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Sistema de Automatización Industrial para Lean Manufacturing

Autor:

González García, Jorge

Ángel Manuel Gento Municio

Universidad de Coímbra

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ALUMNO:	Jorge González García
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TUTOR:	Jérôme Mendes

Resumen

Español

Este trabajo consiste en el desarrollo e instalación de un sistema de automatización industrial para gestionar la reposición de piezas del almacén a las estaciones de trabajo en una planta de producción, siguiendo el método Kanban japonés.

El objetivo principal es crear un sistema electrónico Kanban(E-Kanban) versátil para el Factory Lab de la Universidad de Coimbra, que gestiona dos métodos de reposición: Kitting y Line Stocking. Este sistema automatiza el proceso de reposición, señalando en tiempo real qué piezas se necesitan y en qué estación de trabajo, garantizando una producción continua, reduciendo tiempos de ciclo y minimizando errores humanos.

El E-Kanban ha mejorado significativamente la eficiencia, asegurando la disponibilidad de piezas, reduciendo tiempos de espera y proporcionando retroalimentación visual. Su adaptabilidad a la demanda dinámica lo convierte en una herramienta clave para la mejora continua, alineada con los principios de Lean Manufacturing.

Palabras Clave: Lean Manufacturing, E-Kanban, Kitting, Line Stocking, Automatización.

Inglés

This work involves the development and installation of an industrial automation system to manage the replenishment of parts from the warehouse to workstations in a production plant, following the Japanese Kanban method.

The main objective is to create a versatile electronic Kanban (E-Kanban) system for the Factory Lab at the University of Coimbra, which manages two replenishment methods: Kitting and Line Stocking. This system automates the replenishment process, signaling in real time which parts are needed and at which workstation, ensuring continuous production, reducing cycle times, and minimizing human errors.

The E-Kanban system has significantly improved efficiency by ensuring part availability, reducing waiting times, and providing visual feedback. Its adaptability to dynamic demand makes it a key tool for continuous improvement, aligned with Lean Manufacturing principles.

Key words: Lean Manufacturing, E-Kanban, Kitting, Line Stocking, Automation.

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Jorge González García

Industrial Automation System for Lean Manufacturing

Dissertation within the scope of the Master's degree in Industrial Engineering and Management supervised by Doctor Jérôme Mendes and Professor Doctor Cristóvão Silva and presented to the Department of Mechanical Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

July 2024

University of Coimbra
Faculty of Sciences and Technology
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Abstract

This work involves development and installation a multidisciplinary industrial automation system to manage the replenishment of parts from the warehouse to workstations in a manufacturing production plant, following a parts replenishment methodology using the Japanese Kanban method. In the Lean Room of the Factory Lab at the University of Coimbra, there are workstations where products need to be assembled. Effective management of replenishing parts from the warehouse to the workstations is essential when these parts run out. The project includes studying the problem, identifying objectives, analyzing the market for existing commercial solutions, selecting hardware, developing software, designing in 3D, conducting functional tests, and installation.

The main objective is to develop a versatile electronic Kanban (E-Kanban) system for the Factory Lab at the University of Coimbra. This system manages two replenishment methods: kitting and line stocking, controlling the replenishment of materials at workstations by automatically signaling in the warehouse which parts are needed and at which workstation, thus ensuring continuous production, reducing cycle times, and minimizing human errors.

The E-Kanban system has significantly improved production efficiency by automating the replenishment process, ensuring parts availability, reducing waiting times, and minimizing errors through real-time management and visual feedback. The system's adaptability to dynamic demand enhances its functionality, aligning with lean manufacturing principles by maximizing value through waste elimination and continuous improvement.

The system has effectively enhanced production efficiency and demonstrated its potential for future innovation. Its ability to manage different replenishment methods, provide real-time feedback, and adapt to changing demands ensures sustained competitiveness and operational excellence, laying a solid foundation for ongoing improvements in production processes.

Key words: Lean Manufacturing, E-Kanban, Kitting, Line Stocking, Automation, Pick to Light.

Resumo

Este trabalho envolve o desenvolvimento e instalação de um sistema de automação industrial multidisciplinar para gerir o reabastecimento de peças do armazém para as estações de trabalho numa fábrica de produção, seguindo uma metodologia de reabastecimento de peças utilizando o método Kanban japonês. Na Sala Lean do Laboratório de Fábrica da Universidade de Coimbra, existem estações de trabalho onde os produtos precisam ser montados. A gestão eficaz do reabastecimento de peças do armazém para as estações de trabalho é essencial quando essas peças acabam. O projeto inclui estudar o problema, identificar objetivos, analisar o mercado de soluções comerciais existentes, selecionar hardware, desenvolver software, projetar em 3D, realizar testes funcionais e a instalação.

O principal objetivo é desenvolver um sistema versátil de Kanban eletrônico (E-Kanban) para o Laboratório de Fábrica da Universidade de Coimbra. Este sistema gere dois métodos de reabastecimento: kitting e line stocking, controlando o reabastecimento de materiais nas estações de trabalho ao sinalizar automaticamente no armazém quais peças são necessárias e em qual estação de trabalho, garantindo assim a produção contínua, reduzindo os tempos de ciclo e minimizando erros humanos.

O sistema E-Kanban melhorou significativamente a eficiência da produção ao automatizar o processo de reabastecimento, garantindo a disponibilidade de peças, reduzindo tempos de espera e minimizando erros através da gestão em tempo real e feedback visual. A adaptabilidade do sistema à demanda dinâmica aumenta a sua funcionalidade, alinhando-se aos princípios da manufatura enxuta ao maximizar o valor através da eliminação de desperdícios e melhoria contínua.

O sistema melhorou eficazmente a eficiência da produção e demonstrou o seu potencial para futuras inovações. A sua capacidade de gerir diferentes métodos de reabastecimento, fornecer feedback em tempo real e adaptar-se às demandas em mudança assegura competitividade sustentada e excelência operacional, estabelecendo uma base sólida para melhorias contínuas nos processos de produção.

Palavras-chave: Manufatura Lean, E-Kanban, Kitting, Line Stocking, Automação, Pick to Light.

Contents

List of Acronyms

3D Three-Dimensional.

CAD Computer-Aided Design.

FL Factory Lab.

GPIO General Purpose Input/Output.

GUI Graphical User Interface.

HMI Human-Machine Interface.

IP Internet Protocol.

JIT Just in time.

KT Kitting.

LED Light-emitting diodes.

LM Lean Manufacturing.

LS Line Stocking.

MiR Mobile Industrial Robots.

PLA Polylactic Acid.

PLC Programmable Logic Controller.

RFID Radio Frequency Identification.

RGB Red Green Blue.

UC University of Coimbra.

USB Universal Serial Bus.

WH Warehouse.

Wi-Fi Wireless Fidelity.

WS Workstation.

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Chapter 1

Introduction

In order for the students to learn different aspects of how the industry works, the University of Coimbra is setting up a new educational space called "Factory Lab (FL)" under the concept of Factory learning. This project was developed on Factory Lab. The FL consists of a laboratory that will replicate different parts of a modern industrial production plant. Factory Lab is a long-term project that seeks to be a space in constant development and at the service of learning. It is intended that in a few years, it will be a great learning tool for university students. The Factory Lab has three main spaces: Robotics, a Lean Room, Virtual Control, and Augmented Reality. This project was developed in the Lean Room (see Figure 1.1).

Regarding to the Lean Room, it intends to replicate a manufacturing production line of modern industry. For this purpose, many items have been purchased from item Gmbh, a German company with a wide range of professional items for lean production and other solutions. Among the items in the Lean Room, we find:

- Multiple workbenches so that students can actively experience what it is like to participate in an assembly line.
- Trays for storing, sorting and transporting the parts to be used in the assembly as well as the parts already assembled.
- Several storage racks, with the objective of creating a warehouse that will house the trays containing the parts, ready to be transported to the workstations.
- Trolleys to transport the trays containing the parts to where they are needed.
- Other elements related to lean production, such as Karakuris, rail systems, etc.

1.1 Problem formulation and motivation

In a manufacturing plant, it is crucial that operators stay focused exclusively on assembly tasks rather than being distracted by the need to replenish parts. Replenishment should be managed by a dedicated operator to ensure continuous production flow. Inefficient parts replenishment can lead to increased cycle times, causing delays in the manufacturing process. Production interruptions occur when assembly line operators run out of necessary components, disrupting the workflow and reducing overall throughput. Human errors in replenishment can result in incorrect inventory levels and misplaced components, further affecting production efficiency and product quality.

Figure 1.1: Lean Room of the Factory Lab

Figure 1.2: Students Working at the Lean Room of the Factory Lab

Effective management of replenishment information is therefore essential, ensuring that the replenishment operator can accurately and efficiently handle parts inventory. Additionally, the physical distance between workstations and the warehouse can pose logistical challenges in communicating replenishment needs promptly and accurately. This underscores the importance of streamlined processes and effective communication systems to maintain production efficiency, reduce operational costs, and minimize human errors.

In a manufacturing plant, it is crucial that operators stay focused exclusively on assembly tasks rather than being distracted by the need to replenish parts. Replenishment should be managed by a dedicated operator to ensure continuous production flow. One of the key challenges in replenishment operations is the potential for human error. Mistakes made during replenishment can significantly disrupt the production process, leading to delays and increased costs. Effective management of replenishment information is therefore essential, ensuring that the replenishment operator can accurately and efficiently handle parts inventory. Additionally, the physical distance between workstations and the warehouse can pose logistical challenges in communicating replenishment needs promptly and accurately. This underscores the importance of streamlined processes and effective communication systems to maintain production efficiency.

The idea of the creation of the Lean Room in the "Factory Lab" (FL) at the University of Coimbra is to provide a practical learning experience that imitates the operations of a modern manufacturing plant. This initiative involves several manufacturing workstations where students can engage in the assembly of various parts (see figure 1.2). Additionally, a warehouse has been set up with shelves to store these parts, and essential components of a manufacturing production plant have been incorporated. From these elements, the students will be able to get involved in the execution of different replenishment methods allowing them to understand and compare them, increasing their knowledge about modern manufacturing processes and Lean Management principles.

Two replenishment methods are intended to be used for the replenishment of parts at the workstations in the Lean Room: kitting and line stocking:

- Kitting involves collecting all materials required for an assembly and delivering them to the workstation as a single package.

- Line stocking places individual parts directly at the workstation in quantities sufficient to meet production needs.

In today's industry there is an important need to enhance manufacturing efficiency. Effective management of production processes directly impacts a company's competitiveness by reducing costs, minimizing production delays, and improving overall operational efficiency. This enables companies to remain competitive by reducing operational costs, minimizing waste, and ensuring timely delivery of products. From this need arises Lean Management, a work philosophy that focuses on maximizing value by eliminating waste and continuously improving processes. It aims to streamline production, reduce costs, and increase efficiency, thus enhancing a company's overall competitiveness.

As the world leans towards digitalization, electronic automation systems for managing processes have become essential in improving efficiency and reducing production costs in the industry. These systems are increasingly implemented to manage various production activities. For managing parts replenishment, E-Kanban systems are commonly used. The E-Kanban system, derived from the Kanban method in Lean Management, is an electronic method for managing parts replenishment at workstations. It signals when parts are needed, displays relevant information in the warehouse, and allows operators to request parts quickly and remotely. This ensures continuous production, reduces delays, and minimizes human errors by efficiently guiding the warehouse operator and managing data.

One key improvement sought with the installation of such systems in production plants is to speed up the parts replenishment process, reduce cycle times, and minimize production interruptions. Utilizing technology to manage inventory and guide operators will significantly reduce human errors, leading to more reliable and consistent production output. According to Lean Management principles, effective inventory management and waste reduction are crucial to lowering production costs, making the company more competitive in the market.

This technology aligns with the broader goals of Industry 4.0, promoting digitization and the integration of advanced technologies to create more efficient, flexible, and sustainable manufacturing environments.

1.2 Objectives and developed work

Once in the situation and with the requested requirements in mind, the following main objective is to develop a versatile electronic Kanban (E-Kanban) system for the Factory Lab that can efficiently manage the two distinct replenishment methods: kitting and line stocking. The system will control the flow of materials in the manufacturing process by signaling at the wharehouse when parts are needed at the workstations. This will allow operators to signal the need for parts replenishment quickly and remotely from their workstations, ensuring continuous production without delays. The system must handle the complexity of signaling, guiding the warehouse operator, and managing data effectively to avoid human errors and optimize the overall production process.

The system must be independent of commercial solutions produced by external companies to maintain control and adaptability. Moreover, it should be educationally effective, providing students with a clear understanding of modern manufacturing processes and methodologies, including the selection and organization of replenishment methods, the layout and replenishment of workstations.

The project aims to leverage Lean Management principles, specifically the Kanban method, to reduce cycle times, and minimize production interruptions and reduce human errors, leading to more reliable and consistent production output.

The main contributions and developed work were:

1st. Market research

The first step in this project involved conducting extensive market research to gather ideas about the currently commercialized solutions used in the industry for similar purposes. This research was performed to seek for existing technologies, methodologies, and products for the development of the proposed system.

2nd. System definition and organization

After the initial research, it was defined the system to be developed. This includes determining the organization methodologies for the system, understanding how it will function, and specifying the requirements across different areas. This phase is crucial for establishing a clear blueprint of the system to be developed.

3rd. Component selection

Once the system was conceptualized, a second round of market research was done to find the electronic components that meet our requirements at the best possible price. This includes selecting the most suitable technologies, such as connection networks and protocols, that will be used in the system.

4th. Software development

The next step involved developing a software solution that connects the components and provides the required functionalities to the system. This software must be capable of interconnecting heterogeneous industrial and electronic components, which requires meticulous development and testing to ensure reliability and performance.

5th. Installation and integration

Following the development phase, the selected components were installed and interconnected according to the system design. This step involved the practical assembly of the system within the Factory Lab, ensuring that all components work together seamlessly.

6th. Testing and optimization

Finally, the completed system underwent rigorous tests to verify that it meets all specified requirements. This ensures that the system functions as intended and provides a reliable and effective learning tool for students.

1.3 Project Structure

The structure of the document is divided into 6 chapters. The information in the remaining chapters will be organized as follows:

- The Chapter 2 presents the state of the art. This includes a literature review and an explanation of the importance of the problem being studied, putting into context the different methods of replenishment and management of manufacturing production plants in modern industry. It covers concepts such as manufacturing efficiency, lean management, Kanban systems, and replenishment methods including kitting and line stocking.

- The Chapter 3 presents the Case Study. It describes the development of the solution in the factory lab, detailing the elements available, the initial planning, and the specific methodologies used in the implementation of the kitting and line stocking methods. Additionally, it includes a brief market study to understand the technologies currently used in the industry for similar purposes, which helps in selecting the appropriate technologies and methodologies for the project.

- The Chapter 4 presents the implementation. It outlines the main objective of the electronic solution and the hardware selection process, which includes a detailed market study for each component to ensure the best possible choices in terms of performance, cost, and compatibility. It also explains the software development, 3D design, and the practical assembly of the system within the factory lab. Finally, it details the installation process carried out and presents the results and performance of the system.
- Finally, in Chapter 5 It evaluates how well the system met the initial objectives and requirements. It provides a summary of the findings, the implications of the results, and potential improvements for the system. It also discusses possible future updates and expansions, including the integration of new technologies and additional functionalities to enhance the system's capabilities and educational value.

Chapter 2

Literature review and concepts

With the objectives defined, we will do a brief review of the literature to explain the importance of the problem that is being studied and put into context the different methods of replenishment and management of manufacturing production plants in modern industry.

2.1 Manufacturing Efficiency in the Modern Industry

The improvements of manufacturing efficiency in modern industry are essential in order to get more efficient production rates and to minimize costs as much as possible. To this end, it is crucial to select the appropriate workstation layout and methods of replenishing. This is because the degree of production efficiency is directly proportional to the competitiveness of the company in the market, and, therefore, it is essential to examine the various replenishment strategies to determine which one is most effective.

Workstation configuration

The organization of workstations is one of the crucial elements within a plant to ensure that continuity and efficiency of production are maintained. As Groover [1] rightly notes, carefully designed workstations enable the sequence of operations to be smooth and decrease the time between operations. Furthermore, Tompkins et al. [2] also points out that well-designed workstations helps in minimizing the cycle time, and thereby increasing the working time which is essential to meet the market requirements. Reduced cycle times will have a direct impact on the market competitiveness as well.

Parts replenishment from a warehouse

Internal supply logistics, especially the replenishment of parts from a warehouse, is critical to maintaining production continuity and efficiency. According to Slack et al. [3], an effective replenishment system ensures that workstations receive the necessary materials at the right time, thus avoiding costly delays in production. Krajewski et al. [4] emphasize that a well-managed inventory system significantly reduces the probability of supply chain disruptions, which is essential for maintaining a steady and efficient production rate.

In summary, a good workstation configuration and an efficient parts replenishment system are essential to optimize the production process. These factors not only improve operational efficiency but also play an important role in the company's competitiveness to meet market demands. Innovation and continuous improvement in these aspects will be decisive for the future of manufacturing.

2.2 Lean Management

Lean Management, originating from the Toyota Production System, is a work philosophy focused on optimizing efficiency, reducing waste, and offering maximum value to customers. This management approach has revolutionized manufacturing and various other industries by promoting continuous improvement and efficient resource utilization. Let's see how Lean Management can add value to the line production operations.

2.2.1 What is Lean Management?

Lean Management is a systematic methodology that enhances customer value by eliminating unnecessary activities and improving process efficiency. The primary goal is to create more value with fewer resources through continuous improvement and adapting production to customer demand. [5]

There are some core principles that identify lean management and we are going to look at them from the point of view of the authors K. Liker [6] and P. Womack et al[7]:

1. Identify what the requirements are from the customer's perspective: understand what exactly the customer wants and needs in order to identify the activities that really add value to achieve it. [6]

2. Value Stream Mapping: identify the flow of materials and activities that lead to the creation of a product or service. This involves identifying all the steps involved in production in order to distinguish between those that add value and those that do not. [7]

3. Creating flow: ensure that production has no breaks or delays. This principle seeks to eliminate bottlenecks and guarantee the continuous movement of elements within the production line. [7]

4. Establishing a Pull System: implement an on-demand system where production is driven by actual customer demand. This avoids overproduction and allows us to really adjust to the customer's requirements. [6]

5. Pursuit of continuous improvement: continuously evaluate processes to look for aspects to optimize and processes that no longer provide value. This will allow a production line in constant development. [6]

These principles can help a company significantly reduce its production times and associated costs. Liker [6] highlights in his book "The Toyota Way" how the implementation of Toyota's 14 management principles, based on lean management, has allowed the company not only to significantly reduce costs, but also to improve the efficiency and flexibility of its production processes. The adoption of techniques such as Value Stream Mapping and the pull system has been vital to achieving these results.

This proves that applying these principles in my project to seek efficiency and continuous improvement within our production plant can be beneficial.

2.2.2 Lean Manufacturing Tools

Lean manufacturing, based on the Toyota Production System, focuses on eliminating all activities that do not add value to the production process. From this method limited only to production, the principles were extrapolated to all areas of a company, and lean management emerged.

Lean Manufacturing uses a variety of tools and techniques to identify and eliminate waste, improve efficiency and optimize production processes. Two of the most important and widely used tools in Lean Manufacturing are:

- Just-In-Time (JIT): JIT is a production methodology that reduces inventory and lead times by producing only what is needed, when it is needed, and in the quantity needed.

- Kanban: Kanban is a visual management system that uses cards to signal the need to produce more material or move materials inside a production process

As the U.S. Environmental Protection Agency points out [8], these two tools combined contribute to produce only what is necessary and thus reduce the called "waste" in terms of production time and cost. It also reduces the required input inventory as well as the required post-production inventory. This also leads to less material waste due to production errors, which is a crucial aspect to minimize if a company wants to have optimal production and be competitive.

2.3 Kanban System

2.3.1 What is Kanban System?

Kanban is a crucial tool in lean manufacturing that helps achieve minimal inventory levels and improve overall efficiency. The term "Kanban" is Japanese for "visible record", and it refers to a signaling system using cards to activate the production based on actual demand, not a prediction. This ensures materials are produced or moved only when needed, minimizing waste and optimizing resource use.

According to Abdul Rahman et al. [9], Kanban systems offer numerous operational benefits, including enhanced productivity and reduced waste. By using Kanban cards to signal production needs, companies can speed up processes, minimize overproduction, and cut inventory costs. This system promotes flexible workstations, reduces waiting times, and lowers logistics expenses. It aims also for quality improvement, helping to meet the principles of lean production.

Implementing Kanban effectively requires inventory management that involves categorizing inventory into raw materials, work-in-progress items, and finished goods, ensuring efficient handling and storage. Supplier(external or internal) commitment is crucial for timely material delivery, allowing smooth production flow.

