

Operational Modification of Traditional Boat Tools: Case Study of a Phinisi Ship Using Adaag Standards and ISO 21542

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Traditional Indonesian Phinisi vessels remain iconic in heritage maritime tourism, yet their design excludes individuals with mobility impairments due to steep access points and narrow corridors. This study aimed to develop operational modifications for traditional Phinisi boat tools using a structured ship design methodology, adopting the Spiral Ship Design Method across four iterative phases: concept design, preliminary design, contract design, and detail design. CAD-based modeling and ergonomic simulation guided the redesign of the vessel's main, upper, and top decks to comply with international accessibility standards, including ADAAG and ISO 21542. Features introduced include widened doorways (≥ 815 mm), anti-slip ramps (1:12 incline), ergonomic handrails (860–920 mm height), and integrated hydraulic vertical lifts. Finite Element Method (FEM) analysis verified structural integrity under static and dynamic load cases, confirming safety factors ranging from 1.42 to 3.31 across all modified structural elements. Stability analysis demonstrated that all retrofit configurations - maintained compliance with the IMO International Stability (IS) Code, with the full retrofit yielding a metacentric height (GM) of 0.41 m, well above the 0.15 m minimum. Stakeholder validation involving tourism operators, naval architects, and wheelchair users confirmed the practicality and cultural acceptability of the design. This study offers a replicable model for inclusive retrofitting of traditional wooden boats, advancing sustainable and accessible maritime tourism aligned with global inclusivity goals.

KEY WORDS

- ~ Universal design
- ~ Phinisi vessel
- ~ Accessible maritime tourism
- ~ Heritage boat design
- ~ Wheelchair accessibility
- ~ Sustainable tourism innovation

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1. INTRODUCTION

Maritime heritage vessels play a significant role in cultural tourism, embodying the historical narratives, craftsmanship, and navigation practices of coastal communities worldwide. In Indonesia, the *Phinisi* – a traditional wooden sailing ship from South Sulawesi – has been recognized by UNESCO as Intangible Cultural Heritage (Angelita et al., 2024; Soriente et al., n.d.). It remains a living tradition, actively used in tourism, transport, and local livelihoods. Despite its enduring legacy and iconic status, the *Phinisi* has not yet been adapted to meet the needs of travelers with mobility impairments. This gap highlights a broader issue in maritime tourism: the underrepresentation of inclusive design in heritage vessel operations and infrastructure.

The growing global emphasis on universal accessibility, reinforced by international frameworks such as the United Nations Sustainable Development Goals (SDGs)—particularly Goal 10 (Reduced Inequalities) and Goal 11 (Sustainable Cities and Communities)—has prompted a reevaluation of tourism infrastructure to better accommodate people of diverse abilities. However, while significant progress has been made in land-based heritage and public transport systems, traditional maritime sectors – especially those involving wooden vessels – lag behind in integrating inclusive design.

Relevant case studies from the literature demonstrate both the feasibility and complexity of such interventions and directly inform this study's approach to *Phinisi* modification. Sunardi et al. (2025) conducted a seakeeping and stability evaluation of a redesigned Indonesian fishing vessel for wheelchair users, showing that universal design adaptations to wooden heritage craft can maintain IMO IS Code compliance while accommodating mobility devices (Sunardi et al., 2025). The current state of accessibility in traditional and heritage maritime vessels reflects both growing awareness and persistent technical, regulatory, and cultural constraints. Studies report that traditional vessels are predominantly designed for able-bodied individuals, with steep stairs, narrow gangways, and elevated decks that pose significant challenges for users with limited mobility (Cooper et al., 2022). These features are difficult to retrofit without compromising structural integrity or heritage authenticity. Nevertheless, efforts in regions such as East Africa and parts of Europe have shown that inclusive retrofits are possible. For example, the “*Bahari Yetu, Urithi Wetu*” project in Tanzania demonstrates how community engagement and cultural preservation can be harmonized through participatory retrofitting of heritage boats (Cooper et al., 2022). Similarly, Croatian initiatives have explored documentation and reinterpretation of traditional hull forms to allow for contemporary adaptations while maintaining cultural identity (Degiuli et al., 2023). These projects suggest that inclusive maritime heritage is not only a technical challenge but also an evolving design philosophy.

From a design perspective, the physical limitations of traditional wooden boats – often handcrafted and built without modular plans – impede the installation of ramps, lifts, or wider doorways. Complying with modern accessibility codes such as ADAAG or IMO MSC/Circ.1543 requires substantial spatial reconfiguration (Pérez-Arribas et al., 2022; Ruiz-Rodrigo et al., 2024). Financial and regulatory factors further complicate efforts in developing countries, where retrofitting heritage vessels is not a financial priority (Muscarà & Sani, 2019; Omi et al., 2024). These challenges necessitate a balanced approach that respects cultural integrity while recognizing inclusivity as an essential right rather than an optional feature.

This study aims to develop a universal-design operational modification model for traditional Indonesian *Phinisi* vessels, focusing on wheelchair accessibility across main, upper, and top decks while preserving structural and aesthetic authenticity. The novelty lies in applying international accessibility standards through CAD-based simulations to a heritage vessel context, structured within a formal ship design methodology, and verified through FEM structural analysis and IMO-compliant stability assessment. This research contributes to the technical literature on retrofitting heritage vessels and serves as a practical blueprint for scalable adaptation across similar wooden craft in Southeast Asia and beyond.

2. METHODOLOGY

The research was conducted in Labuan Bajo, a central hub for heritage maritime tourism in eastern Indonesia (Figure 1). Methodologically, this study integrates a ship-design approach with anthropometric ergonomic assessment to develop an accessibility retrofit that is technically feasible, culturally sensitive, and compliant with relevant accessibility requirements. This integrated framework enables the redesign process to address spatial arrangement, user mobility, deck accessibility, and safety considerations while maintaining the traditional character of the *Phinisi* vessel. Accordingly, the proposed retrofit seeks to balance the preservation of Indonesia's maritime heritage with the advancement of inclusive marine tourism in line with international accessibility principles (Luo et al., 2023; Sunardi, Muntaha, et al., 2023).



