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# [D4.1]
# [Collaborative cell layout description]


**Abstract:**

This deliverable is made of a report that describes the design and implementation of a collaborative cell where the development of the remainder activities will take place.

The structure was conceived to accommodate a cobot and a set of sensors for real time 3D perception of the cell and its occupancy.

Several specifications were taken into account in the design of the collaborative cell, named LARCCell, or in short LARCC. That covers the necessary space and clearance to include a robot manipulator and one or more operators interacting with it. The structure allows positioning of sensors in a wide variety of places and orientations for large flexibility and scalability.

Besides the computational unit to interface the sensors, the system also includes the switchboard for all electrical power sources and interfaces along with protection and communications units.

The result is a flexible system, which is expected to cover many different situations, either present in the partners uses cases or for applied research in the field.

This Cell was developed exclusively by the University of Aveiro, although inputs from the industrial partners were taken into account when designing the solutions.





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**Document relating to:**

| | | |
|---|---|---|
| **Activity** | **A4** | Design and Development of a Collaborative Cell |
| **Task** | **A4.T1** | Implementation of the Cell Layout |
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| **Project Team Leaders** | | University of Aveiro - Vitor Santos, Daniela Rato, Afonso Castro, Filipe Silva, Miguel Oliveira |


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# 1 Introduction

To carry out the tasks inherent to activities A1, A2 and A3, and their present and future deliverables (D1.X, D2.X, D3.X), it was necessary to design and develop a structure with automatic perception of the environment and its agents (namely human operators), where one or more job places can be created and that will be supported by a collaborative robotic manipulator (COBOT).

The perception of the space must be robust to ensure safety and fast response in detection. Robustness is achieved by the number and diversity of sensors, that is, redundancy provided by the number and multiplicity of perception modalities. The decision taken at the design stage was made with the option for LiDAR sensors, visual cameras (RGB) and 3D cameras (depth).

Thus, it was necessary to create a space large enough to allow the coexistence and activity of its agents but, at the same time, being supervised by sensors for that monitoring for safety and collaboration between the operators and the COBOT. A collaborative cell was thus created, referred to in abbreviated form as LARCCell, or also by the simplified acronym LARCC, both of which will be used hereinafter.

This deliverable describes the developed structure, its equipment and sensing, as well as the electrical switchboard.

# 2 Developments

## 2.1 General mechanical structure of LARCC

The structure was built in aluminum profiles interconnected with suitable connectors, described in the following figures.

