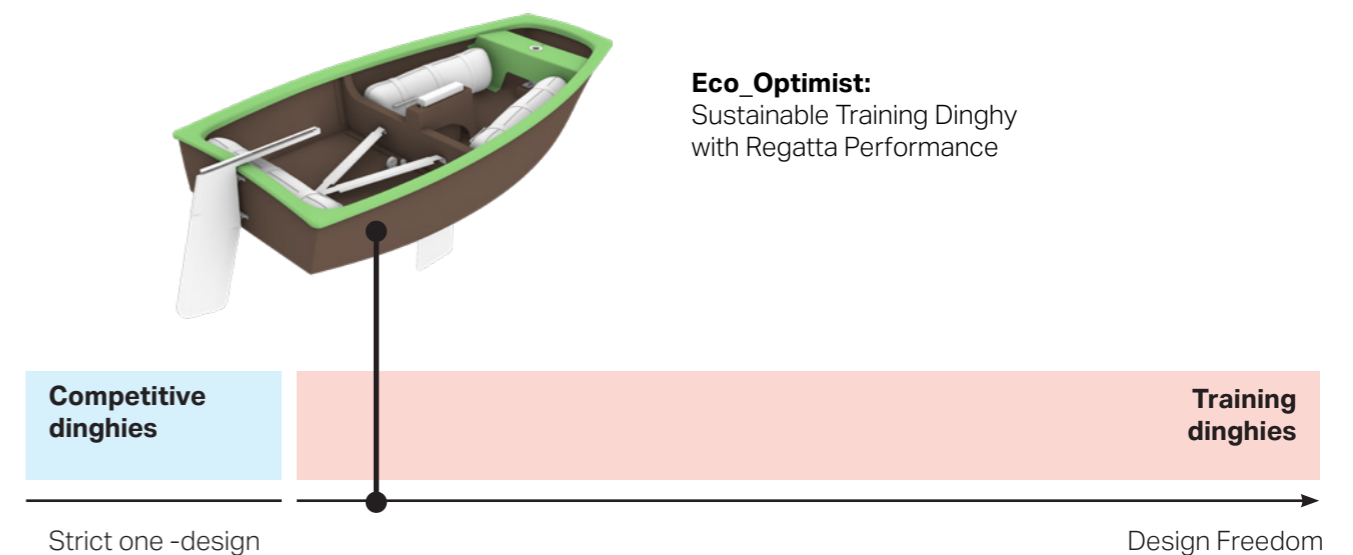


Fig. 11 Market position of the Eco_Optimist

3. ANALYSIS



Fig. 12 Optimists on the second hand market

3.1 Stakeholders and Their Influence	28
3.2 Optimist Class Rules	30
3.3 Future Embodiment Opportunities	32
3.4 LCA Comparison	34
3.5 Second Hand Market Mapping	36
3.5.1 Results	36
3.5.2 Conclusions	37
3.6 Usage Patterns (at Sailing Schools)	40
3.6.1 Extrapolation of Life Expectancy	41
3.6.2 Competitive vs. Leisure-Time Sailing, Travel and other Implications	41
3.7 From Usable to Obsolete	42
3.7.1 Maintenance & Repairs	42
3.7.2 Failure Modes	42
3.7.3 End of Life	43
3.7.4 Potential for Remanufacturing	44
3.8 Marketing and Circular Business	46
3.8.1 Closing the Liability Loop	46
3.8.2 Marketing Strategies to avoid EoL Issues	47
3.9 Life Cycle Summary & Key Findings	48
3.8.3 Life Cycle Summary	48

3.1 Stakeholders and Their Influence

The Optimist's lifecycle consists of three main phases: Manufacturing, Use, and End-of-Life (EoL), as shown in Figure 13. These three phases serve as a general framework for this analysis chapter.

To better understand all processes and activities throughout the Optimist's lifecycle, identifying the stakeholders is crucial. The most relevant stakeholders are illustrated in Figure 14, mapping their respective power to induce sustainable change and their interest in doing so. This reveals an interesting tension between players, who have the power to make changes but are less willing to act, and those who are eager for change but lack the influence to bring it about.

The International Optimist Dinghy Association (IODA), publisher of the Optimist class rules (equipment requirements), has the greatest influence on the future development of the Optimist. They are a crucial player in driving change; however, the association appears to be more focused on competitive sailing and ensuring fair competition, therefore avoiding significant changes to the class rules (see chapter 2.2).

On the other hand, children - the sailors of Optimists - are most concerned about the environmental crisis, yet they lack the power to influence change.

World Sailing, the global governing body of the sailing sport and organiser of Olympic sailing, also has a strong focus on competitive sailing but, at the same time, the organisation is driving sustainable change. These initiatives have a trickle down effect into many boat classes, among them 32 different dinghy classes. One current project is mapping the emissions in a LCA for the Olympic boat classes (Videlo, 2025).

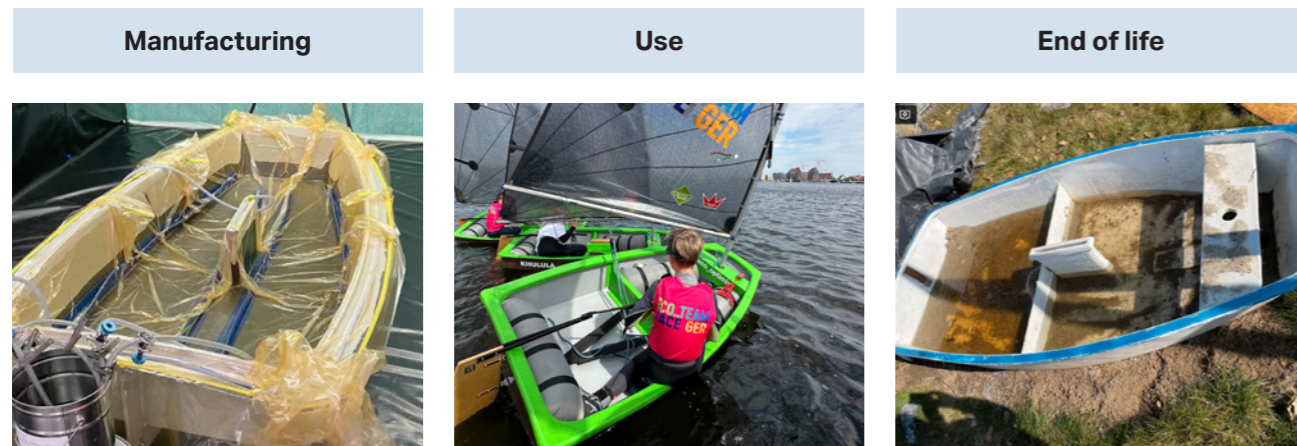


Fig. 13 The three main stages of an Optimist's lifecycle: manufacturing, use and EoL (left and middle photo, image rights Khulula)

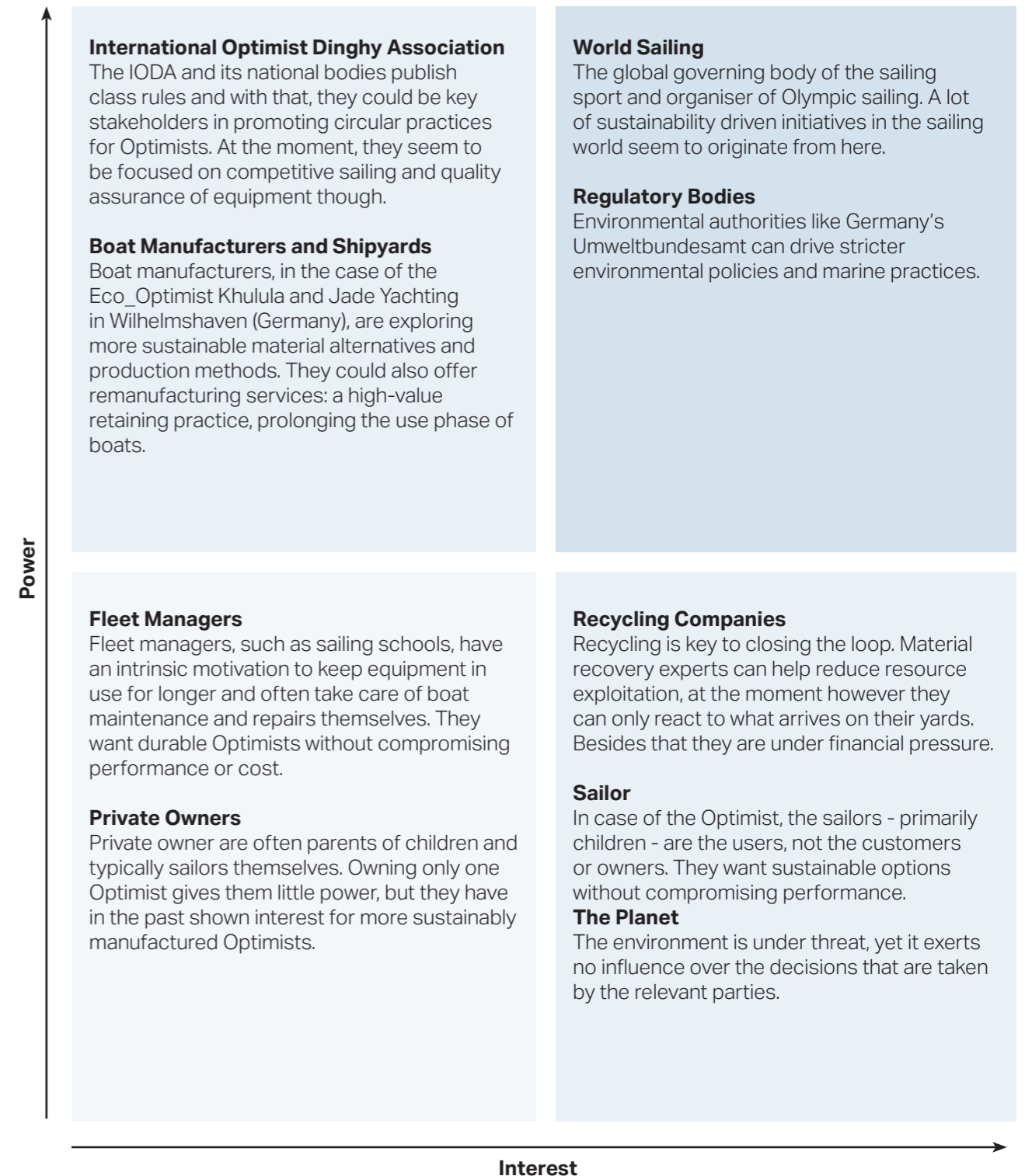


Fig. 14 Stakeholder diagram and their respective influence

3.2 Optimist Class Rules

The Optimist Class Rules, updated and published on a yearly basis by the International Optimist Dinghy Association (IODA), ensure fair competition with Optimists. A number of manufacturers are licensed to produce them, and every single dinghy has to pass the same rigorous measurement procedure. The dimensions, weight and partially the appearance of every component from sail, rig, hull, rudder, daggerboard and every attachment are defined. For the hull, the class rules as of 2025 prescribe the overall dimensions, its weight, and its manufacturing: the hull is to be made of glass-fibre-reinforced-polymer (GFRP) or wood, with the second becoming more and more extinct. GFRP hulls are to be constructed out of three pieces, using no more than three single sided moulds and a precisely defined composite laminate build-up, as illustrated in figure 16 (IODA, 2025). The shape, material thickness, overall weight, buoyancy, attachments and the number of bolts, down to the exact location and diameter of holes are all defined, essentially leaving no room for changes in design.

The high standardisation on the one hand makes the Optimist highly suitable for circularity, as it ensures a steady supply of spare parts and the possibility to automate condition inspections and repairs in the future. At the same time the standardisation also limits the design space for other sustainable innovations, such as material substitutions or other physical interventions that make the boat more durable and easier to repair.

The Eco_Optimist is constructed in accordance with the regulation regarding the dimensions and composite build up, the only exception being the material choice. This is why Khululula had to revert back to selling it as a training dinghy with competition performance (Ambroselli, 2025). Most children are not competitive sailors, therefore training dinghies, which do not strictly comply with the class rules, have their space in the market too (around 2/3, see chapter 3.5 and 2.6). Either way, the materials used in manufacturing and the boat's overall embodiment are not the alone thing that can lead to more sustainable sailing.

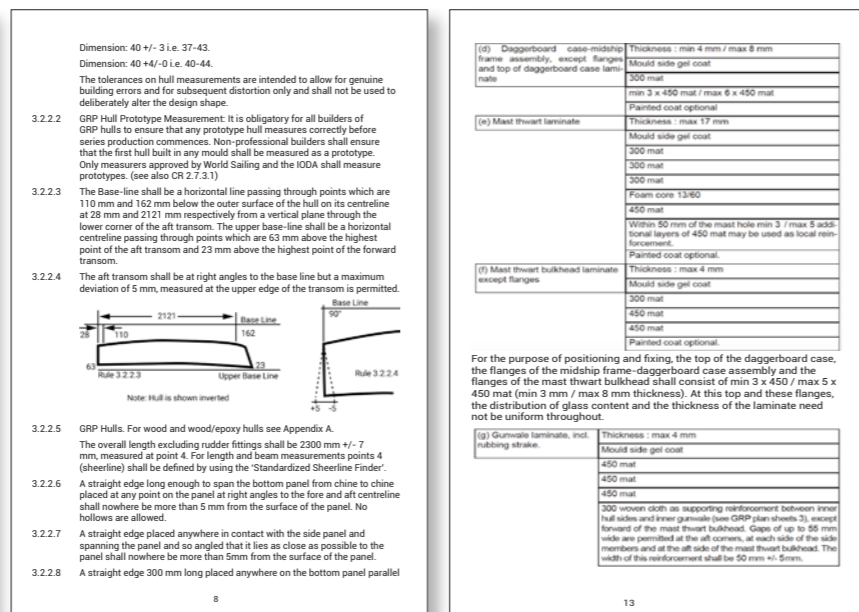
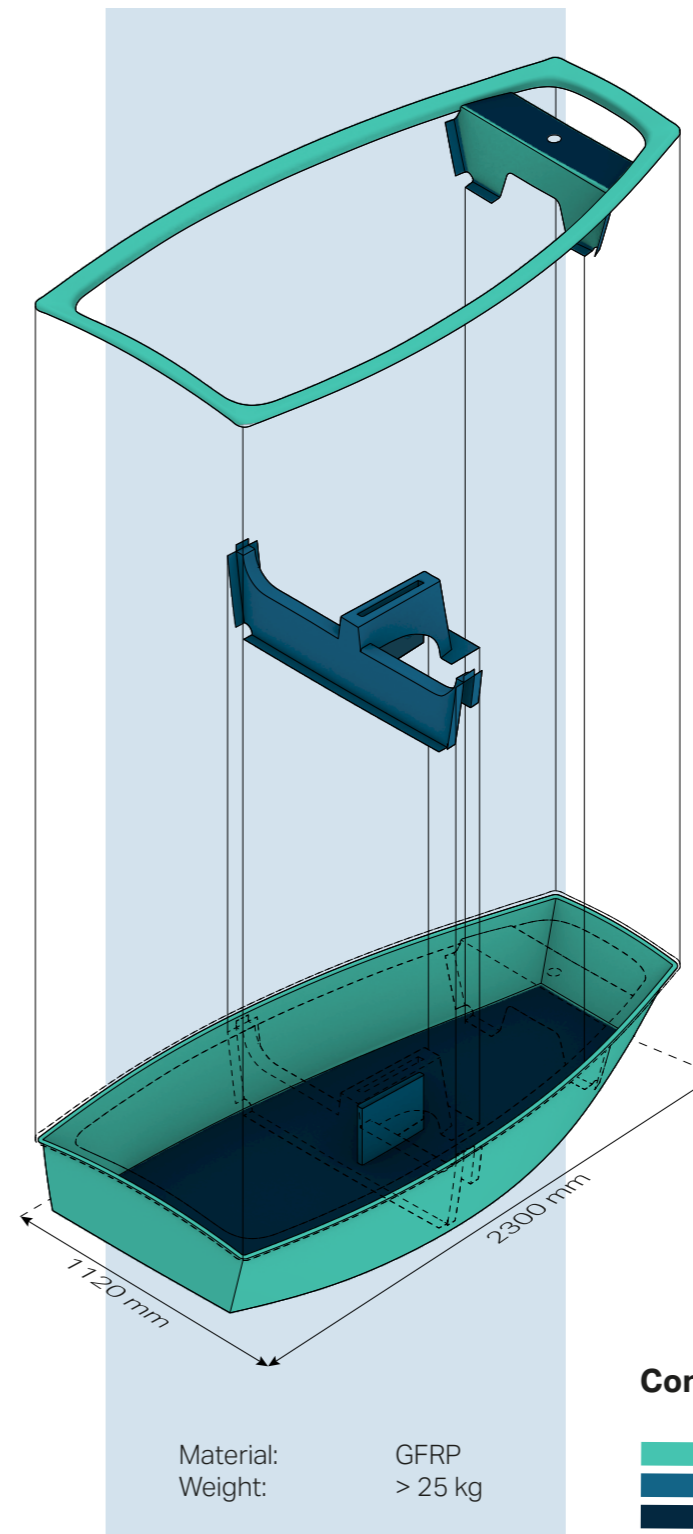


Fig. 15 One- design class rules for the Optimists issues by IODA. Cover and exemplary pages



Component 2:
Gunwale - Mast Thwart

Total mould surface area: 1.01 m²

- Construction:
- Mast Thwart (e): < 17 mm (0.11 m²)
 - Mast Thwart Bulkhead (f): < 4 mm
 - Gunwale (g): < 4 mm

Component 3:
Daggerboard Case - Midship Frame

Total mould surface area: 0.65 m²

- Construction:
- Daggerboard Case - Midship Frame laminate (d): 4-8 mm

Component 1:
Hull shell

Total mould surface area: 4.12 m²

- Construction:
- Bottom laminate (a): < 19 mm (1.87 m²)
 - Side and transom laminate (b): < 4 mm
 - Daggerboard slot laminate: (c): 4-8 mm (0.15 m²)

Material: GFRP
Weight: > 25 kg

Construction Types

- Composite material t < 4 mm: 2.95 m²
- Composite material 4-8 mm: 0.83 m²
- Sandwich material < 19 mm: 2.00 m²

Fig. 16 Construction diagram and component overview of the Optimist in accordance to the class rules

3.3 Future Embodiment Opportunities

The constraints prescribed by the strict one-design class rules, make any investments in a more sustainable redesign hard to argue for. Closing the material loop however is a vital component of CE, which is why material choice absolutely matters. Evaluating the Optimist’s environmental footprint also comes in handy, to evaluate the effectiveness of any intervention aiming to reduce environmental harm. When designing a new boat or reviewing class rules, reversible joints, ease of repair, lower integration should definitely be considered. Having no influence on the class rules, this aspect of a redesign is not the focus of this work and only the material choice is considered.

The sailing boat itself, in particular the hull is the largest piece of equipment and it has a considerable environmental impact on sailing. This is true for the Optimist as well, as shown in table 1. Largely made out of glass fibre reinforced polymer (GFRP) composites, a suitable material in wet and harsh environments, these boats are very durable if maintained properly. This exact material property however causes environmental harm when their usable life span comes to an end (EBI *et al.*, 2023). No viable option has been found for recycling them to date. Both burning the material in cement-kilns (incineration, for energy retention) or shredding it and using it as filler have not become profitable ways of handling the issue (ten Busschen, 2017). This poses the question of how boats need to be made in future to avoid said issues. A lengthy sustainability section with workshop materials for children on IODAs website (<https://www.optiworld.org/content/Sustainability+introduction>) gives hope, that things might change. It is noteworthy

here, that the sustainability section is written by World Sailing and not the IODA itself, indicating that sustainable changes are mostly inspired by the global governing body of the sailing sport and not the Optimist association itself. Despite ambitious sustainability goals, Europe remains a net-importer of goods and resources using resources beyond planetary boundaries. This year’s “Earth overshoot day” was reached on July 24th, earlier than ever, meaning all sustainably regenerative resources of the year are used up within the first half of every year, the rest being exploitative practice - a market failure (Global Footprint Network, 2025).

Building a boat clearly requires material resources, this must be done consciously though. Analysis of material flows within Europe (see Sankey diagram, figure 17), shows that roughly 2/3 of all material being used is accumulated and does not go back into waste treatment. With so much material being accumulated, this gives a clear goal to reach for: use of renewable materials, as M. Lepelaar (2025) points out. Renewable resources however are not abundantly available and their cultivation would soon be competing with food production, which in turn would be a pitfall causing hunger, poverty and social injustice (Vågsholm *et al.*, 2020). This gives a second goal to reach: using recyclable materials. A renewable and recyclable material would of course be an ideal middle ground, this however remains an unfulfilled dream, particularly within the realm of outdoor usage. These two directions are explored further, one aiming for high renewable material content and the other aiming for high recyclability, both while considering a low carbon footprint.

Table 1 Carbon hotspots of GFRP Optimist (done with MarineShift360 LCA tool)

Component	Material	Weight	Cradel to Gate Emissions
Hull	GFRP, PS	22,00 kg	217,52 kg CO2e
Daggerboard	GFRP	3,00 kg	29,66 kg CO2e
Rudder with head/tiller	GFRP, Aluminium	2,50 kg	33,83 kg CO2e
Spar (Mast+Boom+Sprit)	Aluminium	5,50 kg	126,00 kg CO2e
Sail	Polyester (Dacron) 3,3m2	1,05 kg	12,91 kg CO2e
			419,93 kg CO2e

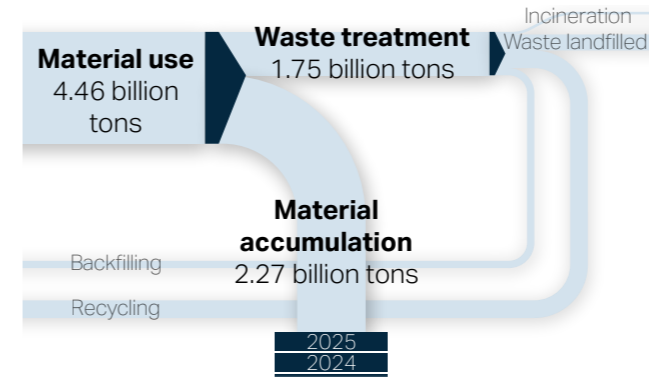


Fig. 17 Diagram based on part of a Sankey diagram on material flows in the EU (EU, 2017)

Recyclable Alternatives:

Aluminium

An Optimist out of aluminium would weigh more than twice as much, disqualifying it for further analysis (5,78m² * 0,003m * 2700kg/m³= 55kg). The embodied carbon could be reduced to ~ 50 kg CO₂e though, if using recycled aluminium (~ 900kg CO₂e, if not recycled).

Polypropylene, Fibre reinforced

Regular thermosetting plastics like PP have a much higher viscosity, making fibre impregnation only possible at high pressure (at melting temperature 220-280°C). Therefore they can only be reinforced with short fibres, making it less stiff than a long fibre reinforced composite. An Optimist produced this way exists (WWSailor, n.d.). It is ~5kg heavier (20%), less stiff and has a different shape that allows for injection moulding (not conform to class rules).

Elium resin, Basalt fibre composite

Elium resin is a recent material innovation. Before curing, it is a low viscosity suspension that allows fibre impregnation just like a regular, thermosetting resin. After curing, Elium has the properties of a thermosetting plastic, meaning, it can be recycled at EoL.

Renewable Alternatives:

Wood

Building a wooden Optimist cannot be automated as much as GFRP boats, making it expensive and more prone to variation (issue for regulatory reasons). Wooden Optimists are less durable and require more maintenance, which is another reason they are no longer being built.

Flax fibre, biobased resin composite

Flax fibres are a strong contender to replace glass fibres. At EoL this material is not recyclable, but with both components being biobased (for the most part), the emissions are offset by carbon sequestration in the growth phase.

Choice for further Comparison

The most promising renewable alternative is biobased-resin and flax-fibre, and the most promising recyclable alternative is Elium-resin and basalt-fibre. Composite materials are used for a good reason in a lot of sporting goods: They offer extremely high performance at unrivalled low costs, high material efficiency and durability. It is therefore logical that both contenders for GFRP replacement are composite materials too. A LCA comparison of GFRP, the biobased and the recyclable alternative can be found on the next page.

3.4 LCA Comparison

A Life Cycle Assessment (LCA) is a widely applicable method of analysing all emissions occurring in production (stage A), during usage (stage B) and at the end of a product's life (stage C). The associated emissions are converted to CO₂ equivalence values, for fair comparison.

Comparison

As outlined in the preceding section, a composite consisting of flax-fibre and biobased-resin, as well as a composite consisting of Elium-resin and basalt-fibre are compared to the GFRP composite (baseline). Further information regarding the properties of each material and their implications for design can be found in appendix A1. Both contenders are drop-in replacements for GFRP. This means that manufacturers can continue to use the same (or very similar) Vacuum-Assisted-Resin-Transfer-Moulding (VARTM) process (see figure 13) as well as the moulds and equipment they already have. The material replacements require minimal financial investment, thereby facilitating its rapid adoption.

Method

The LCA comparison is conducted using an "Educational-light" licence of MarineShift360, a specialised LCA tool for the maritime industry. In this comparison, the scope of the three studies conducted, aims to represent the entire product life cycle (cradle to cradle). At present the MarineShift360 database however predominantly focuses on cradle-to-gate analysis. Additionally, a clear misrepresentation regarding the emissions of basalt-fibre is found in the software. The emissions are significantly underestimated, as the data only represents basalt rock mining and not basalt fibre pulling (at the time of conducting this study). Therefore it is important to note that the assessment is manipulated in these two instances, to provide a more accurate representation of emissions. Despite the fact that all three options in this comparison are fibre-reinforced-polymer composites, the material composition still must be adjusted, to account for the respective properties of each material (density, strength, etc.). This ensures functional equivalence between the GFRP baseline and the two contenders for replacement. The baseline data is derived from the class rules and a 3D model to analyse quantities. For more details see appendix A1.

Results & Discussion

The results support the adoption of recyclable material composition in boat manufacturing in the future: Elium-resin and basalt-fibre composite. Not only does this construction reduce carbon emissions, it also promises to be more durable and long-lasting, while potentially improving performance through weight savings. For the time being, this option represents an increase in the cost of the bill of materials.

There is one more caveat: The optimal carbon performance is only then reached, if it is actually recycled at the end of its lifecycle. In other words, it is feasible to manufacture boats in a more sustainable manner and to circumvent issues that arise at the end of their lifecycle. However, establishing the appropriate logistics and processes to facilitate this, must also be initiated - perhaps the more significant challenge. As long as boats are not recycled, the biobased version represents the best option.

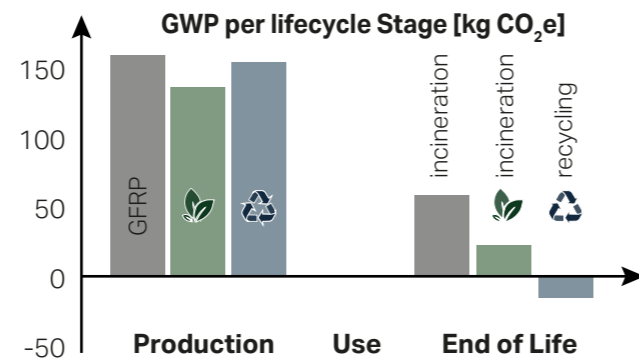


Fig. 18 LCA Comparison: Global warming - fossil

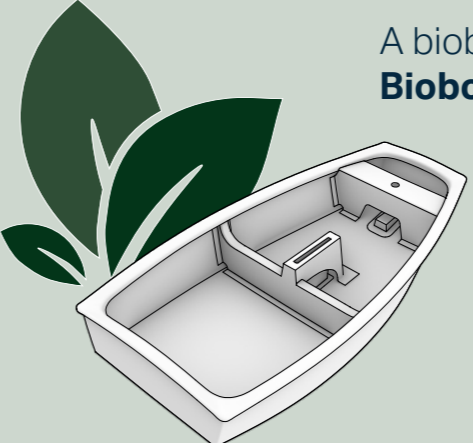
Find the full LCA comparison in Appendix A1

Baseline: Glass-Fibre & Polyester-Resin



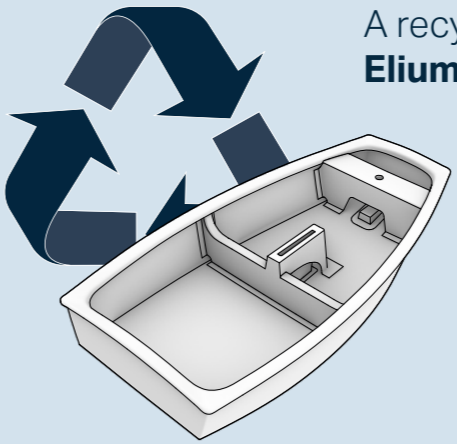
Cradle to Cradle Emissions:	218 kg CO₂e
Life expectancy:	25-30 years
Impact / year:	7.25-8.70 kgCO₂e/year
Weight (at same stiffness):	24.56 kg
Price:	102 € (bill of materials) 3.67-4.40 €/year

A biobased version of the Optimist: Biobased-Resin & Flax-Fibre Composite



Cradle to Cradle Emissions:	161 kg CO₂e - 26 %
Life expectancy:	20-25 years
Impact / year:	6.43-8.04 kgCO₂e/year
Weight (at same stiffness):	26.27 kg (+7%)
Price:	+185% (bill of materials) 12.58-15.73 €/year

A recyclable version of the Optimist: Elium-Resin & Basalt-Fibre Composite



Cradle to Cradle Emissions:	143 kg CO₂e - 34%
Life expectancy:	30-35 years
Impact / year:	4.08-4.76 kgCO₂e/year
Weight (at same stiffness):	23.18 kg (-6%)
Price:	+65% (Bill of Material) 5.13-5.98 €/year

Fig. 19 LCA results for recyclable and biobased construction alternatives for the Optimist

3.5 Second Hand Market Mapping

New competition Optimists retail for 4000€ - 7000€, with cheaper training Optimists starting at 2000€.

Optimists are boats for children aged between eight and fifteen years. This limit and the fact that a child might switch to a newer, more competition oriented Optimist, results in periods without use or frequent changes of ownership.

To better understand these phenomena, the reason and timing for sales as well as the Optimist's value development, a scan of the second hand market was conducted.

Data on 120 Optimists was collected on eBay.de, kleinanzeigen.de, dba.dk, marktplaats.nl and facebook.com/marketplace for Germany, Netherlands and Denmark. The full data table is attached to this document (appendix A2) and images of each Optimist can be found on the following spread.

This mapping of the market only gives an overview of availability on the market, not the demand. No follow up study has been conducted on whether the Optimists were sold, and if so, at what price.

The annotations and categorisation do not exactly match the dataset of the sailing school study (see chapter 3.6), as the sailing schools could not be asked to report as many categories for each of their boats. For this reason the data of the two studies is not overlaid.

3.5.1 Results

The results of the market mapping are shown in figure 20. In this case it is both interesting to analyse what is shown and for what it not shown. On the left (large box), only 26% of the dataset shown, as the age of 74% of the Optimists was unknown. This part of the data is displayed on the right side of figure 20.

Construction:

Most offerings did not disclose any construction related details, such as the manufacturer or the construction type. Identification is therefore based on visual inspection of the images within the offerings. 81% of the Optimists are constructed out of GFRP, 8% out of Polypropylene and 11% are wooden Optimists. It is noteworthy that the oldest boats within this dataset are all wooden Optimists, offered at comparatively high prices. This indicates that wooden boats are more durable and have a higher value retention. This is not the case though. Statements like "...build by my grandfather in 1970...", suggest that the value is rather of sentimental type and with no one building wooden Optimists anymore, these boats are becoming exhibition objects, making them outliers in this dataset.

Condition:

Upon visual inspection and analysis of the offering description, 53% of the boats are categorised as "ready to sail", 30% have "minor damages" and 17% are "damaged", partially beyond repair.

Price:

The prices only represent the sellers expectations and might therefore be inflated. As each boat is offered in a different package (with/without rig, sail, trailer etc.) the prices are all aligned to represent the hull only (hull 65%, rig and sail 25%, trailer 10%). As figure 20 shows, competition Optimists are sold at a mean value of 1200€, while Training Optimist are sold for a mean value of 330€ (see appendix A2).

Age:

The mean age of all Optimists is 13,8 years; however, it should be noted that this figure is based on data from which the age is unknown for 74% of the subjects. The oldest reported age is 26 years, outliers not considered (see construction section). This loss of data shows an information loss for 45% of all competition Optimists and a staggering 91% for training Optimists (usually older).

3.5.2 Conclusions

Considering that the year of construction isn't passed on to the next owner, this means that other vital information would be lost here too. This might not be such an issue in this case, as basically all boats are GFRP Optimists, but if a company launches Optimists with another material composition, this would be troublesome as it would make proper EoL treatment guesswork, if anyone even takes the time find out.