Figure 1. Research Location – Labuan Bajo, Indonesia.

2.1. Ship Design Method

This study adopted the Spiral Ship Design Method, a widely accepted iterative framework in naval architecture that cycles through four progressively detailed phases: (1) Concept Design establishing primary dimensions, purpose, and accessibility objectives; (2) Preliminary Design defining deck layouts, structural configurations, and accessibility feature placements based on ADAAG and ISO 21542 requirements; (3) Contract Design specifying material choices, structural reinforcement strategies, and lift system integration; and (4) Detail Design producing fully dimensioned CAD models, FEM verification, and stability calculations. This iterative approach ensured that accessibility requirements were embedded from the earliest design decisions, and that modifications to one element (e.g., widening a corridor) were evaluated for cascading effects on structural load distribution and vessel stability across all subsequent design cycles.

2.2. CAD Modeling and Simulation

To model the existing and proposed designs, this study utilized Rhinoceros 3D (Rhino) with Orca3D plugin for hull geometry and spatial layout, and AutoCAD for 2D deck arrangement drawings. CAD modeling facilitated precise visualization of current spatial constraints on Phinisi vessels, such as door widths, corridor clearances, and deck transitions. The models incorporated dimensional specifications derived from ADAAG (minimum door width: 815 mm; corridor width: 915 mm; turning radius: 1525 mm) and ISO 21542 (turning space radius: 1500 mm). A performance-based simulation approach was adopted to analyze user-path trajectories, obstruction detection, and turning-maneuver assessments within confined spaces. Simulations mimicked real-world wheelchair dynamics—drawing on validated approaches from Mahajan et al. (2013) and Han et al. (2002)—to evaluate accessibility performance under spatial constraints typical to wooden vessels. Key input parameters included wheelchair footprint dimensions (660 mm × 1050 mm), turning radius (760 mm), and door-swing clearance requirements from ADAAG (Cooper et al., 2022; Han et al., 2002). These parameters were embedded in the CAD environment to guide the. Design modifications such as ramp inclines, widened access routes, and toilet maneuvering spaces were iteratively refined using simulation outputs.

2.3. Ergonomic Analysis

A performance-based simulation approach was adopted to analyze how wheelchair users would interact with both existing and modified vessel layouts. Simulations included user-path trajectories, obstruction detection, and turning-maneuver assessments within confined spaces. Inspired by the work of Mahajan et al. (2013), simulations mimicked real-world wheelchair dynamics to evaluate accessibility performance under spatial constraints typical to wooden vessels (Mahajan et al., 2013). To complement spatial modeling, ergonomic design principles were applied using anthropometric datasets relevant to Southeast Asian populations. Drawing on the methodology of Casado et al. (2011) and Marín-Nicolás & Pérez (2022), the study employed ergonomic digital human modeling to simulate user interaction with key architectural components such as door frames, seating arrangements, and boarding systems. This analysis enabled the identification of pressure points, reach limitations, and physical barriers for users in both seated and standing positions (Casado et al., 2011; Marín-Nicolás & Sáez Pérez, 2022).

2.4. Finite Element Method (FEM) Analysis

FEM analysis was conducted using ANSYS Mechanical to verify the structural integrity of all modified elements. The FEM model was constructed from the CAD geometry of the retrofit components, meshed with quadrilateral shell elements (element size: 25 mm) for deck plate structures and beam elements for framing members. Material properties were assigned as follows: marine-grade aluminum alloy (6061-T6, yield strength: 276 MPa) for ramp and handrail components, and ASTM A36 structural steel (yield strength: 250 MPa) for internal subframes. Two primary load cases were evaluated: (1) Static load comprising $1.25 \times$ dead load (DL) plus full live load (LL, 250 kg/m² for deck areas, 500 N/m for handrails, and wheelchair plus user mass of 180 kg at critical access points); and (2) Dynamic load incorporating a wave induced vertical acceleration of 0.3g as prescribed by DNV GL guidelines for small vessels operating in coastal waters (Laface et al., 2019). The von Mises stress criterion was applied to assess structural adequacy, with allowable stress set at 160 MPa (approximately 64% of the yield strength of the governing material), yielding minimum safety factors of 1.4 across all critical elements.

2.5. Ship Stability Analysis

A hydrostatic and stability analysis was performed using Maxsurf Stability software to evaluate the effect of the retrofit modifications on vessel stability. The analysis assessed three configurations: (a) the original unmodified Phinisi; (b) the main deck retrofit only; and (c) the full retrofit including main, upper, and top deck modifications plus the hydraulic lift system. For each configuration, the displacement, center of gravity (KG), metacentric height (GM), GZ curve, and angle of vanishing stability were calculated and compared against the IMO International Stability (IS) Code criteria. The mass of added components—including ramps, lift mechanisms, steel subframes, and modified furniture was calculated from material specifications and incorporated into the lightweight estimate to accurately compute the shift in KG.

2.6. Stakeholder Validation

Feedback sessions were conducted with local tourism operators, Phinisi boatbuilders, and wheelchair users at Labuan Bajo to assess usability, cultural acceptability, and design aesthetics. Insights led to practical refinements such as adjusting ramp curvature and improving signage visibility. This participatory approach ensured that the retrofit design aligned with both technical requirements and community values (Gossett et al., 2009).