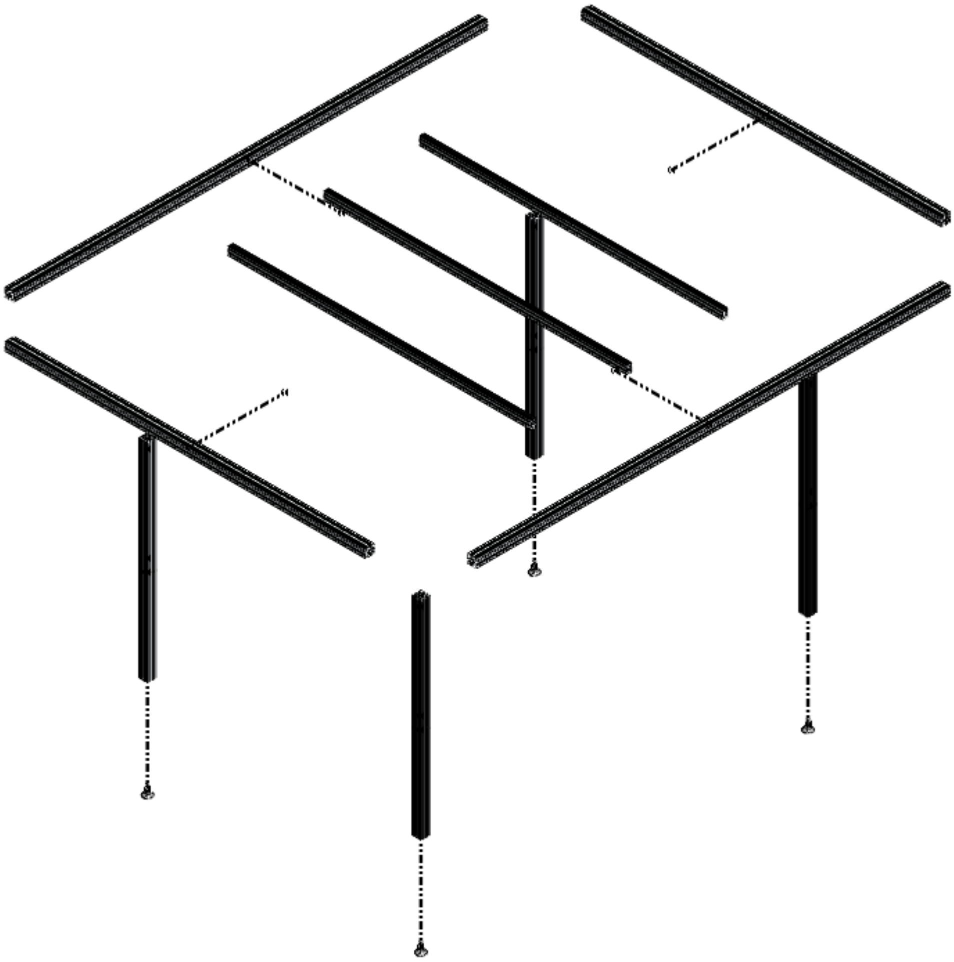

Figure 1 - Exploded view of the collaborative cell structure

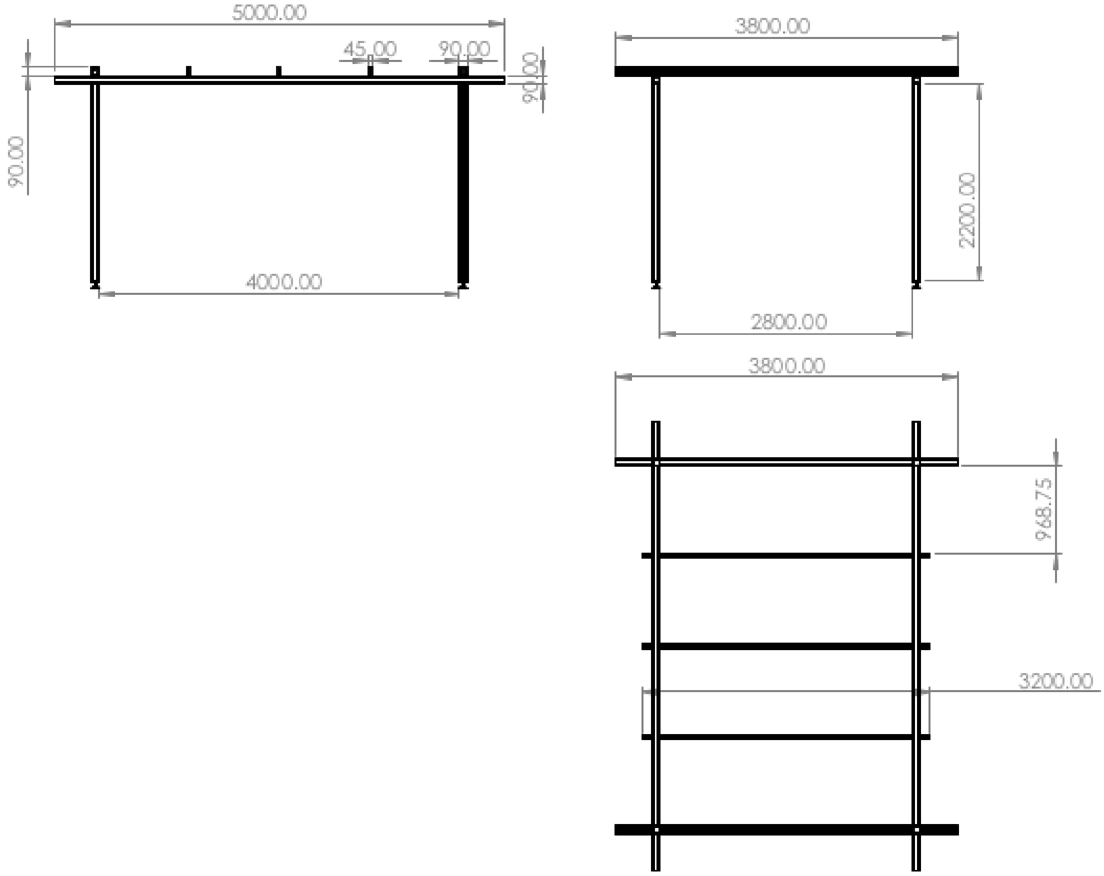


Figure 2 - Dimensions of the collaborative cell.

The mechanical solution allows for some flexibility in dimensions if it becomes necessary to adjust or rectify some spaces or positioning of components.

## 2.2 LARCC sensing and equipment

To equip the cell, sensors and a collaborative manipulator were installed, interconnected by a computer that will allow the development of applications throughout the project.

### 2.1.1. Manipulator and its support bench

The manipulator selected to be installed at LARCCell is the UR10e (Universal Robots 10 e-Series). This option is explained by the versatility and openness of the manipulator, and also by the fact that Universal Robots brand is a solution that industrial partners of the project are familiar with.


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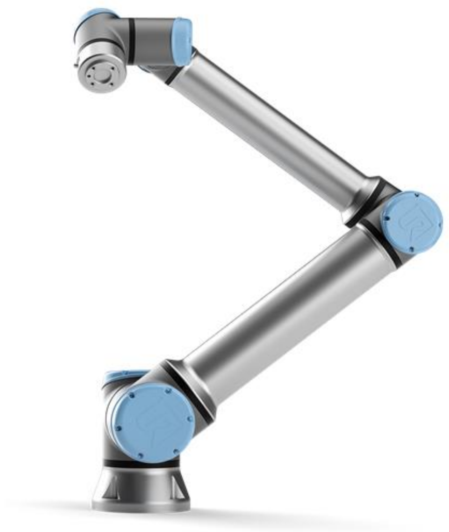

Figure 3 - Collaborative robot UR10e (Universal Robots 10 e-Series)

The UR10e consists of 6 rotating joints (base, shoulder, elbow, wrist1, wrist2 and wrist3), all with a joint range from -360° to +360° (two full turns). The maximum speed reached by some of the joints reaches 180º/s. The workspace has a reach of up to 1300mm radius around its base. The materials of this robotic arm are mainly aluminum and PP plastic, giving the manipulator a mass of 33.3 Kg and an optimal working temperature range between 0ºC and 50°C. The UR10e is a collaborative robot (cobot) and operates under 17 advanced safety functions, respecting, among which, the standards EN ISO 13849-1:2008 and EN ISO 10218-1:2011, clause 5.10.5. This manipulator is also equipped with a force torque sensor on the tool flange (tool flange - last link of the arm).

Two grippers are available to be used on the LARCCell UR10e: 2F-85 and 2F-140.


Figure 4 - Adaptive grips 2F-85 (left) and 2F-140 (right)

The name of both grippers refers to the number of fingers and distance from the TCP (tool center point): 2 finger / 140 mm - 2F-140 claw. These Robotiq grippers are suitable for the various models of Universal Robots e-Series manipulators, already containing the proper installation software to be easily recognized by the robotic arm controller and also allowing the correct use of the force sensor present. at the end of the arm.

Figure 5 - UR10e collaborative manipulator with adaptive gripper 2F-140, installed in the LARCCell

The UR10e manipulator receives instructions directly from the controller.

Figure 6 - UR10e Collaborative Handler Controller Model

The controller, with dimensions of 460x250x450 mm, has several inputs that allow communication through sources other than the console (Teach Pendant) that the controller itself carries from factory.

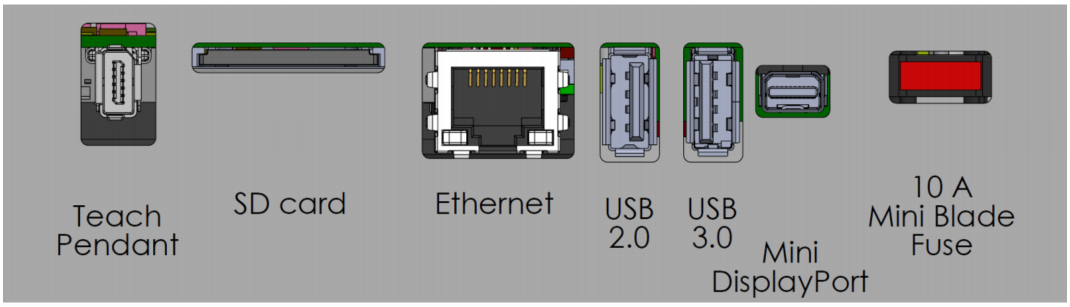


Figure 7 - Bottom of the control box, with several ports that allow additional connections.