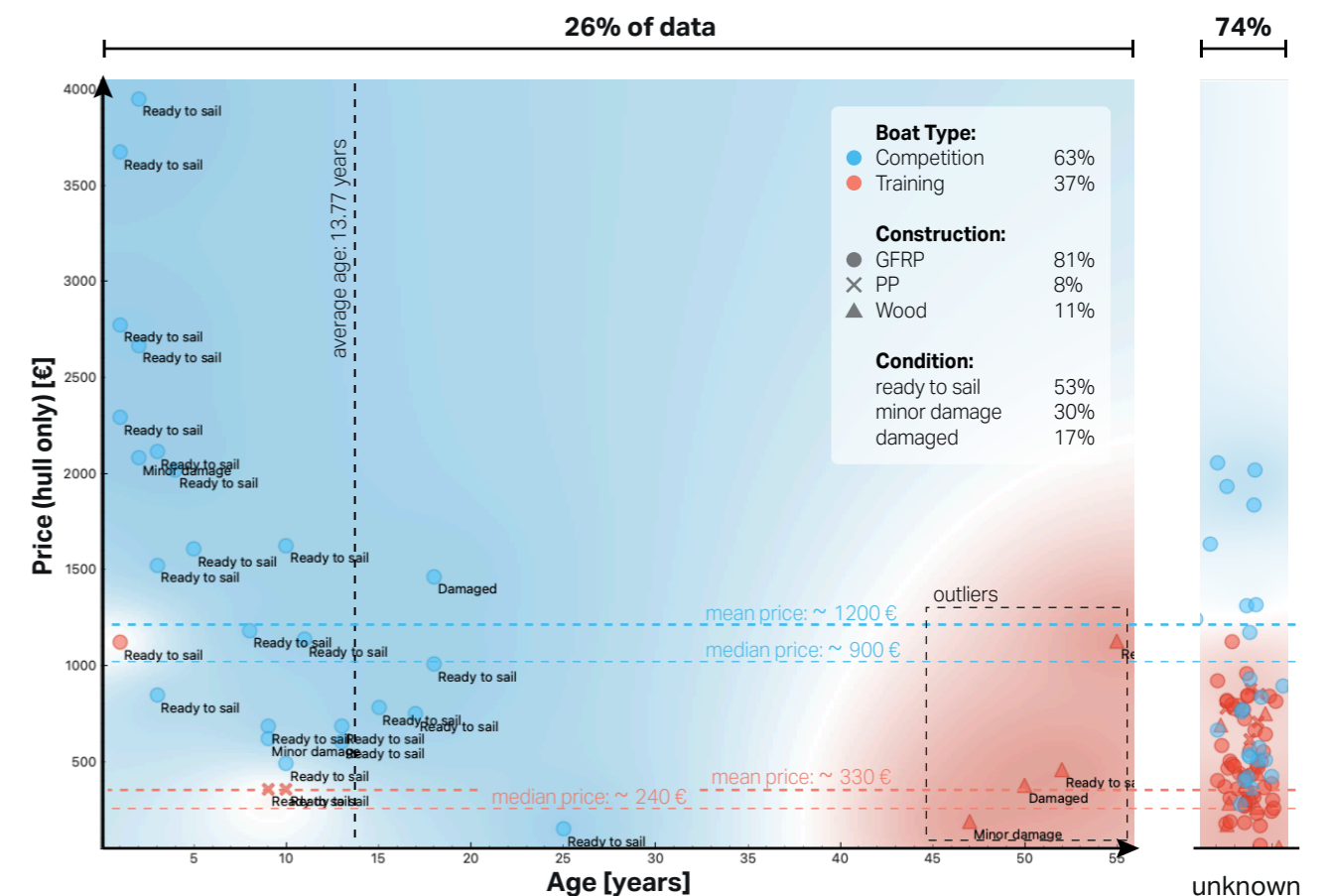


Fig. 20 The left part of the diagram showing price over age of Optimists on the second hand market, with indication of construction type and type of dinghy. The right part displays the data for all boats with unknown age (74%). (n=120)

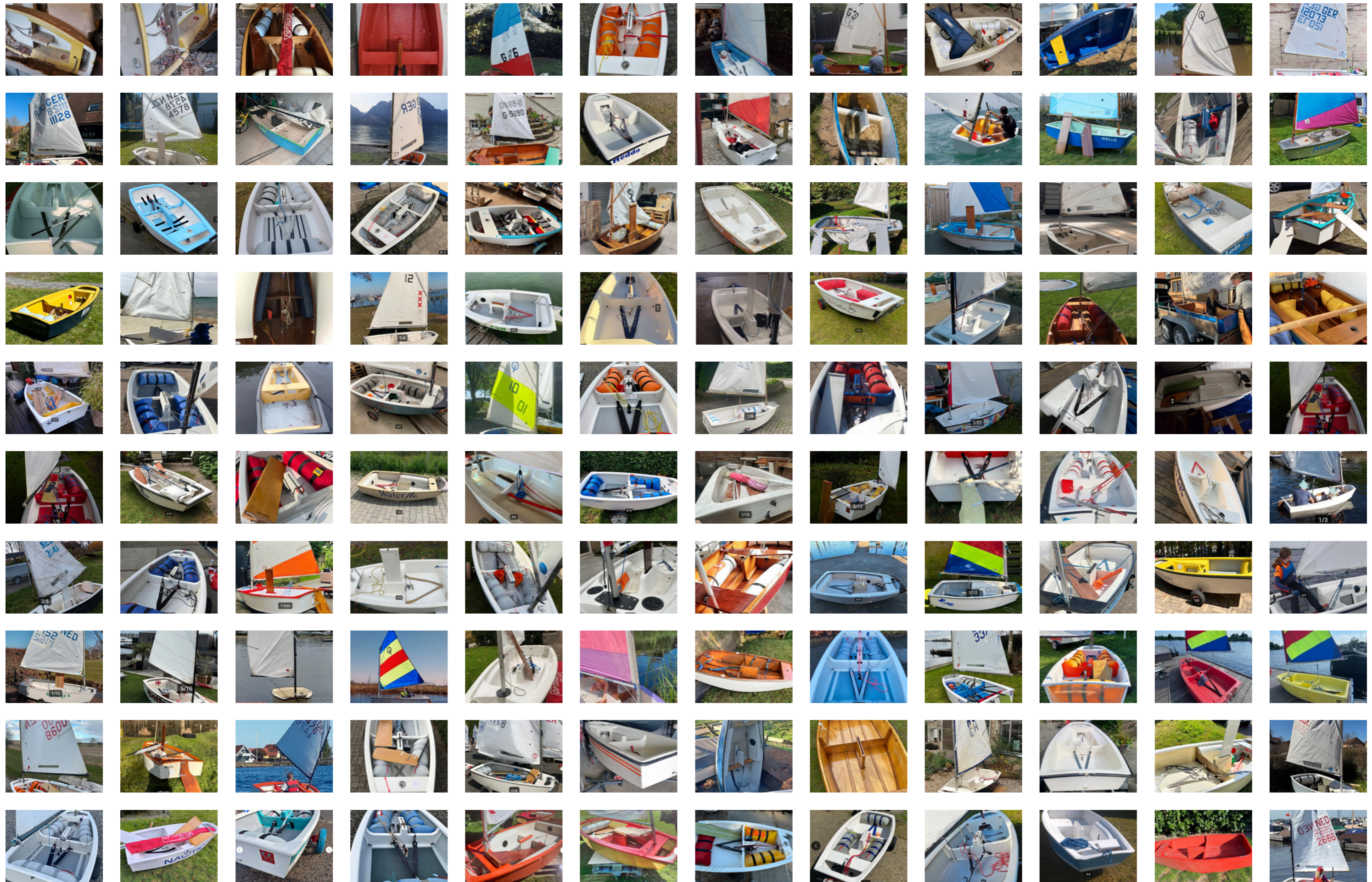


Fig. 21 Images of 120 sales offerings of Optimists on the second hand market

3.6 Usage Patterns (at Sailing Schools)

Next to parents buying Optimists for their children, a lot of Optimists are owned by sailing schools as well, in this case often overlooking the boats entire use phase. This makes for an ideal environment to analyse usage patterns. Responses to a questionnaire sent out to sailing schools (see appendix A3) provide insights over the life cycle of Optimists. Three out of eleven recipients sent back a filled in form. The reason for the low response rate is likely the that fact that spring is a very busy period for them. The insights are based on a total of 120 Optimists at Bodensee-Yacht-Club-Überlingen (DE), Egaa Sejlklub (DK) and Horsens Sejlklub (DK). It is a pure coincidence that both the sailing school study and the second hand market mapping is n=120. The majority of the boats at sailing schools are owned by the school (84%) and either leased to one child or used by multiple children and simply paid for with the club membership fee. The data (see figure 22) shows that 83% of the boats are between 0 and 20 years of age, relatively equally distributed. Dinghies older than 20 years are represented much less. Regarding the boats condition, there looks to be a clear correlation between the boat's age and its condition, with older boats understandably being in worse condition. Boats older than 20 years are reported to be "in need of repair" or "close to EoL", coinciding with fewer boats of this age group being part of the fleet. Older boats are also reported to be used less frequently.

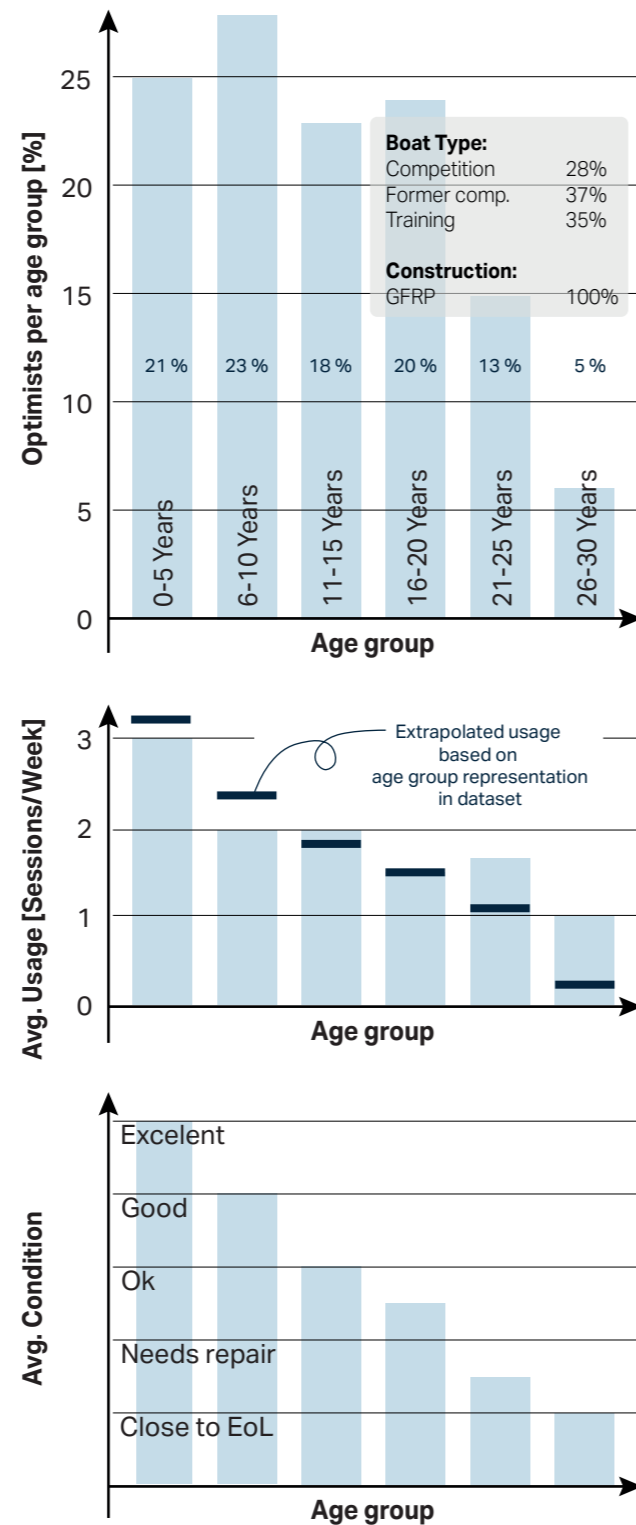


Fig. 22 Age composition of Optimists and at sailing school and corresponding usage and condition (n=120)

3.6.1 Extrapolation of Life Expectancy

The data suggest a typical life expectancy of 25 to 30 years, matching the sailing schools response to how long they have the boats in use, even though one sailing school reported to only have up to 15 year old boats.

Based on the findings and assumptions below, the life expectancy of an Optimist can be extrapolated (see table in appendix A3 for the calculation):

- Age group representativeness (%)
- Adopted usage frequency (dark blue bars)
- Sailing season: April – October, without holidays, sickness etc. (~26 weeks)
- Up to 30 years per boat usage

~ 25 Years
~ 1300 Sailing Sessions
~ 4000 Usage hours

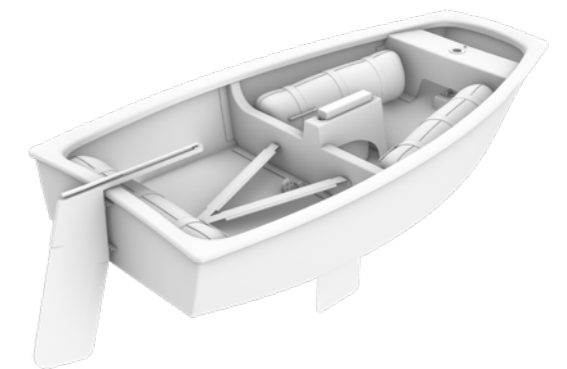


Fig. 23 Life Expectancy of Optimist hull

3.6.2 Competitive vs. Leisure-Time Sailing, Travel and other Implications

When children start sailing, they do so just for the fun of it. Depending on their ambitions, some children then start competing in regatta sailing. For most Optimist dinghies this happens in reversed order: The new dinghies are used for competitive sailing and after around 10-15 years they are handed down to be used for trainings or leisure time sailing only (Samek, 2025). One sailing school usually only hosts one or two regatta events a year, meaning that the boats get transported to other events on car-trailers, which results in high stress on the equipment and damages. The embodied carbon of the Optimist (420 kg CO₂e, see chapter 3.3) is roughly equivalent to driving 1650km in a regular passenger vehicle (MarineShift360). This implies, that travelling can quickly become the bigger emission factor, at least for more ambitious regatta sailors. At some large (international) regatta events, sailors can often rent an Optimist for around 500€ for the weekend, although this mainly takes away the burden of having to haul their own boat, as the rental boats are transported to site too. For the most part it seems like sailing schools have use for the boats as long as they are fit (more on that in chapter 3.7), with boats being handed over from competition boats to training boats and pure leisure time sailing.

3.7 From Usable to Obsolete

3.7.1 Maintenance & Repairs

In-between sailing sessions, Optimists are usually stored upside down in racks (see figure 24) or flipped on their trailers. Maintenance is mostly limited to washing them every now and then or hosing them off after a sailing session, if used in salt-water.

Newer boats are usually stored in covers to prevent scratches and material degradation, for instance through sun radiation. Older boats don't usually have covers. In winter, the boats are usually brought to a boat hangar.

The most common damages that need to be repaired are gelcoat damages, composite damages (typically at corners and edges), rigging repairs and replacement of blocks, sheets and less frequently the sails. Sailing schools say that they cannot afford professional repairs for their dinghy fleet. There is one exception to this, a sailing school in Poland that sends their boats for professional maintenance at the end of the season (Samek, 2025). Usually, sailing schools rely on motivated parents or sailing instructors to do repairs. For this reason M. Agerbæk (2025) reports that this works well one year with the boats hardly degrading and less well in other years, when damages get little attention and the boats therefore degrade faster. For this reason, age and condition of the boats don't necessarily correlate.

3.7.2 Failure Modes

L. Rees (2025), a former worker in a shipyard, states that a common cause for making repairs infeasible, is that boat manufacturers no longer deliver replacement parts due to bankruptcy or other reasons. This is not the case for Optimists, thanks to its high standardisation (class rules) and there being many manufacturers globally.

Typically, older regatta boats become training boats for younger/less experienced sailors. The more scuffs a dinghy has and the worse its condition gets, the less they are cared for, causing more damages, requiring more frequent repairs and attention in order to maintain its functionality (Giling, 2025; Samek, 2025).

Over time the repairs cause the boats to become heavier and less stiff, decreasing its performance and seemingly being a major cause for obsolescence.

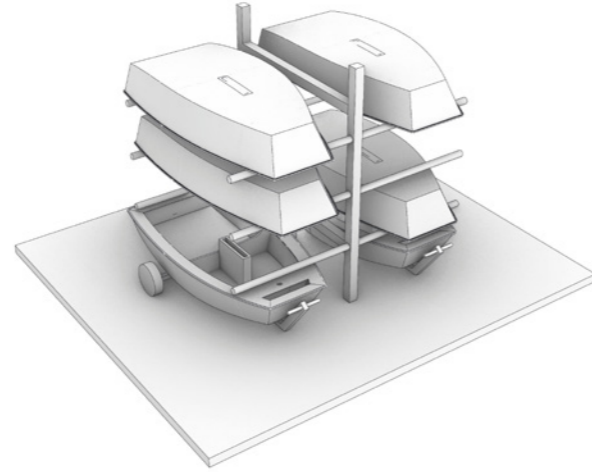


Fig. 24 Optimists in a typical storage rack (outside)

Composite damages are the most common damage (Samek, 2025; Kraus, 2025; Agerbæk, 2025; ten Busschen, 2025). If not treated in a timely fashion, this causes osmotic damage: Capillary forces suck water into hair-width cracks. This causes weight gain and repeated material failure if left untreated over time, especially when the water freezes. Osmosis is an overall accelerator to reaching critical failure. Eventually, they would become of little use to anyone, due to the overall condition: the boat has become obsolete. M. Agerbæk says, he never had to dispose off an Optimist because it had "critically failed", but at some point it is cheaper to replace it with another used one (fully functioning starting from around 500€), rather than taking the time to properly fix it or pay for professional repair (Agerbæk, 2025).

3.7.3 End of Life

Optimists are often repurposed at EoL, due to their status as iconic dinghies. One sailing school states that all their out of use Optimists have been turned into flowerpots, clothing racks etc. (Kraus, 2025). This is not representative for all Optimists though, and certainly not for larger boats. The very reasons GFRP is used in the first place (durability and resistance), cause environmental harm at EoL, leading to chemical leaching into the environment when landfilled (Lu *et al.*, 2016).

"Recycling", in case of GFRP, meaning dismantling for scrap metal with the rest doomed for incineration or landfill, costs around 5000-7000€ for a 10m sailing yacht (Schadewaldt, 2025). For an Optimist (2.15m long and only 25kg), disposal is usually free of charge, but it still requires effort to dismantle and transport it to a disposal facility. This means both the Optimist and all other GFRP boats have a negative value at EoL - it requires serious effort (and money) to dispose them off, in turn being the reason for many orphan boats. It is estimated that 30,000 boats are becoming obsolete in Europe every year, showing the true scale of the issue (EBI, 2023).

Figure 25 shows four abandoned boats in Reffen, a city district of Copenhagen - supposedly the greenest/most sustainable city in the world (The Telegraph, 2024). The image to the right shows the same boat that is also depicted in the very article making this claim. A year later the boat is obviously no longer in use and is left abandoned some 200m further. This is only anecdotal evidence, it still goes to show the scale of the issue.

While more promising end-of-life practises, such as structural retention are being tested with some success (ten Busschen, 2017), new boats have to be build in ways that allow for an extended use-phase and recycling. There is a need for policy intervention and strategic business model innovation, adding EoL processes into manufacturer's practices and responsibilities. Predictive maintenance of boats and equipment to extend the lifetime needs to become the norm, while boat owners need to become more aware of the issue. Right now there is a lack of recycling facilities, and that for a good reason: Recycling companies currently have no business case, as EoL thinking has been left out in product development and/or business strategies.

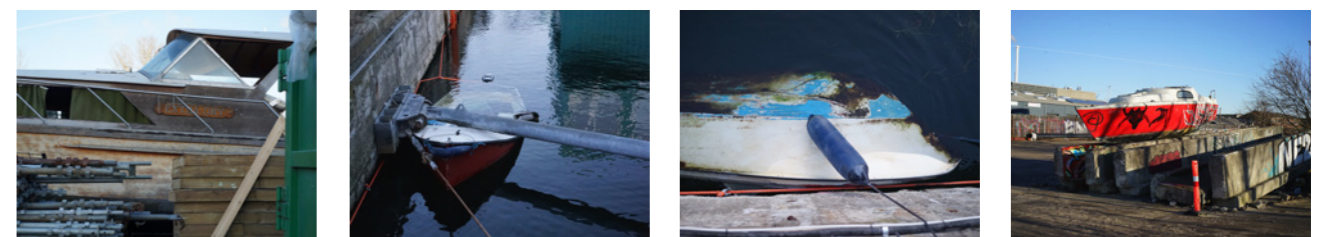


Fig. 25 Four abandoned boats in Reffen, Copenhagen - supposedly the greenest/most sustainable metropolis in the world. Not to blame Copenhagen, but it goes to show the scale of the issue. (copyright: Riebesehl)

3.7.4 Potential for Remanufacturing

A composite part owes most of its value to stress optimised fibre orientation during production, making its performance value much higher than the bill of material (BoM) suggests. After shredding composite parts, this is never again achievable when reusing the material. For this reason, the value of Optimist hulls lies in its shape and therefore also its initially intended use. With this in mind, recycling becomes a last resort and other value retaining measures move into focus. Refurbishment and remanufacturing are value retaining processes, that restore a product's value to its close-to or as-new quality, core principles within a circular economy (Stahel, 2019). In case of the Optimist this can be considered an extensive overhaul done by the manufacturer or a remanufacturer, such as a shipyard. Particularly with composite materials this represents a far higher value retention, certainly for GFRP, but also for thermoplastic composites, as recycling requires energy and material fractions are lost. The gathered data from the second hand market mapping suggests that a suitable "core" (product to be overhauled, in this case an Optimist) can be purchased for around 500€ (median price of 900€ for competition Optimist, and 260€ for training Optimist). The qualitative research on failure modes of old Optimists suggests, that they are still structurally intact for the most part and only need a visual revamp, sanding them down and applying a new gel coat. With labour costs of around 70€/hour net (90€/hour with taxes), plus material costs, mean that after one days work the Optimist would need to reach a resale value of anywhere between 1500-2000€. Its biggest selling point over a privately sold Optimist would be the trust people have in a professionally inspected and overhauled Optimist, potentially with some form of warranty .

Given the standardised shape of Optimists, composite repairs could potentially be automated in future, reducing the cost and increasing profitability (Maple Robotics, n.d.). There are also more systematic challenges though: Maintenance and repair requires more manual labour with increasing product age (and little material input compared to new manufacturing (Stahel, 2019). The systematic challenge consists of high labour prices compared to material prices (vastly different some 50 years ago), and the additional taxation of labour and not of material consumption. This gives manufacturing new products, which allows for far higher automation, a competitive edge over value retaining practices, such as remanufacturing (Stahel, 2019). A visit to Rematec, a world leading remanufacturing fair in Amsterdam, further reveals the industry's lack of market insights. Furthermore, an anxiety over losing intellectual property or competitors offering cheaper replacement parts (covered as quality assurance) makes manufacturers hold on to disassembly maps and other documents that would help with repairs and the profitability of remanufacturing interventions. Lastly, resource allocation (time, money, people) for remanufacturers presents an issue, as cores to be remanufactured infrequently land in their yards, giving them a hard time planning. To conclude, lifetime extension through professional repair is possible, but, at least for dinghies, the viability remains questionable, at least when remanufacturing is the only business case (see more in chapter 4.2).



Fig. 26 Condition inspection of Eco-Optimists after winter storage

3.8 Marketing and Circular Business

Marketing plays a crucial role in contemporary business, spanning from fashion to consumer electronics, vehicles, and, in this case boats. For consumer goods, marketing means promoting new, bigger, better, faster, safer or indeed greener products. As new products with the same functionality become available, the old products become less attractive, and customers will be tempted to switch to the new options. In a linear economy, supply chains have been optimised to the point of sale. Here, a longer life span of products would result in fewer sales, potentially having a negative effect on the balance sheet (Stahel, 2019).

In a linear economy, product liability is transferred to the product owner at the point of sale. From this point forward it's the owner's responsible to keep a product in functional condition and to eventually disassemble it and deliver it to the right recycling route (Stahel, 2019). Clearly, much of the time this does not happen, considering the large amount of abandoned boats out there.

In order to transition away from such consumption oriented practices, a sustainability minded business like Khulula needs to consider both their business strategy and marketing.

3.8.1 Closing the Liability Loop

Current GFRP boats have no, or even negative value at EoL due to the significant effort disassembly and transportation take for the owner. This, paired with the fact that the last owner of a boat typically has lower financial power compared to previous owners, causes owners to abandon their boats. Without a liable owner these boats then ultimately cause environmental harm, showing that something is clearly going wrong here.

Stahel (2019) sees legislative instruments, forcing producers to take back their products, as a way of solving such EoL issues, boosting CE at the same time. In the EU, this issue is addressed by regulations such as the Waste Electrical and Electronic Equipment Directive (WEEE) (European Parliament & Council, 2012), the End-of-Life Vehicles Directive (ELV) (European Parliament & Council, 2000), and the Packaging and Packaging Waste Directive (European Parliament & Council, 1994). These frameworks shift responsibility for manufactured goods back to producers, holding them accountable for proper collection, recycling, and disposal. The Product Liability Directive additionally makes manufacturers responsible for the safety and integrity of products throughout their lifetime (European Commission, 2024).

As a first mover, Khulula could capitalise on its competitive advantage of implementing circular business, before it becomes legally binding. However taking responsibility over a product over its lifespan creates additional complexity for a business, as it introduces customer service and asset management as additional business areas. One highly critical aspect of taking responsibility for a product over its lifespan, is to organise the return logistics of products, once they reach EoL, allowing for product life extending interventions such as remanufacturing or recycling. The traditional product sale strategy of ownership transfer is rather unsuitable in facilitating the return of products (Stahel, 2019).

3.8.2 Marketing Strategies to avoid EoL Issues

Trade-in/Buy-back Program

Taking back obsolete boats would be an immediate relief to owners, as they don't have to take care of things themselves, resulting in fewer abandoned boats and thus the prevention of environmental harm. Considering the high costs for dismantling a boat, this could be turned into a business opportunity, if the returned parts could become "cores" (term in remanufacturing for old parts to be overhauled) to be remanufactured.

Such a take back system, set up as a trade in program would increase the service adoption without cannibalising the sales of new equipment. It would ensure a steady inflow of cores to be remanufactured and a 1:1 sales share and effort allocation, both to new and old equipment manufacturing/ remanufacturing.

Product as a Service

One approach to move to a circular economy is to sell the performance of a product, instead of the ownership over it (Stahel, 2019). In this scenario the producers have an intrinsic motivation to reduce waste and to produce more durable and less environmentally harming goods, as they have to take care of EoL themselves.

Along the lines of "don't be gentle, it's a rental" P. Kraus (2025), a sailing instructor, opposes this take: Optimists in private ownership are treated with an increased level of care over those owned by the sailing school. This indicates that ownership creates a sense of responsibility and therefore could lead to longer use of Optimists.

Given the seasonality of sailing, the space required for (winter) storage and the short time one child sails the Optimist (compared to the Optimists life expectancy), leasing models for the Optimist could still become a real opportunity for private owners, relieving them of the hassle of reselling the boat once the sailor has grown out of it. Sailing schools on the other hand make full use of the Optimist lifespan, rendering a leasing only attractive to them in terms of reducing the upfront costs.

Selling/leasing the performance of the Optimist instead of the ownership over it would ensure that the product remains in the manufacturers hands and can be repaired, remanufactured or recycled correctly and more efficiently.

Deposit or Funding System

Deposit systems are a widely spread instrument to facilitate product returns and reuse for many multi-use products. The long life expectancy of an Optimist however poses a challenge here, as the deposit might lose value over time due to inflation. Perhaps even more challenging would be an efficient handover from one owner to the next, ensuring their trust in the refund system since Khulula is a small brand and the long term future unsure. The deposit would therefore need to be handled by a third party (financial institution).

A study by the European Commission (2014) exploring financial instruments to improve ship recycling concluded that the system "must be capable of inducing a change in behaviour on the part of ship owners towards the recycling of their ships". The proposed method to achieve this is the implementation of a Ship Recycling Licence (SRL) and a fund where boat owners pay a licence fee that is paid back to the owner upon recycling at a safe and environmentally sound recycling facility (European Commission, 2014).

Similar systems are already in place in France and in Norway, where boat owners can dispose of their boats free of charge (WreckFree, n.d.) or are even rewarded 1000 NOK (~85€) (ReMidt, n.d.). These systems are a nation wide systems, where buyers of new boats have to pay the same amount at purchase, which is then given to someone returning an obsolete boat. This however would require legislative intervention, hence not making this an actionable opportunity for boat manufacturers.

Motivational Measures

An informational campaign about the importance of responsible handling, maintenance and responsible EoL practices would be cheap and easy to implement. Targeting the right people however would be difficult.

The environmental pressure should already be high enough as it is, so the effectiveness of such an approach would be questionable (European Commission, 2014).

3.9 Life Cycle Summary & Key Findings

3.8.3 Life Cycle Summary

Roughly speaking, the Optimist undergoes three main stages during its lifespan; production, use and end of life, all visualised in figure 27. In the production stage, the value is comprised of the bill of materials and the machining and labour input in manufacturing. On top of that the “value added” represents the unique value proposition of a product (e.g. best performance, extra features, more sustainable etc.). During the use phase the financial value of the product drops exponentially. Noteworthy is an immediate value loss at the point of sale with the ownership transfer from producer to the owner/user. After around ten years, the Optimist is no longer fit for competitive use and is used for more

beginner level sailing. With increasing age, the dinghy is cared for less, causing more damages, requiring increased repairs and attention in order to maintain its functionality. Every change of ownership tends to represent a small spike in care for the boats though (Giling, 2025). At EoL, the Optimist’s value is negative, as GFRP cannot be recycled and disposing of it, requires effort and time for dismantling and transporting it to a waste collection facility. The lessons from this analysis and their implications on designing the circular future of the Optimist dinghy are listed to the right.

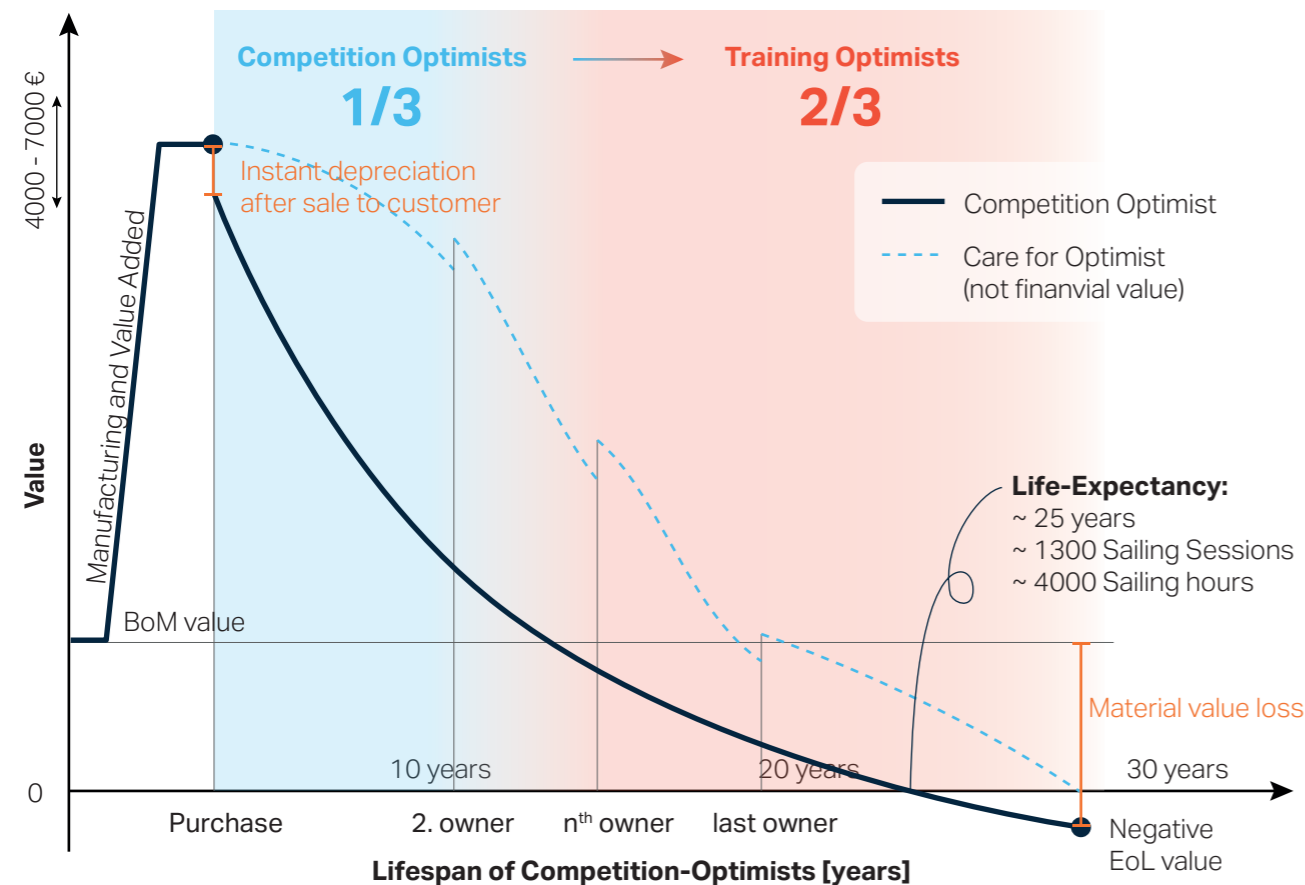


Fig. 27 Value development of an Optimist over its lifespan

3.1 Stakeholders and their Influence

The class association’s technical team has the highest influence on the product embodiment.

Class-associations have a focus on performance sailing, a field where equipment is replaced much more frequently. Innovating and changing up the design makes it non-conforming to the class rules consequentially means competing in the market against used and at this point cheaper equipment.

3.2 Optimist Class Rules

The Optimist class require standardised design.

Standardisation is very positive in terms of regatta sailing, as it ensures fair competition. In terms of circularity it ensures a steady supply of spare parts and could potentially increase chances for professional repair. On the negative side the standardised design can only be changed incrementally and prevents more sustainable options to find application in competition boats.

3.3 Future Embodiment Opportunities

The negative impact happens at the end of the boats lifecycle.

GFRP construction becomes an issue at end of life for the same reasons it is used in the first place: durability. There are material alternatives that can help circumnavigate these issues. Furthermore a less integrated embodiment could improve reparability and extend the products lifetime.

3.4 Life Cycle Assessment

There are more sustainable alternatives, feasible and viable alternatives to glass-fibre-reinforced-polymer boat construction.

Compared to GFRP, Elium-resin and basalt-fibre composite is recyclable at end of life. It outperforms it in terms of strength and durability. Setting up appropriate logistics and processes to facilitate recycling becomes the next challenge. If the boat is not recycled at EoL, a material composition from biobased-resin and flax-fibres is the more favourable option.

3.5 Second Hand Market Mapping

Optimists go through many hands due to the limited time a child uses an Optimist (compared to the boats life-expectancy).

In a conducted mapping of the second hand market of Optimists, the age of only 26% of the boats is known (n=120). This means that vital information such as the manufacturer, material composition etc. is lost for 74% of Optimists. This would be extremely fatal if this happened for a boat that is recyclable, as it would render all recycling efforts unlikely.

3.6 Usage Patterns at Sailing Schools

Optimist life expectancy: ~ 25 years, ~ 1300 Sailing Sessions, ~ 4000 Sailing hours

Optimists are handed down from competition usage to more beginner level sailing. Comparing the emissions of boat’s manufacturing and EoL to the travelling emissions from getting from and to sailing sessions, particularly in regatta sailing, transport leaves a bigger carbon footprint.

3.7 From Usable to Obsolescence

Professional repair for Optimists is more expensive than replacing it with used one.

Sailing schools, having an intrinsic motivation to extend the boats lifetime and take care for their boats themselves. This needs to be supported. The demand for used boats seems quite low, meaning that life extension needs to happen both for competitive use and for training use.

3.8 Marketing and Circular Business

Circular Product Design goes hand in hand with business model innovation.

Linear business models are largely at fault for wasteful consumption patterns. Currently, with purchase, the liability over a product is transferred to the owner, including EoL fate. Business model integration that facilitate reverse logistics open up opportunities for lifespan extending measures, such as remanufacturing and efficient material collection for recycling.

4. CONCEPTS & VISION



Fig. 28 Render of Optimist

4.1 Ideation	52
4.2 Concept 1: Circular Business at Khulula	54
4.2.1 Market Positioning of the Eco_Optimist	54
4.2.2 Introduction of the ReSail_Optimist	54
4.3 Concept 2: Designing the Information Flow	56
4.3.1 Digital Product Passports	57
4.4 Concept 3: Eco_Optimist Optimisation	58
4.5 Concept Choice & Vision	59

4.1 Ideation

Based on the insights gathered throughout the analysis phase, further supported by various ideation techniques applied, three concept directions emerged.

Facilitating the Information Flow

Drawing from the second hand mapping, a finding of some concern is that for 74% of the 120 mapped Optimists the age was no longer known. Considering the production year “getting lost”, this would consequently make information loss for other important product related information like material composition, the manufacturer or environmental impact data, very likely too. For a boat made of an innovative material, this information would be absolutely vital in assuring that someone repairing, remanufacturing or recycling it, knows how it needs to be done. If its information gets lost, a potentially recyclable boat would also end up in landfill or incineration, rendering all efforts taken to make a more sustainable boat irrelevant. Designing the information flow therefore becomes a very relevant direction to pursue further.

Circular Business at Khulula

Circular business means taking care of products over their entire lifecycle, for example by remanufacturing it. Taking back old equipment to overhaul and resell it, is an approach that ensures high value retention and a longer life span. This however, has been found to be very expensive compared to the value of a used Optimist dinghy. However, when incorporating it into the business model of selling new equipment, this could change. Developing such a strategy could therefore become a real contribution to circularity.

Designing a Recyclable Boat

A comparative LCA demonstrates that recyclable material alternatives exist, offering additional advantages in both weight and durability. Even if the class rules do not allow for changes to the embodiment of the Optimist, a prototype, tangibly showcasing the product and more importantly repair and recycling processes, would be a crucial contribution to support decision making to adopt such approaches in the future, not necessarily only for the Optimist, but for other boats too.

The next three chapters detail these three concept directions further. Eventually one is chosen to continue with.



Fig. 29 Peak into ideation process

4.2 Concept 1: Circular Business at Khulula

4.2.1 Market Positioning of the Eco_Optimist

The Eco_Optimist is not licensed to be sold as a competition boat, due to the more sustainable materials used.

As a training dinghy (with competitive performance) it is competing against older competition boats handed down to more beginner level sailors. More expensive materials for production and the low sales volume of the Eco_Optimist only allow Khulula to sell them at a higher price compared to its competitors. Their value proposition is that they were designed very diligently to have a more sustainable footprint.

This makes the product appeal to environmentally conscious customers, presumably with a higher financial freedom and no immediate ambitions of competitive sailing. This is a rather small audience, given sailing schools are usually limited in their financial freedom.

4.2.2 Introduction of the ReSail_Optimist

An additional offering by Khulula that combines both environmental friendliness and low costs could benefit Khulula's business, as it would make sustainable sailing accessible at a more affordable price, increasing their customer base.

A remanufactured Optimist could present such an additional offering (see figure 30). Linking back to the 10-R-strategy of value retention (introduced in chapter 2.1), the life elongation of an old boat tackles R2: Reduce, R3: Reuse and R6: Remanufacture. This has an immediate effect on reducing the exploitation of materials and ensures high value retention of materials already in use.

As outlined in chapter 3.7.4, the business case of remanufactured dinghies is deemed to be questionable. Pairing it with a trade in programme, ensuring 1:1 sales of new boats and remanufactured boats, could drive sales of the new boat too, which as a standalone presently has a tough position in the market.