This method relies on visual signals, typically Kanban cards, to manage and control the flow of production. Kanban consists in:

- **Visual Signals**: Kanban cards serve as visual signals that represent tasks or items in the production process. Each card contains essential details such as the task title, description, due date, and key stakeholders [10].

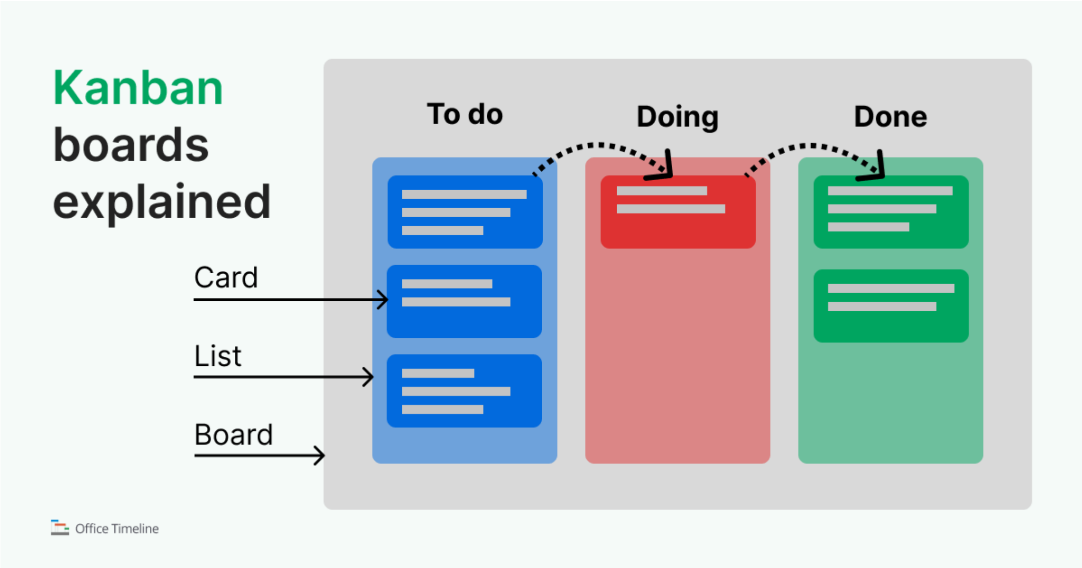


Figure 2.1: Scheme of Kanban boards with the Kanban cards. [14]

- **Pull System**: Kanban operates on a pull system, meaning production is initiated by demand rather than forecasts. When a process requires materials or products, it pulls them from the higher-level process. This is signaled by moving the Kanban card to the appropriate location [11].

There are generally two types of Kanban cards [12]:

- **Production Kanban**: Indicates when and what quantity of a specific product should be manufactured.

- **Withdrawal Kanban**: Authorizes the movement of materials from one process to another.

Workflow Control: Kanban cards move through various stages of the workflow, such as "To Do," "In Progress," and "Done"(see figure 2.1) . It is therefore also a visual tool that allows to visualize the status of tasks and helps manage workflow efficiently [13]. This in turn will facilitate continuous improvement because it can highlight inefficiencies and areas for enhancement. Teams can review the flow of Kanban cards to identify and eliminate waste. Limits are usually added to the number of tasks that are in each stage of the process. This helps prevent bottlenecks and ensures a smooth production flow .

Therefore, a hypothetical process in a kanban system will first involve a production demand, which will be represented by a kanban card in the to-do. Subsequently, an operator will start executing that order and may activate other demands (movement of materials or new demands from other previous processes), so that card will be passed to the doing column. Once this process is finished, the card will be moved to the done column. A key aspect of the method is that it does not limit what we can consider as process, requirements, demand or kanban cards. We can assign whatever meanings and rules we need to each element to create our own system.

By using these principles, Kanban search for a balanced and efficient production process that responds dynamically to actual customer demand, leading to reduced waste, lower costs, and improved overall efficiency [13].

2.3.2 E-Kanban System

Nowadays, the development and use of technology are essential in all phases of production. In modern industry are equally important the production methods used and the way they are carried out. The industry is rapidly moving towards digitalization, and production management solutions are following the same trend.

Therefore, it is necessary to develop electronic solutions that provide tools to apply, monitor, and manage production methodologies in a more intuitive, fast, and effective way. These solutions help prevent human errors in the production plant, reduce production times, and increase control over the variables involved in the system's proper functioning. From the fusion of the Kanban method with modern technology, E-Kanban was born. An E-Kanban system is an electronic solution designed to implement the Kanban method.

E-Kanban is a broad concept that covers various areas, such as the incorporation of sensors for stock control within warehouses and production lines. It also includes the connection between different areas of production, storage, and management through communication networks, as well as the software involved in managing the method application.

Usually, this kind of systems also offer real-time data tracking, which can help in making more informed decisions and improving overall efficiency. They can automate the replenishment process, ensuring that stock levels are always optimized, thus reducing waste and downtime. E-Kanban systems operate by utilizing digital tools to monitor and control the flow of materials and information within a production environment. The components that are usually used are:

- **Software**: the core of an E-Kanban system is a software platform that tracks inventory levels, generates Kanban signals, and manages the flow of materials. This software can be integrated with other enterprise systems to provide a comprehensive view of the production process [15].

- **Sensors**: sensors are used for real-time monitoring of stock levels. They can be sensors placed on shelves or bins that detect when materials are running low and send automatic signals to the system to trigger a replenishment order. Barcode scanning or RFID (Radio Frequency Identification) tags can be used to track the movement of materials throughout the production process

- **Communication Networks**: the integration of wired and wireless communication networks allows data transfer between different parts of the production and storage facilities. This ensures that information about inventory levels, production status, and order requirements is always up-to-date and accessible.

There are several advantages derived from using this system. They bring in automation to many manual tasks, which, in a way, saves time and energy that would have been used in managing inventories and production schedules. The use of real-time data tracking reduces entry errors and provides accurate inventory levels, a well designed system can also prevent human errors or highlight them to be resolved due to E-Kanban monitor the process. Through managing the inventory level and minimizing wastage it minimizes the overall costs of production. It's also a flexible solution because it can respond to real-time events or changes in the demand. It improves the communication between the various segments of the production, this creates a global interconnected system, these types of systems are the trend we are moving towards with Industry 4.0. [15]

Finally, upgrades or expansions to an E-Kanban system are relatively straightforward as software can be improved or new sensors, technologies or functionality can be added to an existing solution.

2.4 Replenishment Methods

In a manufacturing production plant, the flow of materials from the warehouse to the workstation is one of the critical factors in ensuring adequate production rate. If we want an effective material flow management, we must ensure that production lines receive the right part at the right time and in the right quantity for reducing time wastage. The industry employs different approaches to replenishment in order to attain these objectives, all of which have specific benefits and drawbacks. Among the different practices, two of them will be compared in detail below: kitting and line stocking.

2.4.1 Kitting vs Line Stocking

Kitting

Kitting is a method that involves collecting all the materials required to assemble a particular product and packaging them before forwarding them to the production line. This method of organization makes assembly easier because those who are charged with the assembly process are provided with a package of everything needed to accomplish a particular task.

Thus, the first benefit of kitting is the reduction of preparation time in the workstation, which is one of the most significant advantages of this method. It also reduces the number of human errors in the workstation because the operator does not have the task of choosing the pieces. It also saves time because all the requirements for a particular surgery are in a single set, reducing the chances of missing items. In addition, kitting improves organization within the work area, since only the parts needed for a specific operation are taken to the working station, minimizing confusion.

Kitting also has some issues. The kits need to be prepared, and this may take time and resources. In the replenishment process, a new task appears, the task of preparing a 'kit', which requires an operator to dedicate his time to it or even hire a new operator to perform this task exclusively. Furthermore, having these kits in the warehouse in case they are required in the production line takes up more space, which might be a constraint, especially in companies with small warehouses. Another problem is that kitting may be less friendly to the changes in production since kits are pre-established and, therefore, may not accommodate new needs without a prior configuration task. [16]

Line Stocking

Line stocking, also known as line-side stocking, is a process in which each ingredient that is required in production is located at the workstation available for use and separated from the others, when replenishment of such parts is required, the necessary quantity is brought from the warehouse. This approach is used to replenish items and materials in the working areas so the production line can continue without delays.

The first and foremost benefit that results from line stocking is that it ensures that there is a constant supply of materials hence enhancing the flow of production. This method reduces the space needed for storage and the associated costs because parts are stored by type in the warehouse. Secondly, line stocking provides more flexibility than batch storage where there can be a faster and easier changeover in the production line since the material is restocked depending on the current requirements.

As much as line stocking is efficient, it has some drawbacks. One of them is that it is quite challenging to manage materials that should be available just in time, which is why it takes very careful and efficient coordination to achieve. This means that any problems with the delivery of raw materials can be a major problem and can lead to production delays, which are very costly. As for the manufacturing operator, this method requires the operator to maintain a high level of concentration in order to avoid human error, since he must be the one who knows and chooses the correct parts for the correct manufacture of the articles. [17]

Comparision

As we have seen, both methods have their advantages and disadvantages, the choice of one of them will depend on the individual needs of each production plant or the philosophy of the company that applies them.

If you need a system that seeks to reduce errors as much as possible or to make the operations performed by the manufacturing operators as mechanical and simple as possible, then kitting will be a better option since working with ready-made kits allows the operator to assemble with the certainty that he is using the correct parts. On the other hand, if we want to stick to the Japanese philosophy derived from Lean Management of reducing processes that are not strictly necessary or do not add direct value to the product, applying Line Stocking will be the option to choose since it eliminates a task that consumes extra time and labor, in exchange, manufacturing operators must be much more careful since they will be in charge of choosing the right parts from those available at the workstation to assemble a specific product. This is why Line Stocking is often used in Japan while in Europe, due to having a different work philosophy, they usually work with Kitting in the production lines.

Chapter 3

Case Study

In this chapter, the elements present in the lean room of the factory lab will be analyzed and organized. The different sections into which the manufacturing plant will be divided and the operational plan for the restocking methods will be outlined. Finally, a market analysis of the technologies used in the industry for a similar purpose will be conducted.

3.1 Lean room analysis

The solution will be developed in the factory lab, specifically in the industrial manufacturing production plant (Lean Room) of the Factory Lab, which currently has different elements, as presented in Figure 3.1:

- Workstations: the workstations have a work table and different interchangeable shelves to temporarily store the trays that will contain the parts involved in the production. These trays can be placed on the different vertical levels of the workstations. In this way, we find different types of shelves: flat shelves where to leave the trays so that they remain static, and shelves with rails to deposit the trays so that they are stacked in order (see Figure 3.2). The workbenches will be where the manufacturing processes will be carried out and where the necessary parts will be received.

- Trays: there are trays that will be used to transport and store the parts and will be of vital importance when organizing the processes since they will be the units transported between the warehouse and the workstations.

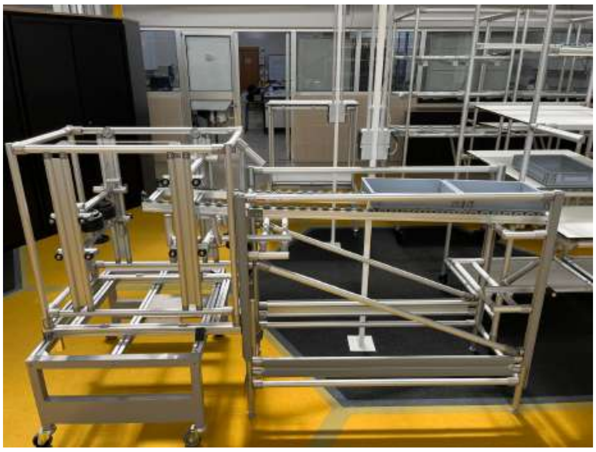
- Storage racks: in the Factory Lab there are also these storage units (also configurable) that have different cells with mobile rails to store the trays that will contain the parts. These will be the fundamental piece of our warehouse. Each storage rack will have 8 different storage cells divided into two columns and four rows.

- Trolleys: there are trolleys that will be used to transport the trays containing the parts within the replenishment cycle, they can be charged with the trolley following LIFO(Last In, First Out).

- Karakuri: there are different Karakuri systems that can be used to move the trays from one place to another using mechanical elements. One notable system allows

(a) Workbenches.

(b) Storage racks.

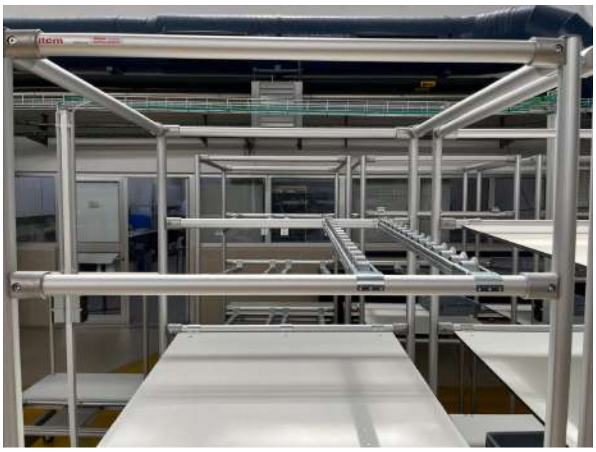


(c) Karakuri.

(d) Trays.

Figure 3.1: Elements available in the Factory Lab's industrial manufacturing plant.

(a) No Rail configuration.



(b) Rail configuration.

Figure 3.2: Different workbench shelving configurations.

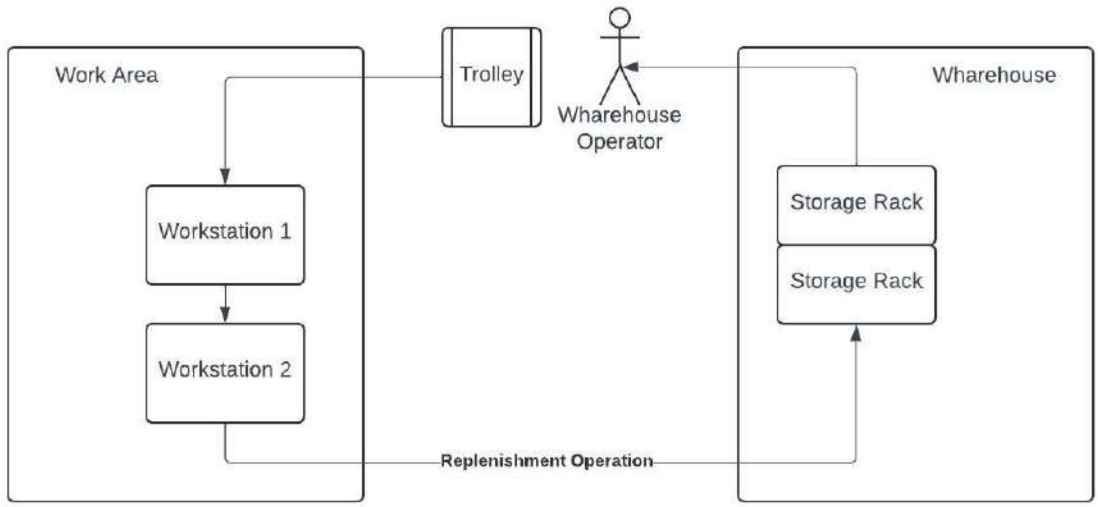


Figure 3.3: Scenario for the case study.

trays to be inserted from the top and extracted from the bottom, creating a FIFO (First-In, First-Out) storage system.

- Warehouse Computer: We will have a computer in the warehouse, which is a notable aspect as the main solution to be developed can be adapted to run on it. Additionally, there will be a screen connected to it that can be used to display useful information for replenishment in the warehouse.

- There are also various components at our disposal from Item GmbH that can be used to reconfigure and customise the aforementioned elements. Once we are familiar with the main components we have, we will designate the different zones or how the space will be distributed to get an overall view of the plant.

  The scenario for the case study is presented in Figure 3.3. The lean room will be divided into two zones: the work area and the warehouse. The work area will be considered a zone that will house the workstations, each with an operator performing manufacturing operations. It will also include various Karakuri elements if required in the solution. The warehouse will be the place where trays are stored and managed for replenishment. It will have a certain number of storage racks and a computer. Between the work area and the warehouse, there will be a third virtual division of the system: this will consist of an operator with a transport trolley performing the replenishment operations and associated processes. This third unit will connect the warehouse and the work area.

3.2 Design and Planning of the Restocking Process

The objective will be to create an E-Kanban system to control the replenishment of parts for the workstations from the warehouse. At the workstations, workers will assemble products that require specific parts. These parts will be brought from the warehouse by an operator who will handle the trolley and carry out the replenishment cycle, which consists of sending trays with parts from the warehouse to the workstations and, once at the workstation, collecting the empty trays and returning them to the warehouse.

In this way, the workstations will always have the necessary parts available to continue production, since the warehouse operator will be constantly replenishing the required parts at the stations. The problem that the solution to be designed needs to solve is enabling the operators at each workstation to quickly and remotely indicate to the warehouse which parts have been depleted and, therefore, need to be replenished. This will allow a system in the warehouse to manage these signals and guide the replenishment operator to select the correct parts and deliver them to the corresponding stations.

The system must also manage how the collection of empty trays is executed, as this will be done by the warehouse operator within the replenishment cycle. The operator needs to know, at a glance, which tray to collect from each station.

The solution cannot be commercial as there is an intention to update it in the future. Therefore, it must be developed entirely from scratch. Additionally, new functionalities are planned to be introduced in the future, which will require using the data generated and stored by the system. Thus, it must be robust and have good data management.

The solution must also be flexible to easily expand the elements involved, such as workstations and storage racks. Under this project, the system will be designed and tested to accommodate 2 workstations, with one operator at each station, and 1 storage rack in the Factory Lab, which, as described before, it will have 8 different storage cells available.

In the lean room, the assembly process for the product which can be seen on figure 3.4 will be carried out. To manufacture this product, 8 types of parts initially stored in the warehouse will be used. Six of these parts will be present in all versions of the product, and the last two will be connectors of type A and B, which will differentiate 3 different finishes of the product:

- The finish called ”A” will use 2 straight type A connectors in its 2 slots.
- The finish called ”B” will use 2 type B connectors, with a 90º angle, in its 2 slots.
- The finish called ”C” will not use connectors, leaving the slots free.

Assembly will be carried out in two sequential phases creating an assembly line:

1. The first phase will be carried out at workstation number 1. It will consist of assembling the first four parts of the assembly. Once this operation is completed, the semi-assembled product will be passed to workstation number 2.
2. The second part of the assembly will be carried out at the second workstation, starting with the semi-assembled product received from the first workstation. Three new parts will be assembled, and depending on the finish, the corresponding type of connector will be assembled or not in the slots. It is important to note that this workstation is where the parts that differentiate the finishes will be assembled.

The system has to be able to handle the two different replenishment methods, Kitting and Line Stocking, to restock the parts used in this process, allowing variation between them when necessary

(a) Finish ”B”. (b) Finish ”C”.

Figure 3.4: Product to be assembled with different finishes.

3.2.1 Kitting Planning

The first replenishment method to be used, and which the system must manage, is “Kitting”. In this method, all the pieces needed to assemble an order must first be collected in a tray or “Kit”.

Therefore, the operator in the warehouse, depending on the type of product to be assembled, must collect these elements in a single tray. Given that several stations will carry out the assembly process following a production line and that this method aims to make the assembly work as mechanically as possible, the trays will be divided into several sections. Each section will be assigned to a single station, and will store only the parts to be used in the partial assembly process at that workstation.

The production will be guided by a demand list, which will contain the next items to be produced. The idea of this list is to continuously add product demands generated in real-time from the market. In other words, the system should be connected to other company platforms, such as a website where customers place orders, to produce what is needed according to the JIT (Just-In-Time) philosophy of Lean Management. This way, only what is needed is produced, and when it is needed, saving storage space associated with already manufactured products and creating a flexible system that can adapt to changes in demand.

In the case of the “Kitting” method, the demand list must be managed in the warehouse since each “Kit” preparation must be done with the necessary parts to produce the next product on the demand list. With this method, we also need to establish a limit on the number of Kits at each station because, while the demand list can be as large as needed, the capacity to store Kits at the stations awaiting manufacture is limited. This limit must be properly managed to avoid two important problems:

- One of the stations may be left waiting because they have finished producing the previous order and have not yet received the tray for the next order at their station. In a production line, the goal is always to be constantly producing. Delays and costs associated with having labor idle are considerable and must be avoided at all costs.

- One of the workstations might complete its manufacturing subprocess faster than the next station can handle, causing an accumulation of trays waiting at the second workstation, thus creating a bottleneck in production.

To avoid this, the system must be able to manage and limit the number of trays at each workstation. A limit must be set for the number of trays at each workstation that the system can control, informing the warehouse operator to prepare new Kits when this limit has not been reached at the stations, and preventing the preparation of new Kits when this limit has been reached at any of the stations. This limit must be adjustable to adapt to the manufacturing of different parts with different stock requirements at the station and different production times.