The collaborative manipulator and its gripper were installed on a dedicated table-like support that also accommodates the controller and space for other accessories. This support was dimensioned and built with the necessary structure to ensure the possible forces and moments caused by the movement of the manipulator during its operations. At the end of each of the 4 legs of the support, adjustable anti-vibration feet were installed, reducing the risk of vibrations and other unexpected motions. In addition, a through hole was made in the center of the table top, allowing the passage of the only cable that connects the manipulator to its controller: in this way, the controller is protected in the lower part of the bench and no other cable is needed to be on the table.

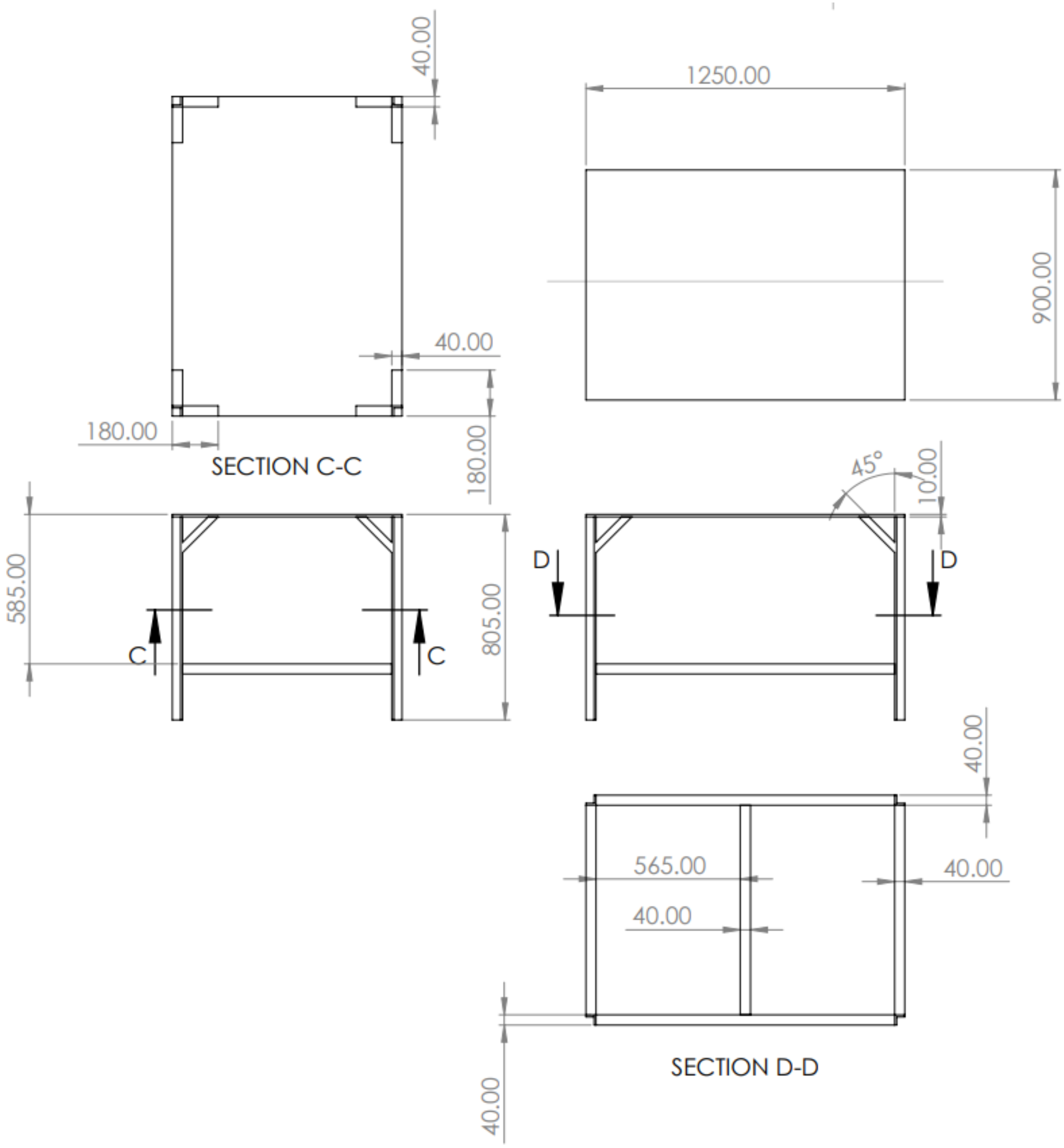


Figure 8 - Technical drawing of the manipulator bench, present at LARCCell.

Figure 9 - UR10e manipulator and 2F-140 gripper, mounted on the support in the collaborative cell.

### 2.1.2. Installed Sensors

The main sensors selected to install in the cell are shown in the following figure:


Figure 10 - Velodyne VLP16 and Orbecc Astra Pro camera.

Velodyne VLP16 are 16-channel LIDAR sensors with a 360º horizontal and 30º vertical field of view. These sensors have a low energy consumption and light weight, which allows them to be easily installed and moved. They also have a vision range of up to 80 to 100m, depending on circumstances.
Concerning the RGBD cameras, Orbecc Astra Pro cameras were selected, with a minimum field of view of 0.6m and maximum of 8m. Both the Depth (Depth) and RGB components generate data at 30fps; the RGB component has a resolution of 1280 x 720 and the Depth component has a resolution of 640x480. They are compact sensors, powered by USB and with drivers compatible with Linux OS.

To fix the sensors (cameras and LiDAR sensors) on the structure (beams and pillars), while ensuring flexible adjustment of their position and orientation, a solution based on an adjustable ball and socket was designed as described next.

Figure 11 - Mini panoramic ball head used for fixing sensors.

