



Report

Deliverable D.2.1.3

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Title **ENGINEERING PROJECTS FOR THE RECONSTRUCTION
OF TWO PILOT BOATS & LIFE CYCLE ANALYSIS (LCA)**

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1. DELIVERABLE D.2.1.3 BACKGROUND

Within the framework of the TOFOLA Project, which focuses on preserving maritime heritage through digital innovation, for deliverable D.2.1.3 “ENGINEERING PROJECTS FOR THE RECONSTRUCTION OF TWO PILOT BOATS & LCA ANALYSIS” two emblematic vessels were selected as pilot cases: the Croatian batana and the Italian bragozzo. These traditional boats represent the cultural and technical richness of Adriatic seafaring and serve as models for exploring new methods of heritage conservation, including 3D digitalization and sustainable restoration.

The two case studies refers to engineering projects for the reconstruction of two pilot boats and together contribute to the TOFOLA Project’s broader goals of cultural preservation, digital accessibility, and sustainable maritime innovation.

2. CROATIAN PILOT BOAT

Batana is a historical wooden boat used mostly for fishing and transportation in the northern part of the Adriatic. It is flat bottomed, form 4-8m long, designed for shallow waters. Its name comes from the Italian word "battere" (to beat), rferring to the sound the flat bottom makes when hitting the water.

Short description of the activities

The reconstruction will be divided in two separate paths, one will be focused on reconstruction of the acquired wooden batana, using traditional methods in wooden boatbuilding. Second will be focused on new materials and technologies in boatbuilding, but with preservation of traditional shape and look of batana.



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Traditional reconstruction activities

Traditional reconstruction will consist of several steps:

1. Removal of rotten wood elements
2. Scraping of old paint
3. Sanding of remaining wood
4. Recreation of removed elements using oak and pine wood
5. Filling of board joints
6. Waterproofing of elements
7. Painting

Modern reconstruction activities

Modern reconstruction will consist of several steps:

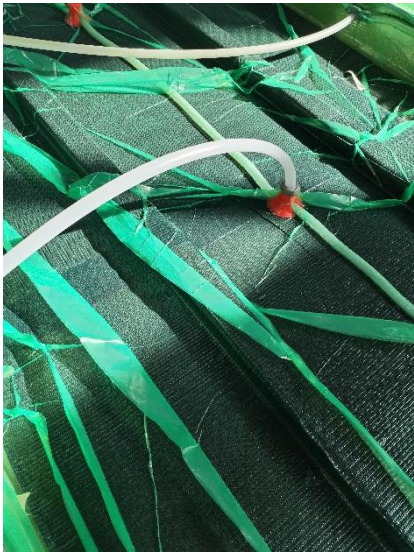
- Digitizing the shape and structure of batana using ProLiner
- CNC milling of styrofoam model using Fusion software
- Mould production from modelled Styrofoam
- Vacuum infusion with flax fibres and epoxy resin. During vacuum infusion special consideration is given to leaks since they cause the final product to be defective. Leaks are tested with FLIR leak detector.
- Demoulding and surface detailing - polyethylene used for structure elements will be 40kg/m³ EPE foam, containing 30% recycled content and is 100% recyclable to keep the process within reasonable ecofriendly limits.



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Milling process



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Vacuum infusion process

Raw Flax fibre

Technical description of batana

Overall dimensions of batana are as follows:

- Length: 5,460m
- Breadth: 1,985m
- Height: 0,520m

Batana is made of oak and pine tree, in transverse framing system. Structural elements are of oak, and planks are of pine tree.

Bow post is 80x50mm, narrowed in the front to hold the planks. It sits on a centre 110x20mm bottom girder which continues into a stern keel at the last third of the bottom length finished at 300x80mm. There are two side planks 200x30mm at the first third of the bottom length.

Bottom planks are 135x20mm. Bottom and deck frames are 65x40mm, side frames are 50x40mm. Side plating is made of 8mm planks, 180mm in height.

Batana is a traditional fishing boat made for rowing, there is one bench with wooden oar holders at frame 5 and one small triangular bow bench.

Batana reconstructed in a modern way will be adjusted to meet the needs of disabled persons. There will be sufficient space to accommodate people in wheelchair.

Drawings of modern flax fibre batana are given in Annex.

Accessibility solutions

A lot of consideration has been given to accessibility options for boarding of disabled persons. Since batana is a small vessel, it is our recommendation not to install any additional systems on the vessel due to possible stability issues during transfer of disabled people from



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and to the vessel. Therefore, the best solution for disabled people to board the batana is ensuring a lifting davit on quay.

Depending on the nature of sailing, whether it is a round trip or a line transfer, quay davit should be adjusted to lift only the disabled person or the complete wheelchair and put them on a designated place on board.



