UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería electrónica industrial y automática

DESIGN OF THE MOBILE ROBOT “SHERPA” PARKING/LOADING STATION

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TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: DESIGN OF THE MOBILE ROBOT “SHERPA” PARKING/LOADING STATION

ALUMNO: Pablo Martín García

FECHA: 3/06/2025

CENTRO: Faculty of mechanics

UNIVERSIDAD: Vilnius Tech

TUTOR: Andrius Dzedzickis

Resumen en español:

La estación de carga desarrollada en este proyecto es una estación de acoplamiento para el robot móvil autónomo Sherpa-b (AMR), pensada para almacenes inteligentes. Permite al robot realizar tareas de carga automática. La estructura combina componentes mecánicos y electrónicos. Está construida con un perfil robusto de acero S235JR y cuenta con protecciones de goma en zonas clave. Los elementos electrónicos se alojan en una caja de ABS. La estación incorpora un sistema de medición de peso con cuatro celdas de carga, el peso se muestra en una pantalla, y un sistema de medición de distancia mediante sensor ToF que activa luces de advertencia según la cercanía. Esta tesis presenta una solución práctica y económica para integrar estaciones de carga de AMR en la logística industrial, mejorando la automatización sin comprometer la seguridad.

Palabras clave: Robot móvil autónomo, estación de acoplamiento, Sherpa-B, automatización industrial, estación de carga.

Abstract:

The loading station developed in this project is a docking point for the Sherpa-b Autonomous Mobile Robot (AMR), designed for use in smart warehouse environments. It enables the robot to perform automatic loading tasks efficiently. The structure combines mechanical and electronic components. It is built from a robust S235JR steel profile with rubber protection in key areas. The electronic elements are housed in an ABS enclosure.The station includes a weight measurement system using four load cells, with the value displayed on a screen, and a distance measurement system based on a ToF sensor. Depending on the measured distance, warning lights of different colors are activated. This thesis presents a practical and cost-effective solution for integrating AMR docking stations into industrial logistics, improving automation while maintaining safety standards.

Keywords: Autonomous Mobile Robot, docking station, Serpha-B, industrial automation, loading station.

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

Pablo Martín García

DESIGN OF THE MOBILE ROBOT "SHERPA" PARKING/LOADING STATION

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,

Code 612H73002

Vilnius, 2025

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

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Head of Department

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2025/05/22

(Date)

Pablo Martín García

DESIGN OF THE MOBILE ROBOT "SHERPA" PARKING/LOADING STATION

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,

Code 612H73002

Supervisor: Dr.Andrius Dzedzickis ________ 22/05/2025
(Title, Name, Surname) (Signature) (Date)

Vilnius, 2025

DECLARATION OF AUTHORSHIP IN THE FINAL BACHELOR'S PROJECT

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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Mechanics Faculty

(Faculty)

Mechatronics and Robotics

(Study programme, academic group no.)

DECLARATION OF AUTHORSHIP IN THE COURSE PROJECT

22/05/2025

(Date)

I declare that my Course Project entitled DESIGN OF THE MOBILE ROBOT "SHERPA" PARKING/LOADING STATION is entirely my own work. I have clearly signalled the presence of quoted or paraphrased material and referenced all sources.

I have acknowledged appropriately any assistance I have received by the following professionals/advisers: Andrius Dzedzickis

The academic supervisor of my Course Project is Andrius Dzedzickis

No contribution of any other person was obtained, nor did I buy my Course Project.

PABLO MARTÍN

(Signature) (Given name, family name)

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
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TASK FOR BACHELOR THESIS

14 March 2025 No. PMG01
Vilnius

For student Pablo Martin Garcia

Bachelor Thesis title: Design of the mobile robot "Sherpa" parking/loading station

The Final work has to be completed by 22 May, 2025.

TASK FOR FINAL THESIS:

Initial data:

The aim of the task is to develop a parking/loading station for the Sherpa B mobile robot. This station should serve as a connection point between mobile and stationary robots; it should be equipped with corresponding sensors and signalization units.

Explanatory part:
1. Introduction. Analysis of analogical devices. Substantiation of the taken technical decision.
2. Overview of specific nodes. Decision on component type best suited for application.
3. Calculations needed for the design process.
4. Description of the construction and operational principle. Kinematical and electrical block schemes, and an algorithm.
5. General requirements for safe working and environmental protection and for the development of the device.
6. Evaluation of economic indicators of the designed or upgraded device.
7. Final conclusions and recommendations.
8. Literature reference list.

Drawings:
1. General drawing of the device (1 sheet A1);
2. Assembly drawing of the device (node) (1 sheet A1);
3. Robot workspace scheme (0.25 sheet A1);
4. An operating algorithm (0.5 sheet A1);
5. The structural scheme of the device (0.25 sheet A1);
6. The work drawing of the 2 chosen parts (2×0.25 sheet A1);
7. Economic indicators (0.5 sheet A1).

Supervisor .... Doc. dr. Andrius Dzedzickis
(Signature) (Academic Title, Name, Surname)

Task accepted

(Student‘s signature)
Pablo Martín García
(Student‘s Name, Surname)
2025-03-14
(Date)

Vilnius Gediminas Technical University
Electronics Faculty
Electrical Engineering Department

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Electric power engineering/Automatics study program bachelor thesis

Title: **Design of the mobile robot "Sherpa" parking/loading station**

Author **Pablo Martín** Academic supervisor **doc. dr Vardenis Pavardenis**

Thesis language

X	Lithuanian
	Foreign (English)

Anotacija

Įkrovimo stotis, sukurta šiame projekte, yra dokavimo stotis, skirta autonominiam mobiliajam robotui „Sherpa-b“ (AMR). Ši stotis skirta naudoti kaip dokavimo taškas išmaniųjų sandėlių aplinkoje, leidžianti robotui automatiškai atlikti krovimo operacijas. Sukurta struktūra integruoja mechaninius ir elektroninius komponentus. Struktūra susideda iš tvirtos S235JR profilio konstrukcijos, tam tikrose vietose padengtos guminėmis apsaugomis. Elektroniniai elementai įrengti ABS dėžėje. Įkrovimo stotis suprojektuota su svorio matavimo sistema (svorį matuoja 4 jėgos davikliai, rodoma ekrane) ir atstumo matavimo sistema (atsižvelgiant į ToF jutiklio matuotą atstumą, įsijungia tam tikros įspėjamosios lemputės spalvos).

Šis baigiamasis darbas parodo praktišką ir ekonomišką sprendimą, kaip integruoti AMR įkrovimo stotį pramoninėje logistikoje, padidinant automatizavimo efektyvumą ir išlaikant saugos standartus.

Struktūra: analoginių konstrukcijų apžvalga, specifinių mazgų apžvalga, konstrukcijos skaičiavimai, konstrukcijos ir veikimo principų aprašymas, darbo sauga, ekonominiai rodikliai, išvados ir literatūra.

Raktažodžiai: Autonominis mobilusis robotas, dokavimo stotis, Serpha-B, pramoninė automatizacija, krovimo stotis, svorio matavimas, atstumo matavimas.

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☐ Lithuanian

☒ Foreign (English)

Annotation

The loading station designed in this project is a docking station designed for the Sherpa-b Autonomous Mobile Robot (AMR). This station is intended to be use as a docking point in a smart warehouse environment, allowing the robot to do automatic loading operations.

The designed structure integrates mechanical and electronic components. The structure consists of a robust S235JR profile covered with rubber protections in specific areas. The electronic elements are incorporated in an ABS box. The loading station has been designed with a weight measurement system (The weight measured by 4 load cells is shown in a display) and a distance measurement system (Depending on the distance measured by the ToF sensor specific warning lights colors will turn on).

This thesis demonstrates a practical and cost-effective solution for integrating an AMR loading station in industrial logistics, enhancing automation efficiency while maintaining safety standards.

Structure: overview of analogic constructions, overview of specific nodes, calculations for design, description of the construction and operational principles, work safety, economic indicators, conclusions and references

Keywords: Autonomous Mobile Robot, docking station, Serpha-B, industrial automation, loading station, weight measurement, distance measurement.

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INTRODUCTION

Nowadays, industrial automation has evolved significantly thanks to the development of Autonomous Mobile Robots (AMRs). These kinds of robots are able to move autonomously without needing human intervention, what makes them useful in production settings. In work environments with AMR robots, docking stations are used as infrastructures that provide a precise reference zone where the AMR can position itself accurately.

Docking Stations normally incorporate advanced detection systems, such as sensors, RFID readers, or machine vision cameras, which ensure that the AMR is correctly positioned in the designated area. Their design facilitates the integration with other automated systems, for example conveyors and smart shelves, facilitating loading and unloading of materials without needing human intervention.

These stations are designed to ensure controlled and reliable interactions between the robot and the handled objects, minimizing operational risks and reducing errors in the process. The implementation of these infrastructures in industrial environments has proven to be useful for the optimization of logistics processes, allowing greater operational autonomy for AMRs and improving efficiency in areas such as production lines, assembly systems and high-precision logistics operations.

In this context, this work focuses on the development of a loading station for the Sherpa-B AMR within a smart warehouse. In this case, the robot will move to the docking station, and once it’s detected that the robot is correctly positioned, it will automatically receive the load before transporting it to the next phase of the production process.

The Sherpa-B is an autonomous mobile robot developed by *Sherpa Mobile Robotics*. This robot is equipped with advanced sensors, autonomous navigation and localization capabilities using LiDAR technology. Its design allows it to interact efficiently with automated transportation systems and perform autonomously loading and unloading missions. Thanks to its integration with FleetManager and other software tools, the Sherpa-B can optimize routes, avoid obstacles, and communicate with other devices.

The main objective of this project is to develop a functional design of a Docking Station, which will serve as a loading station that could be integrated into an automation system, ensuring that the Docking Station meets the necessary standards for its proper implementation in the specified logistics environment.

1 OWERVIEW OF ANALOGIC CONSTRUCTIONS

1.1 Design of a docking station using QR codes

One design option for the automatic docking system could involve using QR codes. By employing this methodology, the AMR would be able to locate the station through visual recognition of a QR code and adjust itself to the optimal predefined position. This solution can be integrated into industrial and logistics environments to optimize processes.

The main components of this type of docking station, ensuring a safe and efficient robot docking process, would include a base platform, side guides and a QR marker. The base platform is a flat and stable surface where the robot docks, minimizing possible alignment errors and providing a visual reference point. The side guides are structures used to align the robot in the correct position, reducing the need of corrections. Finally, the QR marker must be positioned optimally in order to be detected by the robot camera, allowing it to efficiently identify its location.

The robot docking process in the docking station can be divided into several steps:

1º The robot is equipped with an RGB camera that helps it to spot the QR code at the loading station. These cameras work by capturing light in the visible spectrum, which means they see the same wavelengths as the human eye and can recognize the same colors. RGB stands for Red, Green, and Blue, and by mixing these three primary colors it is possible to create any color.

The process of detecting the QR starts with the RGB camera taking real-time images, carefully positioned to focus on the area where the QR code should be. To enhance detection, the images are prepped with some preprocessing steps, like applying filters to cut down on noise and using edge detection algorithms, such as the Canny Edge Detector, to bring out the important parts of the image.
(https://learningdata.hubiberiaagrotech.eu/camaras-rgb/)

2º The robot employs a specialized QR code detection library to locate the code within the image. This process is based on identification of geometric patterns characteristics of a QR, such as its three alignment marks in the corners. (https://softmatic.com/qr-quick-response-es.html)

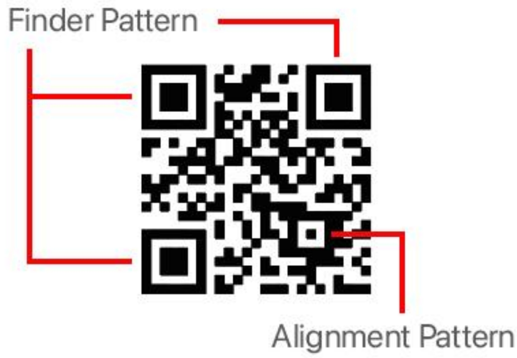

Fig. 1.1 Description of the significant parts of a QR code, the three Finder Patterns and the Alignment Pattern (https://softmatic.com/qr-quick-response-es.html)

These structures are compared with predefined models to confirm their authenticity. Then, the geometric features are extracted, and the aspect ratio and symmetry of the code are verified to avoid false positives. In case the QR code is tilted or distorted, a homography transformation is applied to correct the perspective, obtaining a clearer image of the code. (https://en.wikipedia.org/wiki/Homography_(geometry))

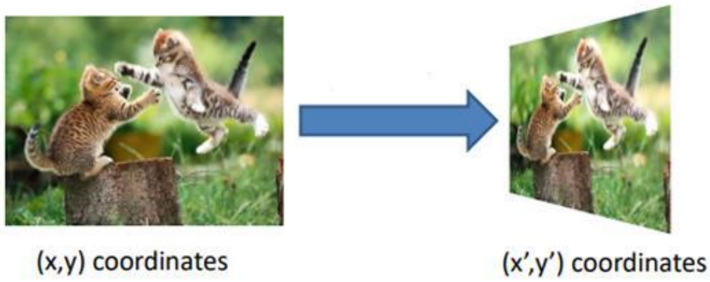

Fig. 1.2 Application of homography to the points in the left image, resulting in the corresponding points in the right image.
(E. Ramírez. 2021)

3º Once the QR code has been located and corrected, it is decoded using specialized functions from the library that is using, allowing the extraction of the information contained in the QR code. Based on this data, the robot adjusts its orientation and translation according to the relative position of the QR code, using control algorithms such as PID Controllers to perform smooth and precise movements.

4º The robot interprets the decoded information and makes decisions about its movement. If the QR code provides positioning data, the robot calculates the optimal trajectory to dock precisely at the docking station. For this, it can use route planning and obstacle detection algorithms to optimize its navigation.

5º The robot adjusts its orientation and starts moving toward the docking station in two phases: an approach phase, in which the robot moves closer to the docking area while ensuring the QR code is inside its field of view, and a final alignment and docking phase, where it makes small adjustments to position itself accurately at the station.

6º In this final stage, the system verifies that the robot is correctly positioned, allowing the loading process to begin.

The positive aspects of this solution include the fact that using QR codes and homography ensures precise localization of the docking station, reducing dependence on more expensive sensors.

However, it has some negative aspects. The system needs good lighting and clear visibility of the QR code, this can be problematic in low-light environments or if there are any obstructions.

KMP 1500P (KUKA)

There are docking stations on the market that utilize QR codes for precise and efficient docking. KUKA KMP 1500P platform is an autonomous mobile robot that employs this QR code method, designed for flexible automation in industrial settings. (https://www.kuka.com/es-mx/productos-servicios/amr-robotica-movil-autonoma/plataformas-m%C3%B3viles/kmp-1500p-diffdrive)

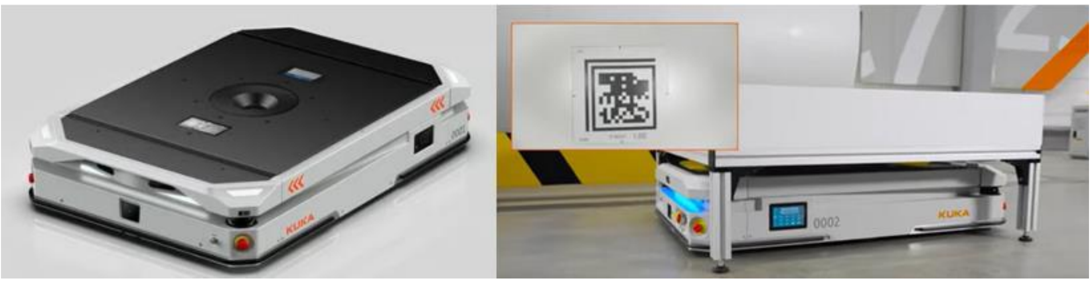

Fig. 1.3 The left image shows a KMP 1500P. In the right image we can observe how the KMP 1500P is positions using the QR code in the bottom of the loading station (https://www.kuka.com/es-mx/productos-servicios/amr-robotica-movil-autonoma/plataformas-m%C3%B3viles/kmp-1500p-diffdrive)

This platform relies on SLAM (Simultaneous Localization and Mapping), a technique that allows a robot or autonomous vehicle to navigate through an unfamiliar environment using just its onboard sensors, all while creating a map of its surroundings to help it figure out where it is.

On top of that, this device comes with a downward-facing camera designed to read QR codes, achieving a positioning accuracy of ±5 mm. Plus, it is also equipped with laser scanners and 3D cameras for detecting obstacles, ensuring autonomous and secure docking at its loading station.

C-MATIC (LINDE MATERIAL HANDLING)

Another example of an AMR that uses this methodology is the Linde C-MATIC.

Fig. 1.4 C-MATIC (https://www.linde-mh.com/en/Products/Automated-Trucks/C-MATIC/)

This AMR relies on QR code-based localization, where codes are placed in key locations to act as reference points, allowing the AMR to identify its position. By constantly scanning and interpreting these QR codes, the system guarantees smooth navigation and accurate docking at its loading station.

Additionally, the C-MATIC comes with advanced sensor technology, including systems for detecting obstacles.

1.2 Multi-Stage Location-Based solution for AMR docking stations

A possible design of docking stations for AMRs is the one presented in *A multi-stage localization framework for accurate and precise docking of autonomous mobile robots (AMRs)* article, written by Abdurrahman Yilmaz and Hakan Temeltas, and published in 2024.

The solution offered in the article is based on a multi-stage localization framework that uses particle filter-based localization during the delivery phase and scan-matching-based methods during the docking phase. The proposal is structured in two principal phases: The delivery phase, which uses a large-scale localization, and the docking phase, which is based on a precise localization method. The transition between phases is managed through a mechanism of probabilistic decision that is constantly evaluating the similarity of the points captured by the AMR sensors.

During the delivery phase, the system uses the SA-MCL algorithm for doing continuous estimations of the AMR position in big trajectories. The SA-MCL algorithm is based on the generation of random samples to simulate a situation, allowing the evaluation of multiple scenarios and their associated risks.

When the distance from the AMR to the docking station is shorter, the docking phase starts. In this phase, precise scan-matching-based methods are used to align the Amr with the reference points of the docking station.

These methods rely on comparing the points measured by the laser sensor incorporated in the robot with a reference map previously designed, allowing the AMR to detect unexpected obstacles.