A trade in option would be interesting as it ensures a steady supply of cores to be remanufactured while also relieving owners of an EoL boat. Staying true to the naming of the Eco_Optimist, a remanufactured Optimist could be named the ReSail_Optimist, a play on the words sail and sale.

A scan of the second market reveals, that training Optimists are sold with a median price of 260€ while

competition boats are sold for a median price of 900€ (see figure 31). This gives Khulula room, mainly for labour expenses, to refresh these old boats and resell them, at a much lower price than a new Optimist (4000 € upwards). Finding a line between giving the old boats a new branding, while still preserving its story would be an interesting study to continue with.



Fig. 30 EVR Decision Matrix: Value proposition of Khulula offerings and potential customers (based on (Van Boeijen et al., 2021))

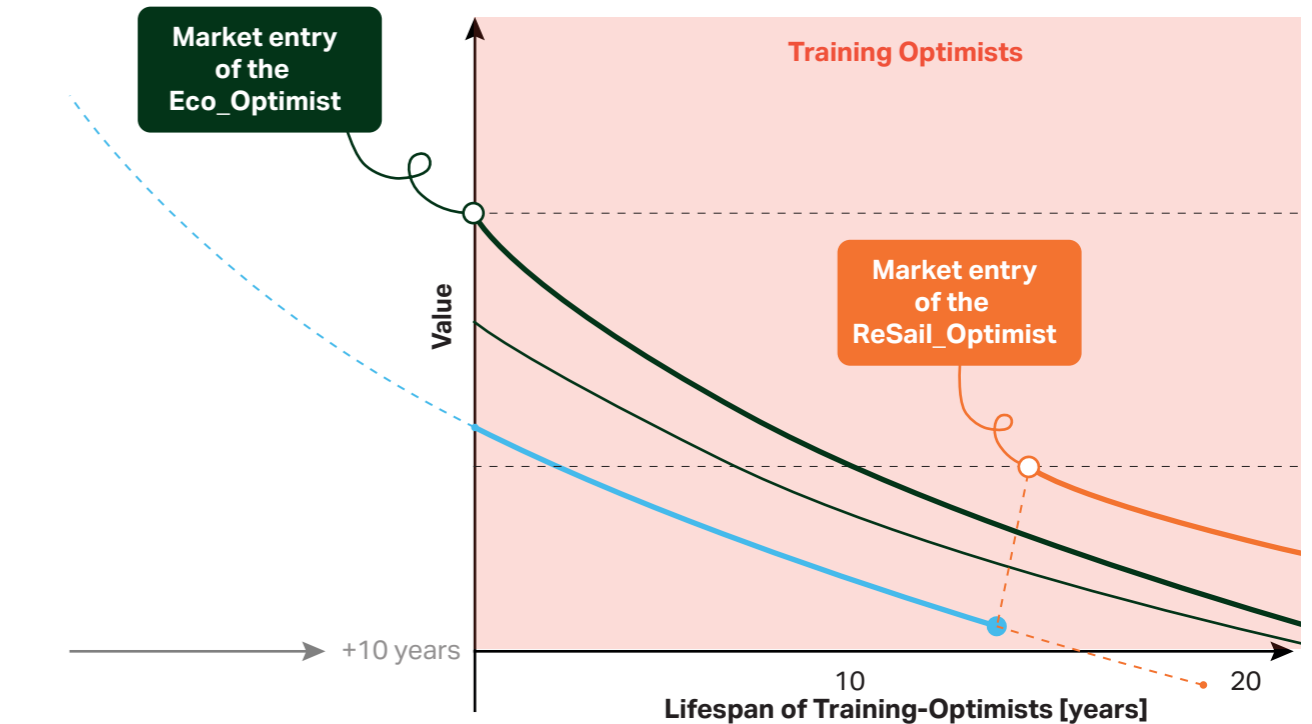
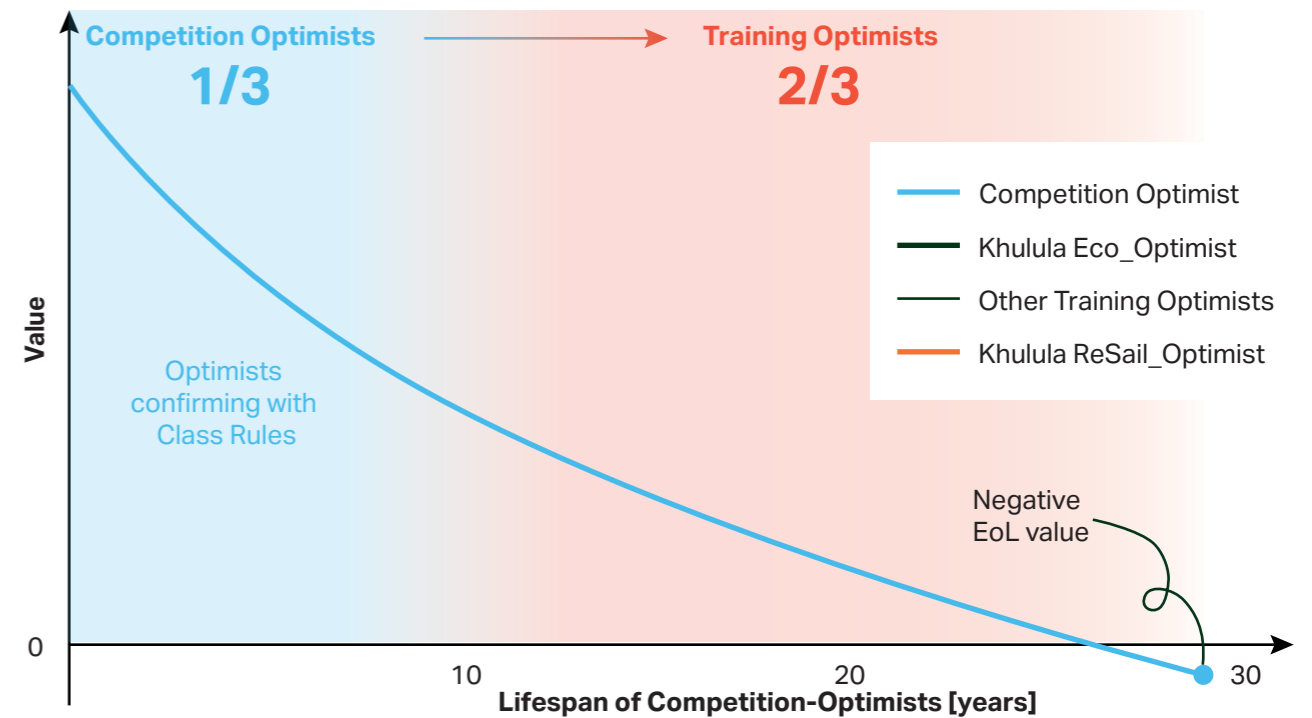
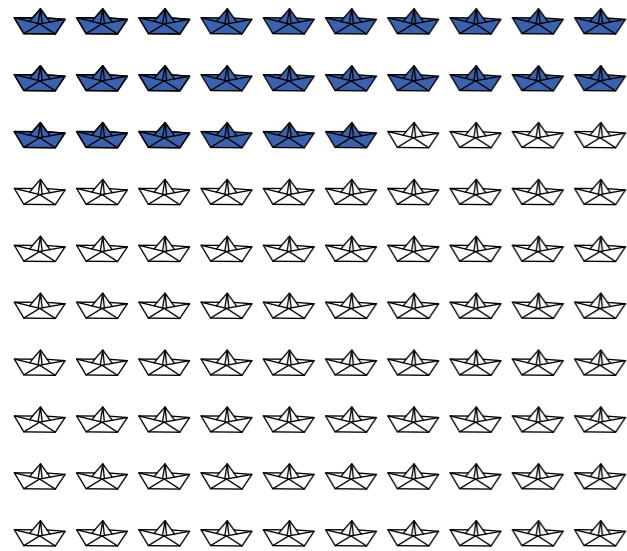


Fig. 31 Market entry of the Eco Optimist, competing with older competition boats

4.3 Concept 2: Designing the Information Flow



**74% of all Optimists
lose vital information,
during their lifespan.**

Fig. 32 Illustration showing 74% product related data loss through an Optimist's lifespan.

Due to the frequent change of ownership, vital information is lost for the majority of Optimists. The outcome of this can be observed in unclear product descriptions in offerings on the second hand market, with things like material composition, manufacturer etc. only traceable through visual inspection of photos at best.

Competition Optimists are required to come with a physical documentation carrying information like the hull ID, the measurement certificate, the assigned sail number etc., issued by a licensed measurer. This documentation seemingly gets lost throughout the Optimists lifespan. Once the boat is no longer used for competition, the information seems to hold no value and is therefore no longer passed along. A recent update to the class rules requires all certified competition Optimists to have a RFID (Radio-Frequency Identification) tag embedded in its composite, from July 2025 forward. This RFID tag stores information like the measurement producer, production date, mould and part number and measurement certificates (IODA, 2025). The specifics are so far only disclosed to licensed manufacturers and the reason for this change to the class rules is unknown.

This RFID tag will likely improve the mentioned information retention, however it seems that the focus of this initiative and the included data aims at ensuring adherence with regulations only (save and temper proof storage of measurement certificates). There is no apparent focus of this tag including information relevant with respect to sustainability. No source is available, specifying how this data can be accessed, likely meaning that it is not intended for private use and can only be read with compatible RFID readers provided by IODA. This would conceal the information from private access and thereby not improve data flow all that much.

4.3.1 Digital Product Passports

The Digital Product Passport (DPP) is a digital carrier of product related information, accessible to owners and other relevant stakeholders. In the EU the DPP is soon finding widespread regulatory implementation, with EV-batteries being the first products required to carry it in 2027 (CEPS, 2024). Referring back to the issue of information loss during the Optimists use-phase (see chapter 3.5, figure 20), which would be particularly troubling for boats with recyclable construction, a DPP would be a suitable carrier ensuring the information reaches even the final owner.

This means that expanding the scope of data stored on the RFID-tag or the data accessible through it, would be very beneficial in terms of circularity. If accessible to the owners as well, this could increase transparency in the second hand market, especially, if for instance repair histories can also be added.

Furthermore, including usage data (for instance collected by a tracking device), could provide insights for R&D and logging transfers of ownership would ensure a contact person is available for EoL boats. Figure 33 illustrates, how the DPP could become much more than a tool ensuring correct EoL treatment and what benefits such usage data could provide. This way, other stakeholders benefit from the system too, rather than the RFID-tag benefiting the sailing association alone.

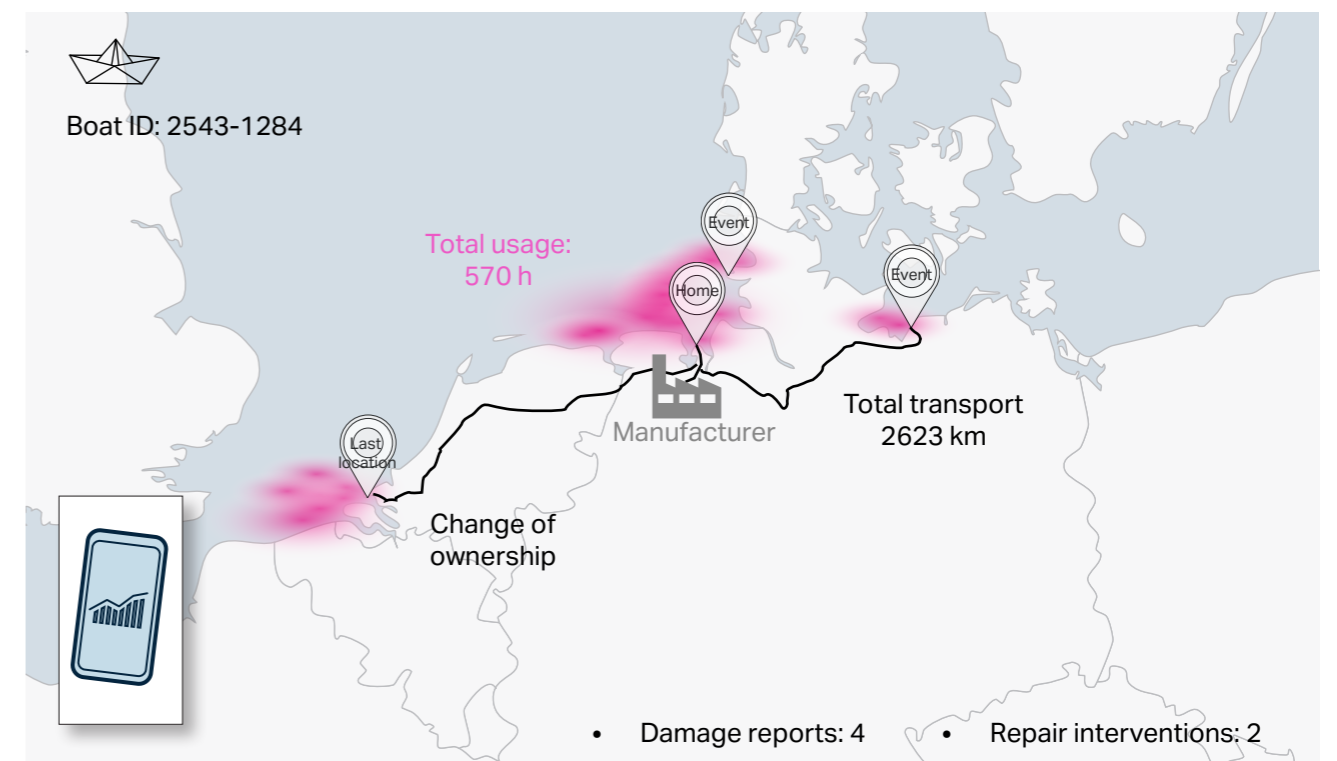


Fig. 33 Concept illustration of digital product passport with an integrated track and trace system

4.4 Concept 3: Eco_Optimist Optimisation

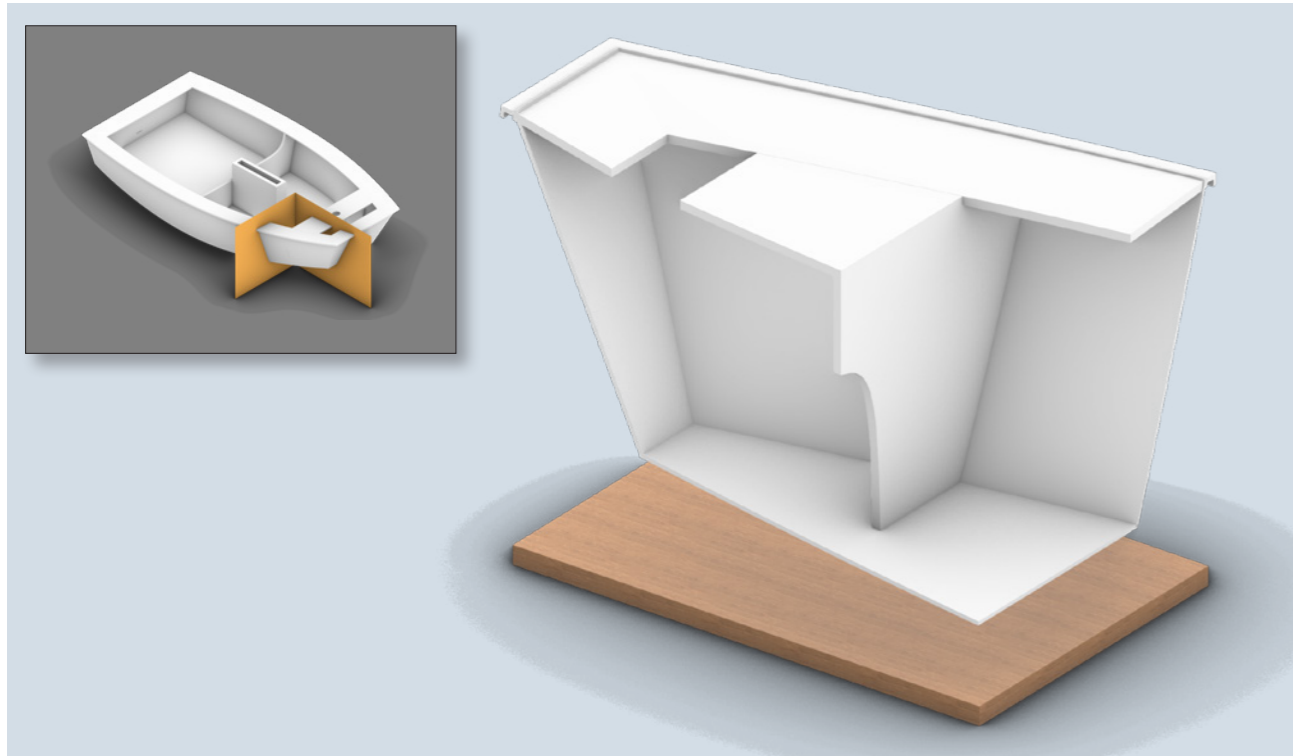


Fig. 34 Rendering of a mock-up showcasing a representative section of the Optimist to be produced out of Elium resin and basalt fibre to showcase the feasibility, to be displayed at boat fairs for instance

Elium-resin and basalt-fibre have been identified to be a suitable contender to replace GFRP and to make a recyclable hull (see chapter 3.3 and 3.4). However, even amongst composite material experts, the Elium-resin and basalt-fibre construction variant remains a bit mystical (Schadewaldt, 2025). An experiential prototype/showcase would be essential to deliver trustworthy answers to manufacturers concerns: Can we use the same moulds? What other differences are there in the manufacturing process? How do we best repair it? How do we need to recycle it or who does it?

Other advantages this new construction method promises to deliver, are higher durability and lower weight. The weight savings of 6% (at same stiffness as GFRP) make this recyclable construction method particularly interesting, as it would allow overlap of new and old boats in regatta sailing, with the new ones having a small extra weight attached to it. In case of the Optimist the difference is approximately 1kg. This could also extend the use phase of Optimists and other dinghies in regatta sailing, as the added weight could be adjusted after every repair. This way, both new and older dinghies can compete, to facilitate a transition phase from the old material composition to the new one.

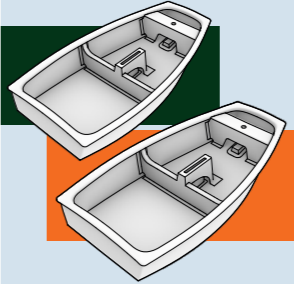
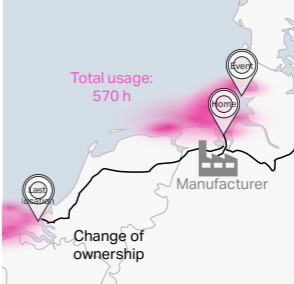
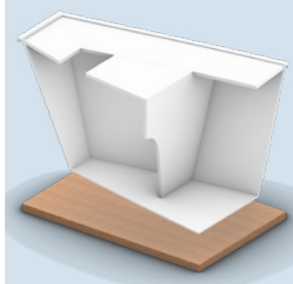
4.5 Concept Choice & Vision

To choose a concept direction to develop further, a decision matrix was used (as seen in table 2).

The concept to “Design the Information Flow”, by means of a Digital Product Passport (DPP), comes out on top. With no blueprint of what data a DPP needs to contain, how it is accessed etc., this project direction holds a big innovation potential and promises to be applicable to other maritime equipment too, increasing its potential impact.

The vision statement of the next page lays out the path for the work to come, and with that, the next chapters.

Table 2 Concept choice, decision matrix

	 Circular Business Strategy Remanufacturing of Re_Sail Optimist	 Designing the Information Flow Digital Product Passport	 Eco_Optimist Optimisation Elium Resin, Basalt Fibre
	2.	1.	3.
Environmental impact	2 Giving otherwise obsolete boats a new life	1 Potential is high, depends on acceptance	0 Only few Eco_Optimist sold
Involving Stakeholders	1 Owners and manufacturers	2 Almost all are involved	0 Mainly manufacturers
Cross compatibility	1 Business model might spread if successful	2 Can be applied to other boats/products	2 Can catch on to other boats
Innovation potential	1 Business model innovation	2 No standardises DPP yet, relevant now	1 More of a demonstrator rather than innovation
New skills to learn	2 Business perspective, stakeholder management	2 Digital prototyping	1 VARTM manufacturing
Score:	7	9	4



Vision:

**“Designing an information flow
for the Optimist
by means of a
Digital Product Passport with a
Track and Trace solution
to facilitate
circular business
and sustainable sailing”**

5. DIGITAL PRODUCT PASSPORTS FOR BOATS

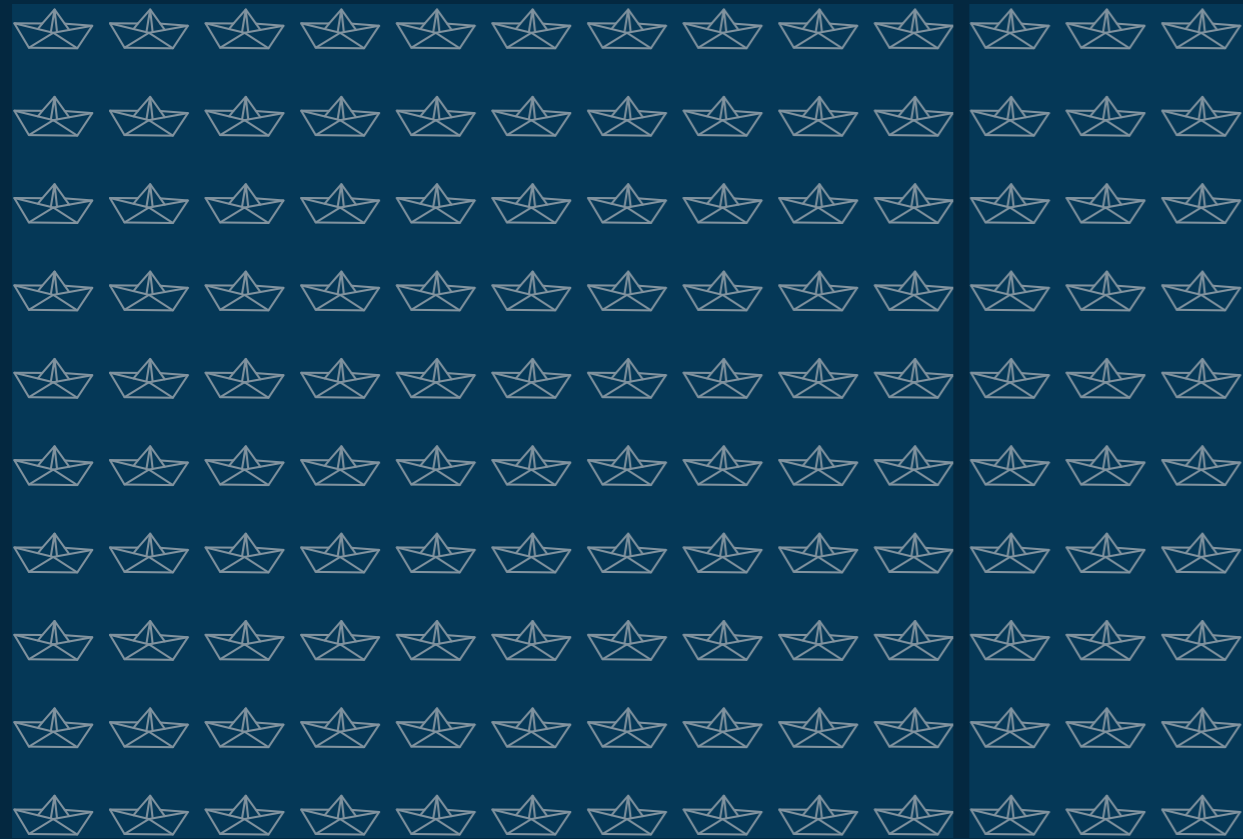


Fig. 35 Abstracts illustration of boats

5.1 Existing DPP Solutions	64
5.2 Dynamic & Open Access Approach	65
5.3 Considerations for Usage Data Tracking	68
5.3.1 What to measure	68
5.3.2 How to measure	69
5.3.3 Concept 1: "Strava" Experience (cellular)	70
5.3.4 Concept 2: Focus on Essentials (LoRa)	71
5.3.5 Concept 3: Unobtrusive Measuring (Black-box, Bluetooth)	72
5.3.6 Concept Choice	73
5.4 Open Access Intervention Reporting	74
5.4.1 What Information to Collect	74
5.4.2 How to Report Data	75

5.1 Existing DPP Solutions

A Digital Product Passport (DPP) can be considered a digital collector for lifecycle information of a product, collected from all stakeholders (manufacturer, partner organisations, owners), with the goal to support sustainability, promote circularity and strengthen legal compliance. It emerged out of the need for tracking the reusability of components with real-time information on their condition and for overall resource management (Voulgaridis *et al.*, 2024).

DPPs are part of the “Circular Economy Action Plan” (CEAP) and the “Ecodesign for Sustainable Products Regulations” (ESPR) by the European Commission, two programmes promoting supply chain transparency and sustainability by enabling circular solutions.

Due to the specific information needs of different industry sectors and product categories, there is currently a lack of a detailed blueprint on what information a DPP needs to contain, what format it should be in and where it is stored (Götz *et al.*, 2022). While standardised DPP adoption could be beneficial in terms of comparability, interoperability and overall information accessibility, the current sprouting of DPP initiatives could also boost innovation and a more product tailored adoption (Psarommatis & May, 2024). Besides that, a concern over loosing intellectual property related information, causes reluctance in different industries to adopt it (Lopes *et al.*, 2024). Either way, managing information over the entire product lifecycle is challenging, mainly due to the interdisciplinary efforts needed to obtain, process, store and share relevant information (Zimmermann *et al.*, 2024).

Batteries for electric vehicles are the first product category with mandatory DPP rollout in 2027. A much wider range of product categories is supposed to follow in the years after that (textiles, electronics, furniture, tyres, etc.). As of now, Optimist and sailing boats do not directly fall into these categories, however this could change. The ESPR is set up as a framework regulation, allowing the EU to add product categories through delegated acts. For this reason, complex products, such as larger boats (especially if motorised) could follow, which would make the development of DPPs a liability for boat builders in the near future and early adopters could benefit. This is speculative for now, but given the issue with obsolete boats and the loss of vital information

throughout their lifetime (in the case of Optimists at least, see chapter 3.5), implementing DPPs for boats makes sense either way.

Product passports for boats already exist, as of now, they are still rare and have only been adopted in commercial shipping or for luxury yachts. The Danish shipping company Mærsk launched a “Cradle to Cradle Passport” for their container ships to track all materials of their ships, represented in a 3D model (digital twin). Their scope is to facilitate the operator/owner of the ship to make repairs and disposal easier (Adisorn *et al.*, 2021).

MyLime offers DPPs for different products, one of them being yachts. For 100 products the price is 72€/product/year and for 6000 products: 3€/product/year, in this case only holding static data (Becchio, 2025). From a technological point of view, this offers two apps, (one app for the manufacturer and one for the owner), different permissions for data entry and partial data storage in blockchain to ensure temper-proof storage. The pricing makes it mostly appealing for luxury items, particularly when interactive features are enabled (higher price tier). This results in the DPP shifting its focus towards a greater emphasis on status and brand originality, signifying authenticity, rather than enabling circularity. Bellini Yachts (2024), to name another example, have also recently announced the creation of a DPP for one of their yachts.

5.2 Dynamic & Open Access Approach

The mentioned examples show that for now only products with high profit margins or high sales volume have a DPP, highlighting the challenging conditions for a smaller company to implement a DPP for their products especially for products with a lower sales volume. There are examples of simpler and far cheaper items as well, for instance fashion brands have launched product lines with DPPs before, creating some transparency over their supply chain, this however is only static data (accessible via QR code), not fulfilling the needs of a DPP for boats.

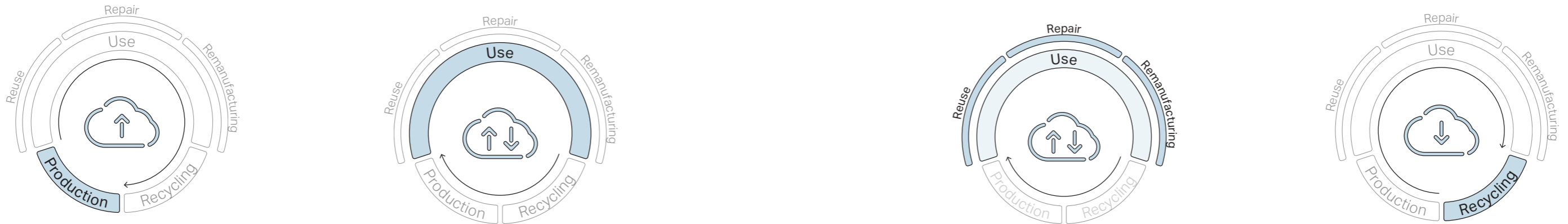
While the before mentioned examples of already existing DPPs for boats do for instance provide previews into the manufacturing of a yacht while waiting for its completion or for tracking repair interventions (the higher tier services at least), none of them integrate active usage data tracking. With all of these larger boats having high tech navigation systems (AIS) onboard, this seems to be a missed opportunity, especially since the location data for these larger boats is already publicly accessible through for instance www.vesselfinder.com, without however, any of the advantages of life expectancy prediction. This leads to a blueprint for the DPP for Optimists: it needs to be cheaper and information access needs to be handled differently.

Designed to reduce friction from authorisation processes and to drive its adoption and frequent usage, the DPP for Optimists needs to be web-based, dynamic & open-access.

The Optimist passes through many stakeholder’s hands throughout its lifecycle, the manufacturer, multiple owners (parents or sailing schools) and even more sailors. Compared to the other mentioned DPPs for boats, the DPP for Optimists must be a web-based tool, to avoid any barriers of usage (downloading an app). Additionally, complicated access controls should be avoided as this would likely lead to less frequent usage, for instance when reporting a damage or repair. Occasional cleaning of a database is potentially easier than maintaining a complicated access control system. Authorised access for approved updating and editing would become a secondary feature. Temper-proof data storage in blockchain, costing around 0,80€ per transaction (Becchio, 2025) is dismissed for the same reason. The open access approach is deemed beneficial in case of the Optimist, as its users are young children (and their parents) and repair interventions are often carried out by non professionals. Including dynamic usage data (sailing) and condition reports by the user/owner/shipyard etc. is essential to create transparency over the entire life cycle to be able to set up efficient maintenance schemes and create insights for R&D (see chapter 6.7). The open access approach aims to offer a highly user-friendly tool which will enable easy product data retrieval and usage history uploads, ensuring an extended life span of the boat and facilitating Information driven recycling and insights for R&D of future boat manufacturing.

The blueprint presented in table 3 on the following page, gives a full overview of what kind of data is considered important to include into this DPP, how it can be done, who it might concern and who is responsible for its provision.

Table 3 Overview of important life cycle information of the Optimist



WHAT

WHAT

Upfront Data:

- Manufacturing date
- Origin
- Materials and quantities
- Environmental impact
- Components and certificates

Usage Data:

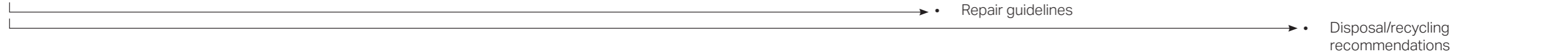
- Water hours
- Location and time

Intervention Data:

- Change of ownership
- General condition reports
- Damage reports
- Repair, remanufacturing interventions
- Event participation

EoL Data:

- Location
- Owner
- Condition
- Material quantities



HOW

HOW

Standardised Format:

- Gather data
- Upload data
- Provide safe and future-proof storage

Track & Trace Solution: (see following pages)

- No batteries
- No app for interaction
- Automated uploading
- Automated data management
- Automated data provision/visualisation
- Future-proof device

Online Form:

- Easy and fast data entry
- Access to product history

Filtered Data:

- Retrieval of relevant manufacturing info, such as emission data
- Machine readable data format

WHO (Responsibility)

WHO (Responsibility)

- **Manufacturer**
- **Shipyard**
- **Suppliers**
- **Class Association**

- Automated IoT system

- **User**
- **Owner/Sailing School**
- **Repair Workshop**
- **Shipyard/Remanufacturing Workshop**

- **Manufacturer**
- **Shipyard**
- **Recycler**

5.3 Considerations for Usage Data Tracking

5.3.1 What to measure

The purpose of tracking usage data is to gain insights into usage patterns and the condition of a product throughout its lifetime (see chapter 3.6). Similar to how the odometer (kilometer counter) of a car is a good indicator of its history and usage, a metric, informing over a boat's life expectancy, is needed.

To reliably predict the condition of the Optimist using such a metric, data from multiple boats is required, which makes this a long-term project.

The following measurements are considered:

Physical Measurements:

- Water sensor in use or not
- GPS location, speed, time
- Strain gauge composite deformation
- Accelerometer speed, crashes
- Gyroscope angles of boat
- Vibration sailing/transport

Biological Measurements:

- Water quality environmental conditions
- Water salinity corrosion
- Sun exposure/ UV corrosion
- Wind/Weather stress of material

A water sensor would be the most reliable way of telling if a dinghy is in use or not (typically stored on land) and a strain gauge would provide the most accurate insights on the strains on the equipment. Both of these measurements however require the installation of sensors in exposed positions, which appears to be prone to damage, considering the partially rugged usage as well as the handling and lifting before and after every session.

A core requirement is therefore, to install all sensors in a protected position in a small, robust and watertight form-factor. For this reason, all types of biological measurements like a water sensor, that measures use, water quality and salinity, or a wind sensor up on the mast, is not considered further.

Instead, a GPS tracker is considered most valuable. Knowing the location and time of usage/movement allows for a much more holistic indicator of wear and tear, as it also provides information over transports. A lot of other information like water salinity, weather data etc. are available online and can be overlaid with the data in post processing. This approach is perhaps a little less accurate in assessing the exact usage times and stress on the equipment in a quantifiable way, but its reduced and protected footprint and potential for additional information overlay seem to make up for it, perhaps even surpassing the capabilities of other sensors.

5.3.2 How to measure

Having established what data would be beneficial to collect, technological constraints need to be considered too. The Eco_Optimists are dispersed over Germany and worldwide considering all Optimists. Installing routers or gateways to track them at every harbour the boats are used at, is therefore no viable option. In order to ensure the accuracy and reliability, it is crucial that data is collected and transmitted in an automated and location independent manner. This is referred to as "dispersed objects asset tracking", which essentially involves making use of existing network infrastructures, which are visualised in figure 36 (Wang, 2018). Considering the long lifespan of an Optimist, a contract based network infrastructure should be avoided, as the costs would outweigh the benefits of usage tracking. On top of that, manual data transfers and switching of batteries needs to be avoided to improve reliability.

Based on the considerations for both the type of measurement and the options for data transmissions, three concepts are developed further (see next pages), the first based on cellular infrastructure, the second one based on LoRa/NB-IoT and the third one on bluetooth and a blackbox (no automated data transmission).