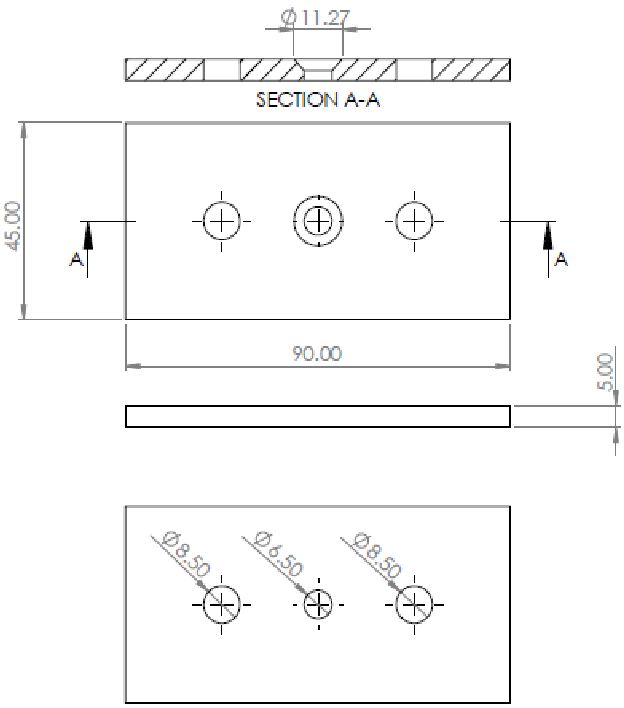


Figure 12 - Fixing plate to connect to the ball joints.

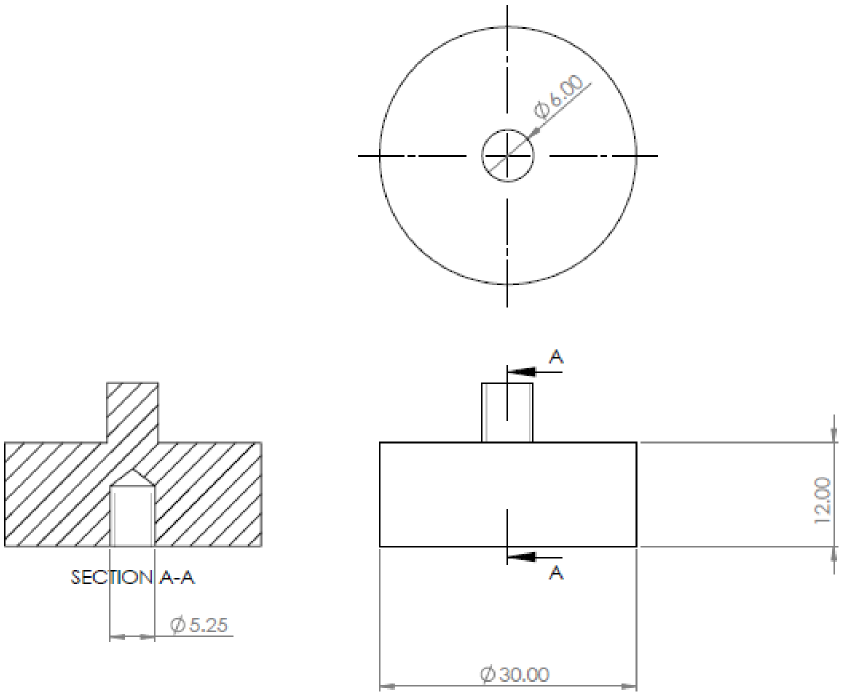


Figure 13 - Adapter for connecting the cameras to the supports.


Figure 14 - Velodyne and Orbecc Astra Pro installed in the collaborative cell

### 2.1.3. Computational unit and interconnections

To carry out all the acquisition and processing of information and the future development of algorithms, a computer and respective connections to sensors and monitors were installed. The computer installed is an HP ProLiant ML350p Gen8.

Figure 15 - LARCC Central Computer - HP ProLiant ML350p Gen8

Due to the amount of data that is expected to be captured and stored in the future, and also due to the intended speed of reading and/or writing this same data, 2 HP SSD S700 Pro 2.5'' disks of 1 TB each were purchased to install in the computer.

In order to make the most of the space, both disks were placed on the same logical drive, in the computer's RAID 0. Thus, instead of working in mirror, the disks work together, as if it were a single disk with a capacity of 2TB. In reality, the available space is 1.86TB. Ubuntu 20.04.2 LTS 64-bit (Linux) operating system with GNOME 3.36.8 GUI (graphical user interface) was installed.

In this installation, 3 partitions were created:

- " / " with 50 GB
- "swap" with 32 GB
- " /home " with the remaining space: 1.79 TB

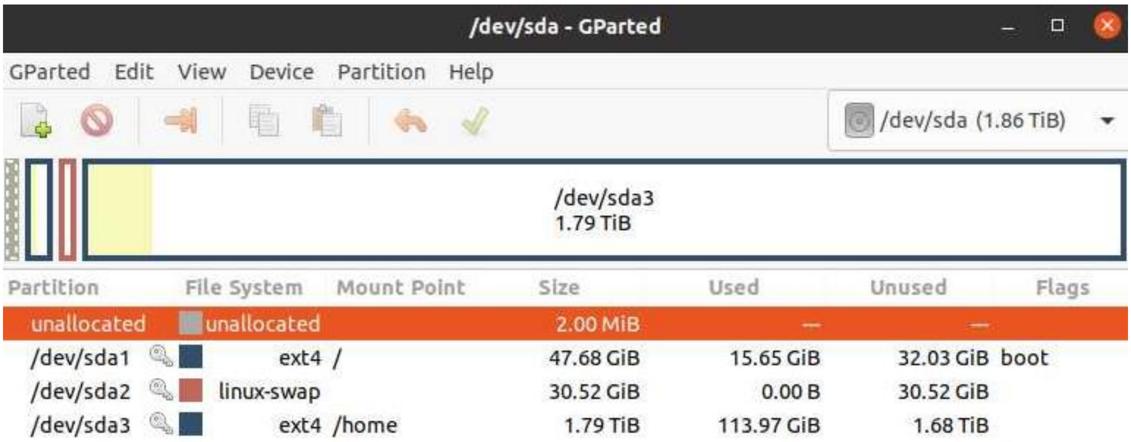


Figure 16 - LARCCell computer memory partitions

The value assigned to the swap partition was calculated to be twice the computer's RAM memory: 16 GB (actually 15.6 GB). The computer is also equipped with an Intel Xeon(R) CPU E5-2640 0 (2.50 GHz x 12) and a Radeon RX 580 Series graphics card. Due to the number of USB cameras that are intended to be connected to the computer and the large bandwidth required by each camera, PCI Express cards with additional USB ports were installed.

In addition to the computer, there is also a large monitor (55 inches) installed on an adjustable support in the structure to allow easier visualization of information from the entire cell area and even from outside it.