The key part of this system is creating a mechanism able to establish the optimum moment for changing from one phase to another, securing that the AMR gets to the docking station with the required precision. Establishing the change of phase in a specific point can cause problems due to measurement errors and physical limitations of the robot. Instead, a change region with hysteresis is established, securing a soft and stable transition.

For improving the reliability of the commutation-phase decision the article suggests an approach based on correntropy. This method combines correlation and entropy concepts to calculate more robustly the similarity between the data obtained by the AMR and the reference model of the docking station. This improvement allows decisions on when to switch between both phases to be more accurate and reliable. (https://www.cambridge.org/core/journals/robotica/article/multistage-localization-framework-for-accurate-and-precise-docking-of-autonomous-mobile-robots-amrs/7C4B7AB733A729E538F50B9CCDBAC3F3)

To validate the performance of the multi-stage localization framework experimental tests were done using an ITU-AGV type AMR, equipped with:

1. LiDAR sensors: These sensors emit laser light pulses into the environment, which bounce off in surrounding objects and go back to the sensor. The speed of laser light is constant, so the sensor measures the time it took to each pulse to return and calculates the distance traveled by the laser light pulse. This process is repeated all over the area using millions of light pulses, collecting the measurements of the individual points obtained and processing that information into a point cloud.(https://www.neonscience.org/resources/learning-hub/tutorials/lidarbasics)

Fig. 1.5 Example of a point cloud done with LiDAR sensors
(https://store.clearpathrobotics.com/blogs/blog/how-to-choose-a-lidar)

2. IMU (Inertial Measurement Unit): This electronic device measures and informs about a body specific force, angular velocity, and sometimes about the magnetic field surrounding. This is achieved by using a combination of accelerometers, gyroscopes, and occasionally magnetometers. (https://www.sbg-systems.com/es/glossary/inertial-measurement-unit-imu-sensor/)

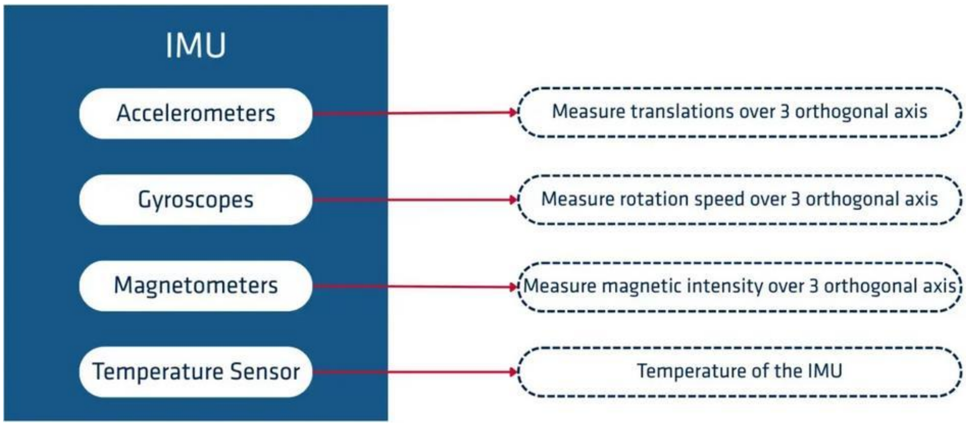

Fig. 1.7 IMU components and for what are used (https://www.sbg-systems.com/es/glossary/inertial-measurement-unit-imu-sensor/)

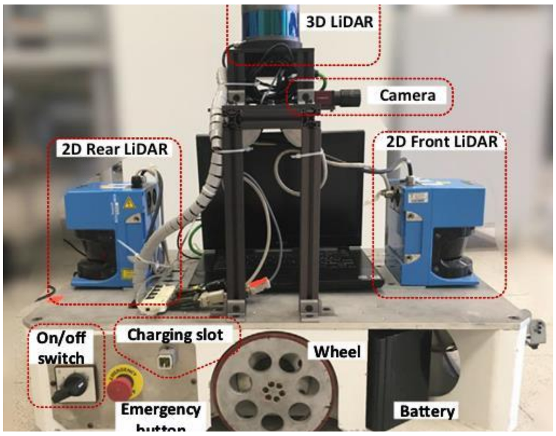

Fig. 1.6 AMR robot used in the article tests (ITU-AGV) (A.Yilmaz et al. 2024)

The test environment was based on a map designed using SLAM (Simultaneous Localization and Mapping). Three different scenarios were used in order to evaluate the systems precision and stability.

The test results validated the commutation mechanism based on correntropy effectiveness. Besides that, it was proved that this method optimizes computational efficiency in comparison with other traditional methods.

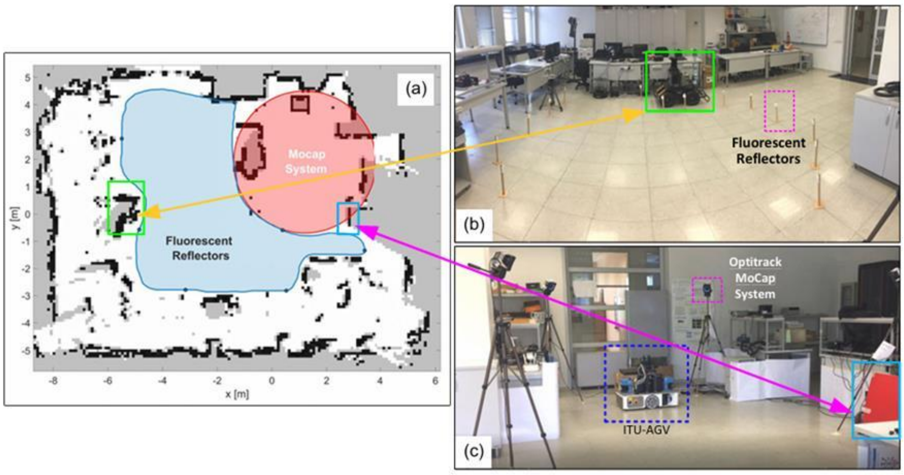

Fig. 1.8 The field test environment: (a) The occupancy grid map of the environment, the real scene from (b) the delivery, and (c) Docking zones of the lab.

(A.Yilmaz et al. 2024)

There are no references of docking stations and AMR robots that use this exact methos, so I assume that this technology is still being investigated.

1.3 Visible Light Positioning and SLAM Fusion solution for AMR docking stations

Another possible design of docking stations for AMR robots can be based in *Robot Localization and Navigation using Visible Light Positioning and SLAM Fusion* article.

This solution is based on combining the information obtained from Visible Light Positioning (VLP) and simultaneous localization and mapping (SLAM). In this methodology, each of the sensors processes and calculates its position and orientation independently, after that they mix the data obtained in a global estimation.

The technology used is:

- VLP: This method is based on using Rolling Shutter cameras (RSE-camera), which capture luminous patterns emitted by LEDs which are ubicated in specific and strategic positions, for example in the loading station. LEDs transmit information by modulating their light intensity at a high frequency and send a unique identification (LED-ID). This isn't visible to human eyes, but the Rolling Shutter Camera perceives these luminous signs and obtains information about the AMR global position in the previously defined map (This predefined map is done with the LEDs ubication).

- SLAM: A lidar sensor is used for exploring and constructing a map of the environment. This map determines through which areas the AMR can navigate and where the obstacles are located. In addition, SLAM uses the information obtained by the LIDAR sensors to localize the AMR position in the environment. (https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-77432013000200010)
- Odometry: This method uses motion sensors to identify the relative movement of the robot.

Firstly, the region of interest (ROI) is identified using the RSE camera. The RSE camera captures patterns like barcodes that are generated by the LEDs modulating their light intensity at a high frequency. In these conditions the natural features are not observable, instead, bright objects can be easily observed. To identify the ROI, the captured image is converted into a grayscale and binarized and then dilate the binary image to fill the strip gaps. After that, the LED-ROI is captured in the image by using the match template method (is a technique in image processing used to find portions of an input image that matches a reference or smaller image). After the ROI is detected, the pixels surrounding this are verified in order to secure the precision of the result obtained.

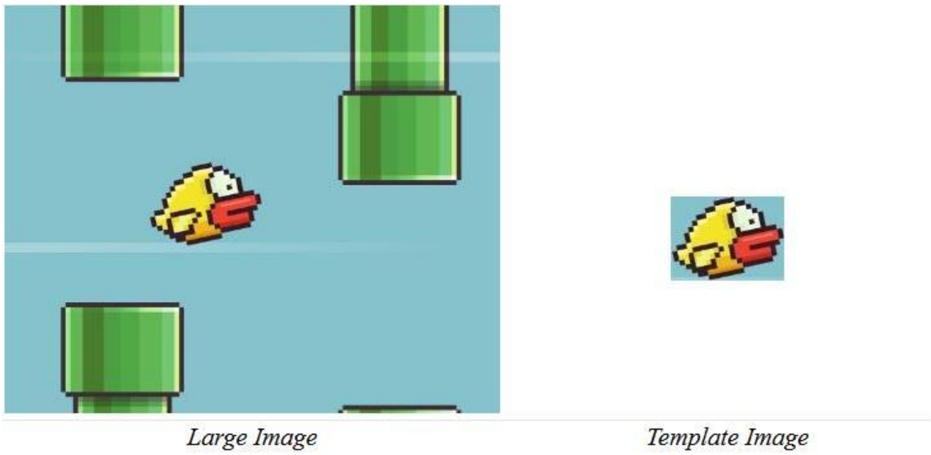

Fig. 1.9 Example of the math template method (What is Template Matching? An Introduction).

Secondly, the VLP is calculated using the pinhole camera model. This model describes the mathematical relationship between the coordinates of a point in a 3D space and its projection onto the image plane of an ideal pinhole camera.

Using the pinhole model and an additional transformation that establishes the relationship

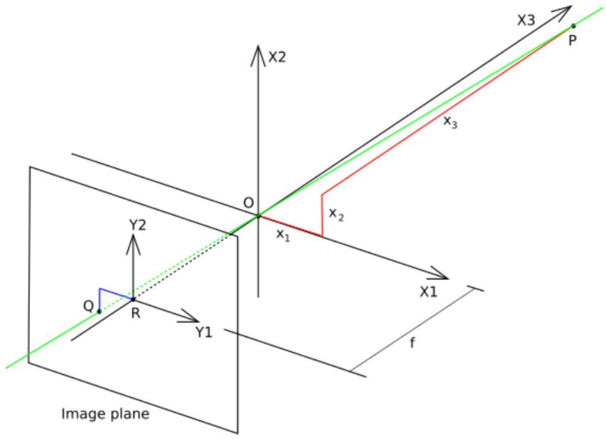

Fig. 1.10 The geometry of a pinhole camera. The x1x2x3 coordinate system in the figure is left-handed, that is the direction of the OZ axis is in reverse to the system the reader may be used to. (https://en.wikipedia.org/wiki/Pinhole_camera_model)

between the camera center and the reference system of the AMR, the position and orientation of the robot is estimated. However, a LiDAR scan matcher is used to compensate for the possible errors obtained during the odometry method.

After these two steps, the visible light positioning calculations are finished, obtaining the global map constructed with the exact position of the LEDs.

Thirdly, from the map obtained before, a SLAM process is executed using LiDAR to identify and represent the traversable zones and obstacles using binary regions, this is unified with the LEDs map. This local map can have some errors because its origin is established in the starting position of the AMR. For resolving this problem, it's stablished in the map, the VLP system since the beginning, using the LEDs position to correct automatically the origin of the local map named before.

Finally, the location fusion is established. This process can be divided into two steps. In the first step the AMR position is predicted using odometry, estimating the ubication and orientation based on the AMR relative movement. In the second step, an Extended Kalman Filter (EKF) algorithm is used to incorporate the measures obtained in the VLP system and the LiDAR scanner. (Extended Kalman Filter (EKF) — Copter documentation)

The experimental results done using this technology showed that is obtained a precision of 2.5cm, with a time response of 42ms. However, the integration of the LEDs markers in the SLAM map could be more effective, optimizing more the estimation of the robot position and orientation.

1.4 Detection of Docking Stations in AMRs Using LiDAR and Digital Maps

One solution for the design of a docking station for AMR robots is based on using a combination of LiDAR sensors, localization algorithms and software tools specialized in planning routes. This solution permits the robots to navigate autonomously, detect with high precision the docking station and correctly align to start the loading process.

The first step consists of creating a map of the environment. During this phase, the AMR scans the surrounding area with the LiDAR sensors. The data obtained by the LiDAR sensors is registered and stored while the AMR is moving, saving detailed information about the elements of the work environment such as walls, obstacles and possible docking stations.

The data compiled by the LiDAR sensors is later processed in software tools like *MapFabric*, where the environment map is optimized by deleting not useful data or irrelevant elements. In this step, specific elements can be identified by their specific elements or their

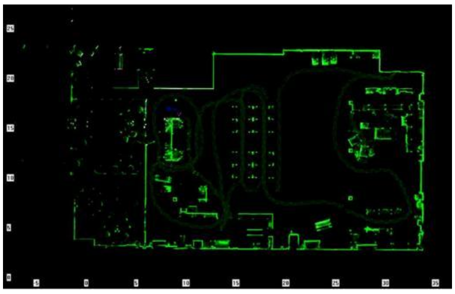

Fig. 1.11 Example of a map obtained using Road editor

(Sherpa Mobile Robotics. 2023)

mechanical structure. In case LiDAR sensor generated map itself does not identify all the elements considered of interest, labels or landmarks can be added by using the software tools, assigning specific coordinates of that element and specifying which element it is. Also, restrictions can be set on the map, such as non-accessible areas or safety zones, ensuring that the AMR maintains the optimum trajectory to the defined final coordinates.

The second step for the system configuration is the route and approach planning to the docking station, which is done using software tools such as *Roadeditor.* An approximation point is defined at a specific distance from the docking station. To improve the approach precision, it can be used physical references such as specific structures detected by LiDAR sensors, these references allow the AMR to adjust its trajectory when is near the docking station.

During the operation phase, when the AMR robot needs to get to the docking station, its navigation system uses the previously generated map combined with the real-time information captured by its sensors. As it approaches, the robot analyses the previously registered structures and modifies its trajectory depending on the detection of obstacles or changes in the environment, trying always to return to the predefined route. To ensure a successful coupling some stations can be equipped with RFID (Radio-Frequency Identification) bars or proximity sensors that provide an additional validation that the robot is correctly positioned.

Fig. 1.12 Example of a RoadEditor map and the edit options

(Sherpa Mobile Robotics. 2023)

The use of LiDAR sensors and digital maps for the docking station detection provides a robust, flexible and adaptable method for various environments. By combining real-time mapping technologies, software for planification tools and precision sensors, the AMR can navigate autonomously and realize different operations with high efficiency and reliability

1.5 Substantiation of the decision

For this work, it has been decided to implement the fourth solution (Detection of the docking station based on LiDAR and digital maps).

This decision has been taken because this solution is already implemented in Sherpa-B, which is the AMR that will be used in this work. So, this solution takes advantage of the systems integrated in the AMR, optimizing its performance without needing to add extra hardware or implement other software tools that are not already defined in the Sherpa-B system.

Sherpa-B is equipped with two Lidar sensors at different heights (One at 8cm from the ground and another at 42cm), allowing it to generate a detailed map of the environment by using SLAM (Simultaneous Localization and Mapping) algorithms. This map is saved and processed in MapFabric and RoadEditor., which are software tools that are already integrated in the AMR system and allow managing to find the location of the docking station without requiring hardware or software modifications.

This technology has been chosen over the other explained solutions because it has various advantages that optimize the AMR performance and reduce the implementation complexity:

- It is not required to make changes or add sensors in the AMR because the technology used is already incorporated.
- Compatibility with MapFabric and RoadEditor allows easy configuration and environmental adjustment without needing more software tools.
- LiDAR sensors proportionate millimetric resolution, allowing a precise localization of the docking station and efficient navigation through the workspace.
- It works correctly in dynamic environments because the map can be actualized in real time if there are any changes in the environment.
- Unlike systems based on cameras or physical markers, Lidar sensors don’t need the installation of tags, QR codes or lines for detecting the docking station
- Its efficiency doesn’t depend on the luminosity of the environment, so it can work in conditions of low visibility.
- The use of Lidar sensors minimizes the collision risks and ensures safety navigation in environments with human workers or vehicles because these sensors detect the obstacles and change the route if needed.
- Thanks to MapFabric, if the docking station changes of position or there are any other modifications in the environment the map can be edited without needing to intervene in the AMR hardware or making manual reconfiguration.
- RoadEditor facilitates the creation of optimal routes. By defining approximation zones and destination points the AMR behavior can be adjusted in order to ensure that it aligns correctly with the docking station
- RoadEditor allows to establish restricted zones and security areas, preventing the robot from taking non-secure routes or interrupting other processes

Even though this solution offers a lot of advantages compared with other possible solutions it also has some limitations or disadvantages:

- If the docking station is obstructed by other objects its detection can be less precise.
- LiDAR sensors show difficulties in detecting transparent or reflective objects.
- It can be a little delay in map actualization if there are a lot of changes in a short period of time.

- In open spaces or with not many structural references the LiDAR, because it has a detection radius of 13.5 cm, can have difficulties in trying to map correctly the docking station.
- Even though the system is autonomous, the initial map configuration has to be realized with precision to ensure correct navigation.

Despite all these disadvantages, the positive aspects that offer this technology in this work case are enough to consider that this is the best solution to the problem of this work, even though it would possibly need some few changes for solving some problems.

2 OVERVIEW OF SPECIFIC NODES

2.1 Arduino

Arduino is an electronics open-source platform. It consists of a physical programmable circuit board (Normally it is a microcontroller) and a piece of software or IDE (Integrated Development) used for developing software code efficiently that can be uploaded to the physical board. For specifying the board what to do it is send a set of instructions to the microcontroller situated in the board using Arduino programming Language and software (https://www.arduino.cc/en/Guide/Introduction/).

Unlike other circuit boards the Arduino doesn't need a programmer (Is a separate piece of hardware) for loading a code onto the board. Instead, it can be used a USB cable, which simplifies the loading code process.

This platform offers some advantages over other systems:

- Arduino boards are cheap compared to other microcontroller platforms. <for example, a pre-assembled Arduino module cost less than 50€.
- The Arduino Software (IDE) runs on various operating systems: Windows, Macintosh OSX and Linux.
- Arduino software is an open-source tool. The language used for programing can be expanded through C++ libraries.
- The plans of the Arduino boards are published, so anyone can design a version of the module for extending it or improving it.

Arduino has different boards with different capabilities. In this work it will be used the Arduino ESP32 board.

