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Integrating Sustainability and Innovation in Traditional Wooden Boat Reconstruction: TOFOLA Project

Abstract

This paper explores environmentally friendly approaches in the reconstruction process of traditional wooden boats, focusing on sustainability, innovation, and the preservation of maritime heritage. Through the TOFOLA project, methods that combine traditional shipbuilding with modern technologies, such as reverse engineering and digital modelling, are analysed to ensure the authenticity and longevity of the restored vessels. Special attention is given to the procurement of materials, the use of local and certified wood, and reducing the ecological footprint throughout the boat's life cycle. Solutions for environmentally friendly propulsion and the integration of reconstructed boats into sustainable tourism along the Adriatic coast are also considered. The conclusions of this research highlight the importance of synergy between traditional craftsmanship, innovative engineering solutions, and environmentally conscious logistics of wood procurement to preserve and revitalize the maritime cultural heritage of the Adriatic region.

Keywords: traditional wooden boats, sustainable reconstruction, eco-friendly materials, TOFOLA project

1. Introduction

The TOFOLA project [10] has been designed to generate sustainable (economically, environmentally and socially) tourist products based on the historiography of shipbuilding during the Serenissima Republic of Venice to diversify the current tourist services in the Northern Adriatic area and promote underexploited destinations. The main challenge the project aims to address is the diversification of touristic flows aimed at ensuring equal access to tourist destinations and cultural heritage [11].

To face this challenge, the TOFOLA project starts from the notion that the area represented by the coastal provinces of the Veneto Region, the Friuli Venezia Giulia and Istria Regions has got a strong history, characterised by the supremacy of the Serenissima Republic of Venice that determines a very culturally rich environment to be exploited for tourism purposes.

The project aims to contribute to the development of the cross-border area by starting from what constitutes the 'intangible' and common foundations: the historical memory and local traditions of the above-mentioned regions. However, these are not intended as mere testimonies of the past or museum material, but as a means of bringing people back in an active and conscious way to the waterways that have contributed so much to this region and which are now largely underused, starting with the historic forests (of the plain in Veneto region, Cansiglio in Friuli Venezia Giulia region and Montona in Istria region) and their wood, which today, as then, provide for the construction of historic and traditional boats to be used for tourism purposes. The project intends to achieve this goal by bringing together local citizens and workers in a project revives the past by connecting it to the present and future with creativity and innovation.

The reconstruction of traditional wooden boats offers an opportunity to preserve maritime heritage while embracing sustainable practices in shipbuilding. Throughout history, wooden boats have been integral to coastal communities, serving purposes ranging from fishing and trade to transportation and cultural identity. However, the rise of industrial shipbuilding and modern materials such as fiberglass and metal have led to the decline of traditional shipbuilding techniques and a loss of craftsmanship. Today, there is a growing interest in reviving these boats, not only for their historical significance but also as part of sustainable tourism and environmentally friendly maritime practices. The TOFOLA project, an initiative dedicated to the reconstruction of traditional wooden vessels along the Adriatic coast, aims to integrate heritage conservation with innovative and eco-friendly approaches.

The paper starts with detailing the historical and cultural significance of the *batana* boat, a traditional wooden fishing vessel integral to the maritime heritage of Rovinj, Croatia. It emphasizes the boat's design which is uniquely adapted to the shallow waters of the Adriatic Sea, making it vital for local fishermen.

Following this, the preservation efforts for the *batana* boat are discussed, particularly through the Batana Eco-Museum, which is recognized by UNESCO. This

museum promotes the continuity of traditional boat-building techniques and organizes community-centric sailing events, ensuring that the legacy of the *batana* is sustained for future generations

The third paragraph then shifts to specific sustainable practices in the reconstruction and use of the *batana* boat. It explains how sustainable boatbuilding is implemented by selecting environmentally friendly materials and employing low-impact construction techniques. The use of certified wood, natural sealants and recycled materials emphasizes the commitment of the project to minimize environmental impacts.

Next, the text delves into the sourcing and selection of wood for constructing the *batana*, maintaining historical accuracy while integrating modern sustainability standards. The selection of appropriate timber plays a crucial role in balancing historical accuracy with ecological responsibility. This section discusses efforts to source wood from sustainably managed forests, including the use of FSC (Forest Stewardship Council) [7] and PEFC (Programme for the Endorsement of Forest Certification) [15] certified timber, as well as the potential of reclaimed or repurposed wood to reduce the environmental impact.

Further, the discussion in the next paragraph extends to the structural and functional design considerations in the reconstruction of the *batana*. It covers the detailed engineering aspects that ensure the boat is suited for shallow waters while incorporating modern enhancements for durability and functionality.

The paper concludes with a broader look at the reverse engineering and digital modelling techniques used in the reconstruction of the *batana*. This process involves detailed analysis and 3D documentation of existing *batana* boats to preserve their design accurately. The application of CAD and other digital tools facilitates precise reconstruction, ensuring that the *batana* remains a functional and sustainable vessel honouring its rich heritage.

2. The *batana* boat and its historical significance

The *batana* boat is a traditional wooden fishing vessel deeply rooted in the maritime heritage of Rovinj, a historic town on the western coast of the Croatian Istrian peninsula. With its flat-bottomed design, the *batana* is uniquely suited for navigating the shallow waters of the Adriatic Sea, particularly in the coastal lagoons and rocky shores surrounding Rovinj. This feature made it indispensable for generations of local fishermen, allowing them to reach areas inaccessible to deeper-draft vessels. Figure 1 shows a typical rowing-type *batana* boat.

