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Specification and vertical integration

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DOCUMENT HISTORY

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0.1	12/07/21	First draft with the document structure	Draft	GHENOVA, AIMEN
0.2	19/07/21	Added double hull block from GHENOVA	Draft	GHENOVA, NODOSA, BIS, AIMEN
0.3	11/08/21	Design submitted to NODOSA for manufacturing with available materials	Draft	GHENOVA, NODOSA, BIS, AIMEN
0.4	19/08/21	New version adjusted to be manufactured	Draft	GHENOVA, NODOSA
0.5	20/09/21	Double hull block installed at AIMEN	Draft	AIMEN
0.6	17/01/22	Added information about FT devices received	Draft	AIMEN
0.7	31/05/22	Document prepared with the current layout	Draft	ALL
1.0	18/06/22	Added some minor contributions and updated the machinery used	Final	EC

SUMMARY

This document includes a detailed description of the three testbenches used in the Mari4_YARD project. Pictures of the testbenches and the related infrastructure and equipment are also included in the document.

TABLE OF CONTENTS

1 INTRODUCTION

The design and manufacturing of testbenches have a two-sided objective. In the one hand, it will be served as a basis for the development and integration of technologies and in the other hand will be used as validation, demonstration and showroom to maximize the project impact. To this end, it is not only the case of having a realistic environment to develop technologies in shipbuilding, but it is also necessary to include the corresponding infrastructure in accordance with the use planned for them. Testbenches will be used for development, validation, demonstration and training.

Three different testbenches are included to cover different manufacturing stages and application environments: steelwork production, confined welding operations and outfitting and construction supervision. In the following sections each of the testbenches will be described with the corresponding equipment included.

2 STEELWORK PRODUCTION

The testbench for steelwork production is centred on the pre-manufacturing stage, with the handling and welding of parts to assemble blocks and subblocks structures. The infrastructure for the laboratory setup is divided in three different robotized solutions that will serve as a basis to develop the Mari4_YARD technologies; a high-payload robot cell for the handling and assembly of complex structures, a welding robot in gantry configuration with 9 DoF for fast teaching and autonomous operation, and a collaborative robot for pipe welding.

2.1 High-payload robot cell

This production cell is equipped with a robot of 205 kg payload and a range about 1.9 m, to be used in both handling and welding operations. The robot is installed in regular position, elevated from the floor to maximize the available working space when installing the welding torch or the manipulation gripper. It is also equipped with a force and torque sensor attached to the wrist with a maximum load capacity in the Z axis in the range of the robot payload.

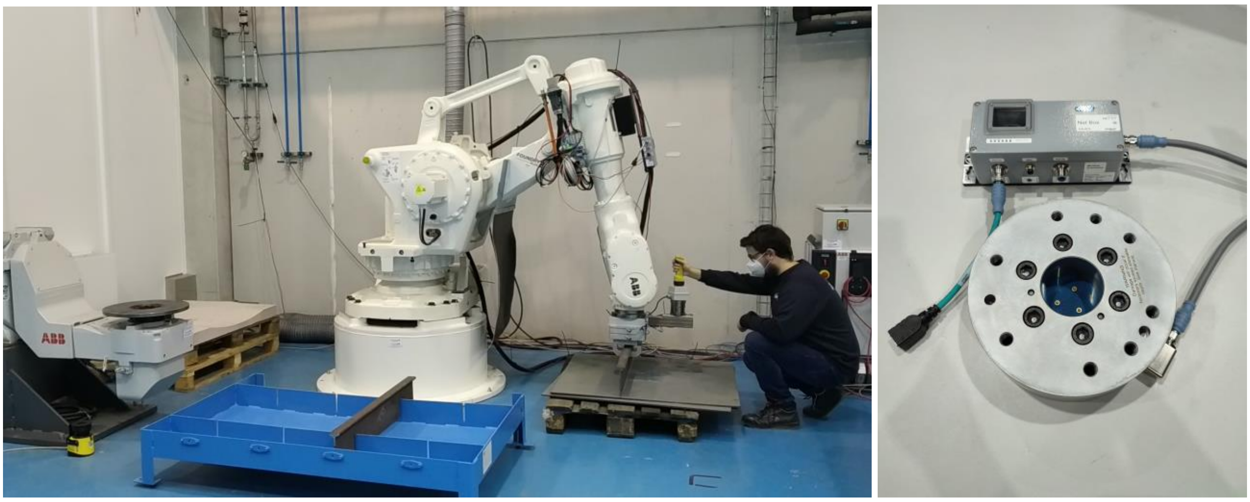

Figure 1. High payload robot and FT sensor FTN-Omega-191.

To easily implement autonomous or hand-guided manipulation using the robot, a couple of containers for positioning the elements have been included as part of the setup, Figure 2. The first one is designed to store reinforcements used in the pre-manufacturing stage, whilst the second one was designed to position small elements for autonomous manipulation, . The size of the reinforcements has been reduced to implement the demonstrator with the available equipment at AIMEN facilities, the use of bigger elements will require adding an external axis to the industrial robot. The small container has a set of magnets to keep the parts in a given preferred orientation and also to help during the clamping operations. It is expected to be involve in the handling of small elements in the initial manufacturing stages in the subblock structures assembly.