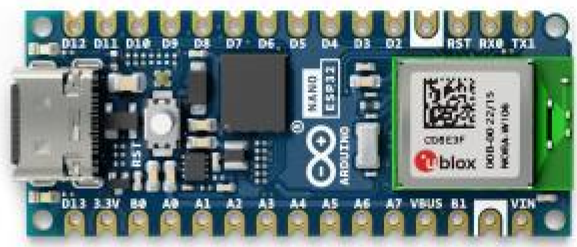

Fig. 2.1 Arduino ESP32 (https://docs.arduino.cc/resources/datasheets/ABX00083-datasheet.pdf)

The Arduino ESP32 is a board based on the usage of ESP32 microcontroller of *Espressif*. ESP32 is a low-cost and low-power system on a chip with Wi-Fi and Bluetooth capabilities.

Arduino ESP32 has built-in components and interfaces such as capacitive touch, ADC (Analog to Digital Converter), DAC (Digital to Analog converter), UART (Universal Asynchronous Receiver/Transmitter), SPI (Serial Peripheral Interface), I2S (Integrated Inter-IC Sound), CAN 2.0 (Controller Area Network), PWM (Pulse Width Modulation), RMII (Reduced Meida-Independent Interface) and more.

This board comes with a microUSB interface for connecting the computer to the board in order to upload code or apply power. It also has a reset button to restart the board.

The ADC and DAC features are assigned to specific pins, but it is possible to assign in the code which pins are UART, I2C, SPI ... This assignment is possible due to ESP32 chip multiplexing features.

The ADC input channels have a 12-bit resolution, which in Analog reading establishes a range from 0 to 4095 (0 corresponds to 0V and 4095 to 3.3V). These pins don't have a linear behavior, meaning that it isn't able to distinguish low voltage differences.

There are 2 DAC channels with 8-bit resolution to convert digital signs into analog voltage signal sources.

In addition, there are pins with specific characteristics that are designed to be used for specific functions. In the following image is shown for which functions each pin is designed.

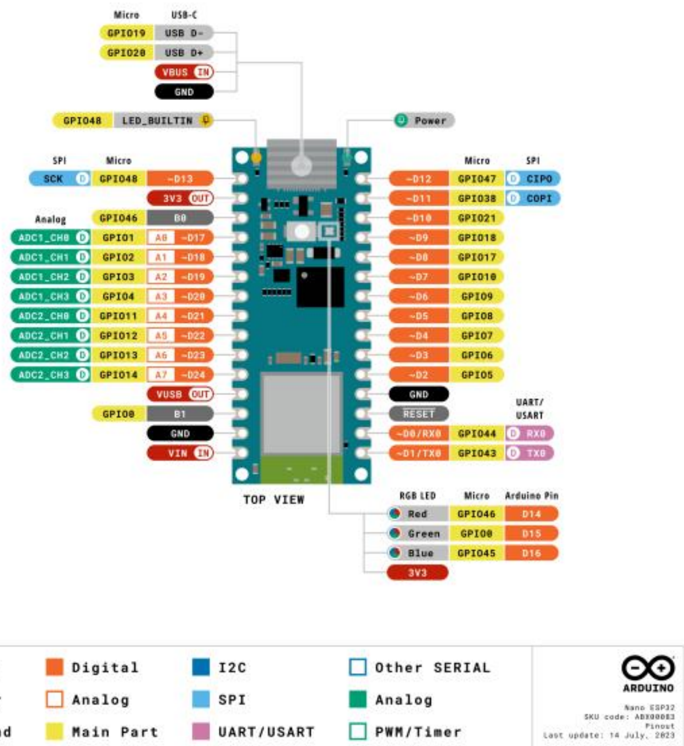

Fig. 2.2 Pinout ESP32

(https://docs.arduino.cc/resources/datasheets/ABX00083-datasheet.pdf)

In fig 2.2 it is shown all the input and output pin of the ESP32, some of them will be used in this project for the weight and distance measuring systems

2.2 ToF sensor

A ToF (Time of Flight) sensor is a sensor that uses time of flight to measure depth and distances. This sensor is sensitive to a specific wavelength(850-940nm). Objects are illuminated with a modulated light source like a laser VCSEL or LED. The light is reflected on the object and the ToF sensor captures the light that has been reflected on the object and measures the time it took to the light to come back to the sensor (ΔT). Knowing the time, it took the light to come back to the sensor it calculates the distance to the object by using the following formula:

$$distance = Speed\ of\ light \cdot \frac{\Delta T}{2}$$

In this project it will be used the TOF Laser Range Sensor (B) of *Coolwell.*

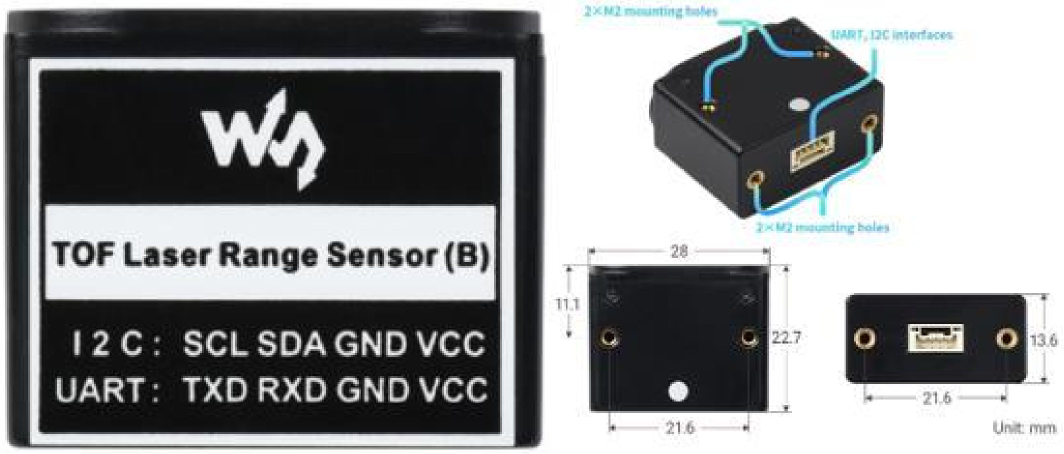

Fig. 2.3 TOF Laser Range Sensor (B)
(https://www.waveshare.com/tof-laser-range-sensor-b.htm)

This sensor is a TOF-based laser ranging sensor with embedded MCU and a ranging algorithm. This sensor can have a measuring range from 0.1m to 15m with $\pm 2\%$ accuracy and 1mm resolution. It supports UART and I2C communication bus. Its longer measuring distance and its light interference resistance capability is due to its narrow Field of view (1º-2º). This sensor is designed for being used in applications like common distance measuring, robot obstacle avoidance, robot route planning…

The sensor can be connected to Arduino. In the following image, it is shown how this sensor should be connected with Arduino. (https://www.e-consystems.com/blog/camera/technology/what-is-a-time-of-flight-sensor-what-are-the-key-components-of-a-time-of-flight-camera/)

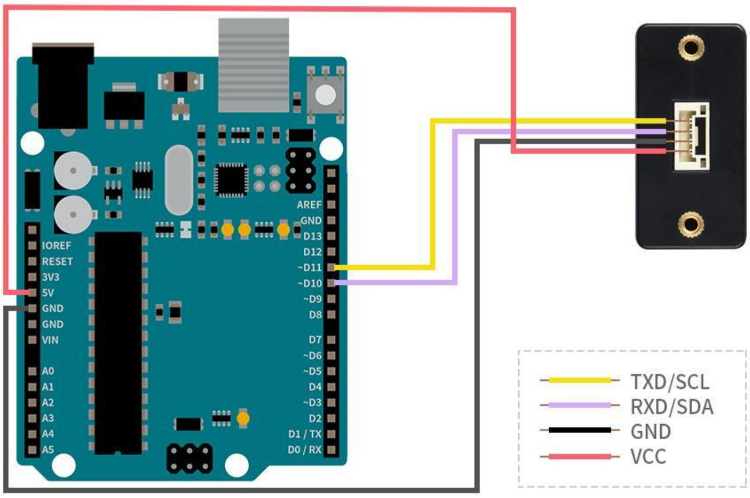

Fig. 2.4 Connection of TOF Laser Range Sensor (B) with Arduino board (https://www.waveshare.com/tof-laser-range-sensor-b.htm)

In fig 2.4 is shown how the ToF sensor will be connected to the Arduino for using the distance information of the ToF sensor.

2.3 Warning Lights

Depending on the distance from the AMR robot to the docking point specific warning light colours will turn on.

Fig. 2.5 ONPOW HBJD-40 serie warning lights (ONPOW. 2016)

For helping the operators to detect when the AMR is in the docking station it will be used for visual and acoustic signalization. The warning lights that will be used are the Serie HBJD-40 of ONPOW. Specifically, is the three layers with buzzer model.

HBJD-40 warning lights work at temperatures between -25ºC and 55ºC, with a maximum humidity of 98% and it has a vibration resistance If 50Hz with an amplitude of approximately 1.2 mm, allowing the warning lights to work in exigent work environments.

The continuous LED light model has a lifespan of 40000 hours, while the intermittent model reaches 25000 hours of lifespan. Its sound level is between 80 and 90 dB for one meter.

The lights have a diameter of 40mm and can operate with 220 AC/DC voltage or 220 AC voltage.

This specific model includes three different LED color layers positioned vertically: Red, yellow and green. It also incorporates a buzzer able to emit a sound signal of 80-90 dB at 1 meter distance. There are two sound and light types: continual buzzer with continual light or discontinuous buzzer with continual light.

There are 5 cables for connecting the warning lights. The black (-) and red (+) wires are connected to the power supply. Each LED layer is controlled individually by the yellow (Controls the first LED layer), green (Controls the second LED layer) and orange (Controls the third LED layer) cable, allowing each color to activate independently. The buzzer doesn't have independent wiring because it's integrated with the lights, meaning that the buzzer activates when a light layer is activated.

2.4 Weight measurement system

The sherpa is designed to support a maximum of 100Kg. To detect that this weight is not excided the table of the loading station will indicate the weight that is supporting. For this, the following devices will be used: Load Cell 50Kg, Hx711 Load Cell Amplifier Module and LCD Display with I2C adapter.

Load Cell 50Kg

Fig. 2.6: Load Cell
(https://www.zemiceurope.com/en/catalogsearch/result?q=50Kg)

A load cell is a force sensor that converts weight into an electrical sign.

When the weight is applied to the load cell, the metal body slightly deforms. This deformation is extremely small and can't be observed by the human eye.

The load cell principle of operation is based on the piezoelectric effect, which is the ability of certain materials to generate an electric charge in response to applied mechanical stress. Based on this principle, it uses one or more strain gauges forming a Wheatstone bridge, and when a deformation is applied to it, its resistance varies. (https://www.zemiceurope.com/en/catalogsearch/result?q=50Kg)

In this case, there will be used 4 Load cells, one in each corner, and the weight detected by each cell will be added.

Hx711 Load Cell Amplifier Module

Fig. 2.7: HX711
(https://www.sparkfun.com/sparkfun-load-cell-amplifier-hx711.html)

This is a module used for load cells, and its function is to take the analog signal received from the load cells and convert it into a digital sign. This specific ADC converter is a 24-bit high-precision converter, and it has two different input channels, so two HX711 will be needed.

1602 LCD Display with I2C adapter

Fig. 2.8: 1602 LCD Display Module with IIC I2C Serial Interface
Adapter LCM Blue Backlight Screen AIP31066 Controller 16X2 LCD for Arduino
(https://www.amazon.com/Interface-Backlight-Controller-RaspberryTinkerboard/dp/B0D2L9JHLD?th=1)

A 1602 16x2 LCD display with an integrated I2C interface is a screen module capable of showing two lines of 16 characters written in white with a blue blacklight. The use of I2C interface reduces the number pf required connection pins to only two data lines (SDA and SLC). This screen is compatible with Arduino and ESP32 and it will be used to show the weight measured.

2.5 MOTOMA HC10DTP

Motoma HC10DTP is a human-collaborative robot for sensitive environments designed for industrial applications with 6 edges and a load capacity of 10Kg. This robot is robust and has an IP67 protection rating, protecting it from dust, coolants and welding spatter. Thanks to the 6 integrated torque sensors (one in each joint) the robot can be used in human robot collaboration without any protection fence.

Fig. 2.9: MOTOMA HC10DTP (https://www.yaskawa.es/productos/robots/collaborative/productdetail/product/hc10dtp_17024)

One of its most notable features is the possibility of manual guided programming, this functionality simplifies its installation and commissioning, allowing users to program the robot by moving its arms along the desired trajectory.

This robot can operate with a maximum velocity of 1000mm/s in collaborative mode and 2000mm/s in non-collaborative mode, always depending on the risks evaluation. It is compatible with several controllers such as YRC1000 and YRC1000micro and teach pendant and Smart Pendant devices.

About its typical applications, HC10DTP is especially useful for component assembly tasks, machine tending and loading, material handling, packaging and palletizing, and quality inspections on production lines.

2.6 WISE-4060-B_DS

The WISE-4060 is a wireless IoT I/O module designed to provide digital input and output communication through Wi-Fi connectivity. This device offers 4 digital input channels and 4 output channels, making it ideal for integrating sensor-actuator systems into IoT infrastructures. With support for 2.4GHz Wi-Fi and configuration via a web-based HTML5 interface, the WISE-4060 significantly reduces wiring requirements and simplifies communication in industrial environments.

Key features include RESTful API support, compatibility with cloud services (like Azure, AWS, Dropbox), data logging with timestamps, and Peer-to-Peer (P2P) communication, which allows real-time interaction between multiple devices. The relay outputs can switch up to 250VAC/5A A or 30VDC/3A, and digital inputs accept both dry and wet contacts with isolation up

Fig. 2.10: WISE-4060-B

(https://www.advantech.com/en/products/229f9f5b-d073-4cc2-ac54-d90147e04c12/wise-4060/mod_bb247acb-d538-4e6f-9402-6030fe8dbc31)

to 3000 Vrms.

In the loading station, the WISE-4060 will be used as a communication bridge between a collaborative robot (MOTOMA HC10DTP) and the Sherpa-B. The goal is to trigger a loading mission on the Sherpa once the collaborative robot has completed its task. This is achieved by wiring the digital output of the collaborative robot's control system to a digital input of the WISE-4060. When the collaborative robot finishes placing the load it sends a digital HIGH signal to the WISE-4060.

The WISE-4060, connected to the local Wi-Fi network, detects this change in input and sends a digital output signal (via relay) to the Sherpa's integrator interface or to a Shercom device, which has been preconfigured in the Sherpa's peripheral configuration. The Sherpa system recognizes this signal and automatically launches a predefined loading mission using its MissionEditor interface.

3 CALCULATION OF PROJECT

3.1 Materials

The structure designed can be divided into two different parts:

The first part is a metallic structure composed of hollow square section profiles of 40x40 mm with a thickness of 4mm. The material used for constructing this structure is structural steel S235JR. The S235JR characteristics can be seen in the following table

Table 3.1 S235JR Properties

Property	Value	Units
Elastic Modulus	210000.0031	N/mm^2
Poisson's Ratio	0.28	N/A
Shear Modulus	79000	N/mm^2
Mass Density	7800	kg/m^3
Tensile Strength	360	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	235	N/mm^2
Thermal Expansion Coefficient	1.1e-05	/K
Thermal Conductivity	14	W/(m·K)
Specific Heat	440	J/(kg·K)
Material Damping Ratio		N/A
Elastic Modulus	210000.0031	N/mm^2
Poisson's Ratio	0.28	N/A

The second part is vertical and horizontal supports designed for the legs to protect the AMR of possible collisions with the docking station structure and provide stability. The material used for constructing this part is rubber. The rubber characteristics can be seen in the following table.

Table 3.2 Rubber Properties

Property	Value	Units
Elastic Modulus	6.1	N/mm^2
Poisson's Ratio	0.49	N/A
Shear Modulus	2.9	N/mm^2
Mass Density	1000	kg/m^3
Tensile Strength	13.7871	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	9.23737	N/mm^2
Thermal Expansion Coefficient	0.00067	/K
Thermal Conductivity	0.14	W/(m·K)
Specific Heat		J/(kg·K)
Material Damping Ratio		N/A
Elastic Modulus	6.1	N/mm^2

3.2 Static analysis

Static analysis is a process used to apply external forces to an object or structure. In this analysis the structure is subjected to external displacements, and the structure response includes internal forces/moments and internal stresses that are used in the design process. (https://ascelibrary.org/doi/10.1061/9780784413609.224)

In the case of the designed geometry, it is designed to support at least as much weight as the Sherpa-B is able to support. Sherpa-B is designed to support a maximum of 100Kg.

$$100Kg \cdot 9.8\, {}^{m}/_{s^2} = 9800N \qquad (3.1)$$

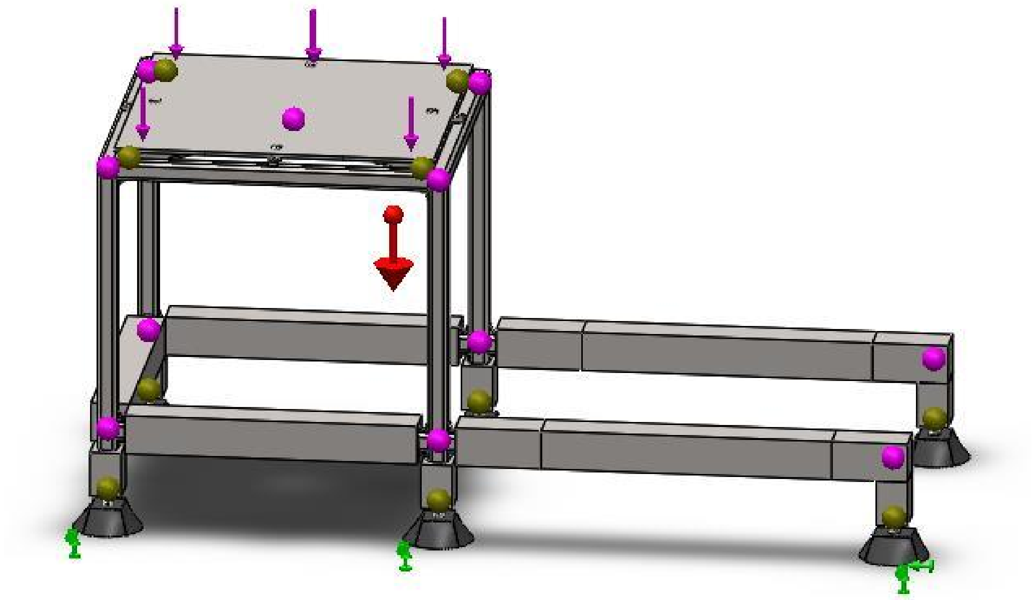

Fig. 3.1 Simulation Setup

The loading extension designed must be able to support at least 9800N, so for doing the simulation a force of 1000N has been established in the desk of the docking station. The parts that will be in contact with the floor (The four desk supports of rubber) have been established as fixed geometry in the face which will be in contact with the wall. Gravity has also been included in the simulation adjustments. The simulation design can be shown in the next image:

<u>Stress analysis (Von Mises)</u>

Stress analysis determines the internal distribution of internal forces in solid objects, identifying if the generated stresses could lead to structure failure.

