Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks

Deliverable report – D9.3

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Author(s)	Angeliki Deligianni (GLM), Leonidas Drikos (GLM)
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HISTORY OF CHANGES

Date	Written by	Description of change	Approver	Version No.
05/12/2023	GLM	First ToC of the draft	GLM	V0.1
31/01/2024	GLM	First Draft of the D.9.3	GLM	V0.2
26/03/2024	GLM	Final Version	GLM	V0.4

REFERENCED DOCUMENTS

- D9.1 Large-scale pilot specification and integration plan
- D9.2 Large-scale pilot: Integration

These documents are stored on the file sharing site hosted by CNRS.

Executive summary

Deliverable 9.3, titled "Large-Scale Pilot: Demonstrations" presents the findings and outcomes of the BUGWRIGHT2 project, which aimed to develop and demonstrate innovative robotic solutions for hull services in the maritime industry. Through large-scale pilot demonstrations and stakeholder engagement activities, the project evaluated the capabilities and performance of robotic platforms for tasks such as inspection, cleaning, and maintenance of ship hulls. Key insights were gained regarding the efficiency, accuracy, and cost-effectiveness of robotic systems in conducting these tasks, even in challenging maritime environments. The demonstrations showcased the adaptability and versatility of robotic solutions, as well as their potential benefits in terms of safety and operational efficiency. Furthermore, stakeholder engagement played a crucial role in shaping the project's trajectory and ensuring the relevance and applicability of the technology to real-world industry needs. The report concludes with implications for future research, development, and deployment efforts in the field of robotics for hull services, highlighting the importance of continued innovation, collaboration, and stakeholder engagement in driving the adoption and integration of robotic technologies across the maritime industry.

1. INTRODUCTION

The BUGWRIGHT2 project endeavors to transform hull services using multiple robotic platforms, with the goal of improving efficiency and effectiveness in ship maintenance. Embedded within this project, the large-scale pilot assumes a pivotal role, synchronizing with broader objectives by showcasing the tangible applications and advantages of robotics in authentic operational contexts. From its inception, BUGWRIGHT2 has been designed as a large-scale pilot, emphasizing validation through practical testing on end-users' sites. This approach is integral to the project's overarching goal of advancing the adoption of robotics solutions in the maritime industry.

The large-scale pilot demonstrations served multiple objectives. Firstly, they provided a platform to validate the performance of the BUGWRIGHT2 system in real-world operational environments, including shipyards, ports, and maritime facilities. Through extensive field testing, the project aimed to demonstrate the effectiveness and practical applicability of the system in meeting the needs of end-users. Furthermore, the BUGWRIGHT2 provided experimental inspection services using the BUGWRIGHT2 system. These services were offered to 20 vessels per year, facilitating thorough evaluation and validation of the system's capabilities. The target audience for these services included shipowners, operators, and other stakeholders involved in ship maintenance and operations.

Expected outcomes of the large-scale pilot demonstrations include an enhanced understanding of the BUGWRIGHT2 system's capabilities and benefits among stakeholders, validation of the system's performance and effectiveness through practical field testing, gathering valuable feedback from end-users to refine the system's functionality and usability, and advancement of the adoption of robotics solutions in the maritime industry by showcasing the potential of the BUGWRIGHT2 system.

2. DEMONSTRATIONS OVERVIEW

In this section a comprehensive examination of the demonstrations conducted at each location as part of the large-scale pilot for the BUGWRIGHT2 system is presented. These demonstrations represent a pivotal phase in the project's mission to showcase the practical applications and advantages of advanced robotics technology within the maritime sector. Through meticulous scrutiny of the activities and technologies showcased during these demonstrations, the section endeavors to offer a nuanced understanding of the BUGWRIGHT2 system's capabilities and its potential to transform hull services. By exploring stakeholder participation and feedback, valuable insights are gleaned into the demonstrative impact and efficacy of these initiatives in fostering innovation and efficiency across maritime operations.

2.1. Deployment Locations and Process

The deployment of the BUGWRIGHT2 system encompassed three primary locations: the AASA Shipyard in Lisbon (PT), TRH Harbour in Trondheim (NO), and GLM's Commercial Survey Activities in Piraeus (GR). Each location presented unique characteristics and requirements for the successful implementation of the system.

AASA SHIPYARD, LISBON

Arsenal do Alfeite stands as a premier industrial establishment, specializing primarily in the repair and maintenance of naval vessels as a leading contractor. With a diverse portfolio, AASA also possesses the capability to construct military ships, manage complex programs, and execute industrial maintenance and integrated logistic support services. Central to its operations is a steadfast commitment to environmental preservation, actively contributing to environmental sustainability and striving to enhance its environmental performance while adhering to principles of sustainability and pollution prevention. Emphasizing social corporate responsibility, Arsenal prioritizes the health and safety of its workforce. AASA operates as a Portuguese State-owned entity governed by Portuguese Public Law and adheres to public procurement regulations. Certified by APCER in compliance with ISO 9001:2015 standards, AASA has remained at the forefront of technological advancements since its establishment in 1939, maintaining a longstanding partnership with the Portuguese Navy. This enduring relationship is driven by AASA's dedication to delivering value to customers and partners alike.

TRH HARBOUR, TRONDHEIM

The Trondheim Port Authority operates under the purview outlined in its articles of association, which mandate the execution of all managerial and administrative duties pertinent to The Port and Seaways Act, as well as those relevant to the collective harbor area, on behalf of its participants. With a strategic focus on assuming a leading role in transportation, the authority is committed to fostering the development of efficient transport and logistics solutions that contribute to the advancement of business, urban development, and environmental sustainability. At the helm of the Trondheim Port Authority is a Port Council comprising 16 members, tasked with overseeing its operations. The Port Council convenes at least twice annually to deliberate on matters of significance. Additionally, the authority is governed by a Board of Directors, entrusted with the management of its activities and strategic direction.

GLM'S ACTIVITIES, PIRAEUS

Regarding Task 9.3 Large-Scale Pilot: Demonstrations to End-Users, GLM in collaboration with SBK have accomplished to complete the construction of the mock-up in Perama ship-repairing zone, in Greece during the BUGWRIGHT2 project. Though at first it was intended to construct the hull mock-up in the Aspropyrgos industrial zone, due to legal concerns and the relative impossibility of meeting the strict requirements imposed by the authorities (municipality, urban planning, and the Ministry of the Environment due to the size and volume of construction), this was abandoned. The COVID-19 pandemic's delays and bad effects were added to this situation, making it much more challenging to carry out the project. This construction is significant for the project since Integration Weeks, several field tests of the robotic platforms and demonstrations to end-users have been taken place there. To do so, GLM painted the mock-up, installed containers to host the necessary equipment for test trials and personnel.