Figure 1. Rowing-type batana boat in Rovinj [12].

Traditionally constructed using local wood from forests in Istria and Veneto, the *batana* reflects centuries-old craftsmanship, passed down through oral tradition and apprenticeship among shipwrights. The boat length typically ranges from 4 to 8.5 meters and it was originally propelled by oars, though many were later adapted for small outboard or inboard engines. The *batana* boat is considered an essential part of the cultural identity of Rovinj, as it provided a means of livelihood but also played a role in social and communal traditions, such as regattas and maritime festivities. A wireframe model of the *batana* is shown in Figure 2.

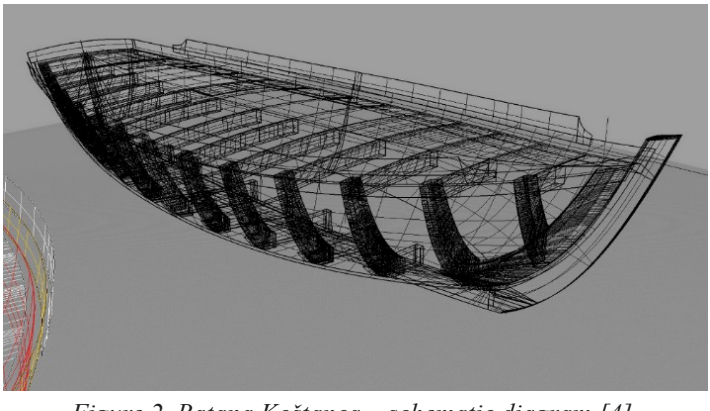

Figure 2. Batana Koštanca – schematic diagram [4].

Despite the advent of modern fishing vessels, the *batana* remains a symbol of Rovinj's maritime history. Today, it is actively preserved through initiatives such as the Batana Eco-Museum [3], recognised by UNESCO as an example of best practices in preserving intangible cultural heritage. This museum and its associated programs promote *batana*-building workshops, community sailing events, and historical documentation, ensuring that future generations remain connected to this maritime legacy. A 3D render of the *batana* is shown in Figure 3.

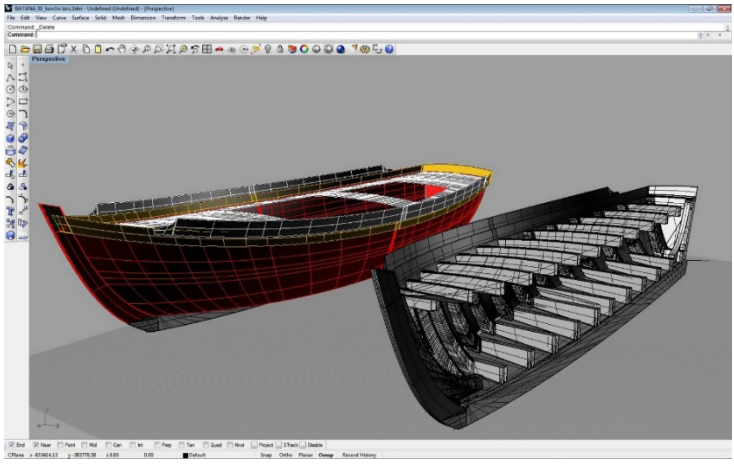

Figure 3. Batana Koštanca – 3D render [5].

The *batana* reconstruction as part of the TOFOLA project is more than a technical endeavour. It is a commitment to cultural revival, sustainable tourism, and local craftsmanship. By adhering to historical building techniques while incorporating modern sustainability principles, this initiative will ensure that the *batana* boat continues to be a living symbol of Rovinj's seafaring traditions. Therefore, the reconstruction of the *batana* presents a unique challenge: maintaining the authenticity of traditional craftsmanship while integrating modern building techniques to enhance efficiency, durability and sustainability. The TOFOLA project aims to strike a careful balance between these two approaches, ensuring that the *batana* boat retains its historical identity while benefiting from advancements in precision, materials and environmental considerations.

2.1. Sustainability and environmental considerations in reconstruction and exploitation

Sustainable boatbuilding relies heavily on the careful selection of materials, ensuring that environmental impact is minimised while preserving the historical integrity of traditional wooden vessels such as the *batana*. Historically, these boats were built using locally sourced hardwood (inner construction) and softwood (outer planking), primarily from the forests in Istria and the Veneto region. To maintain this authenticity while incorporating modern sustainability principles, the TOFOLA project prioritizes the use of certified sustainable timber, such as FSC or PEFC wood, ensuring that materials come from responsibly managed forests. Additionally, the project seeks to incorporate reclaimed or recycled wood whenever possible, reducing the need for fresh logging and promoting circular economy principles. Recognising the importance of responsible forestry management, sustainable replanting practices will be implemented to compensate for any wood used, maintaining ecological balance in forested areas. Waste minimisation strategies will also be employed, optimising cutting techniques to maximise material efficiency and repurposing wood offcuts for boat components or other applications. Furthermore, to reduce environmental contamination, the project emphasises the use of natural, biodegradable sealants and coatings rather than synthetic chemicals, which can enter into marine ecosystems and cause long-term harm.