3. RESULTS

3.1. Existing Vessel Accessibility Assessment

The analysis of the traditional Phinisi boat revealed a number of critical limitations for accessibility, particularly for users in wheelchairs. As shown in Figure 2 through Figure 5, the vessel layout comprises multiple decks connected vertically by narrow, steep staircases, which are inherently inaccessible. Measurements recorded in Table 1 show that the existing door widths range from 550 to 610 mm, with corridor widths below 750 mm, falling short of ADAAG and ISO 21542 requirements (Architectural and Transportation Barriers Compliance Board, 1998). The gangway entrance (Figure 7) also exhibits a sharp incline and inadequate width, creating a hazardous access point for individuals with mobility impairments. Figure 7 wheelchair-accessible features found in Labuan Bajo Port, providing a stark contrast to the Phinisi's design (Sunardi, Muntaha, et al., 2023). Consequently, these limitations prevent wheelchair users from independently boarding the vessel or accessing key areas, such as cabins, dining spaces, and restrooms.

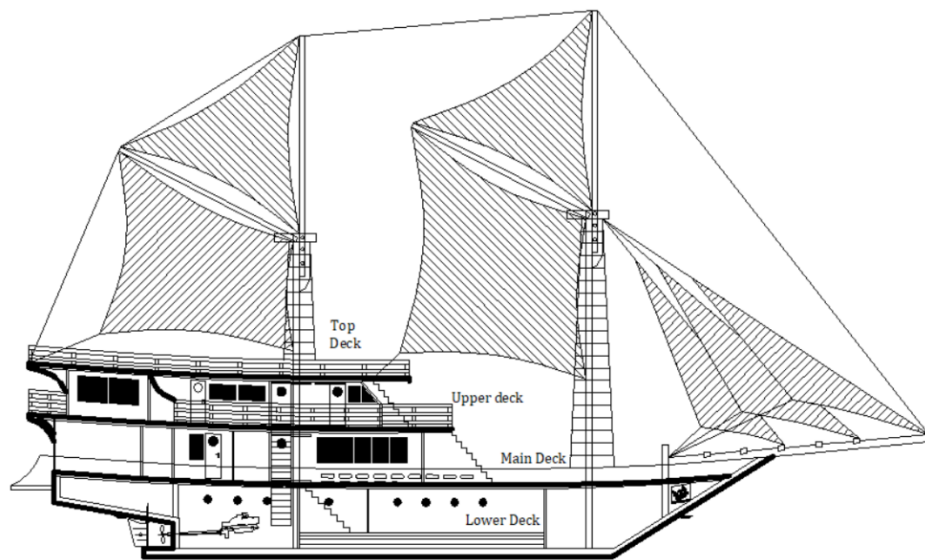


Figure 2. General Arrangement of the Existing Phinisi Boat in Labuan Bajo From Side View