Figure 17 - Monitor support adjustable to the structure, mounted on LARCCell

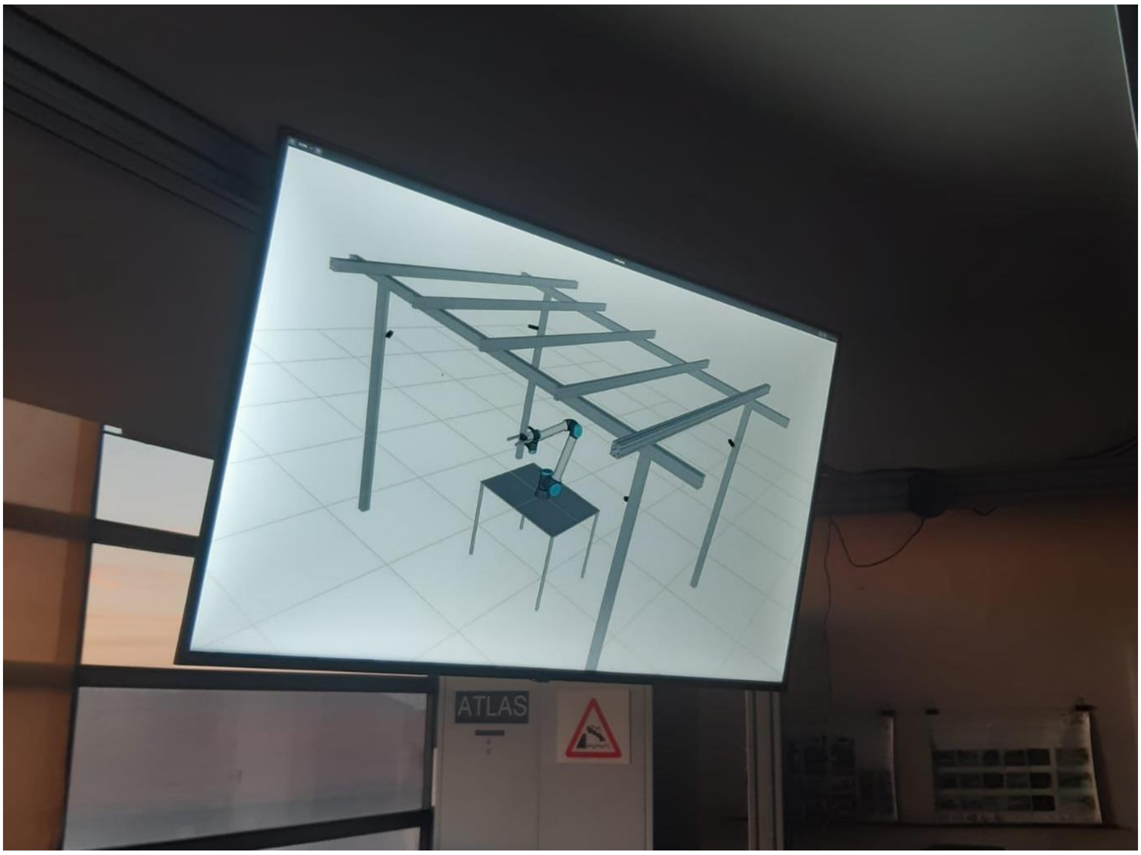


Figure 18 - Monitor mounted on the collaborative cell structure

In short, at this stage of the project, there is a computer responsible for the operation and communication of the various components of LARCCell. This computer is connected to 3 Velodyne VLP 16 sensors, 4 Orbecc Astra Pro cameras, monitor and UR10e manipulator controller. Nevertheless, the system is prepared to accommodate more sensors and components when this becomes necessary. Each device communicates with the computer through its own communication channel. Thus, there are cables of different natures responsible for interconnecting the entire collaborative cell. The following illustrates a representative scheme where the existing connections in LARCCell can be visually perceived.