The reconstruction of the *batana* boat will adhere to low-impact construction techniques, reflecting the eco-friendly nature of traditional shipwright craftsmanship. Historically, wooden boatbuilding has relied on manual skills and simple hand tools rather than industrial-scale manufacturing. The TOFOLA project will continue this practice by prioritising handcrafted techniques over machine-intensive processes, ensuring that boat construction remains sustainable. Non-toxic, water-based adhesives and finishes will replace chemical-laden alternatives, further reducing the ecological footprint of the reconstruction process. To minimise emissions related to transportation and wood procurement, materials will be sourced as locally as possible, and boat assembly will take place in regional workshops close to their intended deployment areas.

The propulsion systems of reconstructed wooden boats are a critical factor in their overall environmental impact. Traditionally, the *batana* boat was a rowing and sailing vessel, meaning it had zero emissions and operated in harmony with nature. As part of the TOFOLA project adaptation for modern tourism and accessibility, it is crucial to ensure that any propulsion modifications align with sustainable marine practices. To preserve tradition while minimising emissions, human-powered propulsion, such as rowing, remains the primary propulsion mode. However, the project also explores silent, non-polluting electric propulsion options, powered by renewable sources. Hybrid solutions, which integrate sails, rowing and electric motors, will be tested to enhance flexibility while maintaining a low environmental footprint. Furthermore, the establishment of solar charging stations at docking points will enable electric boat

batteries to be powered using renewable energy, ensuring that reconstructed *batanas* remain carbon-neutral in their operation. By promoting clean energy alternatives, the project actively contributes to preserving marine ecosystems and improving air quality in coastal regions.

Sustainability considerations extend beyond the construction and propulsion of the *batana* boat, as its entire life cycle is carefully planned to ensure long-term functionality and minimal waste. Through a Life Cycle Analysis (LCA) approach, the boat will be designed with durability and repairability in mind. When a *batana* reaches the end of its functional life, its materials can be disassembled and recovered through recycling, composting or repurposing, significantly reducing landfill waste. In cases where disposal is necessary, eco-friendly methods will be prioritised, such as biodegradable wood composting or energy recovery from wood waste. By integrating these principles of circular economy, the TOFOLA project will ensure that the environmental footprint of the *batana* remains minimal throughout its entire lifecycle, from construction to decommissioning.

A major environmental advantage of reconstructing wooden boats like *batana* is the significant reduction in marine pollution as they do not use fiberglass or plastic materials. The TOFOLA project enhances this sustainability by ensuring that the boats will not contribute to water contamination, habitat destruction caused by improper docking techniques damaging seagrass beds or carbon emissions. The project will also focus on community education, hosting workshops, public exhibitions and collaborations with marine conservation groups to raise awareness about sustainable maritime practices. By advocating for responsible navigation, waste management and pollution prevention, the TOFOLA project will establish an environmentally conscious approach to maritime heritage conservation.

Beyond its ecological considerations, the TOFOLA project aims to integrate the *batana* boat into sustainable tourism initiatives, leveraging its historical significance to promote eco-tourism. The reconstructed *batana* will serve as a platform for low-impact tourism activities, offering tourist experiences such as guided rowing tours, cultural storytelling excursions and noise-free boating. This will ensure that maritime heritage remains accessible to the public while promoting environmentally friendly tourism practices. Additionally, the project will actively engage local communities and artisans in the reconstruction process, ensuring that the economic benefits of heritage tourism are distributed equitably. Tourists will also be educated about maritime sustainability, gaining insights into traditional boatbuilding techniques, environmental protection measures and coastal heritage preservation. To maintain the sustainability of these tourism activities, limits will be implemented to prevent over-tourism, ensuring that the operation of the *batana* remains ecologically responsible. By aligning its initiatives with sustainable tourism principles, the TOFOLA project will ensure that reconstructed traditional boats are not only cultural artefacts but also functional assets contributing to environmental conservation, community development, and economic sustainability.

2.2. Selection and sourcing of wood for the construction of the *batana*

The selection and sourcing of wood for the construction of the *batana* plays a critical role in maintaining the authenticity, durability and sustainability of the reconstructed boats. As a vessel traditionally built using locally available timber, reconstructing the *batana* will follow strict material selection guidelines that honour historical accuracy while integrating modern sustainability standards. Ensuring that the wood is sourced responsibly is key to balancing cultural preservation with environmental conservation. Historically, *batana* boats were crafted using a combination of durable hardwoods and lightweight softwoods, chosen based on their strength, flexibility and resistance to moisture. The most commonly used species include:

◊ Oak (lat. *Quercus robur*, *Quercus petraea*) – highly resistant to water and decay, traditionally used for structural elements such as keels, ribs and frames (Figure 4).

Figure 4. Oak wood texture [13].

◊ Larch (lat. *Larix decidua*) – known for its natural resin content, offering superior resistance to rot, often used for planking and outer hull surfaces (Figure 5).

Figure 5. Larch wood texture [16].

◊ Pine (lat. *Pinus nigra*, *Pinus sylvestris*) – a lighter wood commonly used for decking, interior structures, and non-load-bearing components due to its workability and availability (Figure 6).

Figure 6. Pine wood texture [14].

