MARI4YARD
MARI4ALLIANCE

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Deliverable D6.4
BEST PRACTICE HANDBOOK

Work Package 6
SUSTAINABILITY ASSESSMENT and REPLICABILITY

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Executive Summary

Within the Mari4_YARD project, WP6 (Sustainability Assessment and Replicability) has the important task to **assess that the solutions developed in the project will be technically, environmentally, and safety-wise suitable to achieve the impact** envisaged in the project, i.e., that they can be successfully applied in real life after the end of the project. Complementary to WP8 (Dissemination, Communication and Exploitation) which will roll-out solutions once being developed, this work package will investigate in more technical and environmental detail the solutions and compare them with known external experiences, relevant to the target community. As this activity is starting in the second project period, the early assessment by WP6 can be seen as an early check and guidance to technology developers to ensure the practical impact of solutions both in partner shipyards and in the wider community.

This Deliverable D6.4 gives a first overview of the best practices with respect to the different Mari4_YARD technologies. Each technology is briefly presented, and the potential applications are described. Expected benefits and obstacles are explained as well. Replicability and Life Cycle Performance Assessment results even though already foreseen in this document in most cases will be included in the update at the end of the project.

1 MISSION, PURPOSE, AND METHODOLOGY

1.1 Role of this Deliverable in Mari4_YARD

1.1.1 Mission and Impact:

The Mari4_YARD project aims to significantly improve **competitiveness and sustainability of European small and medium sized shipyards** by adapting and implementing a set of modular and flexible "human centric" equipment. Small and medium sized shipyards are typical for the European maritime industry and form the economic background of many regions, however due to specific factors they often lack behind compared to larger specialized yards and other industries in terms of productivity and sustainability. This becomes a particular problem in connection with de-carbonization as small and medium sized shipyards will need to build, maintain, repair and retrofit a substantial portion of the European and world fleet, especially of smaller commercial ships and offshore structures. Target impact figures of the Mari4_YARD project are described in Chapter 2 of the Grant Agreement (Part B).

1.1.2 Role of WP6:

Within the Mari4_YARD project, WP6 (Sustainability Assessment and Replicability) has the important task to **assess that the solutions developed in the project will be technically, environmentally, and safety-wise suitable to achieve the impact** envisaged in the project, i.e., that they can be successfully applied in real life after the end of the project. Complementary to WP8 (Dissemination, Communication and Exploitation) which will roll-out solutions once being developed, this work package will investigate in more technical and environmental detail the solutions and compare them with known external experiences, relevant to the target community. As this activity is starting in the second project period, the early assessment by WP6 can be seen as an early check and guidance to technology developers to ensure the practical impact of solutions both in partner shipyards and in the wider community.

The work of WP6 is clearly driven by an **end-user perspective**, involving the two shipyards (BIS and NODOSA), two shipbuilding industry associations (CMT and NMTF) as well as two organizations with vast experience on productivity and environmental impact assessment in the shipbuilding industry (CMT and BAL), all partners in the project. It is further expected that technology suppliers (GHENOVA, GIZELIS and others, not directly involved in the WP) will actively contribute to a critical assessment putting themselves in the perspective of potential customers in the maritime sector.

1.1.3 Connection to the WP5 demonstrators

While most of the experience and feedback collected so far is based on the installation and tests in labs and during trainings, the WP5 demonstrators will provide valuable information from test runs of the technologies in a shipyard environment. Since these activities will be performed during spring and summer of 2024, their impact on the best practice descriptions will be included in D6.8 which will be an update of D6.4 at the end of the project. The respective chapters are already included in this document.

1.1.4 Qualitative and quantitative assessment

The assessment activities within WP6 can be roughly grouped into two streams:

- A **qualitative assessment** including the identification of technical solutions, experiences and success stories from outside the project (T6.4), the identification of potential "showstoppers" in legislation, ship related safety rules and work safety (T6.5) as well as the benchmarking of the results towards the technological solutions developed in Mari4_YARD. "Benchmarking" shall not only include a "passive marking" of external versus internal technologies, but also constructive proposals to align the development within Mari4_YARD towards a maximum practical impact.

  The qualitative assessment will comprise three main phases:

  1. a preliminary **first scouting and assessment** (this Deliverable)
  2. the Best Practice Handbook including a questionnaire (D6.4)
  3. the final assessment wrapping up internal and external views in D6.8. To facilitate this sequential approach, the due date of D6.3 has been shifted from M36 to M28.
- The second stream of activities in the work package is a **quantitative assessment** comprising a careful data analysis (T6.1), modelling of the relevant production processes (T6.2) and a life cycle cost and environ-mental impact assessment (T6.3). The quantitative assessment is more labour-intensive and requires detailed information about the baseline processes and the envisaged processes after the end of the project, as well as verified impact data for the introduction of new technological solutions.

  Due to the general delay of the project and in particular the late start of WP5 (Demonstration in Shipbuilding and Retrofitting) the activities and deliverables related to the quantitative assessment (D6.3 and D6.6) had to be delayed correspondingly. The quantitative assessment will be primarily conducted for the processes in the partner shipyards which will be affected and demonstrated within Mari4_YARD.

In general, it should be noted that the impact of certain technological improvements on the competitiveness and sustainability of shipyards can only be done in the context of specific processes and products (see also 1.2) which requires a certain majority of the technical developments and preliminary testing (WP1 – WP4) as well as specific ideas on demonstration and (post-project) application (WP5).

1.1.5 Best Practice Handbook and Communication with the End-User Community

This Deliverable 6.4 is aimed at potential users of the Mari4_YARD solutions. It will describe in detail what the technologies may be used for, how to apply them and what advantages or disadvantages can be expected. Since the deliverable is public, some internal findings cannot be described. In case of interest in using any of the technologies it is recommended to get in touch with the developers. Contact information can be found on the project website (https://www.mari4yard.eu/).

1.2 Methodology used in this Deliverable

The following chapter describes each solution, following a unified structure:

- The description briefly explains the main characteristics of the different solutions.
- Potential applications outline the processes at the yard where the technologies can be applied.

- Replicability provides information about the application at other shipyards, maritime enterprises or even outside the maritime environment.
- Expected benefits are structured into economic, sustainability and societal benefits.
- Guidelines for the application will provide information about the way a technology can be introduced into shipyard processes.
- Potential disadvantages, risks and barriers are also covered to describe issues that might prevent the technologies from being introduced.
- The results of the LCPA analysis will be included in D6.8

2 MARI4_YARD TECHNOLOGIES AND POTENTIAL IMPACT

2.1 Technology: Logistic Planning Platform for Shipyards

2.1.1 Description

The use of technologies linked to 3D Laser scanning and Lidar is giving to the shipyards a very powerful tool not only for 3D modelling and reverse engineering, but also for production control.