Quay davit example

Life cycle analysis (LCA)

This Life Cycle Analysis evaluates the environmental impacts of reconstructing a 6-meter wooden batana using flax fibres and bio epoxy resin as an alternative to traditional wooden construction. The analysis covers the entire life cycle of the boat, from raw material extraction to end-of-life disposal.

a) Raw Material Extraction and Processing

Flax is a renewable resource grown primarily in Europe and Canada. Its cultivation requires minimal pesticides and fertilizers compared to other crops. Processing involves retting, scutching, and hackling to extract fibres, which is energy-intensive but has a lower carbon footprint than synthetic fibres.



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Bio Epoxy Resin is derived from plant-based sources such as soybean oil or linseed oil. Production involves chemical processing, which emits greenhouse gases (GHGs) but is less energy-intensive than petroleum-based epoxy. It is biodegradable and non-toxic compared to traditional epoxy resins.

Traditional Wooden Construction requires high-quality timber, often from slow-growing hardwood trees. Logging and processing contribute to deforestation and habitat loss. Energy-intensive drying and treatment processes are required to make the wood durable.

Comparison

Flax fibres and bio epoxy resin have a lower environmental impact in terms of resource depletion and GHG emissions compared to traditional wood.

b) Manufacturing and Construction

Flax fibres are woven into mats and combined with bio epoxy resin to create composite panels. The process requires less energy than traditional woodworking and produces minimal waste. Lightweight and strong, reducing fuel consumption during the use phase.

Traditional wooden boatbuilding involves cutting, shaping, and joining wooden planks, which generates significant waste. Requires skilled labour and energy-intensive tools. Heavier construction may lead to higher fuel consumption during use.

Comparison

Flax-bio epoxy construction is more energy-efficient and generates less waste than traditional wooden construction.

c) Use phase

Lightweight design of flax-bio epoxy boat improves fuel efficiency if the boat is motorized. Resistant to rot, UV degradation, and marine borers, reducing maintenance needs. Long lifespan comparable to traditional wooden boats.

Traditional wooden boat requires regular maintenance (e.g., sanding, varnishing, and treating for rot). Susceptible to damage from marine organisms and weathering. Higher maintenance costs and environmental impacts over time.



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Comparison

The flax-bio epoxy boat has lower maintenance requirements and environmental impacts during the use phase.

d) End of life disposal

Flax fibres are biodegradable, and bio epoxy resin can be broken down under specific conditions. There is potential for recycling or repurposing composite materials. Lower environmental impact compared to other fibre materials.

Wood can be repurposed or recycled, but treated wood may release harmful chemicals. Disposal in landfills contributes to methane emissions if not properly managed.

Comparison

The flax-bio epoxy boat has a more sustainable end-of-life profile due to its biodegradable and recyclable components.

e) Environmental impact assessment

Global Warming Potential: Flax-bio epoxy construction has a lower carbon footprint due to renewable materials and reduced energy use.

Resource Depletion: Flax and bio epoxy rely on renewable resources, whereas traditional wood construction contributes to deforestation.

Toxicity: Bio epoxy resin is less toxic than petroleum-based alternatives and traditional wood treatments.

Waste Generation: Flax-bio epoxy construction generates less waste during manufacturing and has better end-of-life options.

f) Conclusion

Reconstructing a 6m wooden boat using flax fibres and bio epoxy resin offers significant environmental benefits over traditional wooden construction. By optimizing material sourcing, improving production efficiency and designing for recyclability, the environmental footprint can be significantly reduced. It is highly recommended to develop standardized



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recycling processes for bio-composite materials and promote flax cultivation and bio epoxy production to support sustainable industries.

While the initial costs of flax-bio epoxy materials may be higher, the long-term environmental and economic benefits make it a sustainable alternative for boat reconstruction.

By adopting flax fibres and bio epoxy resin, the marine industry can reduce its environmental impact while maintaining high-performance standards.

Approximate CO2 emissions comparison in all 4 stages are given below.

	Material	WOOD	FLAX	EPOXY RESIN
	Weight [kg]	600	50	75
Raw material extraction and processing	Unit emission	0,8	0,8	2,2
	Total emission	480	40	165
Manufacturing and construction	Unit emission	0,4	0,6	0,6
	Total emission	240	30	45
Use phase		Considering the same propulsion on both boats, only maintenance has been taken into consideration		
End of life disposal	Unit emission	0,2	0,2	2
	Total emission	120	10	150

Maintenance (Annual Estimate for Batana)

Maintenance Activity	Wooden Boat (kg)	Flax Fiber Boat (kg)
Antifouling Paint & Coatings		
Varnish/ Epoxy Repairs		
Structural Repairs (Wood vs. Composite Patches)		
Total Annual Maintenance Emissions		

Regarding end of life, more detailed analysis of recycling possibilities is given.