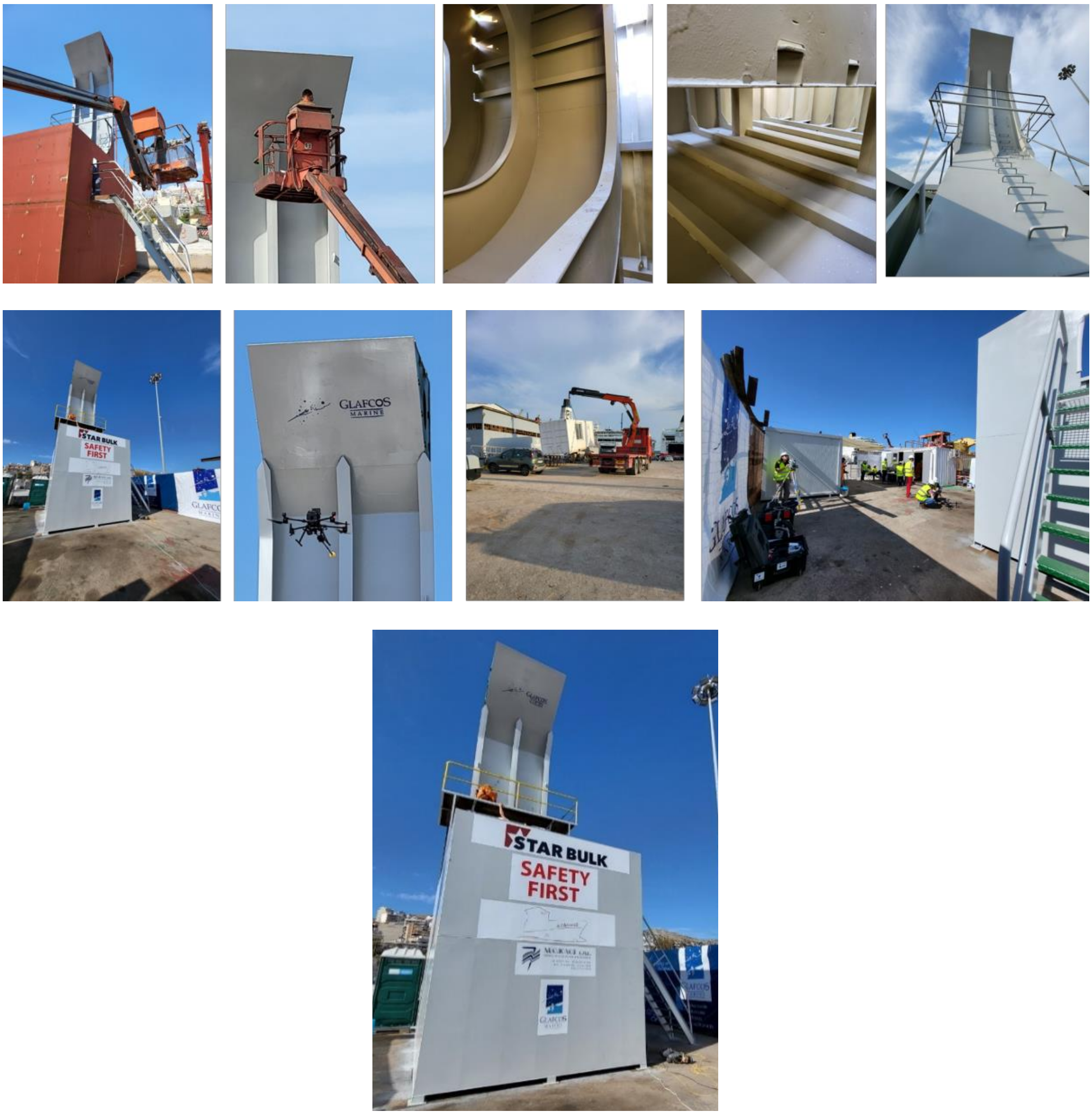

Figure 1: Different images of the mock-up

2.2. Demonstrations and Fields Visits

In the realm of BUGWRIGHT2 project, numerous experiments and demonstrations have been conducted to explore the capabilities and potentials of developed robotic platforms in ship maintenance and inspection. Each of these experiments represents a significant step forward in the ongoing evolution of maritime robotics, offering valuable insights into their functionality, reliability, and adaptability to real-world environments. In this subsection, a detailed overview of individual experiments conducted across different locations, categorizing them based on the robotic platform employed and the specific objectives pursued. Through this exploration, we aim to provide a comprehensive understanding of the progress made in maritime robotics research and its implications for the future of ship maintenance and inspection practices.

REMOTELY OPERATED VEHICLE (ROV) AND AUTONOMOUS UNDERWATER VEHICLES (AUV)

Throughout the duration of the BUGWRIGHT2 project, various experiments were conducted to assess the progress and development of remotely operated vehicle (ROV) and autonomous underwater vehicle (AUV) technologies. These experiments were carried out at different locations and aimed to evaluate the performance, capabilities, and advancements of ROVs and AUVs in various maritime applications. Table 1 provides a comprehensive overview of the milestones achieved and the progress made in enhancing the functionality and effectiveness of these underwater vehicles.

Table 1: Progress of ROV and AUV platforms during the BUGWRIGHT2 project

Date and Location	Robotic platform/ Technology	Progress
September 2020 Piraeus, Greece	ROV	Trial inspection conducted on small vessels
September 2020 to April 2022 Trondheim, Norway	ROV	Tests conducted in water to determine the correct sensor setup for the project
January 2021 Piraeus, Greece	ROV	Another trial inspection conducted on small vessels.
May 2021 to September 2021 Trondheim, Norway	ROV	Tested autonomy in open water, following autonomously simple paths created by the user
September 2021 to March 2022 Trondheim, Norway	ROV	Tested detection of defects while inspecting the hull
May 2022 to November 2022 Trondheim, Norway	ROV	Conducted autonomous inspection of the ship hull, navigating around the hull and adapting to its shape while estimating it using sonar data
October 2022 Klagenfurt, Austria	AUV	Worked on improving the localization system based on the MaRS framework
January 2023 Trondheim, Norway	ROV	Conducted point-specific inspection focusing on important parts like the propeller, chest gratings, and keels to model them.
April 2023 Trondheim, Norway	ROV	Automatic summary generation based on the operation data.

During the course of the experiments conducted between September 2020 and April 2023, several significant advancements were made in the development and utilization of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) for maritime inspection and maintenance tasks. The initial trials in Piraeus, Greece, in September 2020 and January 2021 involved the use of ROVs for conducting trial inspections on small vessels. These experiments served as foundational steps in assessing the feasibility and effectiveness of ROVs in maritime environments. In Trondheim, Norway, extensive testing was conducted between September 2020 and April 2022 to determine the optimal sensor setup for ROVs deployed in underwater environments. These tests focused on fine-tuning the ROV's sensory capabilities to ensure accurate data collection and analysis during inspection tasks. Subsequent experiments in Trondheim from May 2021 to September 2021 saw the ROVs operating autonomously in open water, demonstrating their ability to follow predefined paths created by users. This marked a significant milestone in advancing the autonomy of ROVs in maritime operations, reducing the need for constant human intervention. Continuing in Trondheim from September 2021 to March 2022, further progress was made in enhancing the ROVs' capabilities to detect defects while inspecting the hull of ships. These tests aimed to improve the accuracy and efficiency of defect detection, crucial for ensuring the structural integrity of vessels.

A notable achievement occurred between May 2022 and November 2022 when ROVs conducted autonomous inspections of ship hulls in Trondheim. These experiments showcased the ROVs' ability to navigate around the hulls and adapt to their shapes while estimating them using sonar data, demonstrating a high level of autonomy and precision in maritime inspection tasks. In October 2022, in Klagenfurt, Austria, efforts were focused on enhancing the localization system of AUVs based on the MaRS framework. These improvements aimed to enhance the AUVs' navigational accuracy and efficiency in underwater environments, contributing to overall mission success. Finally, in January 2023, in Trondheim, Norway, ROVs conducted point-specific inspections focusing on critical parts of vessels such as propellers, chest gratings, and keels to model them accurately. Additionally, in April 2023, automatic summary generation based on operational data was demonstrated, highlighting advancements in data analysis and reporting capabilities for maritime inspection tasks.

In conclusion, the experiments conducted during the project timeline demonstrate significant progress in the development and application of ROV and AUV platforms. From initial trials to advanced autonomous operations, these experiments have contributed to improving the capabilities and functionality of underwater vehicles for maritime operations.

MAGNETIC CRAWLER

The development and testing of magnetic crawler technology have been pivotal in advancing the capabilities of inspection and maintenance in maritime environments. Through a series of experiments conducted at various locations, the progress of magnetic crawlers has been assessed, focusing on their performance, functionality, and integration with user interfaces. These experiments spanned from initial measurements and basic parameter testing to more advanced tasks such as 3D localization, failure scenario testing, and ultrasonic imaging. The following paragraphs and Table **2** provide a comprehensive overview of the progress achieved for magnetic crawler technology during these experiments.

The experiments commenced in April 2021 in Piraeus, Greece, where magnetic crawlers were utilized to conduct measurements within the context of ship surveys. Over the course of the project, significant milestones were reached, including the testing of 3D localization in Bazancourt, France, and the processing of thickness measurement and user interface demands in Lisbon, Portugal.

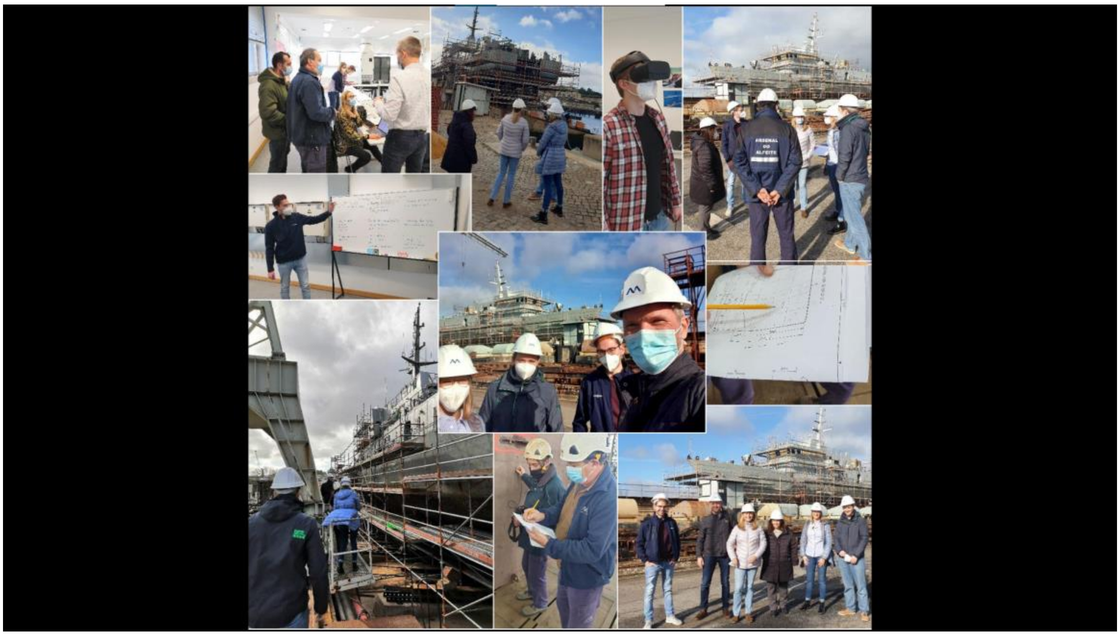

Figure 2: TRU field visit of AASA, in Lisbon, PT - December 2021

In January 2022, experimental inspections were carried out on a steel vessel in Lisbon, demonstrating the versatility and effectiveness of magnetic crawlers in different environments.

