LAPIN AMK
Lapland University of Applied Sciences

Designing and implementing a carrying device for the Smart Factory in the Kosmos Lab

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Abstract of Thesis

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The focus of this thesis was on the feasibility of using additive manufacturing to create a pallet that could facilitate workpieces in the Festo Smart Factory training kit. To achieve this, the original pallet provided by Festo was examined to determine the necessary features. The drawings of both the original and newly designed pallets are included in the appendices.

The additive manufactured pallet was tested for compatibility with the applications in the Smart Factory located in the Kosmos Lab of Lapland UAS in Kemi. The components and applications of the Smart Factory are described in detail in the thesis.

However, the purely additive manufactured pallet did not meet the required strength standards to operate seamlessly with the Smart Factory applications. Therefore, the manufacturing process was adjusted by increasing the infill density of the pallet to 100% and using aluminium instead of PLA for the pins that are directly connected to the grippers in the Smart Factory. Despite these adjustments, the pins were still displaced during the operation of the ASRS grippers.

A second adjustment was made by implementing a stainless-steel support sheet inside the PLA print. This improvement prevented the pins from displacement and ensured frictionless operation with the grip system in the storage module. Furthermore, enabled the testing with all the other applications along the assembly line.

Key words	Additive manufacturing, Smart Factory, Reduce metal, MES, PLA strength
Other information	Thesis includes drawings of the designs

CONTENTS

FOREWORD

I would like to express my gratitude to Lapland University of Applied Sciences for providing me with access to additive manufacturing, software, and the Festo Smart Factory kit, which enabled me to conduct my thesis. I would like to extend my thanks to Arto Jäntti and Jouni Kanto for their assistance during the testing process. I would also like to express my gratitude to Ari Pikkarainen for providing assistance during the reporting process.

SYMBOLS AND ABBREVIATIONS

ABS	Acrylnitril-Butadien-Styrol
AM	Additive Manufacturing
ASRS	Automated Storage and Retrieval System
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computer Numeric Control
CP	Cyber-Physical
ERP	Enterprise Resource Planning
FDM	Fused Deposition Modelling
ID	Identification
IoT	Internet of Things
LA	Length Adjustable
LAs	Length Adjustable supported
MES	Manufacturing Execution System
PETG	Polyethylene terephthalate glycol
PLA	Polylactic acid
RF	Radio frequency
RFID	Radio frequency Identification
SCADA	Supervisory control and Data acquisition
STL	Standard Transformation Language
UAS	University of Applied Science
3D	3 Dimensional

1 INTRODUCTION

The processing and production industry has undergone rapid evolution in recent years, with the latest stage of progress being Industry 4.0. This concept involves a widely spread network of interconnected machines, transparency of processes by collecting data throughout the production process, technical assistance for decision-making and problem-solving, and total automation.

To prepare students for their careers and introduce them to this new technology, Lapland University of Applied Science (UAS) is working with the FESTO Industry 4.0 learning system. This system includes a CP High-bay storage for pallets, CP Factory mill with loading robot, Robotino 4, and various stations along the production line.

The pallets used in the Smart Factory have size limitations, as they are manufactured by Festo for the training kit. To enable lecturers and students to operate with larger products, new pallets will be designed and additive manufactured, which increases the variety of work process in the Kosmos Lab at the Lapland UAS in Kemi.

The new pallets will be designed while considering the size restrictions of the processing line. The aim is to reach the maximum size of operated workpieces while ensuring compatibility with each of the Smart Factory components.

1.1 Objective

The objective of this thesis is to create and execute a carrying mechanism for the Festo Smart Factory, which is located in the Kosmos Lab at Lapland UAS. This device will facilitate the adjustment of size and enable operation with products of varying sizes throughout the assembly line. The enhanced carrier will be utilized by both teachers and students of Lapland UAS for academic purposes.

Through a thorough examination of the Festo Smart Factory environment and the current carrying mechanism in use, the size restrictions and necessary dimensions are identified. These findings serve as the basis for the development of the new carrying device. Additionally, the operational aspects of the assembly line are enlightened, including any constraints and limitations that must be taken into account during the design process. By providing a detailed explanation of the assembly line's functioning, this study aims to ensure that the new additive manufactured carrying device will seamlessly integrate into the existing system and fulfil all necessary requirements.

