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The Design of a Hydro Docking System for a Small Town Harbour

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Abstract

Traditional Graving and Floating docks, are expensive and require more space, rendering them economically unsuitable for small-town. Small to medium-sized vessels use the congested Durban harbour which is costly because of long queues for docking, maintenance, repair, and inspection. The paper presents a of a hydro-mechanical dry-docking system for a small town using a case study in KwaZulu-Natal, South Africa. The design employed a quantitative approach to find the dock size and the dewatering system using hydraulic gates. The hydrostatic loads, dewatering times, and power consumption were determined whilst the monthly operational and sequencing logistics will be determined when the small harbour start to operate. The system, can dewater a 19,800 m³ basin in 5 hours using a 368 kW centrifugal pumps. The dock uses the Digital Twins (DT) for predictive maintenance and AI-driven operational optimization, to enhance long-term efficiency and sustainability. The dry dock would offer a practical, cost-effective systems suitable for sustainable maritime operations in developing coastal regions.

Keywords
Hydro dry dock; pumping system, hydraulic gate system, dry docking feasibility, small harbour infrastructure.

1. Introduction

Dry-docking facilities are indispensable assets in the maritime sector, providing a controlled, water-free environment for the inspection, maintenance, repair, and statutory certification of vessels. The availability of such infrastructure is a critical determinant of fleet readiness, operational efficiency, and overall lifecycle costs (Einpresswire., 2025). The global market for ship repair and maintenance services is substantial and projected to grow, underscoring the continuous demand for accessible and efficient docking solutions (Finance, 2025). However, the dominant dry-docking technologies primarily graving docks and floating docks are engineered for large-scale commercial and naval shipyards. These systems involve massive capital investment, extensive civil engineering works, and significant spatial footprints, making them unsuitable for the unique constraints of small-town and regional harbours (D., 2018). In many coastal nations, including South Africa, small harbours are vital economic and social hubs, supporting local fishing fleets, tourism, municipal services, and other maritime activities. Yet these harbours often suffer from decaying infrastructure and limited financial resources (Africa., 2024). The chronic lack of local dry-docking facilities forces vessel operators to travel long distances to major ports like Durban or Cape Town. This practice incurs significant direct costs like fuel, crew time and indirect costs like operational downtime, delayed repairs, which collectively undermine the economic viability of local maritime enterprises. This infrastructure gap represents a significant barrier to the sustainable development of coastal communities and the growth of the blue economy as envisioned by national strategies like Operation Phakisa (Department of Forestry).

The central problem this research addresses is the absence of a technically sound and economically feasible dry-docking solution designed specifically for the constraints of small harbours. While alternative systems like slipways and synchro-lifts exist, they often have limitations regarding vessel size, load capacity, and operational flexibility. Hydro-mechanical dry-docking systems, which utilize a simplified basin with controlled flooding and dewatering, present a promising alternative. These systems can potentially reduce construction complexity, capital outlay, and land usage. However, their successful implementation hinges on a rigorous, integrated engineering design that ensures structural integrity, efficient dewatering, reliable gate operation, and uncompromising safety.

1.1 Objective

The objective(s) of this study is to:

i. To identify and define the functional; and operational requirements of a hydro dry-docking system suitable for small to medium sized vessels operating in small harbours.
ii. To develop an integrated engineering design for the primary subsystems of a hydro dry-dock, including the dock structure, dewatering and pumping system, hydraulic gate mechanism, fire fighting and safety infrastructure.
iii. To assess the feasibility of the proposed hydro dry-dock concept for small harbour implementation by evaluating operational efficiency, infrastructure simplicity and adaptability
iv. To apply analytical engineering methods to size and evaluate the performance of critical subsystems with particular emphasis on dewatering capacity, gate operation reliability and operational safety.

2. Literature Review

The literature on dry-docking infrastructure is extensive but heavily skewed towards large-scale facilities. This review synthesizes existing knowledge on conventional technologies, identifies recent innovations in port engineering, and highlights the specific research gap that this study aims to fill.

2.1 Conventional Dry-Docking Technologies and their Limitations

The primary methods for dry-docking are graving docks, floating docks, and mechanical lift systems. Graving docks are permanent basins excavated on shore, sealed by a gate, and dewatered by high-capacity pumps. Their robust, long-lasting nature is offset by extremely high construction costs and long development timelines, making them unviable for small ports (D., 2018); (UFC, 2020)Floating docks are U-shaped pontoon structures that can be submerged to allow a vessel to enter and then de-ballasted to lift the vessel out of the water. While offering locational flexibility, they require sheltered, deep water, are subject to complex stability challenges, and demand continuous maintenance (Sasono, 2021); (Tu, 2024). Mechanical systems, such as slipways and synchro-lifts, are more common for smaller vessels but are often limited by their load-handling capacity and the lateral space required for vessel transfer.