Figure 3: RBP field visit of AASA, in Lisbon, PT - January 2022

Subsequent tests in Piraeus, Greece, during the summer of 2022 involved various scenarios such as evaluation in test facilities, failure scenario testing, and underwater operations, showcasing the robustness and adaptability of magnetic crawler technology. Integration efforts were emphasized in September 2022, with experiments conducted in Metz and Bazancourt, France, focusing on integrating magnetic crawlers with virtual reality user interfaces. This integration aimed to enhance user experience and streamline inspection processes.

Figure 4: Experiments conducted in Bazancourt (and Metz), FR - September 2022

Additional experiments in Concarneau and Metz, both in France, in October 2022 and March 2023, respectively, further advanced magnetic crawler technology by collecting data for 3D ship modeling and refining integration with user interfaces.

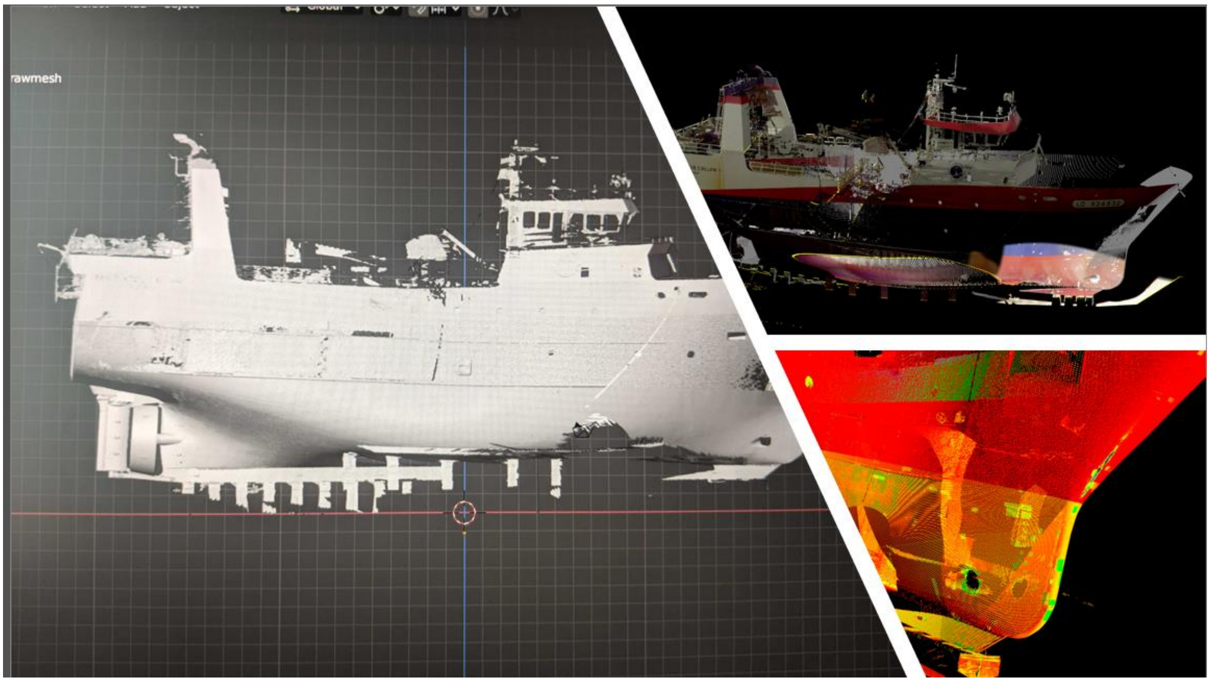

Figure 5: Construction of 3D model from the visit in Concarneau, FR - October 2022

The culmination of the project involved extensive testing of magnetic crawler autonomy for surface inspection in Lyon & Metz, France, from September 2023 to March 2024.

Figure 6: Field testing in Metz, FR – February 2024

This phase evaluated the capability of fleets of crawlers to autonomously conduct surface inspections, marking a significant milestone in magnetic crawler technology development.

Table 2: Progress of magnetic crawler platforms during the BUGWRIGHT2 project

Date and Location	Robotic platform/ Technology	Progress
April 2021 to September 2022 Piraeus, Greece	Magnetic crawler	Conducted measurements in the context of a survey at different internal parts of a ship. A total of four tests were performed
November 2021 Bazancourt, France	Magnetic crawler	Testing of 3D localization with Leica total station
December 2021 Lisbon, Portugal	Magnetic crawler	Processed thickness measurement and user interface demands
January 2022 Lisbon, Portugal	Magnetic crawler	Conducted experimental inspection on a steel vessel in the inclined plane
February 2022 Bazancourt, France	Magnetic crawler	Tested 3D localization with Leica total station
Spring 2022 Piraeus, Greece	Magnetic crawler	Tested basic parameters of the robot on the floor, including electronics, power supply, kinematics, alignment of shafts, and remote operation
Summer 2022 Piraeus, Greece	Magnetic crawler	Conducted various tests including magnetic crawler evaluation in a test facility, failure scenarios testing, testing of water flow and

		pressure, cleaning different adhesive materials, and underwater operation.
September 2022 Metz and Bazancourt, France	Magnetic crawler & VR	Integration of the magnetic crawler with the user interface.
October 2022 Concarneau, France	Magnetic crawler	Collected data to build a 3D model of a ship
March 2023 Metz, France	Magnetic crawler & VR	Integrated between the crawler and user interface
September 2023 Lisbon, Portugal	Magnetic Crawler & EMAT sensors	Angular scanning for ultrasonic imaging of reflectors (edge, weld, stiffener). Linear scans to detect defects (loss of thickness, impact, etc.).
September 2023 to March 2024 Lyon & Metz, France	Magnetic crawler	Testing autonomy of a fleet of crawlers for surface inspection
January 2024 Lisbon, Portugal	Magnetic crawler	Conducted one-day training with a crawler. Experimental inspection, data collection, and evaluation of the thickness measurement
March 2024 Piraeus, Greece	Magnetic crawler	Testing autonomy of a fleet of crawlers for surface inspection in a mock-up scenario

In conclusion, the series of experiments conducted for magnetic crawler platform (Table 2) have demonstrated substantial progress in enhancing the capabilities and functionality of inspection and maintenance systems. From initial measurements to advanced autonomy testing, magnetic crawlers have showcased their versatility, adaptability, and effectiveness in maritime environments. The integration with user interfaces and the development of advanced functionalities such as 3D localization and ultrasonic imaging further underscore the potential of magnetic crawler technology to support operations.

DRONES AND MICRO AERIAL VEHICLES (MAV)

Unmanned aerial vehicles (UAVs), commonly known as drones, and Micro Air Vehicles (MAVs) have emerged as integral components in maritime inspection and surveillance. Through a series of experiments conducted at various locations, the progress of UAVs and MAVs has been assessed, focusing on their capabilities in conducting surveys, mission planning, autonomous navigation, and inspection data collection. The following paragraphs provide an in-depth overview of the advancements made in drone and MAV technology during these experiments.

Table 3: Progress of Drones and MAV platforms during the BUGWRIGHT2 project

Date and Location	Robotic platform/ Technology	Progress
Summer & Autumn 2022 Piraeus, Greece	Drone	Conducted measurements in the context of a survey at different external parts of the structure (mock-up)
September 2022 Spain	Drone	Mission planning for drone testing.
November 2022 Klagenfurt, Austria	MAV	Integrated all motion estimation modules into the visual inspection-oriented drone; evaluated the vision-based odometer and the laser-based odometer, and their fusion through MaRS.
September 2023 Lisbon, Portugal	MAV	Tested the autonomous navigation and inspection data collection capabilities of the drone. Assisted flight to cover the ship from end to end. Initialization of the localization framework.