Three different technologies are combined to create the collaborative solutions:

- 3D scanning by means of 3D laser scan.
- 3D scanning by means of Lidar scan.
- 3D scanning by means of photogrammetry.

One of the most important assets for shipyards is space, as it is required for a variety of tasks: materials storage, big element manoeuvring, transit space for vehicles, equipment and workers, etc. Also, lifting equipment requires traveling, making part of the space unavailable. This situation can be very complex if different works are being carried out and the problem is even worse if the shipyard is small, as the installations size is smaller.

One of the possible approaches to this problem could be using an interactive tool that allows making a planification of the shipyard activities and that allows the user to predict the position of different elements in different moments.

To do so, a 3D model of the shipyard will be input in a platform that allows the introduction of 3D modelled objects that can be positioned and that will allow the user to take ‘timestamps’ of the shipyard configuration in different moments. Such a tool can help to keep track of the available space and allows to schedule actions during shipyard works. Data acquisition will be carried out by drones.

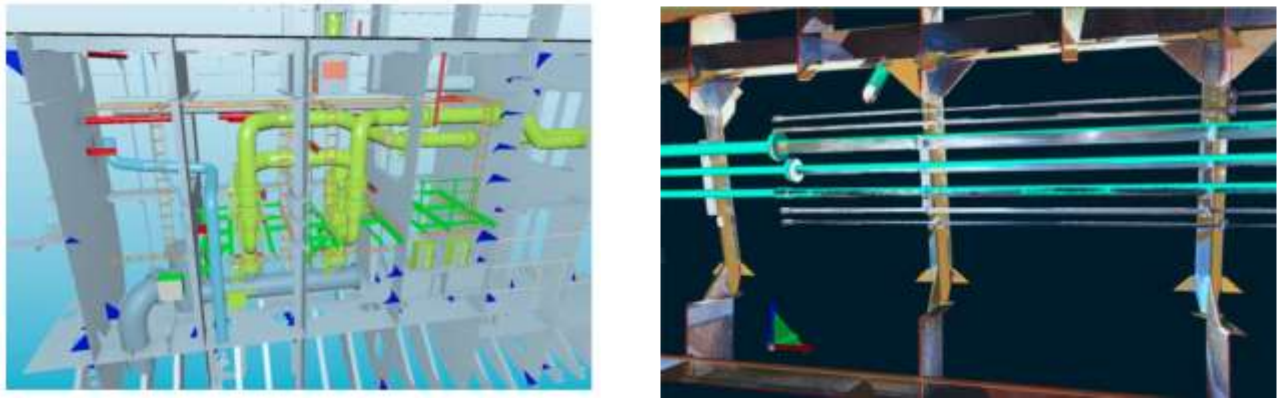

Figure 1. 3D models of piping and production control

2.1.2 Potential applications

Main application of this technology consists of keeping track of the available space in the shipyard. This way, it is also possible to keep track of materials, equipment, cranes, blocks and different elements and schedule their positioning for storage, manoeuvring or transportation.

The process is adaptable whenever there is a need to fast record current state of construction and compare it to plans. Drone reconstruction takes an order of magnitude less time to form a 3d model than a terrestrial laser. On another note, precision of such technology is below precision obtained by laser. Then it follows that this technology could be applicable for every construction work, where small detail is not important, and where changes happen on daily basis.

2.1.3 Replicability

This will be included in the next version of the document.

Expected benefits

Economic benefits

- Time saving in specific shipyard operations such as materials storage, big element manoeuvring, transit space planning.
- Decrease in off-time due to lack of storage.
- Improvement in the work efficiency.

Correlation between plan and reality is established sooner and more accurately than with previous systems (completion percentages subjective reports) thus enabling faster and more precise response to unplanned. System is not complicated or expensive, it is easy to set up and use. All programs are already available (3d model, photogrammetry, cloud compare).

Sustainability

- No environmental impact.

Societal benefits

- Improvement of work quality because of production planning.

2.1.4 Guidelines for the application of the solution

This will be included in the next version of the document.

2.1.5 Potential disadvantages

Acquisition of the point cloud requires a certified pilot and depends on local wildlife. There may be locations in which the use of drones can be limited to specific periods throughout the year.

The accuracy of this system is something that needs to be tested. Applicability in closed environments is something that is desired but not practically feasible currently.

2.1.6 Potential risks/barriers

Flight permissions and local fauna related problems hamper acquisition of point cloud. However, this can be mitigated with a correct flight planning.

Technical

No technical risks expected. A shipyard ERP system must exist (3d model, plan, resources).

Economic

During the drone flight the shipyard must be empty of workers, so the point cloud acquisition must be done in specific moments. However, as the data collecting is made in very short times this should not be a problem to schedule.

On the other hand, flight may be limited due to the presence of local fauna. If this happens, the flights must be carried out in specific moments of the year. This can become a problem specially during birds breeding periods. To avoid attacks and possible accidents, flights must be performed out of the bird’s breeding periods or it is also possible, but with increased economic cost, to use specific devices that prevents these attacks.

Social

No social risks expected.

Legal (Rules, regulations)

One of the main problems that can appear when making a drone operation, is the flight permissions request. The process to acquire them is around one month, but other parameters can influence the flight, such as weather. Careful planification must be done for this.

2.1.7 LCPA results

Results will be added in the updated document at the end of the project.

2.2 Technology: Small drones for confined spaces

2.2.1 Description

Mari4_YARD developed a system to validate the safety of workers inside confined fabrication spaces. It consists of a small drone that should carry out supervision tasks to ensure that the work environment is safe for operators to access; to this end, an oxygen sensor has been added to the drone.

The reading of sensors is done through I2C protocol by ESP32 board, for subsequent packaging based on the CRSF protocol and the information is sent through radio frequency communication in the 868MHz band, from the small drone to its remote control.

Figure 2. Small drone.

2.2.2 Potential Applications

The main application of this system is to monitor oxygen levels inside port tanks. It detects the concentration of oxygen in confined spaces and alerts workers in case of any risk. This solution ensures safety in the work environment by integrating new sensing technologies in small drones.

Another potential application of the technology is the measurement of different parameters inside the tanks, that are relevant not only for safety purposes, but also for technical works. An example of this is the measurement of temperature and humidity levels. These measurements were requested by the end users to assist the painting jobs that can potentially be performed inside the tanks.