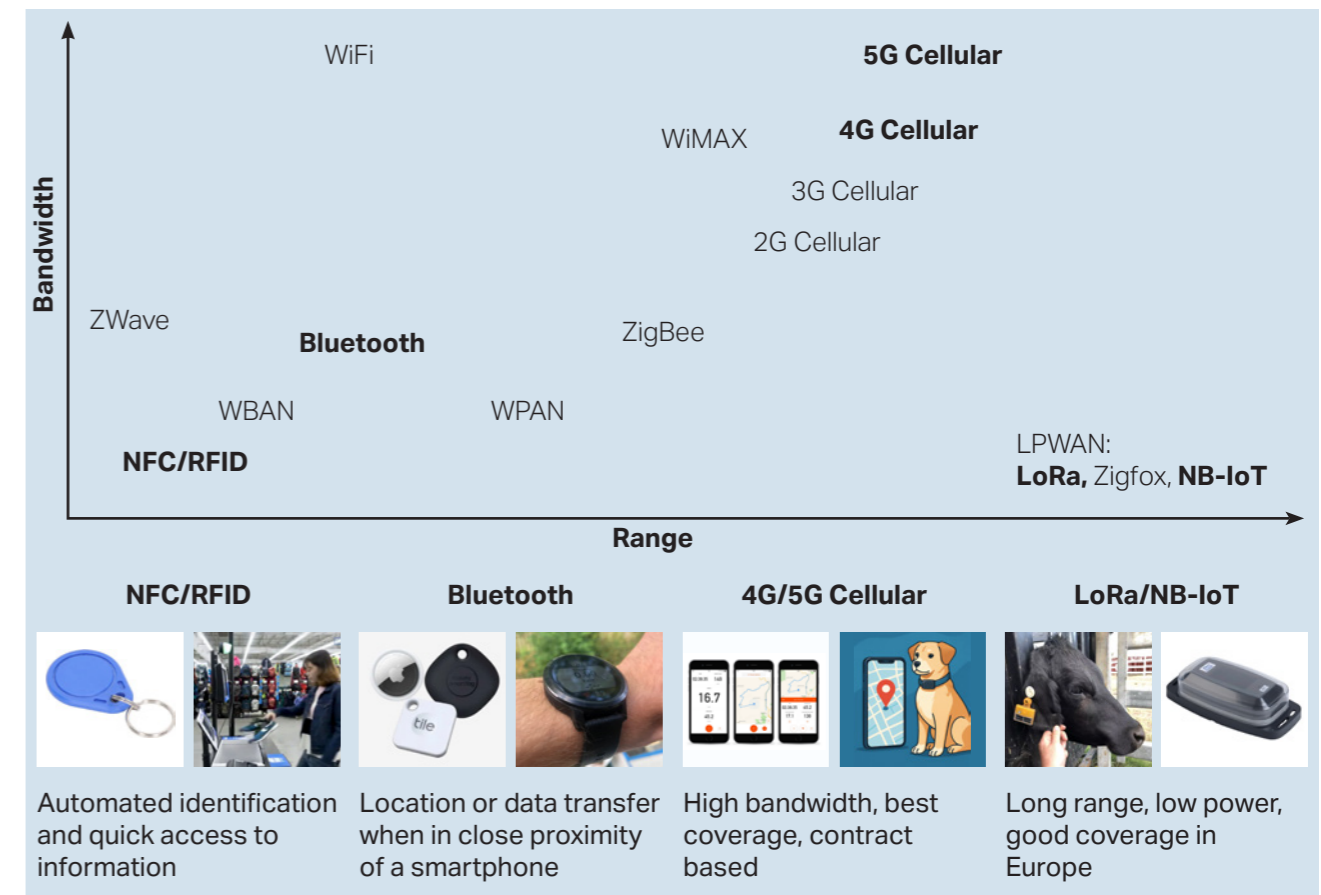


Fig. 36 Technology comparison based on research by Wang (2018): Bandwidth over range and exemplary images of technology utilisation (left to right: 1: (Amazon, n.d.), 2: (NFCW, 2019), 3: (Loca, n.d.), 5: (BikeRadar, n.d.), 7: (Queensland Country Life, n.d.), 8: (DNT, n.d.))

5.3.3 Concept 1: "Strava" Experience (cellular)



Data:

- Location and time
- Distance travelled
- Speed
- Tacking angle
- Lean of boat
- ...

Fig. 37 Concept 1: Dry-box for level storage of the sailor's smartphone to track sailing sessions

There is a trend throughout all sports, from running, tennis or even golf, to track sessions and analyse the statistics for improvement and casual competitions among friends. Strava is a commonly used tracking app, even offering an option for sailing. Strava and other options for sailing are still quite limited, tacking angles, lean of the boat, positions of tacks could all be interesting stats to improve the experience and even offer a suitable tool for improved sailing training. TracTrac is a service commonly used in large regatta events, to track regatta fields, however their devices rely on subscription based contracts, rendering it too expensive for long term usage.

To avoid reoccurring payments, this could all be achieved by utilising the user's smartphone, placing it in a rugged and watertight box, installed on the dinghy in a fixed and level position, to ensure accuracy and comparability of measurements. This approach takes a "the more the better" approach to the data gathering, targeted at the sailor and encouraging their involvement. This way of data collection would at the same time be the most

accurate and complete way to track the use of Optimists. Utilising the smartphone, a device at least the older Optimist sailors already own and carry around, has two advantages: firstly it creates no extra waste, and secondly no additional contract for data transfer would be necessary. However, this method is very dependent on the user, which means the completeness and representativeness of the data for failure prediction would be questionable.

Table 4 Concept 1: Parts and cost estimation

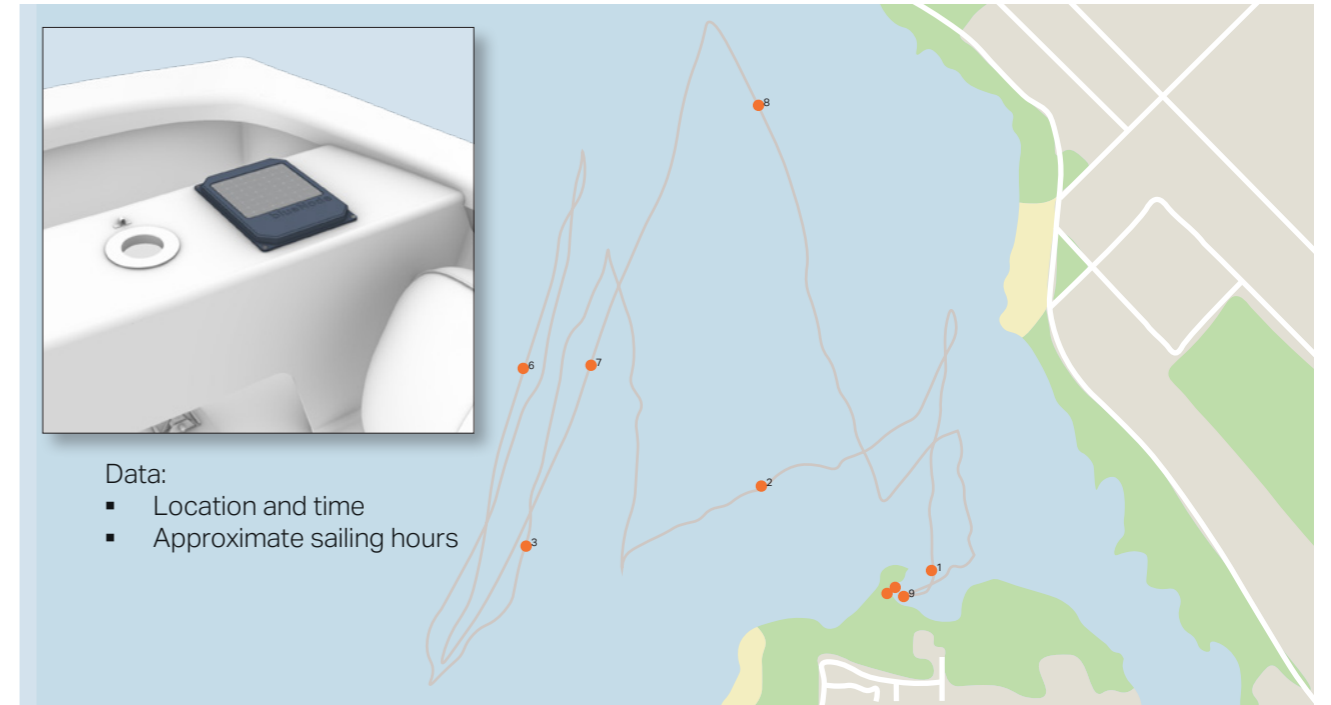
Parts:

Water tight, robust box ~ 50 €

Bill of materials: ~ 50 €

Data management and visualisation would be most expensive for this concept.

5.3.4 Concept 2: Focus on Essentials (LoRa)



Data:

- Location and time
- Approximate sailing hours

Fig. 38 Concept 2: Self-sufficient IoT tracker to track sailing sessions

This proposal aims to create a self-sufficient and user independent system, silently tracking data, representative of the entire usage phase. To facilitate this, energy harvesting by the means of a small solar cell and a wireless network without reoccurring payments would become core requirements for this approach.

LoRa, or NB-IoT are network standards that fulfil these needs (Wang, 2018). LoRa is a long range, low power open source network system. Most gateways are publicly accessible, providing a solid infrastructure with high coverage, see chapter 6.3.1. NB-IoT on the other hand is run by cellular network providers, which makes it more reliable, but bound to country borders and contracts, even though these contracts have recently become far cheaper (13.50€/10years @6MB/month) (Deutsche Telekom, n.d.). NB-IoT is also a long range and low energy demanding networking system.

Both systems only allow for very limited data transfers, the type and frequency of measurements therefore needs to be dialled back to its bare minimum. With that in mind, the location of boat

storage (harbour) and the sailing hours, get first priority. From the change of location the usage duration can be derived. For this purpose, a GPS signal every 15 min. would be enough. Other data, such as weather or water salinity is accessible online and could be overlapped with the usage data at a later point, if needed. The durability of such a tracker and the technological development of network standards remain open questions.

Table 5 Concept 2: Parts and cost estimation

Parts:

Micro controller ~ 30 €
 GPS sensor ~ 10 €
 LoRa or NB-IoT module ~ 30 €
 (NB-IoT contract for 10 years) (~ 15 €)
 Solar cell and energy buffer ~ 15 €
 Housing ~ 30 €

Bill of materials: ~ 115-130€

5.3.5 Concept 3: Unobtrusive Measuring (Black-box, Bluetooth)

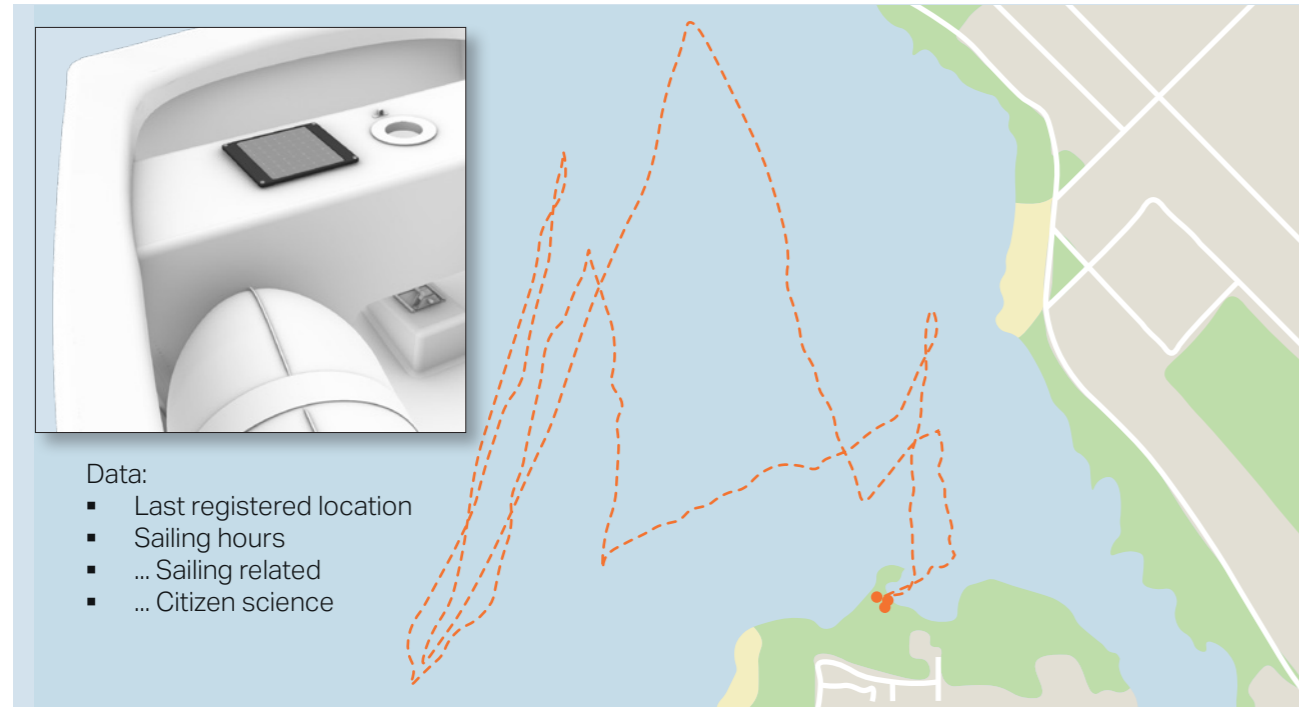


Fig. 39 Concept 3: Solar powered black- box for life cycle tracking and Bluetooth based location tracking. The image is only showing the solar panel, as the black box, would be hidden under the mast thwart.

This concept strikes a balance between the previous two concepts for data collection. The Optimist can be located using Bluetooth trackers such as the Apple AirTag, Samsung SmartTag or alike. This way, the current location is reported every time someone with a smartphone and activated Bluetooth walks past the boat. This would work reliably at land, but it doesn't support usage tracking to indicate wear, a core requirement for life cycle tracking and failure prediction.

For usage tracking, a sensing black-box is installed, that can be read out upon inspection. This would allow for more complex and accurate measurements, similar to concept one. Without automated data transmission, the usefulness of this data becomes more uncertain, as the user or someone doing maintenance and repairs, would be required to upload it.

Both the Bluetooth devices and the black box would be powered by a small solar cell and a battery buffer.

Table 6 Concept 3: Parts and cost estimation

Parts:	
Bluetooth locator	~ 30 €
Micro controller with storage	~ 30 €
Sensors	~ 10 €
Solar cell and energy buffer	~ 15 €
Housing	~ 30 €
Bill of materials:	~ 115 €

5.3.6 Concept Choice

The three presented concepts represent different means of tracking and integrating usage data into the DPP.

Concept one, promises a strong user engagement, which might help to drive adoption rates of the system. Relying on an already existing device, the user's smartphone, is an additional advantage; this approach however is also its Achilles heel: a high dependency on the user also means less reliable usage tracking of the boat. Such a tool for smarter sailing training might have a future, but it shifts the focus to a more sports and performance oriented design and doesn't cater this project's circularity scope accordingly.

Concept two convinces with its perceived simplicity, only aiming to do one thing: reliable usage tracking. The minimalistic approach, due to the constraints of the long range and low power connectivity, might

make it easier to communicate the designs intention of real-time usage tracking as an enabler for the circular economy.

Concept three aims at closing the circularity gap in two almost separate ways: equipping the boat with third party technology ecosystems for location tracking and a sensing black box for usage statics. The uncertainty around the data eventually making its way into the DPP is a big drawback of this concept though.

The decision matrix (see table 7) gives further reasoning for the decision made to continue with a LoRa tracker (see also chapter 6.3). LoRa is chosen over NB-IoT for its open source standard contract less connectivity.

Table 7 Concepts for usage data collection, decision matrix

	'Strava' Experience Smart phone coupling	Focus on Essentials LoRa network	Unobtrusive Measuring Bluetooth & Black-box
	2.	1.	3.
Location	1 Accurate, but user dependent	2 Not as frequent	2 Great, as long as supported by provider
Usage statistics	1 Many options, but user dependent	1 Only computational approximations	0 Only once storage is read out (black box)
User dependency	-1 Not everyone will log sailing sessions	2 Sends data, no matter of the user	1 Location is available, other data not
Cost	-1 Extensive data handling/preparation/visualisation	0 Components are more expensive	1 Cheapest option
Longevity	2 Smart phones already carry sensors	0 Functioning for around 10 years	0 Should last around 10 years
Bandwidth	2 High transfer rates possible	-1 Very limited data transfers	1 Good for location, not the rest
Data justification	1 Benefit for user, might seem excessive	2 Justified if shared with user	0 Difficult to convince user without sharing
Score:	5	6	5

5.4 Open Access Intervention Reporting

5.4.1 What Information to Collect

Intervention reports are the second layer of dynamic information included in the DPP developed here.

The topics listed below are deemed relevant towards assisting fleet management (for instance at sailing schools), transparency in the second hand market and environmental impact reduction/evaluation:

Condition tracking

- | | |
|-------------------------|---|
| ▫ New equipment | Added components to a boat |
| ▫ Damage reports | Insights for R&D and overview of due repairs |
| ▫ Lost equipment | Fleet management |
| ▫ Repair interventions | Transparency in second hand market |
| ▫ Ownership transfer | Contact person to avoid EoL abandonment |
| ▫ EoL fate of equipment | Insights for regulatory bodies and associations |

All report types need a text based description and (photo) documentation to ensure validity. On top of that a name (or alias if preferred) along with a means of contact, for instance email or phone number would be useful information. Additionally, the time of reporting and the boat (name/ID) needs to be collected with every intervention report to enable categorisation.

To the benefit of the user and owner, likely the people interacting with the DPP the most, the following information points are considered too:

Sentimental tracking

- | | |
|------------------------|--------------------------------------|
| ▫ Event participations | indicator for rough usage, transport |
| ▫ Photos | memories, season summary/usage diary |

Once a "reporting" functionality exists, adding such personal information is more a question of the DPPs scope, rather than a question of feasibility. Whether restricting the DPP for things considered to impact emissions or opening it up for other, more personal (but still product related) information too, would be of advantage, remains to be answered. The constrained variant would perhaps be perceived as less intrusive, opening it up, however, could bring some other benefits to the user, thereby driving its adoption and usage. Including the option for additional reporting, makes it the user's choice, whether to use it or not. In an open access model, such integrations are possible, however this information should probably be accessible upon login only.

5.4.2 How to Report Data

Acknowledging that reporting of damages or repairs takes time, the DPP developed here facilitates a user interaction that is easy to understand, time-efficient and pleasant. This is crucial, as reporting would otherwise never be picked up and the data would be much less representative due to a fragmented documentation. As mentioned in chapter 5.2, an open access approach is pursued, aiming at just that: increasing user friendliness and saving time. For this reason the DPP developed here is a web-tool, with the data both retrievable when with the boat, via an NFC chip, and when at home, via web-search (see figure 40 and 41). Data entry is envisioned to be possible without further authorisation. These specifications render an online-form for the reports a viable option, with all functionalities contained within the website, allowing for tailored input fields, so that downloading a file or tool is not necessary. Important categorisation data such as the Boat ID or date, would not need to be filled in, but can automatically be retrieved, to avoid mistakes.

The incorporation of features such as dynamic feedback or nudging, based on the inputs, for instance when reporting EoL fate of components, has the potential to encourage owners to take more sustainable actions.

In an open access model, interventions reported by businesses should be granted authorised access, to prevent people from falsely reporting with their credentials and for a more trustworthy data reference. This could potentially also be relevant for warranty claims towards professional repair interventions.

The open access approach implies that uploads can be done by everyone, meaning wrong and out of place data would eventually end up in the database and in the DPPs as well. Clear photo documentation and potentially the location data of the automated tracking can instil a level of trust into the system. Editing of entries would not be allowed, as this would take away from the systems transparency, for instance by updating/deleting of unfavourable condition report before sale. Cleaning of the database would therefore need to be a service provided by the DPP host, when requested from the users.



Fig. 40 NFC Chip embedded in product for easy connectivity to DPP information and automatic pop-up message on smartphone



Fig. 41 Illustration for web-search of DPP

6. IMPLEMENTATION



Fig. 42 Logo of the new platform for product passport

6.1 Approach and Requirements	78
6.2 A New Digital Platform: DPP.BOATS	82
6.2.1 Hosting, Page-Editing & Coding	82
6.3 blueNode: A LoRa GPS Tracker	86
6.3.1 Range and Coverage	88
6.3.2 Digital Footprint & Data Handling	89
6.4 Tracking a Sailing Session	90
6.4.1 Stage of Development	91
6.5 Cost Calculation	92
6.5.1 Upfront Costs (blueNode)	92
6.5.2 Running Costs	93
6.6 Business Concept Considerations	94
6.7 Optimistic Futures	96

6.1 Approach and Requirements

This thesis has two practical deliveries: firstly the website DPP.BOATS, the environment for the DPPs, in particular with the integrated dynamic usage data, and secondly the blueNode, a small LoRa-GPS-Tracker to track sailing sessions. Together these two deliveries form a coherent overview, showcasing the information flow needed to project the Optimist, or any other boat into a circular future. Some reasoning and considerations for the approach are listed below:



DPP.BOATS

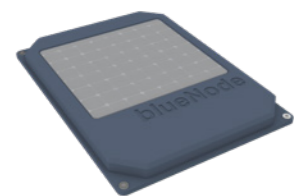
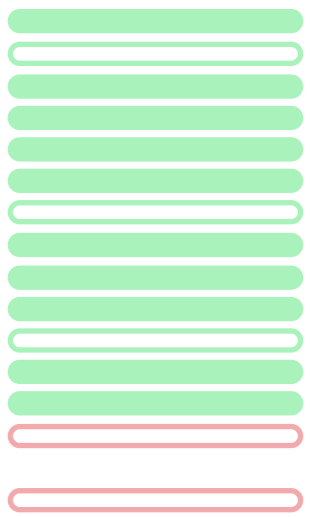
Considerations:

Approaching the task of setting up a prototype for a DPP can be done in manifold ways, from creating a clickable mock-up in AdobeXD or Figma to developing it directly as a code based website. Mock-up pages allow for some interactive features, such as navigating between pages, but they do not allow for live data visualisation, database queries or data up- and downloads, crucial to showcase and evaluate the interactive functionalities of this DPP. These interactive features are vital to the experience of using a DPP, as most data that needs to be visualised is dynamic, stored in a database and only fetched and displayed when needed. For this reason, the DPP.BOATS is developed as a web tool from the get go. While this is perhaps the more complex version to setup, it allows for more design freedom and is a much closer representation of a web-based DPP concept .

Requirements:

- DPP needs to be web-accessible (no application download needed)
- Data visualisation PC and mobile optimised
- Linking a product's DPP with a NFC chip
- View 1: Dashboard (good overview for everyone, with filter options)
- View 2: DPP view, accessible through dashboard, search or NFC
- View 3: Fleet management (sailing schools, bank, insurances, manufacturers)
- Automated referencing/linking between dashboard, DPPs and fleet-overview
- Automated data visualisation from database tables, forms, .json files
- Four phases in DPP (Production, Use, R-strategies, Recycling)
- Static production information without harming confidentiality of IP rights
- Visualising usage tracking (sailing hours and sailing sessions)
- Automated data storage, preparation and visualisation of usage tracking
- Wear indicator calculation
- Authorised and unauthorised reporting for condition (damages and repairs, such as event participation and ownership transfers)
- Certain parameters such as contact information only visible upon login

Achievement Status:



blueNode

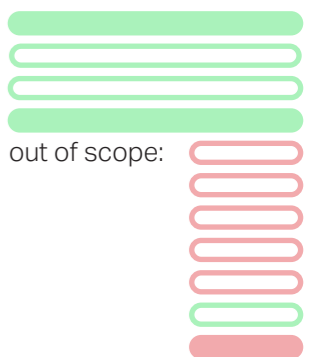
Considerations:

To better assess the feasibility, costs and complexity of using LoRa trackers, tests are performed with three trackers (two different models). The technology has been widely available and successfully deployed in other fields for some time, which proves the technologies feasibility. This being an early stage exploration of using the technology for usage and lifecycle tracking of boats, this thesis focuses on evaluating the desirability and viability of it, over fully developing the device.

Requirements:

- Live data upload into DPP
- Sufficient coverage of network system for reliable usage tracking (NL)
- No/low running costs (provider, service)
- Simulate usage behaviour for 100 boats
- Automated data filtering and preparation
- Powered by solar cell (no battery changes required)
- Water tight housing (IP86)
- Survive winter storage without battery damage
- Durable and temper-proof design
- Conforming with LoRa duty cycle regulation
- Test in real usage-environment (TRL level)

Achievement Status:



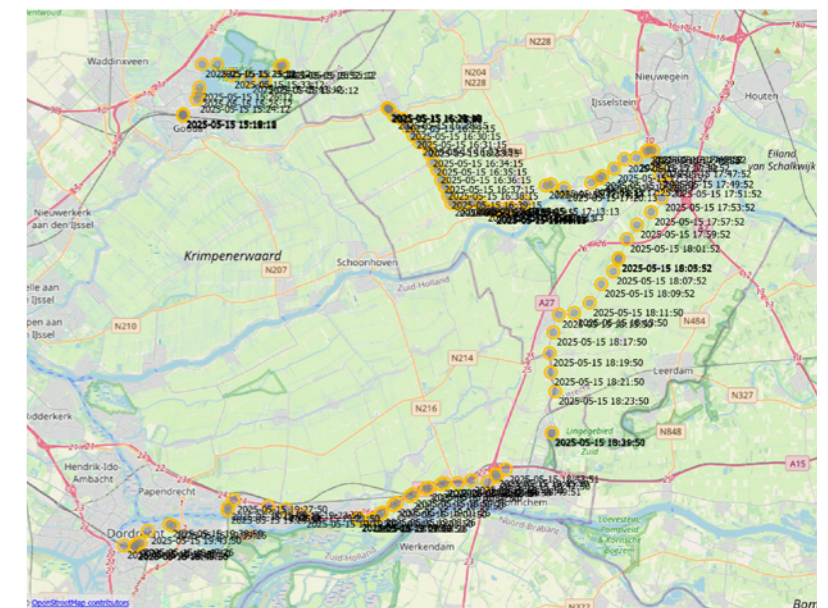
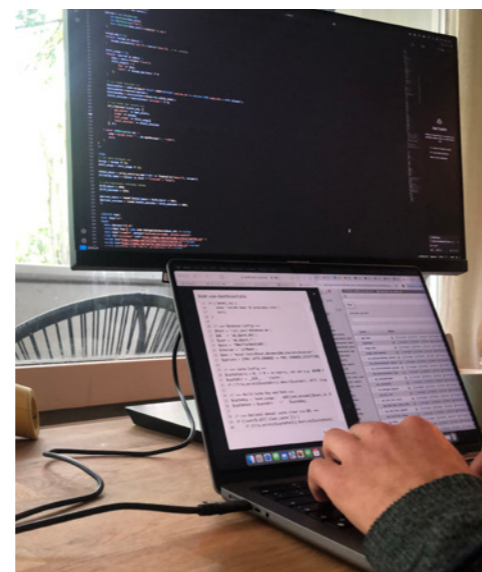
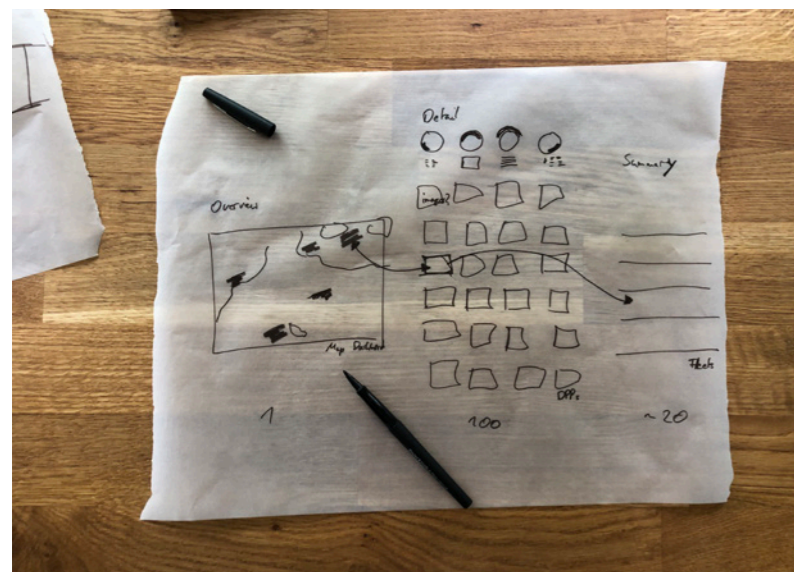
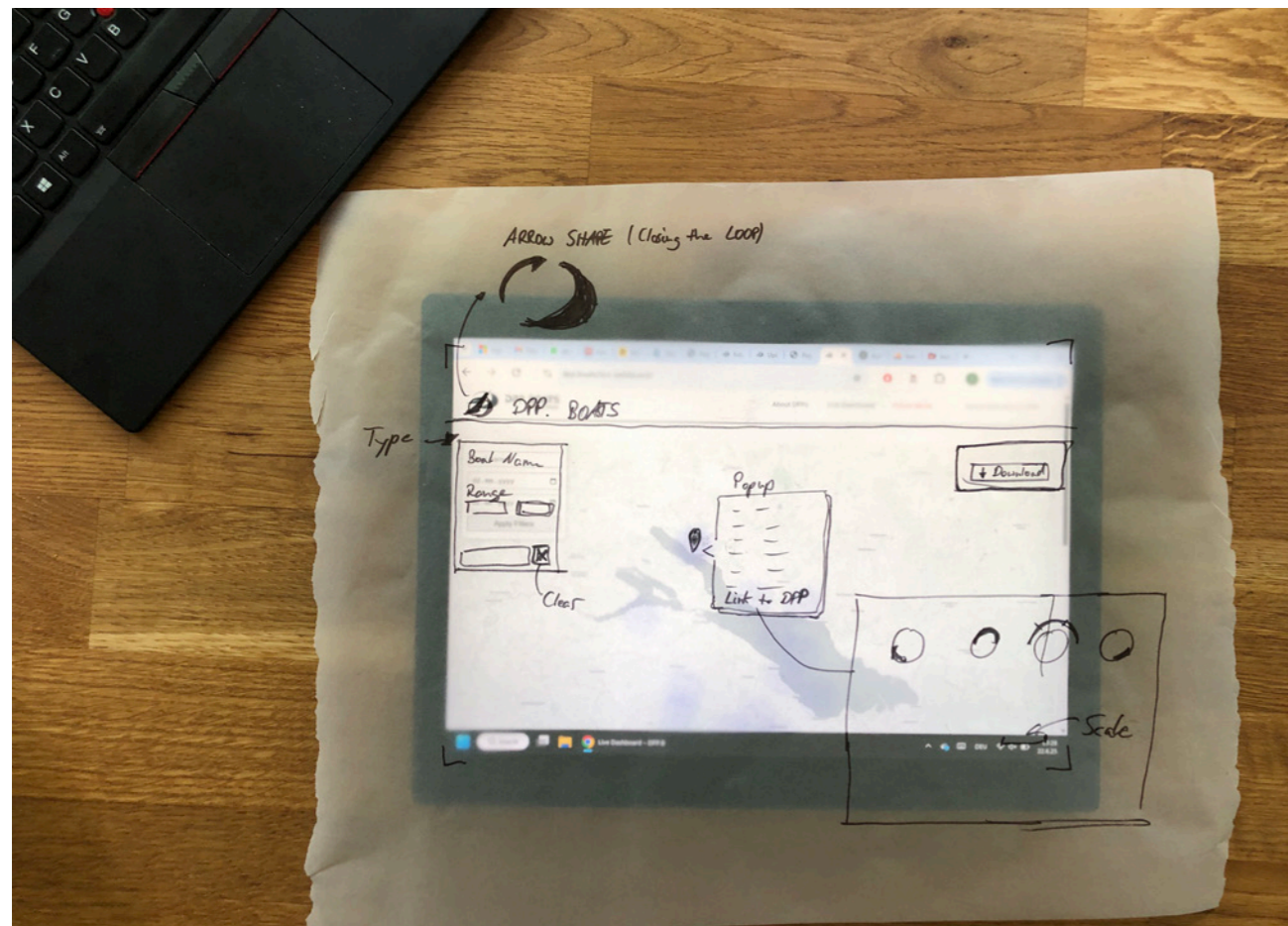


Fig. 43 Process insights into developing DPP.BOATS, a new website hosting digital product passports tailored to boats to project them into a circular future

Fig. 44 Process of developing the blueNode tracker to feed data into DPP.BOATS

6.2 A New Digital Platform: DPP.BOATS

DPP.BOATS is the new web-based environment for a boat's DPP. It serves as a digital prototype showing the future of the digital information flow for boats. The domain this environment is accessible through, is called "www.dpp.boats". The logo shows the system's focus on boats, symbolised by a mainsail and a spinnaker (a large sail used when sailing downwind). The shape of the bulbous spinnaker is continued by an arrow that loops back into it, symbolising the aim of the DPP: circularity and closing the loop.

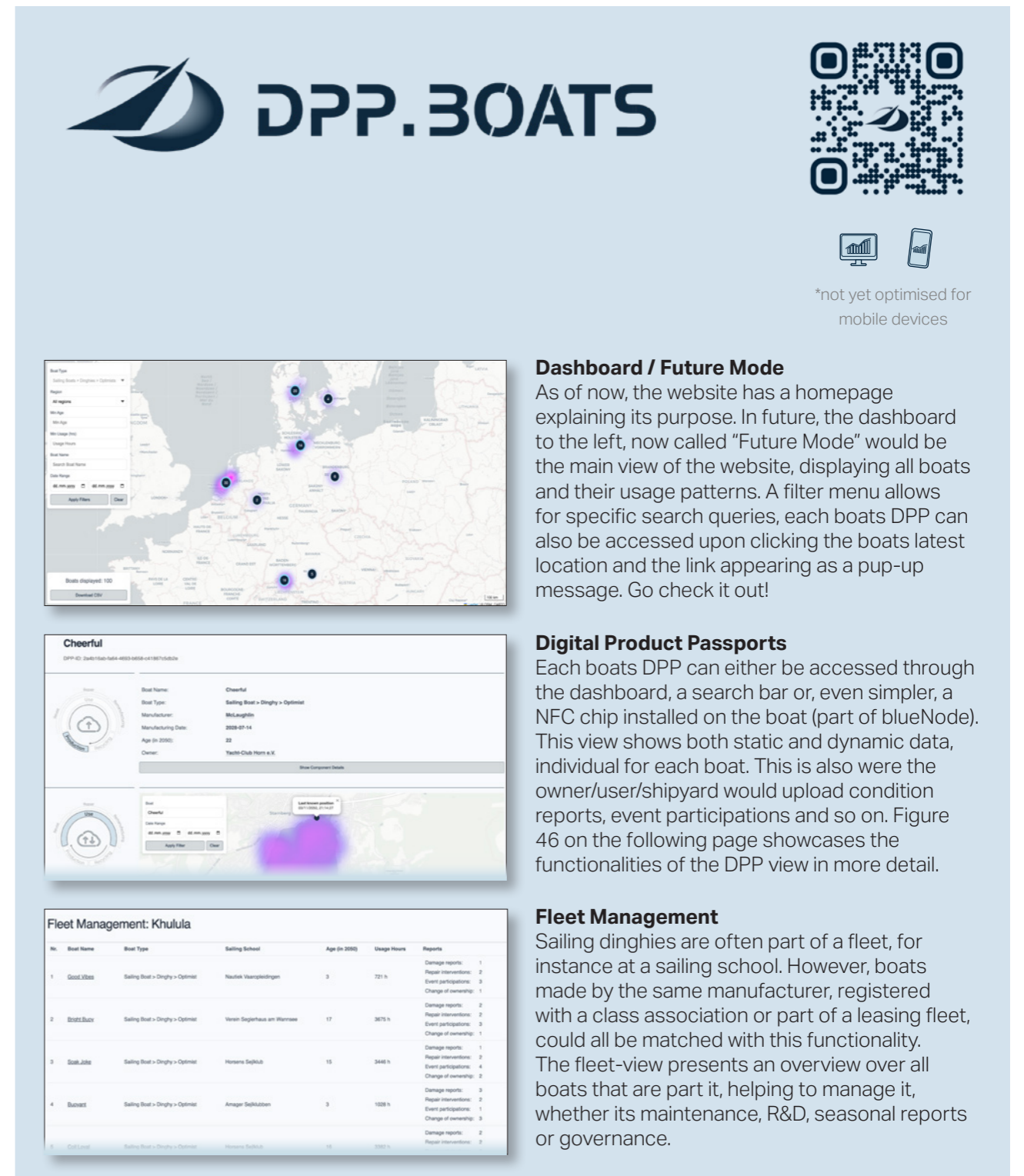
Live data collected by the blueNode tracker is uploaded and visualised on the website, proving the feasibility of this approach. To test and evaluate the DPP blueprint, the website hosts an artificial dataset for 100 DPPs of Optimists, manufactured between now and the year 2050, to convey the systems conceptual state. For this reason, the main dashboard is currently called "Future-Mode". This dataset is python generated, based on the insights gathered throughout the analysis phase. The product related data represents the recyclable construction for boats, identified to be most beneficial in terms of circularity and its environmental footprint in the LCA comparison (chapter 3.4). Each boat's usage data (which would be gathered with the blueNode in future) is based on patterns detected through quantitative data analysis of Optimist usage in sailing schools (chapter 3.5 and 3.6). Damage reports, repair interventions and event participations are generated based on insights from qualitative interviews with sailors and sailing schools (chapter 3.7). At EoL, owners can report the fate of the components, informed and supported by dynamic feedback, which is also based on data gathered in said LCA comparison (chapter 3.3).

This rich dataset, hosted on a live website, allows for an interactive showcase of what the circular future of leisure boating entails and what benefits this DPP holds for all stakeholders, in particular with the dynamic data and open access approach pursued here.

6.2.1 Hosting, Page-Editing & Coding

The website domain has been acquired through "www.namecheap.com". The domain is hosted via Hetzner Online, level 1 webhosting. Page editing has been done via Wordpress. Since the website barely displays any static data or files, the page editor is mostly used for creating containers, to provide structure. The content is integrated via custom-built plugins, including PHP, SQL, JS, HTML and CSS code. The plugins are embedded into the containers via shortcodes, previously defined in the plugin code. The shortcode "[global_dashboard]" for instance integrates the Future-Mode dashboard visualisation and its functionality. This approach allows for editing all DPPs at the same time, since they are all calling the same plugins.