◊ Elm (lat. *Ulmus minor*, *Ulmus laevis*) – historically used for elements in contact with water due to its natural resistance to splitting/moisture absorption (Figure 7).

Figure 7. English elm (hardwood) texture [6].

◊ Chestnut (lat. *Castanea sativa*) – occasionally used in traditional boatbuilding, known for its resistance to pests and fungal decay (Figure 8).

Figure 8. Chestnut wood texture [8].

With modern sustainability concerns, the sourcing of wood for the *batana* construction will follow strict environmental guidelines to minimise deforestation and ecological impact. The TOFOLA project places a strong emphasis on using wood that meets the highest environmental standards. One of the key principles is the selection of timber that carries FSC or PEFC certification, ensuring that all materials originate from responsibly managed forests. In addition to certified wood, the project prioritises local timber harvesting, which significantly reduces the carbon footprint associated with long-distance transportation while also supporting regional forestry economies. Where feasible, reclaimed and repurposed wood will be incorporated into the construction process, helping to maintain historical accuracy while minimising the need for newly felled timber, which will only be used when the existing wood is so badly damaged that it can no longer be used. The project will also include sustainable reforestation programs to ensure that for every tree used in the construction of the *batana*, new trees will be planted to maintain the ecological balance. In addition, low impact harvesting techniques will be used to protect the biodiversity of the forests. This avoids excessive clear-cutting and ensures that only mature, selectively chosen trees are felled for use in the project.

Once the timber is sourced, it will undergo a careful treatment process to improve its durability, resistance to marine conditions and aesthetic appeal. Traditional methods will play a crucial role in this process, beginning with natural air-drying, or seasoning, for up to a year to reduce moisture content and prevent warping. Steam bending techniques will then be employed, allowing planks to take on the characteristic curved forms of the *batana* without compromising structural integrity. The application of natural oils and resins, such as linseed oil and pine tar, will further enhance the resistance of wood to water penetration and microbial decay, ensuring long-term durability. The use of synthetic chemicals will be kept to a minimum, with a preference for traditional, biodegradable sealants that maintain the boat's eco-friendly construction. These time-honoured treatments will ensure that the reconstructed *batana* maintains the same longevity and seaworthiness as those built centuries ago.

Sourcing traditional boatbuilding timber has become increasingly challenging due to forest depletion, regulatory restrictions and climate change impacts. To address modern constraints in material availability, several adaptations have been introduced. Engineered wood products such as laminated oak will be used for structural components while preserving solid wood elements for the hull and decks to maintain authenticity, if feasible. The project will also experiment with thermally modified wood, which undergoes heat treatment to improve durability without relying on chemical additives. Where necessary, alternative biodegradable composites will be explored to provide structural reinforcement while ensuring they do not jeopardise the historical look and function of the *batana*. By combining responsible sourcing, sustainable forestry and innovative treatments, the TOFOLA project will ensure that the *batana* boat showcases not only an authentic historical reconstruction but also a model for eco-friendly maritime craftsmanship.

2.3. Structural and functional design considerations

The *batana* boat is characterised by a simple yet effective structural design, tailored for shallow coastal waters, ease of use and durability. Its flat-bottomed hull, moderate size and lightweight wooden construction make it well-suited for navigation in shallow areas such as coastal lagoons, estuaries and nearshore waters. While remaining true to its traditional form, the reconstruction process must ensure that the boat maintains structural integrity, hydrodynamic efficiency and functionality, simultaneously incorporating sustainable and accessible design elements.

The hull shape, while highly practical, requires careful material selection and precise craftsmanship to prevent excessive drag and ensure optimal buoyancy. The use of oak planking ensures that the hull remains resistant to rot, impacts and deformation over time.

The structural framework of the *batana* consists of a robust wooden skeleton, composed of a keel, ribs, stringers and planking. Some *batana* boats also have a *pasma* (a decorative stripe or band on the hull). The keel, although minimal in depth, provides longitudinal strength, while the ribs contribute to the overall rigidity of the vessel. Traditionally, ribs were heated into shape and fastened using wooden dowels or copper nails. Only later, as techniques developed, ribs started being steam-bent into shape and screws were used instead of dowels.

The functional aspects of the *batana* design are equally important. Originally used for fishing and transport, the boat was designed with an open deck which allowed for the easy movement of nets, equipment and cargo. Modern adaptations will include removable seating, concealed storage compartments and accessibility features for passengers with reduced mobility. However, these modifications must be made with care to ensure that they do not compromise the weight distribution and stability of the boat.

Other important design issues to be taken into consideration are propulsion and manoeuvrability. The *batana* boat is traditionally powered by oars or sails, with a gaff sail providing auxiliary wind propulsion. In contemporary reconstructions, electric propulsion systems will be employed to align with sustainability goals, offering a noise-free, non-polluting alternative. The positioning of oarlocks and rudders must be optimised to maintain traditional handling characteristics while allowing for potential improvements in control, efficiency and accessibility.

To enhance structural longevity, modern reinforcements may be subtly introduced while preserving historical aesthetics. For example, epoxy-based adhesives and biodegradable sealants can replace traditional pitch and tar coatings, providing better protection against water ingress while maintaining an environmentally friendly approach. Similarly, hidden stainless-steel fastenings may be used in areas subject to the greatest stress, ensuring durability without altering the visible appearance of traditional carpentry.