The experiments commenced during the summer and autumn of 2022 in Piraeus, Greece, where drones were employed to conduct measurements as part of a survey on different external parts of a ship structure. These initial experiments laid the foundation for further advancements in UAV technology. In September 2022, in Spain, mission planning for drone testing was conducted, emphasizing the importance of strategic planning and preparation for successful UAV operations. This phase focused on optimizing flight paths and mission parameters to maximize efficiency and data collection capabilities.

In November 2022, in Klagenfurt, Austria, significant progress was achieved in MAV technology, with the integration of all motion estimation modules into a visual inspection-oriented drone. The evaluation of vision-based and laser-based odometers, and their fusion through MaRS (Multi-Agent Robotic System), demonstrated enhanced localization and navigation capabilities essential for autonomous inspection tasks.

Figure 7: Field Visit of UIB in Klagenfurt, AU - November 2022

The advancements continued in September 2023 in Lisbon, Portugal, where MAVs were tested for autonomous navigation and inspection data collection capabilities. Assisted flight was utilized to cover the ship from end to end, showcasing the potential of MAVs to streamline inspection processes and gather comprehensive data for analysis. Furthermore, the initialization of the localization framework marked a critical step towards achieving full autonomy in MAV operations.

In conclusion, the experiments conducted for drones and MAVs (Table **3**) have demonstrated significant progress in enhancing the capabilities of unmanned aerial vehicles for maritime applications. From conducting surveys and mission planning to autonomous navigation and inspection data collection, UAVs and MAVs have showcased their versatility, efficiency, and potential to revolutionize maritime surveillance and inspection operations. The integration of advanced technologies such as visual inspection modules and localization frameworks highlights the continuous evolution of UAV and MAV technology to meet the growing demands of maritime industries.

OTHER TECHNOLOGIES

Virtual Reality (VR) technology and sensor systems play crucial roles in the BUGWRIGHT2 project, contributing to enhanced user interfaces, immersive experiences, and advanced defect detection capabilities. Table **4** provides an overview of the progress made in VR and sensor technology during various phases of the project, highlighting key developments and advancements achieved through experimentation and testing.

Table 4: Progress of different technologies during the BUGWRIGHT2 project

Date and Location	Robotic platform/ Technology	Progress
September 2022 Metz and Bazancourt, France	Magnetic crawler & VR	Integration of the magnetic crawler with the user interface.
November 2022 Piraeus, Greece	VR	Conducted HoloLens virtual world alignment tests.
March 2023 Metz, France	Magnetic crawler & VR	Integrated between the crawler and user interface
September 2023 Lisbon, Portugal	Magnetic Crawler & EMAT sensors	Angular scanning for ultrasonic imaging of reflectors (edge, weld, stiffener). Linear scans to detect defects (loss of thickness, impact, etc.).

In September 2022, in Metz and Bazancourt, France, significant progress was made in VR technology with the integration of a magnetic crawler with the user interface. This integration marked a significant milestone in enhancing user interaction and control over the magnetic crawler, leveraging VR to provide intuitive and immersive experiences for operators. November 2022 saw further advancements in VR technology, with HoloLens virtual world alignment tests conducted in Piraeus, Greece. These tests aimed to refine the alignment and calibration of virtual environments with physical surroundings, enhancing the accuracy and realism of VR simulations for training and inspection purposes.

In March 2023, in Metz, efforts continued to integrate VR technology with a magnetic crawler, further enhancing the synergy between the crawler and the user interface. This integration facilitated seamless interaction and control, optimizing workflow efficiency and user experience during inspection and maintenance tasks.

Figure 8: Integration of the magnetic crawler with the user interface

September 2023 witnessed progress in sensor technology in Lisbon, Portugal, where a magnetic crawler equipped with EMAT (Electromagnetic Acoustic Transducer) sensors conducted angular scanning for ultrasonic imaging of reflectors, such as edges, welds, and stiffeners. Additionally, linear scans were employed to detect defects such as loss of thickness and impacts, demonstrating the versatility and effectiveness of sensor systems in identifying structural abnormalities.

In conclusion, the advancements in VR and sensor technology within the BUGWRIGHT2 project have led to significant improvements in user interfaces, immersive experiences, and defect detection capabilities. The integration of VR with magnetic crawlers has enhanced user interaction and control, while sensor systems have enabled precise and comprehensive defect detection in maritime structures.

INTEGRATION WEEKS

The demonstrations conducted during the Integration weeks at various locations showcased the cutting-edge technologies and capabilities developed as part of the BUGWRIGHT2 project. Below a summary of the activities and technologies showcased at each location is presented.

- Piraeus (May-22, Nov-22, Mar-24): These demonstrations focused on testing in mock-up environment, cargo holds, and underwater hulls. Key activities included validating system robustness, maneuverability assessment in confined spaces, and refining sensing capabilities for inspection tasks. Technologies showcased included MAVs, AUVs, and Crawlers. In May-22, GLM in collaboration with DAN and SBK, provided an integrated framework for conducting the pilot tests (infrastructure, logistics, operations). Specifically, at the beginning of the week, Mr. Drikos, as a safety engineer, presented the participants the safety procedures that must be followed throughout the experiments (Figure **9**), and GLM provided the necessary means of personal protection (helmets, clothing, etc.). Also, the first day in the offices of Danaos Shipping Co Ltd. a review meeting was held as shown in Figure **10** with all the partners that attended at Integration Week in Athens.

Figure 9: Presentation of safety procedures by Leonidas Drikos (GML)

Figure 10: General meeting at Danaos Offices in Athens, GR

During the final iteration week of the BUGWRIGHT2 project (March 2024), pivotal demonstrations were conducted aboard a ship, where the developed robotic platforms were showcased to the ship's captain, chief officer, and other stakeholders. This marked a significant milestone in the project's progression, as it provided an invaluable opportunity to directly engage with end-users and decision-makers within the maritime industry.

- Trondheim (Jun-22): The demonstrations in Trondheim centered on multi-vehicle operations within controlled environments, utilizing a dummy offshore platform and the research vessel Gunnerus. Activities included testing coordination algorithms, communication protocols, and adaptive control strategies. Technologies featured were MAVs, AUVs, and Crawlers.

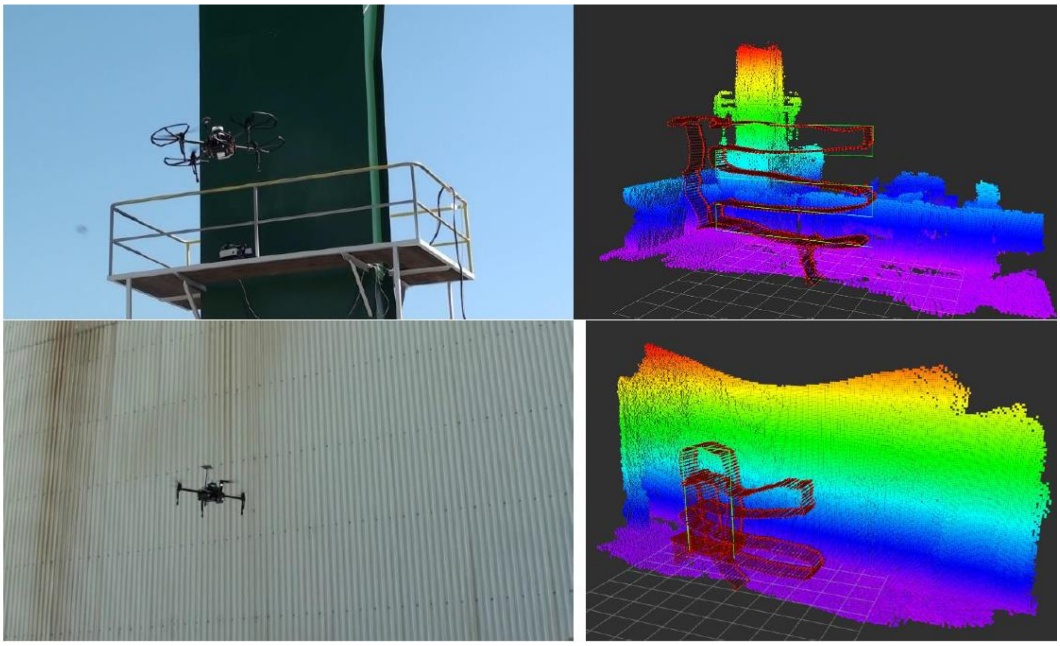

Figure 11: Pictures and path followed/3D point cloud collected for two of the flights taking place during the integration weeks in (top) Athens, GR and (bottom) Trondheim, NO

- Porto (Jun-23): Demonstrations in Porto emphasized testing scenarios tailored to barge environments, focusing on navigation in open waters, obstacle avoidance, and collaborative task execution. Key activities included enhancing platform autonomy, optimizing energy efficiency, and mitigating operational risks. MAVs, AUVs, and Crawlers were the primary technologies showcased.
- Lisbon (Sep-23): The demonstrations in Lisbon prioritized hull inspection and navigation challenges prevalent in maritime operations. Activities included exploring novel sensing modalities, navigation algorithms, and human-robot interaction paradigms to streamline inspection workflows and enhance situational awareness. Technologies highlighted were MAVs, AUVs, and Crawlers.