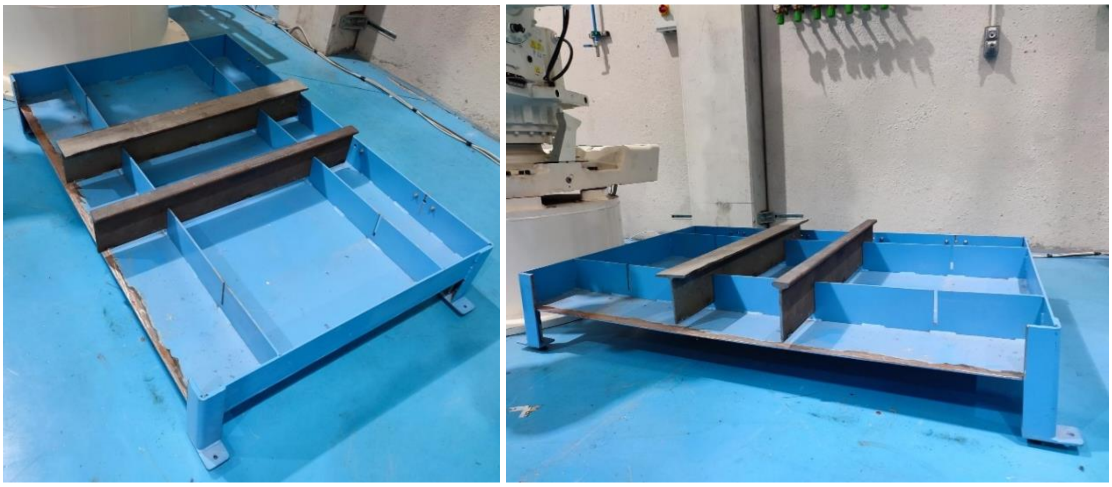

Figure 2. Container for reinforcements.

None of them are fixed to the shopfloor but they are provided with levellers. In this regard, the perception systems under development are designed to allow the deployment of the robotic solutions in changing environments with not fixed structures avoiding the necessity for robot-environment calibration but levelling the devices will be helpful to make it easier perform manipulation by means of hand-guiding.

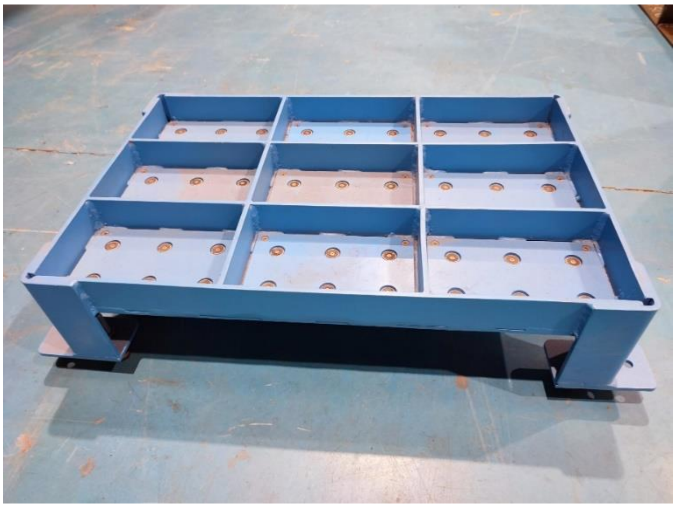

Figure 3. Small container with magnets.

2.1.1 Equipment

This subsection summarizes the equipment used to create the robot cell for assembly in shared space with operators.

a. ABB Robot

The model is an IRB 6660 with a maximum payload of 205 kg and an operational range of 1.9 m. The robot controller is an IRC5 with RobotWare 6.07.01. Figure 4 shows the dimensions, axis distances and the orientation of each joint to extract the Denavit-Hartenberg parameters.

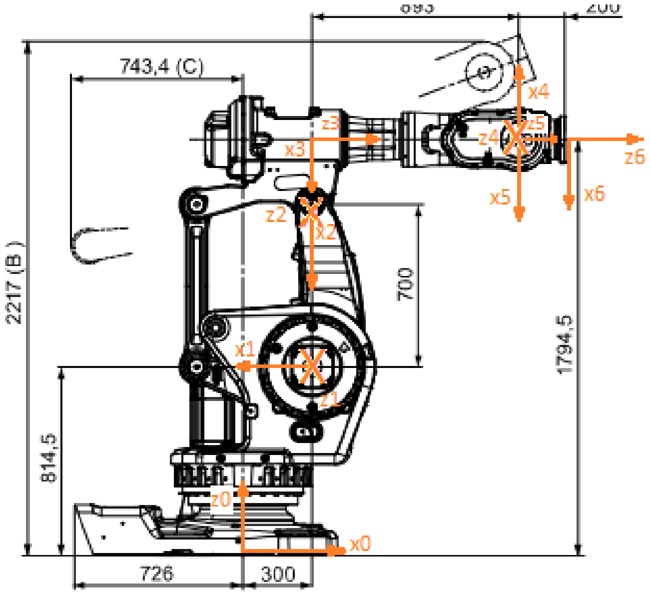

Figure 4. Main dimension of ABB IRB 6660.

The parameters are represented in Table 1 (in degrees an in mm). These values are included in the digital configuration of the robot cell (URDF file in ROS system).

Table 1. Denavit-Hartenberg parameters for the ABB IRB 6660.

Axis	θ_i [degrees]	d_i [mm]	a_i [mm]	α_i [degrees]
1	180	814.5	-300	90
2	-90	0	-700	0
3	0	0	-280	90
4	180	893	0	90
5	180	0	0	90
6	0	200	0	0

b. Force and torque sensor

The sensor used in the robot cell is a Schunk FTN-Omega-191 with enough load capacity in the Z direction to match the robot maximum payload. It is a little bit oversized in the selection to ensure the maximum torque when manipulating long reinforcements or assembly parts.

Table 2. FT sensor main parameters.

Parameter	FTN-Omega-191
Evaluation via	EtherNet/IP
Weight [kg]	9.41
Calibration 1	SI-7200-1400
Range of measurement Fx, Fy [N]	± 7200
Range of measurement Fz [N]	± 18000
Range of measurement Mx, My [Nm]	± 1400

Range of measurement Mz [Nm]	± 1400
Overload Fx, Fy [N]	± 36000
Overload Fz [N]	± 110000
Overload Mx, My [Nm]	± 6800
Overload Mz [Nm]	± 6800
Resolution Fx, Fy [N]	1.5
Resolution Fz [N]	3
Resolution Mx, My [Nm]	0.21
Resolution Mz [Nm]	0.14
Diameter D [mm]	190
Height Z [mm]	64

c. Hand-guiding device

With the aim of implementing certified solutions for human-robot interaction, a safety compliance joystick with a three-position switch from ABB will be used. The JSHD4 - Figure 5 device is designed for use in hazardous environment.