Since a great variety of sensors can be adapted to the Crossfire telemetry (those ones that can be connected through an I2C port for the ESP32), this makes the possibilities unlimited for any parameter that the end users desire to read in confined spaces avoiding workers to be put in risk.

2.2.3 Replicability

The replicability of the technology is guaranteed as the specifications, materials and configuration for the drone have been documented in deliverable D1.5.

On the other hand, also the software required to connect the sensors to the drone telemetry made by AIMEN is replicable since it was also documented in deliverable D1.5.

2.2.4 Expected benefits

Economic benefits

- Reduction of working accidents during inspection tasks.
- Quality improvement of specific jobs due to a better knowledge of the environment parameters.
- Apart from the measurement of the parameters requested from the end users during this project, it is expected that additional uses can be derived for this technology; this means more potential economic benefits.

Sustainability

- No environmental impact.
- Low economic investment.

Societal benefits

An improvement of safety and working conditions is expected when using this technology. People that work in confined spaces will have confirmation that working conditions are acceptable. This is important since working in unacceptable conditions could lead to fatigue, health hazards, and non-motivated workers.

2.2.5 Guidelines for the application of the solution

- Solution must be applied indoors (to avoid flight regulations).
- Drone is sensitive to electromagnetic interference. Welding jobs that could possibly have a direct line of view with the zone where the job is performed, must be avoided.
- This technology must not be applied in explosive environments.
- Pilot training is required.

2.2.6 Potential disadvantages

The only potential disadvantage comparing the current process with the previous one is that it adds some costs to the production chain. However, these costs are very low, and the benefits are worth for them to be borne.

2.2.7 Potential risks/barriers

Technical

There is a potential risk for the technology used:

- Currently, some stability problems are affecting the drone when flying inside a small space due to air recirculation. Different solutions are being tested:
    - Pilot training to get more control of the aircraft in these small spaces.
    - Flight controller tuning to ensure smooth drone movement.
    - Reduction of drone weight to contribute to better control and stability.
    - Trimming and centering of drone weight distribution to improve stability and control.

It is expected that all the measures taken above will improve the overall behaviour of the aircraft and will lead to a successful demonstrator.

Economic
No risks expected.

Social
No risks expected.

Legal (Rules, regulations)
No risks expected.

2.2.8 LCPA results

Results will be added in the updated document at the end of the project.

2.3 Technology: Hand-guiding industrial robots

2.3.1 Description

Mari4_YARD adapted the hand guiding technology, originally developed by AIMEN for ABB robots. For Mari4_YARD this technology is tested in KUKA and adapted for COMAU robots. The main benefit is the adoption of industrial robots for collaborative applications, so working payloads and applications can be increased for industrial robots.

Hand guiding technology consists of moving the robot by direct operator interaction with a device placed at robot’s wrist. Robot is also equipped with a Force/Torque sensor and high-speed communication protocol to monitor forces and torques applied by the operator in real-time. The controller can be configured for smooth operations.

Figure 3. Hand guiding (at LMS)

2.3.2 Potential Applications

The main application of the hand guiding technology is to assist the user to manipulate the heavier loads. Its main effects are the reduction of the risk of human injuries due to load handling, the reduction of programming time and the expansion of the applications of high payload industrial robots.

2.3.3 Replicability

The technology will be integrated into the didactic factory at AIMEN site for the benchmarking and replicability purposes. The information collected during the demonstration can serve as the benchmarks for the replicability.

2.3.4 Expected benefits

Economic benefits

The use-case involves two operators collaborating to complete the manufacturing task. However, with the implementation of a HRC (Human-Robot Collaboration), only one person is required for the manufacturing task, resulting in a productivity improvement of 30 percent.

Sustainability

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

Societal benefits

- Reduction of accidents.
- Reduction of human errors.
- Improvement of the human posture and ergonomics.
- Reduction of a risk of collision with the robot.

2.3.5 Guidelines for the application of the solution

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. The main aim is to provide a graphical life-cycle diagram of the large component manufacturing in small shipyards to help the readers by identifying the different stages of the technology developments and demonstration strategies Mari4_YARD adopted during the project execution.

2.3.6 Potential disadvantages

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

2.3.7 Potential risks/barriers

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

Technical

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. A preliminary list may be found below:

- Standardization and regulations on deployment and integration of such system.
- The transparency of the controllers has the room to be improved by studying the higher order functions. In the present implementation the position and velocity reaction-based control is implemented.

Economic

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. A preliminary list may be found below:

- High initial investment.
- High time span to reach the break even.

Social

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

Legal (Rules, regulations)

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

2.3.8 LCPA results

Results will be added in the updated document at the end of the project.

2.4 Technology: Collaborative robots

2.4.1 Description

Mari4_YARD used small robots to perform semi-autonomous operations to extend the workers capabilities in the pre-fabrication and outfitting stages. This is considered the possibility of deploying the solution in confined spaces and inside the ship for both new construction and retrofitting.

Three different technologies are combined to create the collaborative solutions:

- Collaborative robots with Power and ForceLimiting (PFL) operational mode (conforms to the TS 15066).
- Fast programming by means of hand-guiding and localization using perception and CAD matching.
- Advanced perception for semi-autonomous operation.

Figure 4. light collaborative robot for cutting and welding applications (at AIMEN)

2.4.2 Potential Applications

The use of collaborative robots in welding and cutting operations is an excellent way to increase productivity and efficiency. Collaborative robots are an ideal choice for small and medium-sized manufacturers who deal with low-volume, high-mix production. They can perform different tasks in a day and can adapt to new sizes and geometries. Mari4_YARD collaborative technology solutions are designed to work with humans in a shared space, and they can help reduce the chance of impact with human co-workers.

2.4.3 Replicability

The technology will be integrated into the didactic factory at AIMEN site for benchmarking and replicability purposes. The information collected during the demonstration can serve as benchmark for replicability.

2.4.4 Expected benefits

Economic benefits

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. A preliminary list may be found below:

- Improved accuracy of the cutting operation.
- Improved productivity.
- Intern revenue generated by the process.

Sustainability

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

Societal benefits

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. A preliminary list may be found below:

- Help in adopting technology and shipyard modernization.
- Reduced emissions if used correctly.
- Support to the reskilling and training of workers.

2.4.5 Guidelines for the application of the solution

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. The main aim is to provide a graphical life-cycle diagram of plasma cutting in small shipyards to help the readers by identifying the different stages of the technology developments and demonstration strategies Mari4_YARD adopted during the project execution.