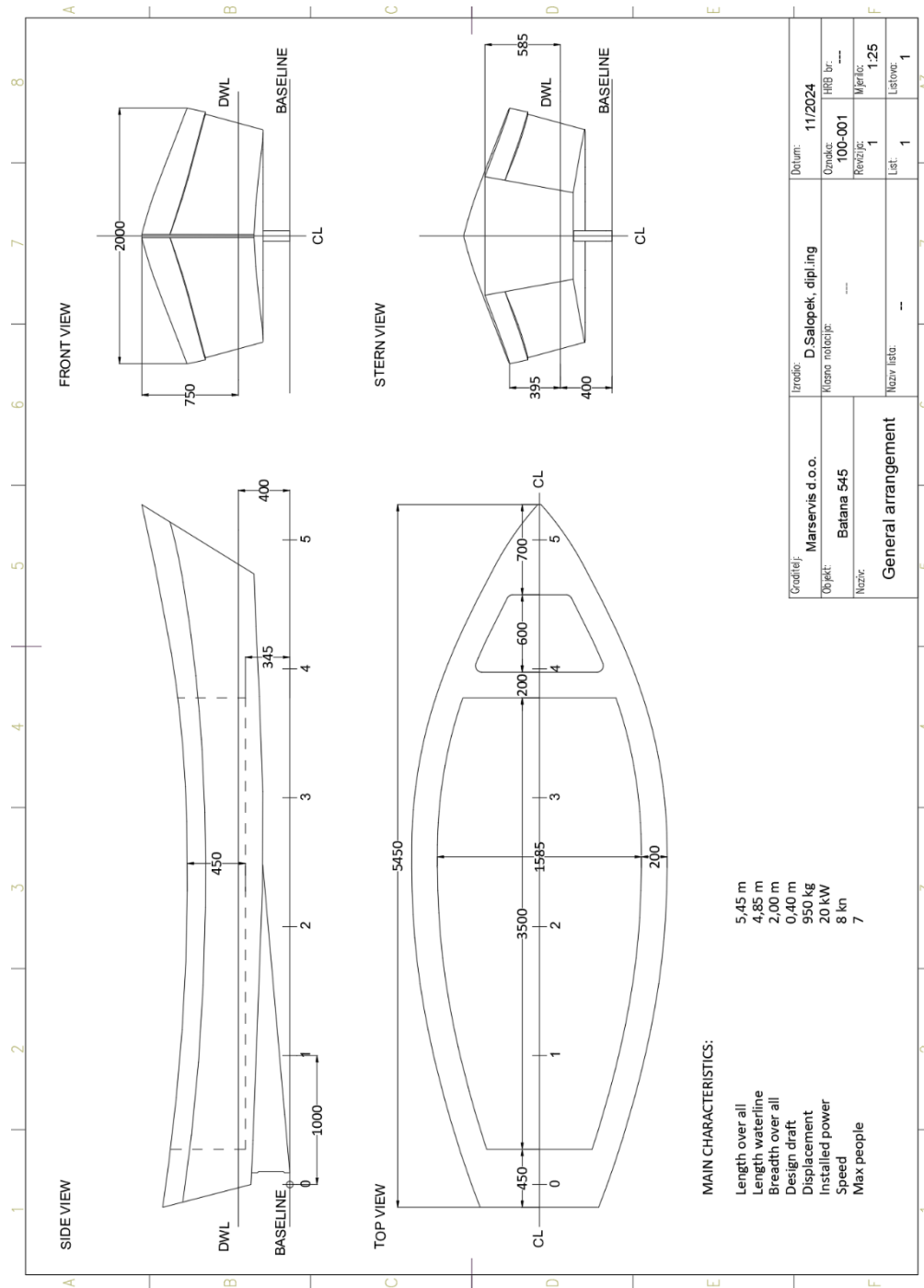
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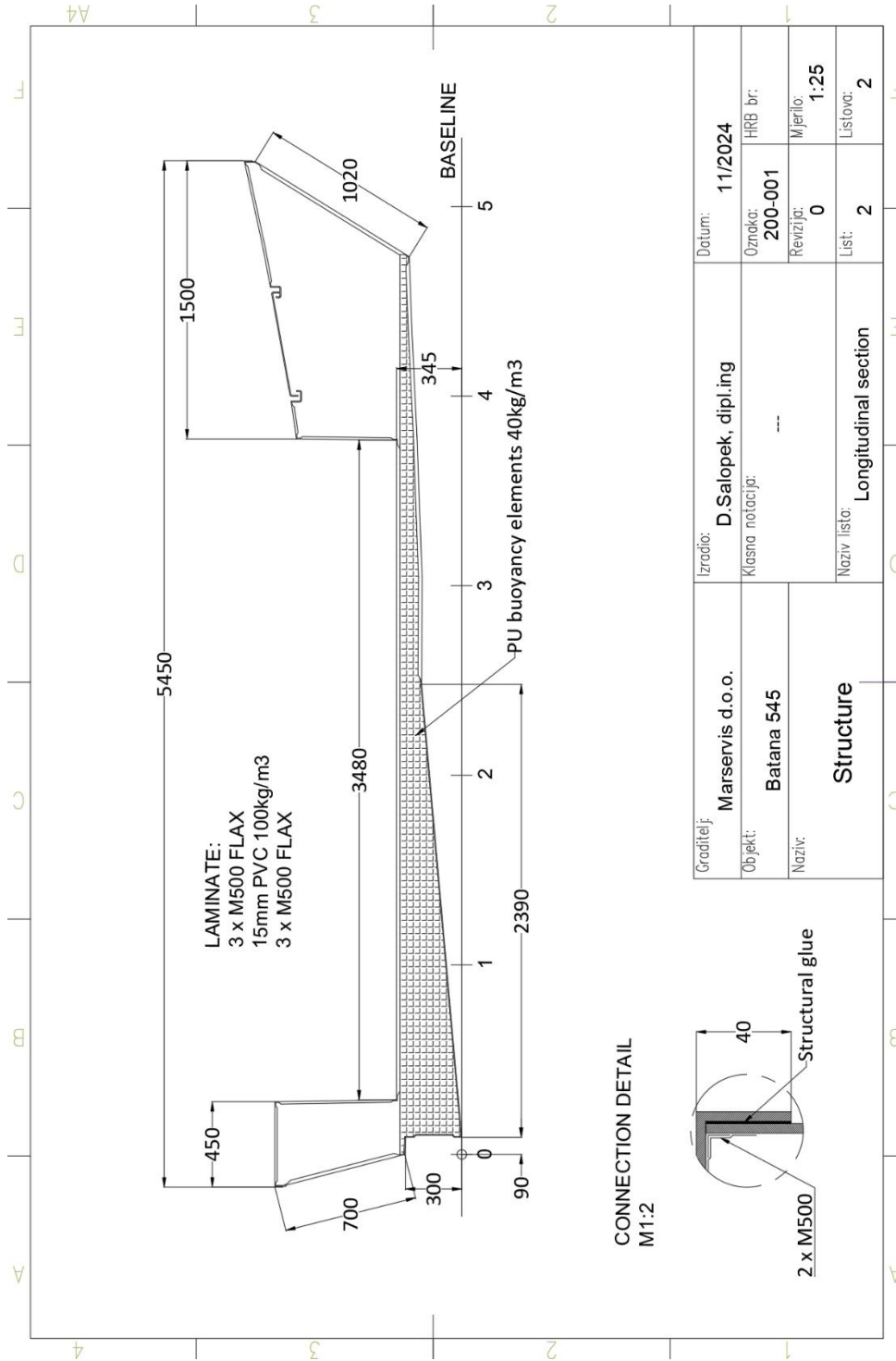