Figure 5. ABB JSHD4

d. Safety sensors

A couple of safety sensors were added to the robot cell to implement a Safety Rated Stop (SRS) when the robot is operating in autonomous mode at full speed. Two Sick S300 sensors with a field of view of 270º and a protective distance of 2 m are installed in the deployment environment.

Figure 6. Sick S300.

Table 3 shows the technical specification of S300 laser scanners. It contains a relation of the features and the corresponding values.

Table 3. S300 main features.

Parameter	Value
Protective field range	2 m
Warning field range	8 m (15 % reflectivity)

Distance measuring range	30 m
Type of field set	Triple field sets
Number of field sets	1
Number of fields	3
Number of monitoring cases	1
Scanning angle	270°
Resolution (can be configured)	30 mm, 40 mm, 50 mm, 70 mm
Angular resolution	0.5°
Response time	80 ms
Protective field supplement	100 mm
Number of multiple samplings	2 ... 16, configurable
Delay of automatic reset	2 s ... 60 s, configurable

e. Digital twin

All the equipment described in the previous paragraph is digitally integrated in a control PC with a digital twin. The system is based on a Linux/Ubuntu 20.04 with ROS (Robot Operating System) Noetic. All the device drivers are available and integrated in a single configuration file. Figure 7 shows a virtual representation of the robot cell, including the robot, the safety sensors and the real-time sensor measures.

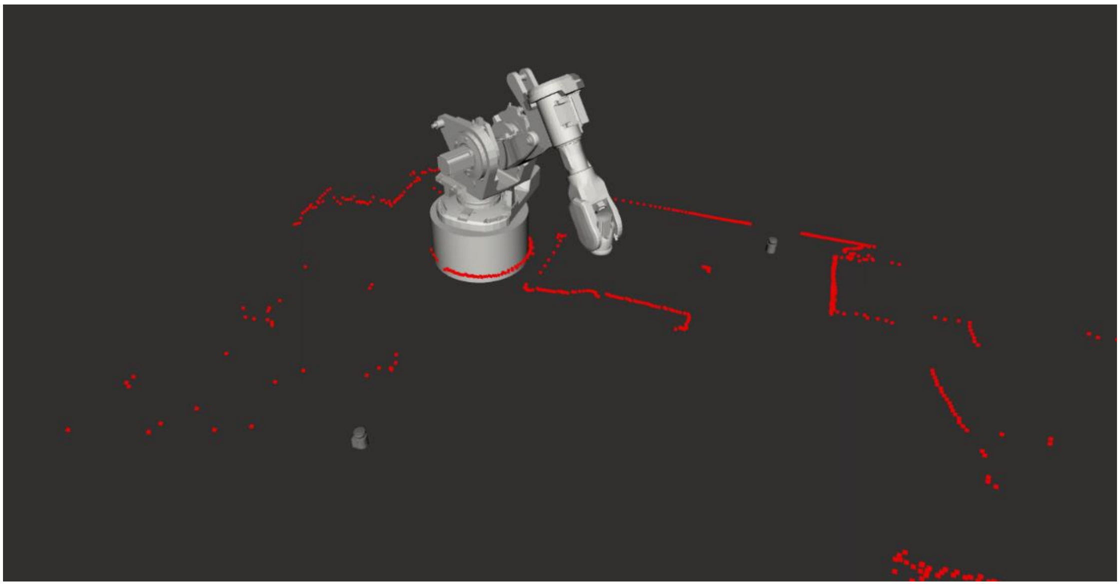

Figure 7. Virtual representation of the robot cell.

2.2 Welding robot in gantry configuration

This robot cell was originally intended to be used under a technological concept of full automated production, but this approach have demonstrated some important drawbacks for the small and medium shipyards. In a scenario where only few units of every vessel model are constructed (with a tendence to one-of-each) it is difficult to make profitable such investment in infrastructure for the automated manufacturing of only few parts in a small shipyard. It will represent a big financial effort difficult to depreciate during the equipment exploitation time. Furthermore, productivity of this solution comes with the repetition of operations and it is something that could not be given for granted as reconfiguring the equipment is also time consuming.

Figure 8. 9 DoF industrial robot with 3 axis crane.

In Mari4_YARD this infrastructure, previously available before the project execution at AIMEN facilities, will be used in a user-centric approach. It will perform structural welding of known and unknown parts, so it will operate in semi-autonomous mode with the capability of being programmed by a non-expert worker. Hand-guiding for robot positioning and fast-teaching of welding trajectories will help to make the already available solutions more profitable for the end-users, also opening an exploitation channel for some of the technologies included in Mari4_YARD. Figure 8 shows the current infrastructure performing autonomous welding of know parts.

2.2.1 Equipment

a. Kuka Robot

The model is a Kuka KR16-2 with a maximum payload of 16 kg and an operational range of 1.6 m. Figure 10 shows the dimensions, axis distances and the orientation of each joint to extract the Denavit-Hartenberg parameters.