Von misses stress analysis represents stress distribution in a structure in which a specific force is applied and allows to predict the possible materials failures. This study is necessary for knowing if the force applied to the structure causes plastic deformations or failure in the materials.

If the von misses value in some areas exceed the yield strength of the material this could have consequences like permanent deformation or even fracture in that part of the structure, so the materials selected for each part should have a yield strength bigger than the

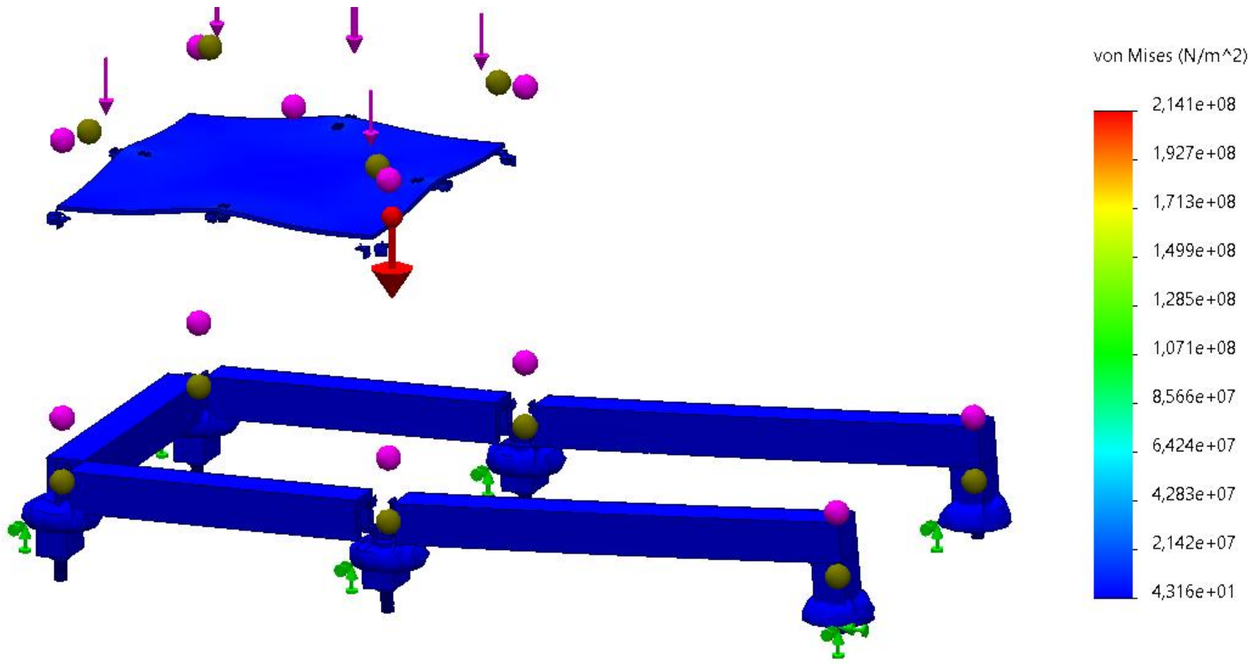

Fig. 3.2 Stress analysis simulation

The scale next to the image shows the stress intensity values in N/m^2. Each color represents a specific value for the intensity of stress.

The blue areas are the ones with lower stress (Approximately 4.31Pa). The blue zones seem to be concentrated in the legs of the structure, near to the fixed geometry. The blue zones coincide with the leg supports, so the leg supports structures must be made of a material with a yield strength bigger than the stress that affects that zone, so a material with a yield strength of at least 4.31Pa would be adequate. Rubber has a yield strength of approximately 9.24MPa, which is bigger than the stress that affects these parts of the structure.

The red areas are the ones that support bigger stress (Approximately 214MPa). These areas seem to be concentrated where the force is applied, specifically in the parts of the table that don't have any metal profile underneath. The concentration of forces in this part of the structure is because forces tend to concentrate at points of application. The material used in the red zones is S235JR, which has a yield strength of approximately 235MPa, so the yield strength in those parts is much bigger than the stress generated.

Static Displacement analysis

The static displacement analysis simulates the response of a structure to the applied forces. This analysis allows to identify the deformation that occurs in the structure due to the load applied to the structure, helping to determine if the displacement is enough for not ensuring the structure stability.

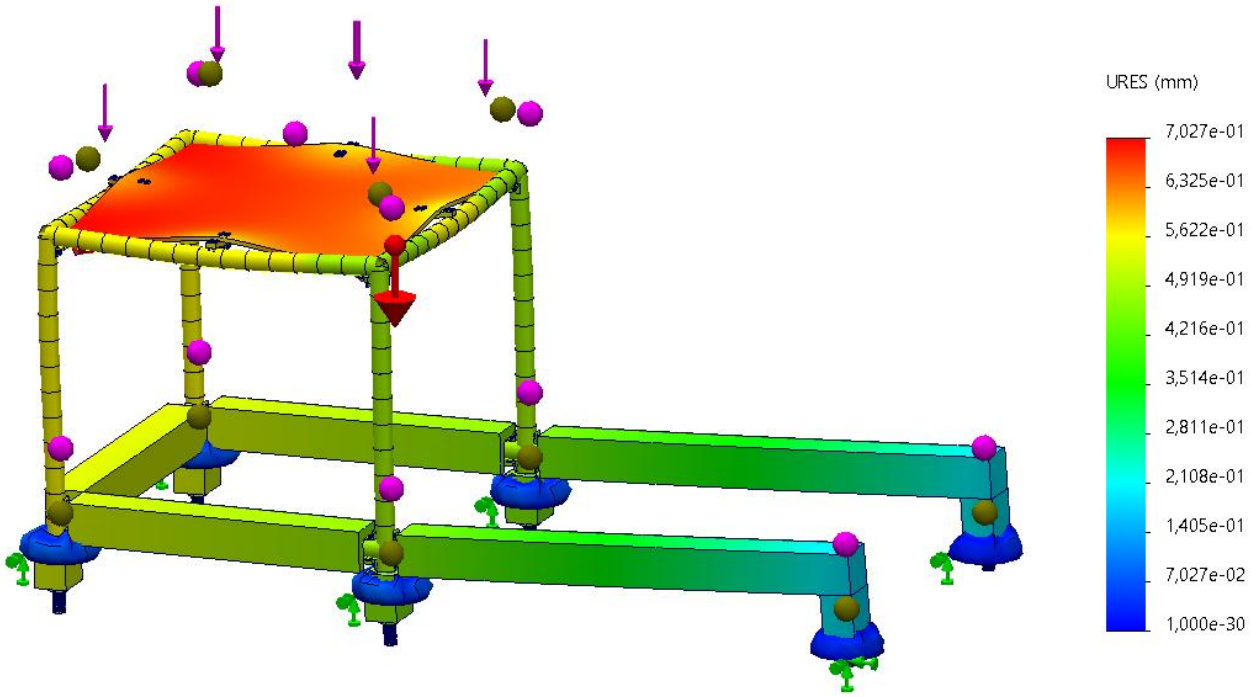

Fig. 3.3 Static Displacement simulation

The scale next to the image shows the different deformation values in mm. Each color represents a specific value of the displacement.

The blue zones are the ones with less displacement ($1x10^{-30}$mm). These areas have less displacement because, even though the force is applied near them, these zones are near to the support points, which are the points with less displacement because they are in contact with the ground.

The red zones are the ones with a bigger displacement (0.727mm). These areas are at the upper part of the structure, where the load is charged and are the more susceptible to bending because it's necessary that they bend in order to measure the weight with the load cells, so they are subjected to bigger load moments and less support, meaning that gravity is enough to generate displacement.

Analyzing the global displacement of the structure, the maximum displacement is less than 1mm, not even bigger than 1% of the longitude or dimension of the structure, so this displacement can be considered minimum and that it won't affect the structure integrity.

Static Strain study

Static strain study is used to simulate how a structure deforms due to a static load. Instead of focusing on displacements this analysis focuses on structure deformations. A deformation is defined as a relative change in the shape or size of a structure due to the application of a load.

This study is done in order to identify the areas that are most affected by stress and verify if there are significant deformations that may affect its functionality or if they are not so big to compromise the stability of the structure.

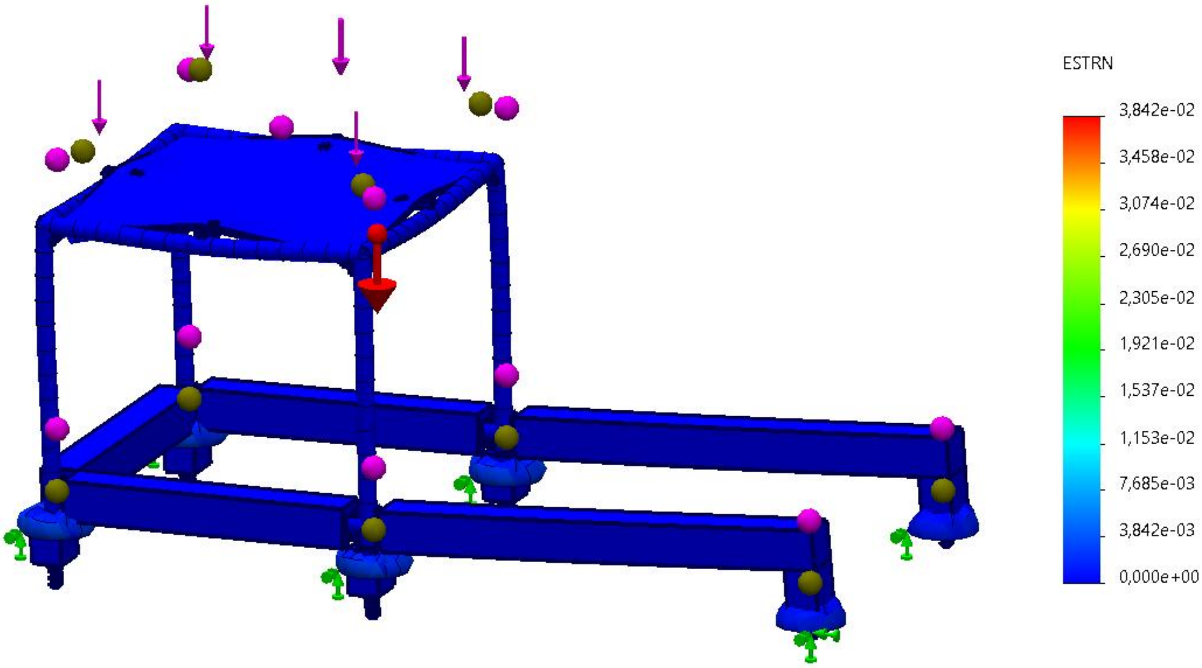

Fig. 3.4 Static Strain simulation

The scale next to the image shows the different deformation in ESTRN (Equivalent Strain), it is a non-dimensional measure. Each color represents a specific value of the displacement.

The zones which have more deformations are the red ones (0.03842ESTRN). Instead, the blue zones are the ones with less deformation (0 ESTRN) and mostly all the structure is represented in blue.

FoS (Factor of Safety)

The Factor of Safety of a structure indicates the relationship between its material resistance and the experimented efforts.

$$FoS = \frac{Yield\ Strenght}{Stress\ aplicated} \quad (3.2)$$

The scale next to the image indicates the FoS values. The lowest values are represented in blue and the highest values in red.

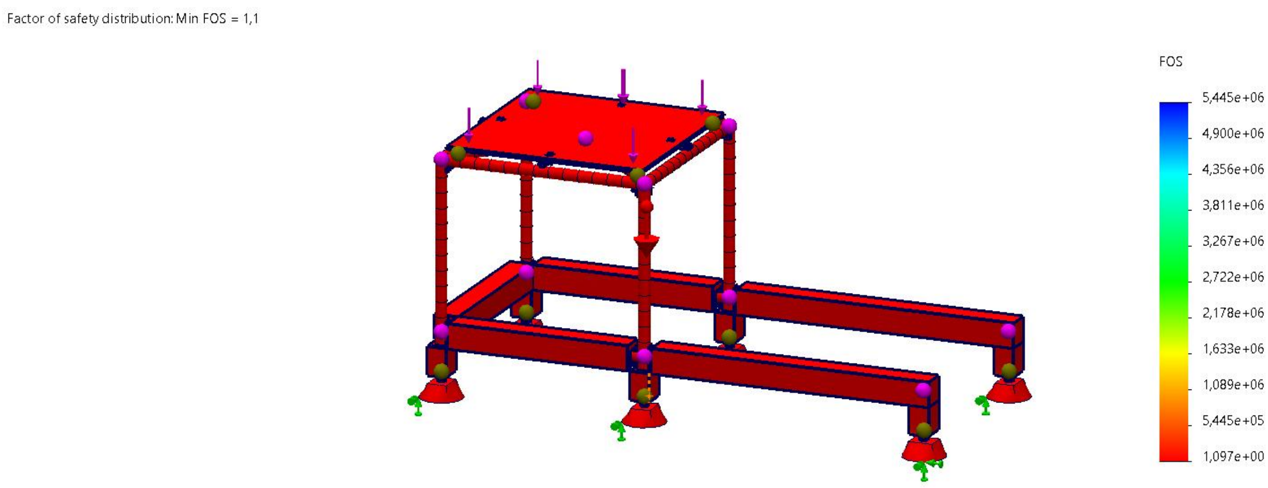

Fig. 3.5: FoS Simulation

The minimum Factor of Safety in the simulation is 1.1. Even though a FoS of less than 1.5 seems low in general terms, in this case is adequate because the loads charged in the docking station are being controlled and monitored through the load cells that support the desk and connect it to the structure. This allows the structure to work correctly in an acceptable safety range and it's not expected that the structure will fail. However, this FoS could be increased by using other material with bigger yield strength, but in that case the desk would probably bend less, which would cause some difficulties for the load cells to measure the weight.

3.3 Vibration analysis

Vibrations can cause several problems in structures, such as:

- Fatigue: Repeated vibration can cause wear and tear, leading to the failure of materials that form part of the structure.
- Resonance: If the natural frequency of the structure resonates it can cause large amplitude vibration generating damage in the structure
- Noise: Vibrations can cause noise that may have adverse effects on people

Vibration analysis is important to identify signs of deterioration or malfunction by detecting signs of structural failure. (https://ocean-me.com/vibration-structural-analysis/)

A vibration analysis of the structure has been carried out, obtaining the first five natural frequencies:

Table 3.3: Mass Participation list

Mode No.	Freq (Hertz)	X direction	Y direction	Z direction
1	16,77	1,4335e-08	4,2426e-08	0,78715
2	23,88	0,82138	0,0003987	1,7487e-06
3	31,221	5,1048e-07	3,9741e-07	0,0017165
4	35,617	9,3549e-07	8,5577e-05	0,00014184
5	36,441	2,6259e-05	5,8521e-06	0,01127

The lowest natural frequency is 16.77 Hz. This value is higher than 15Hz, the minimum recommended for structures. There is no ISO or UNE rule that determines 15Hz as the minimum natural frequency for structures, but there are some references that recommend 15-20Hz as the minimum value like Nasa Technical Standard 5002 or MIL-STD-810.
(https://standards.nasa.gov/standard/nasa/nasa-std-5002)

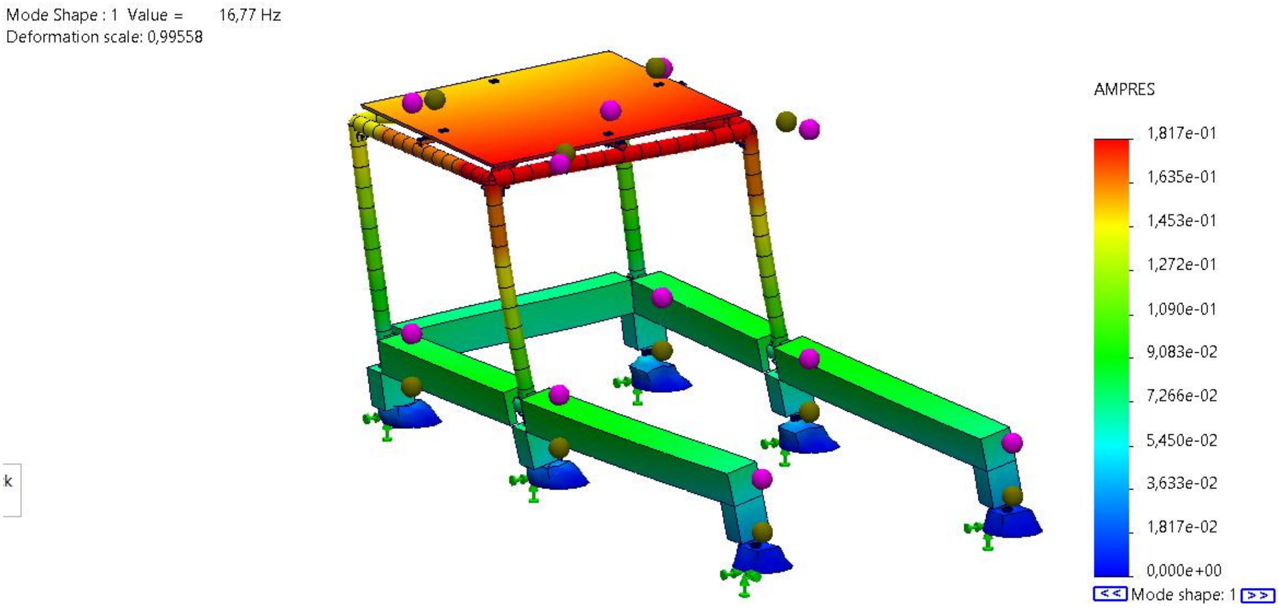

Fig. 3.6: Frequency analysis for natural frequency of 16.77Hz

In the study observed in Fig. 3.6 it represents a predominant modal participation in the z direction. This result, even though it is a little bit low natural frequency value, is completely justifiable for this structure, which is relatively flexible in the vertical direction (z). This natural frequency value represents that the structure has a flexible response to loads.