2.4.6 Potential disadvantages

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

2.4.7 Potential risks/barriers

Technical

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. A preliminary list may be found below:

- Simple shapes can be manufactured from the current technology e.g. circles, rectangles, triangles, etc. More customized and advance profiles can improve the reach of this technology.
- Standardization and regulations on deployment and integration of such system.

Economic

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards. preliminary list may be found below:

- Initial investment needed for the purchase of Robot, Magnetic base, torch, etc.

Social

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

Legal (Rules, regulations)

This will be included in the next version after evaluation of the technology at demonstration sites. This will depend on the information provided by the shipyards.

2.4.8 LCPA results

Results will be added in the updated document at the end of the project.

2.5 Technology: Autonomous mobile robots

2.5.1 Description

Nowadays, the transportation of individual parts in shipyards is still heavily reliant on human operators. This transportation is typically performed by hand or using self-propelled, pulled, or pushed platforms. The logistical complexity of the shipyard extends across warehouses, worksites, various parts, and components. During the shipbuilding process, a wide range of components, including structural steel, pipes, cables, valves, and outfitting, are supplied, normally stored in shelves, big containers, and boxes.

Typically, and from the human operator perspective, these logistic operations involve the execution of tasks that are dull, dirty, and dangerous. As the European population ages and shipyards struggle to hire and retain their workforce, it becomes critical to liberate and empower the current human workforce to perform more added value.

As a result, there is a pressing need in the shipbuilding industry to automate its intra-logistic processes. Indeed, the use of autonomous mobile manipulators to transport raw materials and individually manufactured parts between warehouses and workshops, as well as between workshops and subassembly areas, increases the intra-logistic process efficiency while freeing up human resources for higher-value tasks. To address these concerns, Mari4_YARD proposes the use of a Mobile Manipulator to retrieve individual parts from containers, shelves, and other locations, combining the mobility of autonomous mobile robots with the manipulation dexterity of a robotic arm. Mari4_YARDcombines four different technologies to create a collaborative solution:

- Mobile Manipulator composed of an autonomous mobile platform and a collaborative robot.
- Skill-based programming for fast and intuitive teaching of new robotic tasks.
- Intuitive Human-Robot Interaction based on augmented reality.

- Advanced perception for long-term autonomy (autonomous navigation and CAD-based perception and grasping).

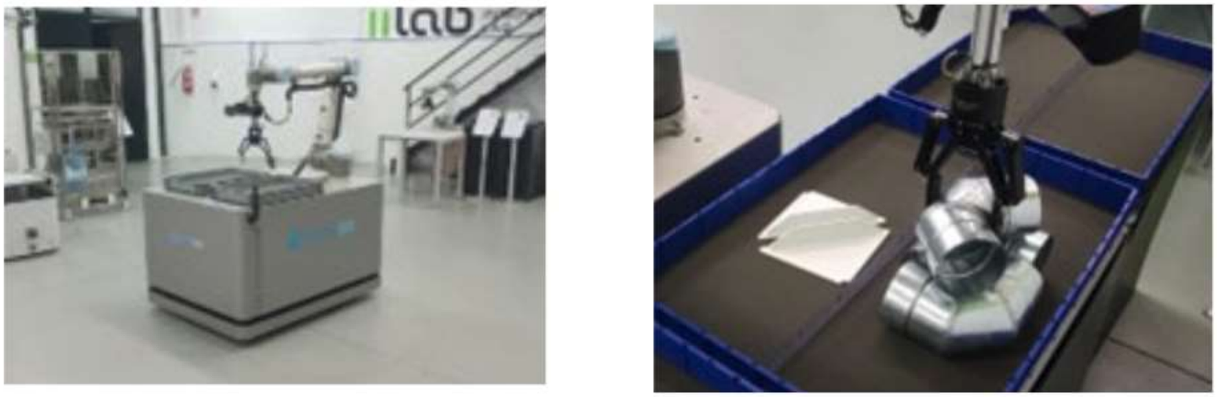

Figure 5. Mobile robot for pick & place application (at INESC TEC)

2.5.2 Potential Applications

In the Mari4_Yard project, the demonstration scenario involves the operation of a Mobile Manipulator in a warehouse at Nodosa Shipyard. The robot is responsible for taking parts from shelves and containers and delivering them to the human operator, in a specific location at the entrance of the logistic warehouse. Despite the chosen scenario, there are others where the solution could be used, e.g., machine tending in a machining centre, transportation of tools/equipment across the construction/production facilities, and quality control, among others.

2.5.3 Replicability

The developed solution fully applies to other shipyards and even application sectors (automotive, aeronautic, metalworking, and others). The Mari4_YARD solution was built modularly, with the upper layers of the robot software being hardware agnostic, allowing for easier customisation of the robotic solution to meet different application requirements.

2.5.4 Expected benefits

Economic benefits

- Reduction of the number of operators working on logistics. Require that part of their time be allocated to monitoring and assigning tasks to robotic systems.
- Better usage of the available workforce.
- Improved traceability of the consumed resources.
- Non-expert robot programming.

Sustainability

- Increased traceability of the parts used/produced during production, contributing to the digitisation of the production process, resulting in better control of the consumed resources.
- Increased resilience of companies to fluctuations/shortness in the available workforce.

Societal benefits

- Relief of workers from dull, dirty, and dangerous operations, owing to the specific characteristics of the parts to be transported.
- Reduction of accidents.
- Transfer of workers from low-value to higher-value production activities that are also more noble for the worker (Worker Satisfaction/Valorisation).

2.5.5 Guidelines for the application of the solution

- The developed solution can be applied indoors, such as in a warehouse.
- The parts need to be stored so that the robot can easily access them.
- The floor where the robot will operate must be in good condition.
- Robot mechanical characteristics and capabilities must be considered (e.g. mobile robot size, robotic arm reachability and payload, robotic grippers) when considering their application.
- Operator training is required.

2.5.6 Potential disadvantages

- To apply the solution, the working environment should be adapted. These adaptations include:
    - Clear corridors where the robot can navigate need to be defined.
    - Parts need to be stored so the robot can easily reach them.
    - The working floor must be in good condition.
- Robotic picking can be slower compared to human operators. Nevertheless, transportation requests can be planned sooner in time.

2.5.7 Potential risks/barriers

Technical

- The CAD model of the parts to be picked is required. In the future, and thanks to the ongoing research work, the solution is expected to work without this requirement.
- There is limited performance regarding highly reflective and transparent workpieces. Research regarding sensing (considering new sensing technologies already reaching the market) and perception in future work should address this problem.