Figure 12: 1st Integration Week in Athens, GR - May 2022

Figure 13: Last Integration Week in Athens, GR - March 2024

Stakeholder participation in these demonstrations was comprehensive, involving shipyards, harbours, ship-owners, service, technology and platform providers, classification society and academics from the consortium. Their involvement ensured real-world validation of the developed technologies and provided valuable feedback for further refinement and optimization. Additionally, collaboration with stakeholders facilitated the alignment of project objectives with industry needs and standards, enhancing the overall impact and applicability of the developed solutions.

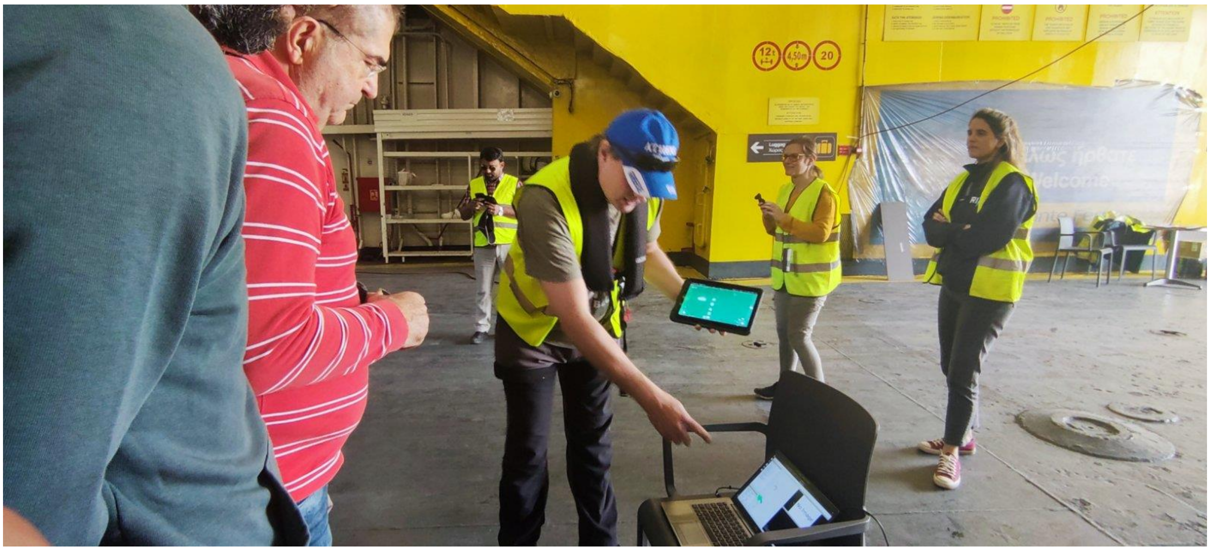

Figure 14: Demonstrations of BUGWRIGHT2 platforms to maritime stakeholders, Athens, GR – March 2024 (1)

Figure 15: Demonstrations of BUGWRIGHT2 platforms to maritime stakeholders, Athens, GR – March 2024 (2)

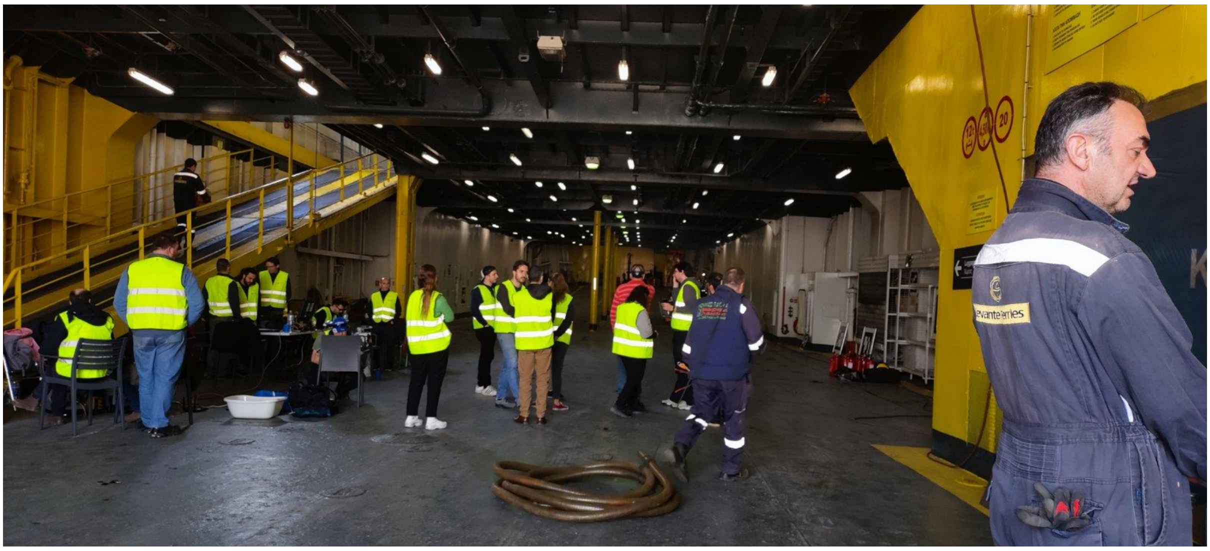

Figure 16: Demonstrations of BUGWRIGHT2 platforms to maritime stakeholders, Athens, GR – March 2024 (3)

Figure 17: Demonstrations of BUGWRIGHT2 platforms, Porto, PT – June 2023 (4)

Figure 18: Demonstrations of BUGWRIGHT2 platforms, Porto, PT – June 2023 (5)

Figure 19: Demonstrations of BUGWRIGHT2 platforms to maritime stakeholders, Lisbon, PT – September 2023 (6)

Figure 20: Demonstrations of BUGWRIGHT2 platforms, Trondheim, NO – June 2022 (7)

Figure 21: Demonstrations of BUGWRIGHT2 platforms, Athens, GR – May 2022 (8)

2.3. Onboard Surveys

The onboard survey demonstrations conducted as part of the project exemplify a pivotal component in the integration of advanced robotic technologies within maritime inspection practices. These demonstrations, meticulously orchestrated by project partners, serve as critical validation exercises for the efficacy and practicality of various robotic platforms and inspection methodologies in real-world maritime environments. GLM participated on onboard class surveys of different vessels with the use of the BUGWRIGHT2 robotic platforms. These activities highlighted the applicability of the BUGWRIGHT2 platforms in real working scenarios and they were persuasive demonstrations to the ship owners. Moreover, presentations of these activities had been prepared by GLM, which supported the dissemination of the project's practical application.

Table 5: Onboard surveys and demonstrations

Class Audit BV	
Date	December 2020
Location	Syros, Greece
Ship Type/Surface	Cargo Holds, Ballast Tanks
Technologies	MAV, AUV, Crawler, ROV
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard inspection & Class Audit ABS	

Date	January 2021
Location	Vattika, Greece
Ship Type/Surface	Cargo Holds, Ballast Tanks
Technologies	MAV, ROV, Crawler
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection	
Date	May 2021
Location	Syros, Greece
Ship Type/Surface	Cargo Holds, Ballast Tanks
Technologies	MAV, AUV, Crawler
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection & Class Audit DNV	
Date	July 2021
Location	Perama, Greece
Ship Type/Surface	Decks, Outer Hull, Underwater Hull
Technologies	MAV, ROV, Crawler
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection & Class Survey	
Date	September 2021
Location	Bakar, Croatia
Ship Type/Surface	Cargo Holds, Ballast Tanks
Technologies	UAV, Crawler
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection & Class Survey	
Date	April 2022
Location	Ploce, Croatia
Ship Type/Surface	Cargo Holds, Ballast Tanks
Technologies	UAV, Crawler
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection & Class Survey	
Date	July 2022
Location	Perama, Greece
Ship Type/Surface	Decks, Hull, Underwater Hull
Technologies	Crawler, ROV, Drone
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers
Onboard Inspection & Class Audit RINA	
Date	August 2022
Location	Perama, Greece
Ship Type/Surface	Small vessels, Yacht
Technologies	Crawler, Drone, ROV
Participants	Class surveyors, Shipowners', Superintendent engineer, and Ship Officers