This value for the minimum natural frequency is valid for the intended use with the Sherpa. This value indicates that the structure is flexible, which is good for absorbing the small dynamic loads without the risk if dangerous resonance. This structure is designed to work with static and controlled loads, which justifies the safety of this value in the context of its application.

3.4 Dynamic analysis

Linear dynamic analysis is used to study how a structure behaves under dynamic loads, such as impacts and vibrations. This analysis will be done to study possible impacts of the sherpa with the loading station, simulating the forces generated by the impact and how it affects the structure. In specific, the study would be possible critical impacts of the sherpa-B with the loading station

Sherpa-loading station impact

The impact which will be simulated is an impact where the Sherpa moves at its maximum speed at constant velocity (acceleration=0) and collision with the docking station in different places and angles.

The energy of an object during an impact is defined as the capacity of work (W). In this case, the Sherpa is moving in the floor, so its energy is only Kinetic energy.

$$E_p = m \cdot g \cdot h \tag{3.3}$$

$$E_c = \frac{1}{2} \cdot m \cdot v^2 \tag{3.4}$$

$$m \rightarrow Mass(Kg); g \rightarrow Gravity\left(9.81\,{}^{m}/_{s^2}\right); v \rightarrow Speed({}^{m}/_{s})$$

$$W = E_c + E_p \tag{3.5}$$

$$E_c \rightarrow Kinetic\ Energy(J);\ E_p \rightarrow Potential\ Energy(J);\ W \rightarrow Work(J)$$

The impact case studied doesn't move vertically (The Sherpa only moves in the floor), so the potential energy is cero.

$$E_p = m \cdot g \cdot 0 = 0\,J \tag{3.6}$$

$$W = E_c + E_p = E_c \tag{3.7}$$

Work happens when an object applies a force to another object during a certain distance, so the work is calculated by the following formula:

$$W = F * D \tag{3.8}$$

$$F \rightarrow Force(N);\ D \rightarrow DIstance\ of\ Impact(m)$$

Knowing these two different formulae for calculating the work it can be calculated the force applied:

$$W = E_c;\ W = F * D \tag{3.9}$$

$$E_c = F * D \rightarrow F = \frac{E_c}{D} = \frac{1}{2} \cdot \frac{m \cdot v^2}{D} \tag{3.10}$$

(https://blog.unicoos.com/como-calcular-la-fuerza-de-impacto/)

Of this formula, the velocity of the sherpa is going to be considered its maximum velocity (2m/s) and the weight of the simulation is studied in a case where its fully loaded.

$$v = 2\frac{m}{s^2}; m = Sherpa_{weight} + Loaded_{Weight} = 75 + 100 = 175Kg \quad (3.11)$$

$$F = \frac{E_c}{D} = \frac{1}{2} \cdot \frac{m \cdot v^2}{D} = \frac{1}{2} \cdot \frac{175 \cdot 2^2}{D} \quad (3.12)$$

For simplifying calculations of the distance of impact it will be considered the impact as a mass-spring system.

In an ideal mass-spring system (Without damping) the moving equation is:

$$m \cdot \ddot{x} + k \cdot x = 0 \quad (3.13)$$

$$\ddot{x} \rightarrow acceleration\ of\ the\ body\ \left({}^{m}/_{s^2}\right);$$

$$x \rightarrow Displacement\ from\ the\ equilibrium\ position\ (m);$$

$$k \rightarrow Spring\ stiffness\ constant\left({}^{N}/_{m}\right)$$

The solution of this equation is an oscillation with angular frequence:

$$w = \sqrt{\frac{K}{m}} \quad (3.14)$$

$$w \rightarrow Angular\ frequency\ of\ the\ system\left({}^{rad}/_{s}\right)$$

From the angular frequency it can be calculated the full oscillation period of the system (time it takes to complete one full cycle):

$$T = \frac{2 \cdot \pi}{w} = 2 \cdot \pi \cdot \sqrt{\frac{m}{K}} \quad (3.15)$$

$$T \rightarrow Period\ of\ the\ oscillation(s)$$

(https://math.libretexts.org/Courses/Cosumnes_River_College/Math_420%3A_Differential_Equations_(Breitenbach)/06%3A_Applications_of_Linear_Second_Order_Equations/6.01%3A_Spring-Mass_Problems_(Without_Damping))

However, in case of impact, the body only completes the first part of the oscillation (From the initial compression to the maximum compression), at which point it comes to rest.

Therefore, the impact duration is half of the period.

$$t_{impact} = \frac{T}{2} = \pi \cdot \sqrt{\frac{m}{K}} \quad (3.16)$$

$$t_{impact} \rightarrow Duration\ of\ the\ impact$$

In this case, SolidWorks provides information on the elastic modulus of each material. So, it's needed to relate the spring stiffness constat with the elastic modulus:

$$k = \frac{E \cdot A}{L} \ (3.17)$$

$$E \rightarrow Young's\ modulus\ (Pa); A \rightarrow Cross - sectional\ Area\ of\ the\ element;$$

$$L \rightarrow Lenght\ of\ the\ deformable\ element$$

(https://en.wikipedia.org/wiki/Stiffness)

Knowing these relations, it can be obtained the equation that will be used to study the possible impacts of the Sherpa-b with the docking station:

$$t = v * D$$

$$F = \frac{E_c}{D} = \frac{1}{2} \cdot \frac{m \cdot v^2}{D} = \frac{1}{2} \cdot \frac{m \cdot v^2}{v \cdot t} = \frac{1}{2} \cdot \frac{m \cdot v}{t} = \frac{1}{2} \cdot \frac{175Kg \cdot 2\frac{m}{s}}{t} = \frac{1}{2} \cdot \frac{175Kg \cdot 2\frac{m}{s}}{\pi \cdot \sqrt{\frac{175}{K}}} \ (3.18)$$

$$F = \frac{1}{2} \cdot \frac{175Kg \cdot 2\frac{m}{s}}{\pi \cdot \sqrt{\frac{175}{K}}} \ (3.19)$$

The impact that would be studied is the worst impact case. As its seen in the formulas, the impact force and the cross-section area are directly proportional, so the worst impact case would be when the Sherpa hits directly to the structure, with the full front face (606 mm) at its maximum speed (2m/s) when is fully loaded (175Kg).

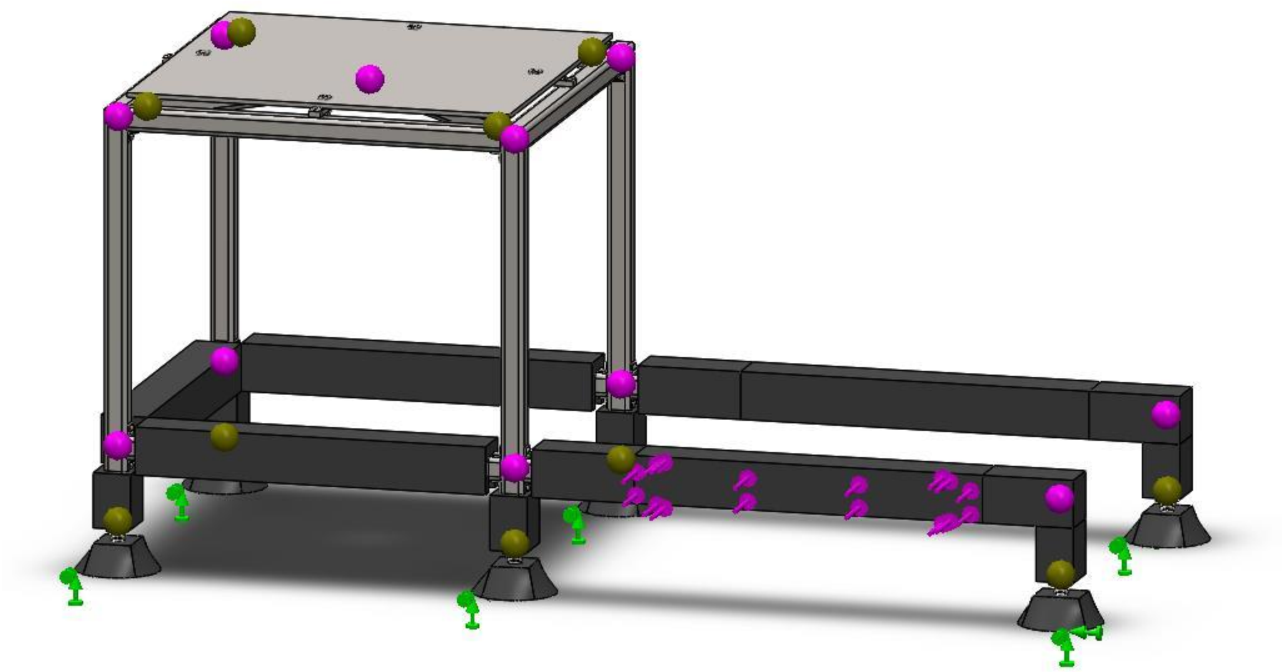

Fig. 3.7: Worst Impact case definition

The impact case studied is one where the Sherpa hits one of the rubber protections of the docking station, so we would have the following data:

$$K_{total} = \left(\frac{1}{K_{Rubber}} + \frac{1}{K_{S235JR}}\right)^{-1} \tag{3.20}$$

$$L_{rubber} = 20mm; L_{S235JR} = 4mm$$

$$A_{rubber} = 82.5mm \cdot 606mm = 49995mm^2 \tag{3.21}$$

$$A_{S235JR} = 40mm \cdot 606mm = 24240mm^2 \tag{3.22}$$

$$E_{rubber} = 6.1MPa; E_{S235JR} = 210000.0031MPa$$

Knowing these we can calculate the maximum force applied to the docking station during the impact

$$k_{Rubber} = \frac{6.1 * 10^6 Pa \cdot 49995 \cdot 10^{-6}\, m^2}{20 \cdot 10^{-3} m} = 1523475N/m \tag{3.23}$$

$$k_{S235JR} = \frac{210000.0031 \cdot 10^6 Pa 24240 * 10^{-6}\, m^2}{4 * 10^{-3} m} = 1.27 * 10^{12} N/m \tag{3.24}$$

$$K_{total} = \left(\frac{1}{\frac{1523475N}{m}} + \frac{1}{1.27 * \frac{10^{12}N}{m}}\right)^{-1} = 1523473N/m \tag{3.25}$$

$$F = \frac{175Kg}{\pi * \sqrt{\frac{175Kg}{\frac{1523473N}{m}}}} = 5197N \tag{3.26}$$

$$t_{impact} = \pi * \sqrt{\frac{175Kg}{1523473}} = 0.0336s \tag{3.27}$$

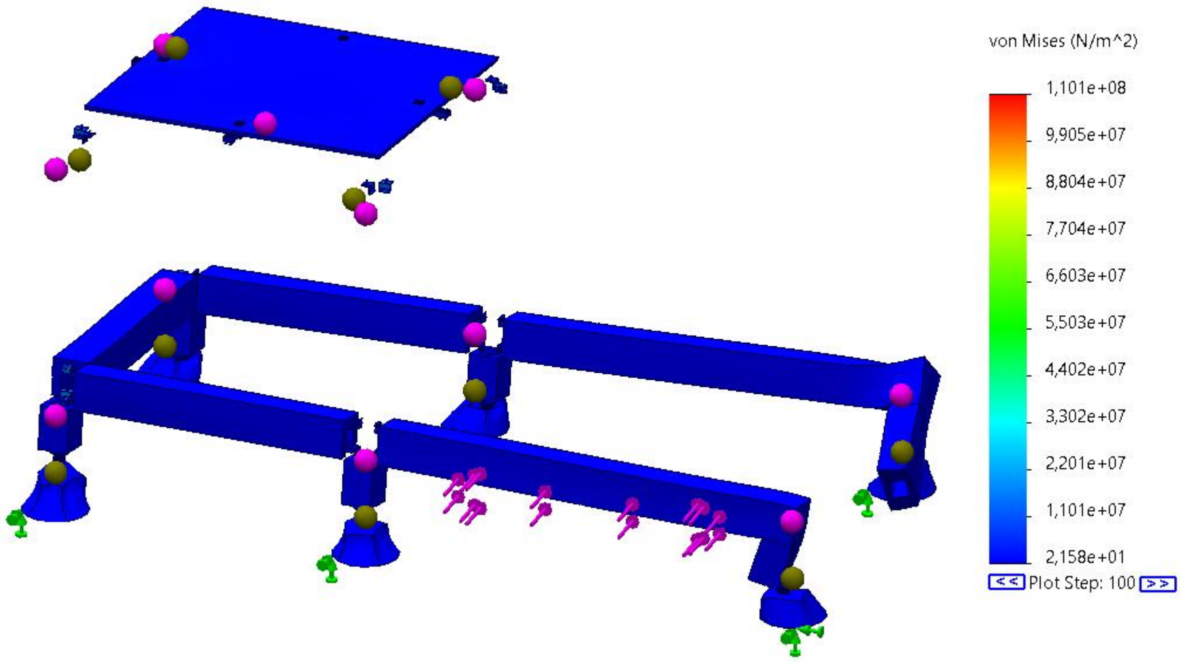

Fig. 3.8: Dynamic stress analysis of first impact situation

In Fig. 3.8 the Von Misses equivalent stress map in the structure after the impact is presented. The maximum stress is 110.8MPa, which is lower than the yield strength of S235JR. So, in the case studied in this simulation, the structure remains completely within the elastic regime, with no risk of plasticization or permanent damage in any of its regions.

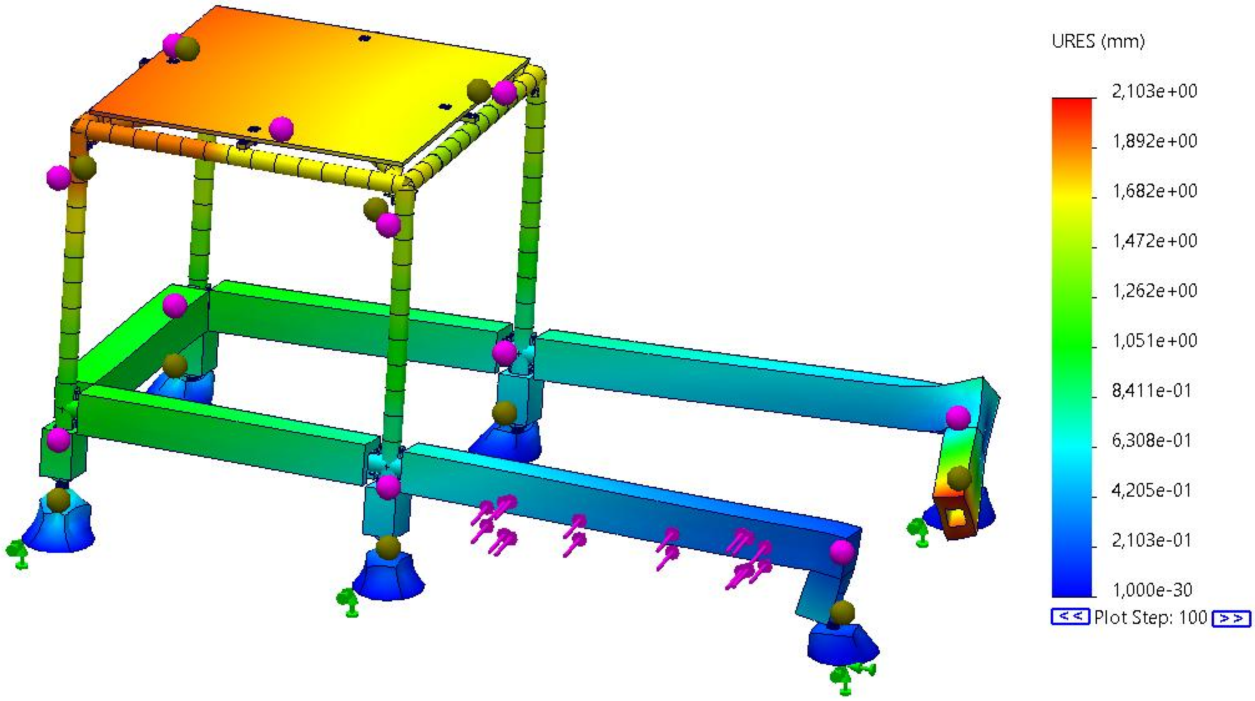

Fig. 3.9: Dynamic Displacement simulation of first impact simulation

In Fig. 3.9 it's shown the dynamic displacement simulation, the analysis shows a maximum deformation of 2mm, localized in one of the leg rubber protections, which is not a problem because it will be connected to the steel profile, so it won't deform that much and, even though it still deforms, it is not a crucial element for the stability of the structure. The rest of the displacement along the structure is lower. In the upper part of the structure there are some places where the deformation gets to 1.8mm, but taking into account that the structure in that part is prepared for the desk to bend in order to detect the weight, it is not a problem The result confirm that there is a low displacement of the structure and that mostly all the energy of the impact is absorbed by the structure, avoiding any significant effect on the metal skeleton or the rubber protections.

4 DESCRIPTION OF THE CONSTRUCTION AND OPERATIONAL PRINCIPLE

4.1 Workcell distribution

The Fig 4.1 shows a possible layout design for a workcell of a store where they could work two Sherpa-B (Or other AMR robots) doing logistic labors simultaneously with a maximum of 10 workers.