Material	Recycling Method		Recyclability (%)	Environmental Notes
Wood	Mechanical recycling (chipping, repurposing)	0.05 - 0.2	80-100%	Can be repurposed into new wood products
Flax Fibers	Mechanical fiber recovery	0.1 - 0.3	50-80%	Can be reused in composites, but fiber degradation limits reuse.
Bio-Epoxy Resin	Thermal recovery (pyrolysis/incineration)	2-5	5-30%	Limited recyclability. Some bio-resins are compostable, but most require energy-intensive processes.
Fiberglass (for comparison)	Grinding, landfill, or incineration	5-8	0-10%	High energy use in recycling. Often ends up in landfills.



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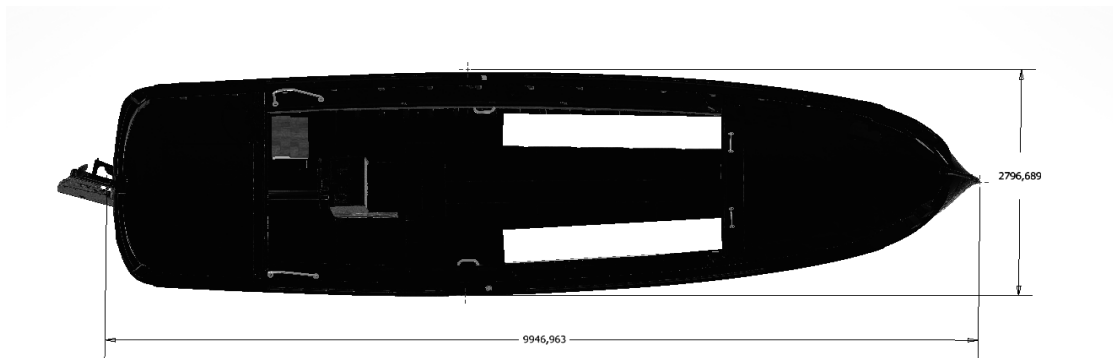


Graditelj:	Marservis d.o.o.	Izradio:	D. Salopek, dipl.ing	Datum:	11/2024
Objekt:	Batana 545	Klasna notacija:	---	Oznaka:	200-001
Naziv:	Structure	Naziv lista:	Longitudinal section	Revizija:	0
				Mjerilo:	1:25
				List:	2
				Listova:	2

3. ITALIAN PILOT BOAT

The bragozzo (also known as baragozzo or bracozzo) is a traditional fishing and/or cargo vessel typical of the central and northern Adriatic Sea, historically used for coastal trade extending as far as the Ionian Sea.