2.2 Innovations in Port Infrastructure and Sustainability

The maritime industry is undergoing a significant transformation driven by goals of sustainability and digitalization. The concept of the Green Port aims to minimize the environmental footprint of port operations through renewable energy, optimized energy consumption, and sustainable waste management (Acciaro, 2021); (Lam, 2022). South Africa has also identified opportunities for developing green ports and establishing itself as a hub for green fuels, aligning with global decarbonization efforts. While these initiatives often focus on major ports, the principles of energy efficiency and reduced environmental impact are equally applicable to the design of new small-scale infrastructure.
Simultaneously, the Smart Port paradigm leverages digital technologies to enhance operational efficiency, safety, and security. Key technologies include the Internet of Things (IoT) for real-time monitoring, Artificial Intelligence (AI) for predictive analytics and process automation, and Digital Twins (DT) for creating virtual replicas of physical assets and systems (Zissis, 2025). A DT of a dry dock, for instance, could enable predictive maintenance on pumps and gates, simulate docking operations to optimize efficiency, and serve as a training tool for personnel (Markopoulos, 2023).

AI-driven systems are already being used to improve predictive maintenance schedules and optimize vessel traffic, which can be adapted for managing docking operations (Kalafatelis, 2024)

2.3 Advances in Hydro Mechanical Subsystems

The core of a hydro-mechanical dock lies in its dewatering and gate systems. Recent research in pumping technology emphasizes energy efficiency and reliability. The use of Variable Speed Drives (VSDs) allows pump performance to be modulated according to the changing head during the dewatering cycle, significantly reducing energy consumption compared to fixed-speed pumps (Vijeesh, 2022). Furthermore, modern dry-prime or self-priming pumps eliminate the need for manual priming, enhancing operational reliability and reducing labour requirements, which is a critical advantage in resource-constrained settings (Tirado, 2022).

Dock gate design has also seen advancements. While traditional meter gates are common in large locks, simpler designs like flap gates are often suitable for smaller docks. Recent studies have utilized Finite Element Analysis (FEA) to optimize gate structures for strength and weight, investigate failure modes, and assess the impact of operational conditions like quoin gaps (Chen, 2023). The reliability of the hydraulic actuation system is paramount, with research focusing on robust design and control strategies to ensure safe and predictable operation under all conditions.

2.4 The South African Small Harbour Context

South Africa's small harbours face systemic challenges, including a legacy of underinvestment, deteriorating infrastructure, and insufficient maintenance funding (Roodt, 2024). Government initiatives like the Small Harbours Development Programme under Operation Phakisa aim to revitalize these assets to support local economies. However, the successful implementation of such programs requires cost-effective and context-appropriate engineering solutions. There is a notable scarcity of published research that applies a rigorous engineering design methodology to develop new infrastructure, like dry docks, specifically for this environment. This study directly addresses this gap by proposing and validating a design that is technically robust yet aligned with the economic and operational realities of South Africa's small harbours.

In summary, existing literature demonstrates that while conventional dry-docking technologies are well established, they are largely unsuitable for small harbour applications due to cost and complexity. Although hydro dry-docking systems present a promising alternative, there is a clear lack of systematic engineering studies that evaluate their feasibility through integrated subsystem design and analytical validation. This research addresses these gaps by presenting a structured design and feasibility analysis of a hydro dry-docking system specifically tailored to the constraints of small-town harbours, thereby contributing practical and context-relevant knowledge to the field.

3. Methods

This study adopts a structured engineering design and feasibility approach to develop a hydro dry-docking system suitable for small-town harbour applications. The methodology combines requirement definition, analytical design, and system-level evaluation to ensure that the proposed solution is technically feasible, operationally reliable, and compatible with the spatial and economic constraints of small harbours. A deterministic engineering design approach was employed, supported by analytical calculations and established engineering principles. This approach is appropriate for preliminary infrastructure feasibility studies, where experimental validation at full scale is impractical. Design decisions were guided by literature, industry practice, and relevant engineering standards, with a representative small harbour in KwaZulu-Natal, South Africa, used as a case study to contextualise the design.