Economic

- Comparatively with other proposed solutions, the initial investment in these robotic systems is relatively high due to their inherent technology complexity. It is expected that their price will decrease with the increased use of Mobile Manipulators across various sectors, pushing for lower-cost robots, sensors, and grippers.

Social

- There is a need for technical personnel that can manage advanced robotic solutions; and thus for upskilling the workforce to interact, perform high-level programming, and maintain complex robotic equipment.

Legal (Rules, regulations)

2.5.8 LCPA results

Results will be added in the updated document at the end of the project.

2.6 Technology: High-payload collaborative robots

2.6.1 Description

Mari4_YARD uses a high-payload robot, empowered by AI, for the picking, positioning, and welding of heavy metal parts in shipyards. Precise parts positioning is supported by manual guidance while welding path teaching is supported by intuitive AR programming interfaces. Safety systems are properly integrated for Speed and Separation Monitoring HRC.

The proposed solution combines several technologies: Speed and Separation Monitoring HRC, direct and indirect human-robot interaction for parts positioning and AR-assisted welding path teaching, advanced perception for bin picking operations, multilayer safety system, and a multimodal gripper (with magnets for picking tasks, welding torch for welding, F/T and vision sensors).

Figure 6. High Payload Robot (at LMS)

2.6.2 Potential Applications

High payload robots are being utilised in shipbuilding to enhance productivity and working conditions. They handle strenuous tasks like manipulating heavy parts, while human operators guide them. The tools developed offer adjustability and ease of use for non-expert users. AI-enhanced machine vision and AR technology support operators in detecting and manipulating parts, programming robot paths, and ensuring safety through a multilayer safety system.

2.6.3 Replicability

The technological modules developed under the high level "High payload collaborative robots" are applicable not only to shipyards but also to various other sectors such as automotive, steel industry, and more. Those technological modules are designed and developed in a modular and reconfigurable fashion allowing easy integration and technology deployment in different robotic setups, towards high customization and production reconfigurability, for dealing with various products in different quantities.

2.6.4 Expected benefits

Economic benefits

- Reduced number of assembly errors that occur from human mistakes.
- Increase of the variants/orders that can be delivered due to a decrease in the cycle time.
- Saved expenses dependent to project requirements overtimes.

Sustainability

- Reduced number of scrap due to higher quality products and less faults.

Societal benefits

- Reduced costs corresponding to worker's health, due to fewer accidents, addressing chronic unergonomic postures and weightlifting.
- Reduced exposure to fumes leads to decreased risk for respiratory health issues.
- Less exposure to UV radiation (concerns for skin cancer, eyes irritation etc.).
- Improved working conditions, also allowing people with disabilities (e.g. shoulder pain etc.) or women to be employed in the very demanding shipyard environment.

2.6.5 Guidelines for the application of the solution

- The developed solutions can be applied indoors, in a prefabrication stage.
- The working space of the robot can be augmented by adding the robot in a linear rail.
- The floor where the robot should be integrated should comply with the installation requirements of the robot manufacturer.
- Electrical/pneumatic systems should comply with the standards.
- Operator and supervisors training for the operator is highly recommended.

2.6.6 Potential disadvantages

A number of shortcomings are presented below, related to the nature of the process and the nature of the technologies:

- Augmented reality path teaching for robotic welding is challenging due to AR environment limited calibration accuracy (*machine vision is used to correct inaccuracies*).
- Speed and Separation Monitoring Human-Robot Collaboration might be in several occurrences difficult to implement to guarantee that all safety precautions are taken into allowance without compromising productivity.

- Machine vision for bin picking is difficult to be applied in parts with high differentiation.

2.6.7 Potential risks/barriers

Technical

- Difficulties in highly accurate AR system calibration.
- Difficulties in bin picking systems for variants with many differences.
- Difficult safety measures application.

Economic

- High initial investment for purchasing safety compliant robots for speed and separation HRC, for AR headset and special for the safety equipment/devices.
- Personnel training cost.
- Used equipment maintenance cost.

Social

- Personnel is not always familiar with digital technologies. Workforce upskilling and continuous learning/training is required.

Legal (Rules, regulations)

- Strict regulation on deploying safe HRC systems (ISO 13849-1:2023, ISO 13849-2:2015, ISO 10218-1:2011, ISO 10218-2:2011, ISO/TS 15066:2016).

2.6.8 LCPA results

Results will be added in the updated document at the end of the project.

2.7 Technology: High-precision projector

2.7.1 Description

Mari4_YARD uses a spatial augmented reality system using a projector with a 3D sensor for assisting human operators performing marking and cutting of metal structures. The solution allows the operator to work faster and without requiring measurement tools and drawings.

The projection mapping solution relies on a 3D perception system, a 3D rendering SDK and a 4K DLP projector, assembled on a tripod, to project information directly in the target object. Its primary advantage is that human operators do not need to use measurement tools. The projector and the 3D sensor are on a moveable tripod to not interfere with the operator's field of view. The system has several modules, which include computer vision software for performing the hardware calibration in the setup phase, while relying on a GUI during the deployment phase for providing an intuitive interface for the operator to quickly load new CAD models, trigger the 3D perception module and project task-oriented information into the environment for marking and cutting operations.

Figure 7. High-precision projection system (at AIMEN)

2.7.2 Potential Applications

The system provides an immersive Human-Machine Interface for helping human operators perform their tasks, such as marking, cutting, assembly of supply modules in outfitting operations, among others. The immersive interface enables the direct transmission of the design specifications into the environment, and as such, allows the human operators to perform these tasks faster, more accurately and with fewer mistakes, without relying on error-prone measuring devices and printed documents.

2.7.3 Replicability

Considering the application context described, the developed solution can be applied in many different scenarios in the shipbuilding and in other relevant industrial use cases, such as construction and metalworking, guiding the operator during cutting, welding, drilling, assembly, and other related activities.

2.7.4 Expected benefits

Economic benefits

- Improved reliability and process efficiency.
- Reduction of errors and need for rework.

Sustainability

- Reduction of errors and need for rework, which also translates in a reduction of the consumed raw materials and other resources.
- Reduction of the number of printed drawings.

Societal benefits

- Support to workers, making them feel more valuable to the company and increasing their satisfaction and valorisation.
- Reduction in the level of attention/focus required to execute the tasks and consequently reduced anxiety, stress and fatigue.
- No need for extensive knowledge to calibrate and operate the system. A short user manual and quick hands-on practice are sufficient for training new users of the projection system.