The Italian pilot boat in TOFOLA Project is a bragozzo dating back to 1948. It is in excellent condition both structurally and in terms of its decorative elements. It measures 9.9 meters in length and 2.3 meters in beam.



Restoration of the Italian boat

The boat selected for the project was chosen due to its excellent state of preservation, significantly reducing the need for extensive restoration. This favorable condition allows a primary focus on maintenance and the implementation of accessibility measures.

Preliminary maintenance and repair activities

To ensure the boats's maintenance in optimal condition, preliminary conservation measures were undertaken prior to the implementation of the planned accessibility modifications.



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These interventions encompassed the application of antifouling treatments, the rectification of discrepancies in onboard accessories, and the remediation of minor hull defects, including small perforations.

Future maintenance and conservation needs

As a historic wooden vessel over 75 years old, the boat will require ongoing routine maintenance as well as targeted conservation measures specific to its age and material composition. In particular, specialized interventions will be undertaken to preserve the integrity of the wood and the hand-painted decorative elements, which are of both historical and aesthetic value.

To support this, the wooden structures will be treated with suitable protective products, helping to prevent deterioration while respecting the boat's original materials.

General inspections and light restoration works will be carried out as needed to maintain the boat's overall condition. In addition, the metal fittings and profiles—some of which may show signs of wear—will be carefully cleaned, smoothed, and refinished to restore their original appearance and ensure full functionality.





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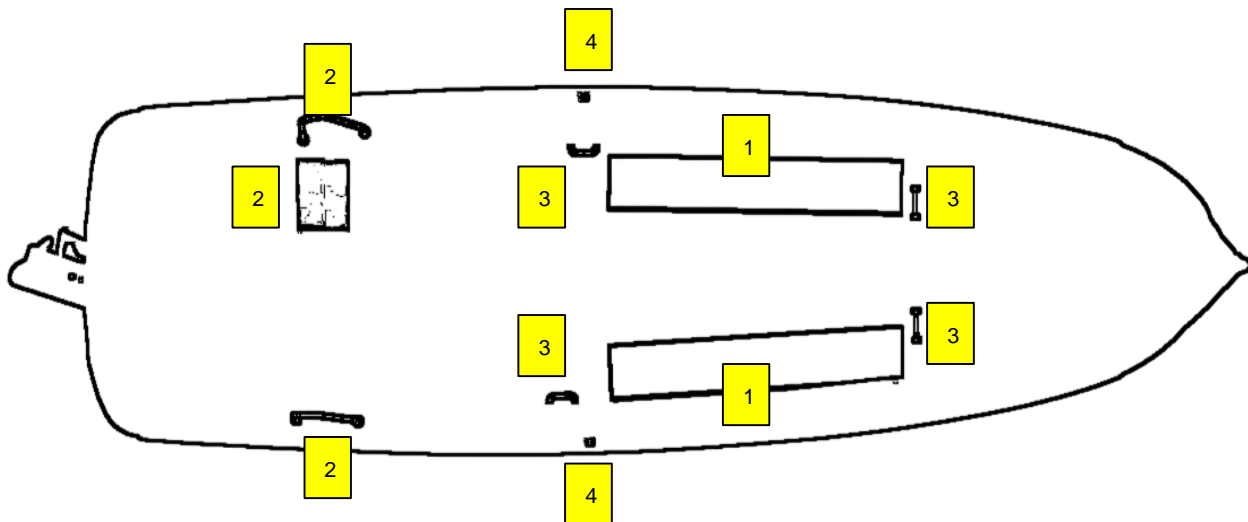