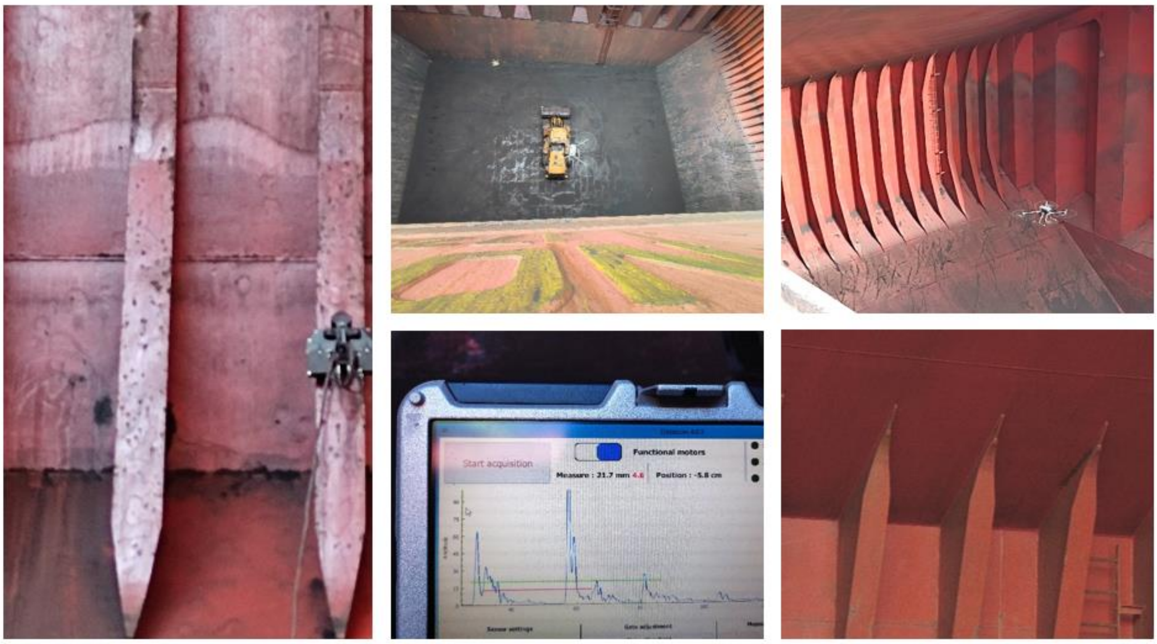

Figure 22: Onboard Inspection & Class Survey – September 2021

Figure 23: Onboard Inspection & Class Survey – April 2022

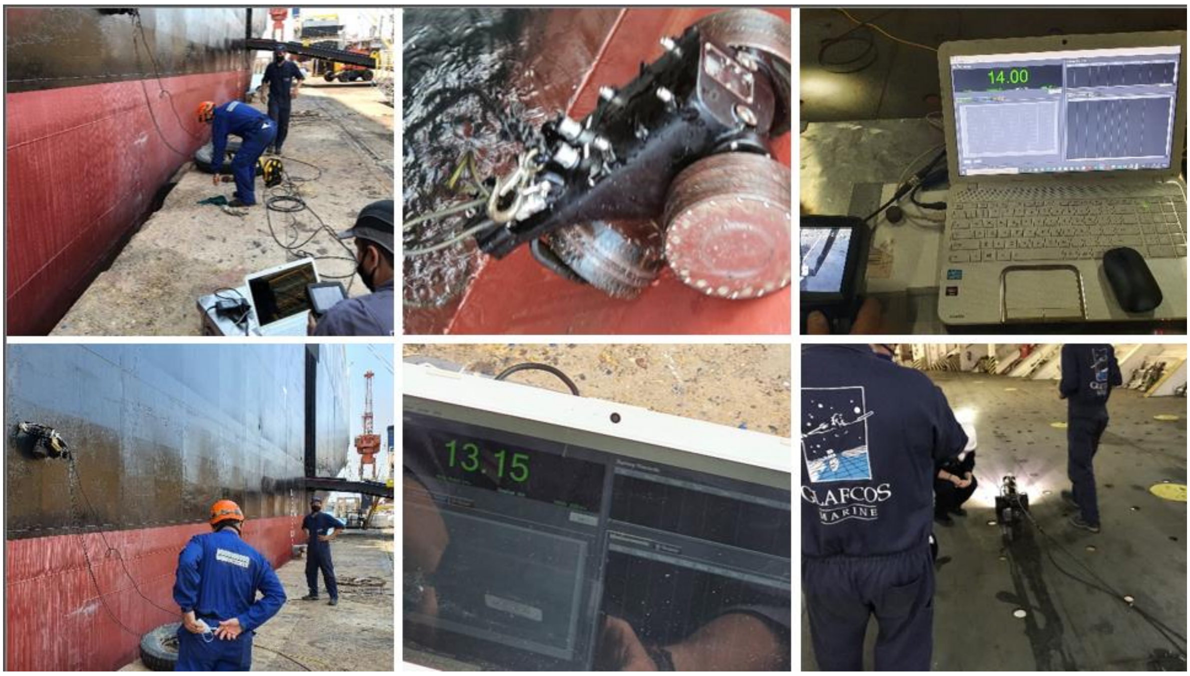

Figure 24: Onboard Inspection & Class Audit DNV – July 2021

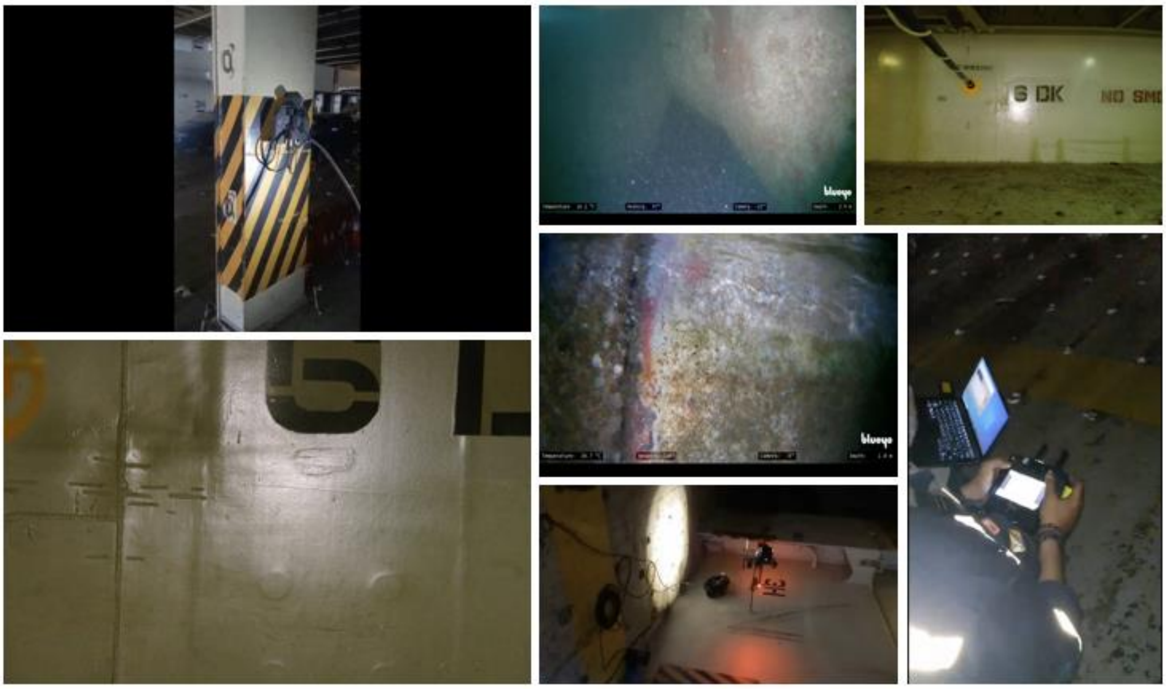

Figure 25: Onboard Inspection & Class Survey – July 2022

2.4. Onboard Cleaning

In the framework of the BUGWRIGHT2 project, emphasis was placed on the development and demonstration of the onboard cleaning magnetic crawler. This specialized platform was designed to address the crucial task of cleaning the biofouling at the outer hull of the ships using water pressure. Through meticulous development efforts, the cleaning magnetic crawler was equipped with advanced cleaning mechanisms (nozzles) and capabilities tailored to efficiently remove debris, fouling, and contaminants from ship surfaces while minimizing operational downtime and environmental impact.

The underwater cleaning phase involved identifying key points of interest on the hull of an actual ship, pinpointing areas with the most severe sea growth fouling. Once these locations were identified, the robotic platform was strategically placed on the hull to commence the cleaning process. Operating under real conditions, the robot-initiated cleaning procedures using a water flow rate (Q) of 50 liters per minute and a pressure (p) exceeding 200 bar, mirroring the parameters employed during earlier test facility experiments. Despite the challenges posed by the actual maritime environment, the experiment concluded successfully, demonstrating the efficacy and reliability of the cleaning platform under real-world conditions.