2.7.5 Guidelines for the application of the solution

- 3D models of the structure, containing the information to be projected are required.
- Due to the use of a DLP projector, the surface where the information will be projected should not be under direct sun light.
- The recommended projection area for maintaining an accuracy of 5 mm, should be around 2.5 by 1.4 meters. Wider projection is viable; however, the projection error will increase.

2.7.6 Potential disadvantages

- The system needs to be transported by the human operator. It is heavier when compared with other AR approaches based on hand/head-held devices.
- It could be difficult to be used in very confined spaces.

Sometimes problem with hull openings is that they are not defined until equipment is contracted, and it could be after hull and block assembly phase. Sometimes actual state on field does not correlate with the 3D model (from which we take positions of openings). Correlation of model and reality must be kept at high levels, along with equipment contracting which should be known before hull assembly.

2.7.7 Potential risks/barriers

Technical

- Need for a 3D model of the structure of interest, where the information to be projected is already represented.
- Need for a relatively flat surface for the tripod to be mounted.
- Need for a relatively flat surface to project. Surfaces with a large depth range may cause the projected information to be out of focus due to the limited depth of focus of the lens of the projector.

Economic

- Faster return on investment if there are a lot of cutting operations in which the projector can be used without the need to be moved a lot. For very few operations and in hard to get ship zones, it might be faster to rely on the traditional methods.

Social

- Need for knowledge of operating software capable of manipulating CAD and mesh models for generating the CAD models and PLY point clouds.
- Upskilling of the workforce.

Legal (Rules, regulations)

This will be included in the next version of the document.

2.7.8 LCPA results

Results will be added in the updated document at the end of the project.

2.8 Technology: Cost-effective projector

2.8.1 Description

This system extends the workers capabilities to perform semi-autonomous operations at the pre-fabrication and outfitting stages. The aim is to replace the traditional paper-based drawings and project such drawings on the target with accuracy and precision.

Scanning the area: This feature is exercised with the help of the pan-tilt unit and low cost RGB-D camera.

Localization algorithm: It consists of matching the point cloud acquired in the scanning phase with the CAD of the area by user initial guess, ICP algorithm, and projection of elements.

2.8.2 Potential Applications

Projection systems in construction and retrofitting increase productivity and efficiency. They are ideal for small and medium-sized manufacturers dealing with low-volume, high-mix production. These systems reduce paper documentation and human errors, allowing technicians to focus on operations. They also serve as a quick verification tool for new designs and features. Mari4_YARD's projection technologies work in shared spaces, reducing the chance of impact with human co-workers.

2.8.3 Replicability

The technology will be integrated into the didactic factory at AIMEN site for benchmarking and replicability purposes. The information collected during the demonstration can serve as benchmarks for replicability.

2.8.4 Expected benefits

Before any outfitting, the projector could make hull cut-outs for pipes and other equipment. In that way there is no time lost afterwards, when that equipment was really scheduled to install (and found out that hull cut-outs are not being open).

Economic benefits

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

Sustainability

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

Societal benefits

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

2.8.5 Guidelines for the application of the solution

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards. The main aim is to provide a graphical life-cycle diagram of the manufacturing process (using Engineering Drawings vs displaying information using projection) in small shipyards to help the readers by identifying the different stages of the technology developments and demonstration strategies Mari4_YARD adopted during the project execution.

2.8.6 Potential disadvantages

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

2.8.7 Potential risks/barriers

Sometimes problem with hull openings is that they are not defined until equipment is contracted, and this could happen after the hull and block assembly phase. Sometimes actual state on field does not correlate with the 3D model (from which we take positions of openings). Correlation of model and reality must be kept at high levels, along with equipment contracting which should be known before hull assembly.

Technical

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards. Some are listed below:

- The projection system is dependent on the CAD files and the manual text transfer to the point clouds. A better CAD preprocessing can help reduce the process lead time.
- The portability of the technology depends on the end effector weight because the magnetic base cannot support high torques although it can handle static weights up to 10s of kgs. If the torques are applied this limit reduce drastically, which interns limit the capability of the technology to be placed on the walls.

Economic

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards. A preliminary list may be found below:

- Initial investment.

Social

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

Legal (Rules, regulations)

This will be included in the next version after evaluation of the technology at demonstration sites. It will depend on the information provided by the shipyards.

2.8.8 LCPA results

Results will be added in the updated document at the end of the project.

2.9 Technology: AR with head-mounted device

2.9.1 Description

Mari4_YARD provides shipyard workers with ruggedized HMD (head-mounted devices) that are attached to safety helmets, having connectivity, monocular camera, microphones, noise cancellation algorithms and TTPSC SkillWorx system leveraging computer vision and remote SLAM. That setup gives the workers full hands-free experience to check, record and document construction progress, completion, and quality of delivered work and follow digital work instructions.

The system serves as a source of information for field workers during on-the-job activities.

Figure 8. AR Tools (at BIS)

2.9.2 Potential Applications

The HMD App will navigate workers within physical environment using spatial intelligence – application streams video feed to remote SLAM server to build in real-time 3D map that allows onsite and remote workers to tag and overlay information on the real 3D world while also maintaining safety, situational awareness, low eyestrain, hands-free use, and full-shift battery life.

The Web App is a collaboration endpoint for over- the-shoulder help during construction, inspection, repair, troubleshooting, review etc. as remote assistance enriched with real-time AR (when onsite worker and remote supporters can collaborate and place sticky, pervasive AR annotations on a live video). AR is placed on video from ultra-low bandwidth low resolution up to 4K and is stored in a form of reusable 3D maps.

2.9.3 Replicability

This will be included in the next version of the document.

2.9.4 Expected benefits

Digitalisation of learning material should greatly improve speed and repeatability of learning courses. One AR headset can contain whole library of user manuals, regardless of type of work (electrician, welder, maintenance, even project engineer).
Main benefits:

- Act as fast as possible during real-time supervision, troubleshooting, inspections, repairs, reviews.
- Access to the right information without sacrificing worker safety nor comfort.

- Streamlined communication and collaboration during field work with increased transparency and situational awareness.

Economic benefits
This will be included in the next version of the document.

Sustainability
This will be included in the next version of the document.

Societal benefits
This will be included in the next version of the document.

2.9.5 Guidelines for the application of the solution

This will be included in the next version of the document.

2.9.6 Potential disadvantages

This will be included in the next version of the document.

2.9.7 Potential risks/barriers

This will be included in the next version of the document.

Technical
This will be included in the next version of the document.

Economic
This will be included in the next version of the document.