Coding was done with ChatGPT 4o and later on with Visual Studio Code. MyPHPAdmin (database) and WebFTP (website folder for plugin integration), two services included in the Hetzner hosting service are used to employ the code, upload datasets and store intervention reports. A caching system is implemented, to ensure fast and responsive browsing, however this only works for previously loaded pages. New search queries in the dashboard still take time to load due to the high number of computational processes to filter the database with over a million rows for usage data alone.



DPP.BOATS

*not yet optimised for mobile devices

Dashboard / Future Mode
As of now, the website has a homepage explaining its purpose. In future, the dashboard to the left, now called "Future Mode" would be the main view of the website, displaying all boats and their usage patterns. A filter menu allows for specific search queries, each boats DPP can also be accessed upon clicking the boats latest location and the link appearing as a pup-up message. Go check it out!

Digital Product Passports
Each boats DPP can either be accessed through the dashboard, a search bar or, even simpler, a NFC chip installed on the boat (part of blueNode). This view shows both static and dynamic data, individual for each boat. This is also where the owner/user/shipyard would upload condition reports, event participations and so on. Figure 46 on the following page showcases the functionalities of the DPP view in more detail.

Fleet Management
Sailing dinghies are often part of a fleet, for instance at a sailing school. However, boats made by the same manufacturer, registered with a class association or part of a leasing fleet, could all be matched with this functionality. The fleet-view presents an overview over all boats that are part of it, helping to manage it, whether its maintenance, R&D, seasonal reports or governance.

No.	Boat Name	Boat Type	Sailing School	Age (in 2050)	Usage Hours	Reports
1	Good Vibes	Sailing Boat - Dinghy - Optimist	Nautik Vierschingen	3	221 h	Damage reports: 1 Repair interventions: 2 Event participations: 3 Change of ownership: 1
2	BoatBuddy	Sailing Boat - Dinghy - Optimist	Verein Segelhaus am Werrasee	17	3875 h	Damage reports: 2 Repair interventions: 2 Event participations: 4 Change of ownership: 1
3	BoatLibra	Sailing Boat - Dinghy - Optimist	Hessens Segelclub	15	3448 h	Damage reports: 1 Repair interventions: 2 Event participations: 4 Change of ownership: 2
4	BoatNET	Sailing Boat - Dinghy - Optimist	Ammer Segelclub	3	1028 h	Damage reports: 3 Repair interventions: 2 Event participations: 1 Change of ownership: 3
5	BoatLibra	Sailing Boat - Dinghy - Optimist	Hessens Segelclub	15	3448 h	Damage reports: 2 Repair interventions: 2

Fig. 45 Overview of the DPP.BOATS website, a new platform for DPPs for boats

Comment:
Link to "Fleet Management" overviews

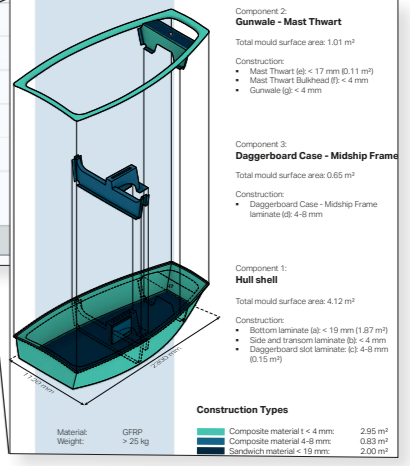
Comment:
When hovering over any button, it changes colour to signal its functionality.

Comment:
Data export for further analysis or as a memory.

Comment:
Total usage and life expectancy

Comment:
Table created after first "Report EoL Fate" report upload.

Component	Date	Condition	Material	Weight	Embodied Carbon	Certificate Nr.
Hull	2028-07-14	new	Basalt Fibre, Elium, rPET	22,00 kg	137,34 kg CO ₂ e	506245
Daggerboard	2028-07-14	new	Basalt Fibre, Elium	3,00 kg	18,73 kg CO ₂ e	873685
Rudder with head/tiller	2028-07-14	new	Basalt Fibre, Elium, Aluminium	2,50 kg	19,18 kg CO ₂ e	364309
Spar (Mast+Boom+Sprit)	2028-07-14	new	Aluminium (70 % recycled content)	5,50 kg	62,43 kg CO ₂ e	850029
Sail	2028-07-14	new	Polyester (Dacron) 3,3 m ²	1,05 kg	12,91 kg CO ₂ e	939146
blueNode	2028-07-14	new	PCB, Li-Ion Battery, Solar Cell	0,06 kg	5,78 kg CO ₂ e	946543



Report Title *

Type *

- Event participation
- Change of ownership
- Damage report
- Repair intervention
- Other

Description

Upload file

Your Name *

Email Address

Submit Report

Comment:
Submitting the report sends the input data to the database, the DPP page automatically reloads and fetches all data of the specific DPP page and visualises it, including the latest report.

Note: Make sure to only discard an item once it is beyond repair. Try reselling it first, so it can be reused!

Component *

- Hull
- Daggerboard
- Rudder with head/tiller
- Spar (Mast+Boom+Sprit)
- Sail
- blueNode
- Other

Treatment *

- Recycled
- Incinerated
- Landfilled
- Other

Net Benefit: Positive
Component Embodied Carbon: 137.34 kg CO₂e Treatment Emissions: 0.47 kg CO₂e Conserves Resources Low Pollution High Circularity

Describe the condition and why the part is obsolete:

Upload file

Your Name *

Email Address

Submit Report

Comment:
The EoL report form gives dynamic feedback based on the emissions data of the selected component and the selected waste treatment method (both colour and emission data).

Fig. 46 The DPP view and its functionalities

6.3 blueNode: A LoRa GPS Tracker

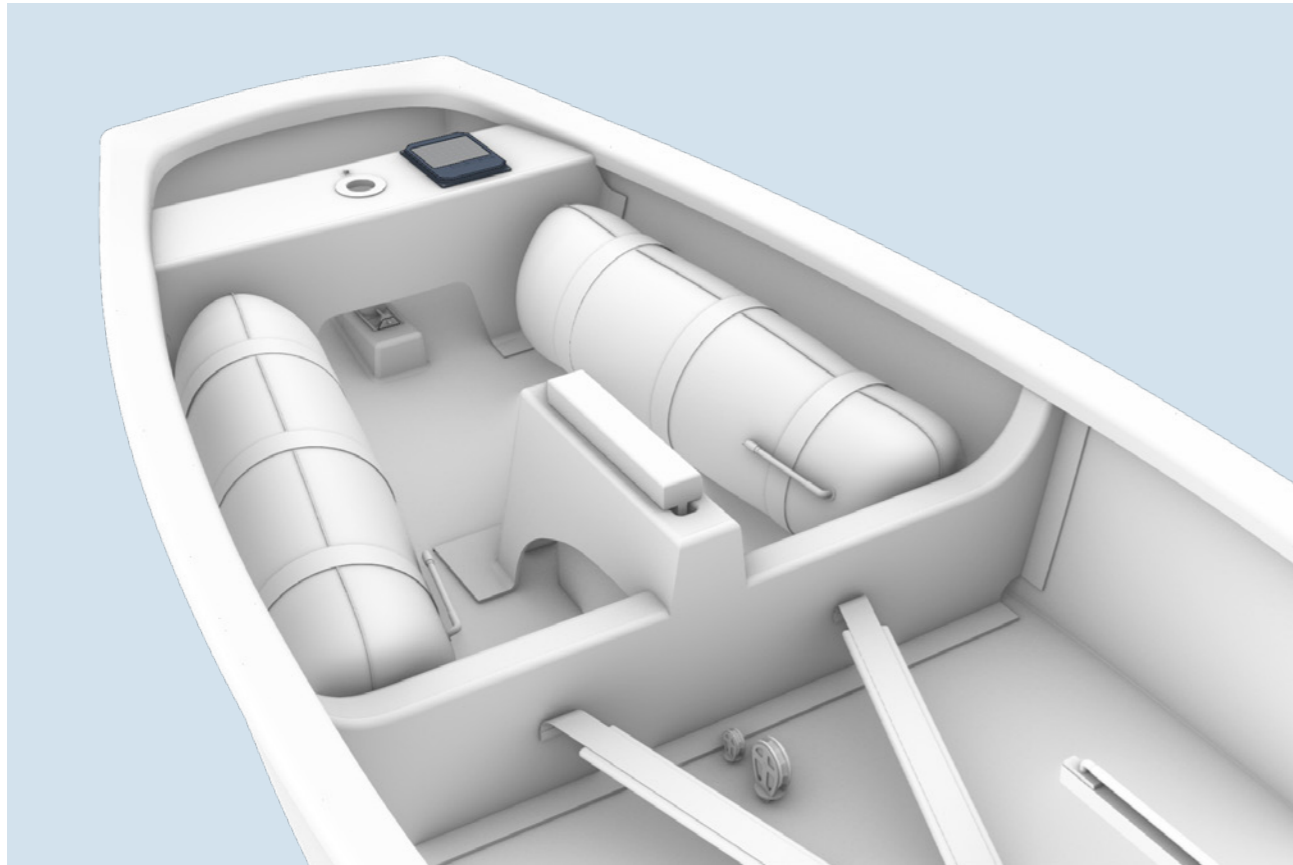


Fig. 47 Illustration of blueNode tracker installed on Optimist

The blueNode is currently based on the "SenseCAP Card Tracker T1000-E for LoRaWAN" tracker (see figure 56). It has a GPS antenna, an accelerometer, temperature- and light sensor, a ESP32 processing unit and, most importantly, a LoRaWan antenna.

The device runs on open source code, editable for instance with Arduino IDE. What it is missing for the purpose of usage data tracking on dinghies is a small solar cell and a charge controller to prevent battery discharge and overcharge. Data collection within this project has been done only with modified code but without an integrated solar cell to power it. Regardless, the tracker has successfully been connected to DPP.BOATS, transmitting live data, as is evident in figure 48.

So far, the device has not been installed on a boat to track its usage. Vital parts of code are missing to post process the collected data, create sailing sessions and calculate usage hours. This is further described on the following spread.

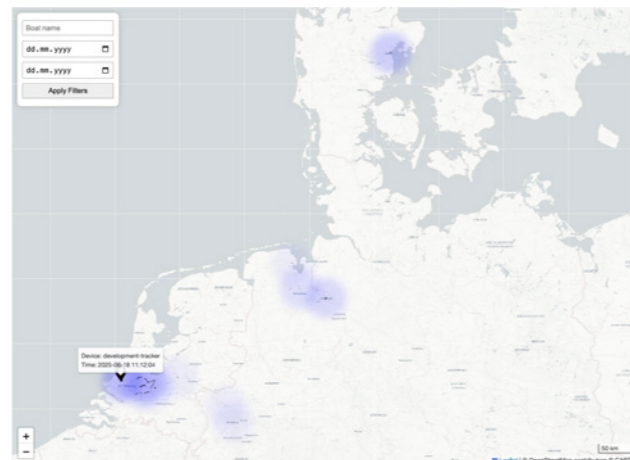
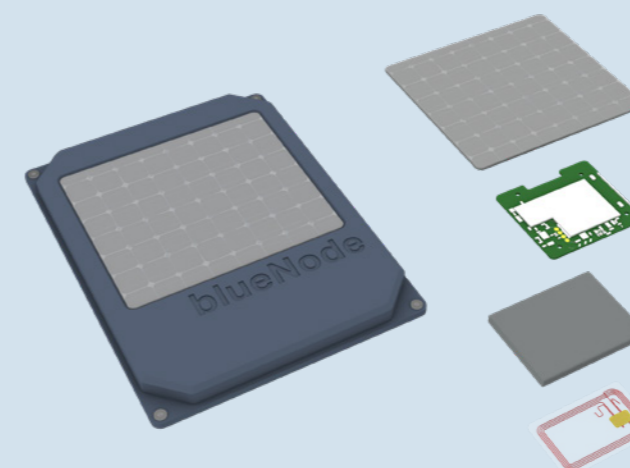


Fig. 48 Data collected by the tracker integrated into dpp.boat/blueNode-live-dashbaord/

Adding a new component to the Optimist with the goal of reducing its environmental footprint isn't very intuitive at first glance. The environmental footprint (Global Warming Potential (GWP)) of the blueNode device is only 4% of the hull environmental footprint, taking the recyclable construction as a baseline (lowest GWP). This means, the lifespan of the Optimist would need to be extended by 1-1.5 years (see calculation below) to compensate the additional emissions, other benefits for R&D and usage pattern detection not considered.

The increased awareness for maintenance, careful usage and more informed EoL practices the DPP is expected to evoke, this seems to be an acceptable tradeoff. This is especially true when taking the other components of the Optimist and their respective GWP into account as well. The same applies when installing the blueNode on other dinghy classes, all of which are larger and have a higher environmental footprint.

Some technical considerations regarding the battery and solar cell size can be found in appendix A4.



Dimensions: **160x120x12 mm**
Weight: **150 g**

Solar Cell

1.2 W
GWP: 2.87 kg CO₂e

Printed Wiring Board

LoRa module, ESP32, Charge controller
GWP: 2.17 kg CO₂e

Lithium Battery

1000 mAh
GWP: 0.60 kg CO₂e

NFC Chip

Storing link to DPP
GWP: 0.02 kg CO₂e

Housing

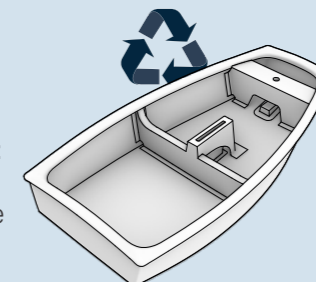
Injection moulded polypropylene
GWP: 0.12 kg CO₂e

Total GWP:
5.78 kg CO₂e

The GWP data referenced here, is based on Ecoinvent and unfortunately cannot be shared.

Optimist constructed with Elium-resin and basalt-fibre composite for GWP reference:

Total GWP of hull: 143 kg CO₂e



What the blueNode needs to achieve to compensate for its emissions:

6/143 = 4 % Life time extension of hull
+ 1 to 1.5 years of use

Fig. 49 Components and GWP of blueNode tracker

6.3.1 Range and Coverage

Open areas with minimal obstructions allow for the greatest range of LoRa devices, reliably transmitting data over up to 50 km in line-of-sight conditions (Gauld *et al.*, 2023). This supports the use of LoRa devices to track usage data of dinghies on lakes and waterfronts. In general field use, devices typically support ranges of around 2 km (Sujatha, 2025). In a coverage test (cycling) in the Dutch countryside (see Figure 44, top), the SenseCap T1000 tracker successfully transmitted 152 signals, out of a total of 186 theoretically scheduled messages (every two minutes), representing a signal loss of 18%. In 84% of the transmitted messages, no GPS signal was collected, in areas where a phone or a smartwatch easily collects location data. This likely indicates poor quality of the antennas of the device, rather than being conclusive evidence for bad coverage in the area. Furthermore, the device sent no data in public transport (trains) or when indoors (see Figure 48). No further range and coverage tests were conducted with the trackers.

To further analyse the coverage of LoRa, The Things Network provides a map showing the availability of gateways and the coverage. Figure 50 shows two screenshots from The Things Network (TTN Mapper, n.d.). The image on the left shows that there are two global hotspots, one in Europe and one in North America.

LoRa uses different frequencies in different regions, depending on the availability of unlicensed radio frequencies:

Europe:	863–870 MHz	China:	470–510 MHz
US:	902–928 MHz	Korea:	920–923 MHz
Australia:	915–928 MHz	India:	865–867 MHz
Asia:	923–925 MHz	Russia:	864–870 MHz

Some LoRa devices automatically detect the local frequency and support, for instance, European, US, and Indian frequencies. Given the different frequencies, the antenna needs to be optimised; therefore, a device that supports all frequencies would be quite inefficient, negatively affecting the device's range. Most of these regions have a duty cycle restriction to avoid one device jamming up the network. For this reason, a LoRa tracker is only allowed to send a signal every 15 minutes in public networks, even though much higher signal frequencies are possible (depending on data size, devices can submit no more than 1% of the time). For the initial focus on the Eco_Optimist, these different global networks represent no constraint. However, considering a class-wide implementation would add additional complexity, as the blueNode device, as it is currently conceptualised, would not provide global coverage. The same is true for all other networking standards as well. For a fleet-wide implementation within Germany or the Netherlands, at least, LoRa looks promising.

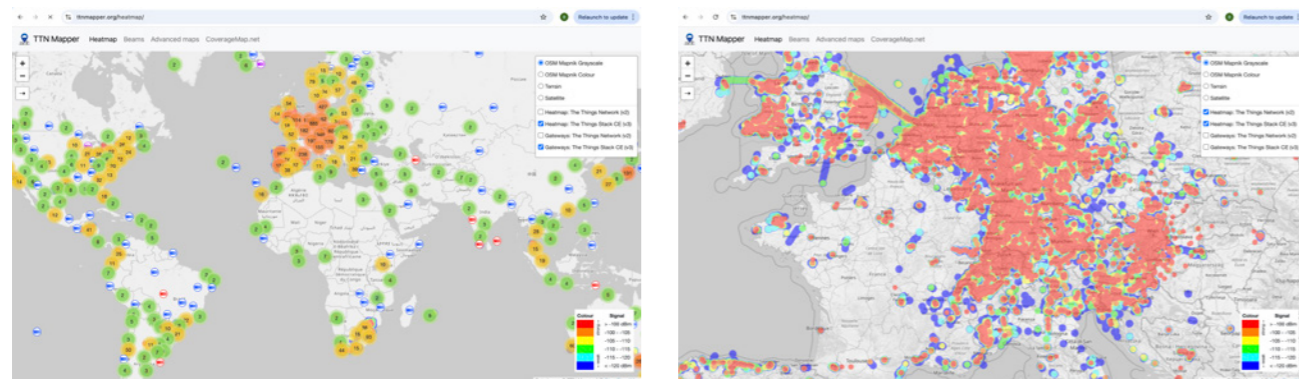


Fig. 50 Screenshots from TTN Mapper (TTN Mapper, n.d.). Left: Nr. of public gateways worldwide. Right: signal strength heatmap.

6.3.2 Digital Footprint & Data Handling

The blueNode collects minimal data due to the LoRa network constraints and to minimise its power consumption. With each signal generating approximately 120 bytes, the data table would grow to a total of around 2.4 MB over the entire use phase of an Optimist (1300 sailing sessions total). For the full calculation please refer to appendix A4. This is a very manageable file size and represents a low digital footprint, although computational challenges arise when filtering and displaying the GPS data, as one Optimist's data table would grow to 230,000 rows over its entire use phase. Figure 51 illustrates the a data collection for three sailing sessions.

Tracking damages or repairs with photos would increase the data footprint, the overall data size is still negligible though, compared to other data stored in cloud storage nowadays.

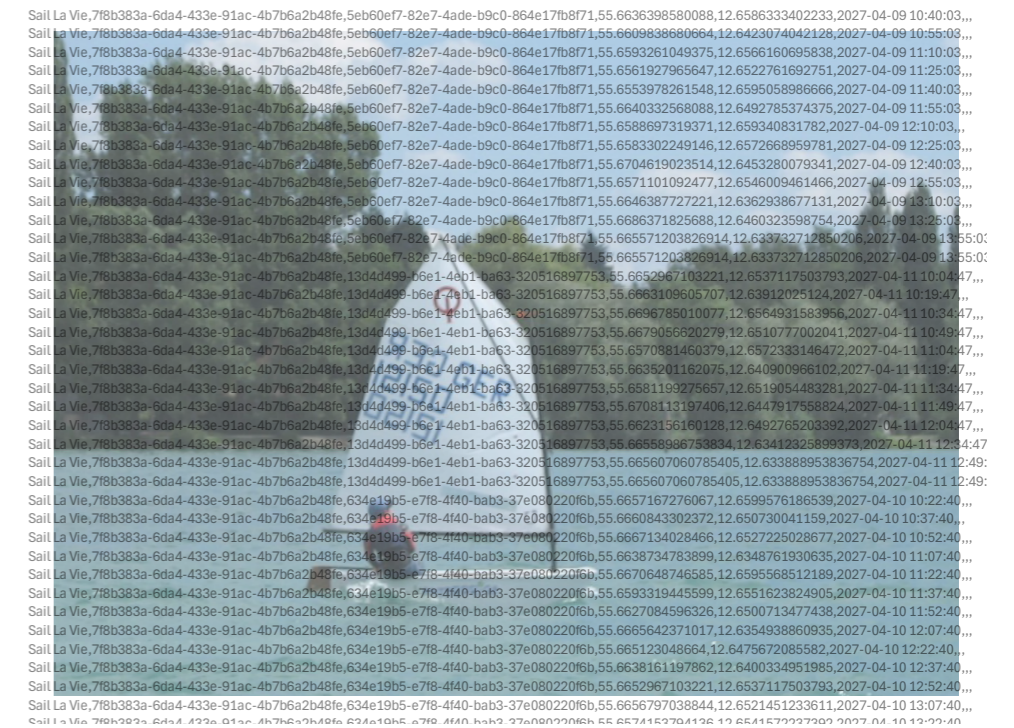


Fig. 51 Image of Optimist sailing at Lake Constance, overlaid with data representing three exemplary sailing sessions (boat name, boat ID, latitude, longitude, timestamp)

6.4 Tracking a Sailing Session

This chapter briefly outlines what one sailing session looks like with respect to the usage data tracking system. The blueNode has not been used to track a real sailing session yet, the following chapter therefore describes how it would work.

Start:

Once the Optimist is taken from the rack it is stored in, and flipped over to be set up for the sailing session, the blueNode receives energy through the solar cell. While the sail and everything else is being set up, the device wakes up from sleep mode and sends the first GPS signal.

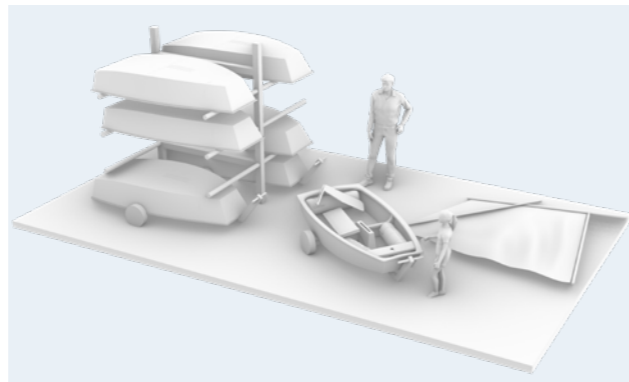


Fig. 52 Optimist being set up before sailing session

Sailing Session:

Once the dinghy starts moving, marking the start of the sailing session, the GPS points are counted towards this session.

While in use, the blueNode sends a data point every 15 minutes. This does not allow for many assumptions on the route, speed etc., but is enough to give an estimation for the total duration of the sailing session (in 15 minute increments).



Fig. 53 Optimist in use

End:

Once back to the harbour and taken out of the water, the blueNode is still sending data, as the battery of the device had some time to charge. Now the data needs to be filtered, so that the points within a radius of 50m are culled out of the dataset and not calculated as part of the sailing session. From here on after, the device goes back into sleep mode to conserve energy, only sending its GPS location once a day, if at all.

In case a part has gone missing or a damage occurred during the session, this is the time the user can connect to the boat's DPP and log a report.

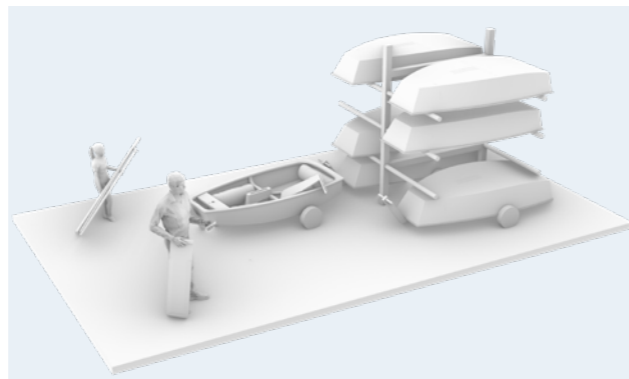


Fig. 54 Optimist back at harbour, person adding maintenance log to DPP

6.4.1 Stage of Development

To understand the blueNode's current stage of development, it is important to understand the network structure, illustrated in Figure 55. The blueNode tracker collects sensor data, GPS, accelerometer, battery level, and whatever else is of interest. The device runs code to read out the sensor data, compress it into binary code, and packages it into a "payload", the data that is being transmitted. This can be up to 51-222 bytes in size, depending on the "spreading-factor" (time duration of signal transmission). The code on the device also manages sleep mode; this would still need revisiting. The data is then transmitted via LoRaWAN to a nearby gateway, which forwards it to a network server (already via regular internet connectivity), in this case, The Things Stack, where the device is registered to an account (not public). Here, the data is decoded and converted back into longitude and latitude data and so on. This data is then forwarded to another web application to store, process, and visualise the

data via a web-hook integration. In this case, the data is sent to a Hetzner database and then retrieved via the webpage DPP.BOATS, where the data is publicly accessible. At this level, the post-processing of signals needs to occur, to assign the data to sailing sessions, delete GPS signals outside of sailing sessions, and calculate the session duration. Other web-accessible data, such as wind or temperature, could be matched with the usage data for a more holistic representation of wear and tear on the equipment. Both of these post-processing steps are not yet integrated, but both are feasible. This thesis focuses on evaluating the system's benefits over delivering a fully functioning tracker. The development of the DPP website and the artificial dataset of 100 boats was given priority. A more comprehensive overview of the data handling and database connectivity on the side of DPP.BOATS, also with respect to handling intervention reports, can be found in appendix A5.

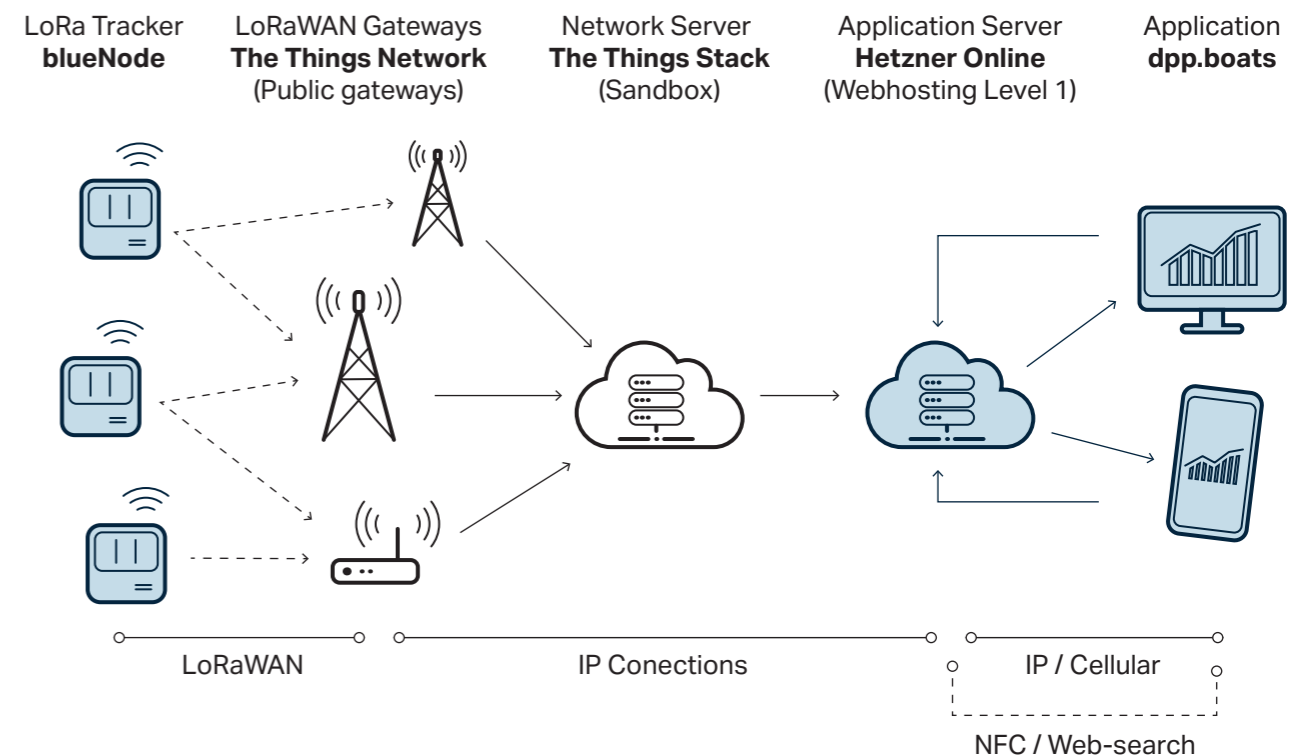


Fig. 55 Network architecture overview of blueNode and its integration with DPP.BOATS (both in blue)

6.5 Cost Calculation

6.5.1 Upfront Costs (blueNode)

The cost calculation for the blueNode is based on a very simple assumption. The SenseCap T1000E tracker, depicted in figure 56, retails for a price of 51€, including taxes (Seeed Studio (1), n.d.). This price includes development costs and profit margin on the side of Seeed Studio. The housing would need to be more robust, and a solar cell (2€) would need to be added. Another development kit (Wio-WM1110 LoRa & GPS Dev Kit with Semtech LR1110 and Nordic nRF52840), depicted in figure 57, which includes a solar cell, power management system, and much better GPS and LoRa antennas, retails for 42€, including taxes (Seeed Studio (2), n.d.). In this case, only the housing is missing. There is an abundance of other trackers available too; overall, the costs for all parts stay in a range of 30-40€ for off-the-shelf components. With this in mind, the assumption is that the device could be sold for three times this value, potentially cheaper for larger quantities. This would make a one-time cost of approximately 70€ per device (see figure 58).

For a calculation of the running costs, please refer to the next section.



Fig. 56 SenseCap T1000E LoraWan tracker (Seeed Studio (1), n.d.)



Fig. 57 Wio-WM1110 LoRa & GPS Development Kit (Seeed Studio (2), n.d.)

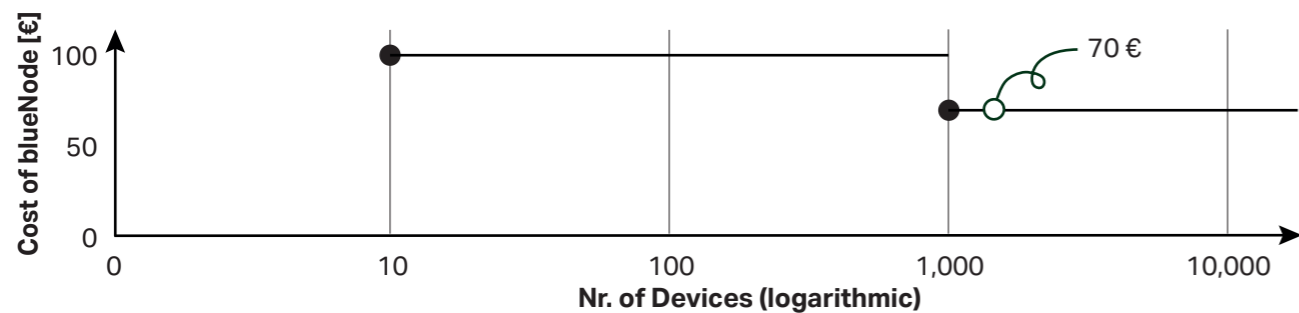


Fig. 58 Costs of blueNode tracker per device

6.5.2 Running Costs

The cost structure of DPP.BOATS needs to be analysed for both the website part and the blueNode part for this DPP.

As shown in figure 59, the service bill of the website domain and web-hosting is relatively inexpensive (30€/year). With a growing number of devices registered, the web-hosting service would need to be changed to increase storage capacity, increasing the bill to around 70€/year, but other than that, the current plan offers everything that is needed. This unfortunately looks a bit different for the running costs of the blueNode. Even though LoRa devices are relatively inexpensive and the networking technology is open source, it comes with considerable service costs. For up to ten devices, the service (The Things Stack) is free, for more devices however, the service charge jumps to 190€ per month (The Things Industries, n.d.). This makes further development of automated usage data collection for smaller quantities of sailing boats rather unattractive. Since LoRaWAN (networking layer of LoRa) is an open-source networking system, self-hosting would theoretically be an option too, not

for a highly distributed fleet though, as all the public gateways are locked to The Things Network/The Things Stack. The option of leaving their stack would necessitate the installation of private gateways at virtually every sailing harbour, rendering this option unviable. By registering every device to its own account in The Things Stack, the service charge could be avoided (up to ten devices are free), this approach however would make reacting to potential changes in LoRa networking standards quite difficult and might not fare well with the service providers. Once the number of devices reaches a thousand or higher, using The Things Stack becomes affordable again, getting there would be difficult though, at least as a small business. This would require a far larger implementation.

What isn't included in this calculation are the expenses of managing the website, implementing new features, or maintaining the database. Another important part of the service would be an advisory roll for all future data integration. This would add salary expenses of a developer to the list of expenses.

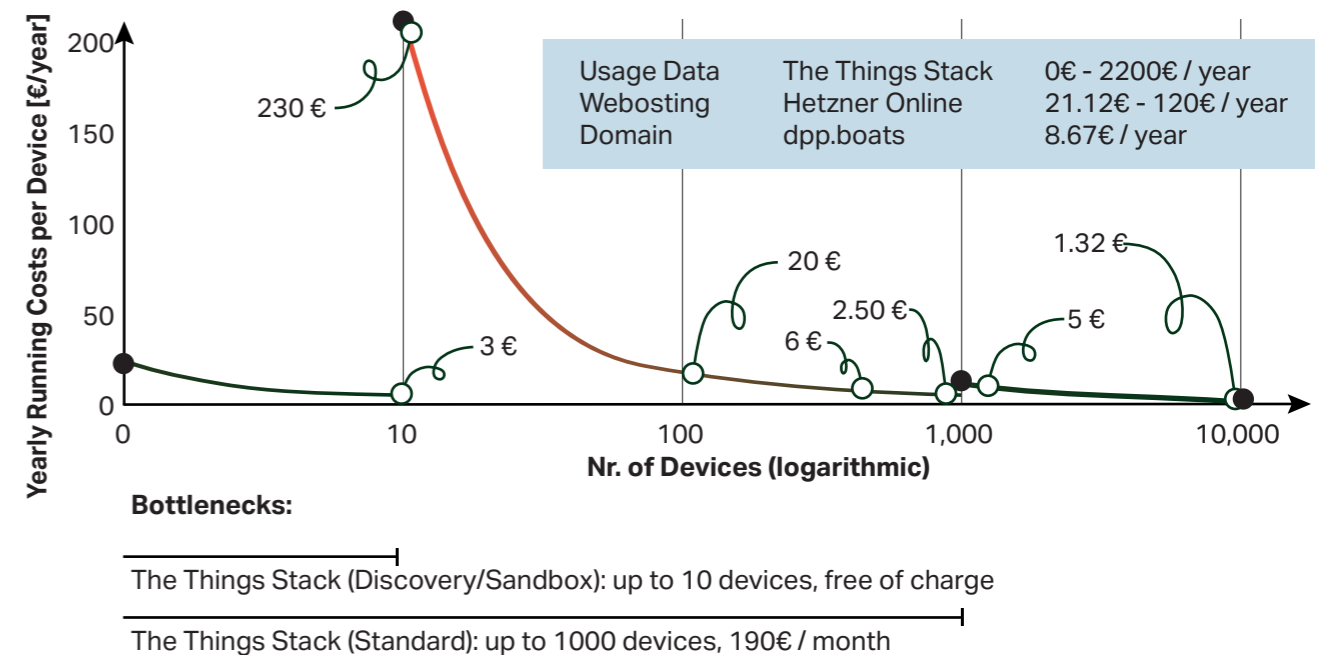


Fig. 59 Running costs, cost of scaling

6.6 Business Concept Considerations

So far, this project has mainly been viewed through a technological and environmental lens, however, it also needs to be viable to be successful. DPP.BOATS is a platform hosting DPPs of boats and offering a service to assist asset/fleet management. It creates transparency and provides insights over a boat's usage. Keeping up this service clearly requires financial resources, as the running costs need to be covered. How these costs can be covered is discussed in this chapter.