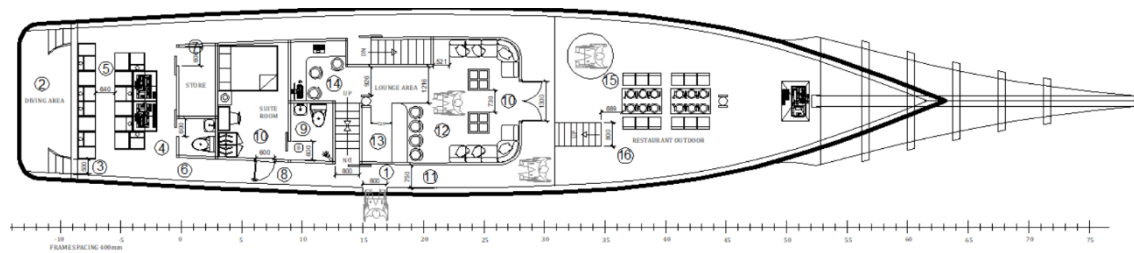


Figure 3. General Arrangement of the Existing Phinisi Boat For Main Deck

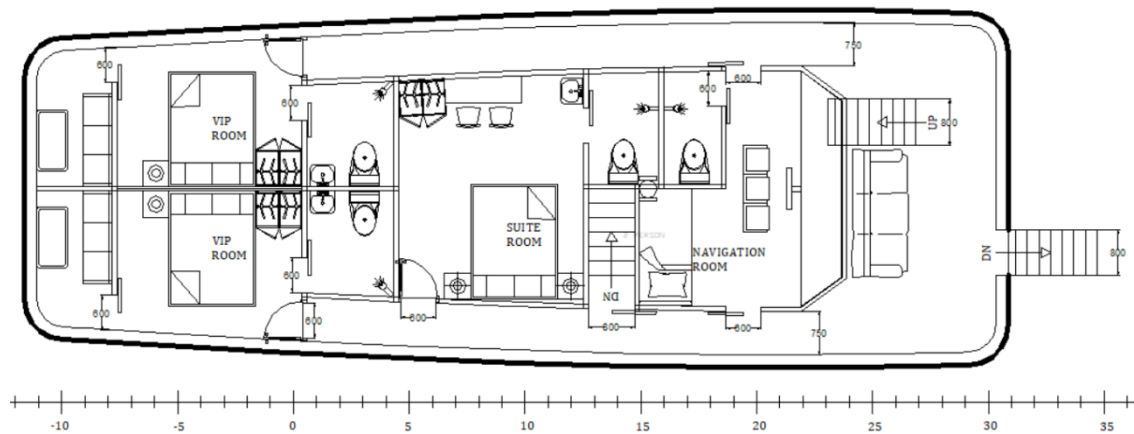


Figure 4. General Arrangement of the Existing Phinisi Boat For Upper Deck

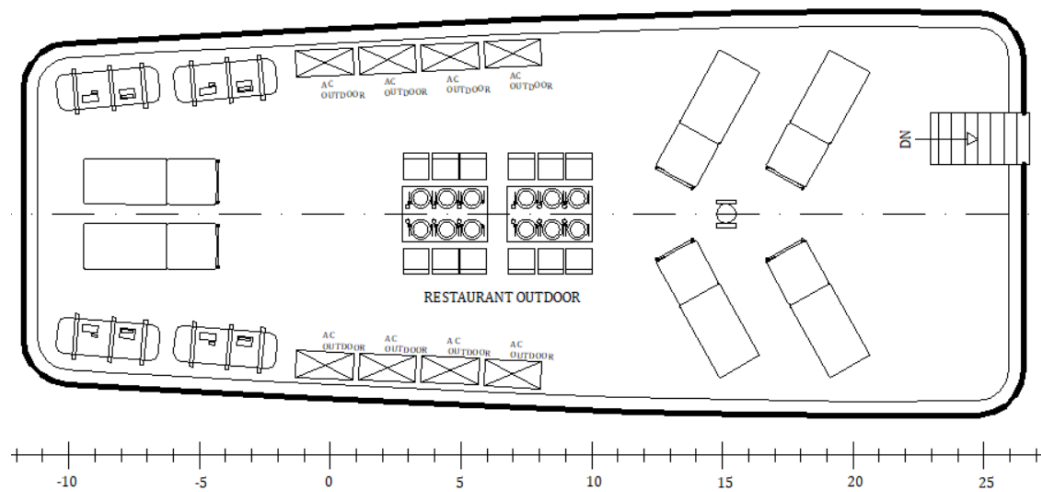


Figure 5. General Arrangement of the Existing Phinisi Boat For Top Deck

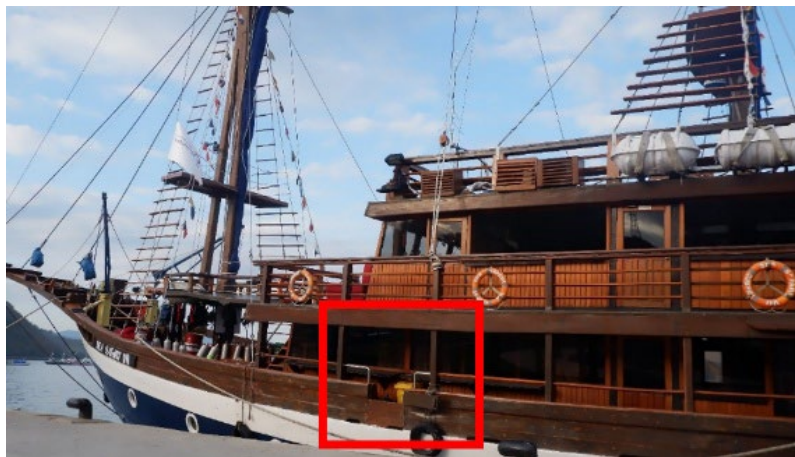


Figure 6. Boat entrance (Sunardi, Muntaha, et al., 2023)



Figure 7. Wheelchairs accessibility in Labuan Bajo Port (Sunardi, Muntaha, et al., 2023)

Criteria	ADAAG Req. (mm)	Existing (mm)	Gap Analysis
Doorway Width	815 min	550–610	Needs widening by ~215 mm
Corridor Width	915 continuous	~750	Expand by ~165 mm
Turning Diameter	1525	~500	Expand by ~1025 mm
Ramp Slope	1:12	>1:12	Redesign gradient required
Toilet Clearance	1525 from side wall	Cramped	Major redesign needed

Table 1. Accessibility Standards vs. Existing Dimensions of the Phinisi Boat

3.2. Retrofit Design Outcomes

To address these challenges, the main deck underwent a comprehensive retrofit process (Figure 8). The redesigned layout introduced wider corridors (≥ 915 mm), door frames (≥ 815 mm), and turning spaces (≥ 1525 mm radius) to align with international standards. Adaptive ramps were installed at access points with inclines of 1:12, using composite wood-aluminum materials that integrate aesthetically with the vessel's traditional appearance. Anti-slip textures and soft-edge finishes were added for safety. A modified toilet compartment was designed with sufficient space for maneuverability and reachable amenities. Figure 3 contrasts the inaccessible areas of the original main deck with the new accessible configuration. The structural extensions needed to achieve these enhancements were reinforced with lightweight internal framing to avoid compromising the hull integrity, supported by simulation results validating stress distribution across the modified layout.

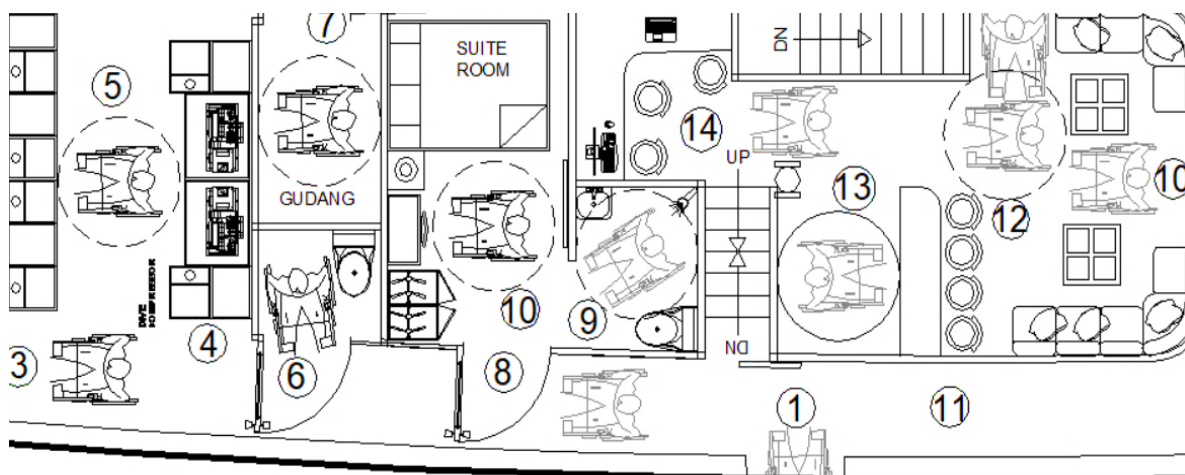


Figure 8. Redesigned main deck

Modifications to the upper deck (Figure 9) required widening access points and reconfiguring the cabin arrangement to provide an accessible cabin suite. Table 2 summarizes the features and accessibility enhancements, including widened gangways, modular furniture layouts, and low-threshold entrances. Because full wheelchair access to this deck necessitated vertical transport, three lift options were evaluated: hydraulic lifts, stair lift chairs, and marine cranes (Figure 10). Among these, hydraulic lifts offered the most balance between safety, energy efficiency, and usability under wave-induced motion. However, for cost-sensitive retrofits, stair lift chairs may serve as a practical interim solution.