Social
This will be included in the next version of the document.

Legal (Rules, regulations)
This will be included in the next version of the document.

2.9.8 LCPA results

Results will be added in the updated document at the end of the project.

2.10 Technology: AR with handheld device

2.10.1 Description

The technology is a user-centric tablet application for easy checking of construction progress in a designated construction area. In addition to this, a web application was developed to prepare and provide the data for the tablets and also serve as a user interface for clear evaluation of the progress recording.

The system serves as additional source of information for the workers, while no special skills are required.

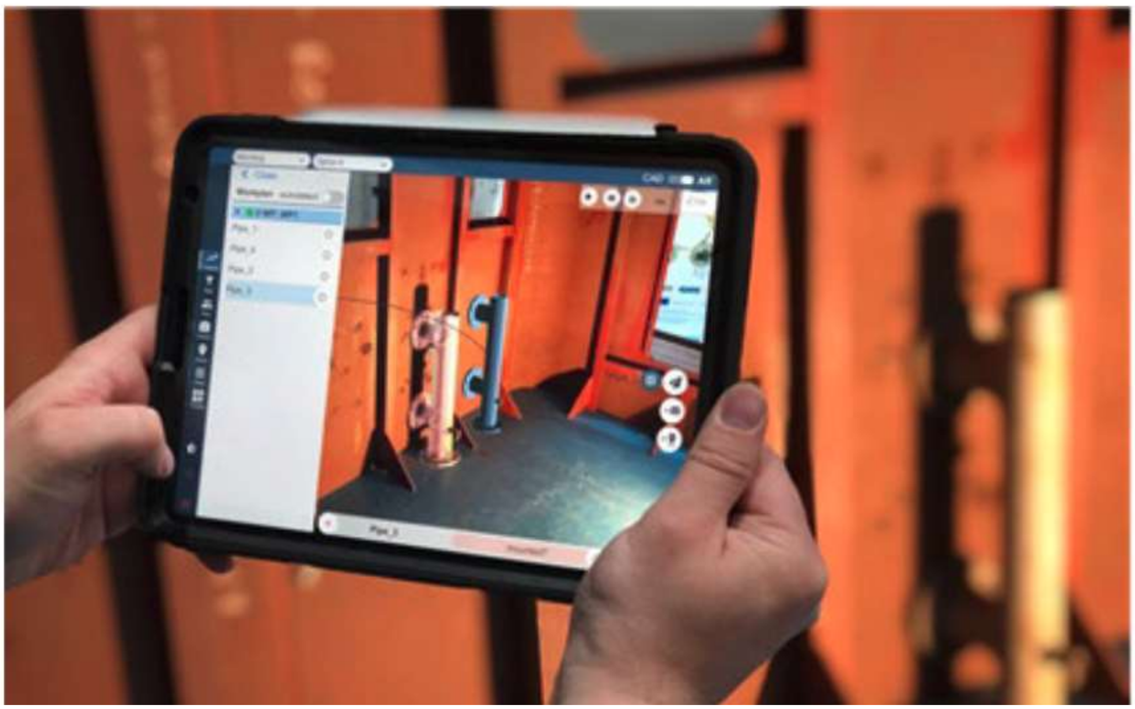

Figure 9. AR handheld device (at AIMEN)

2.10.2 Potential Applications

The Web App can be filled manually or automatically by third party systems. It serves as an endpoint for the Tablet App.

The Tablet App can be used to navigate the working environment in CAD or AR mode, and therefore to carry out described work processes and check their current status. After that, the progress can be monitored by the supervisors in the web Application.

Expected benefits

Economic benefits

- Lowered time consumption of searching for information and fulfilling tasks by around 10-25%, which translates into an economic benefit.
- Faster recording of construction progress.
- More precise recording of the progress.
- Faster and more transparent communication of the actual progress.

Sustainability

- Positive influence on natural resource demands due to digitalisation and reduction of paper-based work.

Societal benefits

- Increase of worker's satisfaction by preventing repetition of tasks that were faulty and by reducing frustrating elements by handling a lot of paperwork.

2.10.3 Guidelines for the application of the solution

- Before the system can be integrated into a shipyard, there are preconditions. The main challenge would be a minimal level of digitalisation of the shipyard.
- Using 3D information (3D models of the working spaces and/or worked on parts) is highly recommended when using this system. If this information is only available as technical drawing without the digital CAD counterpart, this is to be overcome.
- Another point is the shipyards PLM-systems. Evaluation amongst the consortium made clear that most companies and especially shipyards use different file formats and information structure. Interfaces on the import and export side of the solution system needs to be configured to be able to communicate with the shipyards systems.

2.10.4 Potential disadvantages

At the current state, there are no disadvantages visible.

2.10.5 Potential risks/barriers

Technical

- Need for time to learn and adapt if workers are not already used to such applications.
- Data security is a topic when it comes to digital systems. This is, not only, but especially the case, when it comes to systems that are open to external networks. Security measurements need to be fulfilled, while also security updates need to be done ongoing. If shipyard ERP is not up to date than plan, tasks, and resources cannot be used as input for this application. Model should represent reality as much as possible.
- A negative effect could be that energy consumption will slightly increase due to the use of a handheld device.

Economic

Small investment needed at the beginning for the handheld devices, around 1000-1500 € per device. The costs of a full system not precisely calculatable at this stage since it is in prototype stage. The costs will be highly dependent on how established such solutions are already in industry, when a shipyard decides to implement it. Big shipyards will most likely be forerunner there.

Social

- Fear of some workers that such technologies could be used to supervise their productivity.
- Resistance of people that need to adapt to the new technology. A clear communication and transparency can help with both.

Legal (Rules, regulations)

- Legal requirements regarding data security and data privacy need to be fulfilled when implementing such a system.
- Possible new safety rules when it comes to working with handheld devices in a technical surrounding in the future.

2.10.6 LCPA results

Results will be added in the updated document at the end of the project.

2.11 Technology: Exoskeleton for shoulder support and lumbar support

2.11.1 Description

Exoskeletons are wearable mechanical devices designed to provide support to workers by reducing their physical effort. Two occupational exoskeletons, namely a shoulder-support exoskeleton and a lumbar- support exoskeleton, were developed within Mari4_YARD project. Their goal is to reduce physical strain of workers in those production stages characterized by the presence of wearing job movements for the shoulder girdle and the spine, respectively. The shoulder-support exoskeleton is designed to provide antigravitational support to the user's arms for those job activities requiring static or repetitive shoulder flexion.