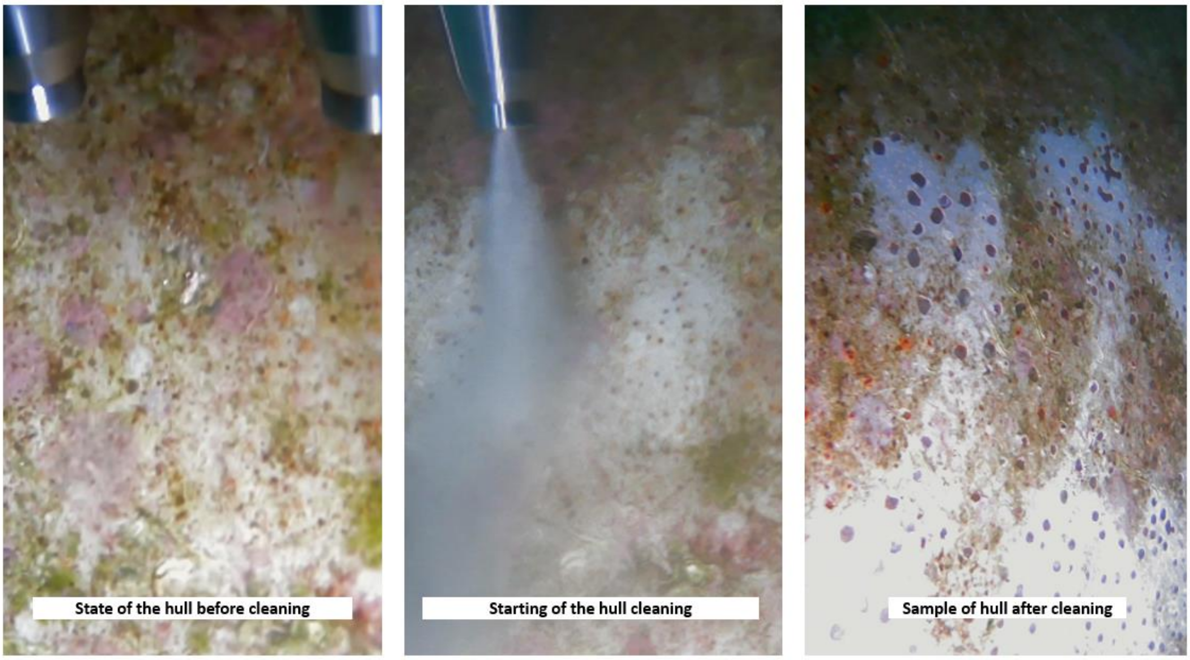

Figure 26: Underwater cleaning - Operation under real conditions

As part of the project's objectives, comprehensive demonstrations of the cleaning magnetic crawler were conducted to showcase its effectiveness and utility to stakeholders within the maritime industry. These demonstrations provided an invaluable opportunity for stakeholders, including shipowners, operators, and maintenance personnel, to witness firsthand the capabilities of the cleaning platform in action. By observing the cleaning magnetic crawler in operation and evaluating its performance in real-world scenarios, stakeholders gained insights into its potential benefits for enhancing onboard cleanliness, preventing corrosion, and optimizing vessel maintenance practices.

Figure 27: Demonstration of cleaning magnetic crawler at Eleusis shipyard, GR (1)

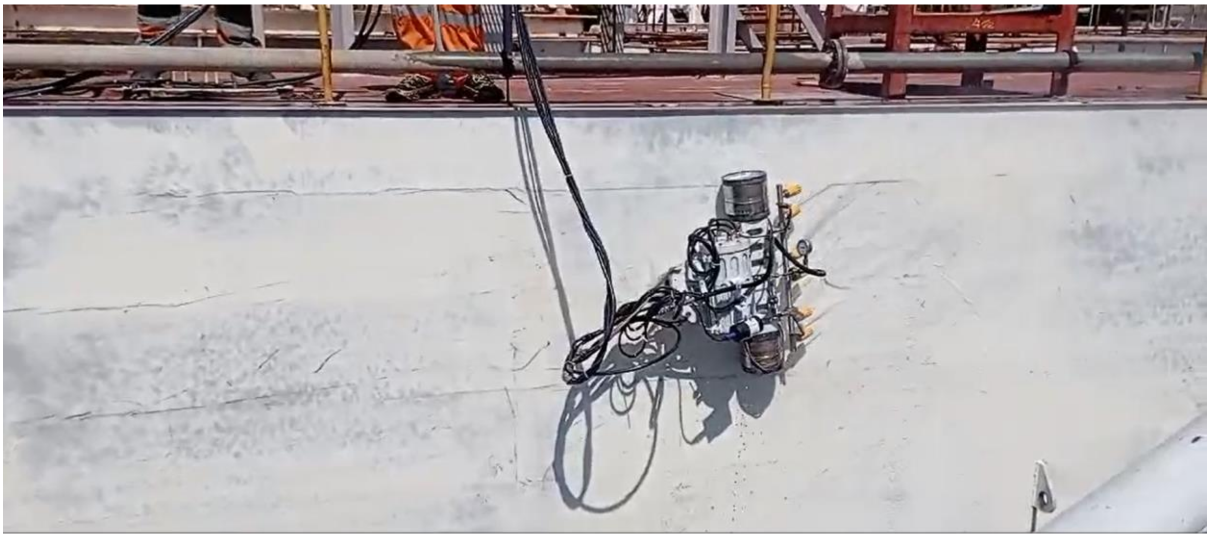

Figure 28: Demonstration of cleaning magnetic crawler at Eleusis shipyard, GR (2)

Figure 29: Demonstration of cleaning magnetic crawler at Syros shipyard, GR (1)

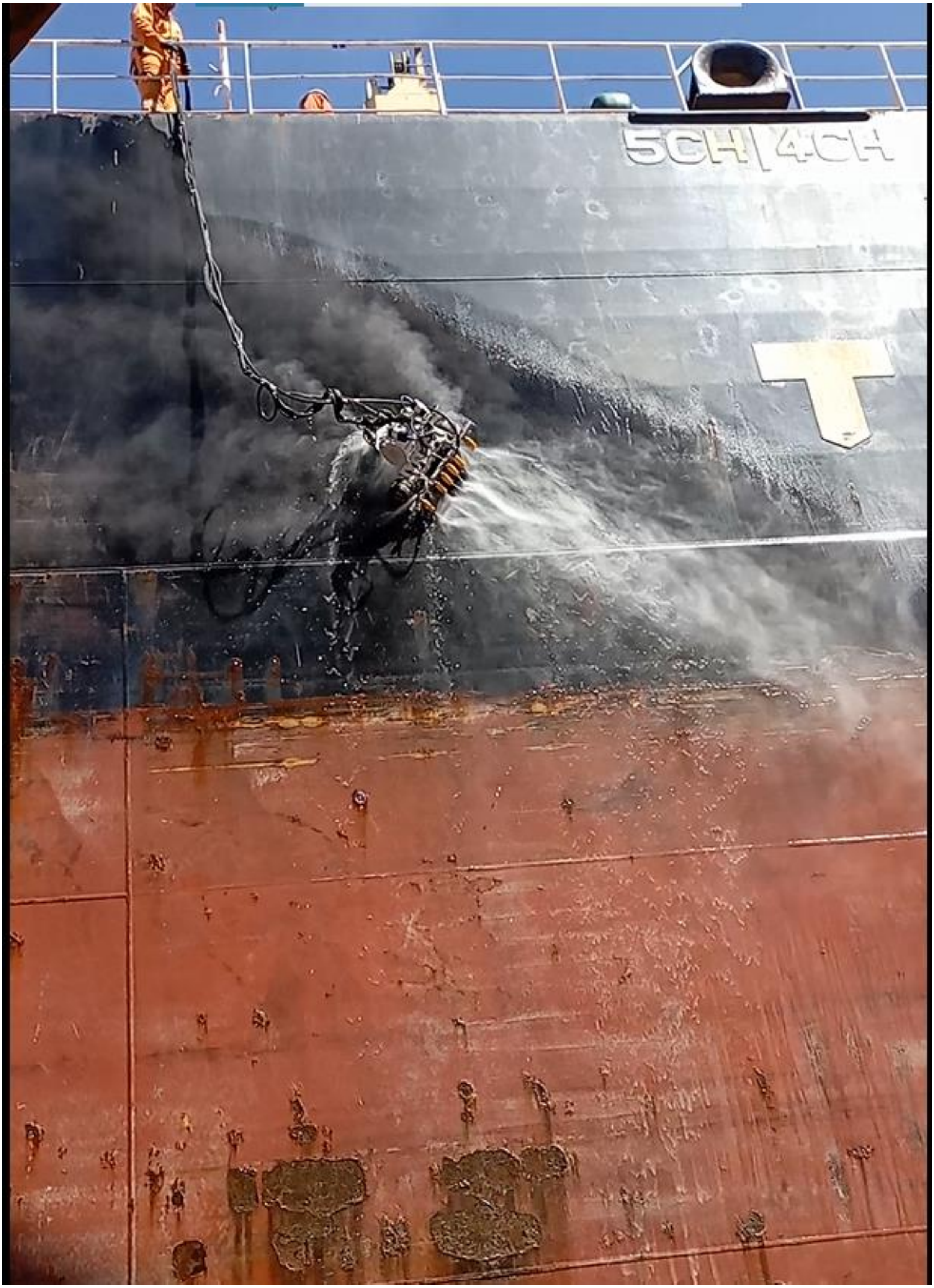

Figure 30: Demonstration of cleaning magnetic crawler at Syros shipyard, GR (2)

Figure 31: Demonstration of cleaning magnetic crawler at Syros shipyard, GR (3)

Furthermore, the demonstrations facilitated open discussions and feedback sessions, allowing stakeholders to provide valuable input on the design, functionality, and usability of the cleaning magnetic crawler. This direct engagement with end-users and industry experts played a crucial role in refining the platform's features, addressing any challenges or limitations, and ensuring alignment with the specific needs and requirements of the maritime sector.