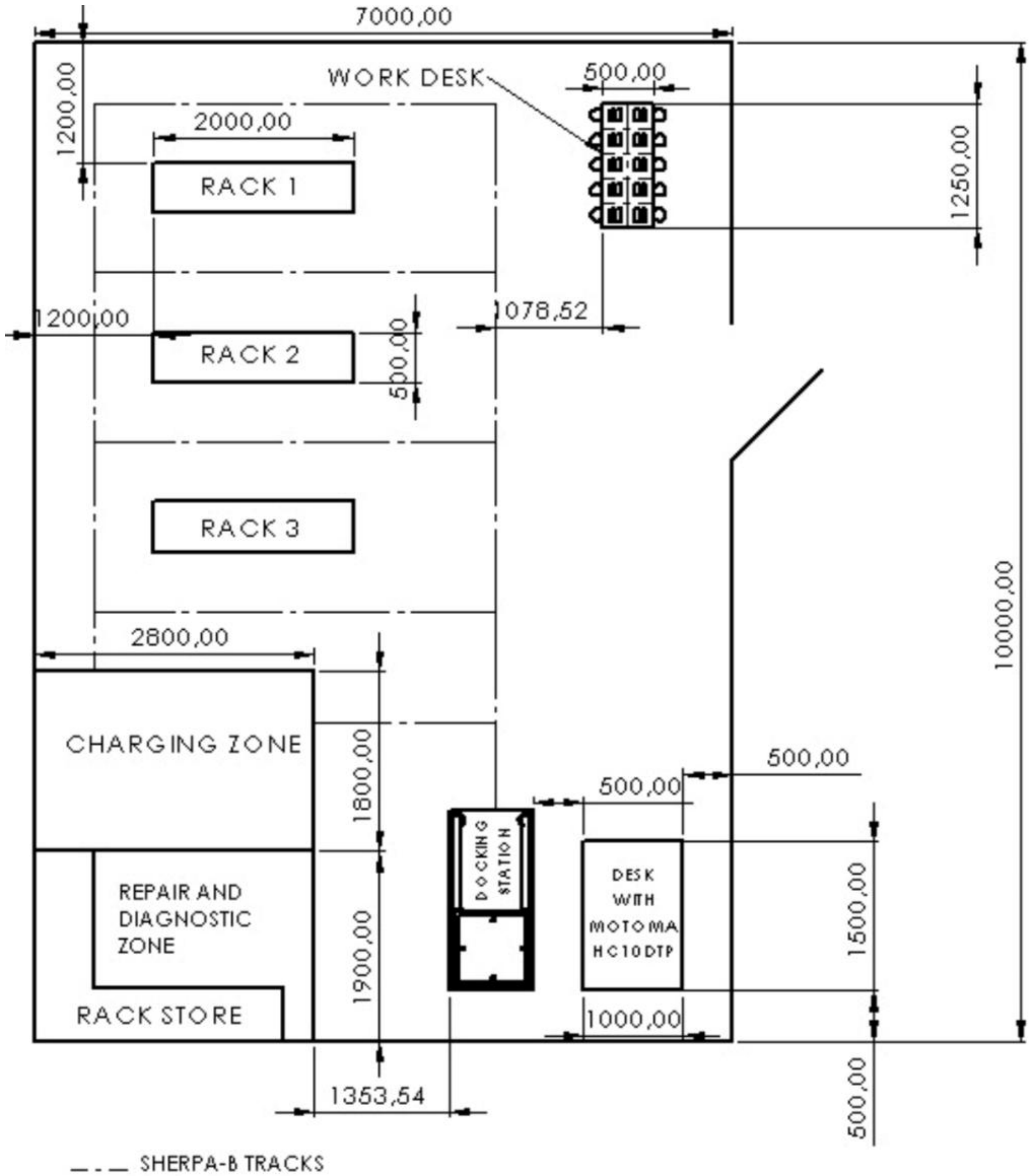

Fig. 4.1: Workcell Distribution Layout

The workcell is divided into different areas where different tasks are done.

The charging zone is where the robots will charge their batteries. It has been designed with enough space for charging two sherpas and it is positioned in a specific area with access to the main track road for the robots.

Beside the charging zone there's a repair and diagnostic zone that incorporates a rack store with tools and other elements that could be useful for doing technical labors of the Sherpa. This zone has been designed for review, maintenance and diagnostic of the robots to detect possible failures or errors and correct them or also to improve some aspects. This area is in a specific place near the charging zone and far from the Sherpa paths, allowing a fast access to tools and spare parts for realizing manual interventions in the Sherpa without interfering in the general operating flow.

On the upper right corner there is a desk with computers where human workers can do their labors or make modifications in Sherpas programs like for example adding new docking stations or deleting some tracks.

The routes marked as tracks indicate the planned paths for the robot. These tracks are designed to avoid interference with critical areas (For example, the work desk) and ensure smooth paths both in Follow me mode and automatic mode. The tracks are designed so both Sherpas can move without interfering between them, having enough track spaces for both to move

This workcell is designed for the Sherpa being able to work in two different forms: Follow me and autonomous docking mode.

The racks one, two and three are situated parallel to each other leaving hallways of 1.2m of width between them and between them and the walls. This area with these three racks is designed for using the Sherpa in follow me mode. In this space, the Sherpa will be following the worker through the designed tracks in order to load the items that the worker puts on its tray. The hallways have 1.2m width for securing enough space for the Sherpa to maneuver following the workers.

In the other part of the room there is the docking station and a desk with a collaborative robot nearby. This space is designed for the Sherpa to work in autonomous docking mode, being not necessary for the worker to move. In this mode, the docking station will send a sign to Sherpa when it has items that need to be loaded and the lading mission in autonomous mode will activate, so the Sherpa will follow the tracks to the docking station so it can be loaded.

4.2 Electric block scheme

The principal device of this system is an Arduino ESP32, which consists of an Arduino board with an ESP32 chip inside, which gestions the sensors and actuators used. This device supports both

Wi-Fi and Bluetooth and is powered by a 5V DC (Direct Current) source from a regulated voltage converter.

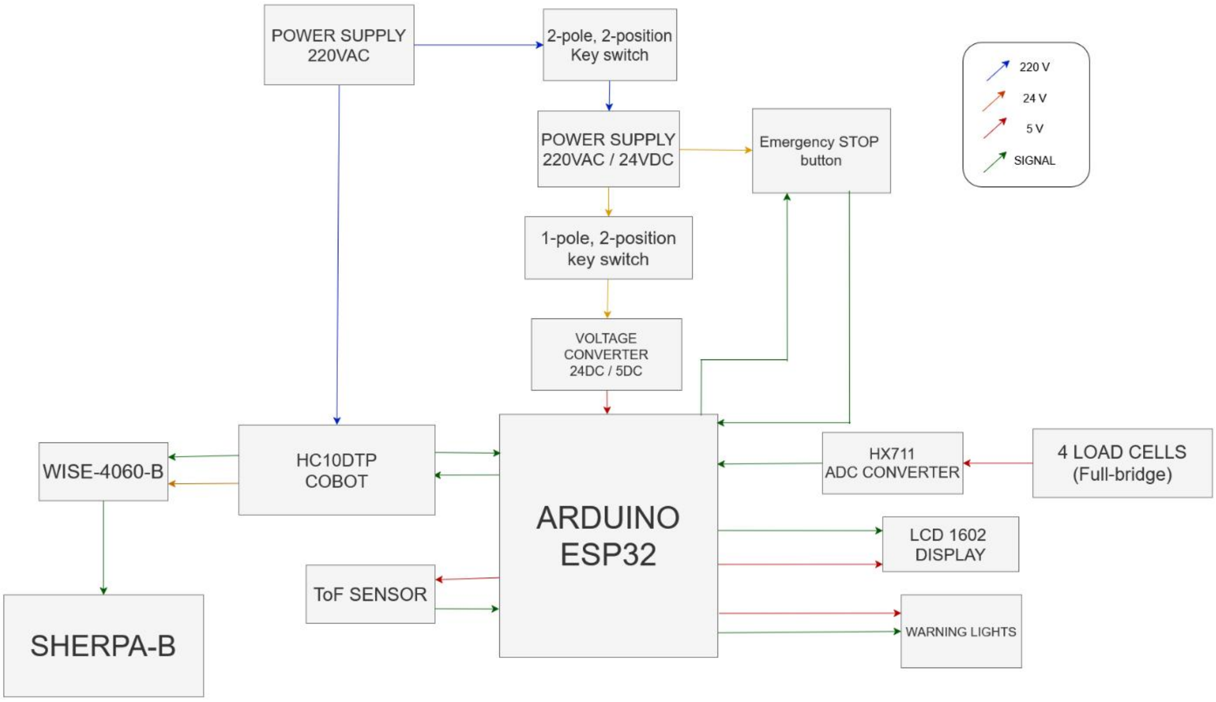

Fig. 4.2: Electric block scheme

The general power supply of the system is a normal plug that provides 220V AC (Alternating Current), this supply is controlled by a two pole, two position key switch. This signal feeds a power supply that converts 220V AC to 24V DC, which passes through a second single-pole key switch. Subsequently, a second power supply converter transforms 24V DC to 5V DC, which is used to power the Arduino ESP32.

The system incorporates an emergency stop button that interrupts the control signal which will be used to stop the system immediately in case of fault detection. This button is powered by the 220V AC to 24V DC converter and transmits data with Arduino ESP32 in order to stop the system if it's necessary.

The Arduino ESP32 receives signs (Information) from the ToF laser range sensor and the HX711.

The ToF sensor provides proximity measurements. In specific, it provides information about the distance from the distance of the AMR to the docking pint where it can be loaded. The ToF sends to Arduino ESP32 a sign representing this distance and depending on the distance measured the Arduino ESP32 sends a sign to the warning lights. Specifically, Arduino ESP32 sends a sign to the specific warning light color that should be on.

For the weight measurement system, the desk is supported by four load cells that measure the weight loaded on the desk. These load cells have a power supply of 5V directly from the Arduino ESP32 and are connected in such a way that mechanical variations are compensated and the sign that is transmitted is proportional to the weight measured (Wheatstone bridge).

The HC10DTP collaborative robot is powered with the 220V AC power supply, and it transmits signs with the Arduino ESP32 in both directions. The HC10DTP detects if there are items for loading in the desk and sends a sign to the Arduino ESP32, which transmits signs alerting if the maximum weight on the table is exceeded. When the HC10DTP detects there are no more items to load, send a sign to WISE-4060-B (This device gets a power supply of 24V directly through the collaborative robot). When the WISE-4060-B detects this sign it sends a digital sign to the Sherpa-B mobile robot for starting the loading mission.

Once the desk is fully loaded, the Arduino ESP32, by a digital pin, sends a sign to the Sherpa-B for starting the loading mission, and once there are no more items to load to the Sherpa send another sign for ending the loading mission process.

The load cells are connected to the HX711, which receives a current from the load cells that depends of the weight measured and converts this analogic sign to a digital sign which will be later transmitted to the Arduino ESP32 in order to interpretate the weight measured. The Arduino ESP32 uses this sign to detect the weight measured and send a sign to the LCD1602 Display so it writes on its board the weight measured (The LCD1602 Display is powered with 5V by the ArduinoESP32).

All modules share a common ground (GND) ensuring an adequate reference of electric potential in the system.

The signal connections are represented with green lines, while power lines 220V, 24V, and 5V are indicated in blue, orange and red respectively.

4.3 Algorithm of management of device or node

Algorithm managements refer to algorithmic systems that use tracked data and other information to organize, assign, monitor, supervise and evaluate work. (https://www.ilo.org/algorithmic-management-workplace)

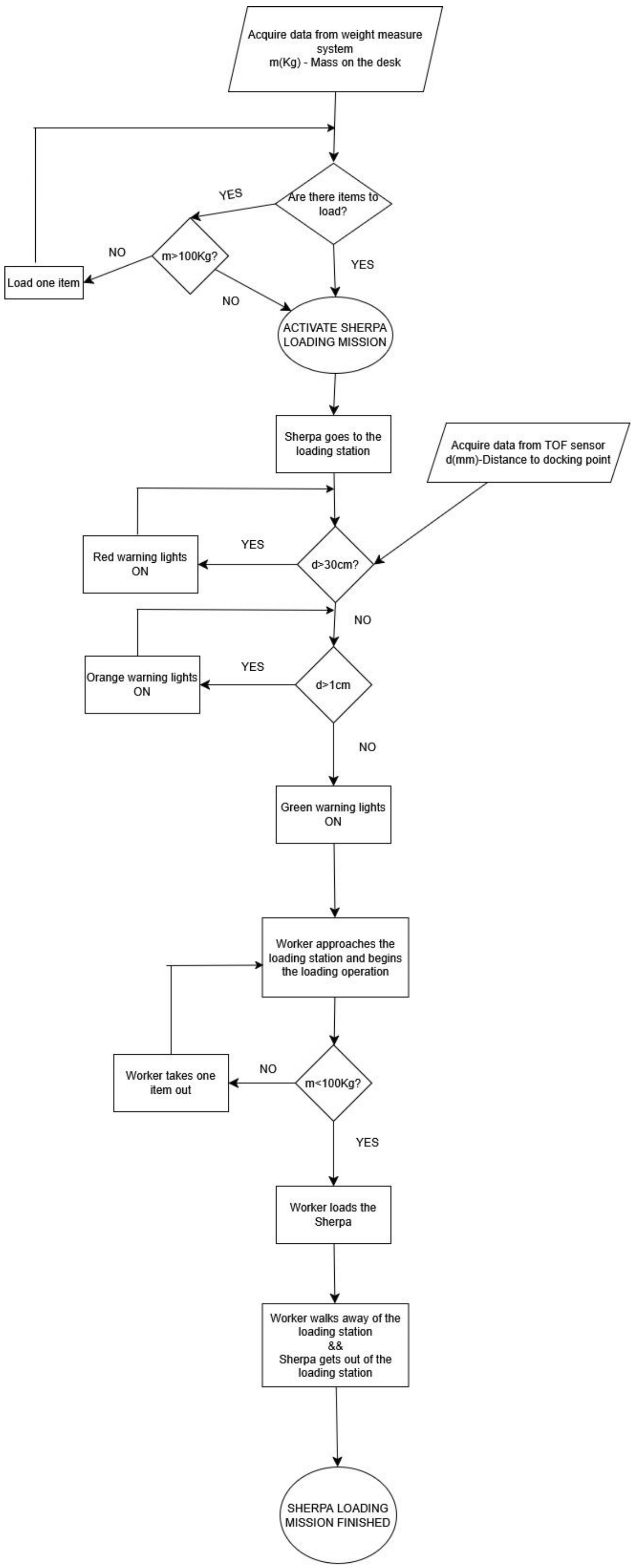

Fig. 4.3: Algorithm of management

In the case studied in this work, the algorithm will be based in the sherpa loading operation, from the acquisition of data detected by the sensors to adding the weight to the sherpa, considering the safety conditions such as the maximum weight that the robot supports.

The system has as input the data acquired from the weight detection system and the ToF sensor.

In the weight detection system firstly the four load cells established in the desk detect the weight that has been loaded on the desk of the loading station and gives an electric sign in function of the weight measured. The electric signs of the four load cells are added together. After that, the HX711 ADC converter changes the analogic sign given by the load cells and converts it into a digital sign of 24-bit precision. Lastly, the board shows the weight that the system has detected, so workers can observe the weight that the desk is supporting and prevent possible errors of the system.

For the measure detection system, the ToF laser range sensor measures the distance to Sherpa. The ToF sensor and the warning lights are connected to Arduino and, depending on how far the robot is from the docking point different warning lights colors will turn on. The warning lights will help the workers to know how far the Sherpa is from the optimize point to load it, knowing that the load can't be put on the robot until the warning lights turns green.

Even though it doesn't appear in the algorithm of management, there would be an emergency stop button. In case this button is pulsed, the process will stop immediately, and it will have to be restarted. This button should only be used in case of emergency.

In the algorithm of management, firstly the data of the weight detection system is acquired and MOTOMAN-HC10DTP puts one item in the loading station desk, and it will continue putting items on the desk until the desk is fully loaded (100Kg) or there are no more items to load. Once the items are on the desk, Sherpa initialize the loading mission and goes to the loading station approach zone and when it is in there it starts to move slowly to the docking point. Depending on the distance that the ToF sensor measures from the robot to the to the docking point the warning lights will change its color. If the distance from the Sherpa to the docking point is more than 30cm the red warning lights will turn on, once the sherpa is between 30cm and 1 cm from the docking point the orange warning lights will turn on until it gets to the docking point (Distance to the docking point less than 1 mm), where the green warning lights will turn on.

When the warning lights turn green, operators know it is secure to approximate to the docking station to start putting the different items on the Sherpa. However, before loading the sherpa, operators must observe the board to detect if the weight on the desk is bigger than the one that the Sherpa is able to support (100Kg). If this weight is exceeded, the operator should take items out until the weight is correct for starting to load the Sherpa.

Finally, when the sherpa is loaded. The operators must separate from the docking station and the sherpa path. In this moment, the loading operation is finished and the sherpa will start the next operation, probably the unloading mission, that can also be done in a similar structure like the docking station designed in this work.

5 WORK SAFETY

5.1 General provisions and requirements for safe working and environmental protection

To make sure a safe and correct operation of the Sherpa loading station it should be followed the following instructions and requirements:

Safe working instructions

- The Sherpa-B robot is designed to support a load of not more than 100Kg, so the load placed on the structure, even though it can support more than 100Kg, it should not exceed more than 100Kg.
- The load must not be placed in the Sherpa robot until the warning lights turn green (When the warning lights turn green, the robot is correctly positioned). Loading the robot before may cause errors in operation.
- Before first use, a recognition round through the working space must be done with the robot. This allows Sherpa to recognize the work environment and map the environment to precise location of the charging and the loading station. In case of that after the recognition round the robot doesn't detect the loading detection it must be added manually in the Road Editor map to ensure correct navigation and docking.

Structure Instructions

- The loading station must be installed on a flat and stable surface, making sure there's no dust or obstacles in that area.
- The rubber footpads must be properly in contact with the floor to prevent slippage.
- Until the robot is ubicated in the correct position a safety clearance of at least 50cm must be maintained around all sides of the station to ensure maneuvering space for the robot and safe conditions for human operators.
- These are the routine checks that should be done to ensure the proper functioning of the loading station:
  - Inspect the structure regularly for detecting signs of rust, deformation or loose joints.
  - Check that the rubber protections are correctly attached to the structure and intact.
  - Clear regularly the structure and surrounding areas for avoiding accumulation of trust that may interfere in the loading operation.

Environmental protection instructions

- Keep chemical substances away from the rubber parts and the steel structure to avoid degradation and contamination of the loading station.

- If the station is no longer in use, its parts must be recycled properly.
- The structure should be in dry, ventilated and indoor environments to minimize material wear and corrosion over time.

5.2 Work safety and environmental requirements

The creation and possible upgrading of the Sherpa loading station must comply some safety and environmental requirements for ensuring a secure working environment and minimize the ecological impact.

Basic alerts

- Before making any change or adjustment of the station, make sure the sherpa is off.
- Personnel must be aware of whether the robot is in autonomous or manual mode before approaching in order to be aware of possible unexpected moves.
- Avoid staying in the robot's path during loading or charging operations.
- Personnel must wear personal protective equipment (PPE), this includes safety footwear and gloves for being secure in assembly, modifying or structure maintenance operations.