While the boat's value is gradually declining the closer to EoL it gets, the DPP's value arguably increases with every repair intervention that is added to it. If owners were required to pay for this service, their willingness to do so, would likely decrease - problematic, considering that the data still needs to be available once the product has reached obsolescence. This is why typically companies/manufacturers/brands pay for DPPs, but they also want to reduce reoccurring costs (for products sold long ago), again undermining long-term circular economy goals. This issue is addressed by EU law, regulating that certain core product data (product composition, repair instructions, environmental information, regulatory compliance data) must be available to the customer free of charge, also when the manufacturer stops paying for more premium functionalities of the DPP (European Parliament & Council, 2024). This assures that owners, repairers, or recyclers can access this data. This regulation of course only applies to those products that are required to have a DPP, which currently isn't true for boats or dinghies. The argument, however, remains just as strong. The owner should not be charged to access core product information, particularly not towards EoL.

This tension, between low willingness to pay for DPP services and its potential for circularity and asset utilisation, may explain why, at the present time, only high-margin products have been offered with a DPP (see chapter 6.2). DPP.BOATS, with its open access approach, is tailored towards sustainable and durable equipment, small scale companies, sailing schools, raising the question of how it can be financed without creating dependencies and keeping its low threshold charm.

Avoiding subscriptions and relying on upfront set-up fees for DPP creation only, would be a way of financing it with a clear cost visibility, particularly for

products with a long life duration, such as boats. This would keep the tools low threshold characteristic, the cost however would be hard to calculate. Long-term revenue streams would be crucial to maintain the platform's functionality and keep everything running smoothly.

A payment at ownership transfer, might work well for the first few years, as is the case with such information carriers of cars (for instance in the Netherlands or US). Towards EoL, payment at ownership transfer likely wouldn't be very attractive though.

In a "freemium model" approach, meaning offering a free tier and a paid tier service, the free tier service is usually stripped of all interactive functionalities, taking away from the DPP's capabilities to extend a product's life duration. In case of DPP.BOATS repair histories and Interactive features to continue tracking damage or repairs should also be available throughout the entire lifecycle. Other revenue streams could be advertisements, an API integration, or a fee for validating a passport. Second hand market platforms perhaps offer the most comparable service: they allow data uploads by users with an account for free and offer premium services for verified sellers and commercial customers.

A collaboration with class associations, who already maintain class registers, would be promising, at the same time allowing for larger scale implementation and offering them a platform to streamline and improve their class registers. For now, the class registers are mostly disconnected from all sustainability endeavours within the boat classes. Aligning the goals between these technical and sustainability driven initiatives could free up money, which could be used to finance a tool like DPP.BOATS, while benefiting both.

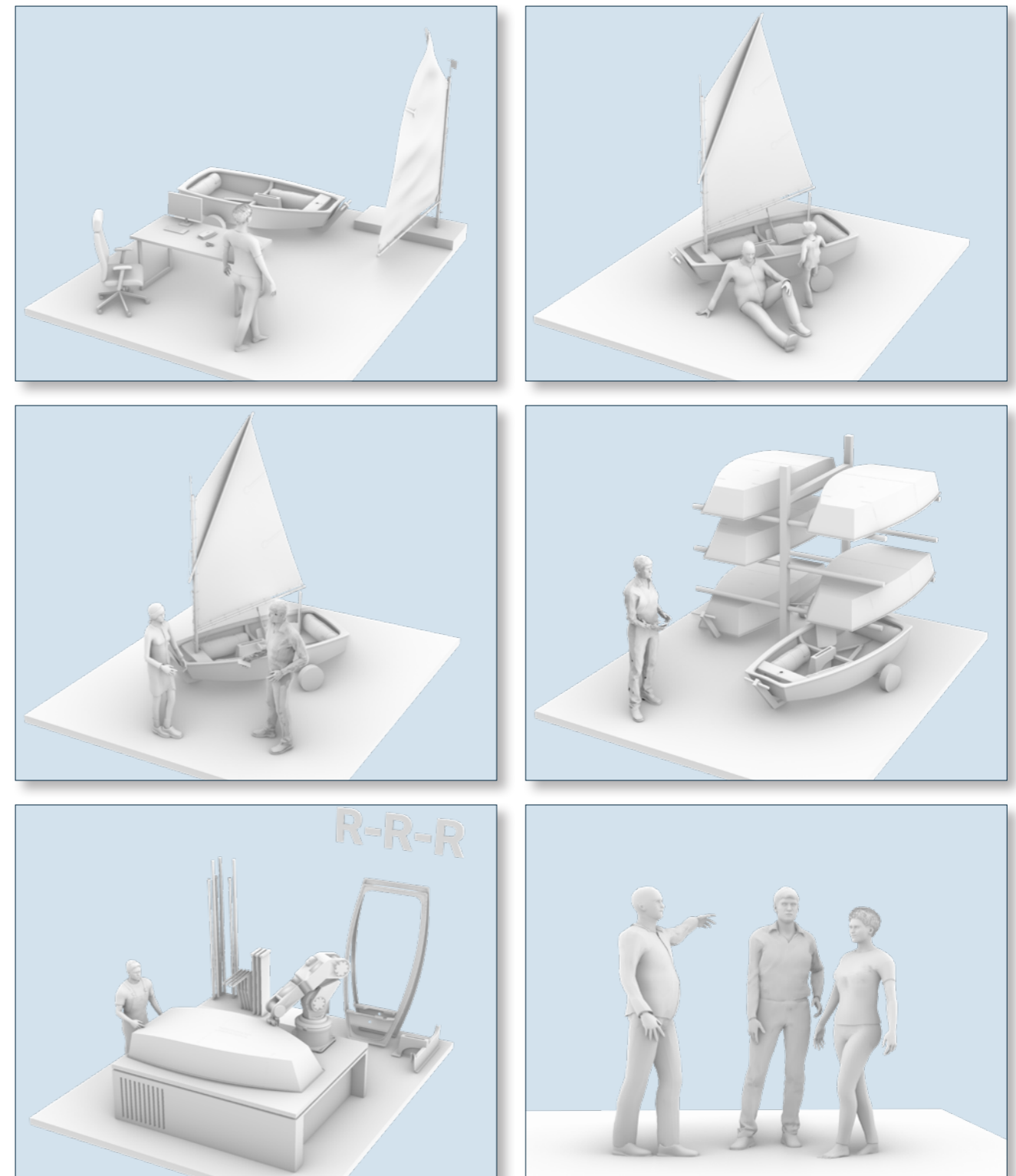


Fig. 60 Illustration of different processes throughout the lifecycle of an Optimist sailing dinghy. Top: manufacturing, sailing. Middle: resale, fleet management (sailing school). Bottom: remanufacturing/EoL, fleet management (class association).

6.7 Optimistic Futures

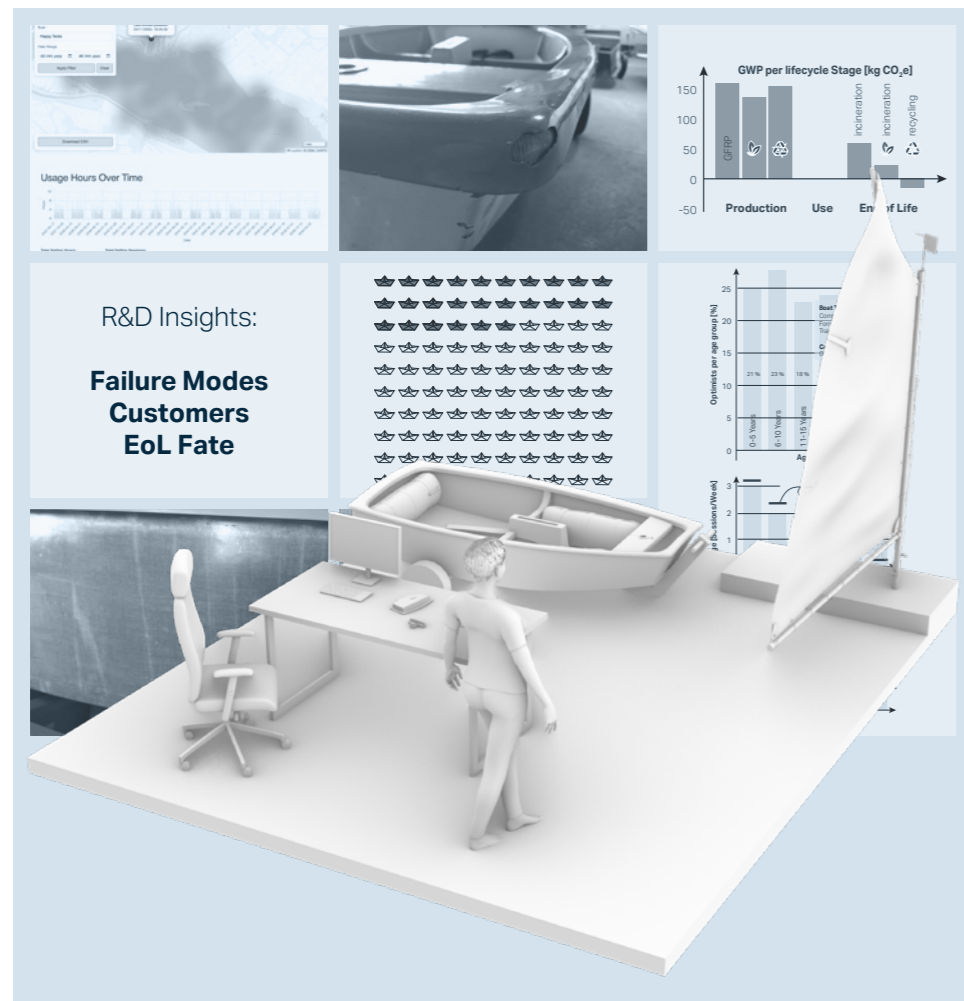


Fig. 61 Optimistic Futures: Benefits of DPP.BOATS for manufacturing

Manufacturer

With growing adoption of the DPP and blueNode (usage tracking), knowledge about the life expectancy of boats is gathered, also in comparison with other construction types and material choices. With that, best practices for durable, long lasting design, would slowly crystallise.

Distinct use environments (region of world, sun exposure, water salinity etc.) would likely show different life expectancies, again leading to more usage specific design requirements and environment specific design choices. Such data-driven decision making for future design interventions and their proven/disproven success, would then be transparent to the customers too.

From manufacturing of truly durable boats, to offering repair kits, manufacturers could then be held accountable for their claims, motivating them to build high quality, long lasting products, which would both be advantageous from a customer's and environmental point of view.



Fig. 62 Optimistic Futures: Benefits of DPP.BOATS for fleet managers

Association/ Fleet Management

For a class association, the DPP offers a previously unavailable overview over usage patterns within the classes fleet, helping them to support training centres where and when needed. On top of that, the system could help streamline their class registers with technical documentation efforts and make signing up to events easier, as high level technical data could easily be linked with the DPP.



Fig. 63 Optimistic Futures: Benefits of DPP.BOATS for the sailor/owner

Sailor/Owner

The upfront and EoL emissions of a product need to be considered with regard to a boat's lifespan. If the lifespan can be increased, which in turn results in lower demand and thus fewer products, the overall emissions can be reduced. The key word here is asset management, here in terms of life expectancy and thus sustainability. Knowledge about a boat's failure modes, usage conditions and so on would lead to more accurate recommendations for boat handling, storage, care and maintenance. Furthermore, the usage tracking and uploaded reports, for instance of regatta participation, provides the sailor with a sailing diary.

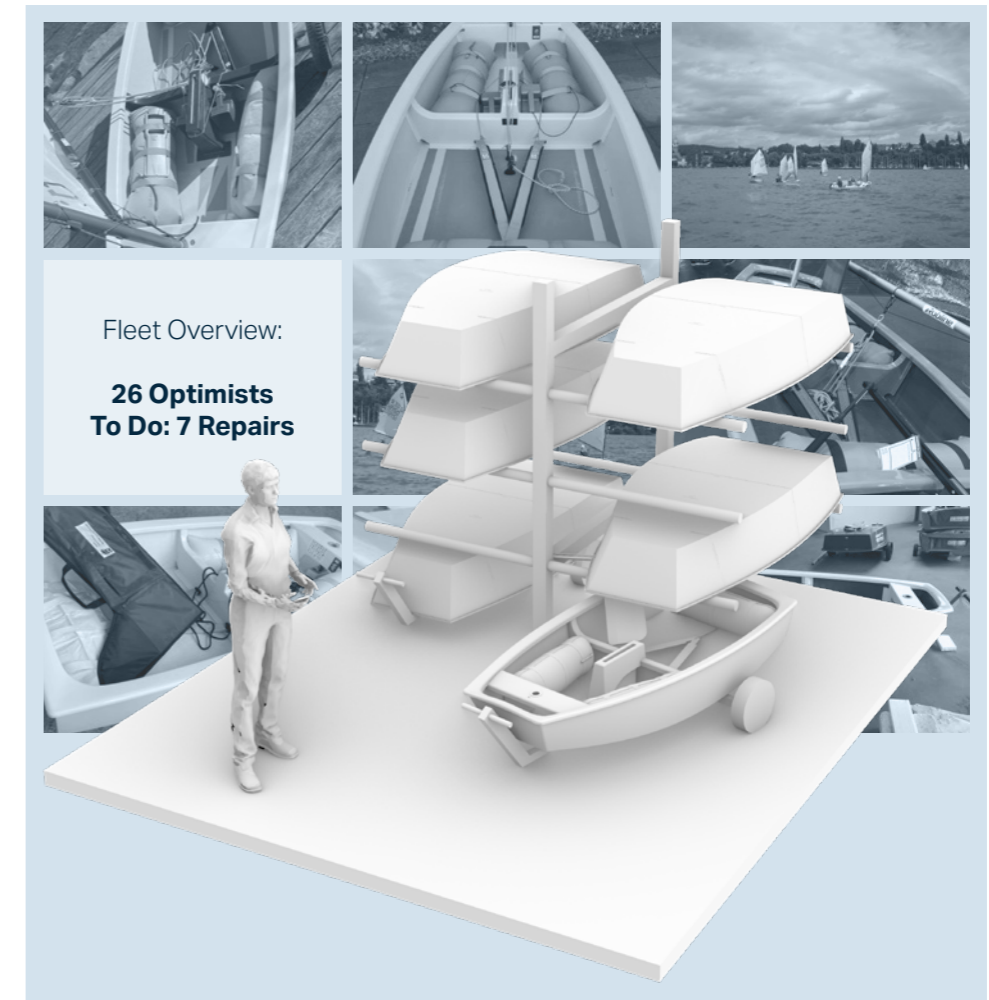


Fig. 64 Optimistic Futures: Benefits of DPP.BOATS for sailing schools

Sailing Schools

Sailing schools (or fleet managers, if you will) already act with an intrinsic motivation for longest possible boat utilisation. T. Schadewaldt (2025), owner of a shipyard, argues that early damage identification and treatment could often extend a boat's lifespan by years. For instance, early detecting of a composite damage before it gets wet and it freezes in winter, would prevent far greater damage. A tool that helps sailing schools to have a comprehensive overview of what replacement parts are needed and all repairs that are due, would make their life easier in achieving said lifecycle extension. This is what the DPP, in particular with the open access approach, would contribute to. It would also help them convey the importance of careful boat handling to counteract the at times reckless usage behaviour of children by conveying a sense of duty for careful treatment through the existence of a maintenance plan.



Fig. 65 Optimistic Futures: Benefits of DPP.BOATS at change of ownership

Resale

The limited usage period one child sails on the Optimist (youth sailing) compared to the product's overall lifespan, corresponds with many ownership transfers in private ownership (or alternatively bad asset utilisation, when not handed to a new user). The transparency in the second hand market, created by a dynamic DPP over the condition and remaining life expectancy would build trust in a second hand purchase and help reduce the environmental impact of boats by potentially extending their lifetime.



Fig. 66 Optimistic Futures: Benefits of DPP.BOATS for remanufacturing

Remanufacturer/ EoL treatment

The dynamic data gathered over the life cycle of the boat would provide insights into the material degradation, crucial for evaluating a materials fitness for remanufacturing or recycling. For large parts, such as a boat's hull (25kg for the Optimist, up to multiple tons for larger recreational vessels), this would be relevant. Once a boat becomes obsolete, the DPP would ensure information, such as material composition, quantities, dismantling guides etc., is still easily accessible to the final owner or a recycling company. This could be the missing piece to solve the currently existing information loss upon ownership transfer. A DPP can assure, that a boat with innovative material composition, can be identified as such and closing the loop becomes possible.

Allowing the user to log a product's EoL fate, supported by dynamic feedback, conveys a sense of significance to the owner's actions in trying to send the obsolete boat (or components of it) towards the least harming EoL route. This would hopefully contribute to a shift in behaviour to more considerate consumption patterns.

7. DISCUSSION & CONCLUSION

7.1 Concept Validation	104
7.2 Discussion	106
7.3 Conclusions	107
7.4 Limitations & Recommendations	108
7.5 Reflection	109

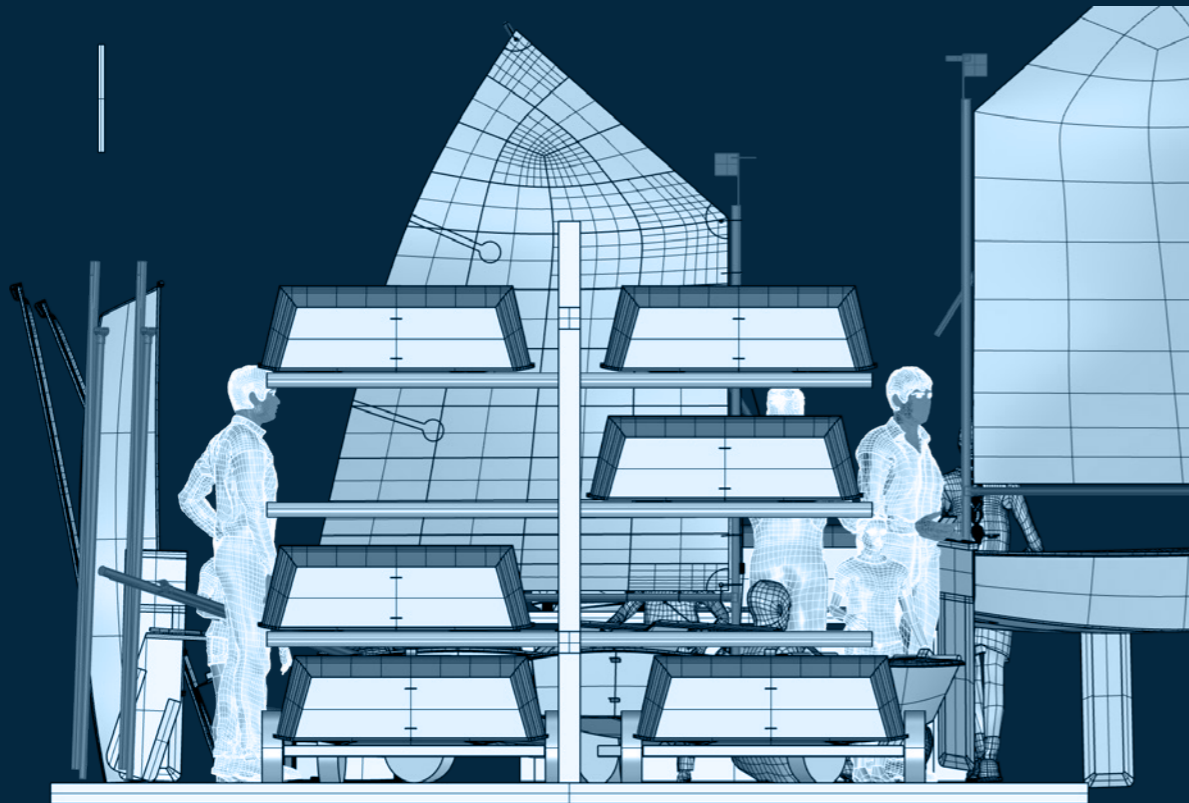


Fig. 67 3D Model of Optimists, depicting different scenarios throughout an Optimist's lifecycle

7.1 Concept Validation

Concept validation for this project is done through expert- and stakeholder interviews, focusing on need/desirability validation and the systems adoption potential. The insights presented here are based on comments made by the following interviewees:

Ir. J.H. Welink	Waste treatment & circularity expert and lecturer, TU Delft
Dr. Ir. J. Coenen	Maritime engineer, smart sustainable manufacturing, The Hague University
M. Agerbæk	Representative of youth committee at Egaa Sejlklub
P. Kraus	Sailing instructor and former harbour-master at BYCÜ
T. Schadewaldt	Managing Director at Jade Yachting Shipyard, former professional sailor
A. Rickham	Director of Sustainability at World Sailing
R. Videlo	Sustainability Executive at World Sailing

Benefits:

Overall there seems to be a clear desirability for a system such as DPP.BOATS. The interviews suggest that everyone involved and affected by it, would benefit, showcasing its true potential, in particular with the dynamic and open access approach pursued here. This adds to the notion of this concept being a true systems solution.

The open access approach, with its easily accessible interface can clearly be regarded as a good choice for the Optimist, with some concerns mentioned too (see section on burdens). The simplicity and ease of access to the DPP environment should work well if the stakes are low in terms of product cost and potential harm to the owner/user. Occasional cleaning of the database might be easier than maintaining a complicated access control and authorisation system.

At sailing school level it again becomes clear that from a technical perspective boats could be used for longer and that current ways of tracking their conditions is relatively primitive (excel tables or memory). DPP.BOATS is perceived as a great way to bring environmental consciousness into sailing training to foster higher levels of care by demonstrating the existence of a care and maintenance plan for the boats. Speaking as sailors themselves, the transparency of the usage data is seen as positive, while doubting it would increase resale prices on the second hand market or reduce spendings on new equipment on club level (Agerbæk, 2025).

From a shipyards perspective, a DPP would be “very useful” to their customers as well, mostly in terms

of transparency at resale or when inquiring about services at another shipyard (Schadewaldt, 2025). Everyone agrees though that such a system would benefit sailing associations and larger fleet managers most.

Such as that, World Sailing, the world governing body of the sailing sport, overseeing 32 dinghy classes among other larger boats and surfing related sports. Naturally their perspective takes on a higher level of abstraction and scale: With the organisations focus on competitive sailing, they see a big potential in managing equipment quality and measurement certificates with the DPP. On top of that it could streamline event entry and vital insight in the boats after life. They see manufacturers and class associations among the biggest beneficiaries, with manufacturers gaining insight on real life use conditions, feeding into the development of new products and class associations gaining an overview of where they have active members, how they could grow and which local training centres need support. In academic circles the DPP is appraised for its potential to drive and facilitate circularity, however many questions are yet to be answered: What information needs to be stored? Who should have access? How do people interact with it? The implementation of DPP.BOATS would therefore be a “very well chosen topic for a longitudinal study” (Coenen, 2025). The cause of youth sailing combined with environmental education, the publicity for involved schools, research institutes and alike provides fruitful conditions to seek sponsorship for a first test run.

Feature requests:

While being appreciative of the (seemingly) low-tech approach in data collection, a life-mode with higher data rates to use as a training tool, was requested by most interviewees with the hope that it could drive adoption rates. While clearly being very desirable, this would not be feasible with the blueNode, given the constraints by the networking standard LoRa. Concept 1 (see previous chapter) was more lenient in this direction, it would be less reliable in achieving representative usage data tracking though, as it relies on the user to track each session. Alternatively contract based mobile networking would be required. Another very interesting remark by B. Videlo was that retrofitting older boats the blueNode system would make it faster to have a holistic overview of the entire lifecycle of boats to see what would need to be addressed most urgently, to make things more circular (Videlo, 2025). Similarly, from the perspective of a sailing school, the maintenance aspect of the DPP (fleetmanagement) would only be beneficial to

Burdens:

Some aspect of DPP.BOATS where also met with some scepticism. Expectedly, concerns about data security and validity of data in an open access approach was the major concern. For boats where the user and owner is the same person, the tracking was a no-go, at least as the location history is openly accessible (Schadewaldt, 2025). Also interventions for product and boats with a higher price-tag than the Optimist and in situations with higher stakes, such as Olympic sailing, there would likely be a need to be some form of authorised access. (Schadewaldt, 2025; Rickham, 2025). This could be solved with a opt-out method or an automatic switch to open access after a duration of say ten years of usage. Another thing a DPP cannot solve is the availability of recycling infrastructure. Particularly, when older boats are sold and end up in developing countries, LoRa wouldn't necessarily work anymore. This would be a big burden for World Sailing as the boats would again drop off the map and this would be the regions where sending a container for collection of EoL boats would be justified and this would again be something where developed countries would be storming away while less developed regions slack behind (Rickham, 2025).

them, if all other boats could be fitted with at least the NFC-tag as well, in order to be able to actually use it as an overview, not only for new boats, but the entire fleet (Agerbæk, 2025).

From the perspective of a shipyard, the possibility for official registration, was also requested (for instance by means of a tax number) to prevent other people from falsely registering interventions in their name (Schadewaldt, 2025).

Further integration of things like weather data for a more realistic/holistic stress and wear simulation was also suggested, as this would reduce time later on, when evaluating the data (Coenen, 2025). Furthermore, additional logging of maintenance intervals for critical components, could also be beneficial to ensure safety on boats (Welink, 2025). Lastly information regarding waste treatment and links to recycling companies were requested (Schadewaldt, 2025).

The accuracy of lifetime prediction is also met with some scepticism, as according to M. Agerbæk the wear of a boat does not necessarily correlate with its age or its usage, as the condition is largely affected by the maintenance. In an environment, where repair largely lies in the hands of motivated parents, boats might be very well maintained one year, and get much more damage in another year. On top of that, simply buying a used boat is often cheaper, than paying for a professional repair (Agerbæk, 2025).

The lack of money in sailing schools also stresses the importance for DPP.BOATS and the blueNode not being sold as a subscription service. Even if the cost of installing it during manufacturing would be handed down to the consumer either way, an upfront cost of 70-100€ is deemed acceptable (Agerbæk; Rickham, 2025). Some scepticism with respect to finding the time to upload a report, for instance of a missing piece or damage after a regatta event, is mentioned too (Kraus, 2025). The simplicity of the open access approach addresses such concerns perfectly: it is created as a web tool that reduces authorization complications and provides a fast and full service to the user.

7.2 Discussion

The positive feedback received throughout concept validation, suggests that conceptualising and pioneering a Digital Product Passport (DPP) is a promising contribution towards circularity in the maritime sector. However some open questions and discussion points regarding various decisions that were taken throughout this project remain.

For its low threshold potential, the open access approach to DPPs pursued here appears to be an appropriate choice for Optimists, with the exemption of high level competitive sailing, as controversial entries to the DPP could quickly fall back on owners and could lead to event exclusion. Who has access to the system and even more importantly who can edit the data needs to be further evaluated. After all, it becomes evident, that even within an open access passport an additional limited access protocol is required.

Even if mostly well received, the blueNode tracker causes some controversy. Adding electronic equipment to monitor product usage needs to be well reasoned, since the added electronic equipment has a significantly higher carbon impact per weight, compared to most other materials (6x higher than GFRP). The benefit in the case of the Optimist is mostly for manufacturers, as it provides insights for R&D and for sailing associations as it gives them an overview over usage patterns. If it provides value in the second hand market remains unknown, on the one hand, as the comparison with a car's odometer shows, it brings transparency. On the other hand, buyers could also be deterred from buying a boat that has reached 90% or higher of its theoretical life expectancy, even if it is still in good condition. Either way, the accuracy of the algorithm for usage detection from GPS signals, would first need to be tested and validated.

Data privacy is another concern the life data tracking brings up. Should only manufacturers and class associations have access to the location data? Does releasing the data a month or year after collection reassure people its not them who are tracked but rather the usage of a boat? For fleet management at sailing schools for instance, sharing this data seems justified, as long as it doesn't give away details that could lead to theft. For boats in private ownership, the data accessibility perhaps needs adjustments.

Without a doubt, the blueNode is also the most expensive part of the service. For now its implementation needs to be justified by its predictive capabilities alone. If the device's capabilities could be extended to be useful as a training tool as well, it would also provide more benefit to the user, driving its adoption. This was a consideration, but the need for a contract based network solution would have either led to very high costs or would have cannibalised the reliability, distorting the data's representativeness for lifecycle tracking (see chapter 5.3). Nonetheless, a combination of both would be ideal. In such a scenario marketing the tool as a subscription service could make sense too, raising money to cover the expenses to run the platform.

For now the costs of such a system cause a bit of a dilemma, as customers should not be charged, because it would undermine the systems usage and manufacturers of equipment, at least in common linear economy models would also want to reduce their expenses for product sold long ago. Ensuring the services availability over the entire use phase of a product, particularly if it is very durable, like a boat, is therefore tricky. For now DPP.BOATS would work without blueNode as well, which would reduce the service's costs. What remains in this scenario, is the open access functionality of the DPP more focused on the tools life extending capabilities, while still ensuring information to facilitate better EoL handling. This would lower threshold even further and still provide many benefits, perhaps making the system more interesting for sailing schools and owners, but less beneficial to manufacturers and sailing associations.

Where and with whom such a DPP should be launched, is perhaps the most important point of discussion. Launching it in collaboration with a sailing association, such as the IODA, perhaps offers the best opportunity for growth and implementation at scale. Within sailing schools or training centres, these new boats fitted with the system would remain a rather "special" thing though. In this regard, an implementation at a sailing school, fitting their entire fleet (old boats too) with the system, would likely be the approach that ensures higher interaction rates with the system, as it would allow for proper fleet management and its integration into maintenance processes.

7.3 Conclusions

This thesis set out to identify ways to promote sustainability and increase circularity in the maritime industry, with a focus on the Optimist dinghy as a case study.

Key Findings

The research shows that sustainable alternatives to conventional GFRP composite hulls exist, which can even be used as drop-in replacements. The longevity and end-of-life outcomes of Optimists are not solely determined by the material composition of the hull. A critical barrier identified is the frequent loss of essential information: for 74% of Optimists listed on the second-hand market (n = 120), data relevant to end-of-life treatment is no longer available. To address this gap, the concept of DPP.BOATS is developed as a systems solution to enable circular business practices by ensuring information flow throughout a boat's lifecycle. Beyond end-of-life management, the DPP can support compliance, fleet management, maintenance, and transparency across the usage phase.

Implications

The study highlights a key tension in today's linear economy: it is often cheaper to produce new boats than to repair or maintain existing ones, in part due to labour costs being taxed, in contrast to material usage. This economic imbalance accelerates premature obsolescence of boats. By providing transparent usage and maintenance histories, DPP.BOATS has the potential to extend a product's lifespan and encourage more responsible ownership. The case study also reveals that while static data is useful for ensuring correct end-of-life treatment, integrating dynamic usage and maintenance data offers additional benefits to stakeholders. However, introducing electronic monitoring solutions must be considered carefully, as electronic components have a significantly higher embodied impact per kilogram compared to composite materials.

Adoption Considerations

Operating a DPP platform requires continuous maintenance, resulting in reoccurring costs. For products with long life expectancy, such as the Optimist, this creates a barrier for adoption. To address this, DPP.BOATS pursues an open access approach, which reduces entry barriers and offers opportunities to integrate existing class registers and other stakeholder data systems.

Broader Perspective

The case study sheds light on an ongoing debate regarding the standardisation of DPPs. While standardised formats could enhance compatibility and cross-industry adoption, tailoring a DPP to stakeholder-specific needs can create additional value, in this project in terms of quality assurance of equipment, streamlining event participation, shipyard operations, and fleet management. This indicates that refraining from standardisation drives innovation and the systems adoption rates whilst integrating other relevant data streams is possible too. This project's open access approach showcases an innovative take on DPPs that facilitates active interaction of all stakeholders, fostering accountability at every level. This approach can be adopted for other non-luxury, long-life products as well.

7.4 Limitations & Recommendations

DPP.BOATS is mostly developed through a circularity and feasibility lens. It is a prototype, meaning certain features need further development. Moreover, no representative market research has been conducted to find the best market fit for its implementation and no tests were performed on how and when people are most likely to interact with such a system. While this is a clear limitation to this work, it also outlines a clear direction for future research: How and when do people interact with a DPP? A more longitudinal research could provide valuable insights over people's adoption behaviours, shedding light on the true benefit of DPPs. Furthermore a more in-depth research for capabilities and limitations of distributed asset lifecycle-tracking, ideally contract independent, and with international coverage, is needed.

For now it seems that implementing the tool in collaboration with a class association or boat manufacturer would offer scaling opportunities, but in terms of facilitating maintenance and longer lifetimes, a fleet wide retrofit program at fleet management level promises to be more beneficial. Either way, both directions are worthwhile pursuing further, initially without the track and trace solution.

Below a couple of points are listed that need to be addressed next:

DPP.BOATS	blueNode 2.0
<ul style="list-style-type: none"> • Improve UI throughout website, for instance readability of tables showing previously sent reports • Optimise the webpage for mobile use • Add authorised access functionalities • Integrate weather data in map view • Implement registration for professional shipyards to prevent fake entries in their name 	<ul style="list-style-type: none"> • Second iteration of blueNode, potentially within another thesis project with Computer Science/ Embedded Systems) • Seek collaboration for instance with TracTrac or Garmin

Pitch Project
<ul style="list-style-type: none"> • Register trademark • Sign up for venture capital pitches, e.g. Boot 2026 • Explore partnership opportunities with class association to implement the NFC chip and dynamic reporting functionality for one boat class (maybe ILCA, as World Sailing has higher control over the class rules here) • The German Sailing League (J70 Segel Bundesliga), managing a fleet of competition boats instead of competitors bringing their own boats, could also be suitable and visible entry point for the implementation. • Retrofit fleet at Sailing School

7.5 Reflection

The DPP, and in particular the blueNode for dynamic data integration, represent a technological approach to addressing a societal issue, applied to one of the purest and most low-tech applications. The issue at hand is wasteful material usage in an economy built on consumption. As a fan of low-tech products and solutions, the idea of adding an electronic device to the Optimist makes me feel ambivalent. Ideally, this wouldn't be necessary if people paid more attention to a product's longevity and put more effort into maintaining its functionality and ensuring its best end-of-life treatment, but that's not the reality. This is why I am excited about the DPP's potential to enable more circular practices, but also to raise awareness and hopefully initiate a shift in mindset towards more conscious material usage and consumption.

Without much experience in coding, committing to begin this very digital project direction took some self persuasion. With plenty of naive confidence, I set out and started building. On multiple occasions the newly hosted website was fully broken, to the point where even the page editor wasn't working anymore. In those moments I would ask myself "What qualifies me to work on such a (digital) project? Why am I doing this?, or in other words, "What does it mean for me to be a designer?". I'm certainly not the most proficient web developer, and I won't be. My contribution towards developing such a project is less defined by developing functionality or tweaking it's appearance, but rather finding out what functionalities are needed, and how they should be integrated to best benefit the users and stakeholders. For me this means to challenge assumptions, ask the right questions and prioritising tasks that help reveal the answers. Developing DPP.BOATS and the blueNode tracker serve the purpose of being a demonstrator, on which basis people can form an opinion, which in turn helps to further develop the project. Starting a project, without a previously defined outcome in mind, also shows how the scope of this project shifted from a product focused research to a much more systematic focus on information flows and lifecycle tracking (also see initial brief in appendix A6). This approach is unique to design and the most valuable contribution I, as a designer bring to the table to drive innovation.

Looking back at this time, I am proud of the outcome and certainly learned a lot. It is a project that I am passionate about, which helped me branch out, search, learn and further develop my professional confidence.

So, does this project see a future?
A little too early to tell, lets say "I'm optimistic"!

REFERENCES & INDEXES

References	112
Literature Sources	112
Image Sources	115
Indexes	116
List of Figures	116
List of Tables	117

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Fig. 50	(TTN Mapper, n.d.)
Fig. 56	(Seed Studio (1), n.d.)
Fig. 57	(Seed Studio (2), n.d.)