When the trays reach the first workstation, the operator in charge of assembly at that station will need to perform the assembly of the part of the piece assigned to them (this should be pre-established). They will have all the exact pieces from the section of the tray assigned to their workstation at their disposal. In this way, even though a"kit" contains parts destined for the sub-assembly processes of several different stations, each station can be sure that they are selecting the correct parts without having to perform a selection task at the workstation.

Once the first workstation has completed its part of the assembly process, it will place the corresponding piece in its section of the tray (which should be empty at that point, having used all the parts for the assembly). This tray will be manually passed to the next workstation in the production line, where the assembly process will continue. The next station will start from the tray received, which contains the assembly done up to that point and the necessary parts in its section of the tray. Thus, the "kit" will move along the assembly line to the final station. After completing the assembly, the final product will be placed in the tray on one of the shelves at the workstation for later collection.

To know the number of trays at each station at any given time, a signal will be used at each workstation indicating that the manufacturing subprocess of an order at that station has been completed. Thus, the number of trays at that station would be reduced by one unit, and at the next station, it would increase by one unit, or in the case of the last station, it would increase the number of completed orders by one unit. In this way, we can control the number of trays at each station, ensuring that there is enough stock at the stations to maintain constant production and avoid overloading a station with trays.

Replenishment Cycle for Kitting

The replenishment cycle that the warehouse operator will perform will be as follows:

1. **Start at the Warehouse:** in this method, each storage cell of the storage rack will contain trays with a specific type of part, and the warehouse operator will need to collect the parts required to make the kits, not the trays. The operator will begin in the warehouse where the system will indicate if any kits need to be prepared for the production line. If so, the system will guide the operator to collect the correct

pieces for the current order sequentially, starting with the pieces needed for the first station. The operator will only need to pick up those pieces and place them in the section assigned to the first workstation in the tray. The section will simply be an area of the tray divided by some kind of partition or similar to differentiate it clearly.

2. **Move to the Next Stations:** Once all the pieces for the first workstation have been collected, the system will indicate which pieces for the second workstation need to be collected. It is important that the system guides the operator clearly and intuitively to avoid errors in collecting the pieces. Error signals should also be managed so the system can indicate or record when an incorrect piece has been picked. The operator will pick up those pieces and place them in the section of the tray for the second station. This process will be repeated as many times as there are workstations, so the tray will have the same number of sections. When the order limit is reached at any station, the system will stop indicating the creation of a new kit, and the kitting process will be completed.

3. **Complete the Current Order:** once the order is completed with the pieces for the last station, the system will move to the next order, provided that the tray limit has not been reached at any of the stations. If there are more orders, the process will proceed in the same manner as before, accumulating the prepared kits on the transport cart.

4. **Transport the Kits:** once the operator completes the preparation of the kits for that cycle, they will transport the kits to the first station and unload them from the cart following the FIFO method to ensure the demand list is fulfilled in order. After unloading the orders at the first station, the operator will proceed to the last station to collect the trays with the finished products accumulated so far.

5. **Store Finished Products:** the operator will take these products to the designated storage area and then return to the warehouse, thus starting again at step 1 of the cycle.

Requirements of the Solution to Manage Kitting

Therefore, the requirements that the solution must meet to manage the kitting method are:

- Manage the demand list in the warehouse, allowing it to be viewed and updated in real-time.

- Manage production based on the stock limits of trays at each station, using signals generated at each workstation for each completed manufacturing sub-process. The system must receive and interpret these signals to make decisions about whether to send new kits or not.

- Guide the warehouse operator through the kitting process in a sequential and intuitive manner.

- Detect errors in the selection of pieces within the kitting process in the warehouse. The system must also display some type of alert so that the operator can notice and correct the error.

3.2.2 Line Stocking Planning

The other method to be used in the industrial manufacturing plant to restock the parts used at the workstations will be "Line Stocking". In this method, each tray will be filled with only one type of part. At the workstations, one or more trays of each type of part will be used in the assembly sub-process of that station to assemble the product. The operators will pick the needed parts from each tray.

This method requires operators to know precisely which parts are needed for the operation they are performing and also requires them to maintain a higher level of concentration when performing the assembly. This is because each assembly operation performed by an operator at a workbench will be associated with a selection operation of the necessary parts. When a tray of a specific type of part runs out, a tray filled with the same type of part will be restocked at the workstation.

This makes this system flexible in terms of changes in the quantity of each type of product that needs to be produced. If more parts of one type are used, simply more parts of that type will be restocked. Another advantage of this method is that the "Kitting" operation within the restocking cycle disappears. Therefore, if we have a very tight time margin to complete the cycle due to a high number of stations to be restocked, this method allows for shorter cycle times and a possible reduction in the warehouse labor dedicated to preparing kits.

Using the "Line Stocking" method, the operators at the workstations will also be responsible for managing the demand list discussed in the other method. This is because the parts will be selected at the workbenches, not in the warehouse, based on the product to be manufactured at any given time.

The workstations will form a production line. Initially, production will start with a specific number of trays filled with parts of each type at each workstation. The first workstation will begin assembly by selecting the necessary parts to perform the corresponding assembly sub-process, according to the product to be assembled, following the demand list that will be at the workstation. Once the corresponding assembly is completed, it will be placed in a tray located at the second workstation.

At the second workstation, the next assembly operation will be performed, adding the previous assembly as a selected part for the next stage. Each different assembly operation will be carried out successively at each workstation until the final station, where the operator will place the finished product in a tray to accumulate the completed products, waiting to be collected by the operator responsible for the restocking cycle.

The operators will use the parts they need, and when the parts in one of the trays run out, the system must send a signal to the warehouse. The operator will place the empty tray on a designated shelf at the workbench for temporarily storing empty trays before they are collected.

The warehouse will receive this signal, which must include two key pieces of information:

- What type of part has run out, and therefore, which tray needs to be sent from the warehouse to the workstations?
- Which workstation sent the signal, and, therefore, which one needs to receive the supply of that tray?

The number of trays of each type at the workstations will always be the same as the number initially placed, so we will not have issues with order accumulation and will not need to set a limit on the number of trays at each station. As with the limit of kits in the kitting method, the number of trays of each type initially placed at the stations must be carefully chosen to ensure that production does not have to stop because there wasn't enough time to restock the parts before all available trays of that type are depleted.

This is a problem that must be avoided, as halting production incurs costs associated with delays and idle labor. These costs are compounded by the fact that, as a production line, the stoppage of one link can sometimes also halt the production of subsequent links.

Replenishment Cycle for Line Stocking

1. **Start in the Warehouse:** The warehouse operator will start in the warehouse, where different storage cells of the storage rack will contain trays filled with only one type of part. The operator will use the tray as the unit of measurement. This means the system will indicate which parts are needed and at which station, based on the signals received since the last tray selection operation was completed. The operator will gather the necessary trays, place them on the cart, and determine which station each tray needs to be transported to.

2. **Transport to Workstations:** Once all necessary trays have been collected, the operator will transport them to the corresponding workstations. Upon arriving at a workstation, the operator will place the trays with new parts on the designated shelf of the workbench. Afterwards, the operator will collect the empty trays from their shelf and move them to the next station.

3. **Collection of Finished Products:** Upon reaching the last station, the operator will also collect the trays of finished products if they are full and will transport all empty trays and the tray of finished products back to their storage location.

4. **Return:** Once the cycle is completed, the operator will return to step 1, where there will be new part requirements in the workstations.

For this method, it will be crucial that the warehouse clearly displays which workstation each required tray corresponds to. Additionally, the system must guide the warehouse operator to select the correct trays from the storage rack when performing the replenishment cycle. This can significantly help reduce the number of human errors.

The system should also include an error control mechanism so that the operator can receive an alert if a mistake is made in selecting the trays, allowing for correction.

Requirements of the Solution to Manage Line Stocking

Therefore, the requirements for the solution to manage the line stocking method will be:

- Each workstation must be able to send a signal to the warehouse, quickly identifying the type of part of the depleted tray and which workstation is sending the signal.

- The warehouse must receive these signals in real-time, process them, and clearly and intuitively indicate to the operator which trays need to be taken from the warehouse and to which workstation each tray should be sent.

- Detect errors in the selection of pieces within the kitting process in the warehouse. The system must also display some type of alert so that the operator can notice and correct the error.

3.3 Study of Technologies Used in the Market

Once we have an overall understanding of the solution's design, we will conduct a brief study on the technologies currently used in the industry for purposes similar to ours, as well as the existing commercial solutions and their details. This will help us gain the necessary knowledge to develop a solution that incorporates the latest technologies and best meets the requirements, using real industrial products as references.

3.3.1 RFID

Radio Frequency Identification (RFID) technology allows for automatically identifying and tracking tags attached to objects using electromagnetic fields. The tags contain electronically stored information that can be read from a distance by RFID readers. RFID can be used to identify products, track them, and quickly scan their information, allowing us to control inventory in real-time. Implementing RFID technology requires a considerable investment because special devices are needed to read and write the tags, in addition to purchasing the tags themselves.

This technology is usually used for large-scale projects that require extensive inventory control. For example, the company **WURTH INDUSTRY** [18] has different solutions to apply RFID to Kanban replenishment systems: 3.5

- IBOX® consists of a box that can read the RFID tags of the trays placed inside it and automatically place the order for the corresponding parts.
- ISHELF® is a shelf that can read the RFID tags integrated into special bins when they are placed on the shelf and automatically place the order.
- iPLACER® is an RFID reader that can be placed in different locations thanks to its design. This allows it to be a flexible tool as it can be adapted to the specific requirements of the application.

3.3.2 Barcode

Barcodes are an optical representation of data that can be read by a device. Traditionally, barcodes have been parallel lines that vary in width and spacing, but nowadays, there are other types of barcodes, such as QR codes, that are capable of storing more data.

Barcodes are the most widespread method for managing inventory because they only need to be printed, barcode readers are inexpensive, and many devices today, like mobile phones, can perform that function. This is typically done by assigning a barcode to each product with its information. This simplicity and ease of integration, combined with effectiveness, make barcodes still the most optimal choice in most inventory classification systems. In the industry, barcodes are used for inventory management, order processing, and asset tracking. 3.6

3.3.3 Pick to Light

Pick to light refers to a type of system that guides the picking operation, which involves removing items from the warehouse. The most widespread pick to light systems consist of an screen that can display numbers and a button on each storage cell in the warehouse.

(a) IBOX® solution.

(b) ISHELF® solution.

(c) IPLACER® solution.

Figure 3.5: Different **WURTH INDUSTRY** products that use RFID technology.

Figure 3.6: Scanning of a barcode.

Figure 3.7: Pick to light system in a warehouse.

When a worker needs to remove an item from one of the storage cells, the screen lights up, displaying the number of pieces to be picked. Once the worker has removed the corresponding units, they press a button to confirm that the operation has been completed, and the system turns off the corresponding light. 3.7

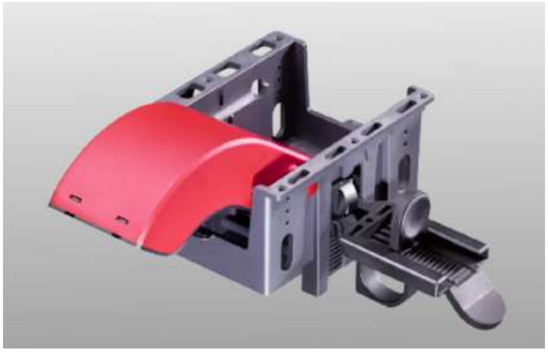
This type of system offers two key advantages in managing item selection operations in the warehouse industry: agility and a reduction in the number of errors committed.

3.3.4 Sensors

In modern industry, different types of sensors are used to control the position and flow of containers that transport parts in an industrial process. Among the most commonly used sensors, we find (see figure 3.8) :

- Optical presence sensors that measure if an item is placed in a specific location. The company **.steute** [19] commercialize laser sensors with this purpose.
- Mechanical sensors that are activated by the weight of the items and measure their presence. The company **.steute** [19] commercialize a tilting sensor that can be attached to the rails of a shelf.
- Weight sensors that measure the weight of containers to control the number of pieces they contain.
- RFID sensors that detect RFID tags, a technology previously explained. The application of these sensors in industrial processes allows for precise control and monitoring of container positions and the flow of parts, leading to increased efficiency, reduced errors, and optimized inventory management.

(a) .steute laser sensor.



(b) .steute tilting sensor.

(c) WURTH weight sensor.

Figure 3.8: Different sensors available on the market.

Chapter 4

Implementation of the Solution

In this chapter, we detail the implementation of the proposed solution designed to meet the requirements outlined in previous chapters. The solution integrates an e-kanban method with a pick-to-light system, leveraging existing elements in the Factory Lab. We discuss the hardware and software design decisions that ensure seamless communication and efficiency. The results of the actual installation of the system will also be presented.

The main objective of the proposed solution will be to meet all the requirements previously mentioned in the preceding chapters. It will be a solution adapted to an industrial environment, aiming to make the most of the elements already available in the Factory Lab.

4.1 Proposed Solution

The solution will consist of a system that implements a version of the e-kanban method to manage the replenishment of parts, combined with a pick-to-light system that will guide the selection of parts in the warehouse. The two systems will be interconnected through the developed software, allowing for future development by other university students. The entire solution was developed in this project from scratch.

4.1.1 Workstation System

A diagram of the developed workstation system is presented in Figure 4.1. The foundation of our replenishment system will be the application of an e-kanban method adapted to our requirements. This system will be responsible for creating and sending replenishment signals for parts from the workstations to the warehouse.

The trays are classified by the type of part they contain and each will be identified with a unique barcode. This way, we can assign the necessary information within the system to each tray's code and identify them when needed.

At each workstation, a controller will be installed along with a scanner. The scanner will read the tray codes, which the controller will receive and send to the warehouse. This setup allows us to create the necessary signals for the two replenishment methods for which we must devise this solution:

- Kitting: for this method, we need to generate a signal each time a workstation completes its assembly operation for an order, containing information that identifies that workstation. This signal will be generated by scanning any barcode at that

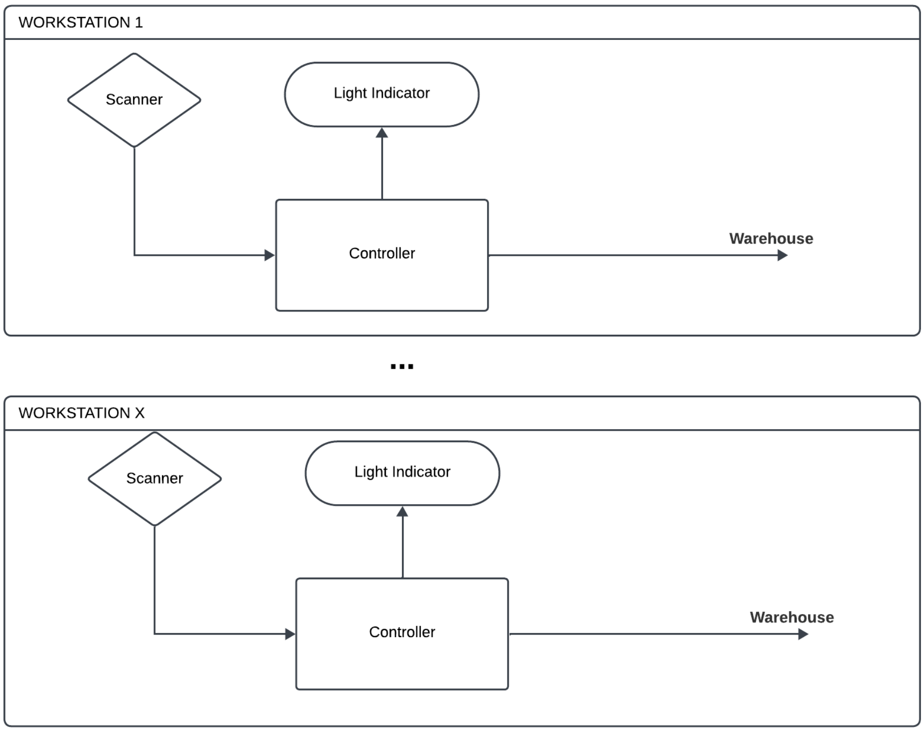


Figure 4.1: Diagram of the developed workstation system.

station since the specific code will not be relevant. Therefore, the trays with the assembly "kit" will carry any barcode, which will be scanned at each station upon completing an order and before passing it to the next. This way, the warehouse system can monitor the number of trays at each workstation, ensuring they do not exceed the established limit.

- Line Stocking: for this method, we need the station's controller and scanner to be capable of generating and sending a signal to the warehouse containing information about the code assigned to that tray and the workstation emitting that signal. This will be achieved because the trays will have the code of the type of parts they contain, and when they are empty, the workstation operator will scan the code just before placing the empty tray on the upper shelf of the workstation. The controller will receive the code and create a signal that it will send to the warehouse, including the code and the identification of that workstation.

With this single system of scanner and controller at the workstations, it will be possible to send signals for each of the two replenishment methods. The controllers will be connected to the warehouse's computer system via a network. An important aspect to consider is that the workstations are mobile and can be reconfigured into different positions in the future. Therefore, the network connections between the workstations and the warehouse must be wireless to allow greater flexibility in their placement.

Each workstation will also have a light alert to indicate if the scanner and controller are available at that moment for scanning and if the message has been sent correctly or, on the contrary, if there was an error.

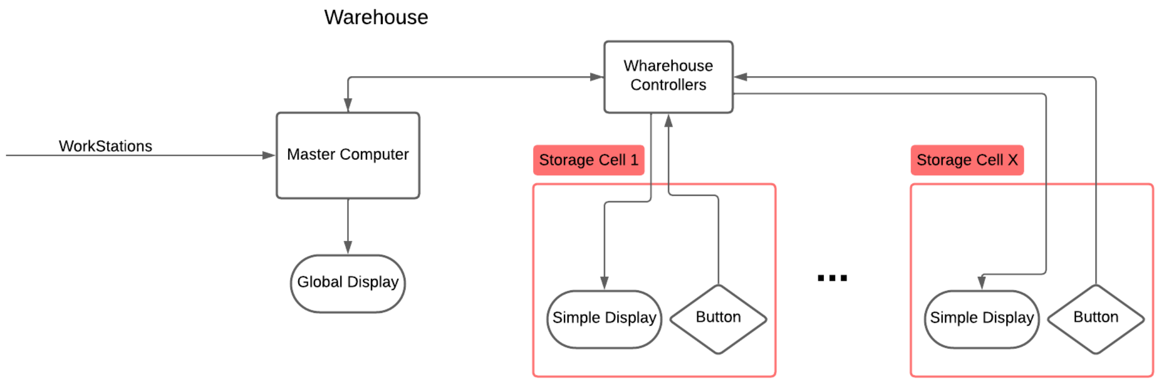


Figure 4.2: Diagram of the developed warehouse system.

4.1.2 Wharehouse System

A diagram of the developed warehouse system is presented in Figure 4.2. In the warehouse, there will be a main computer that will be the fundamental control piece of the system. The computer will be connected to a screen where the system can be controlled through a graphical interface. The computer will be connected to a pick-to-light system, which will consist of a button and a small display for each storage cell, considering a storage cell as each shelf with a rail of the storage racks in the warehouse, where there will be a row of trays.

Storage Rack System

As previously mentioned, the storage rack will have a pick-to-light system. Each storage cell will display information about the units that the operator needs to pick for each type of product. A controller will control one small display and one button per storage cell.

The controller will receive real-time requirements from the main computer via the network and send a signal to turn on and display the number of items to pick on each screen. The operator will pick the units from the cells, pressing the corresponding button once for each unit picked. The storage cell controller will be responsible for receiving the signals from the buttons and sending them to the central computer, which will process them.

Main Computer and Screen

The main computer will run a program in which three different modes can be selected: Kitting, Line Stocking, and Kitting with Variable Demand, which it will be explained in detail later. This program will receive the signals sent by the workstation controllers and process them. At the same time, it will display a graphical interface on a screen where the user can change the most important system parameters, select a mode, and view the restocking orders or "kanban card" on the screen. This will be the way the operator will have to visualize all the information about the orders and the way it is displayed will vary depending on the mode. It will also manage the requirements and the demand list, send commands and receive signals from the storage cells controller.

4.2 Technology Selection

When selecting the hardware, we must consider that it must be a solution with a tight budget and suitable for use in an industrial environment. We also need to ensure that the hardware can be adapted to the Factory Lab, prioritizing elements already available in the laboratory to minimize the purchase of new components and avoid incurring additional costs.

4.2.1 Network

Different options have been studied to meet the requirements for the network that will connect the controllers of the workstations and the warehouse to the main computer located in the warehouse. The network must be wireless so that the system does not depend on cabling between the warehouse and the workstations, which could complicate future reconfigurations of the workstation positions.