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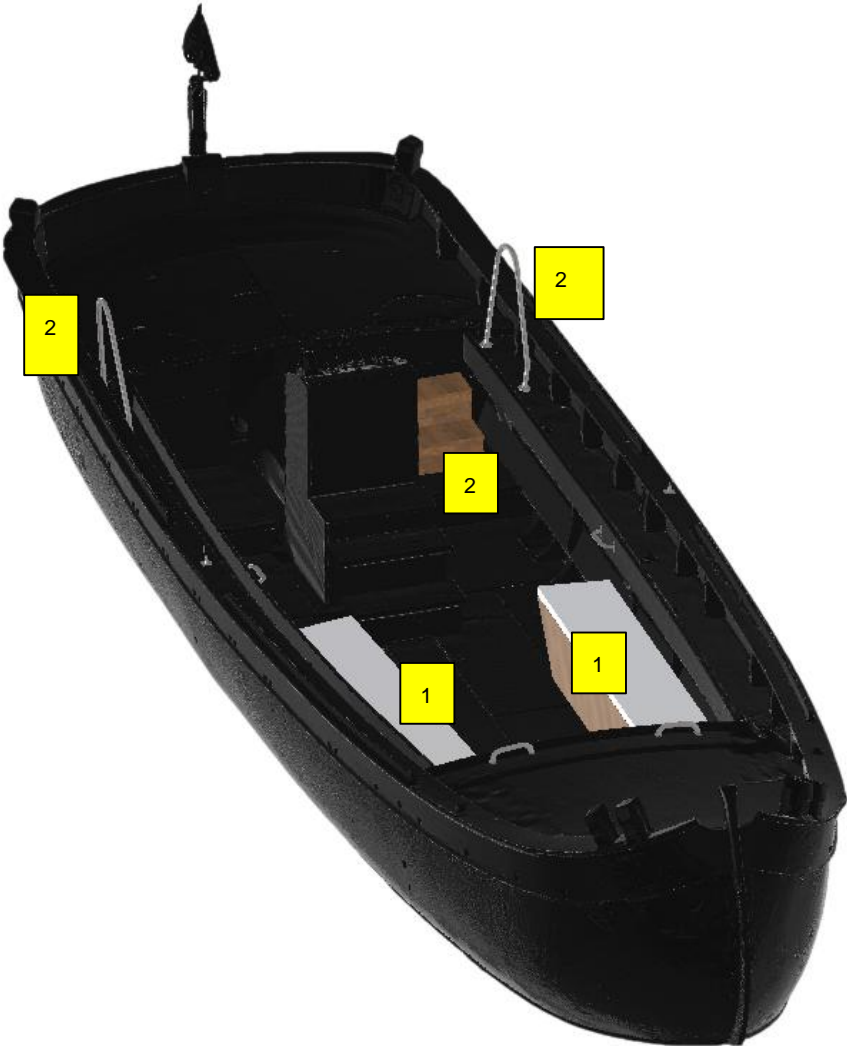


Accessibility solutions

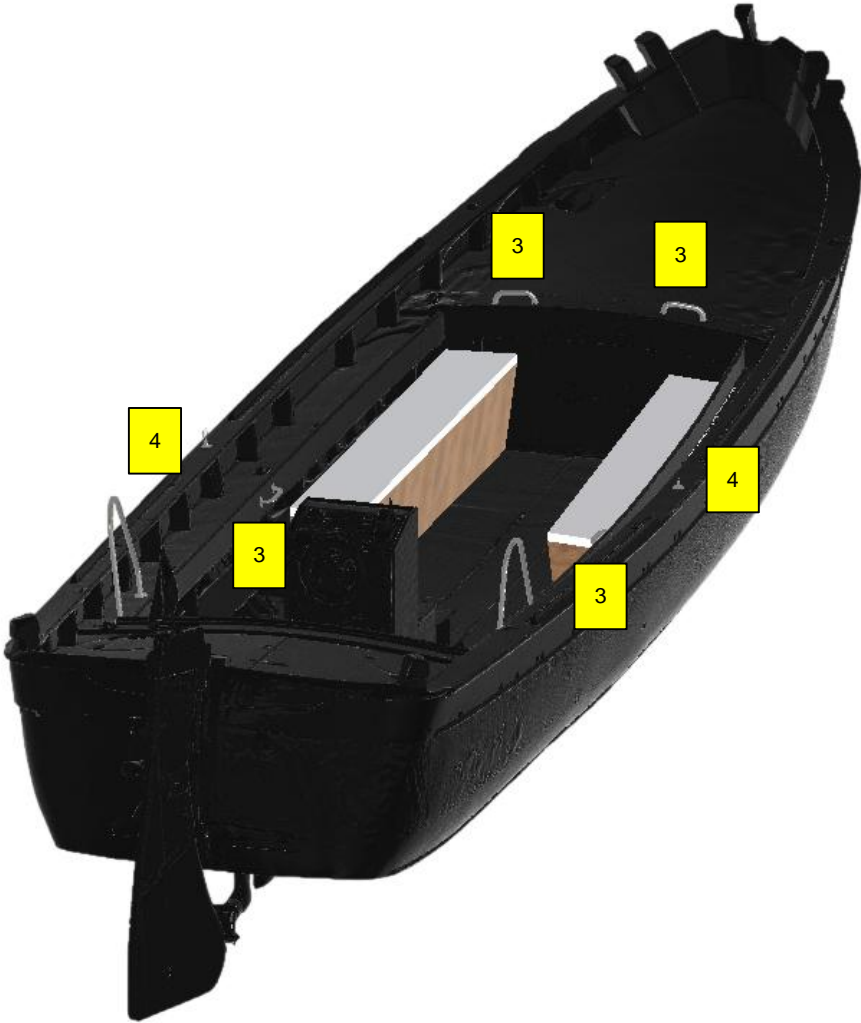
In collaboration with the University of Padua, the most suitable technological equipment and design solutions were identified to ensure accessibility while preserving the historical integrity of the vessel. All interventions were meticulously planned to safeguard the vessel's heritage value and avoid any compromise to its authenticity.