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Indexes

List of Figures

Fig. 1	Abandoned boat causing environmental harm	12			
Fig. 2	Selection of images of obsolete and partially abandoned boats (copyright: ten Busschen, Riebesehl)	15			
Fig. 3	Optimist Regatta Sailing at Lake Constance, Germany, 2013 (author of this project in front of buoy)	17			
Fig. 4	Two Optimist sailing dinghies (image rights: Khulula)	18			
Fig. 5	Value Hill model, outlining a materials/products value development over its life cycle in a linear economy	20			
Fig. 6	Value development of a material/product in a closed loop system	20			
Fig. 7	Parts and components of the Optimist	22			
Fig. 8	Optimist class logo	22			
Fig. 9	Illustration of historic development of the Optimist	23			
Fig. 10	Photos of the Eco_Optimist (image rights: Khulula)	24			
Fig. 11	Market position of the Eco_Optimist	25			
Fig. 12	Optimists on the second hand market	26			
Fig. 13	The three main stages of an Optimist's lifecycle: manufacturing, use and EoL (left and middle photo, image rights Khulula)	28			
Fig. 14	Stakeholder diagram and their respective influence	29			
Fig. 15	One- design class rules for the Optimists issues by IODA. Cover and exemplary pages	30			
Fig. 16	Construction diagram and component overview of the Optimist in accordance to the class rules	31			
Fig. 17	Diagram based on part of a Sankey diagram on material flows in the EU (EU , 2017)	33			
Fig. 18	LCA Comparison: Global warming - fossil	34			
Fig. 19	LCA results for recyclable and biobased construction alternatives for the Optimist	35			
Fig. 20	The left part of the diagram showing price over age of Optimists on the second hand market, with indication of construction type and type of dinghy. The right part displays the data for all boats with unknown age (74%). (n=120)	37			
Fig. 21	Images of 120 sales offerings of Optimists on the second hand market	38			
Fig. 22	Age composition of Optimists and at sailing school and corresponding usage and condition (n=120)	40			
Fig. 23	Life Expectancy of Optimist hull	41			
Fig. 24	Optimists in a typical storage rack (outside)	42			
Fig. 25	Four abandoned boats in Reffen, Copenhagen - supposedly the greenest/most sustainable metropolis in the world. Not to blame Copenhagen, but it goes to show the scale of the issue. (copyright: Riebesehl)	43			
Fig. 26	Condition inspection of Eco-Optimists after winter storage	45			
Fig. 27	Value development of an Optimist over its lifespan	48			
Fig. 28	Render of Optimist	50			
Fig. 29	Peak into ideation process	53			
Fig. 30	EVR Decision Matrix: Value proposition of Khulula offerings and potential customers (based on (Van Boeijen et al., 2021))	54			
Fig. 31	Market entry of the Eco Optimist, competing with older competition boats	55			
Fig. 32	Illustration showing 74% product related data loss through an Optimist's lifespan.	56			
Fig. 33	Concept illustration of digital product passport with an integrated track and trace system	57			
Fig. 34	Rendering of a mock-up showcasing a representative section of the Optimist to be produced out of Elixir resin and basalt fibre to showcase the feasibility, to be displayed at boat fairs for instance	58			
Fig. 35	Abstracts illustration of boats	62			
Fig. 36	Technology comparison based on research by Wang (2018): Bandwidth over range and exemplary images of technology utilisation (left to right: 1: (Amazon, n.d.), 2: (NFCW, 2019), 3: (Loca, n.d.), 5: (BikeRadar, n.d.), 7: (Queensland Country Life, n.d.), 8: (DNT, n.d.))	69			
Fig. 37	Concept 1: Dry-box for level storage of the sailor's smartphone to track sailing sessions	70			
Fig. 38	Concept 2: Self sufficient IoT tracker to track sailing sessions	71			
Fig. 39	Concept 3: Solar powered black- box for life cycle tracking and Bluetooth based location tracking. The image is only showing the solar panel, as the black box, would be hidden under the mast thwart.	72			
Fig. 40	NFC Chip embedded in product for easy connectivity to DPP information and automatic pop-up message on smartphone	75			
Fig. 41	Illustration for web-search of DPP	75			
Fig. 42	Logo of the new platform for product passport	76			
Fig. 43	Process insights into developing DPP.BOATS, a new website hosting digital product passports tailored to boats to project them into a circular future	80			
Fig. 44	Process of developing the blueNode tracker to feed data into DPP.BOATS	81			
Fig. 45	Overview of the DPP.BOATS website, a new platform for DPPs for boats	83			
Fig. 46	The DPP view and its functionalities	85			
Fig. 47	Illustration of blueNode tracker installed on Optimist	86			
Fig. 48	Data collected by the tracker integrated into dpp.boat/blueNode-live-dashbaord/	86			
Fig. 49	Components and GWP of blueNode tracker	87			
Fig. 50	Screenshots from TTN Mapper (TTN Mapper, n.d.). Left: Nr. of public gateways worldwide. Right: signal strength heatmap.	88			
Fig. 51	Image of Optimist sailing at Lake Constance, overlaid with data representing three exemplary sailing sessions (boat name, boat ID, latitude, longitude, timestamp)	89			
Fig. 52	Optimist being set up before sailing session	90			
Fig. 53	Optimist in use	90			
Fig. 54	Optimist back at harbour, person adding maintenance log to DPP	90			
Fig. 55	Network architecture overview of blueNode and its integration with DPP.BOATS (both in blue)	91			
Fig. 56	Costs of blueNode tracker per device	92			
Fig. 57	SenseCap T1000E LoraWan tracker (Seeed Studio (1), n.d.)	92			
Fig. 58	Wio-WM1110 LoRa & GPS Development Kit (Seeed Studio (2), n.d.)	92			
Fig. 59	Running costs, cost of scaling	93			
Fig. 60	Illustration of different processes throughout the lifecycle of an Optimist sailing dinghy. Top: manufacturing, sailing. Middle: resale, fleet management (sailing school). Bottom: remanufacturing/EoL, fleet management (class association).	95			
Fig. 61	Optimistic Futures: Benefits of DPP.BOATS for manufacturing	96			
Fig. 62	Optimistic Futures: Benefits of DPP.BOATS for fleet managers	97			
Fig. 63	Optimistic Futures: Benefits of DPP.BOATS for the sailor/owner	98			
Fig. 64	Optimistic Futures: Benefits of DPP.BOATS for sailing schools	99			
Fig. 65	Optimistic Futures: Benefits of DPP.BOATS at change of ownership	100			
Fig. 66	Optimistic Futures: Benefits of DPP.BOATS for remanufacturing	101			
Fig. 67	3D Model of Optimists, depicting different scenarios throughout an Optimist's lifecycle	102			

List of Tables

Table 1	Carbon hotspots of GFRP Optimist (done with MarineShift360 LCA tool)	32
Table 2	Concept choice, decision matrix	59
Table 3	Overview of important life cycle information of the Optimist	66
Table 4	Concept 1: Parts and cost estimation	70
Table 5	Concept 2: Parts and cost estimation	71
Table 6	Concept 3: Parts and cost estimation	72
Table 7	Concepts for usage data collection, decision matrix	73

APPENDIX

A1 LCA Comparison	120
A1.1 GFRP Baseline	122
A1.2 Material Choice	124
A1.3 Performance Equivalence	126
A1.4 GWP Data	128
A1.5 Results	130
A1.6 Discussion	132
A2 Table Second Hand Market Mapping	136
A3 Questionnaire Sailing Schools	140
A4 blueNode: Technical Considerations	142
A4.1 Energy Consumption	142
A4.2 Digital Footprint & Data Handling	143
A5 Database Architecture	144
A6 Graduation Brief	146

A1 LCA Comparison

A life cycle assessment is a widely applicable method of analysing all emissions occurring in production (stage A), during usage (stage B) and at the end of a product's life (stage C). The associated emissions are converted to CO₂ equivalence values, for fair comparison.

Comparison

As outlined in chapter 3.3, a composite consisting of flax-fibre and biobased-resin, as well as a composite consisting of Elium-resin and basalt-fibre are compared to the GFRP composite (baseline). Both contenders are drop-in replacements for GFRP. This means that manufacturers can continue to use the same (or very similar) Vacuum-Assisted-Resin-Transfer-Moulding (VARTM) process (see figure 13) as well as the moulds and equipment they already have. The material replacements require minimal financial investment, thereby facilitating its rapid adoption.

Method

The LCA comparison is conducted using an "Educational-light" licence of MarineShift360, a specialised LCA tool for the maritime industry. In this comparison, the scope of the three studies conducted, aims to represent the entire product life cycle (cradle to cradle). At present the MarineShift360 database predominantly focuses on cradle-to-gate analysis. Additionally, a clear misrepresentation regarding the emissions of basalt-fibre is found in the software. The emissions are significantly underestimated, as the data only represents basalt rock mining and not basalt fibre pulling (at the time of conducting this study). Therefore it is important to note that is manipulated in these two instances, to provide a more accurate representation of emissions. Despite the fact that all three assessments in this comparison are fibre-reinforced-polymer composites, the material composition still must be adjusted, to account for the respective properties of each material (density, strength, etc.). This ensures functional equivalence between the GFRP baseline and the two contenders for replacement. The baseline data is derived from the class rules and a 3D model to analyse quantities.

Table 8 Carbon hotspots of GFRP Optimist (done with MarineShift360 LCA tool)

Component	Material	Weight	Cradel to Gate Emissions
Hull	GFRP, PS	22,00 kg	217,52 kg CO2e
Daggerboard	GFRP	3,00 kg	29,66 kg CO2e
Rudder with head/tiller	GFRP, Aluminium	2,50 kg	33,83 kg CO2e
Spar (Mast+Boom+Sprit)	Aluminium	5,50 kg	126,00 kg CO2e
Sail	Polyester (Dacron) 3,3m2	1,05 kg	12,91 kg CO2e
			419,93 kg CO2e

Life Cycle Information

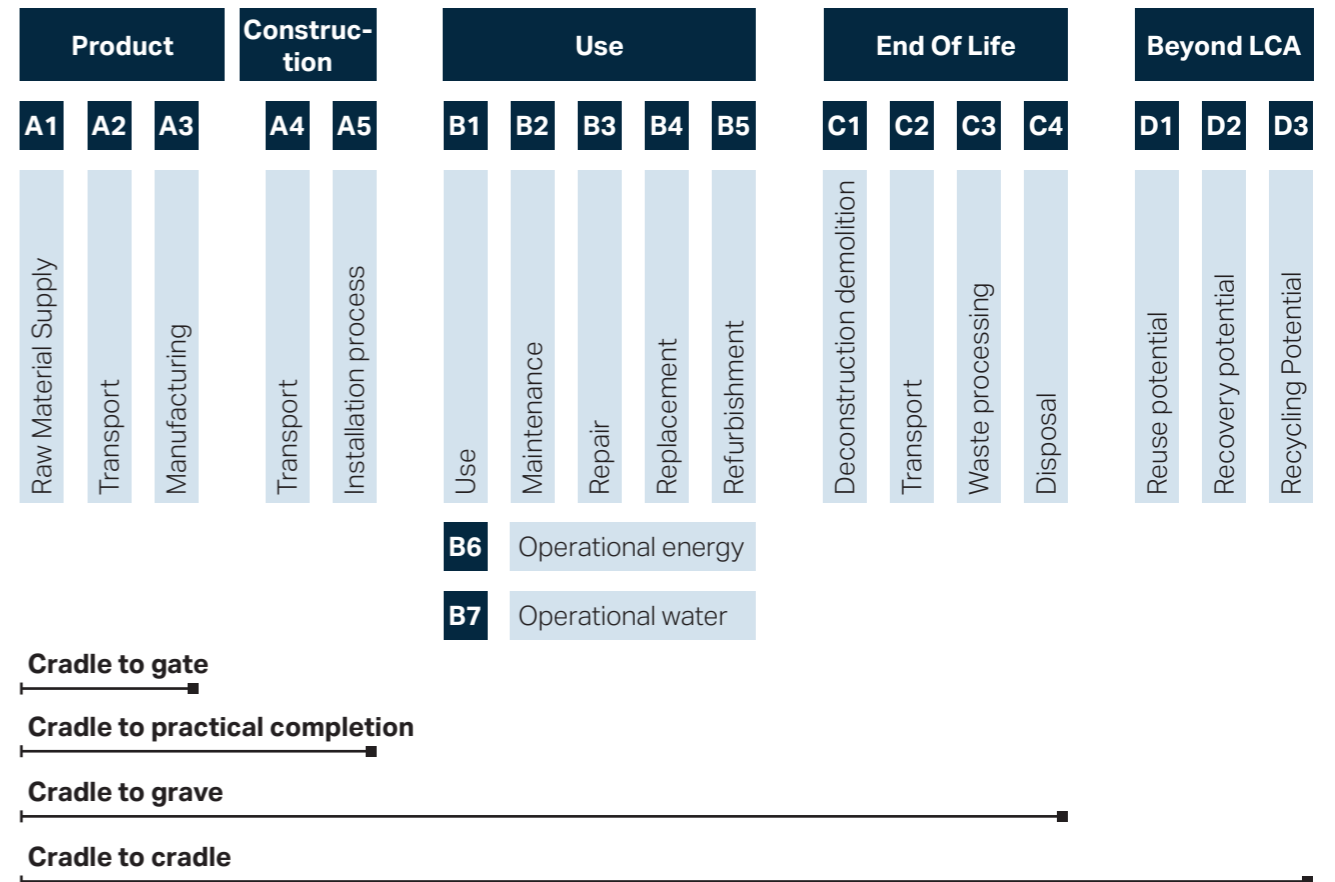


Fig. 68 Life cycle assessment stages (dark blue), associated carbon emissions (light blue) and different scoping of analyses (bottom)

A1.1 GFRP Baseline

Table 9 Results of LCA comparison

	GFRP Baseline		
	Fibres	Matrix	Core
Materials	Glas	Polyester	PS
Density [t/m ³]	2,54	1,20	0,06
Achievable Fibre Volume Fraction [%]	35%	65,00%	
Achievable Fibre Weight Fraction [%]	50%	50,00%	
Composite E-Modulus [GPa]	27.85 GPa		
Stiffness (same thickness)	100%		
Weigt vs. Glas fibre	100%		
Stiffness at same thickness	1 x		
Weight at same stiffness	100%		
Weight in Optimist [kg]	11,50	11,50	1,56

GFRP construction (baseline)

The GFRP construction is based on the Optimist class rules regarding the material choice and construction. A description of the composite build up in the class rules allow for an estimate of total fibre weight of the hull: 11,4kg (see table 10).

Deducting the weight of all other components of the Optimist (based on 3D model and volumetric assessments) from the total minimum weight stated in the class rules, allows for an assumption of resin weight: 11,5kg (see table 11). Equal parts of resin and fibre make up a rather modest fibre content in the composite. Much higher fibre contents (preferable for strong and light parts) are possible in VARTM processing. Higher resin content however increases the composites impact and fatigue resistance. 50% fibre-weight fraction / 35% fibre-volume fraction therefore seems reasonable, also considering the large mould size.

It is noteworthy that, in the laminating process, approximately 3.8 kilograms of auxiliary materials are required for each Optimist dinghy (representing 15% of the Optimist's weight). Those materials are included in the comparison.

Table 10 Fibre weight calculation based on the Optimist class rules 2025

Part	Area [m ²]	Lamiate Layers (Tex) [kg/m ²]	Total Tex [kg/m ²]	Fibre weight [kg]
a Bottom laminate	1,89	300, 300, 450, 450, 300	1,80	3,40
b Side and transom laminate	2,08	300, 450, 450, 280	1,48	3,08
c Daggerboard slot laminate	0,15	300, (2 to 5)*450, 300	2,85	0,43
d Daggerboard Case - Midship Frame	0,65	300, (3 to 6)*450	3,00	1,95
e Mast thwart	0,11	300, 300, 300, 450	1,35	0,15
f Mast thwart, bulkhead	0,21	300+450+450	1,20	0,25
g Gunwale	0,69	450, 450, 450, 300	1,65	1,14
supporting reinforcements (joints)		<5*450		1,00
Full Hull Assembly		5,78		11,40

Table 11 Resin weight calculation based on the Optimist class rules 2025 and a 3D model

Weight [kg]	Part description	Source
32,00	Hull weight including the following < 32kg	Class Rules 2025 (Section 3.2.8.1)
-0,13	Rudder gudgeons with 6 bolts and nuts	estimation based on 3D model (V, ρ)
-0,46	Buoyancy straps (~7.5m) and attachments	estimation based on 3D model (V, ρ)
-0,22	Toe straps (~1m, cushined) and associated fixings	estimation based on 3D model (V, ρ)
-0,18	Mast step and 6 Bolts	estimation based on 3D model (V, ρ)
-0,10	Block fittings permanently attached	estimation based on 3D model (V, ρ)
-1,56	Foam core (13mm; 60kg/m ³)	Class Rules 2025 (Section 3.2.8.1)
-2,89	Gel Coat, considering 0.15% weight loss during curing	Calculation based on Class Rules 2025
-0,58	UV- Protection/Paint insude of hull (dry weighth)	(Scott Bader (Pty) Ltd., 2013)
-0,50	Glue for joining components	(Alexseal, 2025)
-11,40	Fibre weighth	table above
-2,5	Other parts (overlaps etc.)	estimate
11,48	Resin content in composite (weight)	32kg minus other parts

A1.2 Material Choice



Biobased Construction		
Fibres	Matrix	Core
Flax	Biobased	rPET

Biobased construction

With the exception of carbon-fibre composites, the resin system usually has the higher embodied carbon in a composite, compared to the fibres. It is therefore the part that needs to be optimised most urgently (Mindermann *et al.*, 2022; Cáceres *et al.*, 2024).

Biobased resin is an excellent replacement with a lower carbon footprint. A resin with a regenerative fraction of 60% is used in this assessment. Resins with higher biobased fractions are available, however not in large quantities or at competitive prices.

Similarly, natural fibres have a lower carbon footprint than synthetic fibre (Cáceres *et al.*, 2024). They have been used in traditional composite making long before glass fibre was invented. Amongst jute, sisal, hemp and many more, flax fibres stand out for their fast growth, consistent quality and high strength properties. Working with natural fibres brings its own set of challenges though. Their hygroscopic behaviour require proper drying of the fibres before resin infusion. Water uptake is a common failure mode for composite boats. The Optimist is nonetheless a suitable application for natural fibres, as it is taken out of the water when not in use.

A suitable natural replacement for virgin foam used in the sandwich structure in the bottom laminate with closed cells (to avoid resin uptake and weight gain) does not exist. Cork, perhaps being the best natural alternative, has a density of 120g/cm³, double of what is intended. An alternative is recycled PET foam, while not regenerative it has a much lower carbon footprint.



Fig. 69 right: Flax fibre weave. Right: Sailing dinghy using this construction (BOOT Düsseldorf 2025, Fachhochschule Kiel)



Recyclable Construction		
Fibres	Matrix	Core
Basalt	Elium	rPET

Recyclable construction

When talking about recyclability, thermoplasts are an obvious choice, as they can be repeatedly reshaped when heated above their melting point. Injection moulded versions of the Optimist exist (short fibre reinforced Polypropylene), they are much heavier though and thus only suitable for entry level sailing and no real solution for manufacturing of performance boats.

Thermoplastics have a density around 100x higher than that of duroplastics (viscosity of honey vs. water). This material property does not allow fibre impregnation, rendering it unusable for large composite parts.

Recent material innovations have brought about a resin system with low viscosity to be usable in the same VARTM processes while having thermoplastic properties once cured. Elium[®] resin by Arkema[®] is based on a MMA chemistry with its monomers immersed in a solvent. The solvent allows fibre impregnation at atmospheric pressure or at a light vacuum (just like a thermoset resin) and the polymerisation process makes it behave just like thermoplastic resins after curing, meaning it can be put into new shape in molten state (mechanical recycling) but it can also be chemically recycled, a process where the polymer chain is broken and the composite is split into the resin in monomer form and the fibres. Both of these recycling processes however require heat, which gives some constraints

with regards to the fibre material. Flax fibre cannot be used for to reasons, firstly the fibres would partially pyrolyse at these temperatures, making reuse impossible, and secondly the high temperatures induced by the exothermic polymerisation process would evaporate any moisture naturally stored in natural materials, which causes it to steam and form bubbles, creating a foam like material composite, causing the overall stiffness and strength to plummet. Glass fibre, basalt fibre or indeed carbon fibre would be suitable. Carbon fibre is not considered here, due to its high cost and much higher embodied carbon. Basalt fibre (molten basalt rock drawn through a nozzle to thin filaments) however is a very interesting alternative to glass fibre, because its production requires no additional chemicals, unlike glass fibre. Basalt fibre products have a 15-30% lower carbon footprint than glass fibre (see next pages). Besides that, they are non-combustable and have a higher thermal stability than glass-fibre (Fiore *et al.*, 2015).

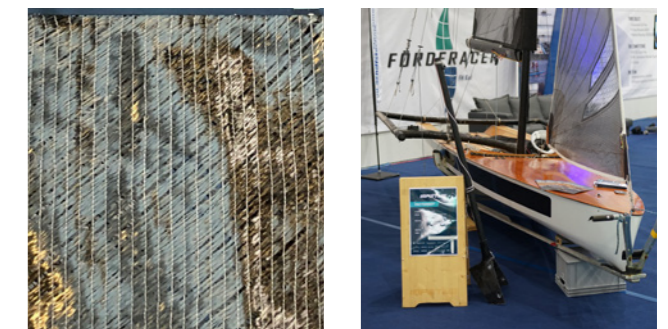


Fig. 70 Left: Basalt fibre weave. Right: Sailing dinghy using this construction (BOOT Düsseldorf 2025, TU München)

A1.3 Performance Equivalence

Table 12 LCA comparison: Fibre to resin ratio and weight

	GFRP Baseline		
	Fibres	Matrix	Core
Materials	Glas	Polyester	PS
Density [t/m ³]	2,54	1,20	0,06
Achievable Fibre Volume Fraction [%]	35%	65,00%	
Achievable Fibre Weight Fraction [%]	50%	50,00%	
Composite E-Modulus [GPa]	27.85 GPa		
Stiffness (same thickness)	100%		
Weigt vs. Glas fibre	100%		
Stiffness at same thickness	1 x		
Weight at same stiffness	100%		
Weight in Optimist [kg]	11,50	11,50	1,56



	Biobased Construction		
	Fibres	Matrix	Core
Materials	Flax	Biobased	rPET
Density [t/m ³]	1,50	1,20	0,06
Achievable Fibre Volume Fraction [%]	30%	70,00%	
Achievable Fibre Weight Fraction [%]	35%	65,00%	
Composite E-Modulus [GPa]	10.50 GPa		
Stiffness (same thickness)	38%		
Weigt vs. Glas fibre	77%		
Stiffness at same thickness	1,38 x		
Weight at same stiffness	107%		
Weight in Optimist [kg]	8,61	16,00	1,56



	Recyclable Construction		
	Fibres	Matrix	Core
Materials	Basalt	Elium	rPET
Density [t/m ³]	2,70	1,20	0,06
Achievable Fibre Volume Fraction [%]	35%	65,00%	
Achievable Fibre Weight Fraction [%]	50%	50,00%	
Composite E-Modulus [GPa]	32.90 GPa		
Stiffness (same thickness)	118%		
Weigt vs. Glas fibre	101%		
Stiffness at same thickness	0,94 x		
Weight at same stiffness	94%		
Weight in Optimist [kg]	10,81	10,81	1,56

Biobased construction

flax fibre density: 1.50 g/cm³ (Cáceres et al., 2024)

The lower E-modulus of flax fibres and the slightly less uniform fibre twills and their inferior draping behaviour generally allow for lower fibre content, resulting in lower mechanical properties of the composite. This can be partially compromised by their lower density (Cáceres et al., 2024).

An equally performing part would therefore need to be 38% thicker, at 7% additional weight compared to a GFRP part.

Recyclable construction

basalt fibre density: 2.7g/cm³ (Cáceres et al., 2024)

Basalt fibres have equally good draping behaviour compared to glass-fibre. The fibre content is therefore considered to be same as glass fibre.

Basalt fibre have an E-modulus that is slightly higher than tat of glas fibre (Cáceres et al., 2024), allowing the part to be around 6 % thinner while still achieving the same mechanical properties.

A1.4 GWP Data

Table 13 LCA comparison: GWP data and consideration

		GFRP Baseline		
		Fibres	Matrix	Core
Materials		Glas	Polyester	PS
Production GWP (per Unit) [kg CO ₂ e/kg]		2,44	5,60	3,74
EoL GWP (per Unit) [kg CO ₂ e/kg]		0,74	2,38	2,38

GFRP baseline

End of life treatment: Incineration
The GWP values are taken from MarineShift360.

Biobased construction

End of life treatment: Incineration
The GWP values are taken from MarineShift360.

With reduced upfront carbon emissions (stage A) a major disadvantage remains. Chemically speaking, a biobased resin cannot be distinguished from its virgin peer, meaning recycling is just as difficult as with GFRP. Incineration emissions of the biobased material fraction would be offset by the carbon sequestered during growth and the organic fraction would increase energy retention on top of that.

		Biobased Construction			Recyclable Construction		
		Fibres	Matrix	Core	Fibres	Matrix	Core
		Flax	Biobased	rPET	Basalt	Elium	rPET
		0,97	4,43	1,57	2,00	6,87	1,57
		0,01	2,38	2,38	-11,59		

Recyclable construction

End of life treatment: Recycling
The GWP values of the white cells are taken from MarineShift360. The cells marked in light grey are altered to provide a more accurate representation of emissions.

The emissions of basalt-fibre are significantly underestimated in the software at the time of conducting this study, as the data only represents basalt rock mining and not basalt fibre pulling (Ecolnvent: Basalt {GLO} market for | APOS, U + Electricity, low voltage {GLO} market group for | APOS, U + Wire drawing, steel {GLO} market for | APOS, U). Basalt-fibre production is very similar to that of glass-fibre, only that basalt-fibre has a higher melting point 1450-1500°C instead of 1300°C for glass fibre (Fiore *et al.*; 2015). No additives are needed for fibre pulling, which makes the process less toxic. The higher processing temperature suggests higher carbon emissions, however the absence of toxins make it have a lower footprint, at least that is what the few existing sources suggest (Cáceres *et al.*, 2024). No source has been found that suggests a higher GWP than glass fibre. Therefore the wrong data point in MarineShift360 is accounted for, by selection glass fibre with 20% reduced weight.

For Elium-resin and basalt-fibres, Marinesshift360 is missing EoL data, which only becomes evident when reviewing the data referencs of the finished report (frustratingly there is no warning when selecting "recycling" as EoL treatment). Arkema & Ecovamed (2024) report that EoL credits for Elium and glass-fibre are -0.85 kg CO₂-e (thermal recycling) and -0.59 kg CO₂-e (mechanical) per kg of composite, reducing the footprint of a boat by 16% in a Cradle to Grave comparison with glass-fibre-epoxy composite. This reference is used for the entire weight of the composite.

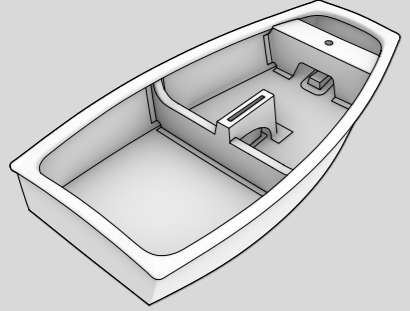
A1.5 Results

Table 14 LCA comparison: full table and results

	GFRP Baseline			Biobased Construction			Recyclable Construction		
	Fibres	Matrix	Core	Fibres	Matrix	Core	Fibres	Matrix	Core
Materials	Glas	Polyester	PS	Flax	Biobased	rPET	Basalt	Elium	rPET
Density [t/m ³]	2,54	1,20	0,06	1,50	1,20	0,06	2,70	1,20	0,06
Achievable Fibre Volume Fraction [%]	35%	65,00%		30%	70,00%		35%	65,00%	
Achievable Fibre Weight Fraction [%]	50%	50,00%		35%	65,00%		50%	50,00%	
Composite E-Modulus [GPa]	27.85 GPa			10.50 GPa			32.90 GPa		
Stiffness (same thickness)	100%			38%			118%		
Weigt vs. Glas fibre	100%			77%			101%		
Stiffness at same thickness	1 x			1,38 x			0,94 x		
Weight at same stiffness	100%			107%			94%		
Weight in Optimist [kg]	11,50	11,50	1,56	8,61	16,00	1,56	10,81	10,81	1,56
Production GWP (per Unit) [kg CO ₂ e/kg]	2,44	5,60	3,74	0,97	4,43	1,57	2,00	6,87	1,57
EoL GWP (per Unit) [kg CO ₂ e/kg]	0,74	2,38	2,38	0,01	2,38	2,38	-11,59		
Production Phase [kg CO ₂ e]	159,37 kg CO ₂ e			137,97 kg CO ₂ e			155,31 kg CO ₂ e		
End of Life [kg CO ₂ e]	58,14 kg CO ₂ e			22,80 kg CO ₂ e			-12,53 kg CO ₂ e		
Total GWP of Optimist [kg CO ₂ e]	217,51 kg CO₂e			160,77 kg CO₂e			142,78 kg CO₂e		
Reduction of emissions	n.a.			-26,09%			-34,36%		
Lifetime Expectancy	25-30 years			20-25 years			30-35 years		
Eco Impact per year [kg CO ₂ e/year]	7,25-8,70 kg CO₂e/year			6,43-8,04 kg CO₂e/year			4,08-4,76 kg CO₂e/year		
Repairability	duroplast, common practice			duroplast, reversable glue joints			thermoplast, not yet common		
Recyclability, EoL Considerations	landfilling, incineration			landfilling, incineration			chemical or mechanical recycling		
Availability/Scalability	industry standard			limited renewable ressources			upcoming technology		
Material Costs	2 €/kg	6 €/kg	10 €/kg	6 €/kg	14 €/kg	15 €/kg	5 €/kg	9 €/kg	15 €/kg
Total Material cost	102 €			291 €			166 €		
Cost Comparison	100%			285%			163%		
Cost per year	3,67-4,40 €/year			12,58-15,73 €/year			5,13-5,98 €/year		

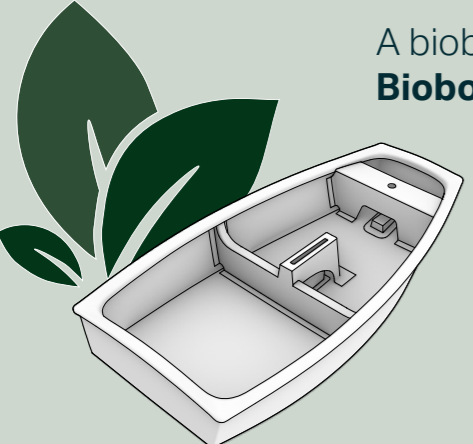
A1.6 Discussion

Baseline:
Glass-Fibre & Polyester-Resin




Cradle to Cradle Emissions:	218 kg CO ₂ e
Life expectancy:	25-30 years
Impact / year:	7,25-8,70 kgCO ₂ e/year
Price:	102 € (bill of materials) 3,67-4,40 €/year

A biobased version of the Optimist:
Bioboased-Resin & Flax-Fibre Composite



Cradle to Cradle Emissions:	161 kg CO₂e - 26 %
Life expectancy:	20-25 years
Impact / year:	6,43-8,04 kgCO₂e/year
Price:	+185% (bill of materials) 12,58-15,73 €/year

A recyclable version of the Optimist:
Elium-Resin & Basalt Fibre Composite



Cradle to Cradle Emissions:	143 kg CO₂e - 34%
Life expectancy:	30-35 years
Impact / year:	4,08-4,76 kgCO₂e/year
Price:	+65% (Bill of Material) 5,13-5,98 €/year

Fig. 71 LCA results for recyclable and biobased construction alternatives for the Optimist

Results & Discussion

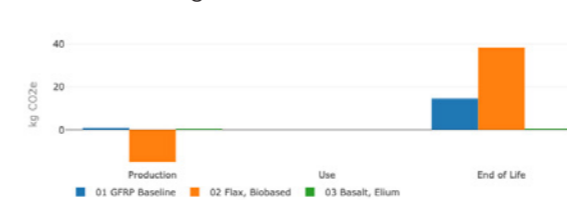
The results support the adoption of the recyclable material composition in boat manufacturing in the future: Elium-resin and basalt-fibre composite. Not only does it reduce carbon emissions, it also promises to be more durable and long-lasting, while potentially improving performance through weight savings. For the time being, there would be a rise in the cost of the bill of materials. There is one more caveat: The optimal performance is only then reached, if it is actually recycled at the end of its lifecycle. In other words, it is feasible to manufacture boats in a more sustainable manner

and to circumvent issues that arise at the end of their lifecycle. However, establishing the appropriate logistics and processes to facilitate this, must also be initiated. Perhaps the more significant challenge. If the Elium version is not recycled at end of life, the emissions are similar to the glass fibre variant. The graphs below show a more holistic view on all emission factors over the entire lifecycle. Especially the "global warming - renewable" and the "Marine Eutrophication" graphs show effects of renewable vs. non-renewable resources.

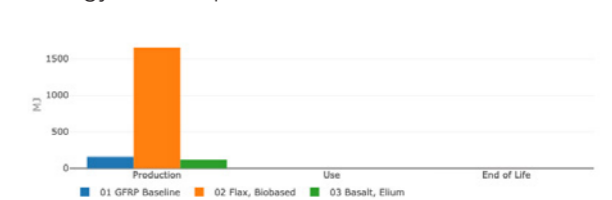
Global warming - fossil



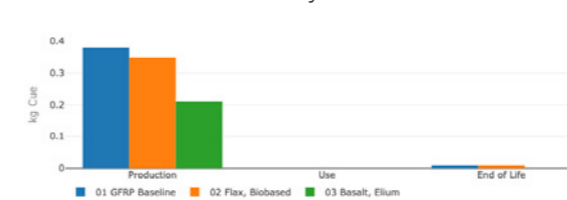
Global warming - non-fossil



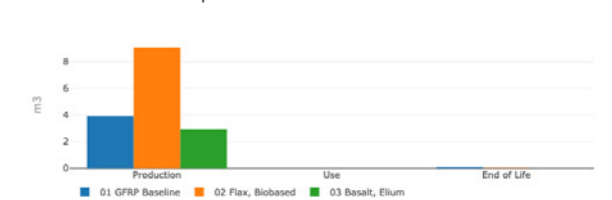
Energy consumption - renewable



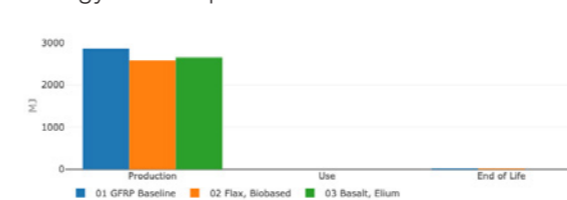
Mineral resource scarcity



Water consumption



Energy consumption - non-renewable



Marine Eutrophication

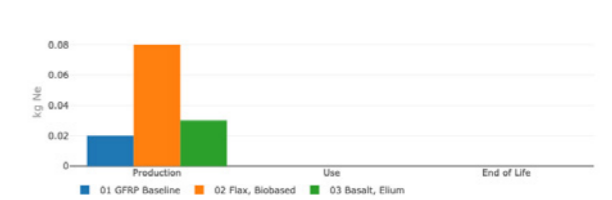


Fig. 72 Result of LCA - Beyond the carbon equivalence scope

Biobased construction: Other remarks

Considering that damages to the composite can't be entirely avoided, natural material fractions such as flax fibres would be at higher risk for permanent damage as they start rotting in wet conditions. Flax fibre boats aren't around for long enough to reach final conclusions here, however a shorter lifespan is to be expected (Lepelaar, 2025).

Addressing repairability, a less integrated design would be advantageous to facilitate part replacement and repair. At least the three moulded components could/should be joined in a reversible way. This can be done with a structural adhesive that can be debonded. Examples would be an acrylic glue, which becomes flexible at higher temperatures (e.g. Plexus®) or MS-Polymers, which are very tough adhesives, that can be cut with metal wire (e.g. Sikaflex®) (ten Busschen, 2025). The repairability aspect of the design is not reflected in the LCA.

Recyclable construction: Other Remarks

With successful material adoption in wind turbine manufacturing and a marine industry wide partnership around using Elium resin, promoting circularity, spreads confidence, that recycling infrastructure for Elium resin composites is developing at scale. (Arkema, 2025).