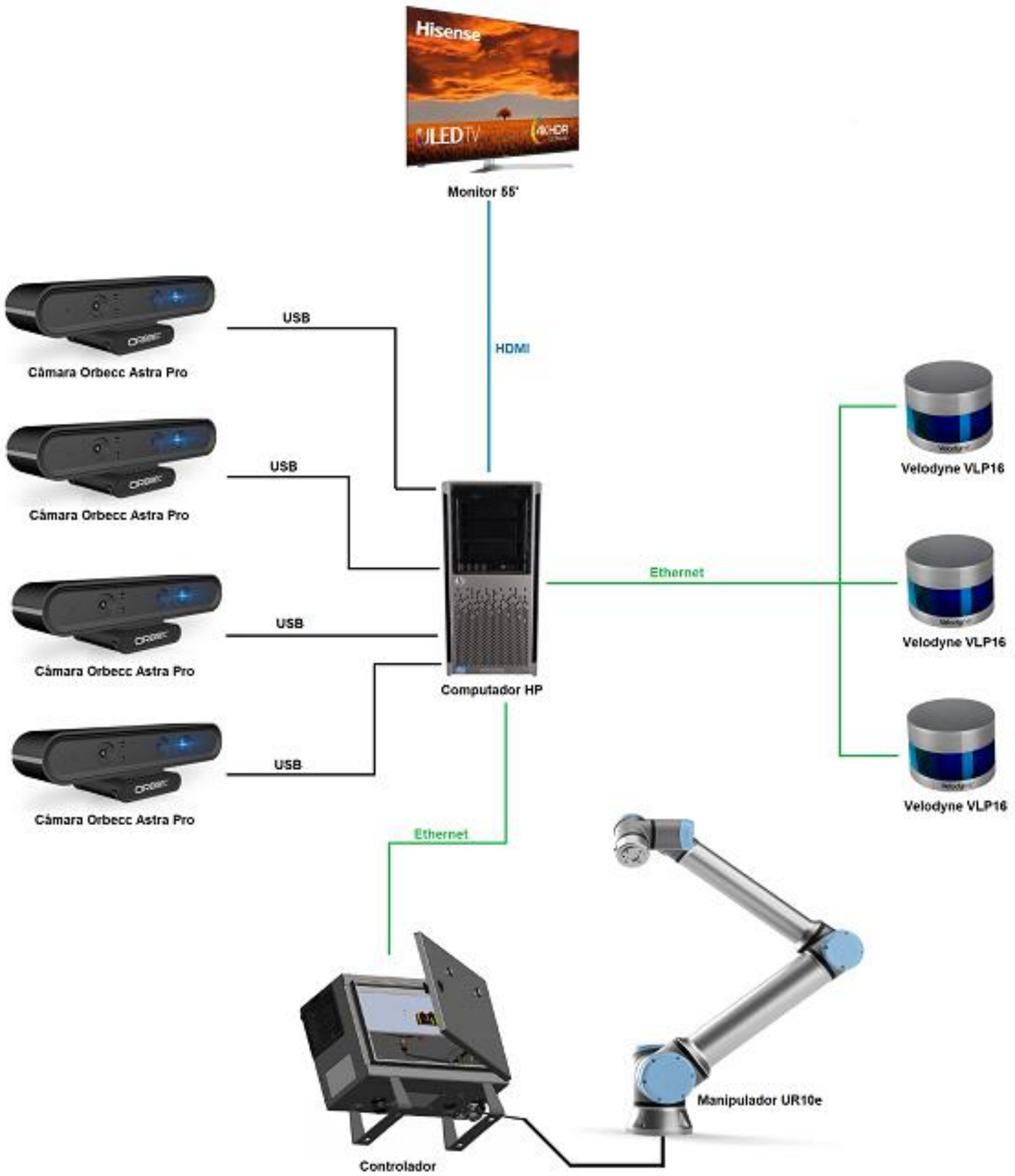


Figure 19 - Communication scheme between the computer and the other LARCCell components

### 2.1.4. LARCC complete model and assembly

The complete structure of the cell with the bench and the robot are illustrated in the following figure:

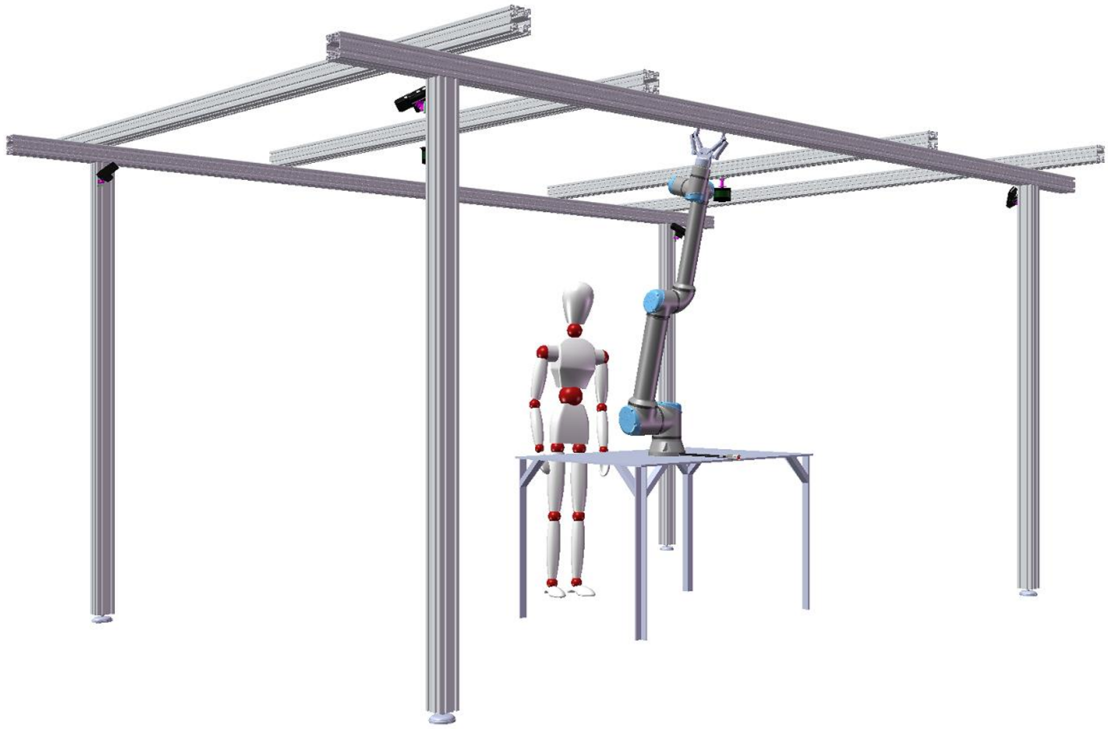

Figure 20 - Illustration of a cell model with COBOT and a humanoid figure

The assembly of the structure required some care in alignment and reinforcement of fixings, given the large spans present.

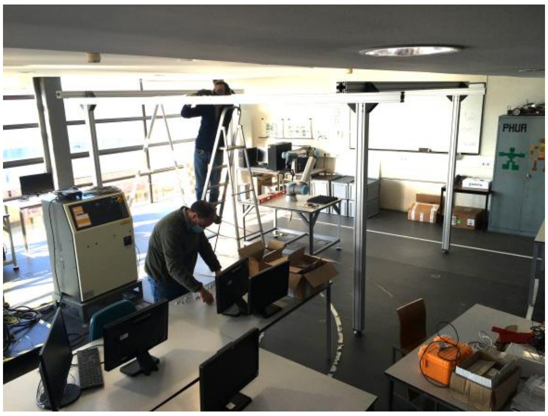

Figure 21 - Illustrations of the assembly phase of the LARCC mechanical structure


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### 2.1.5. Model planned with future expansions by LARCC

Although it was not installed in the initial phase, LARCC expansion studies were carried out to include a suspended motion system as well as a conveyor belt to enhance the range of cell capabilities and functionality possibilities. The electrical switch board or panel, described ahead, was also prepared to accommodate these functionalities.

Figure 22 - Cell model with possible future expansions

## 2.3 The Electrical Switchboard

In addition to the mechanical part, the entire computational and sensory infrastructure described above lacks adequate support for protections and distribution of electrical energy and data. Thus, an electrical panel or switchboard that includes, among others, power supplies, circuit breakers and suitable cut-off and protection systems, etc., was designed. All the elements present in the electrical panel can be categorized by power supplies, connectivity, security, cabling and encapsulation. Each of these categories will be detailed next.

### 2.1.6. Power Supplies

The electrical panel has external power sockets (outlets) with a cover, to power the server, the monitor and the robotic manipulator controller.

Figure 23 – Example of electrical outlet to power external components

Power supplies of 12 V and 24 V were installed to provide some DC low voltage components. These sources are intended for the drivers of active systems in the cell controlled by motors, such as conveyor belts and similar.