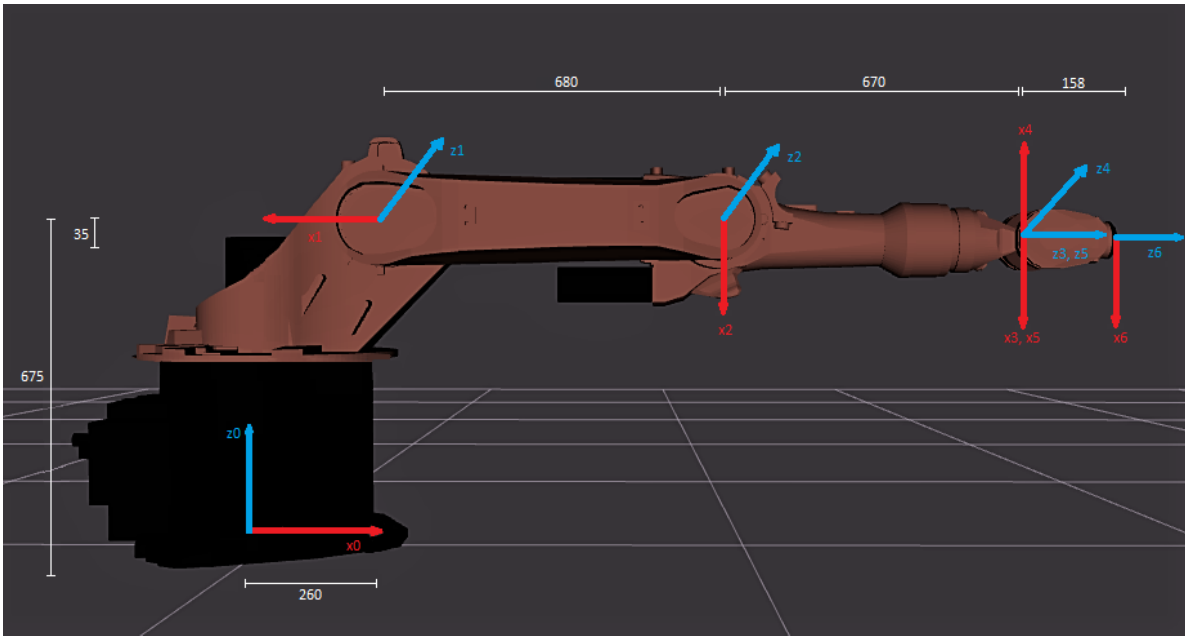

Figure 9. Denavit-Hartenberg references for the KUKA KR16-2 (units in mm).

Figure 10 shows the operational range of the robot, with the working space represented in grey. All the dimensions are represented. It is important to note that this robot it is mounted in inverted position, handling from the gantry.

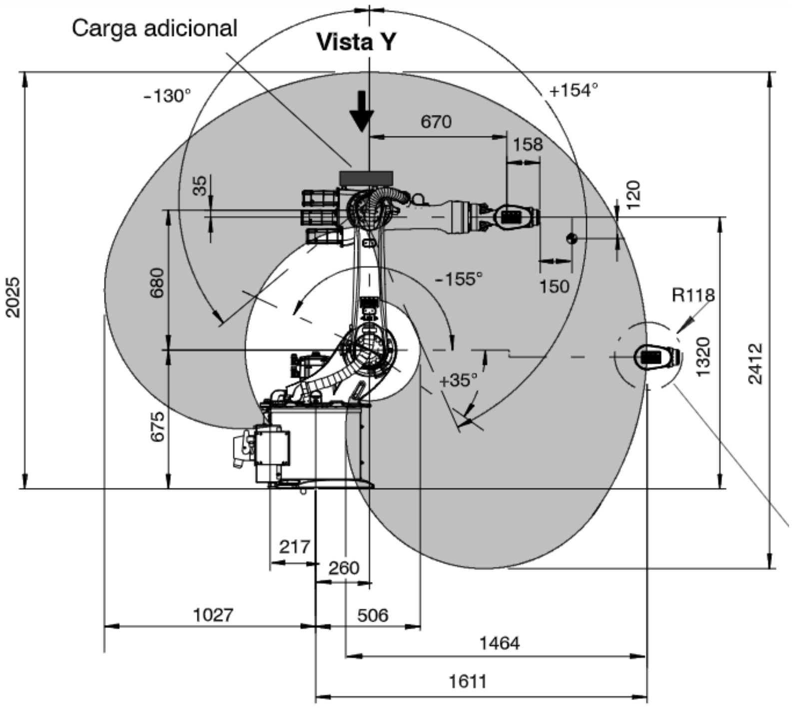

Figure 10. Main dimension of Kuka KR16-2 and working space.

The parameters are represented in Table 4 (in degrees an in mm). These values are included in the digital configuration of the robot cell (URDF file in ROS system).

Table 4. Denavit-Hartenberg parameters for the KUKA KR16-2.

Axis	θ_i [degrees]	d_i [mm]	a_i [mm]	α_i [degrees]
1	180	675	-260	90
2	-90	680	0	0
3	0	670	35	90
4	180	0	0	90
5	180	0	0	90
6	0	158	0	0

b. Welding equipment

A complete welding equipment is included as part of the testbenches configuration, to be used either with the high-payload robots or with the collaborative ones. The equipment is from Fronius, and it is composed by four main elements: the torch (with anticollision fixture), the machine, the wire-feed unit and the connection box. Table 5 includes the models of each element whilst Figure 11 shows the welding machine and the wire-feed unit.

Table 5. Welding equipment from Fronius.

Element	Model
Machine	TPS 400iPulse

	TPSi robotic system
Torch	MTB 330i W R /22°/L246/H27 WF 60i Robacta Drive CMT/W
Wire-feed unit	WF 25i REEL R /4R/G/W
Connection box	SB 500i R /G/W/FSC

Figure 11.Welding machine and wire-feed unit.

2.3 Collaborative robot for pipe welding

One of the main technical challenges faced in Mari4_YARD project is to perform welding operations with collaborative robots. The idea is to deploy small and cost-effective collaborative robots to be an easy-to-use tool for the shipyard operators. The deployment is being considered in different construction stages and among of them is the premanufacturing, in the pipe preparation that is performed in the workshop.

Figure 12. Setup to deploy collaborative robots at the workshop.

The setup consists of an elevated robot base prepared to attach different collaborative robot models. For testing and developing purposes, an UR10 robot is also available.

Figure 13. Pipes and flanges to be used in the development.

Figure 13 shows a set of pipes prepared for welding at the workshop. Fast teaching and visual servoing technologies will support the deployment of collaborative robots in welding operation using small and collaborative robots.

2.3.1 Equipment

a. UR10 Robot

The setup includes an UR10 robot with a maximum payload of 10 kg and a range of 1.3 m. Figure 14 shows the dimensions and the operational working area of the robot.