As part of the functional design improvements, the reconstruction process will also explore ways to enhance the adaptability of the *batana* for eco-tourism and

cultural heritage activities. This may include customised layouts for small, guided tours, ergonomic seating and adjustable fittings to accommodate different operational needs. These considerations must balance tradition and innovation, ensuring that the boat remains both historically accurate and practical for modern use.

By adhering to these structural and functional design principles, the TOFOLA project will ensure that the reconstructed *batana* boat will be a genuine, durable and sustainable representation of the original vessel, capable of serving both cultural and practical purposes.

3. Reverse engineering and digital modelling approach

The reconstruction of a *batana* boat requires a delicate balance between preserving its historical authenticity and incorporating modern methodologies that enhance precision and efficiency. Reverse engineering and digital modelling provide a crucial bridge between traditional craftsmanship and contemporary technology, ensuring that the boat is rebuilt with the highest degree of accuracy while maintaining the integrity of its original design.

Reverse engineering will begin with a comprehensive analysis of the existing *batana* boats, carefully measuring their geometries, analysing materials and structural details. This process will involve both manual measurements and advanced 3D scanning technologies, capturing every curve, joint and plank with precision. Traditional shipbuilding methods often relied on the experience of master craftsmen who could recreate a boat by sight and skill. While this approach remains invaluable, modern digital tools allow for the preservation of these forms in detailed digital blueprints, reducing errors and ensuring consistency in reconstruction.

The application of 3D scanning and photogrammetry will be critical in documenting the exact dimensions and surface geometry of the existing *batanas*. High-resolution laser scanners will create accurate three-dimensional digital replicas, enabling engineers and shipwrights to analyse the structure in ways that had previously been impossible. Such digital twins will serve as the foundation for design refinements, ensuring that every reconstructed *batana* boat maintains the proportions and hydrodynamic efficiency of its historical predecessors.

Beyond capturing the shape of the boat, digital modelling plays a vital role in structural analysis and material optimisation. Modern software enables simulations to test how different wood types react under stress, ensuring that the most suitable materials are selected for durability and sustainability. This approach will also allow for fine-tuning the construction techniques, balancing traditional carpentry with contemporary assembly methods to preserve its authentic aesthetics.

Another advantage of reverse engineering is its ability to standardise and replicate designs without compromising craftsmanship. Digital archives of *batana* structures will make it easier for future generations of shipbuilders to recreate the vessel with precision.

In addition to supporting ongoing conservation efforts, this also facilitates knowledge transfer between traditional artisans and modern engineers, ensuring that the art of *batana* construction continues to evolve while remaining rooted in its historical origins.

The integration of computer-aided design (CAD) further enhances the efficiency of the reconstruction process [1]. Detailed digital blueprints will allow for the visualisation of the boat at various stages, helping to anticipate potential challenges before the construction begins. This proactive approach will minimise costly adjustments during assembly and streamline the workflow from raw timber selection to the final launch.

One of the most transformative aspects of digital modelling is its role in accessibility and customisation. With precise virtual representations, modifications can be made to accommodate inclusive design principles, such as ergonomic seating for elderly passengers or structural reinforcements for enhanced stability. By leveraging 3D printing and CNC (Computer Numerical Control) machining, custom boat components can be produced with high accuracy, ensuring that the reconstructed *batanas* meet both historical and contemporary functional needs.

Despite these technological advancements, the essence of the *batana* reconstruction remains deeply connected to the human touch of master shipwrights. While reverse engineering provides a detailed roadmap, the final execution still depends on skilled artisans who interpret digital data through hands-on craftsmanship. This synergy between technology and tradition will ensure that every *batana* retains its unique character, blending old-world artistry with 21st century precision.

By adopting reverse engineering and digital modelling, the TOFOLA project will not only preserve the legacy of the *batana* boats but also pioneer a model for sustainable heritage boat reconstruction. The methodologies used in this process will create a lasting digital archive, allowing future generations to engage with maritime history in a way that is both innovative and deeply respectful of tradition.

3.1. Boat assembly process and construction stages

The reconstruction of the *batana* boat will follow a systematic, step-by-step process that will ensure both historical accuracy and structural integrity. Although modern tools and precision techniques can enhance efficiency, the fundamental principles of traditional wooden boatbuilding will remain central to the process. The flat-bottomed hull, simple yet sturdy frame and handcrafted carpentry of the *batana* require careful material preparation, precise assembly and skilled craftsmanship at every stage.

The first step in the assembly process will involve selecting and preparing the timber. High-quality, sustainably sourced hardwoods and softwoods such as oak, pine and elm are chosen based on their structural and functional roles. Each plank and beam will undergo seasoning and air-drying to ensure stability and prevent warping. Traditional heat bending will be used to shape curved elements like the planks, allowing them to fit seamlessly into the hull structure. The keel, ribs and stringers will be cut

using a combination of hand tools and modern CNC machines for precision, ensuring each component aligns with the boat's historical dimensions. Pre-cut planks and frames will be numbered and prepared for dry fitting before assembly.

The keel which serves as the *batana* backbone will be the first component to be assembled. It will be laid out on a construction jig or a flat work surface to ensure perfect alignment. Once positioned, the stem (bow post) and sternpost will be attached, providing the framework for the shape of the hull. The ribs (frames) will then be secured at measured intervals, forming the internal skeleton of the boat.