Additionally, maintaining the aesthetics and security of the laboratory is crucial, and a wired network would incur extra costs to conceal and secure the cabling. The distance from the workstations to the warehouse should be able to reach up to 75 meters. The transmission speed does not need to be too high, as the amount of information transmitted in each message will be very small. It must be a network that is easy to integrate and does not require special hardware for use with most devices. The network's power consumption will not be an important aspect to consider when choosing one.

Among the available wireless networks, the feasibility of three options for this project has been studied: Bluetooth, Wi-Fi, and Zigbee.

Bluetooth

Bluetooth is a wireless technology standard for exchanging data over short distances from fixed and mobile devices, creating personal area networks. It is widely used for connecting peripherals such as headsets, keyboards, and mice to computers, as well as for communication between mobile devices.

This network's typical range is 10 meters, and although it can be extended to 100 meters, we would require high-power transmission devices or additional antennas. This makes this network unsuitable as it does not meet our requirement of a minimum 75-meter transmission distance.

Zigbee

Zigbee is a specification for a suite of high-level communication protocols using low-power digital radios for personal area networks. It is used to connect IoT devices in both domestic and industrial environments. It is intended to be simpler and less expensive than other wireless personal area networks, such as Bluetooth. Although ZigBee has a considerably lower transmission speed compared to the other two options, this would not be an issue for this application since it does not require transmitting a large amount of data.

As we can see in the Table 4.1, ZigBee can meet our distance requirements since the range can vary from 10 to 100 meters. However, a problem with ZigBee is that it requires special hardware to adapt most devices which is a problem as it means additional costs.

Wi-Fi

WiFi (Wireless Fidelity) is a technology that allows devices to connect to the internet or communicate with one another wirelessly within a certain area. It uses radio waves to provide high-speed internet and network connections. Wi-Fi technology is widely used both domestically and industrially, making it the most commonly used wireless connection network worldwide. This means that most current devices, such as mobile phones, computers, and modern micro controllers, usually come with a built-in Wi-Fi module, which is a great advantage as there is no need to purchase extra hardware for the controllers to be compatible. As we can see in Table 4.1, its range is up to 100 meters, so it would meet the requirements in that aspect. It can reach speeds of several Gbps, which is more than sufficient for this application.

Feature	WiFi	Bluetooth	Zigbee
Range	Up to 100 meters (328 feet)	Up to 10-100 meters	Up to 10-100 meters
Speed	Up to several Gbps	Up to 3 Mbps	Up to 250 kbps
Frequency	2.4 GHz, 5 GHz, 6 GHz	2.4 GHz	2.4 GHz, 900 MHz, 868 MHz
Power	High	Low	Very low
Use Cases	Internet, streaming, gaming	Peripherals, audio devices	Home automation, sensors

Table 4.1: Comparison of WiFi, Bluetooth, and Zigbee Technologies.

Selected Network: Wi-Fi

Finally, the selected option is the Wi-Fi network because it meets the transmission distance and speed requirements. It should also not require additional hardware to be integrated with the installed devices, unlike Bluetooth and ZigBee. Additionally, the factory lab currently has a high-speed Wi-Fi network already installed that we can use for our devices to communicate, saving us from having to invest in its installation. For these reasons, Wi-Fi is the option that best suits our project and will be the one we use.

4.2.2 Workstation Controller and Scanner

The study of the hardware to be installed at each workstation will be conducted jointly for the controller and the scanner since they must be fully compatible with each other. Depending on the controller, we may or may not be able to use a particular scanner. The scanner must be able to read barcodes, as we will use them to identify the type of items each tray contains. We must consider the following aspects when choosing the controller:

- It should not require additional expenses to connect to the Wi-Fi network.
- It must be easy to install and integrate into the workstation.
- It should be of small dimensions and not require excessive cabling.
- It should be adapted to the task at hand, as there is no need to use a powerful system when we only need to receive signals from the scanner and send messages to the main computer.

Figure 4.3: Siemens PLC S7-1200 1214C. [21]

The device's versatility will also be considered, ensuring it has the capacity to integrate new functions if the system is updated and improved in the future. These new functions could include a graphical interface for the workstations or information exchange with robots in the factory lab, for example.

Programmable Logic Controller

A PLC (Programmable Logic Controller)is a specialized digital device designed to control industrial processes and machines. It is highly reliable and built to withstand harsh industrial environments. PLCs can handle multiple inputs and outputs (I/O) and are programmed using specific programming languages such as ladder logic. [20] The PLC is designed for industrial environments, which would be an advantage for our application since the installation site will be a replica of an industrial plant. However, the PLC presents several disadvantages:

- The average size of a PLC is considerable compared to other options.
- PLCs use specific modular software and hardware from each brand, making it more complicated and expensive to adapt to our application to the use of Wi-Fi than other options.
- There are few barcode scanners compatible with a PLC, and those available are very expensive and beyond our budget.

Industrial Microcontroller

A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. It contains a processor, memory, and input/output (I/O) peripherals on a single chip. Microcontrollers are commonly used in automatically controlled products and devices.

The ESP32 (see Figure 4.4) is an industrial microcontroller with a size of just a few centimeters, featuring both Wi-Fi and Bluetooth connectivity. This microcontroller

Figure 4.4: Microcontroller ESP32. [22]

could be a good option for the project due to its low price, small size, and connectivity. However, it has some disadvantages, such as compatible scanners not being adapted for an industrial environment and the lack of USB ports, a technology widely used for connecting peripherals. This could limit its ability to adapt to future system updates.

Raspberry Pi

The Raspberry Pi is a low-cost single-board computer widely used in electronics projects and industrial prototypes [23]. Its very versatile due to it offers GPIO ports, that are pins which allow the board to interface with various external components, networking capabilities(Wi-Fi 5.0 GHz and Bluetooth on the Raspberry Pi 4), and is compatible with various operating systems.

The Raspberry Pi board offers several advantages:

- It is compatible with most USB scanners. USB (Universal Serial Bus) is a standard interface for connecting peripherals to computers, allowing data transfer and power supply between devices. This board can also work with sensors and actuators designed for microcontrollers thanks to its GPIO pins.

- Its versatility, connectivity, and power allow for future scalability of the system at the workstations.

- The Raspberry Pi connected to a USB scanner is more cost-effective compared to using a PLC with a compatible scanner.

  One issue with using this board is that it is not adapted for industrial environments in its standard version, so it would need to be adapted to ensure its proper functioning over time.

Figure 4.5: Raspberry Pi 4. [24]

Figure 4.6: Eyoyo 2D USB bluetooth ring barcode scanner. [25]

Selected Hardware: Raspberry Pi and Wireless USB Scanner

Due to the multiple advantages previously mentioned, it has been decided to use one of the most modern models of the Raspberry Pi as the controller for each workstation. Specifically, the Raspberry Pi 4 Model B with 8 GB of RAM, which has an integrated Wi-Fi module. This board will allow for the task of scanning and sending messages, and thanks to its capacity, its use can be extended to new applications in future system updates.

Regarding the scanner, it has been decided to use a scanner that the university had already acquired: Eyoyo 2D USB Bluetooth Ring Barcode Scanner (see Figure 4.6). The Bluetooth technology makes them wireless, and they come equipped with a cord to attach it to the finger like a ring. They also include a charging base. The absence of connection cables for the scanner will allow us greater freedom when placing the controller at the workstation, which is a significant advantage.

4.2.3 Pick to Light System

Four fundamental components have been chosen for the warehouse's pick-to-light system. The following describes the selected elements and the reason for their selection.

Figure 4.7: Led Strip RGB WS2812B 60 5V black.[26]

Storage Cell Display

Choosing how the number of pieces would be displayed was a very important task, as this would be one of the most visual parts of the project. It was essential to achieve a modern and attractive appearance for the students. The element needed to meet the following criteria:

- Clearly display the information.
- Differentiate which station was being restocked at any given moment in Kitting mode.
- Be visually attractive and modern for the students.

Various solutions were considered, such as small LED screens, these are devices that use LED segments to show numerical information.LED segments are individual light-emitting diodes arranged in specific patterns to form numbers and characters. This number would indicate the number of pieces to take from each shelf. With this solution, differentiating which station is being restocked would have been more complicated, and that information would be displayed unclearly. Additionally, in terms of aesthetics and attractiveness, it would deprive the warehouse of a modern and appealing look for the young.

Therefore, it was decided to install addressable RGB LED strips that are flexible circuit strips with light-emitting diodes that can display a wide range of colors. in each storage cell. These LEDs operate with the GPIO pins of an Arduino controller or similar device, and each one can be controlled individually to display a different color and intensity.

The chosen LED strip is the **WS2812B** with 60 LEDs per meter (see Figure 4.7), which operates at a voltage of 5V and has a width of 10mm, in black color to make the lit LEDs stand out more. Each LED can be cut and reconnected to the desired number of LEDs, providing flexibility in designing the connections to control all cells with the same GPIO pin. It comes with a silicone sleeve to protect it from dust. Each cell will have 7 LEDs connected to a controller. The number of LEDs lit will correspond to the number of pieces to be taken from that cell. In the kitting method, a different color will be used for each station to differentiate which station is being restocked. For a storage rack, we will have $7times8$, which totals 56 LEDs. If all LEDs are lit simultaneously, this will consume nearly 18W of power. [26] Therefore, the power provided by the controller will not be sufficient, and an external power supply will be necessary. A 5V power supply with a capacity of 2 to 4 amperes will be sufficient, as it is rare for all LEDs to be lit in white simultaneously (this represents the maximum consumption scenario).

Displays Controller

To control the displays of the storage cells, which, as mentioned, will be WS2812B LEDs, a controller with GPIO technology that provides a precise PWM signal is required.PWM (Pulse Width Modulation) is a technique used to control the power delivered to electrical devices by varying the width of digital pulses [27] . It should also be able to connect to the main computer via Wi-Fi to avoid extra wiring and to utilize the network already installed in the Factory Lab. For these reasons, and because it is a very versatile option that can be adapted to new functionalities in the future, the **Raspberry Pi 4 Model B** (Figure 4.5) has been chosen as the controller for the displays. It will be connected via Wi-Fi to the computer, from which it will receive real-time commands to control the LEDs.

The Raspberry Pi 4 Model B has 4 GPIO pins capable of transmitting data and controlling an individual WS2812B LED strip. All the LEDs of a single storage rack will be connected to one pin of the controller, allowing the control of the LEDs of four storage racks with a single Raspberry Pi. Therefore, even though only one storage rack will be initially installed, the system will have the capacity to add three more in the future without needing to add new controllers. Just like with the Raspberry Pi units used in the workstations, we will need to adapt the chosen controller for the lights to the industrial environment. This will ensure durability and reliability in the demanding conditions of the factory lab.

Buttons Controller and Storage Cell Button

For the buttons, we need a robust option that can withstand the numerous presses it will endure over time. Since reliability is the main characteristic sought, the chosen option will be industrial automation buttons. Specifically, the chosen buttons are SIEMENS 3SU1150-0AB40-1BA0, industrial automation buttons from Siemens with a 22mm mounting diameter. These buttons will need to be installed in enclosures that will be fixed to the metal profiles of the storage cells. As the design of the enclosures must be fully adapted to the storage rack, it will be designed in 3D (three-dimensional) CAD (Computer-Aided Design). CAD is the use of computer software to create and manipulate three-dimensional models of physical objects. It will be 3D printed later

Regarding the controller that will receive the button press signals and transmit them to the computer, we need one that is adapted to work with industrial buttons and offers high reliability. In the industry, PLCs are the most commonly used option for this purpose. Therefore, we will take advantage of the **Siemens S7-1200 1214AC PLC** to integrate it into the project for controlling the buttons. This PLC has 14 digital inputs of 24V that we will use to receive the button press signals and comes with an integrated power supply. Having a PLC in the warehouse will allow for the integration of industrial automation elements in future updates such as industrial sensors or HMI (Human-Machine Interface) prepared for PLC. HMI refers to the user interface that connects an operator to the controller of a machine.

4.3 Software Design

It was required to design an IoT network (Internet of Things), as we would have a network of devices connected via Wi-Fi that can communicate and interact with each other and with other systems through the Internet. The software design that controls this network has been divided into the different control programs for the Raspberry Pi boards and the main program that will run on a computer in the warehouse. All the programs will be written in Python, and communication with the main computer will be done via sockets using a connection-oriented TCP protocol to ensure the sending and receiving of messages containing the codes and the commands for the leds. The default socket library for Python, "socket," will be used.

4.3.1 Software of the Workstation's Raspberry Pi

For the design of the program that will control each Raspberry Pi in the workstation, the following tasks and requirements are defined:

1. It must remain in a waiting state for the scanner input.
2. Once it receives a scanned code, it should generate a message and send it to the main computer.
3. It must function as an infinite loop since, due to the lack of easy access to the Raspberry Pi, we need to avoid having to restart the program at all costs. For this reason, robust error control is needed to ensure the uninterrupted execution of the program.
4. The program must run upon device initialization automatically due to the difficulty of access mentioned in the previous point.

The scanner connects via USB to the Raspberry Pi and functions as a keyboard input. Each time it detects a barcode, it inputs the corresponding code via the keyboard and sends it. Therefore, the program will wait for keyboard inputs. When it receives an input, it will attempt to connect to the socket with the IP (Internet Protocol) address of the main computer in the local Wi-Fi network. If a connection is established, it will send the code and wait for a response from the server to confirm receipt.

This will repeat in a loop. If errors occur, they will be displayed on the screen, and the program will wait for 3 seconds before returning to the loop.

4.3.2 Software of the Warehouse Raspberry Pi

For the design of the program that will control each Raspberry Pi in the workstation, the following tasks and requirements are defined:

1. The program must remain in a waiting state to receive messages from the main computer.
2. The program must remain in a waiting state to receive messages from the main computer.
3. Each message will contain a command, which can be either to control the lights or to establish an initial configuration.
   - If the command is for configuration, the program must set up the lights according to the specified parameters.
   - If the command is for control, the program must turn on the corresponding lights based on the control data provided in the message.
4. The program must function as an infinite loop because there is limited access to the Raspberry Pi. Restarting the program must be avoided at all costs. Therefore, robust error handling is necessary to ensure the uninterrupted execution of the program.
5. The program must run automatically upon device initialization due to the aforementioned difficulty in accessing the Raspberry Pi.

The LED lights are connected to the GPIO pins of the board, so we have to use the ”board” library in Python. To control the LED lights, it’s used the ”neopixel” library in Python. The lights are controlled as an object containing a list where each element is an LED. To control each LED, the RGB value of the corresponding list element must be changed.

To initially configure the object, it needs to be initialized with the precise number of LEDs being controlled and the connection pin for proper functioning. For this reason, and due to the intention to expand the system with new modules while seeking maximum versatility we would be able to configure it at any time When the system receives a configuration command, it will contain: the number of storage racks, the number of cells per storage rack, and the number of LEDs per cell. Based on this data, the program will configure its parameters.

For the LED control commands, the message will contain a list where the index corresponds to the cell number, and the value is the number of LEDs that should be on in that cell. It also includes the color with which the LEDs should shine. When executing each control command, the LEDs shine all in the same color, with possible colors being red, blue, green, and orange.

The control of each LED is accessed sequentially according to the configuration parameters and considering the arrangement of the LED strip in the storage rack. Upon completing an iteration of the main loop, the program will wait for a specific period to avoid processing overload. This waiting time will be synchronized with the command sending cycle time from the main computer. If an error occurs during the execution of the program, it will display the error on the screen and wait a few seconds before re-entering the execution of the main loop.

4.3.3 Warehouse Computer Software

The main computer, located in the warehouse, connects to a screen positioned next to the storage racks, visible to the operator during restocking. This computer will run a program that will control and integrate all other parts of the system. It will manage the lights, receive signals from the PLC buttons, and receive signals from the workstations. For the design of the program executed by the warehouse computer, the following tasks and requirements are defined:

1. The program must be configurable through certain main parameters which will control the variations in the system's operation. This is because it needs to be flexible regarding system updates. These parameters must be stored once configured for future program executions.

2. The program has two different modes for managing restocking following the kitting method:

   - In the first mode, the demand list will be cyclical and predefined with the parameters.
   - In the other, the demand list will be dynamic and entered by the user in real-time.

3. The program has a mode to manage restocking following the line stocking method.

4. The program must have a GUI (Graphical User Interface), that is a type of user interface that allows users to interact with the computer through graphical elements. With the GUI the user can interact with the system and change the parameters. The user must also be able to select the mode and run it from the same interface. Depending on the mode executed, it must display the necessary information for the operator to perform the restocking correctly.

5. When a mode is started, two different sub-processes, which will be explained in detail later, with well-defined tasks will begin:

   - The first sub-process will be responsible for waiting for messages from the workstations. Upon receiving a message, it will store its code along with relevant information like which workstation sent it or the parts and the storage cells corresponding to it.
   - The second sub-process will initially establish the connection with the PLC that will receive signals from the buttons and with the Raspberry Pi that will control the lights. Subsequently, it will cyclically manage the restocking operation depending on the mode. A control logic will be implemented for each mode to process and send the message to the Raspberry Pi with the command to control the lights at each moment based on the following: the list of received codes, the demand list, and the signals from the pressed buttons received from the PLC.

6. In the kitting mode with variable demand, there will be a third sub-process in addition to the previous ones. This sub-process will be responsible for waiting to receive codes via keyboard input by the user to add orders to the demand list. This will be done cyclically.

The user interface is a web application programmed in Streamlit, a Python framework. This tool allows the user to choose between four options when starting the program: run

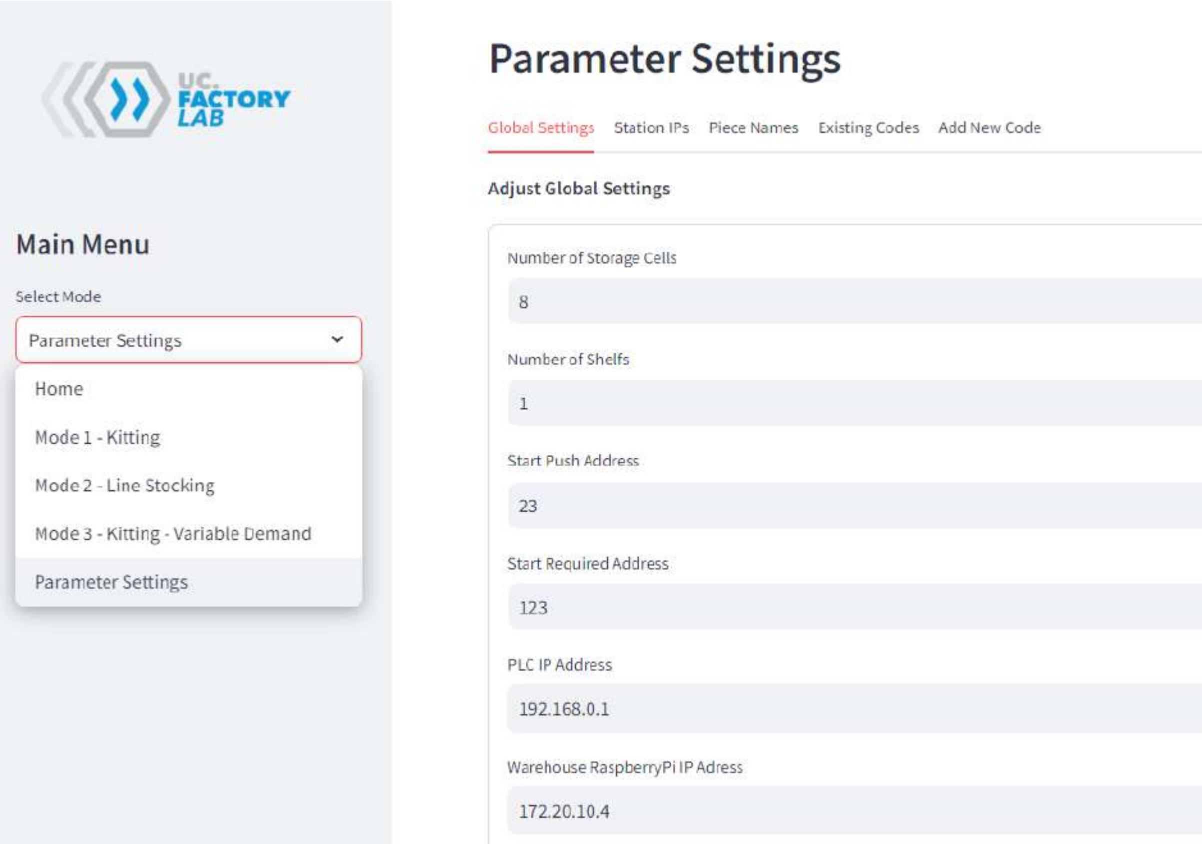


Figure 4.8: Parameter settings tab in the GUI (Graphical User Interface).

one of the three modes or enter the parameter configuration tab (see Figure 4.8). The settings in the configuration window can be divided into three groups.