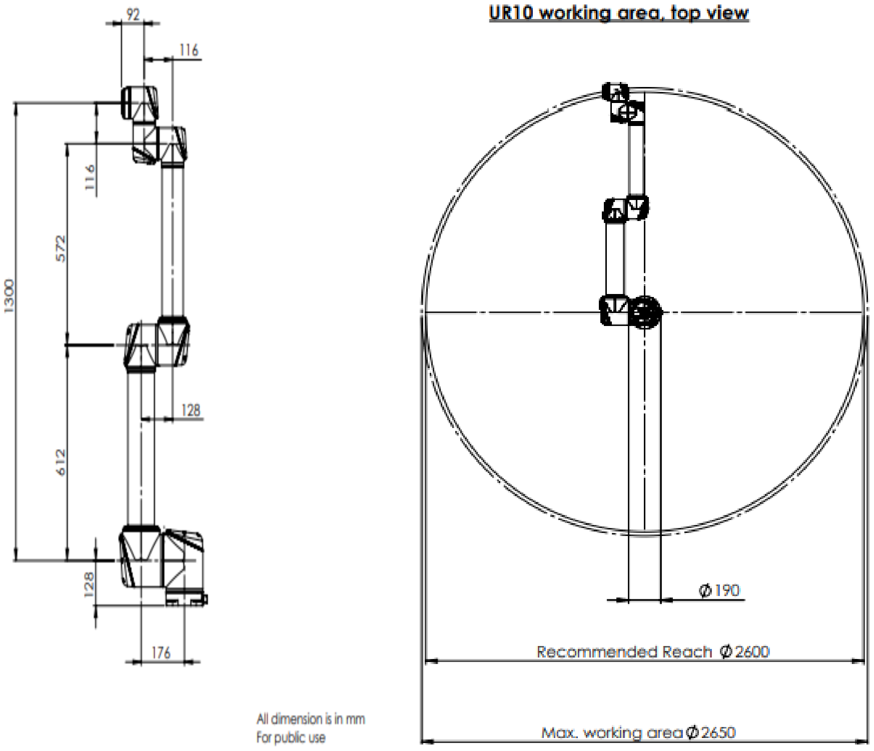

Figure 14. UR10 main dimensions and working area.

Denavit-Hartenberg parameters are represented in Table 6 (in degrees an in mm). These values are included in the digital configuration of the robot cell (URDF file in ROS system).

Table 6. Denavit-Hartenberg parameters for the UR10.

Axis	θ_i [degrees]	d_i [mm]	a_i [mm]	α_i [degrees]
1	0	0	127.3	90
2	0	612	0	0
3	0	572.3	0	0
4	0	0	163.941	90
5	0	0	115.7	-90
6	0	0	92.2	0

b. Welding machine

The welding equipment for this setup is shared with the steelwork production.

3 CONFINED WELDING OPERATIONS

The deployment of technology inside blocks or inside the vessel represents the corner stone for the use of use-centric solutions in shipbuilding. Accessibility and changing environments represent a challenge for the use of new technologies in confined spaces. To simulate the real conditions and create technical solutions adapted to the high demanding specifications, a double hull structure is included as confined testbench. It will be used mainly for welding operations, but it will be also possible to deploy supervision tools.

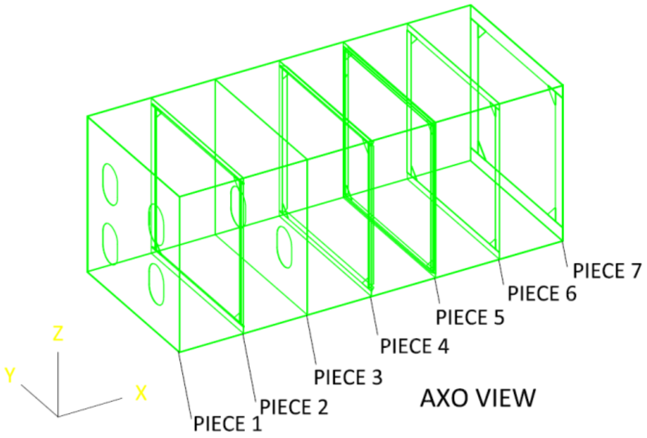

Figure 15.Double hull structure.

A 3D representation of the designed structure is represented in Figure 15, done by GHENOVA and later manufactured by NODOSA.

Figure 16. Confined space structure.

Figure 16 shows the structure at AIMEN facilities. The testbench is divided in 6 subsections that will be used to test the welding operations during the project development. In the upper images it can be appreciated the size of the structure whilst in the lower images it can be seen the structure is not welded yet. The different parts are only fixed to allow the deployment of user-centric welding tools.

The structure will be also used for supervision with augmented or mixed reality, simulating some of the manufacturing stages inside the vessel, more specifically in retrofitting. To this end, it is necessary to have the 3D model of the structure to deploy the supporting tools. Figure 17 shows the digital model of the testbench for confined operations.

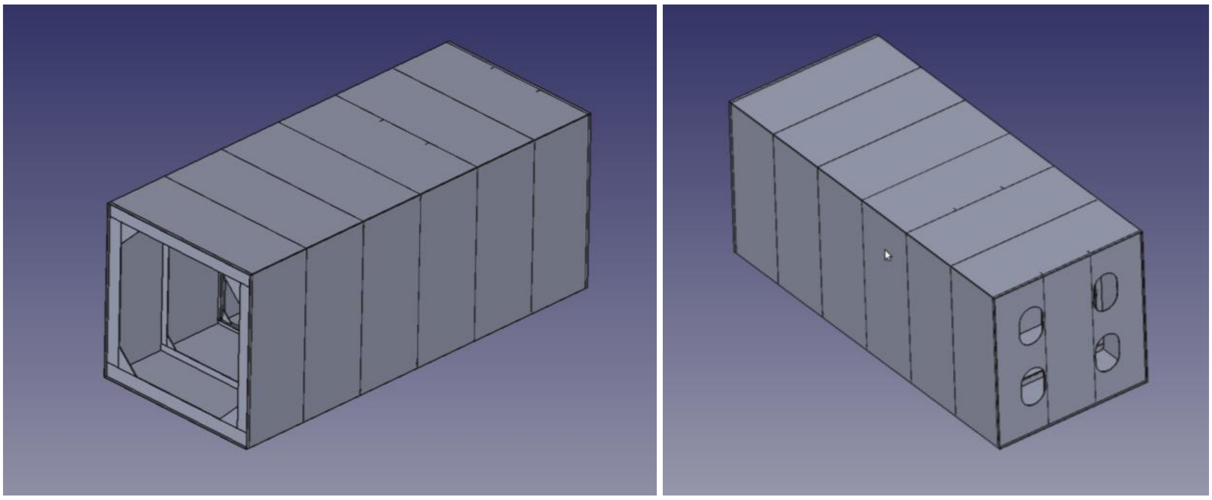

Figure 17. 3D model of the double hull structure.