This stage is critical, as it determines the overall strength and durability of the boat. Mortise-and-tenon joints and screws will be used to secure the structure, ensuring that the assembly remains true to historic craftsmanship. Modern reinforcements, such as hidden stainless-steel fasteners, may be discreetly integrated in high-stress areas to increase longevity without altering the traditional aesthetic.

Once the framework is complete, the next step is attaching the outer planking. Each plank will be fitted carefully along the ribs, beginning with the garboard strakes (the planks closest to the keel) and working upward. The flat-bottomed hull design simplifies this process compared to round-bottomed boats, allowing for quicker and more efficient plank installation. Planks will be screwed into place, depending on whether a fully traditional or hybrid method is used. To ensure a watertight fit, the seams between planks will be caulked with natural fibres such as hemp or oakum, soaked in pine tar or linseed oil. This technique has been used for centuries to make wooden boats resistant to water ingress and swelling. At this stage, any reinforcement elements – such as internal bulkheads or support beams – will also be installed, providing additional structural integrity.

Once the hull is complete, the focus will shift to the deck and internal fittings. The *batana* boat typically features an open or partially covered deck, depending on its intended use. Traditional designs allow for easy movement and fishing activities, while modern adaptations may include removable seating, storage compartments or accessibility enhancements for tourism. Oarlocks, seating benches and gunwales will be installed, ensuring that functional elements align with historical specifications while meeting modern usability standards.

With the structure assembled, the boat will undergo final finishing and waterproofing. This will include sanding and smoothing all wooden surfaces to remove rough edges; applying natural protective coatings such as linseed oil or eco-friendly marine varnish; painting or sealing specific areas of the boat to protect against UV exposure, saltwater corrosion and mechanical wear. Historically, *batanas* were often painted in bright colours, reflecting local traditions and helping fishermen identify their boats at sea. The reconstruction may incorporate traditional colour schemes and decorative elements, ensuring cultural authenticity.

As commented earlier, traditionally, *batana* would be propelled by oars and a simple gaff sail. Within the TOFOLA project, sustainable propulsion systems such as electric motors could be installed. If designed for sailing, the mast, boom and sail

rigging will be set up and tested for balance and manoeuvrability. The rudder and tiller assembly will be attached, ensuring that the boat is responsive and easy to steer.

To prove a *batana* boat seaworthy, it will undergo structural and functional testing. The boat will be placed in the sea for an initial float test, checking for any leaks or balance issues. The boat will be left in the sea to allow the wooden planks to swell and seal naturally. Once the stability and buoyancy are confirmed, manoeuvrability tests will be conducted, ensuring that rowing, sailing and motorised propulsion all perform as expected. Successful completion of these tests means the *batana* boat is ready for full operational use, whether for traditional fishing, cultural exhibitions or sustainable tourism initiatives.

3.2. Blending tradition and innovation in the *batana* boat reconstruction

For centuries, the *batana* boat has been built using handcrafted wooden boatbuilding techniques, passed down through generations of skilled shipwrights. These methods, rooted in the local maritime culture, involve a deep understanding of wood behaviour, manual shaping techniques and time-honoured carpentry practices. Traditional heat bending allows the planks to take shape without causing internal stress on the wood, preserving flexibility and strength. Hand-planing and chiselling ensure that each plank and joint fits seamlessly, while natural adhesives like linseed oil provide waterproofing without synthetic chemicals.

The connection between artisans and materials is central to traditional boatbuilding. Every *batana* is unique, as individual craftsmen rely on their experience and intuition rather than standardised measurements. The process is time-intensive but highly adaptable, allowing for subtle modifications based on the timber grain, the specific needs of the end user and the environmental conditions in locations where the boat will be used.

Another hallmark of traditional craftsmanship is the fastening technique. Wooden boats were historically assembled using treenails (wooden pegs) and natural caulking materials, such as hemp fibres soaked in tar. These methods allowed for a flexible, watertight structure that could expand and contract with humidity changes, enhancing the boat's longevity.

While traditional craftsmanship remains at the heart of any *batana* reconstruction, modern building techniques might offer additional precision, efficiency and environmental benefits. Digital modelling and CNC machining allow for the creation of precise templates and components, reducing material waste and ensuring consistency across multiple reconstructions [9]. Techniques such as 3D scanning of the existing *batanas* help document historical designs in a way that prevents loss of knowledge and structural inaccuracies.

Material science has also provided improvements that enhance the durability and maintenance of the *batana* without altering its traditional appearance. While historically

wooden boats required frequent reapplication of natural sealants and coatings, modern biodegradable marine-grade resins can offer better protection against rot and water infiltration. These coatings maintain the wood's breathability while reducing the frequency of repairs and extending the boat's lifespan.

Another key innovation is the use of hybrid fastenings. While traditional wooden pegs and copper nails can still be used for authenticity, stainless steel screws and hidden reinforcements may be incorporated in high-stress areas to improve structural integrity. This allows the *batana* to withstand heavier use in tourism applications while maintaining the same aesthetic and historical accuracy. One such application is shown in Figure 9.