Emergency stop button

- The system must include a clearly visible and accessible emergency stop button.
- In case this button is pulsed, the loading process will not be done, so the charge will not be put in the robot.
- In case the button is pulsed, the warning lights will turn red, and the buzz will be activated, making a noise for advising the alert.
- The button must be reset only if the situation has been reviewed and it's safe.
- It is recommended that the emergency stop button is regularly checked

Safety precautions when power is turned on

- Confirm that the robot's software recognizes the station location on its internal map.
- Eventually check that the sensors and the warning lights work correctly.

Security measures upon completion of work

- After any modification, assembly or inspection of the loading station:
    - Remove all tools and materials of the working zone.
    - Do a visual inspection to check the structural stability.
    - Restore the rubber parts to their original position and check their correctly assembled.
- Make a recognition round with the sherpa or actualize the robot map if the position or the measures of the loading station have changed.
- Document any intervention in the station's maintenance log.

Fire-security

- The station is made of non-flammable materials. However, fire precautions must still be followed.
- Keep the loading station, especially the sensors and other electronic devices, far from flammable materials.
- A portable fire extinguisher must be available and easily accessible in the laboratory.
- All laboratory processes and tests carried out in the laboratory or working space must be conducted in accordance with the *General Requirements for Occupational Safety and Health* approved by order No.A1-457 of the minister of Social Security and Labour of the Republic of Lithuania. (https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.403202?jfwid=32wf9xll)

6 ECONOMIC CALCULATION

The economic cost and profitability of the loading station for the Sherpa is studied in this chapter. In the next 6.1 table it would be shown the materials and electronic devices that form part of the loading station design. For calculating the necessary amount of each material it has been measured the weight of each part of the structure for being multiplied by the cost per Kg of each material

Table 6.1: Material cost

Number	Item	Quantity	Price per unit (€)	Sumary (€)
1	Arduino ESP32	1	20,40 €	20,40 €
2	Warning Lights HBJD 40-series	1	6,50 €	6,50 €
3	ToF Laser Range Sensor	1	21,23 €	21,23 €
4	Load Cells	4	12,99 €	51,96 €
5	HX711 DAC Converter	1	4,70 €	4,70 €
6	LCD1602 Display	1	16,49 €	16,49 €
7	S235JR	55009,5	1,25 €	68,76 €
8	ABS	16639,5	2,12 €	35,28 €
9	Rubber	21882.82	1.94 €	42.45 €
10	Standardized fastening elements			34,23 €
Total Price				**302 €**

The standardized fastening elements are bolts, screws and ore elements that are used for assembling the structure and have a standard measure, so instead of fabricating them they are bought. In the 6.2 table is shown the different standardized fastening elements used and their price.

Table 6.2: Standardized fastening elements cost

Number	Element	Rule	Measure	Quantity	Price per unit (€)	Sumary (€)
1	Equal leg angle Structural member	ISO	20x20x3x24	22	1,17 €	0,62 €
2	Hexobascular socket pan head screw	ISO 14583	M4x10x8.6-4,8N	44	0,17 €	7,48 €
3	Pan head cross recess screw	ISO 7045	M5x30-30s	32	0,25 €	7,87 €
4	Hex nut grade c	ISO 4034	M5-5	16	0,04 €	0,70 €
5	Plain washer normal grade a	ISO 7089	5	32	0,17 €	5,44 €
6	Hex thin nut fine grade ab	ISO-8675	M24xS	6	0,20 €	1,20 €
7	Socket screw flat point	ISO 4026	M24x60	6	0,11 €	0,66 €
8	Hex bolt grade ab	ISO 4014	M4x25x14-S	4	0,09 €	0,36 €
9	Hex thin nut chamfered grade ab	ISO-4035	M4-S	4	1,75 €	7,00 €
10	Hex bolt grade ab	ISO 4014	M6x35x18-N	12	0,11 €	1,35 €
11	Countersunk slotted raised head screw	ISO 2010	M3x16-16N	12	0,10 €	1,20 €
12	Hexalobular socket pan head	ISO 14583	M3x14x13-4.8N	4	0,03 €	0,12 €
13	Hex nut style 1 grade ab	ISO 4032	M3-W-N	4	0,04 €	0,15 €
14	Pan Head Cross recess screw	ISO 7045	M2x12	2	0,04 €	0,08 €
Standarized fastening elements (Total)						**34,23 €**

For fabricating the docking station, the process starts with the adquisition of the S235JR profiles for fabricating the structure and the desk. The S235JR profiles cost 1.25 €/kg. When the profiles are acquired, they must be cut and assembled. This process requires to use tools such as saws and drills, which is an equipment that consumes electricity. The electricity is estimated to have a cost of 0.075 €/h, based on an average consumption of 0.5KW per hour operation.

Another cost to consider is labor. Operators are required to perform the cutting, welding, and assembly tasks. An operator hourly cost 10 €/h, and the estimated time to manufacture one unit of the structure is 6 hours. This implies a labor cost of 60 € per unit.

Additionally, the rent of the store or laboratory must be taken into account, which is estimated at 1500 €/month. This fixed cost is distributed across the units produced each month, resulting in a cost of 57.69 € per unit if 26 units are produced per month.

The depreciation cost of the equipment used in the manufacturing process (cutting tools, welding equipment, etc.) should also be considered, calculated at 0.15 €/h of operation. Therefore, for the 6 hours of work per unit, an additional cost of 0.9 € per unit is added.

Lastly, the cost of additional materials and tools (such as screws and nuts) is included in the calculations. These costs, along with the costs of producing the structure, contribute to the total cost per unit of manufacturing the structure, as detailed in the following table:

Table 6.3: Variable and fixed costs

Concept	Value
Material cost	1.25 €
Electricity cost (€/kWh)	0.15 €
Average consumption (kW)	0.5 kW
Electricity cost per hour (€/h)	0.075 €
Operator hourly cost (€/h)	10.00 €
Operator cost per piece (€/piece)	60.00 €
Time to produce 1 unit (h)	6 h
Active days per year (days)	250 days
Active hours per day (h)	8 h
Depreciation cost per hour (€/h)	0.15 €
Rent (€/month)	1500.00 €
Units per month	26 units
Total cost per unit (€/unit)	57.69 €

At this moment the costs are defined. Fabricating each unit costs 421.19€. It is expected to have a profit of 100€, so each unit should be sold for 521.19€.

Table 6.4: Cost per unit

Cost per unit	Value
Material cost	302 €
Electric cost	0,45€
Workforce cost	60€
Amortization cost	1,35€
Local renting	57.69€
Net profit	63.17€
Total cost withouth profit	421.19€
Selling price	521.19€

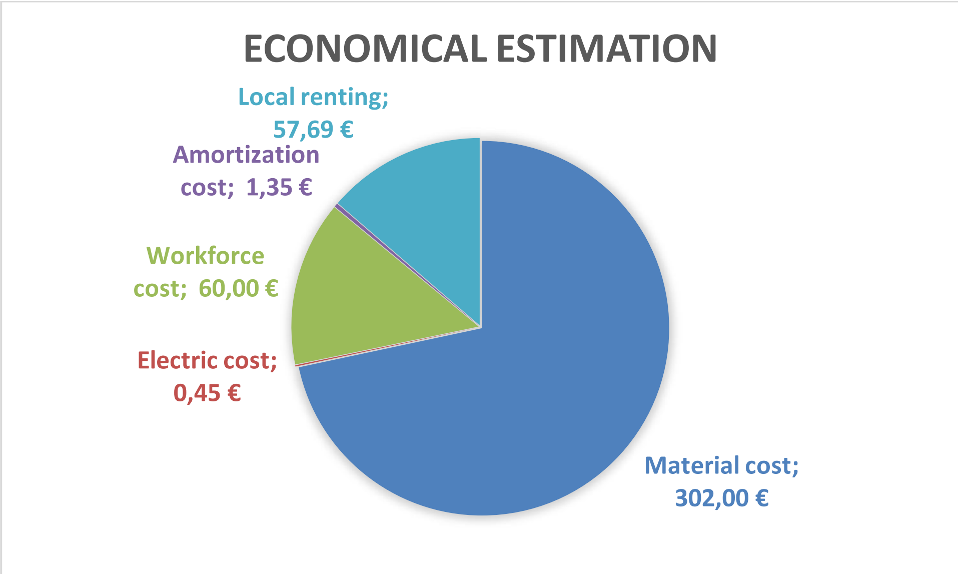

Fig. 6.1: Economical estimation per unit

Knowing the economical estimation and cost per unit it can be calculated the payback period. The equations that model the profit and costs are:

$$Cost(q) = Rent\ Cost + total\ cost\ withouth\ profit * q$$

$$Profit(q) = Selling\ price * q$$

$$q \rightarrow number\ of\ units\ sold$$

With the values calculated for the loading station it's obtained the following estimation:

$$Cost(q) = 1500 + 421.19 * q \quad (6.1)$$

$$Profit(q) = 484.36 * q \quad (6.2)$$

The intersection point symbolizes the units that need to be sold to start having profits (https://ecampusontario.pressbooks.pub/financemath/chapter/6-4-break-even-chart/).

$$Costs(q) = Profit(q) \quad (6.3)$$

$$1500 + 421.19 * q = 521.19 * q \quad (6.4)$$

$$q = 15\ units \quad (6.5)$$

$$Costs(q) = Profit(q) = 521.19 * 15 = 7817.85€ \quad (6.6)$$

Fig. 6.2: Costs VS Profit Char

The loading station designed presents several advantages over its possible competitors, making it an attractive option in the market. Firstly, it integrates advanced technology with load cells for weight measurement, ensuring the AMR robot safety so it can have a bigger life expectancy. The use of ToF sensors minimizes errors and increases operational efficiency, giving it a clear edge over competitors who lack this level of precision. Additionally, the station is designed for being used with the Sherpa-B robot, but it would also work with other AMRs, enhancing its compatibility and versatility in various industrial environments with different AMR robots. The station's design also is cheaper than the competitors' products, offering a more affordable solution for industries looking to optimize their automation systems without overspending. Furthermore, its ease of use and reliable performance reduce the need for specialized training, allowing for quick deployment in production environments.

CONCLUSIONS

1. The materials selected for designing the docking station are commonly available materials like S235JR, steel and rubber, making it affordable. However, it could be studied if some of the rubber protections could be eliminated as the Sherpa robot is designed for avoiding obstacles.
2. The electrical system has been designed to ensure efficient and safe operation. It integrates an Arduino ESP32 for controlling the sensors and actuators. The system is powered by a 5V DC source, and additional safety features like the emergency stop button have been incorporated to stop the system if necessary.
3. The simulations done in SolidWorks for proving the stability and safety of the structure confirm the structure can support the possible applied forces without any issues, but some of the values obtained like the FoS and the first natural frequency could be improved by changing the geometry of the structure, especially the weight measure system, changing it so the desk is fixed to the rest of the structure, making the structure more compact and stable.
4. Load cells and ToF (Time-of-Flight) sensors were selected over other comercial options due to their precision, price, and reliability. The load cells provide highly accurate weight measurements, which are crucial for ensuring that the robot does not exceed its weight capacity, augmenting its life expectancy. The ToF sensor was chosen for its high accuracy in distance measurement, which is an important aspect for establishing the Sherpa in the docking point accurately. Other potential alternatives, such as ultrasonic sensors or infrared sensors, were studied but not selected because of their price, technical conditions or accuracy.
5. An improvement could be made to automate the loading process. Instead of requiring an operator to manually load the items from the desk to the robot, a conveyor belt system could be integrated to automatically transfer the weight from the loading table to the robot. This would further reduce human intervention and streamline the entire operation, increasing efficiency and reducing the risk of errors during the loading phase. Although this modification could be made in the loading station designed, so it won't be necessary to fabricate or buy another docking station, it would only be necessary to make some changes to it. If the conveyor belt is considered a bad option, the collaborative robot used could be monitored for moving the charge from the loading station to the Sherpa robot.
6. Serpha loading station is primarily designed for doing the loading process, but it would be equally valuable for unloading purposes. By adding additional functionalities, such as a reversing mechanism or an automated unloading sequence, the station could be easily adapted to handle both loading and unloading operation, which would be an effective option. This flexibility would increase its utility and make it a more versatile component in logistics systems, further optimizing warehouse operations.

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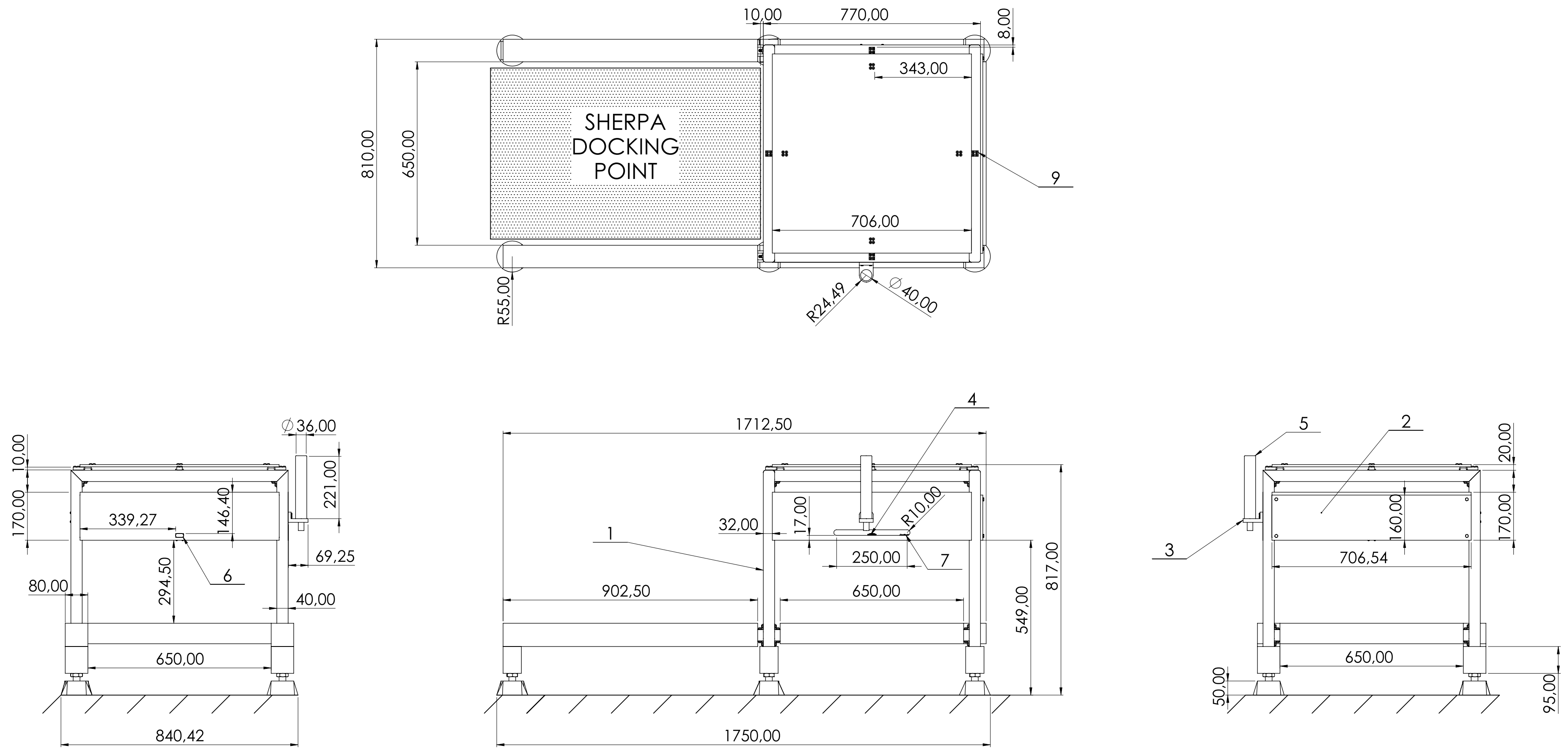
THE ANNEXES

Format	Zone	Position	Tag	Title	Qty.	Remarks
				Document		
A1			MERS BM 25 01 01 00 00 GV	General View	1	
				Subassemblies		
A3		1	MERS BM 25 01 01 00 01 00	S235JR Structure	1	
A3		2	MERS BM 25 01 01 00 02 00	Electronic box	1	
A3		3	MERS BM 25 01 01 00 03 00	Warning Lights base	1	
				Additional Components		
		4	MERS BM 25 01 01 00 04 00	Arduino ESP32	1	
		5	MERS BM 25 01 01 00 05 00	Warning Lights HBJD-40	1	
		6	MERS BM 25 01 01 00 06 00	ToF Laser Range Sensor	1	
		7	MERS BM 25 01 01 00 07 00	HX711 ADC converter	1	
		8	MERS BM 25 01 01 00 08 00	LCD 1602 Display	1	
		9	MERS BM 25 01 01 00 09 00	Load Cell 50Kg	4	

Respon.depart. FMF DIG	Adviser	Document type Specification	Status of the document Educational
Owner Vilnius Tech	Prepared by Pablo Martín Approved by	Title Loading sation general view drawing	Tag MERS BM 25 01 01 00 00 GV Issue A · Date 2025-05-08 · Lang. En · Page 1/1

Format	Zone	Position	Tag	Title	Qty.	Remarks
				Document		
A1			MERS BM 25 01 01 01 01 AD	Assembly drawing	1	
				Subassemblies		
A3		1	MERS BM 25 01 01 01 01 01	S235JR Structure	1	
A3		2	MERS BM 25 01 01 01 01 02	Electronic box	1	
A3		3	MERS BM 25 01 01 01 01 03	Warning Lights base	1	
				Additional Components		
		4	MERS BM 25 01 01 01 01 04	Equal leg angle Structural member 20x20x3x24	22	
		5	MERS BM 25 01 01 01 01 05	Screw ISO14583 M4x10x8.6-4.8N	44	
		6	MERS BM 25 01 01 01 01 06	Screw ISO7045 M5x30-30s	32	
		7	MERS BM 25 01 01 01 01 07	Hex nut ISO4034 M5-5	16	
		8	MERS BM 25 01 01 01 01 08	Plain Washer ISO7089 5	32	
		9	MERS BM 25 01 01 01 01 09	Hex nut ISO8675 M24xS	6	
		10	MERS BM 25 01 01 01 01 10	Socket screw ISO4026 M24x60	6	
		11	MERS BM 25 01 01 01 01 11	Hex bolt ISO4014 M24x25x14-S	4	
		12	MERS BM 25 01 01 01 01 12	Hex nut ISO4035 M4-S	4	
		13	MERS BM 25 01 01 01 01 13	Hex bolt ISO4014 M6x35x18-N	12	
		14	MERS BM 25 01 01 01 01 14	Screw ISO2010 M3x16-16N	12	
		15	MERS BM 25 01 01 01 01 15	Hexobascular socket ISO14583 M3x14x13-4.8N	4	
		16	MERS BM 25 01 01 01 01 16	Hex nut ISO4032 M3-W-N	4	
		17	MERS BM 25 01 01 01 01 17	Pan head cross screw ISO7045 M2x12	2	

Respon.depart. FMF DIG	Adviser	Document type Specification		Status of the document Educational			
Owner Vilnius Tech	Prepared by Pablo Martín	Title Docking Station assembly drawing	Tag MERS BM 25 01 01 01 01 AD				
	Approved by		Issue A	Date 2025-05-14	Lang. En	Page 1/1	

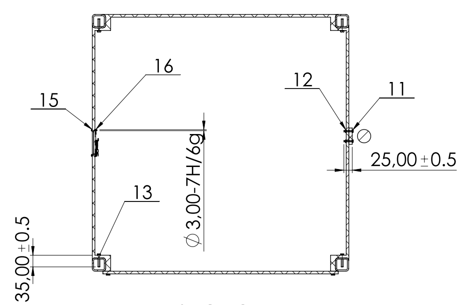


- The Serpha docking station functions as a precise loading and docking area for the Serpha-B robot.
- The robot autonomously approaches the station, where it uses LiDAR sensors and ToF sensors to navigate and align itself accurately.
- Once the robot is correctly positioned, the load cells measure the weight placed on the station, ensuring it does not exceed the robot's capacity.
- The system is designed to automatically start the loading process once the robot is in position.
- Additionally, the station can be adapted for both loading and unloading operations, increasing its versatility in logistics environments.