3.1.1 Equipment

In this testbench will be used not only the welding machine, but also a plasma cutting machine to perform cut openings during retrofitting or late modifications during outfitting stage.

a. Plasma cutting machine

The plasma cutting machine is a Hypertherm PowerMax 85 equipped with a straight torch to be mounted in a robot. Figure 18 shows the machine included in the testbench.

Figure 18. Hypertherm PowerMax 85.

b. Welding machine

The welding equipment for this setup is shared with the steelwork production.

4 OUTFITTING AND CONSTRUCTION SUPERVISION

Supervision tools could be used at any manufacturing stage but Mari4_YARD focuses on the use of these tools onboard the vessel or inside blocks during the outfitting stage. The two main reasons behind this approach are: the potential impact for end-users, as outfitting is more costly and error prone than pre-manufacturing, that takes place in the workshop; Activities related with repairing and retrofitting, usually takes place onboard the vessel. To cover these needs, it was designed a testbench oriented to cabin outfitting.

The testbench consists of a bulkhead and the corresponding ceiling cover. This design is necessary to perform indoor localization and matching using CAD models. This is envisaged for the deployment of robotic technologies and for AR/VR tools used in supervision activities. Regarding the robotic technologies, for precise and autonomous localization the use of advanced perception system supported by a digital model of the environment is required.

The bulkhead was firstly manufactured in the CARLoS[1] project from a standard cabin design (Figure 19). It was used during the development and demonstration stages for autonomous pin welding in outfitting construction stage. This design will allow to simulate different deployment conditions, as working space and distance to the bulkhead could be extended or reduced without having to perform any modification in the layout. As already pointed before, a ceiling was installed to simulate a closed environment in order to avoid noise due to the surrounding environment when acquiring images with the supporting devices (cameras, tables, headsets).

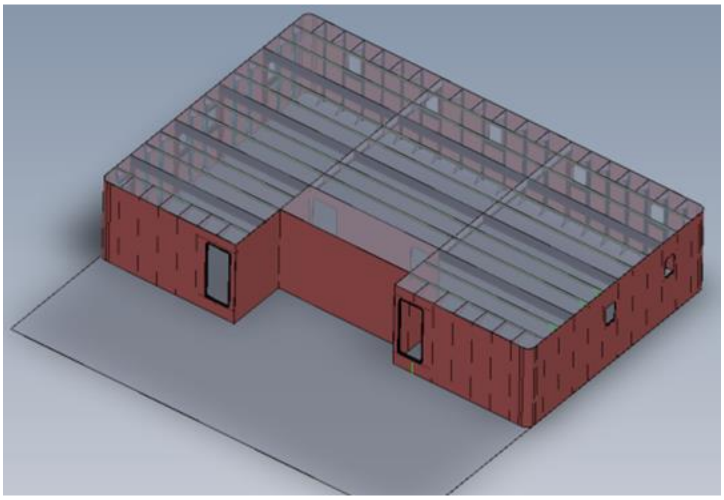

Figure 19. Standard cabin design.

Using the reference cabin from Figure 19, a representative part of it was selected to create the setup. It consists of a bulkhead with the regular reinforcements present in most of shipbuilding scenarios. In the Annex 2 it could be seen the 2D drawing previously used in CARLoS project.

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[1] https://cordis.europa.eu/project/id/606363

Figure 20. Testbench for outfitting and supervision development.

Figure 20 shows the outfitting environment with the modifications included to add the ceiling. The deployment of augmented/mixed reality solutions requires for a digital model of the environment. It was created a precise 3D model of the environment, with the possibility of adding some elements to simulate different manufacturing stages. Some pipes of different shapes and sizes were included in the setup and also in the digital model. Figure 21 shows the 3D model, in the left the clean bulkhead with the ceiling and in the right including some pipes, as shown in Figure 20.