Other material recyclable alternatives to look out for could be DANU (AZoM, 2022) or vitrimer chemistry resins (ten Busschen, 2025)

Sources:

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Fiore, V., Scalici, T., Di Bella, G., & Valenza, A. (2015). A review on basalt fibre and its composites. *Composites Part B: Engineering*, 74, 74–94. <https://doi.org/10.1016/j.compositesb.2014.12.034>

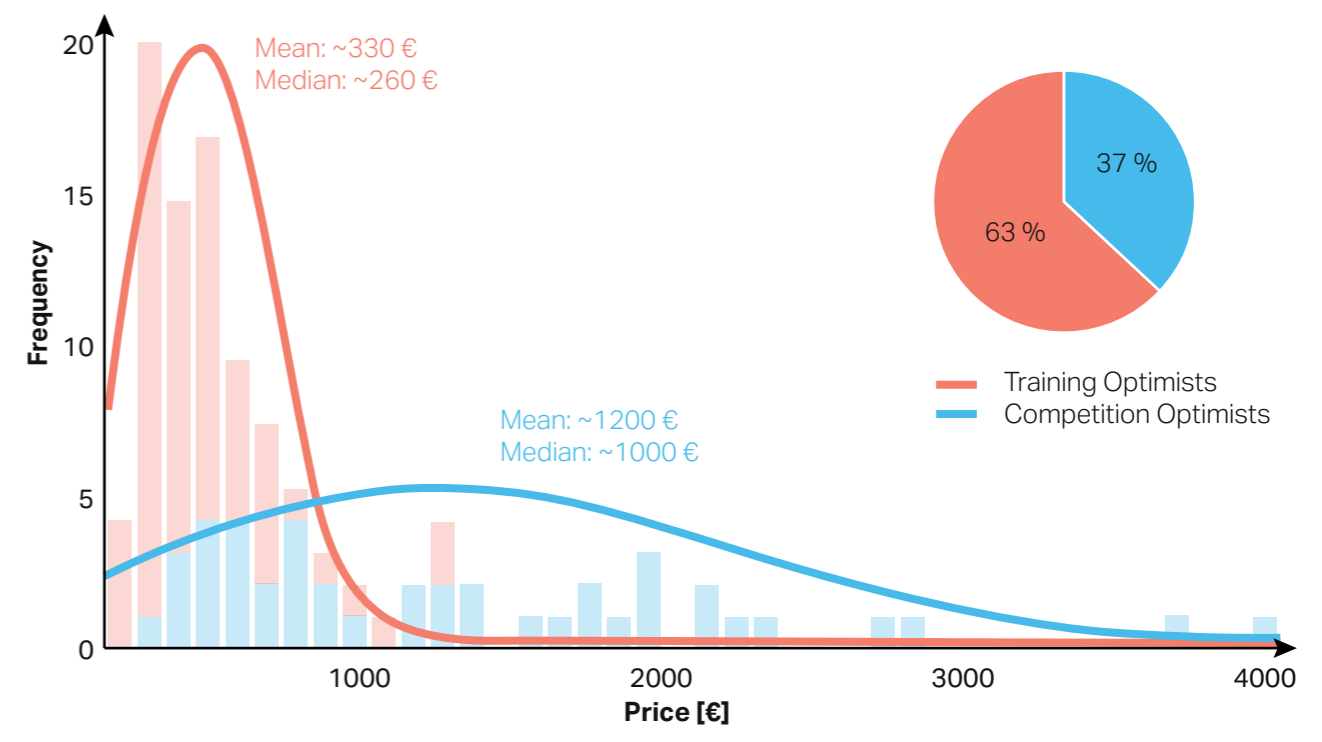
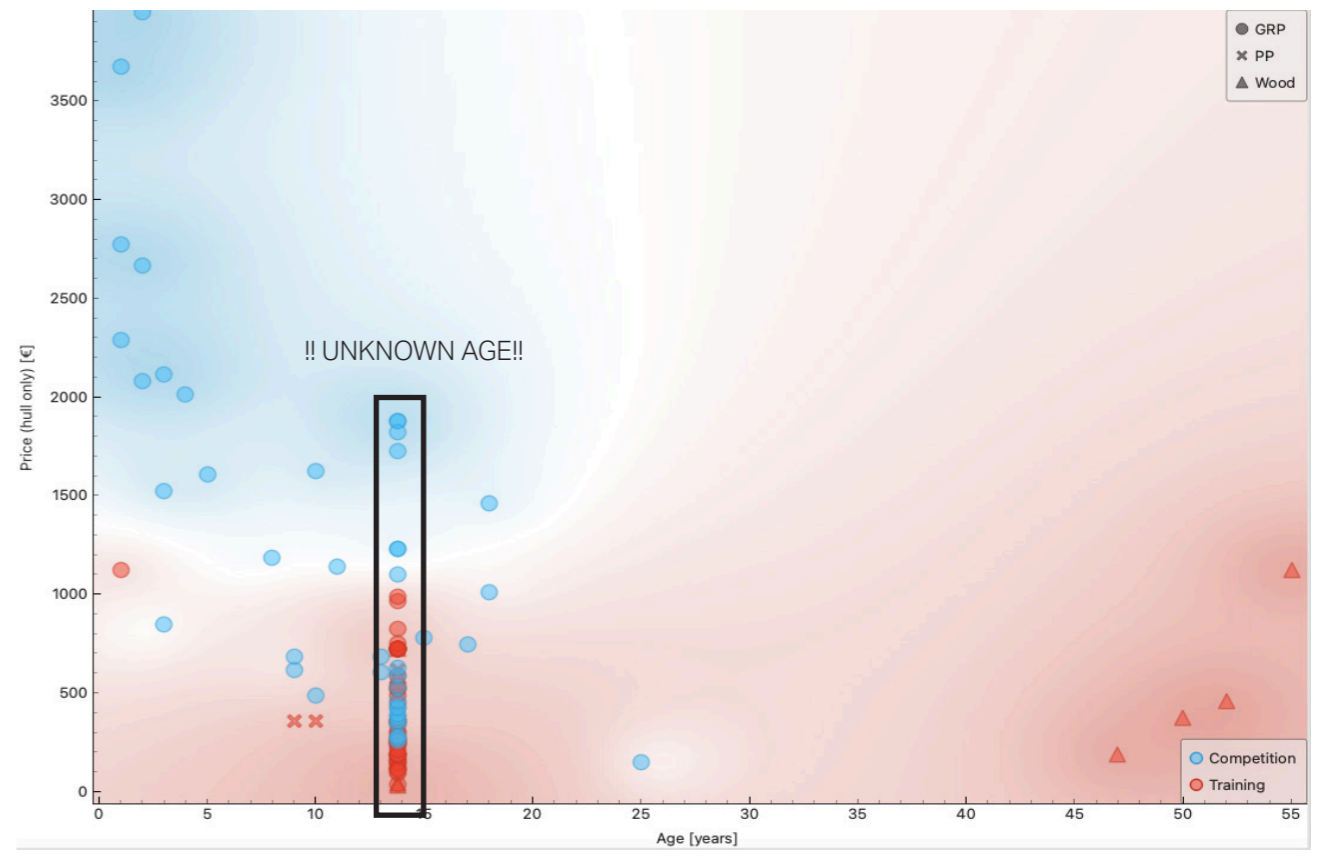
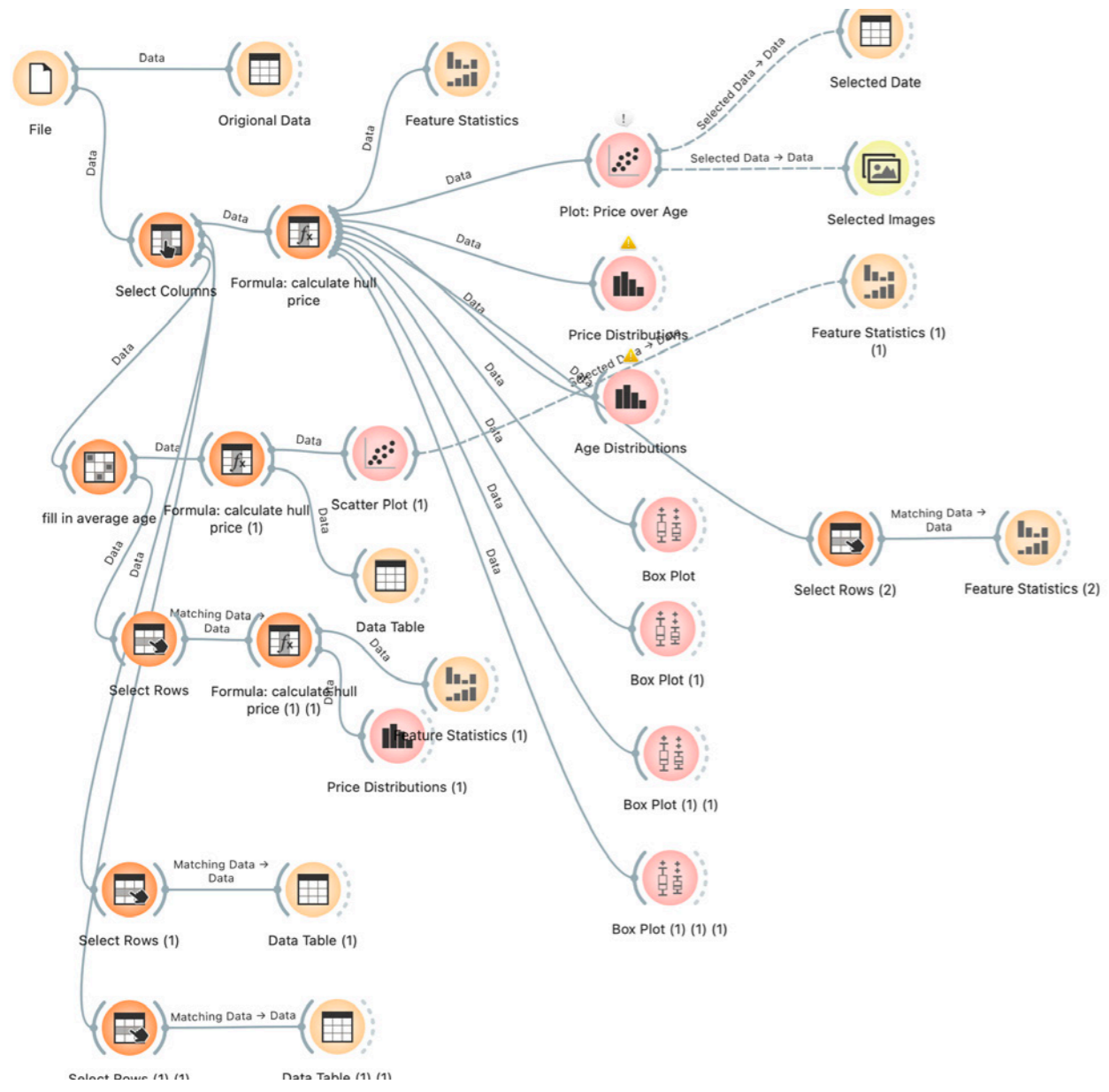
Lepelaar, M., NPSP. (2025): personal interview, online

Mindermann, P.; Pérez, M.G.; Knippers, J.; Gresser, G.T. Investigation of the Fabrication Suitability, Structural Performance, and Sustainability of Natural Fibers in Coreless Filament Winding. *Materials* 2022, 15, 3260.

ten Busschen, A., Hogeschool Windesheim. (2025): personal interview, online

A2 Second Hand Market Mapping

Nr.	Price	Age years	Type	Material	Package	Condition	Comment	Image link	Source	Image ling damage
1	396		Training	GFRP	Hull with rig	Minor damage	looks 20' yr	C:\Users\belas\Doc https://www.ebay.de/itm/256821117440?_skw=optimist		69 250 Training GFRP Hull with rig Minor damage
2	900		Training	Wood	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.ebay.de/itm/286048518345?_skw=optimist		70 650 Competitio GFRP Hull with rig Ready to sail
3	325		Training	GFRP	Hull with rig	Ready to sa	heavy 45kg	C:\Users\belas\Doc https://www.ebay.de/itm/335776581909?_skw=optimist		71 Training GFRP Hull with rig Minor damage
5	3950	2	Competitio	GFRP	Hull with Tr	Ready to sail		C:\Users\belas\Doc https://www.ebay.de/itm/335617323679?_skw=optimist		72 Training GFRP Hull with rig Minor damage
6	450		Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.ebay.de/itm/156574160004?_skw=optimist		73 175 Training GFRP Hull with rig Damaged
7	700	52	Training	Wood	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.ebay.de/itm/334196642258?_skw=optimist		74 1050 13 Competitio GFRP Hull with rig Ready to sail
8	150	25	Competitio	GFRP	Hull	Ready to sa	barely used	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segeljolle-optim		75 250 Training GFRP Hull with rig Minor damage
9	150		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-segelb		76 Training GFRP Hull Damaged
10	300		Training	Wood	With rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/jolle-optimist/30		77 1750 11 Competitio GFRP Hull with rig Ready to sail
11	1550	18	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/winner-optimist		78 Training PP Hull with rig Ready to sail
12	1300	3	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/opti-optimist-joll		79 300 Training Wood Hull with rig Ready to sail
13	550		Training	GFRP	Hull with rig	Ready to sa	with new sa	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-opti-se		80 50 Training GFRP Hull with rig Damaged
14	250		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segelboot-kind		81 200 Training GFRP Hull with rig Minor damage
15	3100	4	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-nautive		82 150 Training GFRP Hull with rig Damaged
16	1500	55	Training	Wood	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/raritaet-und-sar		83 Training GFRP Hull with rig Ready to sail
17	250		Training	GFRP	Hull	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/paddel-training		84 Training GFRP Hull with rig Minor damage
18	250		Training	GFRP	Hull with rig	Ready to sa	Rumpf Ver	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segelboot-optim		85 Competitio GFRP Hull with rig Damaged
19	180		Training	GFRP	Hull	Damaged	Used as sar	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/sehr-schoenes		86 350 Training GFRP Hull with rig Ready to sail
20	3699	1	Competitio	GFRP	Hull with rig	Ready to sa	"new"	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/regatta-optimist		87 Training PP Hull with rig Ready to sail
21	360		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-inkl-slij		88 Training PP Hull with rig Ready to sail
22	2500	10	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/winner-optimist		89 400 Training PP Hull with rig Ready to sail
23	350		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segelboot-optim		90 Training GFRP Hull with rig Minor damage
24	990		Training	GFRP	Hull	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segeljolle-optim		91 30 Training Wood Hull Damaged
25	2290	1	Competitio	GFRP	Hull	Ready to sa	soem parts	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/jolle-optimist-ba		92 4100 2 Competitio GFRP Hull with rig Ready to sail
26	1950	18	Competitio	GFRP	Hull with rig	Damaged	cracks in gr	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-regatta		93 2799 Competitio GFRP Hull with rig Ready to sail
27	4896	1	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-von-wir		94 1890 Competitio GFRP Hull with rig Ready to sail
28	2650		Competitio	GFRP	Hull with rig	Minor damage	chipped ec	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-ger-18		95 475 10 Training PP Hull with rig Ready to sail
29	500	50	Training	Wood	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-holz/3C		96 475 9 Training PP Hull with rig Ready to sail
30	199		Training	GFRP	Hull with rig	Damaged	constructe	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-opti/29		97 1690 Competitio GFRP Hull with rig Ready to sail
31	825		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/jolle-optimist/29		98 325 Training GFRP Hull with rig Minor damage
32	800		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-henriks		99 650 Competitio GFRP Hull with rig Ready to sail
33	1100		Training	GFRP	Hull with rig	Minor damage	"regatta opi	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/regatta-optimist		100 1820 8 Competitio GFRP Hull with rig Ready to sail
34	400		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-segelb		101 3250 3 Competitio GFRP Hull with rig Ready to sail
35	998		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-opti-se		102 275 Training GFRP Hull Minor damage
36	595		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/winner-optimist		103 150 Training GFRP Hull Damaged
37	800		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/segelboot-jolle-		104 150 Training Wood Hull Minor damage
38	420		Training	Wood	Hull	Minor damage	missing par	C:\Users\belas\Doc https://www.kleinanzeigen.de/s-anzeige/optimist-mahag		105 125 Training GFRP Hull with rig Minor damage
39	2500		Competitio	GFRP	Hull with rig	Minor damage	no photos	https://www.kleinanzeigen.de/s-anzeige/opti-segelnumn		106 250 Training GFRP Hull with rig Minor damage
40	2500		Competitio	GFRP	Hull with rig	Minor damage	no photos	https://www.kleinanzeigen.de/s-anzeige/opti-segelnumn		107 450 Competitio GFRP Hull with rig Damaged
41	135		Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		108 390 Competitio GFRP Hull with rig Minor damage
42	550		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/open-		109 2340 3 Competitio GFRP Hull with rig Ready to sail
43	550		Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		110 1495 1 Training GFRP Hull with rig Ready to sail
44			Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		111 2470 5 Competitio GFRP Hull with rig Ready to sail
45	950	9	Competitio	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/open-		112 2080 2 Competitio GFRP Hull Minor damage
46			Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		113 325 Training GFRP Hull with rig Minor damage
47			Training	Wood	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		114 650 Training GFRP Hull with rig Minor damage
48	200		Training	Wood	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		115 1200 15 Competitio GFRP Hull with rig Ready to sail
49	250	47	Training	Wood	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		116 364 Competitio GFRP Hull with rig Ready to sail
50	550		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		117 1150 17 Competitio GFRP Hull with rig Ready to sail
51	930	13	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeil		118 250 Training GFRP Hull with rig Minor damage
52			Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		119 40 Training Wood Hull Damaged
53	500		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		120 700 Competitio GFRP Hull with rig Ready to sail
54	375		Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		121 Training PP Hull with rig Ready to sail
55	1050	9	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/open-		
56	425		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
57	600		Competitio	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/bootoi		
58	900		Training	GFRP	Hull with rig	Minor damage		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
59	950		Training	PP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
60	525		Training	PP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
61	700		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
62	400		Training	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
63	750	10	Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
64	150		Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
65	750		Training	PP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
66	1890		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/og		
67			Training	GFRP	Hull with rig	Damaged		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		
68	900		Competitio	GFRP	Hull with rig	Ready to sail		C:\Users\belas\Doc https://www.marktplaats.nl/v/watersport-en-boten/zeilen-		



A3 Questionnaire Sailing Schools

Optimist-Dinghy Tracker

Future of the Optimist in a circular economy
Béla Steiner | 2025 | Master thesis research

Name of Sailing Club:

How many Optimists does your club have? (Number)

Regatta boats: Former regatta boats: Training boats:

How old are the Optimists? (Number of Optimists per age category)

0-5 years 6-10 years 11-15 years 16-20 years 21-25 years >26 years

How often are the Optimists typically used during the Season? (days per week)

0-5 years 6-10 years 11-15 years 16-20 years 21-25 years >26 years

What condition are the Optimists in? (choose from options)

0-5 years	6-10 years	11-15 years	16-20 years	21-25 years	>26 years
<input type="checkbox"/> Excellent	<input type="checkbox"/> Excellent	<input type="checkbox"/> Excellent	<input type="checkbox"/> Excellent	<input type="checkbox"/> Excellent	<input type="checkbox"/> Excellent
<input type="checkbox"/> Good	<input type="checkbox"/> Good	<input type="checkbox"/> Good	<input type="checkbox"/> Good	<input type="checkbox"/> Good	<input type="checkbox"/> Good
<input type="checkbox"/> Ok	<input type="checkbox"/> Ok	<input type="checkbox"/> Ok	<input type="checkbox"/> Ok	<input type="checkbox"/> Ok	<input type="checkbox"/> Ok
<input type="checkbox"/> Needs repair	<input type="checkbox"/> Needs repair	<input type="checkbox"/> Needs repair	<input type="checkbox"/> Needs repair	<input type="checkbox"/> Needs repair	<input type="checkbox"/> Needs repair
<input type="checkbox"/> Close to end-of-life	<input type="checkbox"/> Close to end-of-life	<input type="checkbox"/> Close to end-of-life	<input type="checkbox"/> Close to end-of-life	<input type="checkbox"/> Close to end-of-life	<input type="checkbox"/> Close to end-of-life

Do the Optimists belong to the sailing club or to the parents of the kids?

Number of Optimists belonging to club: Number of privately owned Optimists:

How long does your club usually keep the boats?

What is the reason for selling / giving away / disposing the Optimists? What condition of the boat makes them unusable for your club?

What are the typical repairs on Optimists that are being done at the club? Are they ever given to a professional repair workshop (if so, why)?

Table 15 Life expectancy extrapolation from dataset

Ago group	Optimists	Representation	Reported usage/week	Adapted usage/week	Total sessions (26weeks)	Total hours (3h/session)
0-5 years	25	20,83%	3	3,13	406	1219
6-10 years	28	23,33%	2	2,33	303	910
11-15 years	22	18,33%	2	1,83	238	715
16-20 years	24	20,00%	1,5	1,50	195	585
21-25 years	15	12,50%	1,67	1,04	136	407
26-30 years	6	5,00%	1	0,25	33	98
	120				Sum: 1311	3933

A4 blueNode: Technical Considerations

A4.1 Energy Consumption

The SenseCap T1000E tracker has a battery with a capacity of 700mAh. According to the device's instructions, this gives it a sleep-mode time of 185 days when sending one signal a day (Seeed Studio (1), n.d.). This would technically be enough to survive over winter (when the boat is in storage) without critical discharge. To provide a bit of a buffer, a 1000mAh battery should be used.

During a sailing session, the battery should be able to fully charge. Considering a session length of three hours, plus a bit of time before, while setting up the boat, and after, while storing everything away, makes 4 hours that the blueNode is exposed to sunlight. The solar panel should fully charge the battery in 4 hours (duration of the sailing session):

Battery:
 $1000\text{mAh} \times 3.7\text{V} = 3.7\text{Wh}$

Solar panel power (W):
 $W = 3.7\text{Wh} / (4\text{h} \times 0.75) = 1.22\text{W}$
 (0.75 accounts for efficiency losses from the charge controller, wiring, and battery charging)

Efficiency loss of the solar panel taken into account:
 18% at solar irradiance of 1000W/m^2

Area:
 $\text{Area} = 1.22\text{W} / (1000(\text{W/m}^2) \times 0.18) = 0.0068\text{m}^2$

This makes for a solar panel size of roughly 8x10cm, which is the largest constraining factor for the size of the blueNode.

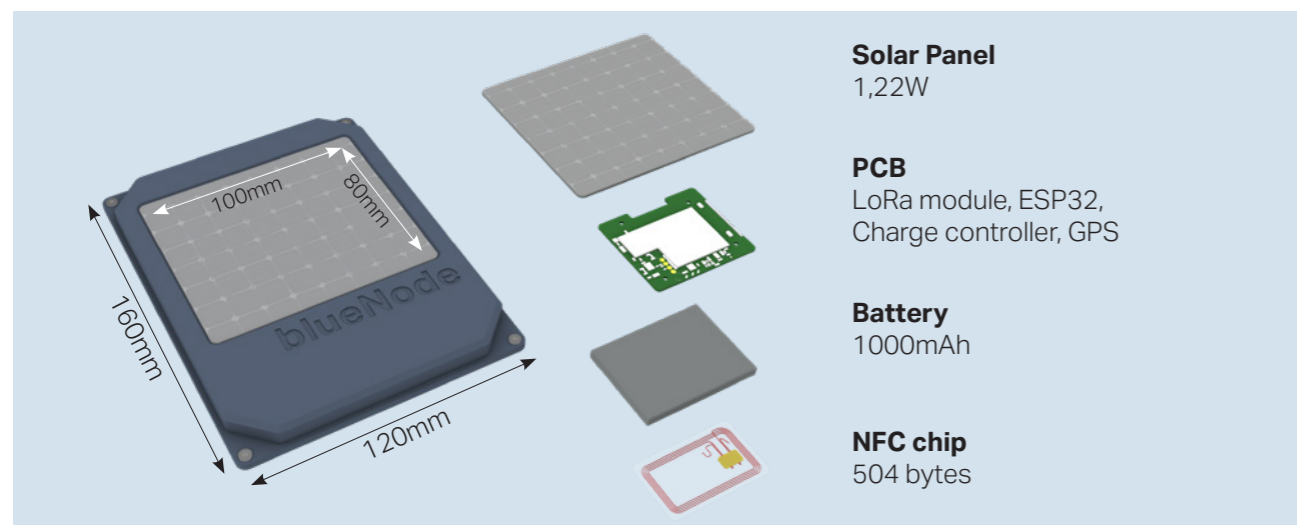


Fig. 73 Technical considerations of blueNode

A4.2 Digital Footprint & Data Handling

The data collected and transmitted by the blueNode needs to be very minimal, due to the constraints of the network. To evaluate the digital footprint created by the approach of usage tracking described in chapter 6.4, the following assumptions are used to make an estimation:

- 1300 Sailing sessions until EoL (see chapter 3.6)
- GPS signal every 15 minutes during usage
- Session duration: 2–4 hours → 8–16 GPS points/session
- Return to harbour: 4–8 additional points (need to be filtered out based on close proximity of points)

≈ 1300 Sessions * (12+6) GPS coordinates = **23,400 rows in database table**

Table 16 below shows an overview of the size of every message send by the blueNode, to evaluate its footprint:

Table 16 Estimated File Size of usage data over the entire lifespan:

	Field	Value	Size (bytes)
blueNode data	Name/UUID of boat:	550e8400-e29b-41d4-a716-446655440000	36 bytes
	Latitude:	52.0016	7 bytes
	Longitude:	4.3698	6 bytes
post processing	Timestamp:	2025-06-26T14:30:00Z	20 bytes
	Session-id (post):	3fa85f64-5717-4562-b3fc-2c963f66afa6	36 bytes
	Session duration (post):	120	5 bytes
	Formatting:	5 commas, new row	7 bytes
			≈ 120 bytes per row

23,400 rows in a database table × 120 bytes ≈ **2.4 MB in .csv file format (similar to excel table)**

The GPS accuracy of the device can be manipulated by the number of digits sent. Four decimal places is equivalent to an accuracy of approximately ±30 m. The UUID 4 format used for the Boat-ID here is a very future proof approach that avoids naming overlap, a shorter identifier would likely be sufficient. While it is feasible to include additional data from for instance an accelerometer or the battery level, the smaller the amount of data, the lower the chance of data loss. The small size of the usage dataset in this minimal approach, implies that tracking the usage of an Optimist over its lifecycle leaves a negligible digital footprint. Tracking damages or repair interventions with photo documentation would leave a significantly larger impact, but compared to other data in cloud storage nowadays, this would still be quite negligible.

The size of the dataset is not a problem, the large number of computational operations needed to filter such a dataset and displaying every GPS coordinate on a map however, creates a challenge.

A5 Database Architecture

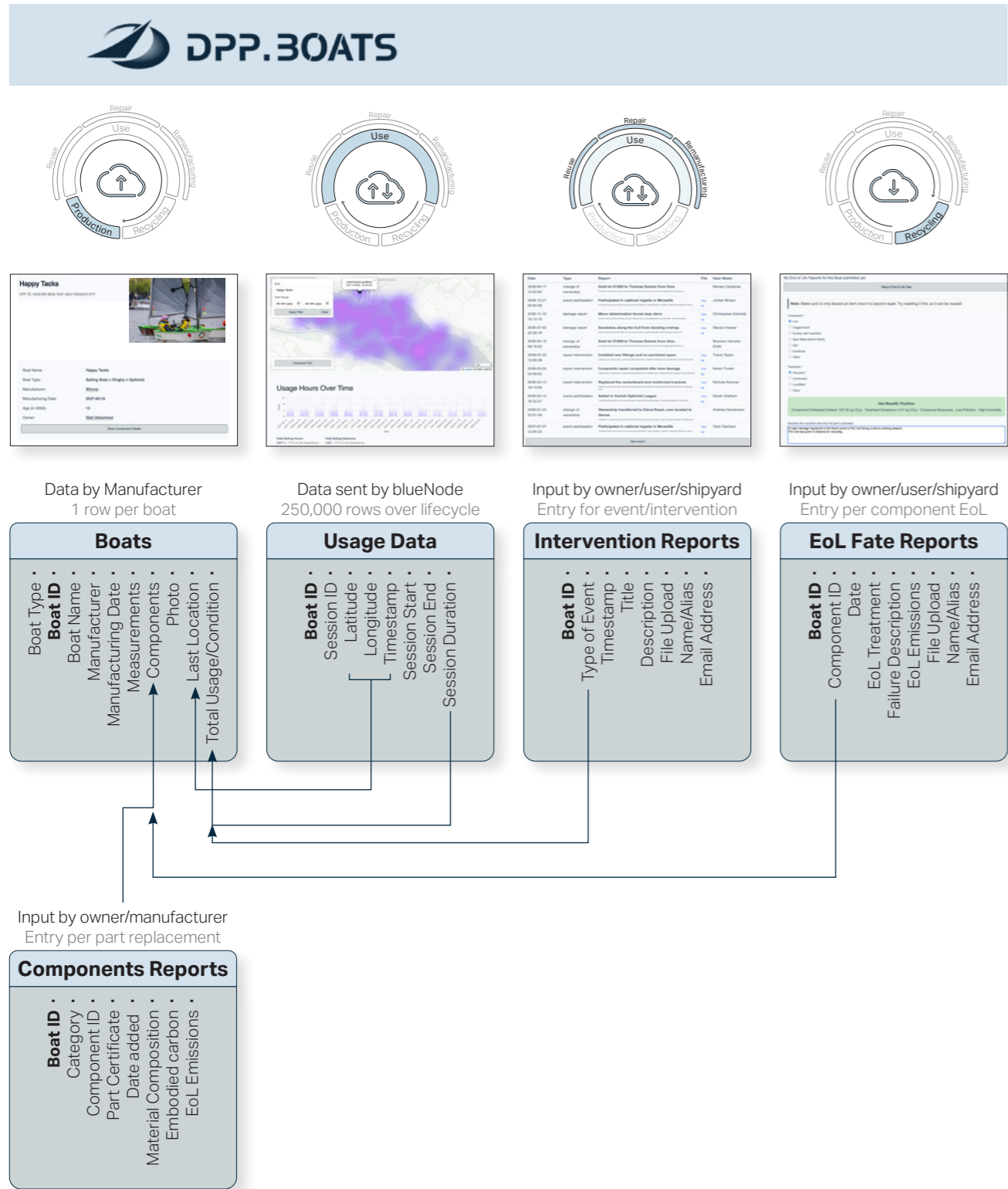




Fig. 74 Database Architecture of DPP.BOATS to handel intervention reports and usage data

9.6 Graduation Brief





IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	<input style="width: 90%;" type="text"/>	IDE master(s)	<input checked="" type="checkbox"/> IPD	<input type="checkbox"/> Dfi	<input type="checkbox"/> SPD
Initials	<input style="width: 90%;" type="text"/>	2 nd non-IDE master	<input style="width: 90%;" type="text"/>		
Given name	<input style="width: 90%;" type="text"/>	Individual programme (date of approval)	<input style="width: 90%;" type="text"/>		
Student number	<input style="width: 90%;" type="text"/>	Medisign	<input type="checkbox"/>		
		HPM	<input type="checkbox"/>		

SUPERVISORY TEAM

Fill in the required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	<input style="width: 90%;" type="text"/>	dept./section	<input style="width: 90%;" type="text"/>	! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why. ! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter. ! 2 nd mentor only applies when a client is involved.
mentor	<input style="width: 90%;" type="text"/>	dept./section	<input style="width: 90%;" type="text"/>	
2 nd mentor	<input style="width: 90%;" type="text"/>			
client:	<input style="width: 90%;" type="text"/>			
city:	<input style="width: 90%;" type="text"/>	country:	<input style="width: 90%;" type="text"/>	
optional comments	<input style="width: 95%;" type="text"/>			

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF

-> to be filled in by the Chair of the supervisory team

Sign for approval (Chair)

Name _____ Date _____ Signature _____

CHECK ON STUDY PROGRESS

To be filled in by SSC E&SA (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total _____ EC	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%;"></td> <td style="width: 10%; text-align: center;">YES</td> <td style="width: 70%;">all 1st year master courses passed</td> </tr> <tr> <td></td> <td style="text-align: center;">NO</td> <td>missing 1st year courses</td> </tr> </table>		YES	all 1 st year master courses passed		NO	missing 1 st year courses
	YES	all 1 st year master courses passed					
	NO	missing 1 st year courses					
Of which, taking conditional requirements into account, can be part of the exam programme _____ EC							

Comments:

Sign for approval (SSC E&SA)

Name _____ Date _____ Signature _____

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM

-> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	<input type="checkbox"/>	Supervisory Team approved
NO	<input type="checkbox"/>	Supervisory Team not approved

Comments:

Based on study progress, students is ...

<input type="checkbox"/>	ALLOWED to start the graduation project
<input type="checkbox"/>	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name _____ Date _____ Signature _____

DESIGN FOR our future
TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student _____ Student number _____

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
 Complete all fields, keep information clear, specific and concise

Project title Redesigning the Optimist Dinghy: A Circular Approach to Sustainable Boat Manufacturing

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Optimist sailing dinghy (see Figure 01) was conceived in 1947, standardized in 1960, and consolidated as a strict one-design in 1995. At present, over 170,000 Optimists are officially registered in the class across more than 115 countries world-wide, making it an icon of the sailing sport, with roughly just as many unregistered Optimist that mostly don't strictly comply with the one-design rules and are used as schooling boats. Countless children have learned to sail in an Optimist thanks to its low cost, ease of operation, and overall accessibility. Less positive is the impact made by such dinghies once they are no longer fit for use (see Figure 02), when many boats get abandoned or sent to landfill, as no viable option for glass fibre composite recycling has been found to date. This MSc project aims to tackle that challenge, looking at the product itself and then especially its materials and manufacturing technology, options for remanufacturing engineering, product lifecycle data management, and business models for product lifetime extension.

The main stakeholders include:

- Khulula, a brand by Ecologii GmbH: A consultancy pioneering eco-friendly watersports manufacturing.
- Sailors and Outdoor Enthusiasts: Consumers seeking sustainable alternatives without sacrificing performance or affordability.
- Sailing schools: Often the owner of Optimists. Act as fleet managers and take care of boat/do repairs.
- Boat Manufacturers (Jade Yachting Wilhelmshaven): Companies exploring sustainable materials and production methods to meet regulations and market demand. Could offer remanufacturing services.
- Recycling Companies: Specialists in material recovery and reuse, essential for a closed-loop system.
- Regulatory Bodies and Environmental Organisations (World Sailing, Umweltbundesamt): Advocates of sustainable marine practices and stricter policies.

→ space available for images / figures on next page

introduction (continued): space for images



image / figure 1 Optimist sailing dinghy, iconic international regatta class for children aged 8 to 15 years



image / figure 2 Example of abandoned and sunk boat causing environmental harm



Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

The number of obsolete creational boats in Europe is estimated to be above 30.000 per year. No viable option has been found to recycle them to date. Partly due to the logistical challenge, most of these boats are essentially left behind to degrade in some backyard or they are shredded and landfilled, causing environmental harm and becoming a burden for harbours and municipalities. Optimists are part of this environmental issue. However, due to the high standardisation of Optimists, their simplicity and sentimental value to most sailors, they offer a suitable platform for sustainable development.

Reasons for obsolescence and its timing need to be understood to effectively tackle this issue. Based on these insights new Optimists have to be built in a less environmentally damaging way, preventing these EoL challenges in the first place. Options for product lifetime extension through repair and remanufacturing need to be explored. To make this happen an efficient information flow needs to be set up that allows for planning and strategic intervention. In a circular future the Optimist lasts longer and materials stay in the loop, allowing for exiting business opportunities for boat builders and alleviating the burden that boats currently become, once obsolete.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Designing the circular future of the iconic Optimist sailing dinghy, focusing on material- and information-flows to facilitate more sustainable manufacturing, prolonged use (repair/remanufacturing) and higher recycling rates to enable more environmentally friendly sailing and inspire sustainable change.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

- Identify reasons and timing of Optimist obsolescence
- Research current practice of boat dismantling and refurbishment to identify barriers and drivers for an extended lifetime
- Analyse value development of Optimists
- Identify promising ways (design, manufacturing and processes) to make the Optimist more sustainable
- Investigating business models that facilitates reuse, remanufacturing and recycling of Optimists
- Map key players and their responsibilities in a circular economy of Optimists
- Use sustainability evaluation methodologies such as LCAs to support design decisions
- Identify reasons that disrupt a circular value chain and design interventions to close these gaps
- Derive design principles that are applicable to other boat classes and outdoor sports products too

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).

Make sure to attach the full plan to this project brief. The four key moment dates must be filled in below

Kick off meeting _____

Mid-term evaluation _____

Green light meeting _____

Graduation ceremony _____

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	<input type="checkbox"/>
For how many project weeks	22
Number of project days per week	5,0

Comments:

I am planning for 10 days off (two weeks) due to public holidays and additional holidays --> 22-2=20 weeks total

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.

(200 words max)

I have a background in engineering with a focus on material sciences and I transitioned into product design for my masters. I have a deep commitment to sustainability and enjoy doing outdoor sports. When I was younger I was sailing a Optimist biweekly and watersports still have a special place in my heart. For these reasons this project serves a lot of my personal and professional interests, which is why I chose to pursue it for my master thesis.

These are personal ambitions I want to pursue with this project:

- Learn more about sustainability evaluation methods
- Use design methodology to make my design process understandable
- Come up with a good physical and digital showcase of my design outcome
- Showcase/improve project management skills both in terms of time management and communication with multiple stakeholders
- Get to know companies and industry sectors for potential employment after graduation

Optimistic Futures

Open Access approach to Digital Product Passports for Boats

Béla Steiner – Integrated Product Design – M.Sc. Thesis – TU Delft