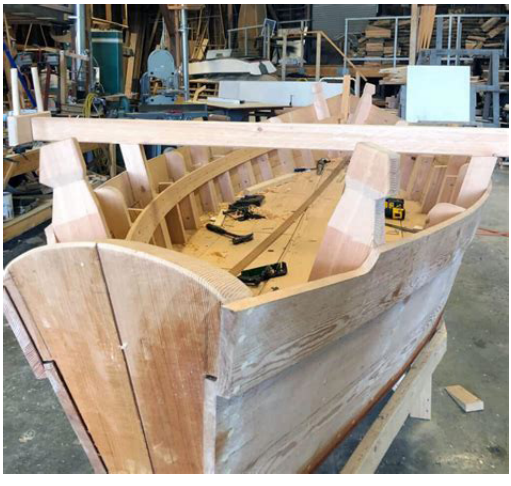

Figure 9. Master shipwright Michael Vlahovich working on the batana project, combining traditional woodworking skills with contemporary tools [2].

As commented earlier, one of the most significant advantages of modern techniques is their contribution to sustainability. Traditional boatbuilding relied heavily on old-growth hardwoods, which are now scarce due to deforestation. To address this, the TOFOLA project will integrate certified sustainable timber, reclaimed wood and engineered alternatives that mimic the properties of historically used materials while reducing the environmental impact.

Additionally, modern adhesives and sealants allow for stronger, longer-lasting wooden joints, meaning that a reconstructed *batana* boat would require fewer repairs and less frequent replacement of structural components. The introduction of solar-powered electric propulsion systems is another modern improvement, ensuring that the boat remains a model of sustainable heritage tourism.

The TOFOLA project approach to the *batana* reconstruction highlights the best of both worlds – preserving the artisanal methods that give each boat its authentic character

while leveraging modern tools to enhance efficiency, durability and environmental responsibility. This combination allows for more precise documentation of traditional techniques, ensuring that future generations of boatbuilders can continue the craft with the support of digital archives, training programmes and updated methodologies. While modern techniques introduce efficiency, the *batana* will remain handcrafted, ensuring that each boat carries the marks of the artisans who build it. This approach respects the legacy of traditional shipwrights while creating a more resilient, accessible and sustainable vessel for contemporary use.

4. Innovations for sustainability and inclusivity: accessibility, eco-friendly solutions and sustainable propulsion

The TOFOLA project emphasises inclusive design in the reconstruction of the *batana* boat, ensuring that it is accessible to a wide range of users, including elderly individuals, persons with disabilities and families with children. Traditionally, wooden boats like the *batana* were built for functionality and fishing, with little consideration for accessibility. However, modern adaptations should allow for improved safety, comfort and usability without compromising the historical integrity of the boat.

4.1. Enhancements for accessibility and inclusive use

The primary focus of the improvements in accessibility is making the *batana* boat easier to board and move around. Traditional small boats often have high gunwales and narrow interiors, which can present challenges for individuals with limited mobility. To address these issues, the reconstructed *batana* accessibility features will include:

1. Lowered gunwales or removable side railings to facilitate easier entry from docks or boarding platforms.
2. Non-slip flooring made from textured wood or coated with an eco-friendly anti-slip finish to reduce the risk of slipping. Strategically placed handrails along the seating and entry points will provide support for passengers when boarding and moving inside the boat.
3. Adjustable seating arrangements to accommodate different physical needs, including removable benches to create additional space for wheelchair users.

While the *batana* remains a small vessel, these design considerations ensure that it is as accessible as possible without altering its traditional form. The *batana* flat-bottomed hull already provides greater stability compared to round-bottomed boats, making it safer for passengers with balance difficulties. However, additional modifications can further enhance security and comfort:

1. Weighted ballast adjustments to maintain stability, particularly when accommodating passengers with mobility aids.

2. Ergonomic seating with back support for individuals who may have difficulty sitting on traditional wooden benches for extended periods.
3. Secure entry points and safety straps to assist passengers when stepping into or exiting the boat.
4. Emergency flotation devices discreetly integrated into the boat design for safety compliance.

These modifications will make the reconstructed *batana* more comfortable and practical for tourists, elderly passengers and persons with disabilities, supporting its use in eco-tourism and cultural experiences.

To ensure the boat is accessible to individuals with hearing or vision impairments, various sensory-friendly adaptations can be implemented:

1. Tactile guides and Braille labels placed on key parts of the boat for visually impaired passengers.
2. Contrasting colours and markers on entry points and seating areas to improve visibility.
3. Audio guides and assistive listening devices for tours conducted aboard the *batana*, ensuring that passengers with hearing impairments can access the information.
4. Vibration-based alert systems for safety notifications, helping passengers with hearing impairment to remain informed about on-board instructions.
5. These enhancements expand *batana's* reach to a more diverse audience, ensuring that historical and cultural experiences remain inclusive.

Although by its size the *batana* boat may be considered small, traditionally built wooden boat, adaptations can be made to improve wheelchair accessibility for passengers who require mobility aids. Some possible modifications may include docking ramps or gangways designed specifically for access to the *batana*, ensuring a smooth transition from the pier to the boat; adjustable, removable seating that allows space for small, foldable wheelchairs and secured anchoring points for wheelchairs, ensuring stability during the journey.

While full wheelchair accessibility may be challenging in a small vessel, these efforts ensure that the *batana* can be as accommodating as possible while maintaining its traditional character.