The first type of settings includes the main parameters where the user can modify most of the variables that influence the system's operation. The second section of the configuration assigns, edits, and deletes the workstation's IP addresses. The third section is where the user can manage the barcodes. The barcodes will be divided into two groups. Numeric barcodes will be used for the line stocking method and will correspond to a type of item within the warehouse. Therefore, they will need to be assigned the cell number where that item is located in the storage rack. Barcodes designated with an uppercase letter will correspond to a kitting order and will have a specific number of each type of part assigned for each workstation where they will be assembled.

The user will be able to add new codes of both types, customizing which parts and in what quantity, for which workstation the order corresponds in the case of kitting, and in which cell and to which item the code corresponds in the case of line stocking. Those added codes will be stored in the system, and the user will also be able to access them through the interface to view their information, modify them, or delete them easily. A JSON file will be used to store all the parameters and preserve them between program executions. If available, the data from this file will be loaded when the program starts.

Now, the functioning of the three available modes in the program will be explained in detail, as well as how the relevant information is displayed in the graphical interface for each mode.

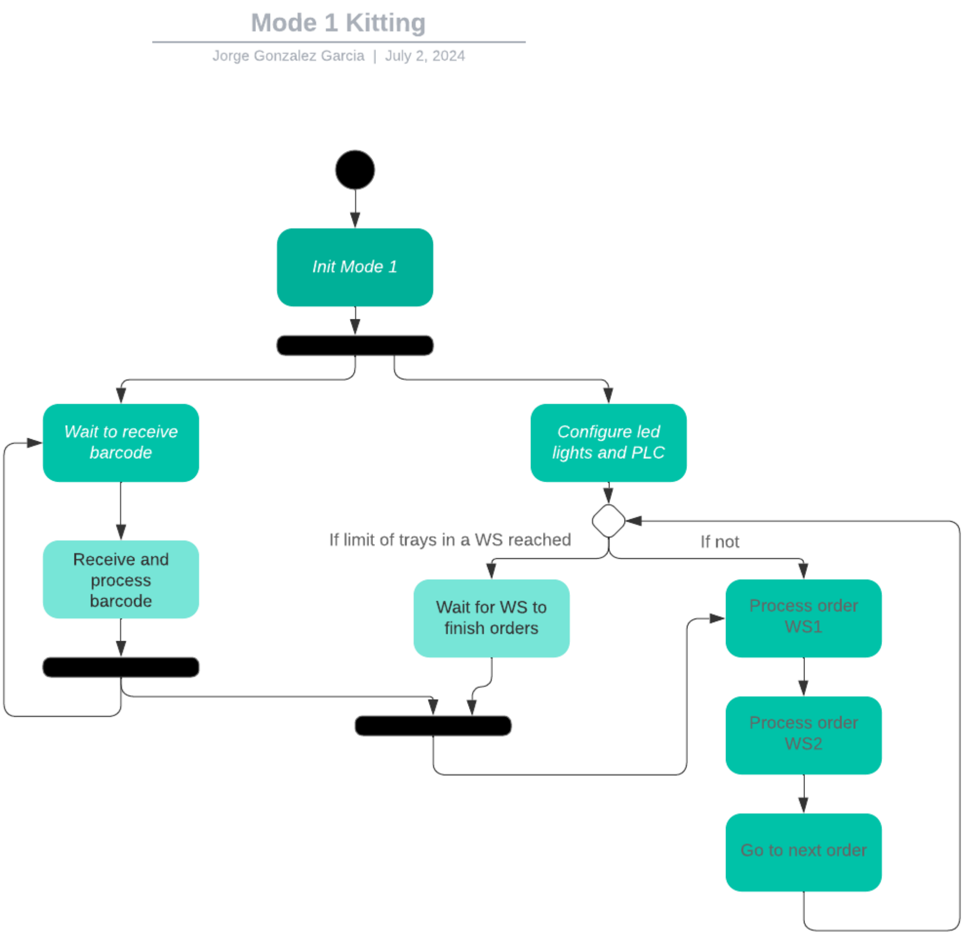


Figure 4.9: Activity diagram for kitting mode.

Kitting mode

This mode will have two concurrent parallel sub-processes, as we can see in the activity diagram in Figure 4.9.

The first sub-process will receive and process the barcodes received from the workstations throughout the entire execution. In this mode, barcodes are signals indicating that orders have been completed at a specific workstation. These codes allow the system to know at which workstation an order has been completed. The other sub-process connects to the PLC and configures the LEDs that display the number of available pieces of each type in the warehouse. Initially, the LEDs indicate that all storage cells are empty and there are no orders in progress.

This mode uses a predefined and cyclical “demand list”, configurable in the parameters. This list contains the order codes in the sequence they should be processed, for example: A, B, C, A, B. Additionally, a maximum limit of pending orders for each workstation is set, which is also configurable. If this limit is reached at any of the stations, the system stops processing new orders. The system constantly checks for new codes, when it receives one, it updates the number of orders at each workstation and removes it.

Orders are processed one by one following the demand list. If there is no current order and the pending order limit has not been reached, the program initiates a new order with the next code from the list.

The system loads the piece requirements of the order for workstation number 1 and displays them on the LEDs. Each LED indicates the number of pieces of a specific type needed for the order. When a button on the PLC is pressed, the program interprets that a piece of a specific type has been removed:

- If the removed piece is correct, the requirements are updated, and the corresponding LED turns off.
- If the removed piece is incorrect, the LEDs for that storage cell turn red to indicate the error and then return to their normal state.

Once all necessary pieces for workstation number 1 have been removed, the LEDs turn green to indicate the completion of this phase. The system then loads the piece requirements for workstation number 2, this time displaying the requirements on the LEDs with a blue color. The order processing at this workstation is the same of workstation 1. Once the order is completed at workstation number 2, the order is considered finished. If the pending order limit has not been reached, the system will initiate a new order following the cyclical list. This process repeats continuously: receiving orders, managing the removal of pieces, updating the LEDs, and completing orders.

As we can see in Figure 4.10, in this mode, the graphical interface displays in real-time during execution: the current order with its code and name, and which workstation is being processed with its corresponding pieces. It also shows a descending list of the next scheduled orders, information on how many kits are currently at each workstation, and the kit limit for each station.

Kitting With Variable Demand Mode

This mode is a modification of the kitting mode, as the demand list is not predefined. Unlike the previous mode, where a pre-configured cyclic list of codes is followed, in this mode, the orders are received dynamically through a terminal during execution. This means that the demand list is updated in real-time as new orders are entered, offering greater flexibility and adaptability to real-time needs.

In this mode, there is an additional sub-process (see Figure 4.11) responsible for receiving new orders and adding them to the demand list. This sub-process operates in parallel with the other two already explained.

Due to this dynamic demand list, the system constantly checks for new orders and whether the pending order limits have been reached. Only if there are orders in the list and the order limits have not been reached does the program initiate a new order with the first code in the list. This introduces an additional condition for processing an order: the need for orders to be in the demand list. Otherwise, the process of loading requirements, removing pieces, and updating LEDs follows a similar logic to the previous mode. The LEDs indicate the number of pieces needed and update when pieces are removed, showing errors if incorrect pieces are removed. Once all necessary pieces for workstations 1 and 2 are completed, the order is considered finished and removed from the demand list.

This cyclical process ensures that the system efficiently manages orders in real-time, adapting to the dynamic input of new orders and providing clear visual feedback to the operators through the LEDs. In this mode, the graphical interface will display the same information as in the previous mode (see Figure 4.10). The only difference is that the order list will be updated each time an order is received, and the orders that have already been processed will be removed.

Mode 1 - Kitting

Current Order

	Nombre	WorkStation	Base	Body	Screw	Piston	Top
0	A	Workstation 2	0	0	2	0	1

Sequence

	Elementos
0	B
1	C
2	C
3	A
4	A
5	B
6	A
7	A

Containers in Workstation 1 : 3

Containers in Workstation 2 : 2

Limit of containers : 3

Figure 4.10: GUI display on kitting mode.

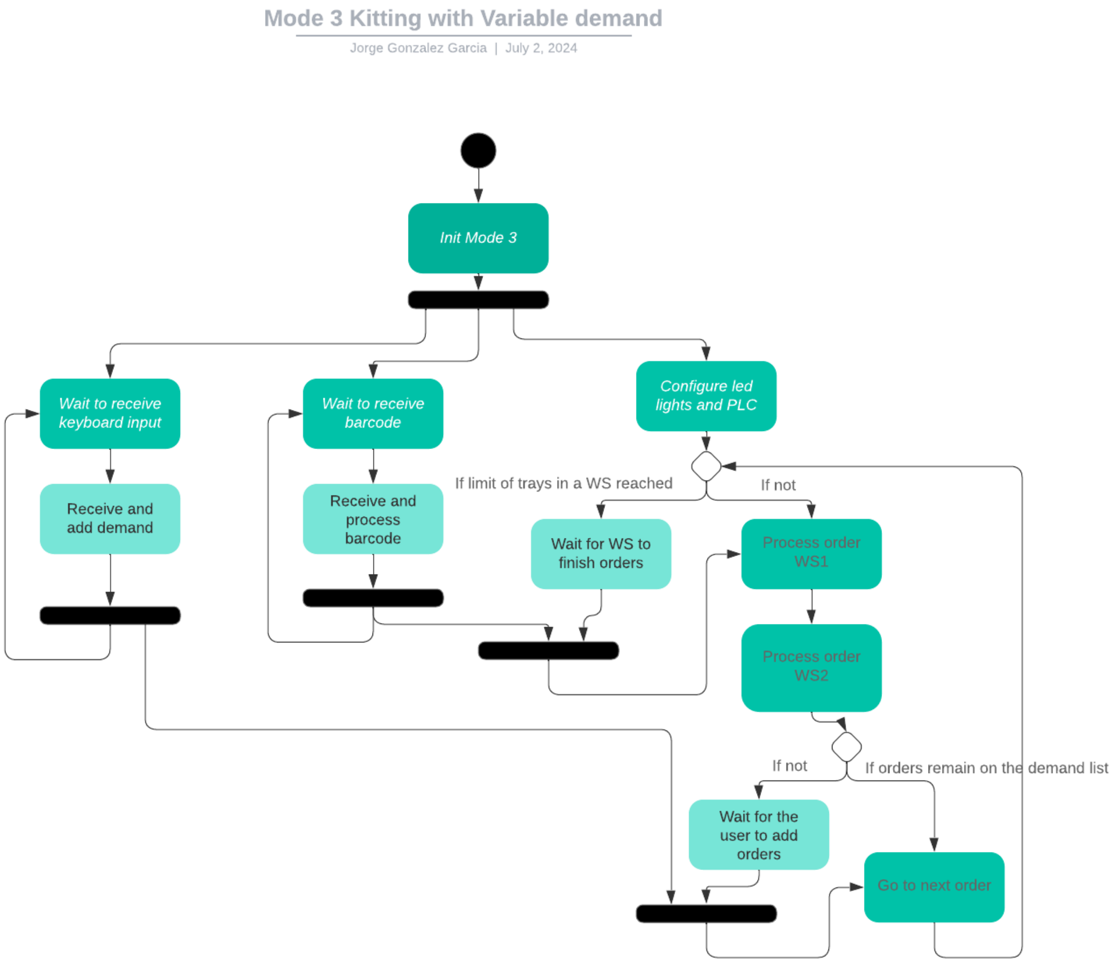


Figure 4.11: Activity diagram for kitting with variable demand mode.

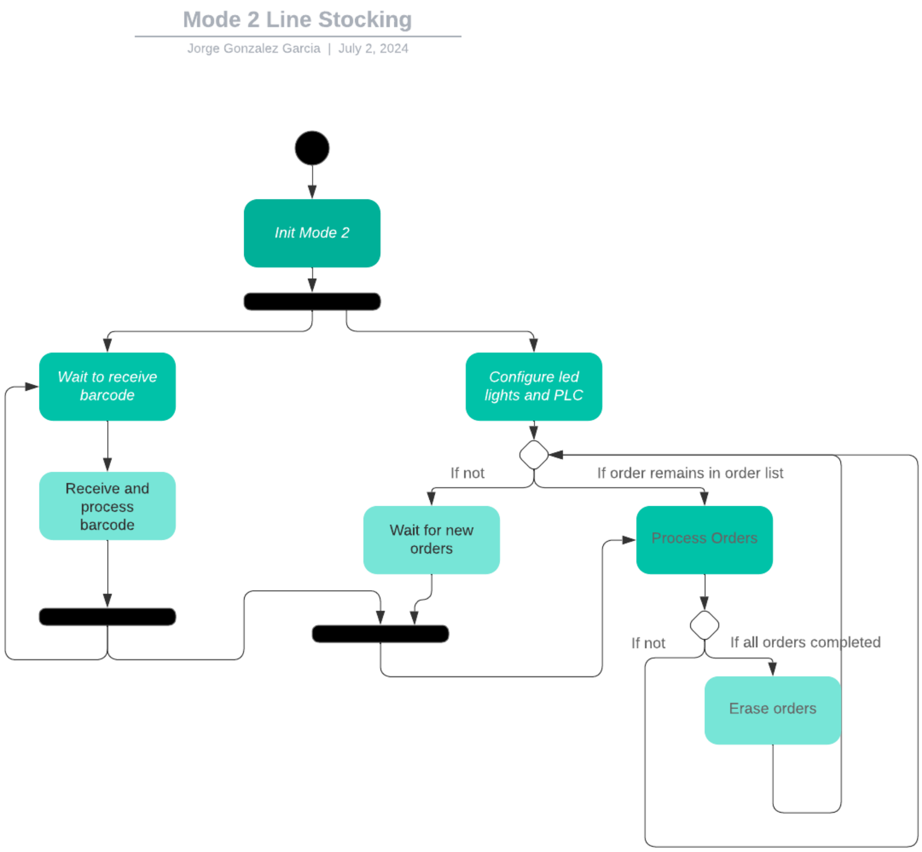


Figure 4.12: Activity diagram for line stocking mode.

Line stocking mode

This mode will have two concurrent parallel sub-processes, as we can see in the activity diagram in Figure 4.12. In this mode, the received codes correspond to a required box of pieces. The first sub-process receives these codes and adds them to a code list. The second sub-process connects to the PLC and configures the LEDs that display the number of available pieces of each type in the warehouse. Initially, the LEDs indicate that all storage cells are empty and there are no orders in progress. It constantly checks for new codes. If a new code is received and it corresponds to a specific cell, the requirement counter for that cell is incremented, so it's accumulative.

When there are pending requirements in any cell, the system reads the signals on the PLC to verify if a piece has been removed. If a button on the PLC is pressed, the program interprets that a piece has been removed:

- Correct Piece: If the removed piece matches the requirements, the pending piece counter is updated, and the corresponding LED turns off.
- Incorrect Piece: If the removed piece does not match the requirements, the LEDs for that cell turn red to indicate the error and then return to their normal state.

The system continues to update the LEDs to reflect the current state of the requirements. If all the requirements in all cells have been met, the LEDs turn blue for 4 seconds,

Mode 2 - Line Stocking

	Code	Name	Cell	WorkStation
0	1	Base	1	Workstation 1
1	5	Top	5	Workstation 2
2	4	Piston	4	Workstation 2
3	2	Body	2	Workstation 1
4	3	Screw	3	Workstation 1

Figure 4.13: GUI display on line stocking mode.

indicating to the operator that all orders are complete. During this time, the operator can check the screen to see which workstation each tray goes to. After 4 seconds, the LEDs turn off, and the completed codes are cleared from the screen, preparing the system to receive and process new codes. This process repeats continuously: receiving requirement codes, managing the removal of pieces, and completing orders. At each step, the LEDs and counters are updated to reflect the current status of the warehouse and workstations.

As we can see in Figure 4.13, in this mode, the graphical interface displays in real-time a list of the different codes received in descending order of reception. The visualized information includes the product name, the code, the cell where the trays of that type of pieces are located, and the workstation that sent the code.

4.4 3D Design

4.4.1 Button Box

To meet aesthetic and functional requirements, it was necessary to adapt the industrial automation buttons to fit onto the metal profiles of the item storage rack. For this, a box was needed to house each button and include a mounting system to attach it to the storage rack. The boxes had to be securely fixed so that frequent pressing would not compromise their stability, but they also needed to be easily assembled and disassembled for button maintenance. The box also needed a hole to allow cables to connect the button to the PLC.

To meet these requirements, a 3D CAD design of a box with a pressure fitting system was created (see Figure 4.14). The box consists of three different parts, each represented with a different color, and the detailed plans for each can be seen in the Appendix A.

- The first part is the top cover (in white in Figure 4.14) with a square shape and a 23mm hole in its centre where the button will be placed. At its corners, there are four 5mm diameter holes with countersinks to be fixed to the lower case with four M5 screws, 60mm long, with flat heads.

- The second part is the lower case, which has a square shape and is represented in dark grey in Figure 4.14. It has a side hole to allow the cables from the button to pass into the interior of the box. Additionally, it has two 5mm diameter holes and

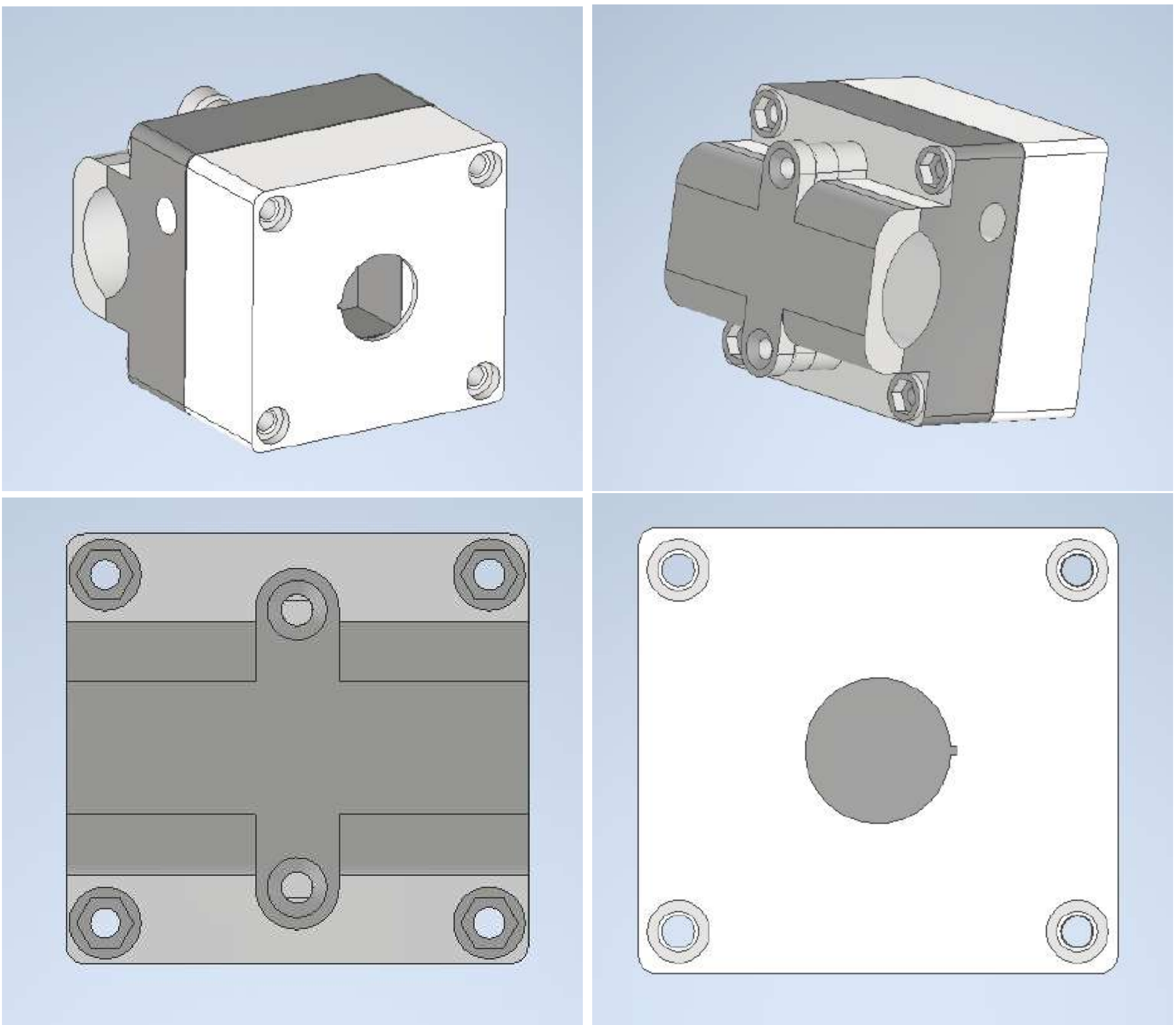


Figure 4.14: Different views of the CAD design of the box for the buttons.