The 24V/5A source will power several LARCCell components such as the switch used to connect the various Ethernet cables to the server, motor sensors, emergency buttons, beacon, among others.

The 12V / 10A power supply will be used to power two USB Hubs and the Velodyne detectors. The following figure illustrates the several powers supplies involved.

Figure 24- Power supplies; 12V/10A, 24V/5A and 24V/20A.

### 2.1.7. Connectivity

The cell has two USB 3.0 Hubs to connect Astra Pro cameras and USB sensors to the server. The two Hubs have 7 ports each and are located above the cell's top rails.

There is also an Ethernet switch with the main function of connecting the Ethernet-based sensors to the server.

Figure 25 - USB 3.0 Hub and Ethernet Switch.

#### 2.1.8. Safety

Five emergency buttons are connected to the electrical panel, mounted in series, which are activated in the absence of 24V at the respective input, that is, they are normally closed. These five emergency buttons will serve to activate the robot emergency along with other mobile systems to be installed in the cell. Four are placed in the corners of the cell and another will have the flexibility to be placed where pertinent depending on the context or the running processes.

There is also a light signal (beacon) to remain active while there is movement by the manipulator or the motors inside the cell. That way, it will be possible to visually notify operators about the state of movement of specific components in the cell.

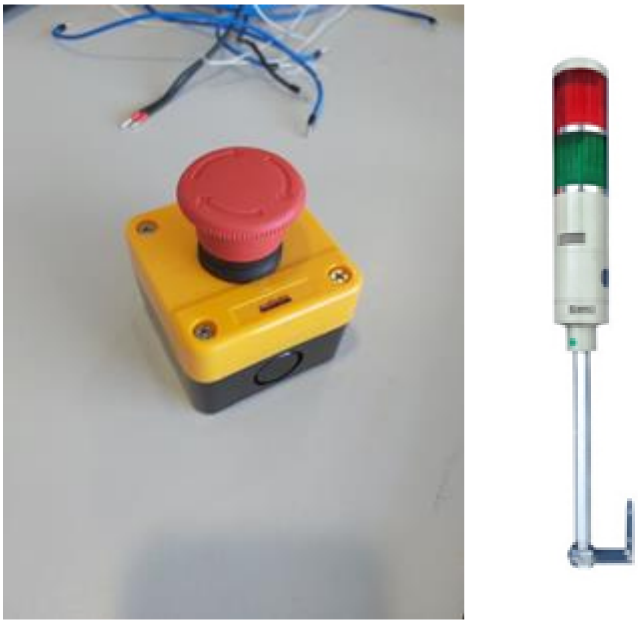

Figure 26 - Emergency button and signaling beacon

In addition to these systems, a pedal was also added to the system to allow the use of the UR10e collaborative robot's manual release command (free-drive) without the need to use the manufacturing console.

Figure 27 - Pedal interface to operate the manipulator's "free-drive"

In terms of circuit safety, in cases of overload or short circuit, 7 circuit breakers with one more neutral pole (1P + N) are used to protect power outlets and power supplies.

Figure 28 - 1P+N Circuit Breaker

Three distinct values of cutting current were established for the circuit breakers:

- 2A for the TV socket (0.56A maximum, ie a 1A circuit breaker would be ideal)
- 6A for the computer (3.5 A maximum)
- 10A for the manipulator socket (8A maximum)

The values result from the fact that breakers should have a cut-off current value about 1.25 times the rated current. Using this same method for source circuit breakers, the following currents are obtained for the remainder breakers:

- 6A for 24V and 20A power supply (maximum 5.3A input)
- 2A for 24V and 5A power supply (maximum 2.6A input)
- 2A for 12V and 10A power supply (maximum 1.3A input)

All components that need power in the circuit were also protected by fuses. To calculate them, the nominal current was again multiplied by 1.25 and fuses with approximate cutoff values were chosen. Proceeding in this way for all material supply branches we have the following fuses:

- 25A for motor power supply
- 0.63A for switch power
- 3.15A for supplying the sensors, together with the emergency buttons, the beacon and the pedal
- 0.63A for motor break power supply
- 0.63A for controller power
- 3A for powering each of the USB Hubs
- 1A for powering each Velodyne detector

For one of the mentioned fuses, more specifically the one of 25A, it was necessary to choose a fuse holder due to the higher current and dimension (10x38 mm):


Figure 29 - Fuse and respective fuse holder

Two types of switches were incorporated into the project: differential switches and disconnect switches.

In addition to circuit breakers and fuses, a differential switch is also required in this project. The chosen switch protects against leakage currents greater than 30 mA (to protect users) and is type A, that is, it protects not only taking into account the AC current but also against DC current spikes. The sum of the maximum current of the components connected to the sockets and the input currents of the sources results in $3.5A + 8A + 0.56A + 5.3A + 2.6A + 1.3A$ = 21.26A.

Therefore, it was decided to use a circuit breaker with a breaking current of 24A.

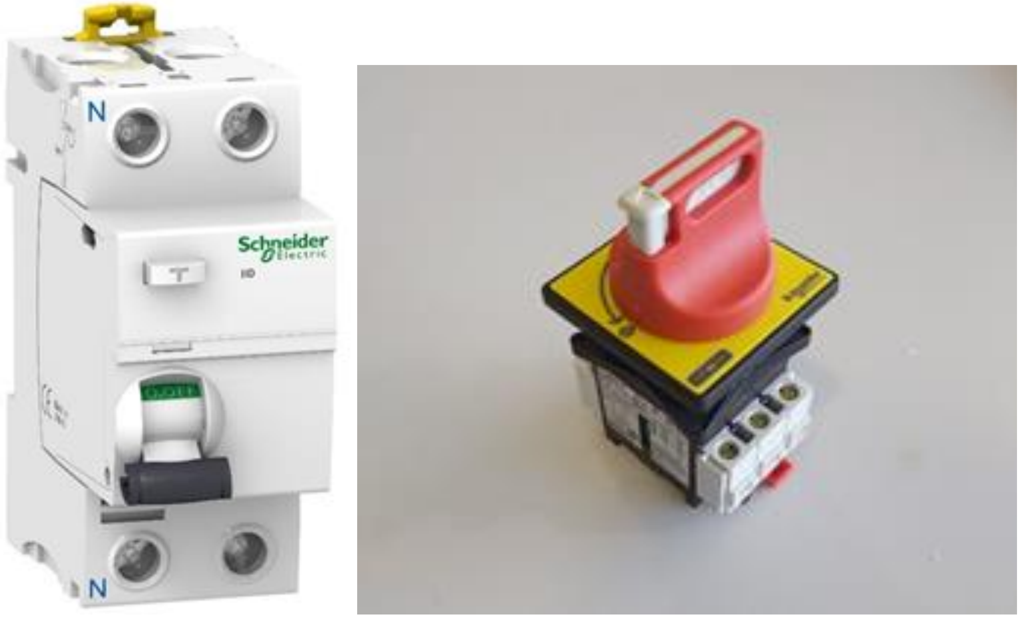


Figure 30 - Differential switch and cut-off switch

Even before the differential switch, a cut-off switch, also rated for 24A, was introduced.