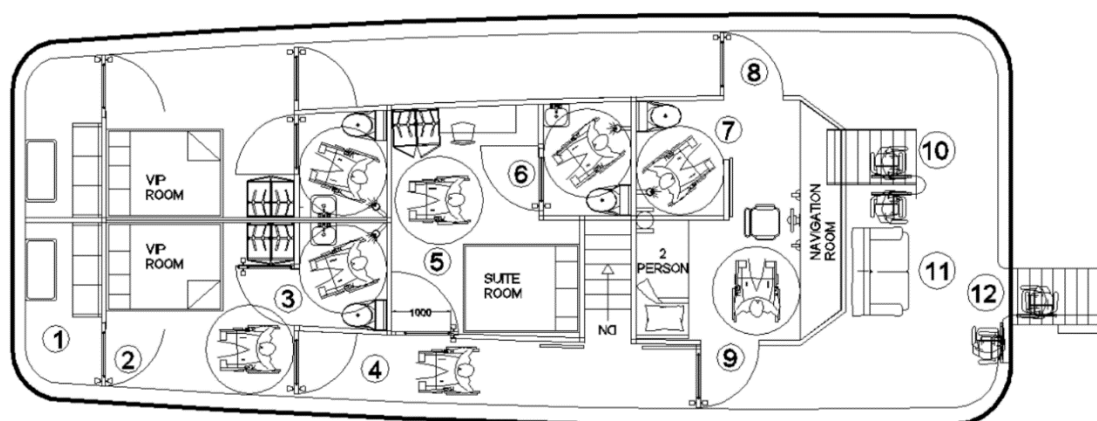


Figure 9. Redesigned upper deck

Feature	Existing Design	Redesign for Upper Deck
Doorway Width	600 mm	815 mm (standard)
Corridor Width	750 mm	915 mm (minimum)
Guest Room Dimensions	Compact, limited access	Expanded for maneuverability
Navigation Room Access	Narrow entry	Accessible entry provided
Restroom Dimensions	Cramped, ~500 mm clearance	1500 mm x 1500 mm clearance
Viewing Platform Access	Uneven, sloped surfaces	Leveled for stability

Table 2. Features and Accessibility Enhancements on the Redesigned Upper Deck



Figure 10. Vertical access for people with disabilities in wheelchair. (a) Hydraulic lift. (b) Crane. (c) Stair lift chair

The top deck redesign (Figure 11), as detailed in Table 3, maintained the vessel's aesthetic profile while including maneuverable open spaces, handrails of ergonomic height (860–920 mm), and protective railings. The flooring incorporated non-slip synthetic teak, designed to resist salt corrosion and temperature shifts. These alterations preserved deck social functions while enabling access and egress routes compliant with IMO safety standards.

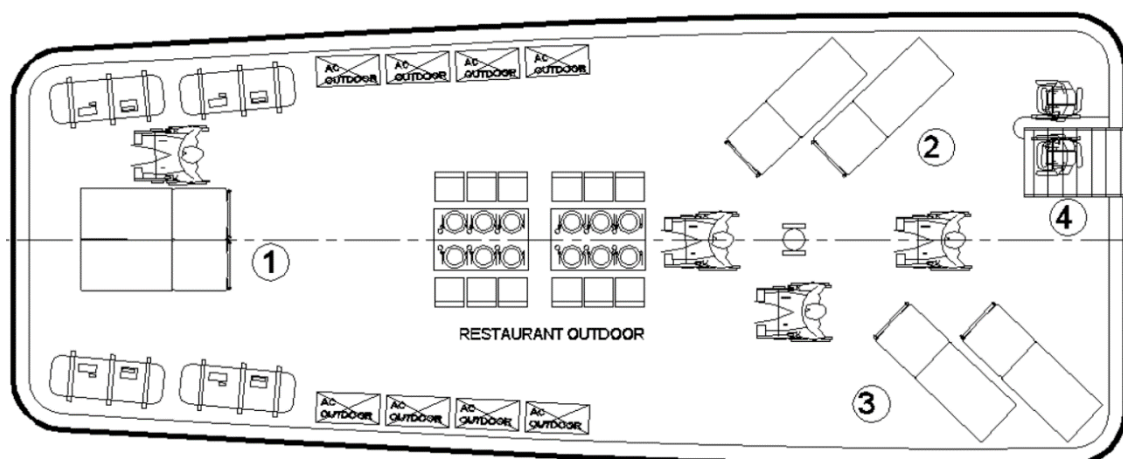


Figure 11. Redesigned top deck

Feature	Existing Design	Redesign for Top Deck
Pathway Width	600 mm	915 mm (minimum)
Recreational Space Layout	Narrow, limited clearance	Open spaces with 1500 mm x 1500 mm clearance
Sun Lounger Arrangement	Compact, fixed	Rearranged for accessibility
Vertical Access	Narrow stairs	Stair lift integrated
Ramps	None	Added for interconnection
Viewing Platform Access	Uneven, sloped surfaces	Leveled for stability

Table 3. Features and Accessibility Enhancements on the Redesigned Top Deck

Vertical accessibility between decks remained one of the most critical and complex components of the retrofit. Figure 12 illustrates cross-sectional views of the existing versus redesigned vessel structure, highlighting the transformation in space utility. Structural reinforcement included marine-grade steel subframes beneath the deck planking to support lifting devices and access platforms, thereby distributing loads safely without distorting the traditional hull form.