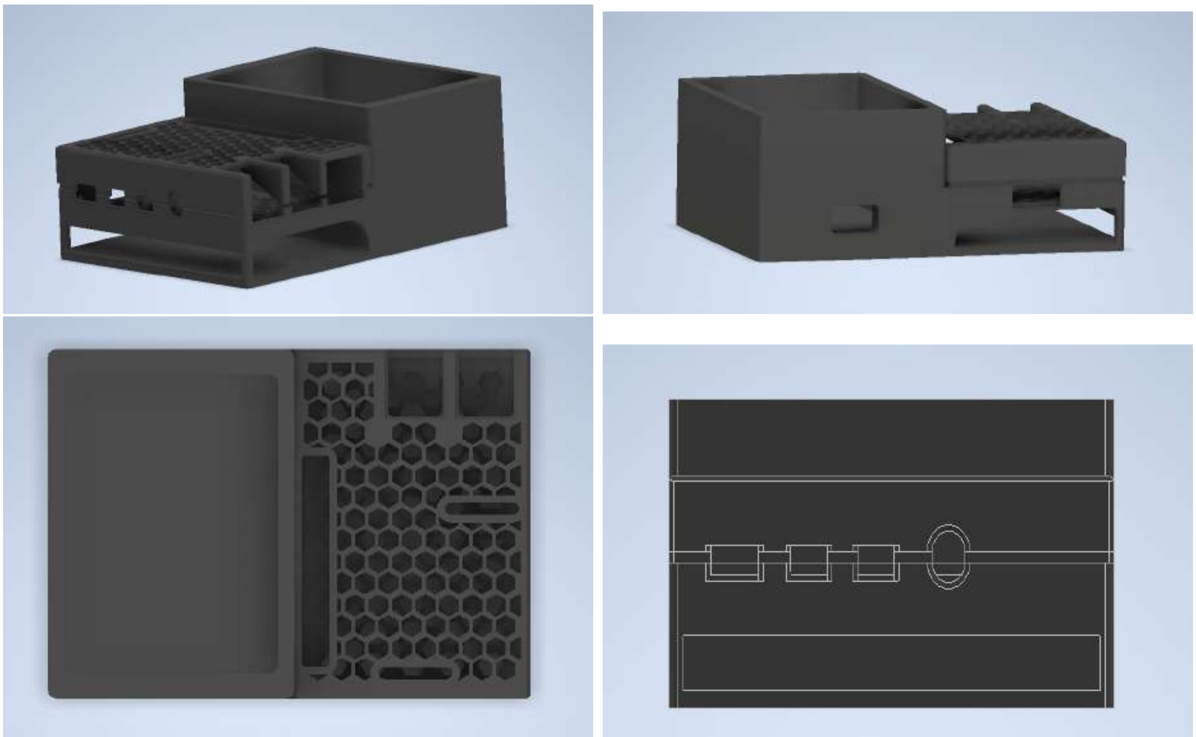


Figure 4.15: Different views of the CAD design of the support.

two hexagonal recesses in the front part that will be inside, designed to house ISO M5 nuts. On its rear side, it has four 5mm diameter holes and a recess for ISO M5 nuts to secure the screws that will attach it to the top cover. It also has a shape that, in profile, is similar to a semicircle to fit the metal profile (30mm in diameter).

- The third part completes the fastening system and is represented in light grey in figure 4.14. It has a semi-tube shape in profile to fit the metal profile. On its lower part, it has two 5mm countersunk holes designed for 50mm screws with flat heads. The box will be secured by screwing this part to the bottom of the case, with the two parts clamping the metal profile and being solidly fixed due to the pressure exerted.

A box for each storage cell will be printed with a 3D printer in PLA (Polylactic Acid), a biodegradable thermoplastic derived from renewable resources like corn starch or sugarcane. It is widely used in 3D printing due to its ease of use, low warping, and environmentally friendly properties. The color of all the parts will be white .

4.4.2 Raspberry Pi Case and Scanner Support

As previously mentioned, the Raspberry Pi 4 is not a device designed to operate in industrial environments. For this reason, a case has been designed to protect the Raspberry Pi in the workstations. In the design, it was important to consider that the Raspberry Pi devices are small but tend to produce a significant amount of heat, which, if not dissipated, can compromise their proper functioning. There are fans designed to dissipate the heat from these devices, but since the intended use is not too demanding, it will be sufficient for the designed case to be open to allow airflow.

The Raspberry Pi devices were to be used in conjunction with the scanners, and it was necessary to create a support for both elements. Taking advantage of the need to design a case as well, these two elements have been combined. The model shown in Figure 4.15 is the CAD design that integrates the case and support for both devices. In the Appendix A, detailed plans for each of the two pieces of this design can be found.

As we can see, the Raspberry Pi case has holes that follow a honeycomb pattern on both the top and bottom. The cover has all the necessary openings to access any of the pins, ports, and the microSD slot with the cover closed. The bottom part has been elevated with supports, leaving an empty volume that, by not having the board flush with the ground, allows for airflow to cool it.

Next to it, the scanner support has a simple design with dimensions that allow the scanner base (Figure 4.20) to fit loosely. It also has a small hole in the back that allows the scanner base to be connected to a power source for recharging without needing to remove it from the support.

One of these models will be printed for each workstation in black PLA using a 3D printer.

A CAD model of an individual case has been designed for the Raspberry Pi, removing the scanner support part and leaving only the case itself (with the same model as the case explained earlier).

4.4.3 Design of Electrical Connections

Explaining the electrical wiring itself is considered not to provide valuable knowledge for this project, so it will not be done. Regardless, the electrical connection design plans can be found in the Appendix B.

4.5 Results

4.5.1 Installation and integration of the system

The installation process began with mounting the 3D printed models of the boxes onto the shelves of the storage rack. Ensuring that the placement was secure and functional, these components were installed precisely according to the design specifications.

Next, all the necessary wiring was performed, making sure to hide the cables for aesthetic reasons. This step was crucial not only for maintaining a clean and organized appearance but also for protecting the wiring from potential damage and ensuring the system's reliability.

Before moving the electronic components into the Factory Lab, preliminary tests of the software were conducted outside of the lab. These tests were essential to ensure that the software functioned correctly and to identify and resolve any issues beforehand.

Following these preliminary tests, all the electronic components of the system were transferred to their designated locations within the Factory Lab. This included the Raspberry Pi, PLC, computer, display screen, and power supplies. Each component was carefully placed to optimize accessibility and functionality.

The programs on both the PLC and the Raspberry Pi were then configured to adapt them to the new IP addresses assigned by the private Wi-Fi network of the Factory Lab. This step was essential for ensuring seamless communication between the devices within the network.

Figure 4.16: Warehouse system completely installed.

Once the configuration was complete, the entire system was integrated. This involved connecting all the electronic components, ensuring that each part of the system communicated correctly and functioned as intended. Each connection was meticulously checked to verify its integrity and functionality. With the storage rack setup completed, the Raspberry Pi units and scanners were installed at the workstations.

After the complete installation, the system was tested to ensure it operated as expected. During this testing phase, a few areas were identified where the code could be improved. Consequently, adjustments were made to certain parts of the code to enhance the system's performance and reliability. Finally, barcodes for the trays in the storage rack were printed and applied.

4.5.2 Warehouse Setup Outcome

The complete installed and connected system can be seen in the figure 4.16 . The overall setup in the warehouse includes the computer, the display screen, the PLC, the buttons, the lights, and the Raspberry Pi. All devices, except for the lights and buttons (which are fixed to the storage rack), have been placed on a table with wheels right next to the storage rack. The display screen is positioned so that it can be seen by the replenishment operator while taking items from the storage rack. The display screen boasts a wide resolution and ample dimensions, which significantly enhance the visibility and readability of the graphical interface. This feature is crucial for the operators, as it allows them to quickly and accurately interpret the information displayed.

Figure 4.17: Different views of the wharehouse's Raspberry Pi in its 3D printed case

The figure 4.17 shows the Raspberry Pi responsible for controlling the lights housed in its custom 3D-printed case, which is a variation of the scanner and Raspberry Pi support model from the workstations. This compact design allows airflow while protecting the board.

The figure 4.18 shows different views of the installation of the button's boxes and the LED strips on the storage rack. The LED lights have been fixed to the metal profile, and the connection wires have been guided along the back of the metal profile for a cleaner appearance. For each storage cell, seven LEDs have been installed. This number was carefully chosen as it is considered sufficient to meet the application requirements. The LEDs provide clear visual feedback on the status of the inventory, making it easy to monitor the availability of pieces at a glance.

The button's boxes have been fixed to the profile, with screws and nuts, using the press-fit system designed in the 3D model. The buttons are housed within the box that is securely attached to the metal profile of the shelving unit, ensuring they remain in place and are easy to access. This method not only secures the buttons firmly inside the box but also maintains a clean and organized appearance.

Finally in the figure 4.19a, we see one of the trays with printed barcodes. As explained earlier, the trays have numeric codes printed on them. Multiple barcodes for each number from 1-8 have been printed. These have been placed on the front part of the trays because it is the part that can be seen by the manufacturing operator when the trays are placed on the shelves of the workstation (see figure 4.19b).

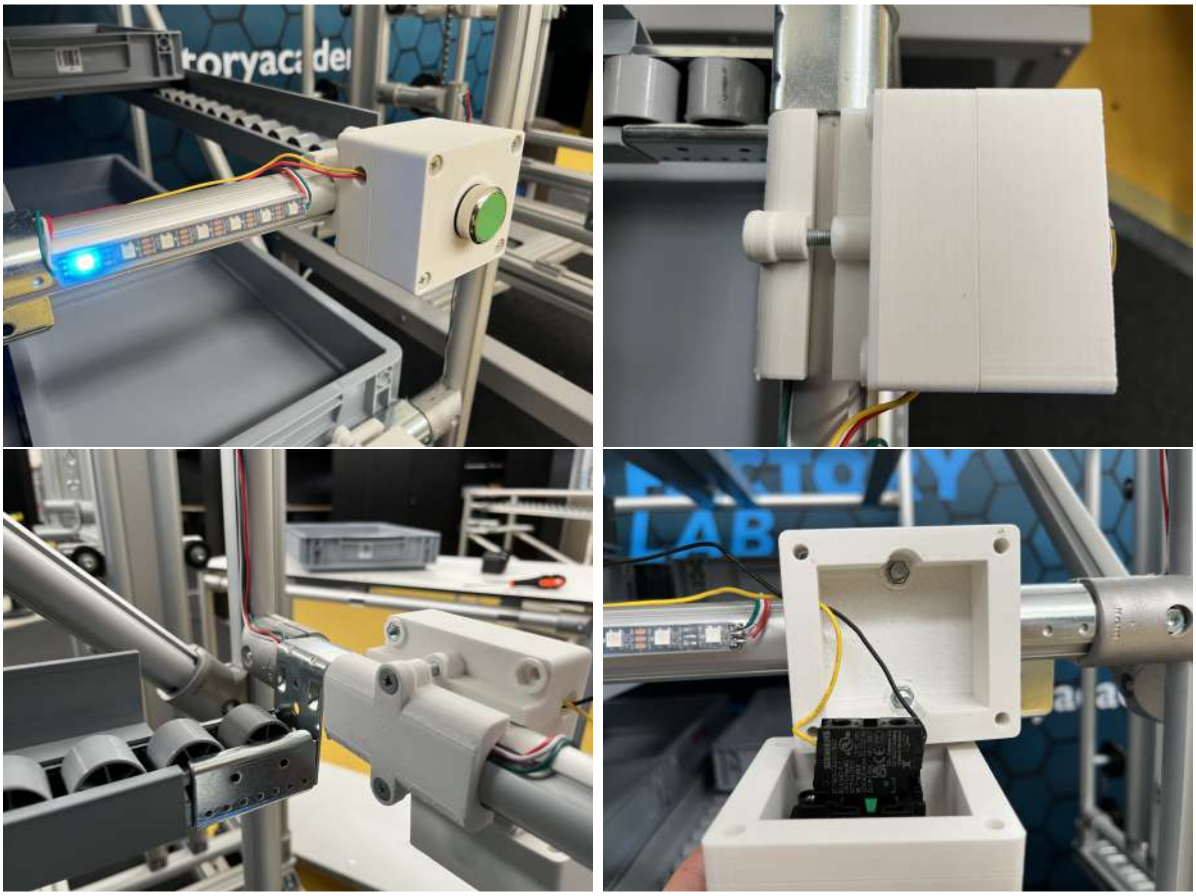
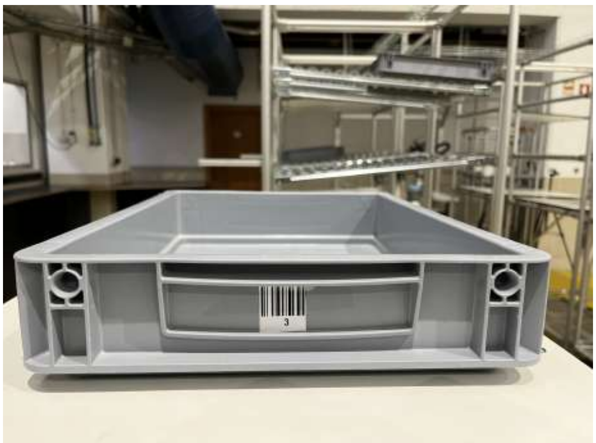


Figure 4.18: Different views of the installation of the button's boxes and the LED strips on the storage rack



(a) Tray with barcode printed on the front.

(b) Trays placed on the workstation shelf.

Figure 4.19: Barcode installation on the trays.

Figure 4.20: Different views of the scanner and Raspberry Pi of one of the workstations in the 3D printed support.

As we can see in the figure 4.20, the scanner with its base has been placed in the 3D printed support along with the Raspberry Pi in its case. It can be seen that this is a compact model that allows for the cooling of the board and access to each of its ports. This way, both devices are secured, and the Raspberry Pi is protected and ready to perform its scanning function safely.

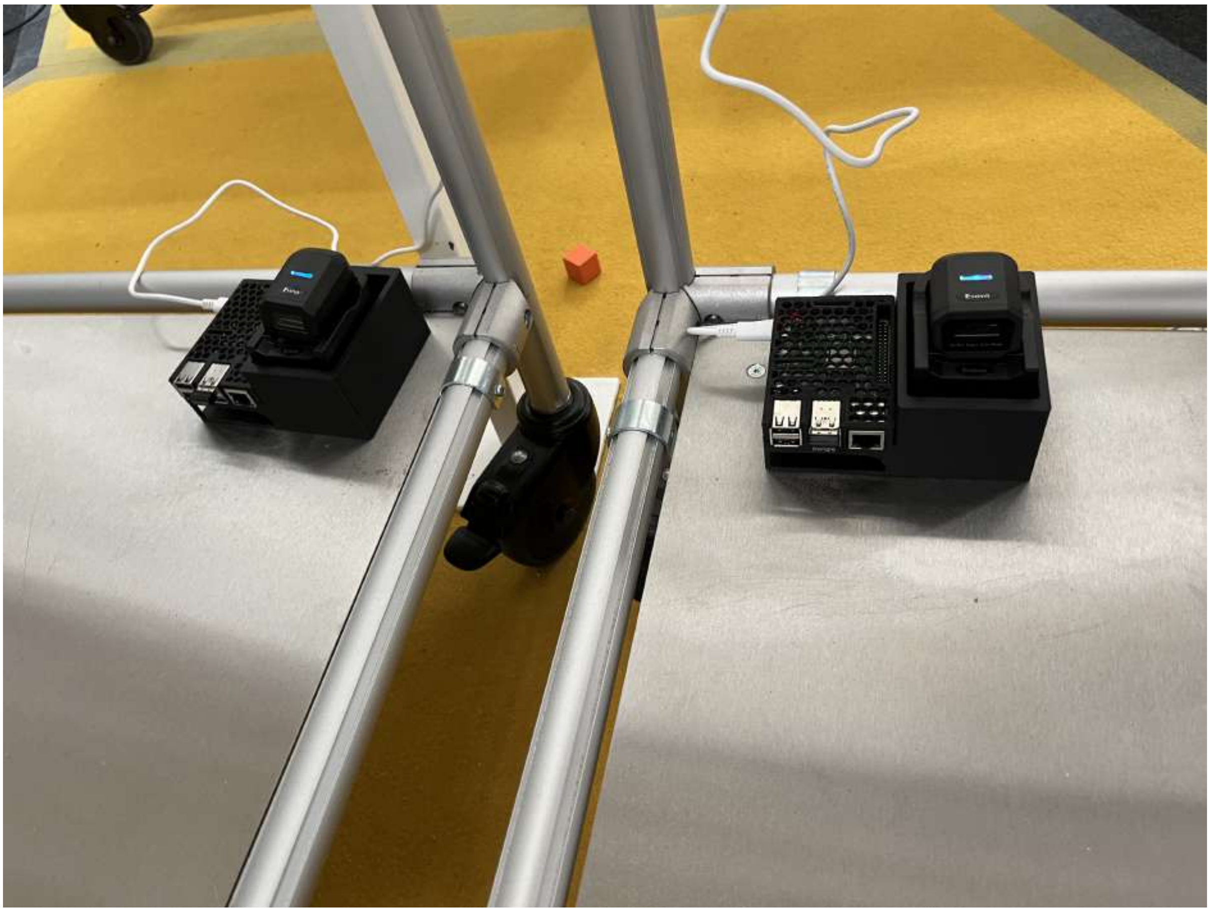


Figure 4.21: System for barcode scanning installed on the bottom shelf of each of the two workstations.

4.5.3 Workstation Configuration Results

As it can be seen in the figure 4.21, ach support with the devices has been placed on a lower shelf of the workstations, close to the power outlets to be powered.. On this shelf, they are protected and isolated from the manufacturing process, allowing the system to stay out of the way of both the tray shelves and the worktable. Bluetooth technology enables the operator to manipulate the scanner without the need for the Raspberry Pi or the scanner base to be connected by cables.

4.5.4 System Testing and Validation

The system underwent extensive testing to ensure its functionality and performance met all predefined requirements. Each mode of operation; Kitting, Line Stocking, and Kitting with Variable Demand; was subjected to rigorous tests under various conditions to evaluate its robustness and efficiency. Additionally, the scanners and the overall system were tested thoroughly to confirm their reliability and accuracy.

In the Kitting mode, the system's ability to handle a predefined, cyclical demand list was thoroughly examined. The LED indicators and button presses were monitored to verify accurate piece retrieval, and any errors triggered the correct visual alerts, allowing operators to quickly address mistakes. Similarly, in the Line Stocking mode, tests focused on the system's capability to manage accumulative requirements for different cells. The correct updating of LED indicators with each button press was confirmed, and the system's response to incorrect piece retrieval was checked to ensure proper error signaling. In the figure 4.22 , we can see the warehouse with the system running, executing each of these two modes.

The Kitting with Variable Demand mode was tested for real time order entry and dynamic demand list updates. The system's flexibility in handling varying order types and quantities was evaluated, ensuring that new orders could be processed without disrupting ongoing operations. Throughout all modes, the accuracy of the LED indicators and the processing of new orders were key focus areas.

The scanners were tested under different lighting conditions and angles to ensure reliable barcode reading. The stability and reliability of the wireless network were monitored, particularly its capacity to handle communication between multiple devices without data loss or delays. The integration of the Raspberry Pi and the scanners was validated to ensure data transmission.

Following the testing phase, several adjustments were made to optimize the system's performance. Minor bugs were identified and fixed in the software, improving the system's stability and reliability. The placement of the Raspberry Pi units and the scanners was optimized to enhance accessibility and functionality. The graphical interface was refined to improve readability and usability.

The implemented system meets all required specifications and operates as intended across all tested scenarios. The integration of the e-kanban and pick-to-light systems significantly improves cycle times, reduces errors, and enhances production efficiency. The system's flexibility and scalability allow for future enhancements and adaptations, ensuring long-term utility and effectiveness in an industrial environment. Overall, the system proves to be a valuable tool for streamlining production processes and achieving operational excellence.

(a) Kitting. (b) Line stocking.

Figure 4.22: System in the warehouse running in two different modes.

Chapter 5

Discussion and future work

As it has been seen, this project addresses a critical need to enhance production efficiency in a manufacturing process, stemming from real-world challenges faced in modern industry. The primary problem was inefficient parts replenishment, which led to increased cycle times, production interruptions, and human errors, ultimately affecting overall productivity and operational costs.

To tackle these issues, we established a set of requirements aimed at creating a versatile system capable of managing both kitting and line stocking replenishment methods. The objectives were clear: develop a electronic automation system that manages parts replenishmen and reduces cycle times, minimizes errors, and ensures reliable production.

Through an academic study of replenishment methods, we explored various strategies and their applications in modern manufacturing. This foundation informed our initial planning, where we considered industry-standard technologies to devise an efficient, practical solution. We designed and developed a comprehensive E-Kanban system, integrating advanced software to connect industrial components such as PLCs, LEDs, and Raspberry Pi devices. The hardware design included 3D-printed cases and supports to protect and house the electronics, ensuring durability and ease of maintenance. Each component was carefully chosen and configured to ensure optimal performance and seamless integration within the existing manufacturing setup.