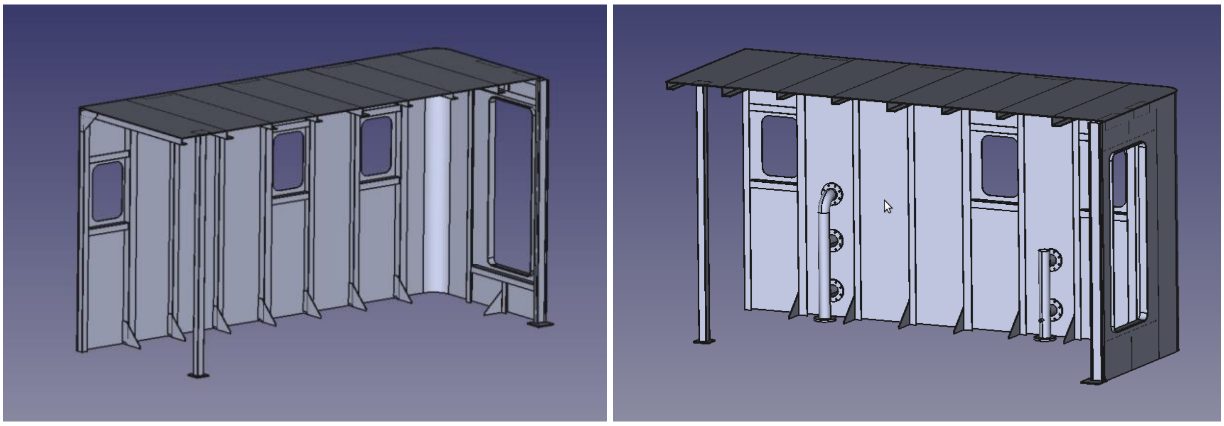


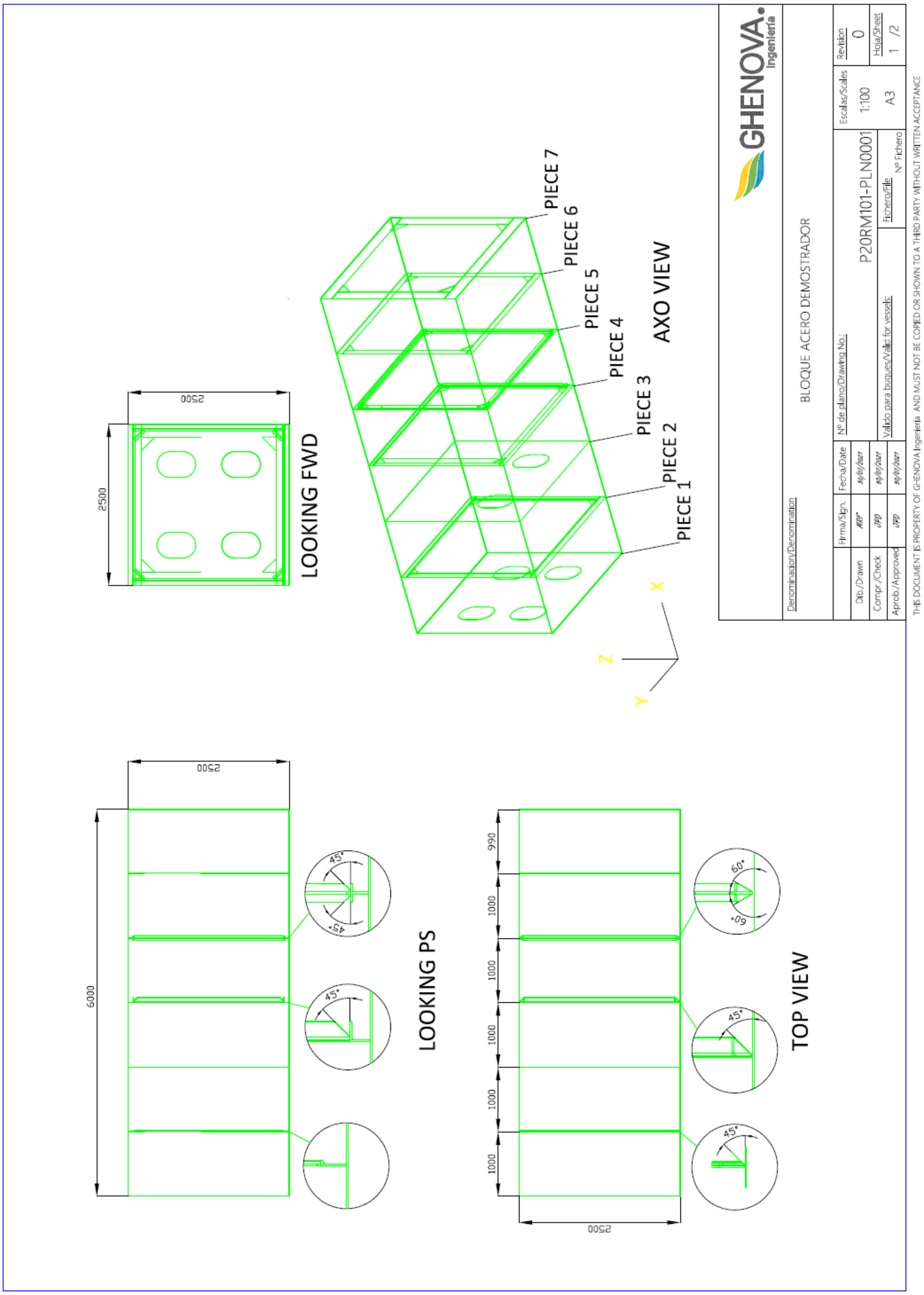
Figure 21. 3D model of the outfitting testbench.

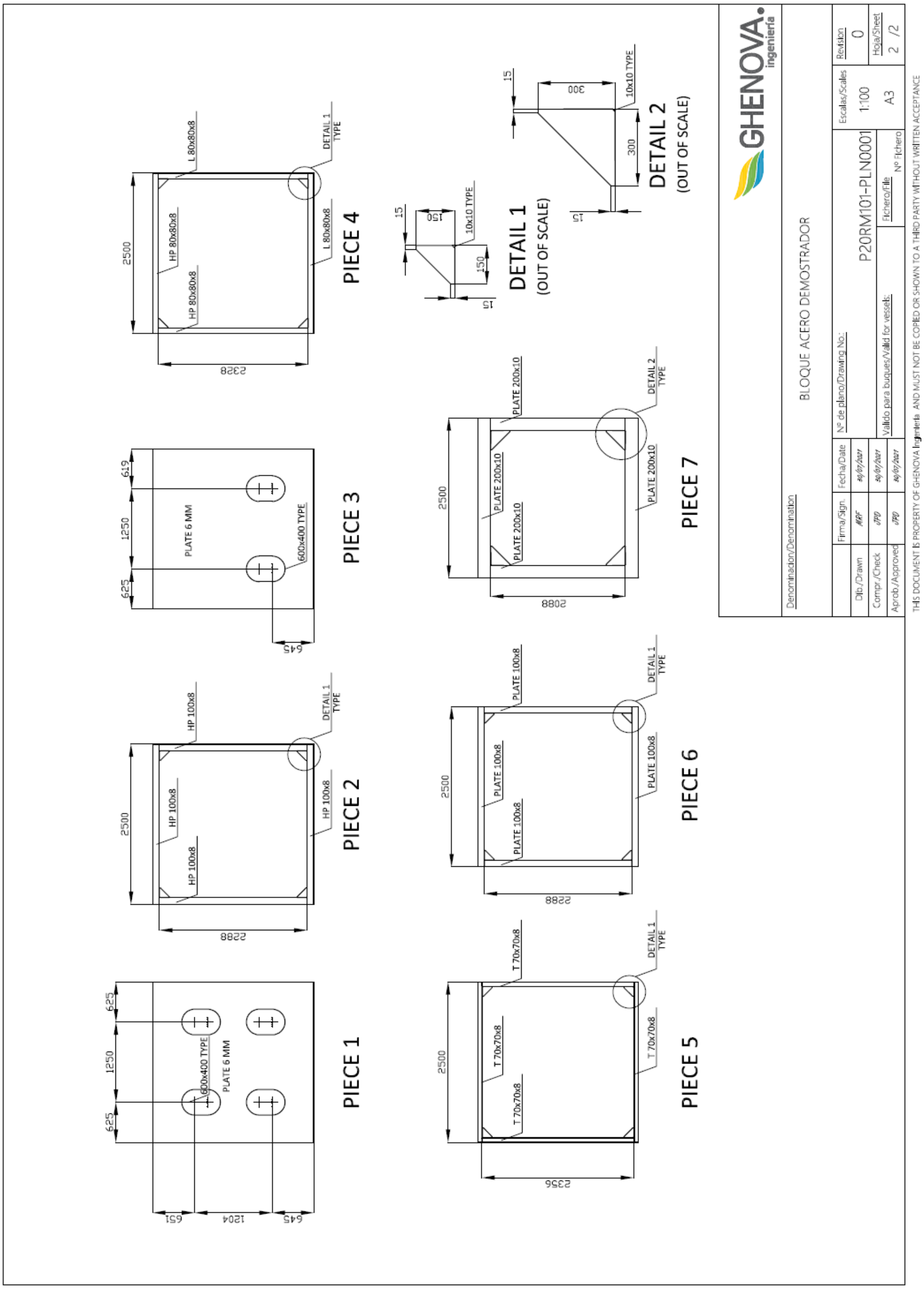
Table 7 includes the main dimensions of the testbench and the number of elements installed in the bulkhead, a total of 10 reinforcements.