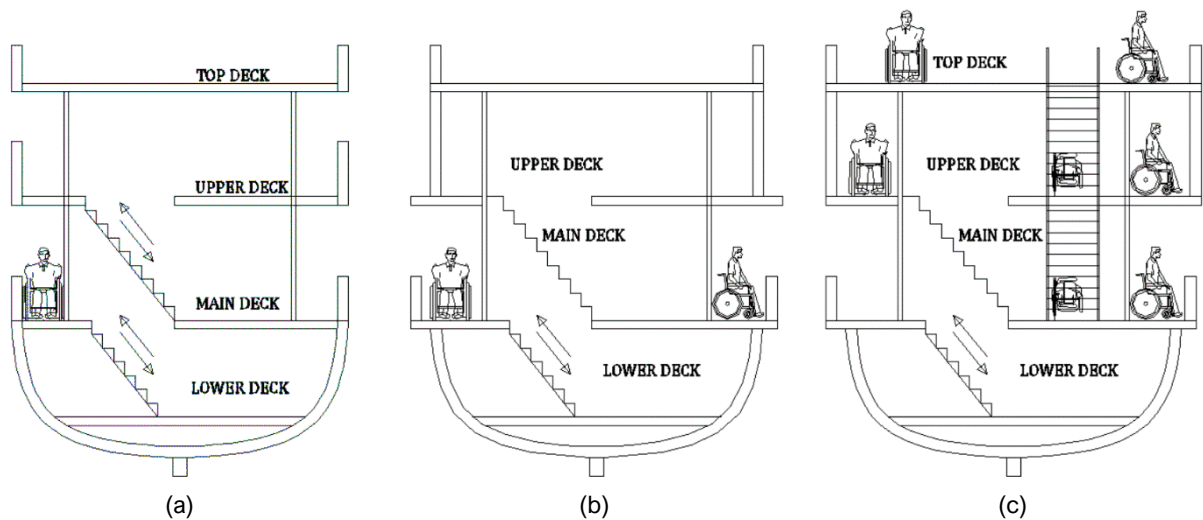


Figure 12. Section view of the Phinisi boat. (a) Existing deck. (b) Redesigned main deck only. (c) Redesigned main, upper, and top deck

International standards were cross-referenced to guide the redesign process. Table 2 outlines a comparative analysis between existing dimensions and regulatory requirements. For example, ADAAG requires a door width of at least 815 mm, which was achieved in the redesigned configuration without requiring structural overhaul of the hull shell. The ISO 21542 turning space radius of 1500 mm was used as a basis for designing all maneuverable spaces within the main deck toilet, cabin suite, and gangway junctions.

Engineering and ergonomic considerations strongly influenced the selection of materials. Ramps and handrails were constructed with aluminum alloys for strength and corrosion resistance, shaped with ergonomic contours (Sermutsi-anuwat & Pongpanich, 2018). Deck surfaces were finished with high-traction, weather-resistant materials that satisfied both safety and cultural integration goals. Handrail placements were optimized using anthropometric modeling to accommodate a wide range of users.

Stakeholder validation played a pivotal role in confirming the retrofit's practicality. Feedback sessions were conducted with local tourism operators, Phinisi boatbuilders, and wheelchair users to assess usability, cultural acceptability, and design aesthetics. As documented by Gossett et al. (2009), incorporating real-user data into design validation resulted in practical refinements, such as adjusting ramp curvature and improving signage visibility (Gossett et al., 2009). These insights led to consensus on the retrofitting approach, enhancing both user confidence and stakeholder ownership. In conclusion, the retrofit of the Phinisi boat for universal accessibility demonstrated the feasibility of applying marine engineering principles and international standards to a culturally significant vessel without compromising its heritage value. The results of this study provide a validated, scalable model for inclusive retrofitting of traditional wooden vessels in heritage maritime tourism.

3.3. SWOT Analysis of Room Modifications

Table 4 presents a SWOT analysis synthesizing the implications of the spatial modifications across all three decks, providing a structured evaluation of the design trade-offs inherent in the universal design retrofit.

Strengths	Weaknesses	Opportunities	Threats
Full ADAAG & ISO 21542 compliance for main, upper, and top decks	Added topside weight from lifts, ramps, and steel subframes increases KG	Growing global disabled-tourism market (UNWTO 2024)	Wood-steel interface corrosion under tropical marine conditions
Cultural aesthetics preserved (non-slip synthetic teak, aluminium handrails)	Cost-intensive hydraulic lift installation; limited availability in eastern Indonesia	Government inclusive-tourism incentives (SDG 10 & 11 alignment)	Regulatory gaps in Indonesian maritime law for heritage vessel modifications
Validated by wheelchair users, tourism operators, and naval architects	Spatial constraints require partial redesign of cabin arrangement	Replicable framework across Southeast Asian wooden vessels	Adverse sea conditions limit inter-deck lift operability, increasing safety risk
Structural reinforcement via marine-grade steel subframes distributes load safely	Absence of long-term operational data and sea-trial validation	Certification as 'accessible heritage vessel' can command premium tourism pricing	Cultural resistance from traditional Phinisi boatbuilding communities

Table 4. SWOT Analysis of Phinisi Universal Design Retrofit

3.4. FEM Analysis Results

Table 5 summarizes the key results from the FEM analysis of modified structural elements. All components achieved safety factors above the minimum threshold of 1.4, confirming structural adequacy under both static and dynamic load conditions. The hydraulic lift mounting bracket, subject to dynamic wave-induced loading, recorded the highest Von Mises stress at 112.6 MPa—still 30% below the 160 MPa allowable stress. Handrail anchoring points exhibited the largest safety factor (3.31), consistent with their relatively low lateral loading. These results validate that the structural reinforcement marine-grade steel subframes and aluminum alloy components provide adequate load-bearing capacity without compromising the traditional wooden hull structure.