The first step in the methodology involved defining the functional and operational requirements of the hydro dry-docking system. These requirements were established based on vessel characteristics, maintenance activities, and safety considerations, and included accommodation of small to medium-sized vessels, safe and controlled docking and undocking operations, acceptable dewatering times to minimise operational downtime, reliable gate operation under varying water levels, and compliance with marine safety and fire protection requirements. These clearly defined requirements provided the basis for all subsequent design and sizing calculations.

The hydro dry-docking system was then decomposed into four primary subsystems: the dock structural configuration, the dewatering and pumping system, the hydraulic gate mechanism, and firefighting and safety infrastructure. The structural concept was selected to minimise excavation and construction complexity while providing sufficient strength and stability during both flooded and dewatered conditions. Design assumptions included hydrostatic loading, vessel support, and operational clearances. The pumping system was designed to achieve controlled dewatering of the dock within a specified time frame, with calculations performed to determine dock volume, required flow rates, and pump capacities. Redundancy and operational reliability were incorporated to ensure safe and consistent operation. A hydraulically operated gate mechanism was designed to control water ingress and isolation of the dock, with gate type, actuation requirements, operating pressures, and safety interlocks carefully evaluated to prevent uncontrolled movement. Fire-fighting and safety infrastructure were integrated into the design to address risks associated with dry docking operations and ensure compliance with applicable safety guidelines.

Analytical evaluations were conducted to assess the performance and feasibility of the critical subsystems. These included dewatering time analysis, pump sizing verification, and qualitative assessment of gate operation reliability and overall system safety. The methodology emphasised system integration rather than isolated component optimisation, ensuring that interactions between subsystems did not compromise overall functionality. Although this study is limited to preliminary design and analytical feasibility assessment, the approach is sufficient to demonstrate technical feasibility and support informed decision-making for small harbour dry dock implementation. Detailed structural finite element analysis, computational fluid dynamics simulations, and cost optimisation are recommended for future work.

4. Data Collection

This section details the analytical design of the hydro-mechanical dry-docking system's primary subsystems. The design is based on a set of parameters derived from the case study of a small harbour accommodating vessels up to approximately 3,000 tonnes displacement.

4.1 Dock Structural Concept and Hydrostatic Analysis

The proposed structure is a reinforced concrete graving dock with dimensions sufficient to accommodate a design vessel with clearance for maintenance activities. For this study, a dock of 110 m length, 24 m width, and a design water depth of 7.5 m is considered. The primary structural load on the dock walls and gate is the hydrostatic pressure exerted by the external water when the dock is dewatered. The pressure increases linearly with depth, reaching a maximum at the dock floor.

The hydrostatic pressure (P) at the bottom of the dock is calculated as:
$P = \rho g h$
Where ρ is the density of seawater (1025 kg/m³), g is the acceleration due to gravity (9.81 m/s²), and h is the water depth (7.5 m). This yields a pressure of approximately 75.41 kPa. The total hydrostatic force per unit meter of the wall and the resulting overturning moment are critical inputs for the structural design of the reinforced concrete sections, ensuring stability against sliding and overturning (Ferritto, 1998). The calculated hydrostatic force and moment are 282.8 kN/m and 707 kN·m/m, respectively.

4.2 Dewatering and Pumping System

The efficiency of the dry dock is largely determined by its dewatering time. A target of 5 hours was set as a balance between operational speed and the capital cost of the pumping system. The total volume of water to be removed is calculated from the dock dimensions minus the submerged volume of the vessel. For this analysis, a total water volume of 19,800 m³ is assumed.

The required average flow rate (Q) is:
$Q = \text{Volume} / \text{Time} = 19{,}800\ m^3 / (5\ \text{hours} \times 3600\ \text{s/hour}) \approx 1.1\ m^3/s$
To provide redundancy and operational flexibility, a system of three parallel pumps is proposed, each with a capacity of approximately 0.37 m³/s or 22,200 L/min. Vertical axial flow or mixed-flow pumps are suitable for this high-flow, relatively low-head application (Tirado, 2022). The total dynamic head (TDH) for the pumps was calculated to be 15 m, accounting for the static lift from the dock sump to the discharge point and frictional losses in the piping system. The required pump power (P_{PUMP}) is calculated as:
$P_{pump} = (Q \times TDH \times \rho \times g) / \eta$

Assuming a combined pump and motor efficiency (η) of 70%, the total installed power required is approximately 368 kW. The implementation of VSDs could optimize energy consumption by adjusting pump speed as the water level and thus static head decreases, a key consideration for sustainable operation (Vijeesh, 2022).