The achievements of this project are multifaceted. Firstly, the implementation of the E-Kanban system has significantly improved production efficiency. By automating the replenishment process, the system ensures that parts are readily available at workstations, reducing waiting times and production delays. This has led to smoother and more continuous production cycles, minimizing downtime and maximizing throughput.

Moreover, the system's ability to manage and track parts in real-time has drastically reduced cycle times. Operators no longer need to manually track and request parts, as the E-Kanban system automatically signals when parts are needed. This automation has streamlined the workflow, allowing for quicker transitions between production stages and reducing the overall time taken to complete manufacturing processes.

The reduction of human errors is another critical achievement. The visual feedback provided by the LEDs and the real-time updates on the graphical interface have helped operators to accurately follow the production requirements. Incorrect parts removals are immediately flagged, preventing assembly errors and ensuring that only the correct components are used at each stage of production. This has not only improved the quality of the final product but also reduced the need for rework and corrections, saving time and resources.

Additionally, the system's adaptability and responsiveness to dynamic demand have enhanced its functionality. The introduction of a dynamic demand list in one of the modes allows the system to adapt to changing production needs in real-time. This flexibility ensures that the system can handle varying production schedules and demand fluctuations without compromising efficiency.

The project also successfully met the objective of providing an educational tool for students. The graphical interface is intuitive and informative, making it easy for users to interact with the system and understand the production status. This educational aspect is crucial in a learning environment like the Lean Room of the Factory Lab, where the goal is not only to improve production efficiency but also to teach best practices and advanced manufacturing techniques. The system effectively manages both kitting and line stocking methods, providing clear visual feedback and ensuring efficient parts replenishment. In conclusion, this project successfully addressed the need for improved production efficiency through the development and implementation of an E-Kanban system. The system's ability to manage different replenishment methods, provide real-time feedback, and adapt to changing demands demonstrates its effectiveness and potential for future innovation. By reducing cycle times and errors, the system enhanced overall operational efficiency and productivity, aligning with Lean Management principles and modern manufacturing needs. This work lays a solid foundation for ongoing improvements in production processes, ensuring sustained competitiveness and operational excellence.

5.1 Future Work

Building on the successful implementation of the E-Kanban system, several avenues for future work have been identified to enhance its functionality. Improving the graphical interface of the system and storing data in centralized databases will facilitate better user interaction and data management, leading to more efficient monitoring and control of the manufacturing process. Integrating a functionality to measure cycle times and generate detailed statistics will enable precise analysis of the system's performance, identifying bottlenecks and areas for improvement to optimize the production flow. Exploring the potential to expand the system to accommodate more workstations and storage racks will ensure the system's applicability to larger manufacturing setups, providing a versatile solution for various production scales. The modular nature of the system and the ability to change parameters through the GUI make it easily expandable with minimal changes

Another improvement would be connecting a MiR (Mobile Industrial Robots) robot to the system. MiR robots are autonomous mobile robots designed for internal transportation of goods within industrial settings. Connecting a MiR to the system for automated parts replenishment will reduce human intervention. Currently, there is a MiR robot in the Factory Lab capable of moving carts and Karakuri systems, which means that integrating this robot with the implemented system would allow the operator to only need to place the trays on the robot. The robot would then handle the restocking process reducing the workload on the warehouse operator. Another potential upgrade could be replace the barcode scanning system to RFID readers. While transitioning to RFID technology would eliminate the need for manual alignment of scanners and allow for more efficient identification of parts, the current barcode system already performs well with minimal issues. The time consumed by scanning barcodes is minimal, and the errors generated are very few, thanks to an auditory signal of the scanner that confirms when a code has been scanned correctly.

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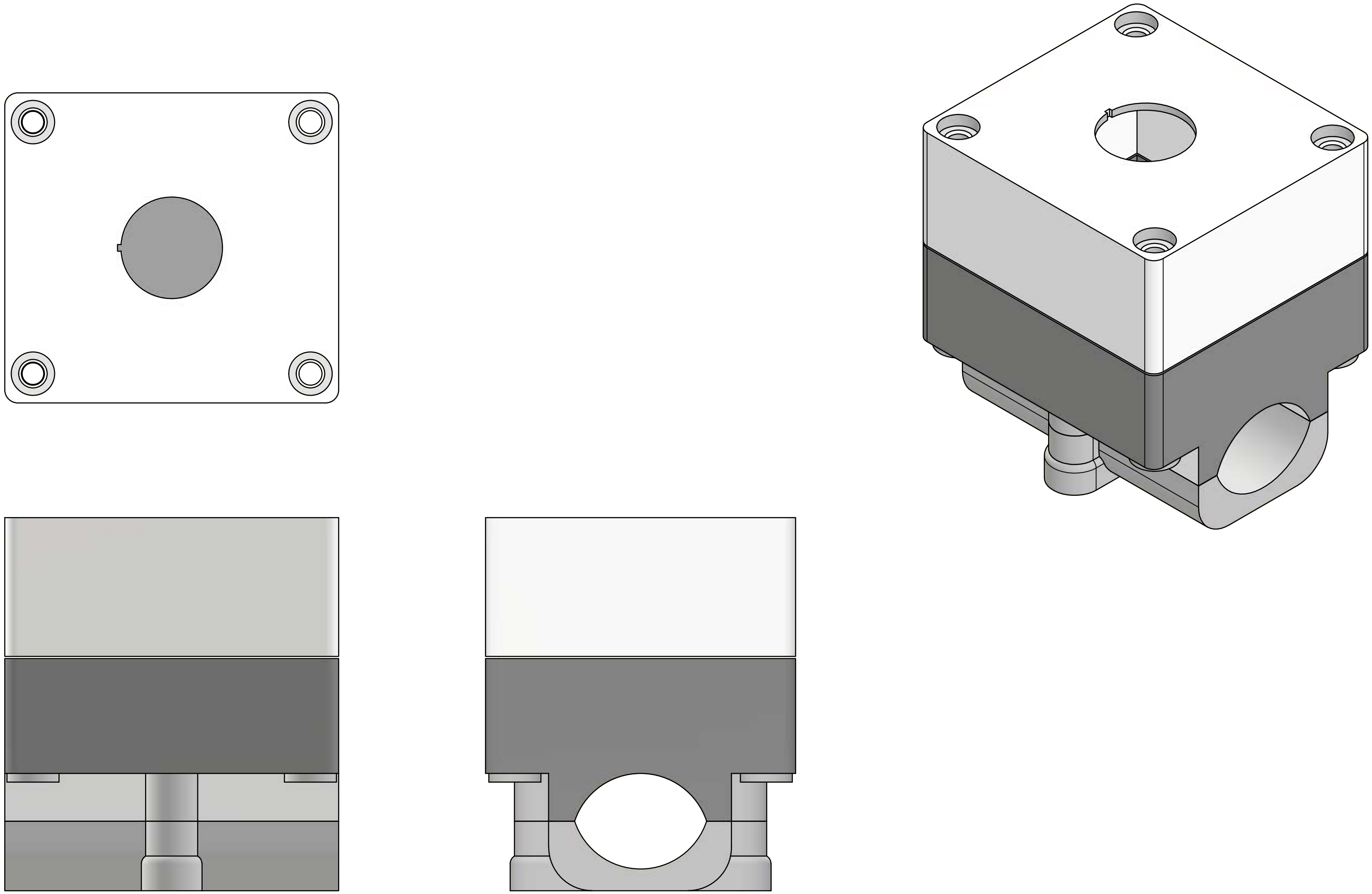
Appendix A

3D Blueprints



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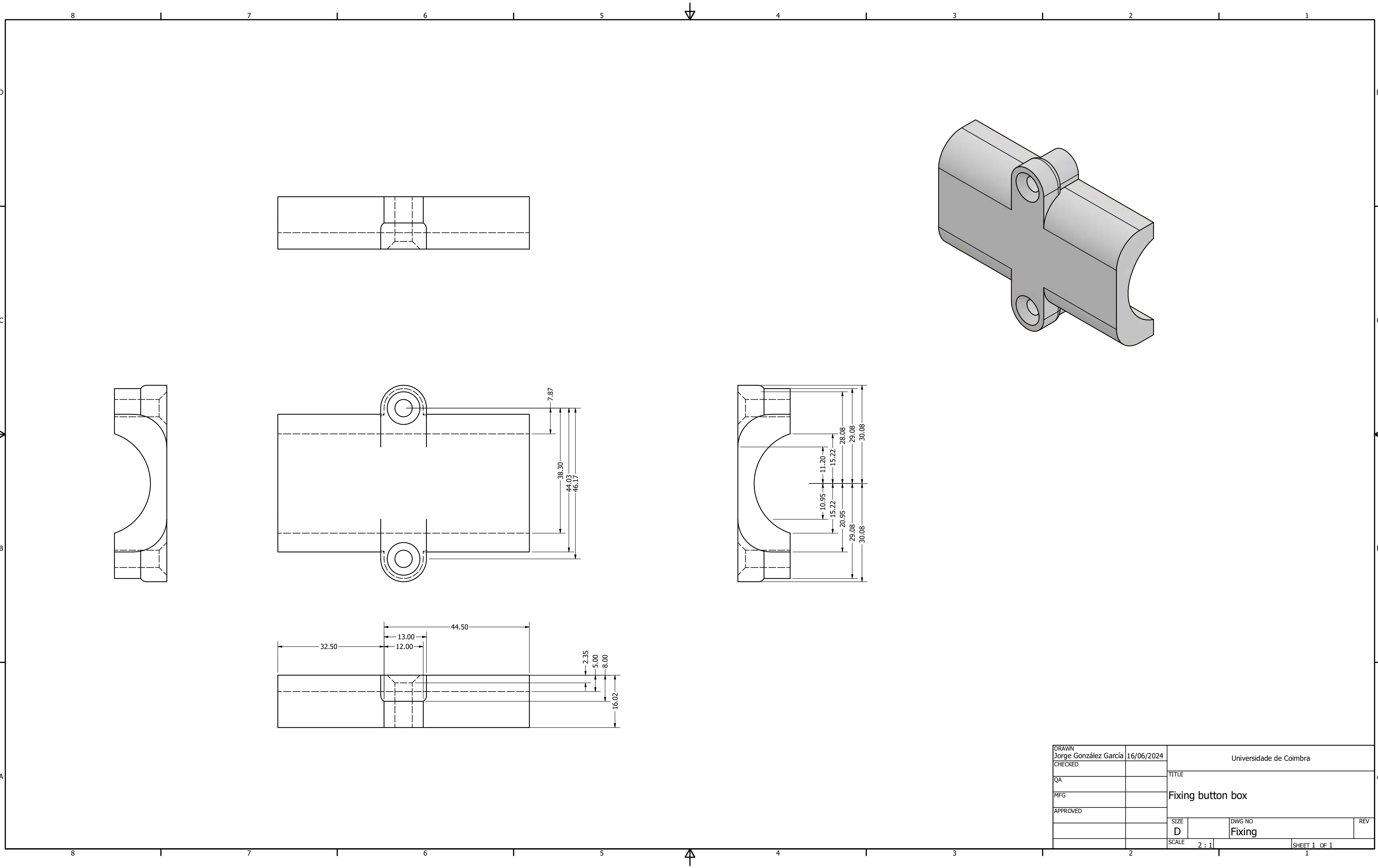
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Jorge González García 16/06/2024
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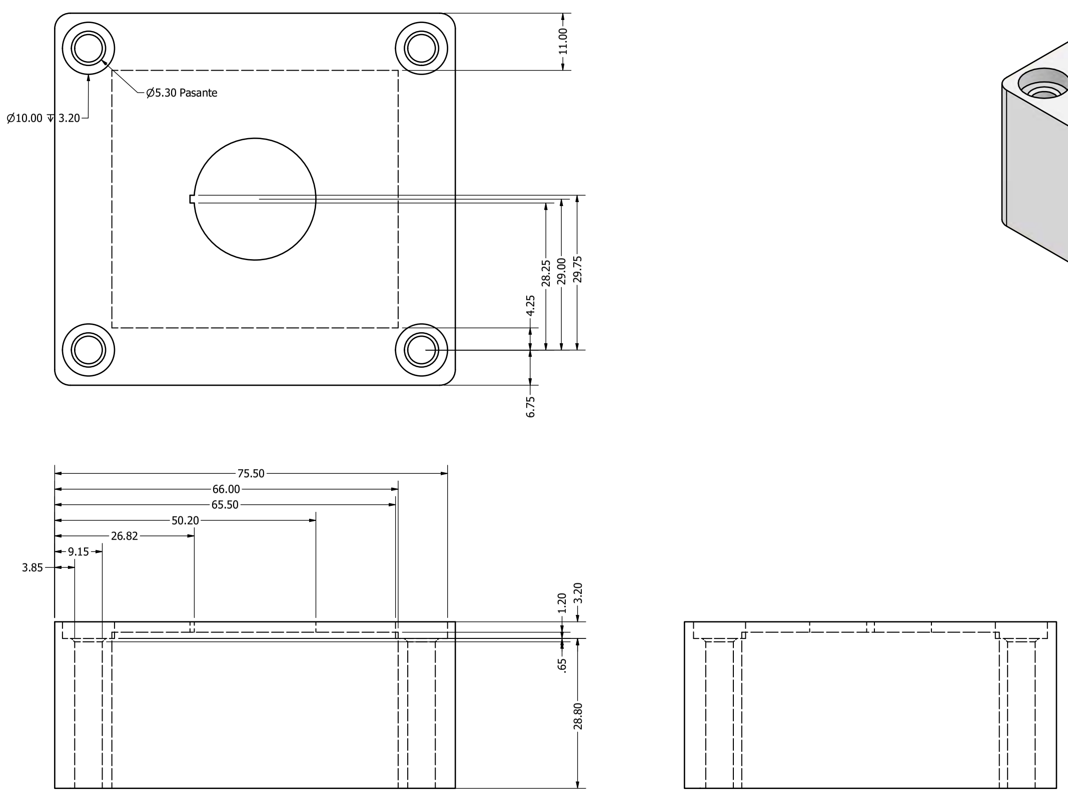

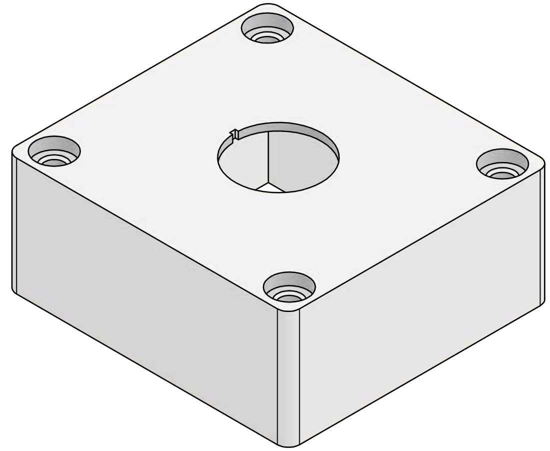

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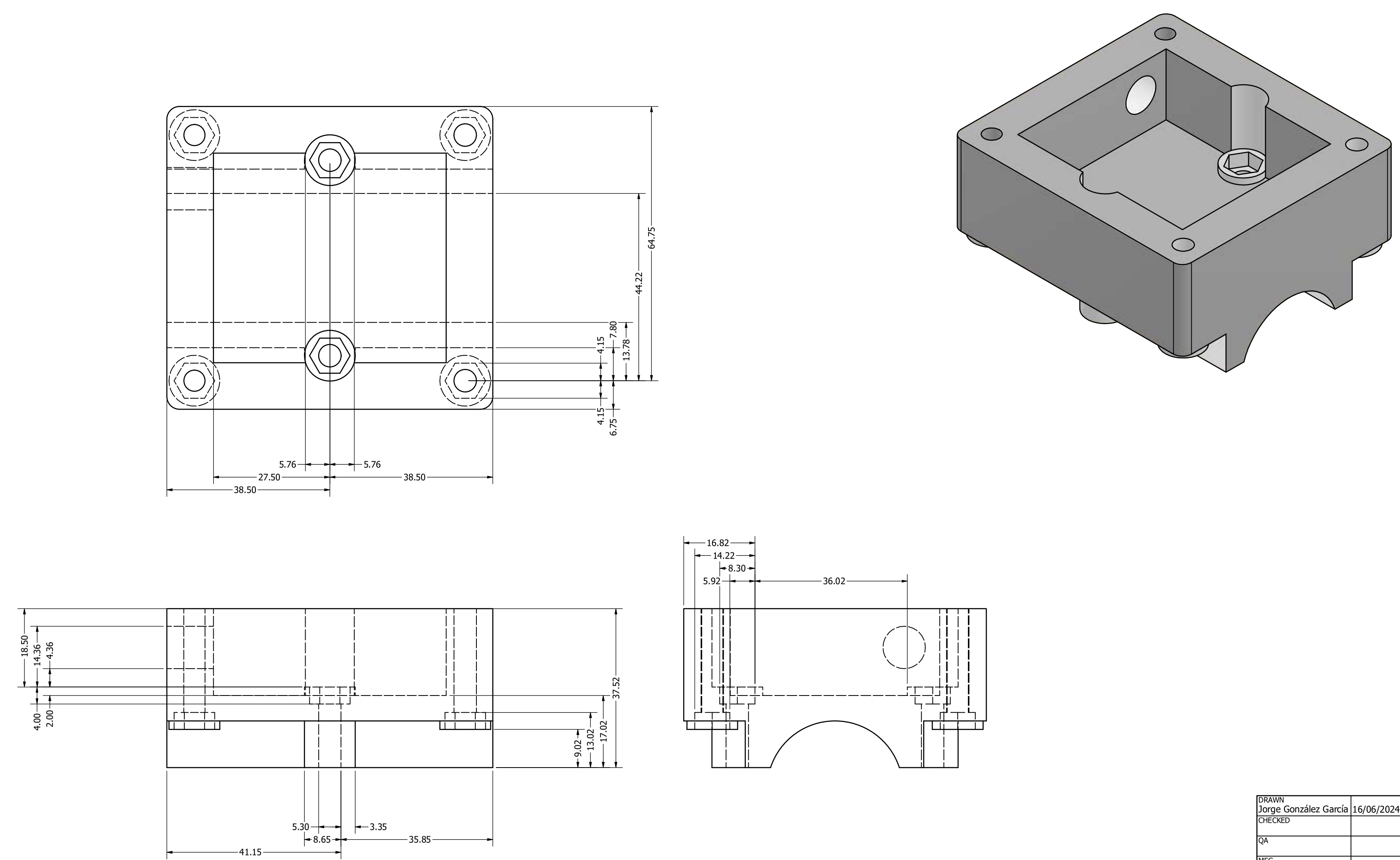

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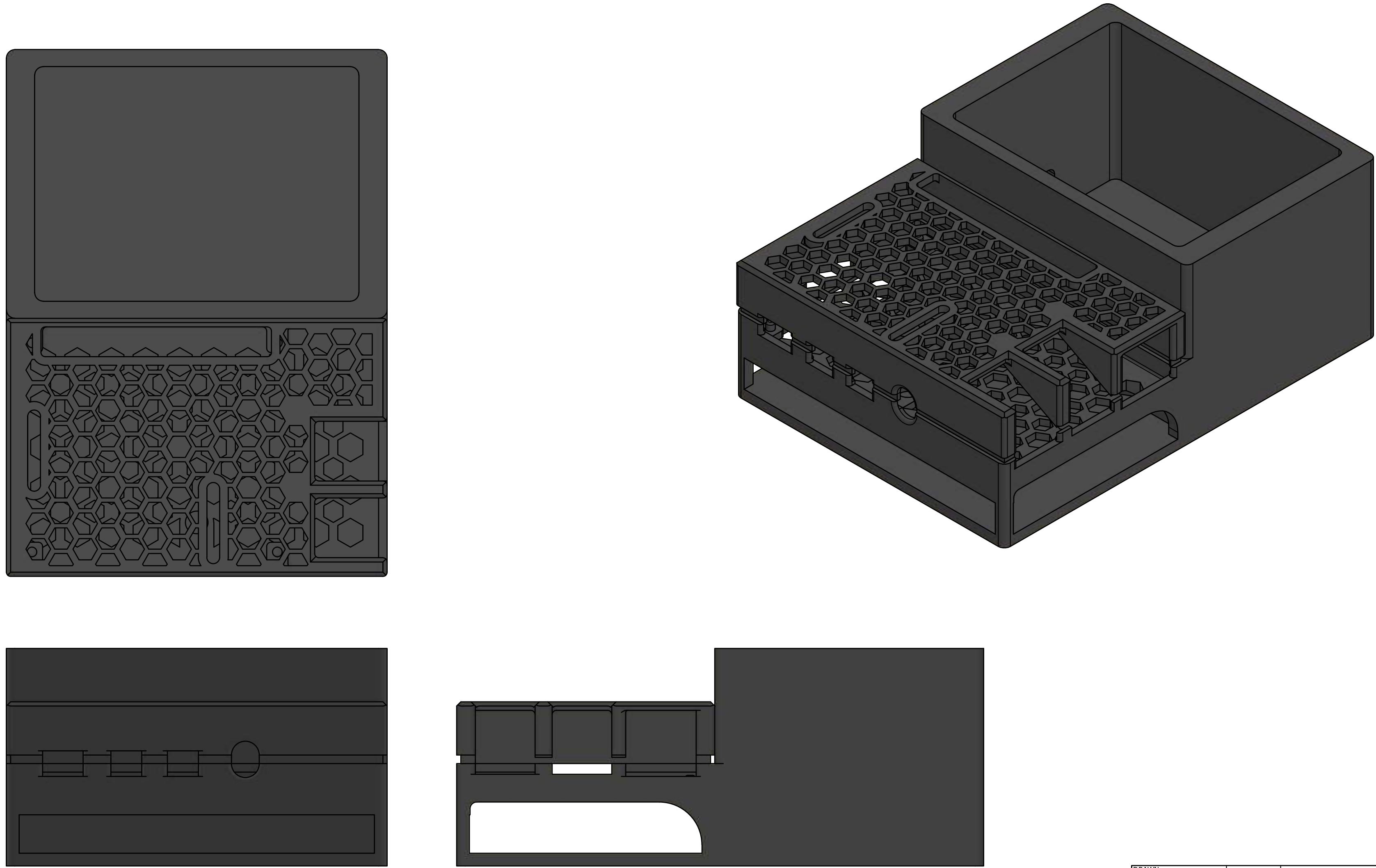