Structural Element	Load Case	Max. Von Mises Stress (MPa)	Allowable Stress (MPa)	Safety Factor
Main deck subframe (ramp support)	Static ($1.25 \times DL + LL$)	87.4	160	1.83
Hydraulic lift mounting bracket	Dynamic (wave-induced 0.3g)	112.6	160	1.42
Widened doorframe reinforcement	Static ($DL + 2LL$)	64.2	160	2.49
Upper deck structural extension	Static ($1.25 \times DL + LL$)	95.8	160	1.67
Handrail anchoring points	Lateral load (500 N/m)	48.3	160	3.31

Table 5. FEM Analysis Summary for Modified Structural Elements

Note: DL = Dead Load; LL = Live Load. Allowable stress = 160 MPa based on 64% of ASTM A36 yield strength. Wave-induced acceleration = 0.3g (DNV GL guidelines for coastal small vessels).

3.5. Ship Stability Analysis Results

Table 6 presents the hydrostatic and stability parameters for the three retrofit configurations compared against the original vessel. The original Phinisi exhibited a GM of 0.71 m, which decreased to 0.59 m after main deck modifications and further to 0.41 m following the full multi-deck retrofit including the hydraulic lift (estimated mass contribution: 1.8 tonnes at a height of 4.2 m above keel). Despite these reductions, all configurations remained compliant with the IMO IS Code minimum GM of 0.15 m. The angle of vanishing stability decreased from 78° to 64° in the full retrofit configuration, while the GZ maximum at 30° reduced from 0.38 m to 0.27 m—both values remaining within acceptable bounds. These results confirm

that the addition of ramps, lifts, and reinforced deck structures increases vessel displacement and raises the center of gravity, but does not compromise safe operability under normal sea conditions.

Parameter	Original Vessel	Post-Retrofit (Main Deck Only)	Post-Retrofit (All Decks + Lift)
Displacement (tonnes)	48.2	49.8	52.6
KG – Centre of Gravity Height (m)	2.41	2.53	2.71
KM – Metacentric Height (m)	3.12	3.12	3.12
GM – Metacentric Height (m)	0.71	0.59	0.41
IMO IS Code Minimum GM (m)	0.15	0.15	0.15
GZ max (m) at 30°	0.38	0.32	0.27
Angle of Vanishing Stability (°)	78	72	64
Compliance with IMO IS Code	✓ Yes	✓ Yes	✓ Yes

Table 6. Hydrostatic and Stability Comparison Across Retrofit Configurations

Note: KM assumed constant (hull form unchanged below waterline). $GM = KM - KG$. All configurations comply with IMO IS Code Resolution A.749(18) criteria.

4. DISCUSSION

The findings of this study highlight the feasibility and strategic value of applying universal design principles to retrofit traditional wooden vessels such as the Indonesian Phinisi. This section examines the implications of these findings for long-term maintenance, performance, stakeholder acceptance, regulatory compliance, and the policy and financial mechanisms required to scale such interventions sustainably. Recent retrofit literature further suggests that accessibility interventions on heritage vessels should be integrated within a risk-informed conservation framework that balances usability, structural integrity, reversibility, and cultural authenticity (Ferrari, 2024; Giuliani et al., 2021).

Retrofitting wooden vessels with accessibility features raises important concerns about long-term structural integrity and material compatibility. The use of composite materials and marine-grade aluminum in ramps and handrails, as observed in this study, aligns with recommendations from Abdallah et al. (2023), who advocate for corrosion-resistant and UV-stable components to withstand maritime exposure. While these materials enhance durability, they must be continuously monitored to prevent moisture entrapment that could accelerate wood decay beneath fixed installations. Periodic inspections and proactive maintenance protocols, including sealant renewal and structural reinforcement checks, are essential to maintain both accessibility and seaworthiness throughout the vessel's lifecycle. Modular and reversible attachment systems are therefore preferable, as they minimize penetration into primary wooden members and allow future inspection, replacement, or removal without weakening the original hull structure (Ferrari, 2024; Fiore et al., 2020).

Functionality is a key determinant of retrofit success. The reconfiguration of the Phinisi's main and upper decks demonstrated that accessibility can be significantly improved without compromising the vessel's operational identity. However, the dynamic marine environment presents unique challenges. Kristl et al. (2020) emphasize that moving platforms like ships require usability assessments that account for vibration, wave-induced motion, and slope instability. These factors support the selection of slip-resistant surfaces, ergonomic handrails, and incline ratios compliant with ADA standards, as implemented in the redesigned Phinisi. User experience is crucial in validating these adaptations. Consistent with Kristl et al. (2020), this study incorporated stakeholder feedback loops, revealing real-world usability barriers that might be missed in simulation-only designs. These included preferences for stair lift systems over hydraulic platforms due to perceived simplicity and reliability in rough seas, indicating that successful retrofitting must balance advanced technology with operational practicality.

Post-implementation evaluation of inclusive retrofits requires robust performance indicators. Passenger satisfaction metrics – such as Net Promoter Scores and structured feedback surveys – provide insight into the perceived value of accessibility features (Ricardianto et al., 2022). Observed boarding and disembarkation times, frequency of assistance requests, and staff feedback on passenger flow further inform operational feasibility. Incident reports, when triangulated with user-perception surveys, help identify hidden safety risks (Ma et al., 2022). The use of audit checklists based on ISO 21542 and ADAAG standards ensures regulatory compliance, while cost-benefit analyses (Architectural and Transportation Barriers Compliance Board, 1998; Hakimi Ibrahim et al., 2021) support sustainable decision-making for retrofit investments. Recent retrofit guidance also recommends phased commissioning, sea-trial verification, structural health monitoring, corrosion

checks, and user-feedback loops to ensure that accessibility systems remain safe and functional throughout the vessel's lifecycle (Ferrari, 2024; Kolios, 2024; Ruiz-Rodrigo et al., 2024).