2 LITERATURE REVIEW

2.1 Digital manufacturing

The manufacturing industry has undergone rapid transformations in the recent decades. These changes are corelated to the enormous progress made in innovations of various technologies such as big data-analytics, real-time communication via Internet of Things (IoT) consisting of computer aided systems, robotics, sensors and actuators that enabled the controlling along the entire process. By integrating cloud storage, the stored and operated data is virtually limitless. (Stankovic 2014, 4.)

Compared to the conventional way of manufacturing, that was used till the revolution of interconnecting the working steps. The process started by designing and creating the required drawings of a product before it was ready to move on to the next step of manufacturing. With the recent implementations enabled the cooperations of different stages to work alongside during the process. Due to Computer Aided Design (CAD) the characteristics of the product can be tested during the design stage. The integration of sensor and control mechanisms allowed to inspect during the manufacturing phase. Figure 1 illustrates the comparison of the change of the manufacturing process. The traditional method was operating in step-by-step mode, while digitalisation enabled the cooperation of several stages at the same time. (Paritala, Manchikatla & Yarlagadda 2017, 983.)

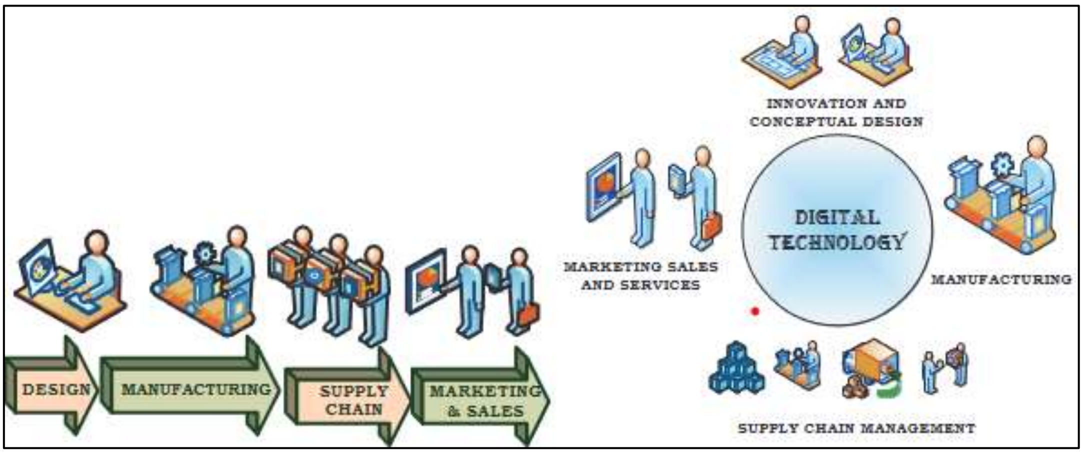

Figure 1. Conventional and Digital manufacturing process (Paritala, Manchikatla & Yarlagadda 2017, 984)

Digital manufacturing is also referred to as Industry 4.0, that marks the dawn of a new era in industrialization, characterized by the connection and collaboration of previously disjointed components. This shift has been necessitated by the current social, economic, and political landscape, which demands rapid development and implementation of innovative solutions. With customers increasingly demanding personalized products, the industry has had to become more agile and responsive to their needs, resulting in decentralized processes that ensure quick accessibility. Moreover, the reduction of development periods has become a critical aspect of the industry's adaptation strategy, as it strives to implement inventions more rapidly and stay ahead of the competition. The industry was compelled to consider the aspect of sustainable resource usage due to the increasing concerns about its impact. (Lasi, Fettke, Kemper, Feld & Hoffmann 2014, 3.)

2.1.1 Internet of Things

The IoT created the foundation for digital manufacturing (Lee, Lapira, Bagheri & Kao 2013, 39). It is defined as the interconnection of devices starting with simple sensors going to complex machineries, to enable real-time communication within the system. In Figure 2 the architecture of the collaboration is illustrated. It shows for the previously isolated components, the connection enabled collaboration enhance and automates the efficiency in the industry. (Jasperneite, Sauter & Wollschlaeger 2017, 17; Serror, Hack, Henze, Schuba & Wehrle 2021, 2985.) As an addition shows, the IoT operates and analyses the data within the system (Serror, Hack, Henze, Schuba & Wehrle 2021, 2988).