Thanks to an embedded battery-operated control unit, the exoskeleton is capable to adjust the provided support depending on the inherent effort of the working activity though effort- based and perception-based adaptive algorithms. The lumbar-support exoskeleton is designed to support the user's trunk erector muscles through an assistive action delivered at the level of the lumbo-sacral joint in those job activities requiring repetitive load lifting actions or static flexion trunk poses. The intensity of the assistance level can be manually tuned over five levels.

As "wearable" tools, both exoskeletons are designed to provide comfortable human- machine interaction thanks to a light-weight structure, high kinematic compatibility ensuring for complete freedom of movement and high adaptability thanks to a set of adjustments mechanisms that allow to tailor the size of the devices to fit on specific users. Both exoskeletons are also endowed with a control unit that is devoted to acquiring kinematics information from an integrated sensory apparatus and implementing wireless MQTT protocol to share information with IoT networks.


Figure 10. Exoskeletons (at NODOSA)

2.11.2 Potential Applications

Exoskeletons have gained attention in recent years as a potential solution for reducing workplace injuries and improving productivity in physically demanding jobs. While automation is often heralded as a solution in industries that require repetitive or heavy manual labor, many shipbuilding working activities require flexibility, adaptability, or sensitivity to navigate and operate in complex environments. This is where exoskeletons result useful advanced tools for supporting workers improving ergonomics in those activities that require prolonged static postures or repetitive movements that can cause musculoskeletal discomfort. Specific example in shipbuilding scenario are assembly tasks such as welding and other related workshop activities. Welding or grinding, especially under the keel of the ship, requires keeping postures with flexed shoulders for several minutes and a shoulder-support exoskeleton can be considered a viable solution to reduce strain of workers and consequently reduce operation time. Assembly activities in workshop are often performed on large tables requiring operators to keep bent trunk postures while manipulating heavy objects; a device designed to reduce the strain at the level of the spine can be relevant for reducing back pain or keeping more ergonomic working postures.

2.11.3 Replicability

This will be included in the next version of the document.

2.11.4 Expected benefits

Manual working processes that require flexibility and adaptivity cannot be easily targeted by automation, nevertheless the physical strain of operators cannot be reduced under a certain extent by reorganizing geometry of workspaces to improve ergonomics. When all the measures taken to minimize the strain are already pursued, still the biomechanical overload represents a huge risk factor in the long-term development of work-related musculoskeletal disorders. Exoskeletons are advanced tools that, by providing mechanical support in synergy with the human articulations, are effective in further reducing the physical strain of workers, still allowing for flexibility and dexterity of their operations. In this sense, exoskeletons can be seamlessly integrated in the working routine without requiring reconditioning of the working environment or operations. In the next sub-sections, more details are provided on the expected benefits under economic, sustainability and societal perspectives.

Economic benefits

From an economic viewpoint, exoskeletons are a cost-effective solution that can have short-term and long-term impacts:

On the short term, exoskeletons can have potential to significantly enhance workforce productivity and efficiency. Reduced biomechanical overload can contribute to:

- Reduced fatigue-induced errors enabling cost saving in terms of repetition of operations and materials.
- Reduced number of discomfort events requiring to stop operations and rest to recover from fatigue.
- Increased precision and speed in the operations.

Exoskeletons could potentially reduce ergonomic risk indexes. Biomechanical overload risk indexes are a predictor of incidence of injuries and development of work-related musculoskeletal disorders. Reducing the biomechanical overload risk indexes may be indicative of long-term economic gains in terms of reduction of health costs, turnover and injuries as well as of insurance costs.

Sustainability

- Enablement of safer operations of current workforce with minimum to null reconditioning of the working place and with only a limited investment in the purchase of the exoskeletons and training. The investment goes in favour of enabling safer operations of current workforce with minimum to null reconditioning of the working place.

Societal benefits

- Increased quality of life of workers, thus increased motivation, well-being and safety by investing in preserving human factor through the provision of advanced tools to improve the working condition of operators, the company or shipyard.
- Promotion of a clear message of attention towards human factor that can have positive impact in attracting competitive young workforce, improving engagement and satisfaction of workers.

2.11.5 Guidelines for the application of the solution

Two main recommendations can apply to the introduction of exoskeletons.

- Firstly, as an innovative tool, despite ease of use, structured user training can significantly boost acceptability and usability of the device. Training sessions on how to wear and operate the exoskeletons can be strategic not only to drive technical aspects but also to educate users about the benefits of exoskeletons This approach ensures that employees are well-prepared to integrate exoskeletons into their daily routines effectively.
- Secondly, setting up a dedicated area for stock and user preparation can significantly amplify the success of their deployment among workers. Setting-up a specific area (a locker room or even a corner close to the production stage) dedicated to exoskeleton stock, donning and doffing, makes the “tool” easily accessible to the users.

2.11.6 Potential disadvantages

As advanced tools the learning curve of the devices is fast, yet it may require an initial effort that may slow down operations in the first place (less than one week).

2.11.7 Potential risks/barriers

Main risks and barriers in the introduction of exoskeletons are represented by the actual usability and acceptability in the workplace.

Technical

- Difficulty of performing working activities in narrow spaces hardly accessible by the operators themselves in their regular working equipment. In this case, it is suggested to encourage use of exoskeletons only in operations that are compatible with their use.

Economic

- Minimum to null economic risk if accompanied by proper training of workforce to the use of the device.

Social

- Accepatabilitycould be an issue. Being an advanced tool, it is possible that not all the workers may be open to accept to learn how to use and take benefit of innovative tools. Forcing an operator to use the device may taint the attitude towards the use of the device with the risk of spreading prejudice. To mitigate the risk, the company should invest in training people that are well-disposed toward the technology and that are able to clearly identify pros and cons of using the exoskeletons. Their experience will then be the main driver to attract other workers in spreading the use of the device.

Legal (Rules, regulations)

- No legal limitations are identified.

2.11.8 LCPA results

Results will be added in the updated document at the end of the project.

3 CONCLUSION AND OUTLOOK

This document is the first version of the Mari4_YARD best practise handbook which gives a first overview of the different solutions, their possible applications and the conditions under which they may be introduced. Since currently no demonstrators have been realised, the enclosed findings are mainly related to tests in the lab and user training that took place inside and outside of the yards. The coming months will bring further insight when the shipyard demonstrations start. The outcome will on side by comprehensive information about benefits as well as potential issues. Furthermore, it will provide input data for the Life Cycle Performance Assessment that will show the viability of the solutions in terms of KPIS covering the economic and environmental impact. These results will be included in the public deliverable D6.8.