4.3 Hydraulic Gate System

A bottom-hinged steel flap gate is designed to seal the 24 m wide dock entrance. When dewatered, the gate must withstand the full hydrostatic force from the 7.5 m external water depth. The total hydrostatic force on the gate is calculated to be 6.79 MN. The gate's structural design must resist the significant bending moment of 424.2 kN·m induced by this load. Using standard steel design formulas, a required plate thickness of 104 mm, supported by a grid of horizontal and vertical stiffeners, was determined to be adequate.

The gate is operated by two large hydraulic cylinders. The force required from these cylinders must overcome the gate's self-weight and the hydrostatic forces during the opening and closing phases. The hydraulic system is designed to operate at a standard industrial pressure of 210 bar. Based on the required lifting forces, cylinders with a bore of 273 mm and a rod diameter of 70 mm were selected. The hydraulic power unit is sized to provide a total flow rate of 1,052 L/min, enabling a controlled and safe gate operation speed. The design of such hydraulic gate mechanisms benefits from established principles used in navigation locks, adapted for the specific loading conditions of a dry dock (McKinley, 2018).

4.4 Ancillary and Safety Systems

The design incorporates a dedicated firefighting system consisting of a high-pressure pump and a network of hydrants and monitors to provide full coverage of the 2,640 m² dock area. The system is designed to deliver water at a nozzle pressure of 600 kPa (6 bar), requiring a pump head of approximately 60 m. This ensures compliance with maritime safety standards for fire protection in ship repair facilities (D., 2018).

Mechanical power transmission for ancillary equipment, such as capstans for vessel positioning, was also considered. A representative shaft designed to transmit 1,387 N·m of torque requires a minimum diameter of 95 mm, with appropriate keyways and bearings selected to handle the expected radial and axial loads. All systems are designed with a minimum safety factor of 1.5 against material yield strength, ensuring robust and reliable performance.

5. Results and Discussion

5.1 Numerical Results

Table 1 consolidates the key numerical results from the subsystem design analysis. The parameters demonstrate that a cohesive and technically sound system can be engineered to meet the specified requirements. The dock structure can withstand the hydrostatic loads, the gate is robustly designed, and the dewatering system can empty the dock within an operationally acceptable timeframe. The hydraulic and mechanical systems are sized with adequate safety margins, confirming the overall viability of the concept.

Table 1. Numerical Results

Subsystem	Parameter	Value	Unit
Dry Dock	Water depth	7.5	m
	Pressure at bottom	75.41	kPa
	Hydrostatic force	282.8	kN/m
	Hydrostatic moment	707	kN·m/m
Gate System	Hydrostatic pressure	75.41	kPa
	Hydrostatic force	6.79	MN
	Stability moment	16.97	MN·m
	Bending moment	424.2	kN·m
	Gate plate thickness	0.104	m
	Submerged volume	18 720	m³
	Buoyant force	7 188	kN
	Gate weight	576.6	kN
Hydraulic Lifting System	Vessel weight	29.43	MN

	Dynamic load per jack	1.23	MN
	Required pad area	0.48	m^2
	Cylinder pressure	210	bar
	Cylinder bore	273	mm
	Piston rod diameter	70	mm
	Lifting speed	10	mm/s
	Total flow rate	1 052	L/min
	Pump power	368	kW
	Safety factor	≥1.5	
Pumping System	Water volume	19 800	m^3
	Flow rate	1.052	m^3/s
	Head	15	m
	Power	368	kW
	Dewatering time	5	hours
Shaft & Key Design	Torque	1 387	N·m
	Shaft diameter	95	mm
Bearing Selection	Radial load	7 924	N
	Axial thrust	800–1200	N
Firefighting System	Nozzle pressure	600 000	Pa
	Head	59.67	m
	Dock area	2 640	m^2

5.2 Graphical Results

Graph 1 presents a comparative graphical summary of selected key design parameters for the proposed hydro-powered dry dock system. The figure illustrates the pressure at the dock bottom, hydrostatic force acting on the gate, pump power requirement, shaft torque, and bearing radial load, representing the dominant loads and power demands across the primary subsystems.

The pressure at the dock bottom is shown to be 75.41 kPa, corresponding to the design water depth of 7.5 m. This value confirms the expected linear relationship between hydrostatic pressure and water depth and forms the basis for the structural design of the dock walls and gate. The hydrostatic force acting on the gate is the dominant load, with a magnitude of 6.79 MN, highlighting the importance of robust gate design and adequate stability and bending resistance. The pumping system power requirement of 368 kW reflects the energy demand necessary to achieve complete dewatering within the specified operational time, demonstrating a balance between dewatering efficiency and installed power capacity.