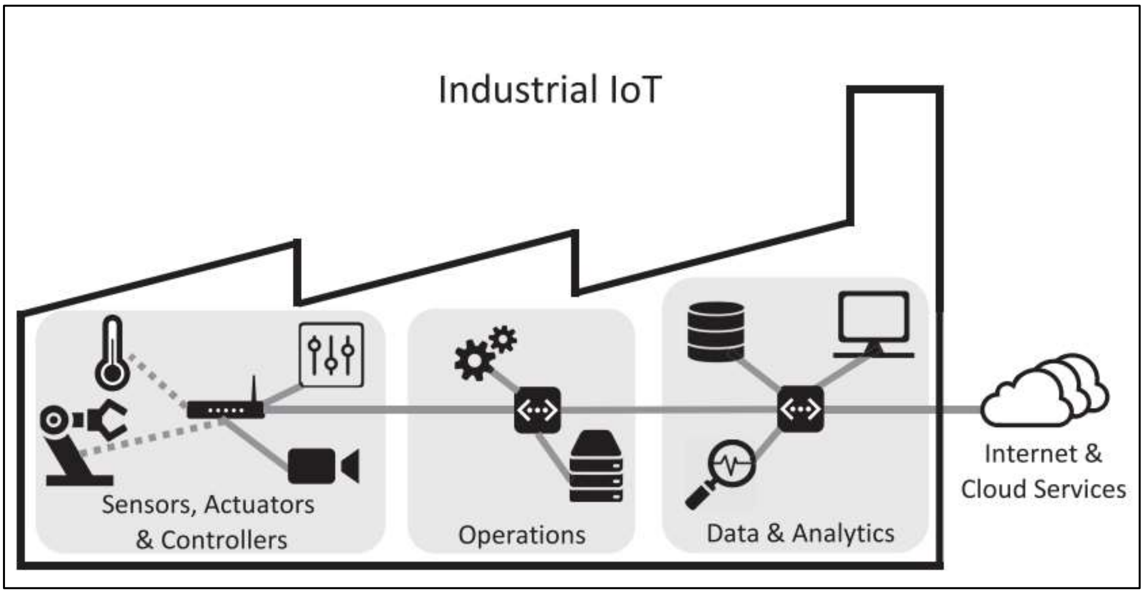

Figure 2. General architecture of the Industrial Internet of Things (Serror, Hack, Henze, Schuba & Wehrle 2021, 2988)

The function of IoT can be broken down into six key elements. The first is identification, which involves recognizing suitable devices. This is followed by sensing, which acquires information and stores it in cloud systems. The third step is communication, which employs several systems, such as Bluetooth, WIFI, near field and wideband communication, depending on the purpose. Computation is the fourth step, which processes the transmitted data and indicates a response as an answer to the received information. The fifth step is service, where the emitted signal is transmitted to a device that executes the task. Lastly, the sixth and most crucial element is semantics, which defines IoT. It enables decision-based services for search algorithms and collaborates with diverse machines to execute essential algorithms. (Singh & Tomar 2018, 643.)

The quickly stacking up data collected in the process, offers an opportunity to enhance the operation and automatization of the systems. While being at the same time a challenge. Since the stored information of customers and insider knowledge is under constant danger of cyber-attacks. (Serror, Hack, Henze, Schuba & Wehrle 2021, 2989.)

2.1.2 Computer Aided Design

Computer-aided design is a digital technology that allows designers to create, modify, analyze, and optimize 2D or 3D models of products and structures. CAD has been used extensively in various industries, including aerospace, automotive, architecture and manufacturing, among others. In recent years, with the rise of digital manufacturing and the advent of Industry 4.0, CAD has become an essential tool in the design process, enabling designers to create more complex and efficient products while reducing the time and cost of production. (Svensson Harari & Fundin 2023, 258.)