### 2.1.9. Cable guides

The wiring along the cell (supply and data) are stored in a technical guides or channels.

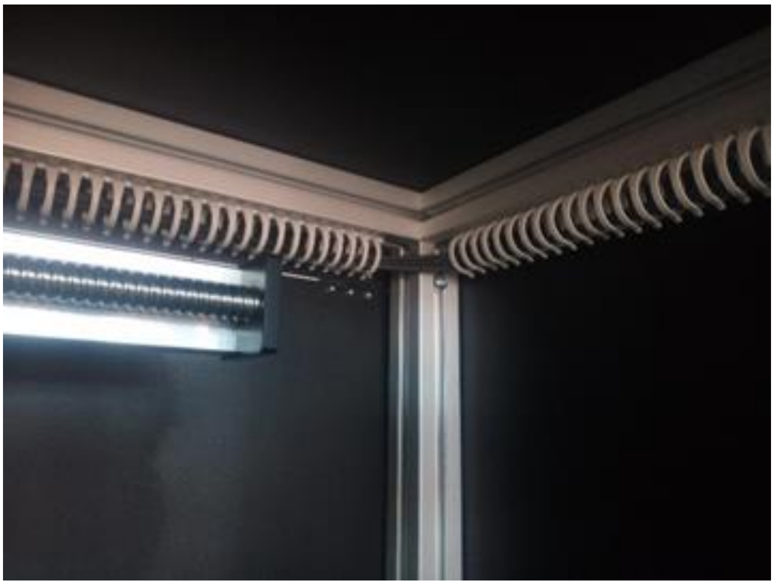

Figure 31 - Technical guides or channels to hold cablings

The cabling procedures involve the cables themselves, cable glands, labels and terminals. In most cases, wires with a section of 2.5 $mm^2$ are used. At the output of the 24V and 20A source the section of the conductors was increased to 4 $mm^2$.

### 2.1.10. Encapsulation boxes

Velodyne detectors have their own connection box with inputs for power and Ethernet cable. They are of reduced volume, but it would be a waste of space if they were placed inside the electrical panel. For this reason, it was thought to place them in the structure in a plastic box with a slightly larger volume, in order to be able to reduce the visual impact of these materials in the structure; the other advantage is the possibility to store the excess of cables, if it is required. This package has dimensions of 240x190x160 mm.


Figure 32 - Connection box of a Velodyne detector and the respective encapsulation box

The enclosure of the switchboard itself was oversized to accommodate future developments of the cell and its components, having dimensions of 800 x 600 mm.

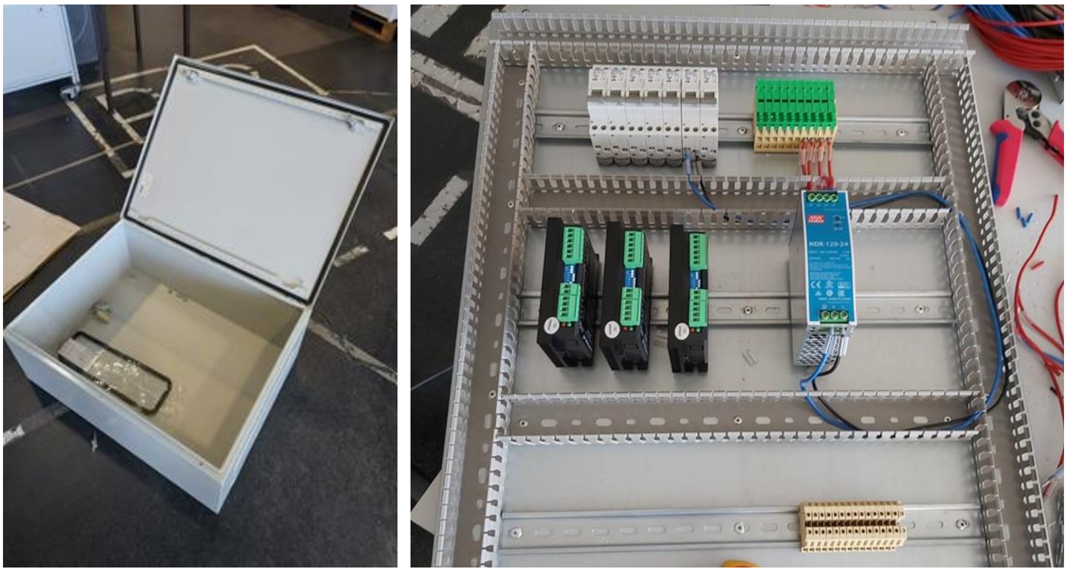

Figure 33 – Box for the electrical panel and intermediate stage of its assembly

All these elements were designed and installed following the usual regulations to ensure the protection and safety of people and equipment. Attached are the implemented circuit diagrams.

# 3 Conclusions

The developed cell allows great flexibility to study the perception and actions of collaborative robotics, and thus be able to explore a wide variety of collaborative processes that were sought to be sufficient to test a many processes in a collaborative robotics environment and associated procedures.

Although it was not foreseen in the initial project, during the design phase of the cell, and also due to the prior availability of some components in the laboratories of the University of Aveiro, the cell was left prepared for possible future extensions, such as the insertion of a conveyor belt to allow emulating certain types of workstations, as well as other testing facilities, mainly oriented towards the investigation and development of robustness systems in the coexistence of human operators with the manipulator.

The developed cell is an original solution and is essential in the subsequent developments of the project.

The presented solution is very general because it intends to serve the study of a wide variety of situations; hence, it is not expected that it will be necessary to replicate it in the infrastructures of the industrial partners. For these cases, it is expected that only a few parts can be useful in each case, namely the number of sensors that in the developed solution is relatively large, but that should be limited depending on the requirements of the processes of the different partners.