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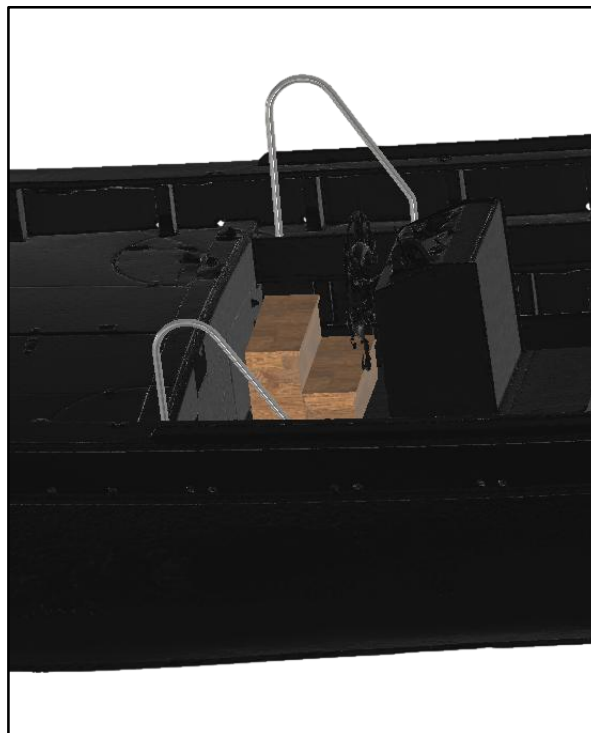
To enhance accessibility for individuals with motor disabilities, stable and spacious wooden seating areas (1) will be installed, equipped with robust handholds (3) to provide additional support and ensure safety while on board.



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Similarly, to facilitate boarding, a wooden boarding ladder will be installed along with handrails (2) designed to assist individuals with balance difficulties, including elderly passengers.



The solutions recommended and supported by the University of Padua, selected for implementation, focus primarily on the strategic placement of handrails and grab handles to provide secure points of support throughout the vessel.

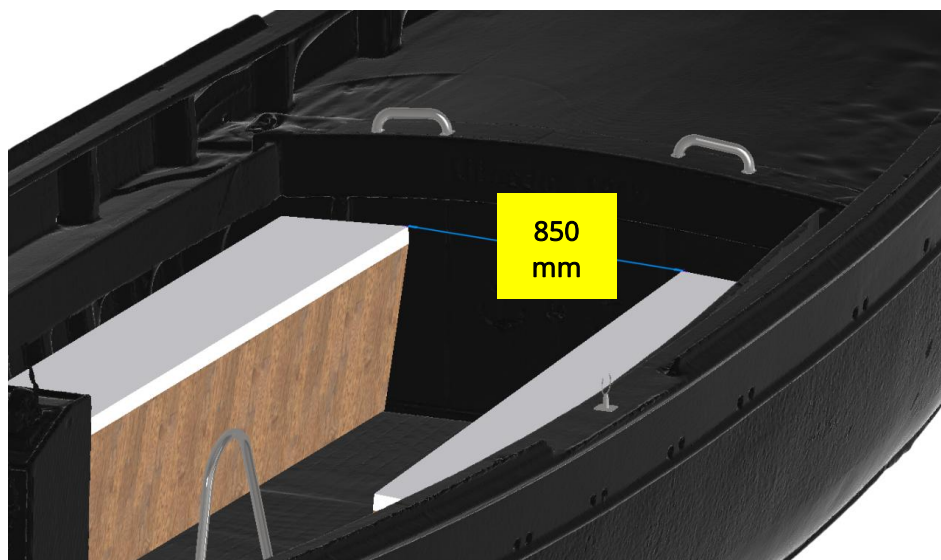
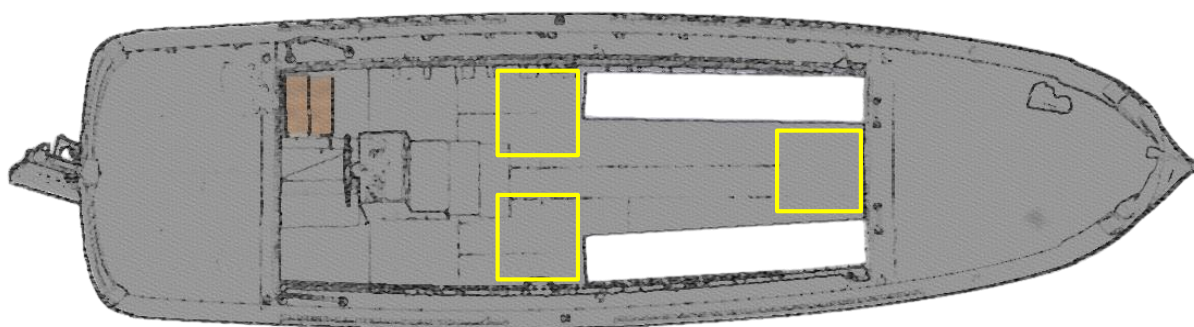
In addition, dedicated tie-down straps will be installed to safely secure wheelchairs in designated areas. These spaces have been carefully designed to accommodate standard wheelchair dimensions and will include appropriately positioned handholds for attaching the securing straps.