The above accessibility improvements for the *batana* align with global sustainable tourism initiatives, ensuring that eco-tourism and cultural heritage experiences are open to everyone. The boat can be used for guided heritage tours, cultural storytelling sessions and inclusive sailing experiences, welcoming passengers of all ages and physical abilities. By incorporating thoughtful design elements, the TOFOLA project will ensure that the *batana* boat remains a vessel for the entire community, allowing tourists, locals and historically underrepresented groups to enjoy the Adriatic maritime heritage in an inclusive, barrier-free manner.

4.2. Sustainable propulsion systems and low-impact solutions

As discussed earlier, the *batana* boat has traditionally relied on oars and simple sailing rigs for propulsion, making it an inherently sustainable vessel. Its historical design was developed for efficiency in shallow waters, where manoeuvrability and adaptability were essential for fishing and transportation. As the TOFOLA project works on reconstructing the original *batana*, there is an opportunity to maintain its low environmental impact while incorporating modern propulsion solutions that align with contemporary sustainability standards.

One of the simplest and most effective ways to ensure that the reconstructed *batana* remains environmentally friendly is by preserving its traditional methods of navigation. Rowing, which has been used for centuries, allows for noise-free boating with zero emissions and remains one of the most practical forms of propulsion in lagoons and coastal areas. Sailing, another method deeply rooted in *batana* history, provides an excellent alternative when wind conditions permit. By maintaining the traditional lug sail, the boat can continue to operate without reliance on engines while offering a cultural and eco-friendly experience. Modern sail materials, though lighter and more durable, can be chosen to preserve historical aesthetics while improving performance and longevity.

For cases where motorised propulsion is necessary, electric systems present the best alternative. Unlike fossil fuel-powered engines, electric outboard motors provide silent operation, producing no local emissions and reducing water and noise pollution. These motors are particularly suited for heritage boats used in eco-tourism, as they allow for smooth and quiet navigation while preserving the experience of being on a traditional wooden vessel. One of the major benefits of electric propulsion is its low maintenance requirements, as these motors include fewer moving parts and do not require oil changes or fuel storage, further reducing the environmental footprint. The integration of solar energy can further enhance the sustainability of the *batana*. Solar panels, either onshore at docking stations or even discreetly incorporated into the boat, can provide renewable energy to recharge batteries, but they are subject to ongoing seaworthiness regulations. Solar-powered charging stations at harbours or along eco-tourism routes can enable extended use of electric propulsion without the need for fossil fuels. This approach ensures that the *batana* boat remains entirely self-sufficient, drawing energy only from renewable sources and eliminating any reliance on conventional power grids.

In addition to propulsion systems, modifications to the boat structural design can also contribute to sustainability. A well-optimised hull shape can improve efficiency by reducing drag and making propulsion, whether by rowing, sailing or an electric motor, more effective. Lightweight yet durable materials can be used to enhance longevity without compromising authenticity. The use of eco-friendly sealants and antifouling treatments prevents damage from marine organisms without introducing harmful chemicals into the water, further minimising the boat's environmental impact. To ensure

the *batana* operates sustainably, attention must also be given to navigation practices. Training programs for operators and eco-tourism guides can promote responsible boating habits, including limiting speeds in protected areas to avoid disturbing marine life and ensuring waste management policies prevent pollution. Using designated docking areas rather than anchoring in sensitive marine environments helps preserve seagrass beds and prevent coastal erosion. Integrating both sustainable propulsion systems and responsible boating practices will make the *batana* boat an example of how heritage vessels can remain relevant in the modern world without sacrificing environmental integrity.

5. Conclusion

Sustainable reconstruction of wooden boats requires a thoughtful approach that balances historical authenticity, material durability and environmental responsibility. Efforts should focus on preserving traditional craftsmanship while adapting to modern challenges such as resource scarcity and ecological impact.

Using responsibly sourced timber is essential to maintaining sustainability. Whenever possible, wood should come from certified forests or reclaimed materials to reduce the environmental strain. In cases where original species are no longer available or sustainable, suitable alternatives that closely match historical characteristics should be considered.

Traditional boatbuilding techniques should be preserved, as they carry invaluable cultural and historical significance. However, integrating modern innovations, such as improved fastenings, protective coatings and structural reinforcements, can enhance durability without compromising authenticity. Restoration methods should prioritise reversibility to allow future adjustments without damaging the original components.

Environmental impact should also be minimised through responsible waste management, including the reuse of original parts when possible. The use of eco-friendly finishes, adhesives and antifouling treatments is encouraged to reduce harm to marine ecosystems.

Finally, proper documentation of all restoration efforts is crucial for future conservation. Detailed records, including material choices, construction methods and any modifications made, will help ensure that future shipwrights and restorers can continue the work with respect for the boat's heritage. Sustainable reconstruction is not just about prolonging the life of a vessel – it is about safeguarding maritime history while embracing responsible stewardship of natural resources.

The TOFOLA project embraces the challenge of making the *batana* boat not just a reconstructed historical vessel but a model for sustainable maritime heritage. By combining rowing and sailing with electric propulsion, utilising renewable energy sources and implementing eco-friendly construction materials, this initiative will ensure that the boat can continue to navigate the waters of the Adriatic for future generations, serving as both a symbol of history and a beacon of sustainability.

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