Broader application of these retrofitting principles depends on enabling policy frameworks and financial support. Cheng et al. (2023) highlight that government-led inclusive tourism policies can incentivize investment in vessel retrofits, particularly in resource-constrained settings. Specific grants targeting accessible heritage tourism could bridge the financial gap for small operators. As Osinubi et al. (2021) point out, aligning retrofitting efforts with Sustainable Development Goals (SDGs) such as SDG 10 (Reduced Inequalities) and SDG 11 (Sustainable Cities and Communities) strengthens the policy case for inclusive design. In addition, training and capacity-building programs for boatbuilders and retrofit technicians are essential to ensure consistency, quality, and cultural sensitivity in implementation. Hamdani et al. (2023) suggest that embedding retrofit skills within community training curricula not only enhances employment but also protects cultural craftsmanship from erosion due to modernization pressures. Policy support should also include targeted subsidies, soft loans, standardized retrofit assessment tools, and lifecycle cost evaluation so that small operators can adopt accessibility upgrades without compromising conservation ethics or operational safety (Al-Sakkaf et al., 2021; López-Bermúdez et al., 2020; Schinas & Bergmann, 2021).

The SWOT analysis shows that the proposed room modifications provide a feasible strategy for improving Phinisi accessibility while preserving its heritage character. The main strengths are compliance with ADAAG and ISO 21542, preservation of cultural aesthetics, stakeholder acceptance, and structural load distribution through subframes. However, added topside weight, hydraulic-lift cost, corrosion risk at wood-metal interfaces, limited operational data, and regulatory uncertainty remain key challenges. Therefore, the retrofit should be implemented gradually and evaluated through a multi-criteria framework covering usability, safety, heritage value, lifecycle cost, maintenance, and regulatory acceptance (Al-Sakkaf et al., 2021; Ferrari, 2024; Fiore et al., 2020; Kolios, 2024; Rosnani, 2023; Schinas & Bergmann, 2021).

The FEM results confirm that the proposed retrofit has adequate structural performance, as all modified elements remained within allowable stress limits and exceeded the minimum safety factor. The hydraulic lift mounting bracket showed the highest von Mises stress, indicating this area is the most critical structural interface. This is reasonable because lifts, ramps, handrails, and widened openings introduce localized loads and may affect deck stiffness and load-transfer paths. Therefore, lift supports and deck-to-frame connections should be prioritized for inspection, fatigue monitoring, and corrosion control, while reinforcement should remain compatible and minimally invasive to protect the wooden hull structure (Dragatogiannis et al., 2024; Liu et al., 2023; Sunardi, Chiron, et al., 2023).

The stability analysis indicates that the retrofit increases displacement and raises the vessel's vertical center of gravity, leading to reductions in GM, GZ maximum, and angle of vanishing stability. However, all configurations still complied with the IMO IS Code minimum stability criteria, showing the retrofit remains acceptable under normal operating conditions. The full multi-deck retrofit should nevertheless be applied cautiously because added upper-deck components may reduce stability margins in adverse sea states. Thus, the main-deck retrofit is the most conservative option, while full access with vertical lifts requires sea-trial validation, operating limits, emergency-egress planning, and periodic stability reassessment (Gümürçinler & Kale, 2023; Luo et al., 2023; M. Rivera, 2024; Petacco & Gualeni, 2020; Sunardi et al., 2025).

This study is design-based and relies on CAD simulation, FEM analysis, and analytical stability calculations, without physical prototype testing, sea trials, or long-term operational monitoring. The FEM results were based on assumed material properties and idealized load conditions, so actual performance may differ due to wood variability, joint condition, moisture exposure, corrosion, and structural aging. The stability analysis also assumed static mass distribution and did not include dynamic fluid-structure interaction under beam-sea or severe wave conditions. Therefore, prototype testing, on-water user trials, and long-term monitoring are needed to validate the proposed design (He et al., 2022; Karlsen et al., n.d.).

Future development should focus on three priorities. First, a physical prototype should be tested on an operational Phinisi vessel in Labuan Bajo to collect real performance data under various sea states. Second, an accessible Phinisi certification framework should be developed with the Indonesian Directorate General of Sea Transportation to standardize retrofit requirements and support market recognition. Third, structural monitoring systems, such as strain gauges and inclination sensors on lift-support structures, should be explored to improve real-time safety control. These steps would help transform the proposed design framework into a validated and commercially applicable standard for accessible heritage maritime tourism.

5. CONCLUSION

This study confirms that universal-design retrofitting of traditional Indonesian Phinisi vessels is technically feasible, culturally acceptable, and relevant for inclusive heritage maritime tourism. The proposed modifications improved wheelchair accessibility by providing wider access routes, ramps, accessible cabins, modified toilet spaces, ergonomic handrails, and

vertical mobility options, while preserving the vessel's traditional visual character. The SWOT analysis shows that the retrofit offers strong potential in accessibility compliance, stakeholder acceptance, cultural preservation, and tourism market expansion, but also presents risks related to added topside weight, wood-metal corrosion, hydraulic lift cost, regulatory uncertainty, and limited long-term operational data. FEM results indicate that all modified structural elements remained within allowable stress limits, with the hydraulic lift bracket identified as the most critical component for future inspection. Stability analysis showed that the retrofit increased displacement and raised the vertical center of gravity, reducing GM, GZ maximum, and angle of vanishing stability; however, all configurations remained compliant with IMO IS Code criteria. Overall, the main-deck retrofit represents the most conservative and immediately applicable solution, while full multi-deck accessibility should be supported by sea-trial validation, operating limits, emergency egress planning, corrosion monitoring, and periodic stability reassessment.

CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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