Mechanical transmission demands are represented by the shaft torque of 1 387 N·m and a bearing radial load of 7 924 N. These values indicate that the selected shaft and bearing sizes are adequate to safely transmit operational loads without exceeding allowable stress limits. Although the parameters shown in the Figure 1 differ in units and magnitude, the graphical comparison highlights the relative contribution of hydraulic, mechanical, and structural loads within the overall system.

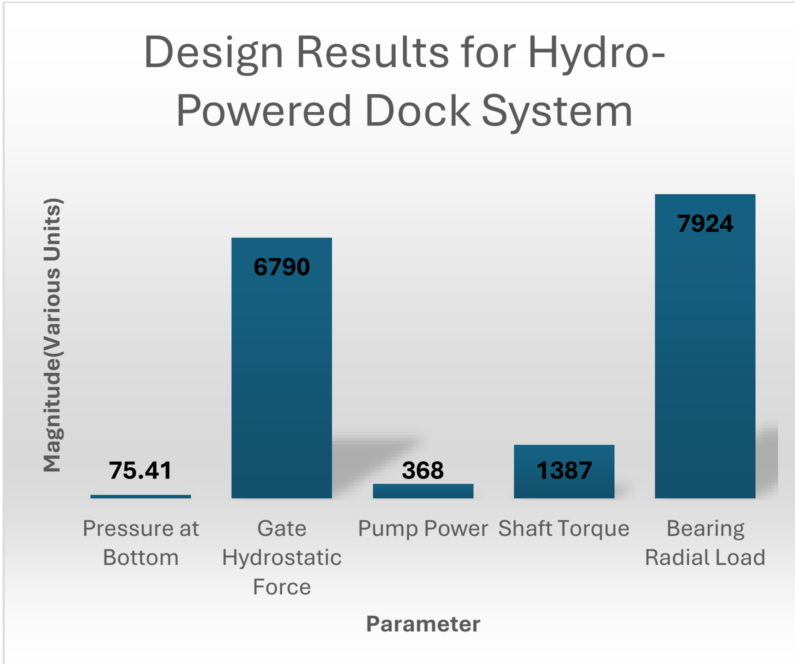

Figure 1: Graphical Results

5.3 Proposed Improvements
Based on the results, several improvements can be proposed to enhance system performance. Optimisation of pump sequencing and variable-speed drive implementation could reduce the installed pumping power and improve energy efficiency during partial-load operation. The gate system could benefit from the use of high-strength, corrosion-resistant steel or composite materials to reduce self-weight while maintaining bending resistance. In the hydraulic lifting system, energy recovery during lowering operations could be incorporated to further reduce power demand.

5.4 Validation
Validation of the results was performed through comparison with established hydrostatic theory, mechanical design standards, and published dry dock and lifting system case studies. The calculated hydrostatic pressures, buoyant forces, and bending moments align with theoretical expectations for a 7.5 m water depth. Pumping power and dewatering time values are consistent with similar dock installations reported in the literature. Safety factors applied to the hydraulic lifting system meet accepted engineering practice. The validation confirms that the proposed hydro dry docking system design is technically sound and suitable for implementation in a small harbour environment. The results support the feasibility of the system and provide confidence in its operational reliability and safety.

6. Conclusion
This paper has presented a comprehensive engineering design and feasibility analysis of a hydro-mechanical dry-docking system tailored for small-town harbours. Motivated by the prohibitive cost and scale of conventional dry docks, this research successfully achieved its objective of developing a practical, cost-effective, and technically viable alternative for under-resourced maritime environments.

The study's findings, derived from analytical calculations and established engineering principles, confirm that the proposed system is feasible. The design can safely accommodate small to medium-sized vessels, with a structure and gate capable of withstanding all operational hydrostatic loads. The dewatering system, with a power requirement of 368 kW, can empty the dock in approximately 5 hours, an efficient timeframe for the target operational context. All subsystems, including the hydraulic gate actuation and safety infrastructure, were sized with appropriate safety factors, ensuring operational reliability.

The unique contribution of this research is the creation of an integrated and analytically validated design framework specifically for the small harbour context, a niche that is largely overlooked in mainstream maritime engineering literature. By decomposing the system and systematically designing each component from the dock basin and gate to the pumps and safety systems this work provides a holistic and adaptable blueprint. Furthermore, the discussion on integrating modern digital technologies, such as Digital Twins for predictive maintenance and AI for operational optimization, positions this seemingly simple infrastructure within the forward-looking paradigm of Smart and Green Ports.