The development of CAD technology can be traced back to the early 1960s, when the first CAD systems were used by aerospace engineers to design aircraft. Since then, CAD has undergone significant advancements, including the development of 3D modeling, simulation, and analysis capabilities. Today, CAD is a developed technology that is widely used in the design and development of a wide range of products, from consumer goods to complex machinery. (Shivegowda, Boonyasopon, Rangappa & Siengchin 2022, 3974.)

With the development of the technology, it is possible to evaluate stress, investigate characteristics and generate numerical control tapes, such as G-codes. This implementation is the foundation of Computer-Aided Manufacturing (CAM). (Hoque, Halder, Parvez & Szecsi 2013, 990.)

2.2 Sensors

2.2.1 Radio Frequency Identification (RFID)

RFID is a technology that transfers information contactless by radio waves. The communications take place in between read and write devices. The data can only be transmitted in one way from the reader to the writer. (Ding et al. 2022, 2.)

Writers are RFID tags, that are carrying the information. Those can be divided in three categories active and passive tags. The active one is equipped with a power source. They emit information actively, therewith the capacity of transmitted information and number of tags read at the same time increases compared to passive tags. The downside of this version are the high costs, relatively big tags and the dependence on the battery life. Passive tags are relying on the energy emitted through radio waves. In this case the data could be read multiple times by different readers. (Ding et al. 2022, 4.)

The reader consists of a radiofrequency (RF) interface, control unit and an antenna. The interface produces power to enable the data exchange. The antennas are responsible for the signal exchange via radio waves. In the control unit the received signal is translated to data form. (Ding et al. 2022, 4.)

2.2.2 Fibre-optic sensor

A Fibre optic system is a type of sensor that uses a pair of bundled fibres - one for transmitting light and the other for receiving it. These fibres are used with a flat reflective target. The system includes a light source, a fibre optic probe, and a photodiode detector. The sensor probe has two plastic optical fibres that are bundled together. (Yang et al. 2014, 334.)

In the system, the presence of an obstacle is recognized when the light signal is interfered with and is not received on the receiving end. When there is an obstruction that blocks or reflects the light, it is not received on the other end, and the system recognizes this as the presence of an obstacle. (Yang et al. 2014, 334.)

2.3 Manufacturing execution system

The first implementations of manufacturing execution system (MES) can be tracked back to the early 1990´s, in order to increase the efficiency along the production lines. Manufacturing Execution Systems are critical components of the Industry 4.0 framework, working in tandem with other key control systems such as Supervisory Control and Data Acquisition (SCADA) and Enterprise Resource Planning (ERP) to facilitate seamless data exchange and efficient decision-making processes (Frank, Dalenogare & Ayala 2019, 17). MES provides a crucial link between the shop floor and the enterprise level, enabling real-time monitoring and control of the manufacturing process. (Chen & Voigt 2020, 1.)

The key services provided by MES are collecting and processing data, exact planning of operations, managing and assigning resources, delegating tasks for machines and employers, monitoring the quality of production and scheduling maintenance programs. Intelligent systems are capable of providing information on the stock of raw materials, machinery failures and delays in the supply chain. (Shojaeinasab et al. 2022, 504.). Based on this information the responsible personal can react on the occurred errors beforehand and prevent interruptions in the process.

In the context of Manufacturing Execution Systems (MES), Figure 3 depicts the crucial information exchange that takes place between the management layer and the shop layer. MES plays a pivotal role in providing real-time operational information to the management layer. However, it is not just limited to delivering real-time data, as it also facilitates decision-making processes by processing data from previous tasks. As a result, MES serves as a valuable tool for enterprises in their efforts to optimize production processes, enhance product quality, and reduce manufacturing costs. MES ensures that the shop floor operations are aligned with the overall goals of the organization and helps in enhancing the efficiency and effectiveness of the entire production process. Additionally, MES can provide a centralized system for data management, improving data accuracy and accessibility. (Shojaeinasab et al. 2022, 504.)