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Each yellow-marked area below measures 80 by 100 cm, offering sufficient space to comfortably accommodate a wheelchair.



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Following additional guidance from the University of Padua, measures have also been developed to address non-motor disabilities, including sensory impairments. To enhance the onboard experience for individuals with visual or hearing impairments, traditional wooden oars and oarlocks (4) will be installed, enabling users to engage with the tactile and physical experience of rowing.



Life Cycle Assessment (LCA)

This document presents the Life Cycle Assessment (LCA) of the Venetian bragozzo acquired and restored as part of the TOFOLA project. The aim is to evaluate the environmental and social impact associated with the recovery, maintenance, and adaptation of the vessel for cultural and inclusive purposes.



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Goal and Scope Definition

This LCA aims to:

- Quantify the environmental benefits of reusing the bragozzo instead of building a new vessel.
- Assess the environmental impact of maintenance activities and accessibility improvements.
- Highlight the added social value generated by the TOFOLA project.

Boat Description

- Type: Venetian bragozzo
- Shipyard: Nezzo Gentile, Chioggia
- Year of construction: 1948
- Engine: AB Volvo Penta – 55 kW
- Length: 9.9 m
- Beam: 2.3 m
- Engine number: 5102981976
- Purchase price: €45.000,00 + VAT
- Intended use: Navigation, cultural events, social inclusion

System boundaries and methodology

The assessment considers the following stages:

- Original construction (estimated based on typical 1940s materials: wood, ironwork, steel)
- Routine maintenance conducted in 2024 (hull painting, engine inspection)
- Planned interventions for improved accessibility
- Direct emissions during current use
- Extended service life as an alternative to new boat construction

Exclusions: detailed historical production data, original surface treatments, and past emissions.



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Simplified Life Cycle Inventory (LCI)

Phase	Action Taken or Planned	Environmental Impact
Original Production	Wooden and metal construction (1948)	Impact amortized over time
Routine Maintenance (2024)	Hull repainting, engine inspection	Limited waste, VOC emissions from paint
Current Use	Diesel engine navigation (55 kW)	CO ₂ , NO _x , particulate matter emissions
Accessibility Upgrades	Handrails, supports, ladder, seats, wheelchair spaces	Moderate emissions, high social impact
End-of-Life Avoided	Reuse instead of demolition	Significant CO ₂ and waste reduction

Accessibility Measures

The following upgrades will be implemented to improve accessibility:

- Installation of handrails and supports for balance and safe movement.
- Rearranged seating for enhanced comfort and stability.
- Two designated spaces for wheelchairs with secure anchoring.

These measures enhance usability for people with disabilities, children, and elderly individuals, contributing significantly to the project's social value.



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Impact Assessment (LCIA)

Category	Estimated Environmental Impact
Direct Emissions	Moderate (engine use and maintenance)
Natural Resources	Minimal new material use due to reuse
Waste	Limited to maintenance phase
Climate (CO ₂)	Over 10 tonnes avoided vs. new build
Inclusivity & Social Impact	Very high: universal access and cultural valorization



4. CONCLUSIONS

The restoration and adaptive reuse of the TOFOLA batana and bragozzo represent an environmentally sustainable and socially significant approach.

By avoiding the environmental impact associated with constructing a new boats, this initiative contributes to sustainability while preserving the historical maritime heritage of Venice.

The accessibility enhancements further position the boats as a model of inclusive navigation and innovation grounded in tradition.

Alongside the bragozzo, the batana also plays a key role in showcasing the value of traditional boatbuilding practices, demonstrating how heritage vessels can be revitalized for contemporary use while respecting their cultural significance.

Life Cycle Assessment (LCA) analysis has confirmed that the environmental impact of restoring and reusing an existing boats is significantly lower than that of building a new ones, further validating the sustainable nature of the project.