Overall, the development and demonstrations of the onboard cleaning magnetic crawler exemplify the BUGWRIGHT2 project's commitment to innovation and excellence in maritime robotics. By delivering a cutting-edge solution for onboard cleaning tasks, the project aims to significantly enhance operational efficiency, safety, and sustainability across the maritime industry landscape.

3. DISSEMINATION

In the realm of large-scale demonstrations, effective dissemination plays a pivotal role in amplifying the impact of technological advancements and facilitating widespread adoption within the maritime industry. As a core component of the BUGWRIGHT2 project, dissemination efforts serve to bridge the gap between cutting-edge research and practical implementation, fostering collaboration, knowledge exchange, and transformative change. This section delves into the multifaceted dissemination strategies employed by the project consortium, which are designed to engage stakeholders, raise awareness, and catalyze innovation in maritime robotics. From publications to industry workshops, stakeholder engagement events to online platforms, BUGWRIGHT2's dissemination endeavors exemplify a concerted effort to propel the maritime sector towards a future defined by technological excellence, sustainability, and enhanced operational efficiency.

In June 2022, GLM took part in the prestigious Posidonia 2022 exhibition, spanning four days from the 6th to the 10th, hosted at the Metropolitan Expo site. This renowned event served as a dynamic platform for showcasing cutting-edge advancements in the maritime industry. Among the attendees were various partners from the BUGWRIGHT2 project (Figure **32**), underscoring a collaborative effort to spotlight innovative robotic technologies. Notably, the robots associated with the BUGWRIGHT2 project were prominently featured in dedicated exhibition windows within the Glafcos showroom (Figure **33**), offering attendees a firsthand glimpse into the project's pioneering developments. This strategic display not only underscored the significance of maritime robotics but also facilitated meaningful engagement and knowledge exchange among industry stakeholders, further amplifying the project's impact and visibility on a global scale.

Figure 32: BUGWRIGHT2 partners at Posidonia 2022 exhibition in Athens, GR

Figure 33: GLM showroom at the Posidonia 2022 (left) and BUGWRIGHT2 robots at exhibition windows (right)

Furthermore, the project's communication identity was prominently displayed through banners and flyers, as depicted in Figure **34**. These visual representations effectively conveyed the essence and objectives of the BUGWRIGHT2 project to the exhibition attendees. Additionally, a dedicated presentation of the project was delivered to the public, as illustrated in Figure **35** and Figure **36**. This special session provided a comprehensive overview of the project's goals, achievements, and technological innovations, fostering greater awareness and understanding among the audience. By leveraging various communication channels and platforms, the BUGWRIGHT2 project successfully communicated its mission and impact, thereby enriching the exhibition experience and fostering fruitful interactions with attendees.

Figure 34: BUGWRIGHT2 banner at the Posidonia 2022. From left to right Mrs. Laura Monnier (CNRS) and Mrs. Aspasia Pastra (WMU)

Figure 35: Presentation of BUGWRIGHT2 project at the Posidonia 2022 exhibition

Figure 36: Presentation of BUGWRIGHT2 project at the Posidonia 2022 exhibition

Also, the main topic of Bureau Veritas (BV) related to inspection technologies on ship, in the context of BUGWRIGHT2 project was coordinated by SBK and was presented by Mr. Leonidas Drikos (GLM) at the Posidonia exhibition in Athens 2022 (Figure 37). On the picture, Mr. Drikos is in front of the campaign cover, which is a snapshot from the onboard ship inspection using the robotic platforms of the project BUGWRIGHT2. The worldwide campaign of BV for the inspection technologies on ships, was presented at Posidonia 2022 in Athens. The cover of the campaign is a snapshot from the onboard ship inspection using the robotic platforms of the project BUGWRIGHT2, which was conducted by GLM in collaboration with SBK at the ONEX shipyard in Syros, Greece.

Figure 37: Worldwide campaign of BV at the Posidonia 2022 exhibition in Athens, GR

The article about this topic is available HERE.

Furthermore, GLM actively contributed to the dissemination of the BUGWRIGHT2 project's achievements by participating in the European Robotic Forum (ERF) 2024 held in March 2024. At the forum, Mr. Drikos presented the project's objectives and outcomes, highlighting its innovative advancements in robotic technologies for maritime applications. This engagement provided an invaluable opportunity to showcase the project's success stories and share insights with the robotics community, further amplifying its impact and visibility on a European platform.

4. CONCLUSION

The large-scale pilot demonstrations (task 9.3) of the BUGWRIGHT2 project yielded significant insights into the capabilities and performance of robotic platforms for hull services. These demonstrations showcased the robustness and reliability of robotic systems in conducting tasks such as inspection, cleaning, and maintenance on ship hulls, even in challenging maritime environments. Efficiency and accuracy were notable features, as the robots navigated complex surfaces, identified defects, and removed fouling with precision. Moreover, the adaptability and versatility of robotic solutions were demonstrated, highlighting their ability to be customized for different vessel types and operational requirements. In addition to their operational effectiveness, robotic platforms exhibited potential benefits in terms of safety and cost-effectiveness. By reducing the need for manual intervention in hazardous and labor-intensive tasks, these systems enhance safety for personnel while optimizing operational costs. Furthermore, comprehensive data collection and analysis capabilities provided valuable insights into hull condition, enabling informed decision-making regarding maintenance schedules and repair priorities.

Looking ahead, these findings have significant implications for future research, development, and deployment efforts in the field of robotics for hull services. Technological advancements will continue to drive improvements in sensor technologies, autonomy, and AI algorithms, enabling more sophisticated and efficient operations. Integration and collaboration between stakeholders will be crucial to drive innovation, standardization, and widespread adoption of robotic solutions across the maritime industry. Moreover, the development of clear regulatory frameworks and standards will be essential to ensure safety, compliance, and interoperability of robotic technologies in maritime operations. Training programs must also be developed to equip maritime personnel with the necessary skills and knowledge to effectively operate and oversee robotic systems. Overall, the insights gained from the large-scale pilot demonstrations pave the way for the widespread adoption and integration of robotic technologies in hull services, offering significant benefits for the maritime industry in terms of safety, efficiency, and cost-effectiveness.

The engagement of stakeholders throughout the demonstrations and dissemination processes played a pivotal role in shaping the trajectory and outcomes of the project. From shipyards and shipowners to classification societies and regulatory bodies, the active participation and input of stakeholders enriched the development and validation of robotic solutions for hull services. Their firsthand insights, operational expertise, and feedback provided invaluable guidance in refining and optimizing robotic platforms to meet industry needs and standards. Stakeholder engagement fostered a collaborative environment where diverse perspectives converged to address complex challenges and identify innovative solutions. By involving stakeholders at every stage of the project, from design and development to testing and evaluation, the BUGWRIGHT2 consortium ensured that the resulting robotic systems were aligned with real-world requirements and operational realities. This inclusive approach not only enhanced the relevance and applicability of the technology but also fostered trust and buy-in from end-users and industry stakeholders. Furthermore, stakeholder engagement played a crucial role in the dissemination of project findings and outcomes. Through participation in industry events, exhibitions, and workshops, stakeholders had the opportunity to learn about the latest advancements in robotic technologies for hull services and provide valuable feedback on their potential applications and impact. This two-way exchange of information facilitated knowledge sharing, collaboration, and capacity building within the maritime community, ultimately driving the adoption and integration of robotic solutions across the industry. In conclusion, stakeholder engagement was instrumental in ensuring the success and impact of the BUGWRIGHT2 project. By actively involving stakeholders in demonstrations and dissemination activities, the project not only validated the effectiveness of robotic platforms for hull services but also fostered a culture of innovation, collaboration, and knowledge exchange within the maritime industry. Moving forward, continued stakeholder engagement will be essential to sustain momentum, drive further innovation, and realize the full potential of robotic technologies in transforming hull services and maritime operations.