File No.	Aditional information	Material	Scale 1:8
Respon. depart. Dep. of mech., rob, and dig. man.	Adviser	Document type	Status of the document Educational
Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin; Approved by	Title: General View	MERS BM 25 01 01 00 00 GV; Issue 1, Date 2025-05-08, Lang. Eng., Page 1/8

MERS BM 25 01 01 00 00 GV

MERS BM 25 01 01 01 00 AD



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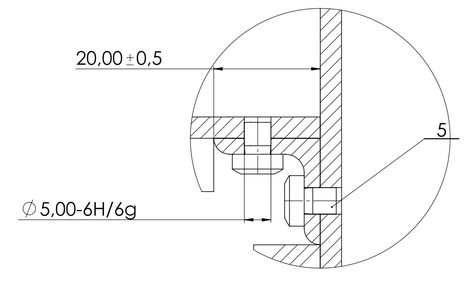
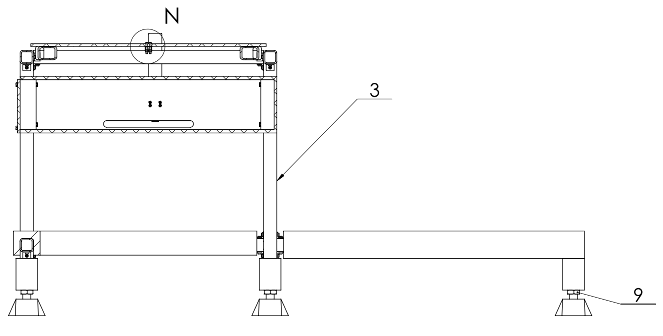


DETAIL B
SCALE 2 : 1



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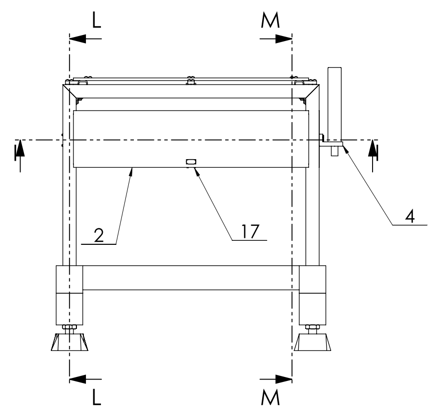

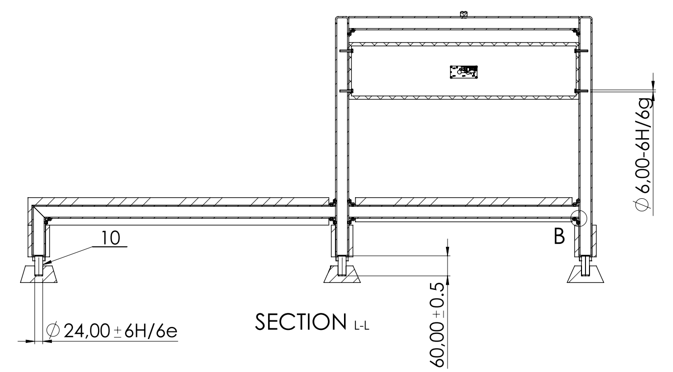

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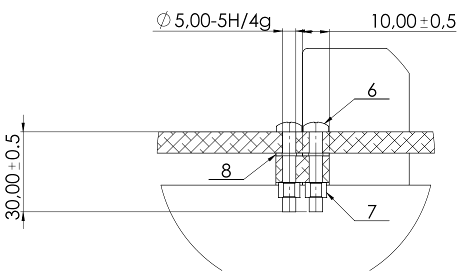


DETAIL N
SCALE 1 : 1

1. The structure is designed to hold an Arduino controller, an HX711 amplifier and a display module in the electronic box. For Arduino ESP32 and hx711 it has been used ISO 2010-M3x16-16N bolts and for the LCD1602 Display it has been used ISO14583 M3x14x13-4,8N bolts and ISO 4032-M3-W-N hex nuts. The tolerances for this connections are 7H/6g

2. Mounting holes are drilled to fit M3 bolts.
Tapped holes (ISO metric thread M3x0.5) use class 6H internal thread tolerance.
Screws are ISO 14583 M3x14 - 4.8N with external thread tolerance 6g.

3. All structural members are cold-formed square tubes of 40x40x4 mm (steel S235JR), cut to lenght with ISO 2768-m tolerances.

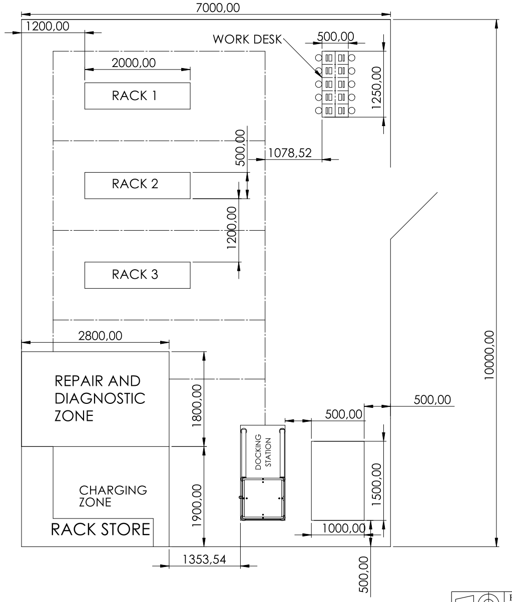
4. Electronic modules such as the HX711 and the display are soldered directly to the support box base, avoiding mechanical fixation.

5. All welds (where applicable) must be continuous, clean and made by MIG/MAG welding following ISO 9696 standard for small structures.
Welding gaps should not exceed 0.5 mm between joined surfaces.

7. Assembly must ensure components are not subjected to residual mechanical stress after tightening or soldering.

	File No.	Aditional information	Material	Scale 1:8
Respon. depart. Dep. of mech., rob. and dig. man.	Adviser	Document type		Status of the document Educational
Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin Approved by	Title Assembly		MERS BM 25 01 01 01 00 AD Issue 1 / Date 2025-05-08 / Lang. Eng. / Page 2/8

MERS BM 25 01 01 00 WD



- This is the proposed design for a potential warehouse where two Sherpa-B robots operate, capable of working in both Follow-me mode and autonomous docking mode.
- The layout is sized to safely and efficiently accommodate up to 10 operators working simultaneously.

File No.	Additional information	Material		Scale 1:50
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type		Status of the document Educational drawing
Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin	Title Workcell Distribution		MERS BM 25 01 01 00 WD
	Approved by			Issue A, Date 2025-05-08, Lang. Eng., Page 3/8

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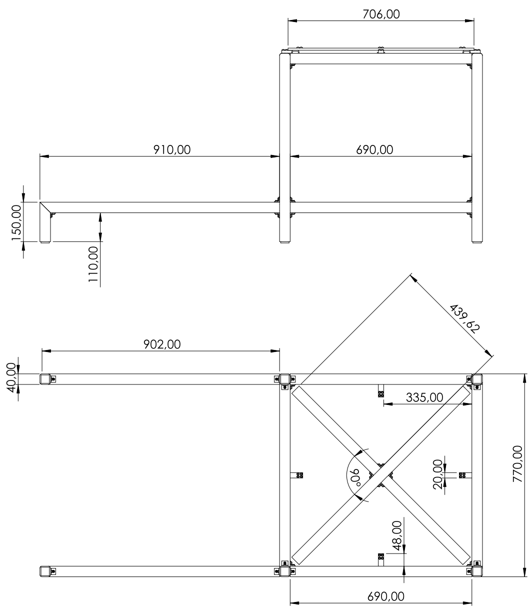
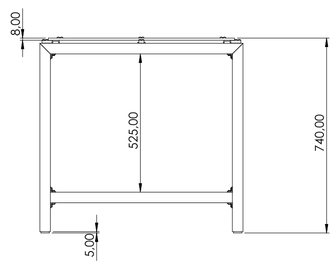
MERS BM 25 01 01 00 01 SS





- The structure is entirely built using square hollow steel sections of 40x40x4 mm, manufactured from S235JR structural steel (EN 10025).
- The table and the supporting frame are connected by bolting through four load cells, which are used to measure the weight of the load placed on the table surface.
- Load cells are mounted between the upper frame (table) and the lower base structure, ensuring mechanical stability while allowing accurate weight sensing.

File No.	Additional information	Material S235JR		Scale 1:10
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type		Status of the document Educational drawing
Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin	Title Structural Scheme		MERS BM 25 01 01 00 01 SS
	Approved by			Issue A, Date 2025-05-8, Lang. Eng., Page 4/8

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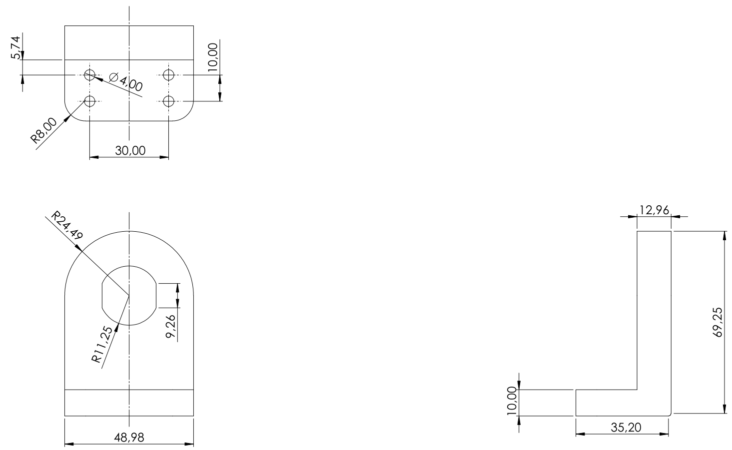
MERS BM 25 01 01 03 WB



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Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin	Title Warning-Lights Base		MERS BM 25 01 01 03 WB
	Approved by			Issue A, Date 2023-04-18, Lang. Eng., Page 5/8

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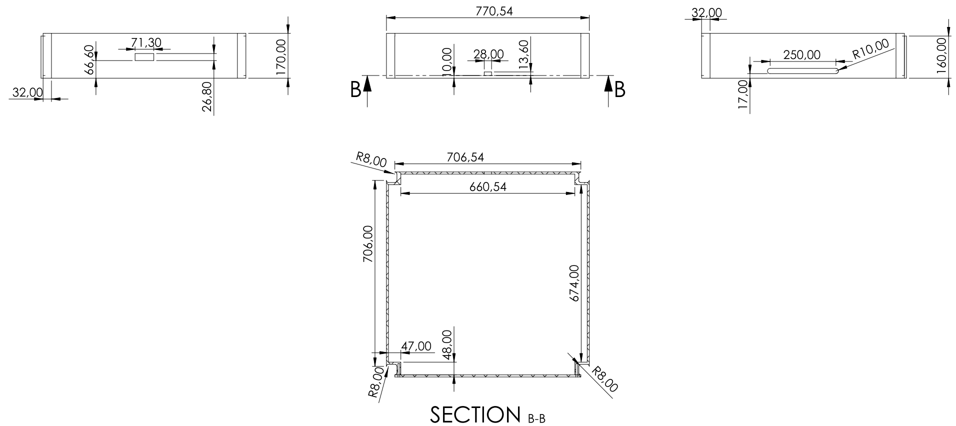
MERS BM 25 01 01 02 BE



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Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martin	Title Box for Electronic devices		MERS BM 25 01 01 02 BE
	Approved by			Issue A, Date 2025-05-08, Lang. Eng., Page 6/8

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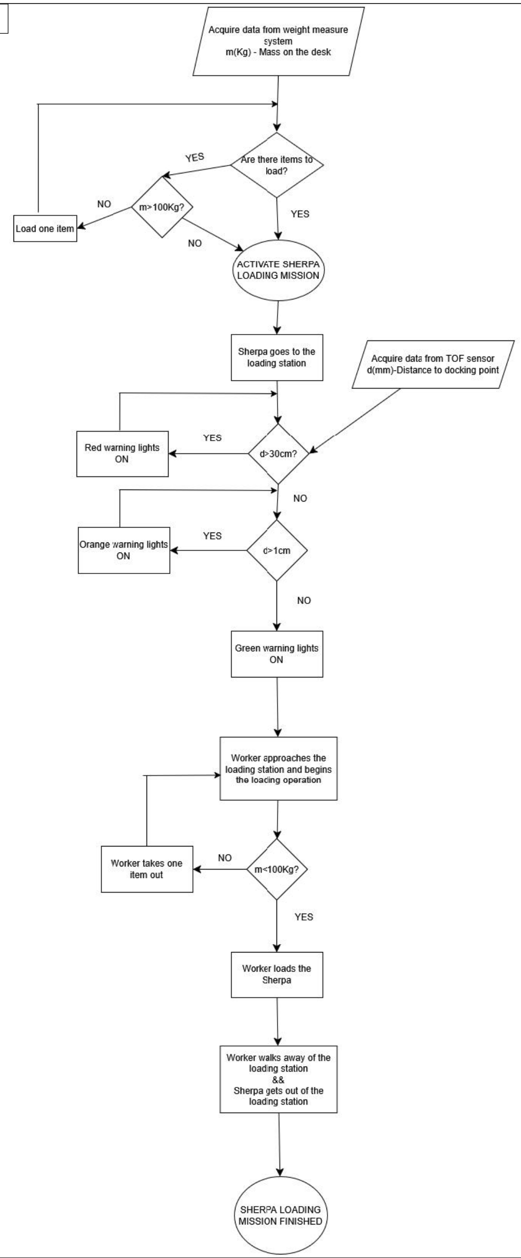

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Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martín	Title Operation Algortihm	MERS BM 25 01 01 00 OA			
	Approved by		Issue A	Date 2025-05-08	Lang. Eng.	Page 7/8

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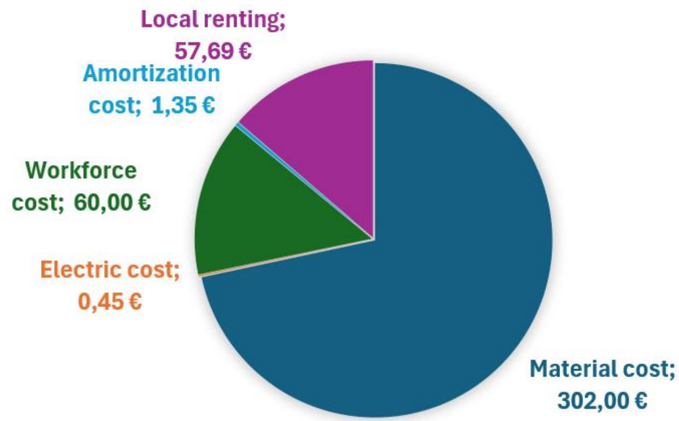
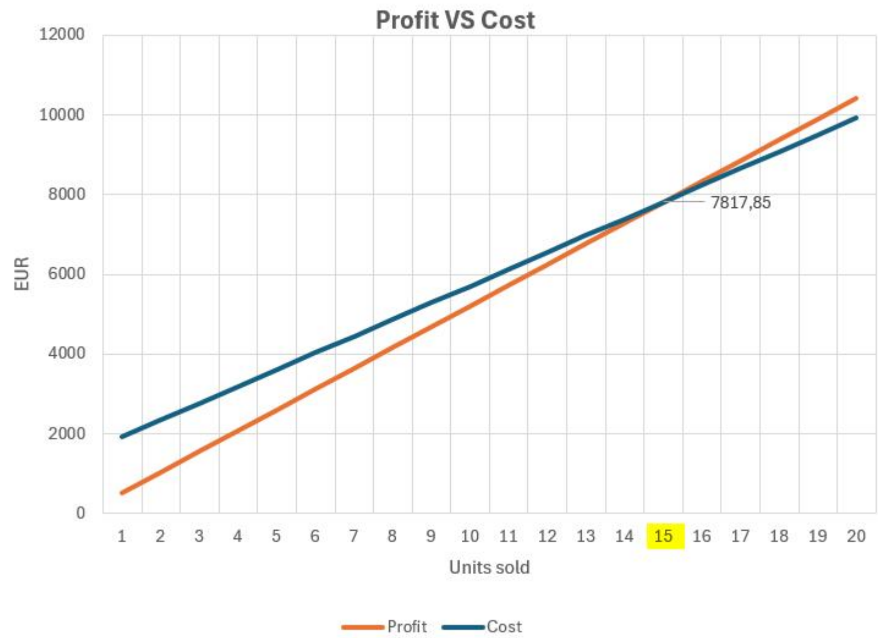
ECONOMICAL ESTIMATION PER UNIT





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Owner VILNIUS TECH MRfu-21	Prepared by Pablo Martín	Title Economic indicators	MERS BM 25 01 01 00 EI			
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