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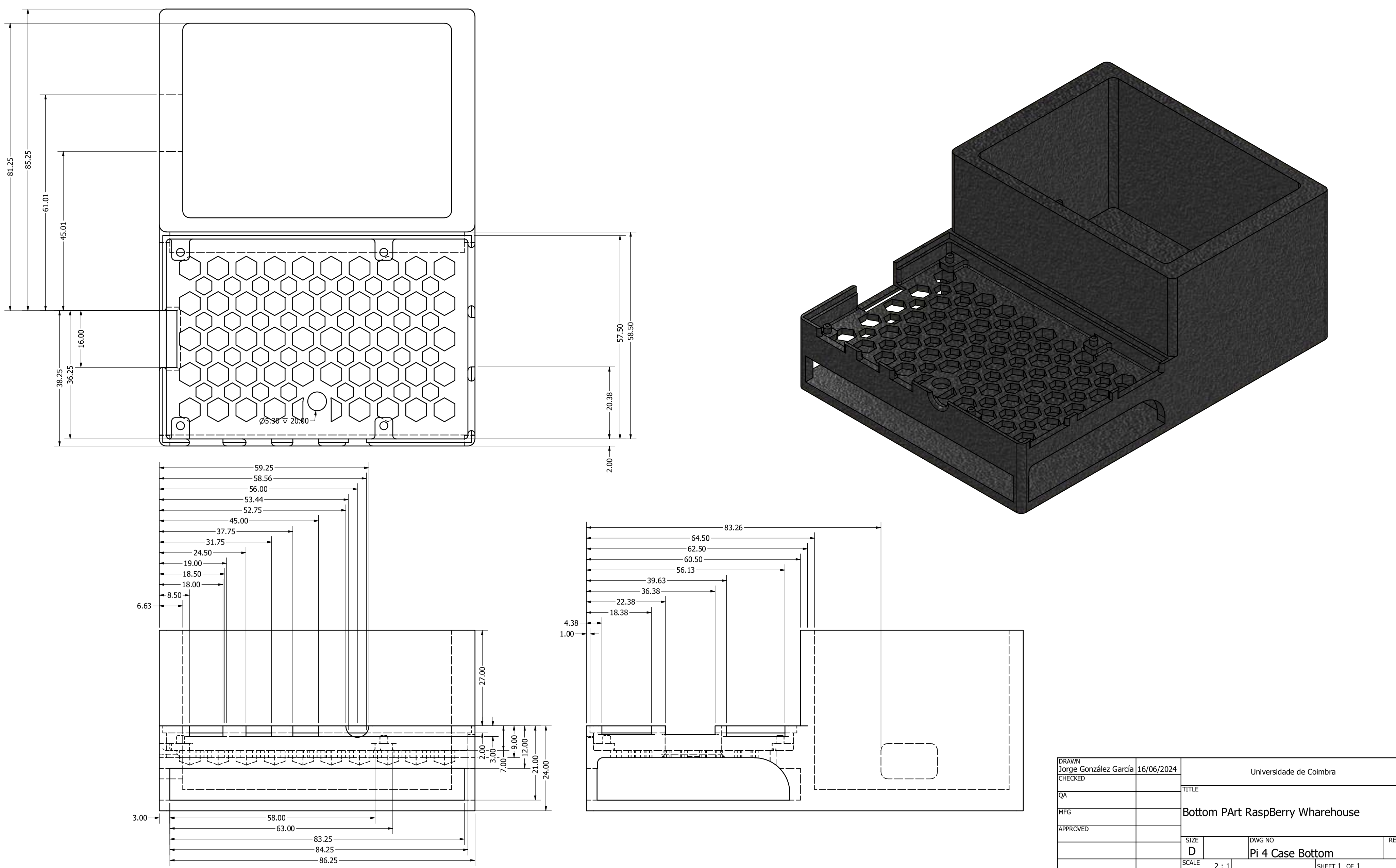

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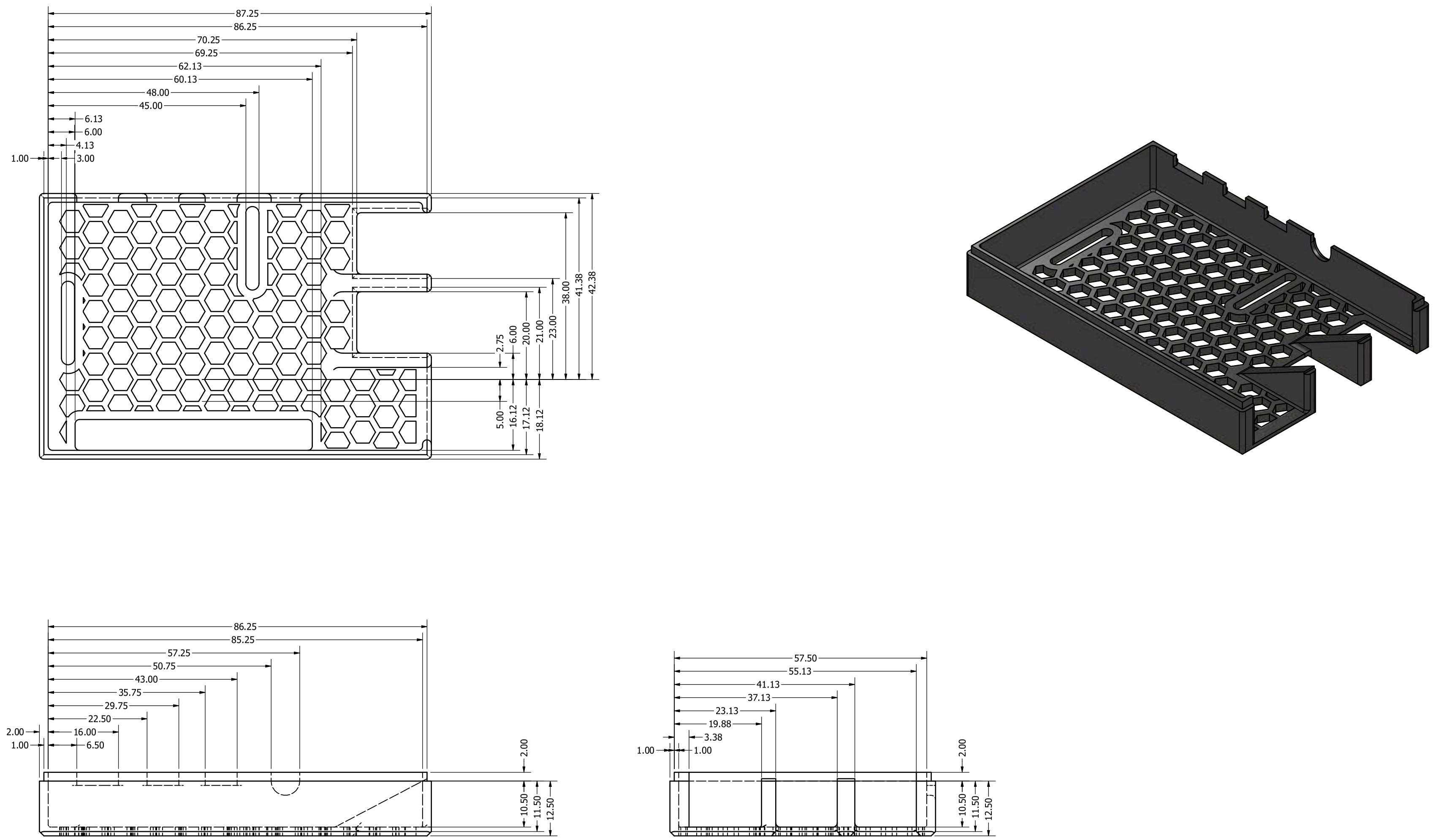

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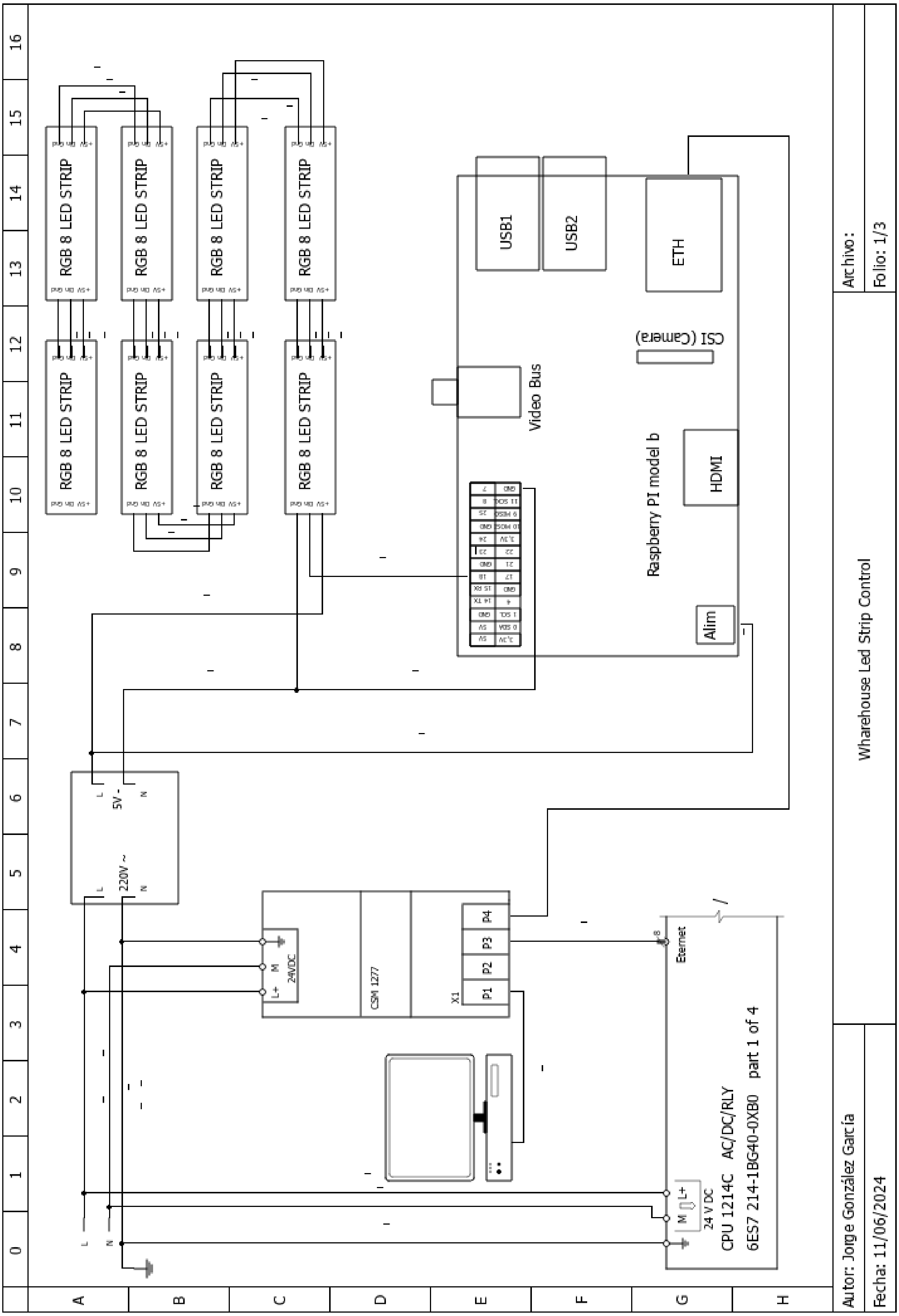
Appendix B

Electric Blueprints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USB2
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HDMI
Alim
5V -
220V ~
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CSM 1277
X1
P1
P2
P3
P4
Eternet
24 V DC
CPU 1214C AC/DC/RLY
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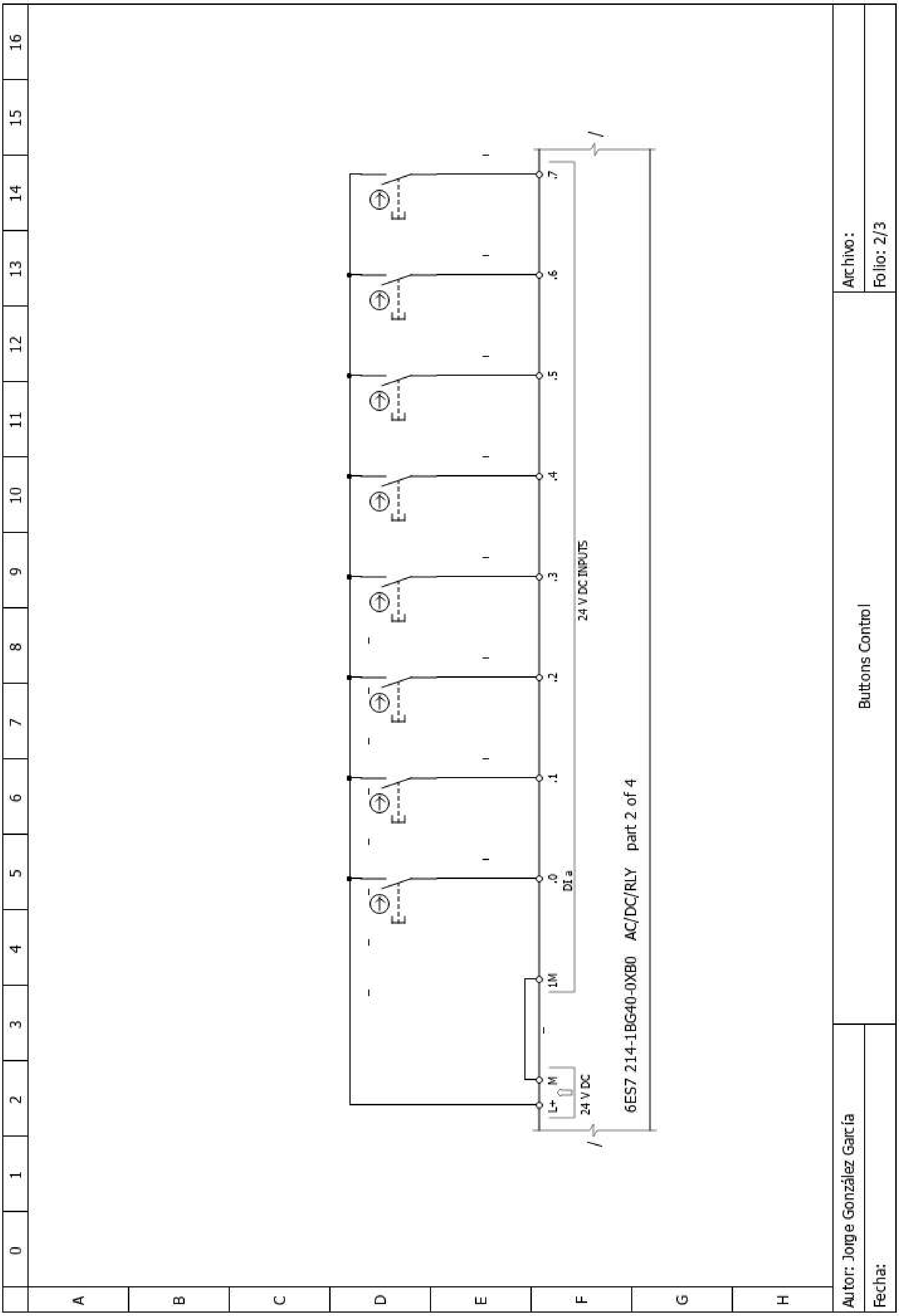
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L+
M
1M
.0
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Buttons Control
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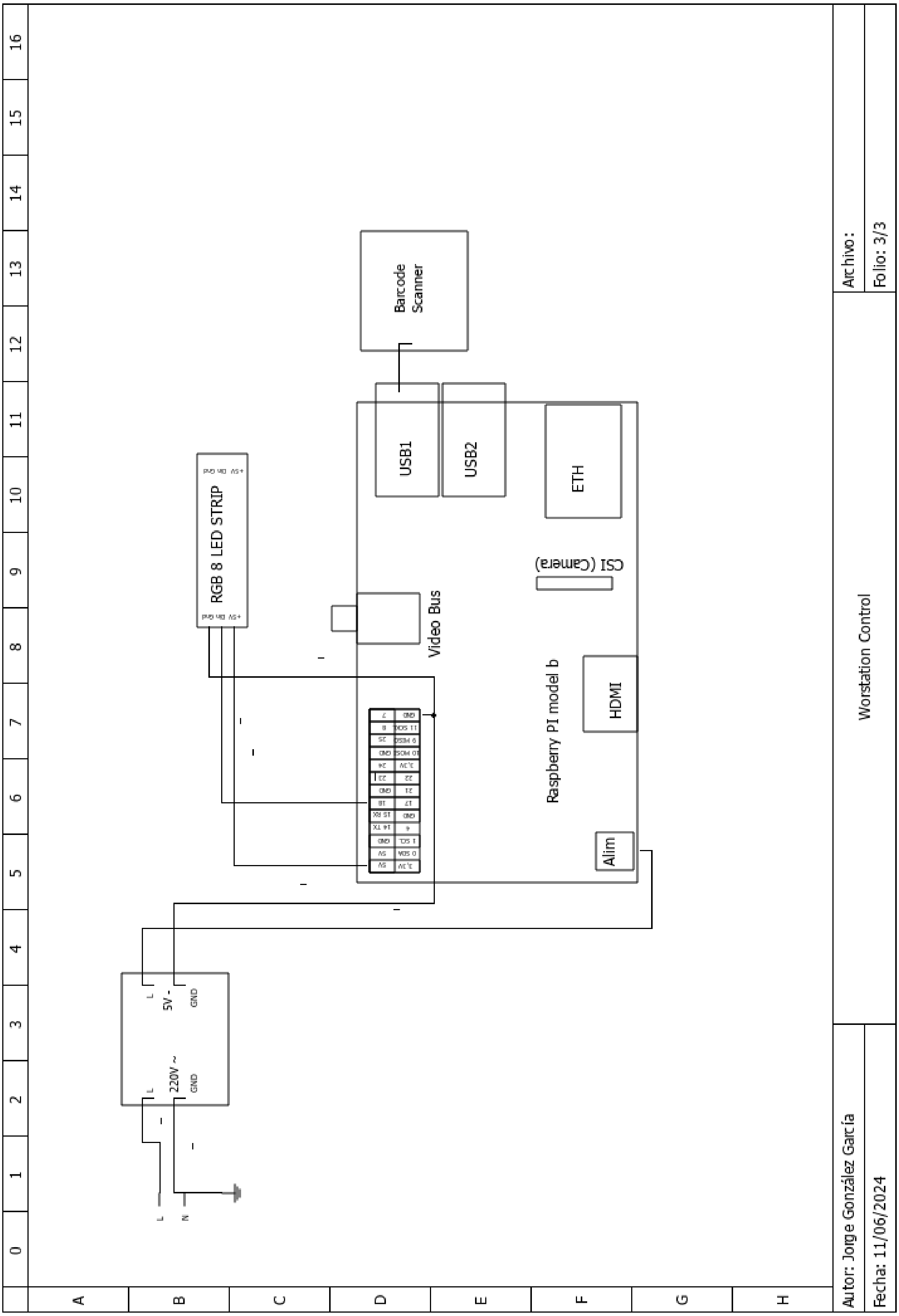
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