Table 7. Cabin main dimensions.

Parameter	value
Height	2.48 m
Width	4.44 m
Depth	1.64 m
Reinforcements	3 of 90 mm
	7 of 75 mm

ANNEX 1. DOUBLE HULL STRUCTURE

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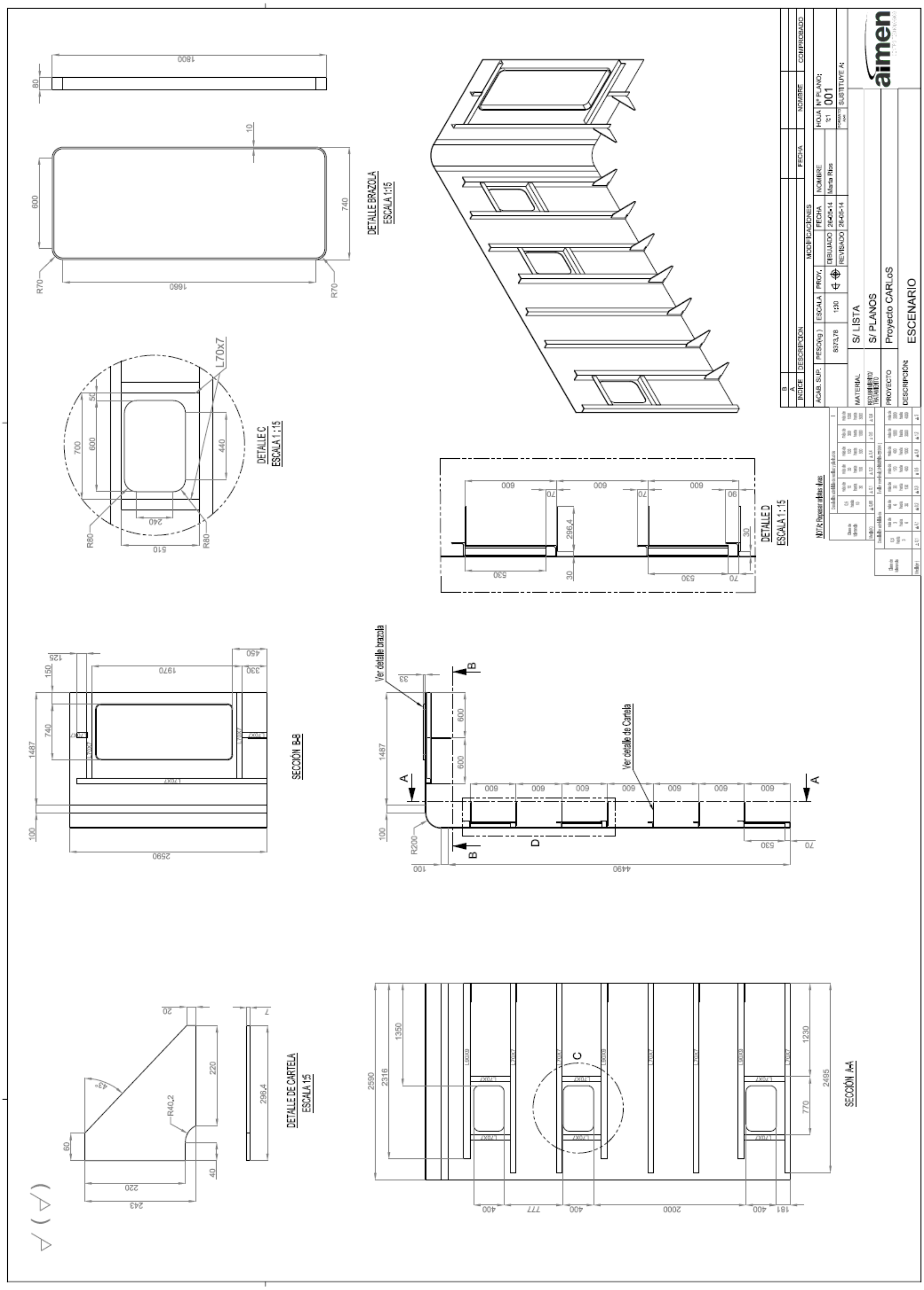
ANNEX 2. DRAWINGS OF OUTFITTING SCENARIO



ANNEX 3. LAYOUT