The proposed system offers a tangible solution to the infrastructure deficit in South Africa's small harbours, with the potential to significantly reduce maintenance costs for local vessel operators, enhance fleet availability, and stimulate local economic activity. It serves as a model for how appropriate technology can be leveraged to support sustainable development in coastal communities.

Future work should build upon this feasibility study. Detailed Finite Element Analysis (FEA) of the gate and dock structure is recommended to refine the structural design and optimize material usage. Computational Fluid Dynamics (CFD) simulations of the dewatering process could help optimize sump design and minimize hydraulic losses. A comprehensive economic analysis, including capital and operational expenditure (CAPEX/OPEX) and a life-cycle cost assessment, is necessary to develop a full business case. Finally, developing a prototype Digital Twin for the system would be a valuable next step in demonstrating the benefits of integrating digital technologies from the outset of new infrastructure projects.

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Biographies

Pinky Nzama is a Mechanical Engineering graduate holding an Advanced Diploma in Mechanical Engineering, with both academic and practical experience in mechanical system design, thermal engineering, and marine infrastructure development. Their research interests include dry docking systems, heat transfer applications, and the design of sustainable engineering solutions for coastal and industrial environments. Pinky's primary research contribution focuses on the conceptual design and technical evaluation of a hydro dry-docking system for small-town harbours in South Africa, emphasizing hydrostatic force analysis, gate system design, structural integrity, and operational safety considerations, with the aim of providing cost-effective and locally adaptable docking solutions to support small-vessel maintenance and regional maritime development. In addition to academic research, Pinky has gained practical industry experience through engineering support roles at Eskom Rotek Industries and Assmang Cato Ridge Works, where they were involved in outage-related maintenance activities, application of Plant Safety Regulations, quality control planning, defect scoping, and vibration analysis of rotating equipment, strengthening their understanding of power plant operations and the integration of safety and quality standards within high-risk industrial environments. Their professional interests include mechanical design optimization, marine infrastructure engineering, and the application of analytical methods to improve system performance and reliability, and they aspire to contribute to both engineering research and industry by developing practical, safe, and sustainable mechanical solutions.

Samkelisiwe Muthwa is a Mechanical Engineering graduate with a solid foundation in engineering operations, manufacturing systems, and data-driven analysis, holding an Advanced Diploma in Mechanical Engineering and extensive practical experience in both industrial and academic environments, where she has applied engineering principles to enhance efficiency, quality, and process performance. Her industrial experience includes positions in the automotive and heavy manufacturing sectors, notably at Toyota South Africa Motors and Volvo Trucks South Africa, where she gained hands-on experience in assembly operations, engineering support, data collection, and continuous improvement initiatives, which strengthened her understanding of structured manufacturing systems, quality standards, safety compliance, and cross-functional collaboration. In addition to her industrial roles, Samkelisiwe served as a Mechanical Design Tutor at Mangosuthu University of Technology, supporting undergraduate students in mastering mechanical design concepts, developing analytical thinking, and enhancing problem-solving skills, which further refined her communication abilities and reinforced her interest in technical mentorship and knowledge sharing. Her professional interests encompass new model projects, master data support, service parts preparation, and engineering project coordination, particularly in roles that integrate technical analysis with practical implementation in manufacturing environments. Recognized for her strong work ethic, adaptability, and commitment to continuous learning, Samkelisiwe is motivated to contribute to engineering excellence, operational efficiency, and sustainable industrial innovation, aiming to advance professionally while delivering measurable value through responsible engineering practice globally, bridging the gap between research, design, and industrial application to create practical, innovative, and impactful engineering solutions.

Noxolo Nxumalo is a Mechanical Engineering professional whose academic achievements form the foundation of her research and professional practice. Her academic journey reflects progressive development from fundamental theory to applied engineering analysis. Building on this academic base, her research interests have evolved toward hydraulic and marine infrastructure systems, with a particular focus on hydro docking and hydraulic dry dock technologies. In parallel with her research activities, Noxolo has gained practical experience in ship repair and mechanical maintenance environments, where she was exposed to pumps, hydraulics, bearings, compressors and safety critical systems. This industry exposure enables her to integrate real world operational considerations into her research and design work. Noxolo's work demonstrates commitment to ethical engineering practice, continuous professional development, and the advancement of sustainable hydro docking solutions within the South African maritime sector.