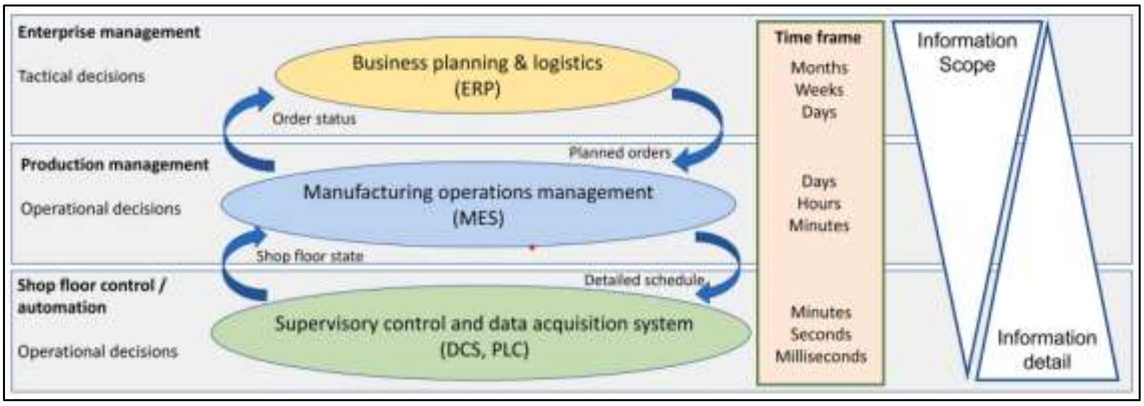

Figure 3. Process information exchange by MES (Shojaeinasab et al. 2022, 504)

2.4 Additive manufacturing

Additive Manufacturing (AM) is a relatively new technology that involves adding layers of material to create complex 3D objects. Unlike traditional manufacturing methods that involve removing material or shaping it through molds or tools, AM does not require specific fixtures or tooling, making it simpler and more flexible. This technology is being increasingly used in various industries, such as automotive, aerospace, and biomedical, due to its ability to create intricate designs, use multiple materials, and integrate multiple functions into a single part. It allows the creation of complex structures that would be impossible to achieve using traditional manufacturing methods, as it has fewer limitations and constraints. (Xiong, Tang, Zhou, Ma & Rosen 2022, 1.)

AM is a digital manufacturing process that is rooted in computer-aided technologies such as CAD and CAM. It involves the process of creating objects by adding layers of material based on 3D model data. (Xiong, Tang, Zhou, Ma & Rosen 2022, 2.)

2.4.1 Fused Deposition Modelling (FDM)

Fused Deposition Modelling is a popular additive manufacturing process that uses a thermoplastic filament to create three-dimensional objects layer-by-layer. FDM printing has gained widespread popularity due to its ease of use, low cost, and ability to produce complex geometries. Research has shown that FDM printing has many potential applications including prototyping, custom manufacturing, and biomedical engineering. (Doshi, Mahale, Kumar Singh & Deshmukh 2022, 2269.)

The quality and processing time of the printed part are influenced by the slicing parameters, build orientation, and temperature conditions that are set for the printing process. These parameters include variables such as layer thickness, extrusion width, flow rate, deposition speed, air gap, and raster angle, and can be optimized to produce parts with desired qualities. However, since process parameters can vary, anisotropic behaviour can play a critical role in the mechanical properties of fabricated parts. Researchers are currently working to optimize the FDM process parameters to improve the mechanical properties of 3D printed parts and provide a comprehensive understanding of their behaviour based on the selected process parameters. (Algarni & Ghazali 2021, 1–2.)

2.4.2 Polylactic Acid (PLA)

Polylactic Acid is a biodegradable thermoplastic filament that is becoming increasingly popular for use in FDM printing. This material can be extruded at relatively low temperatures, typically ranging from 190-215°C, and requires a moderately heated bed during deposition, with temperatures between 25-80°C. The density of printed PLA parts is usually around 1.25g/cubic mm, which is comparable to other common FDM materials. PLA typically produces parts with higher tensile strength and lower ductility than other common materials, with a tensile strength of around 65 MPa and a flexural strength of around 97 MPa. Due to its favorable properties and biodegradability, PLA has found use in a range of applications. (Algarni & Ghazali 2021, 3–4.).

3 FESTO ENVIRONMENT

The Festo Smart Factory is located in the Kosmos Lab of the Lapland UAS in Kemi. It facilitates a variety of applications from the Festo training kit, the exact setup of the system is displayed in Figure 4 and described in the following chapters. To operate the system the Manufacturing execution system software MES4 is used.

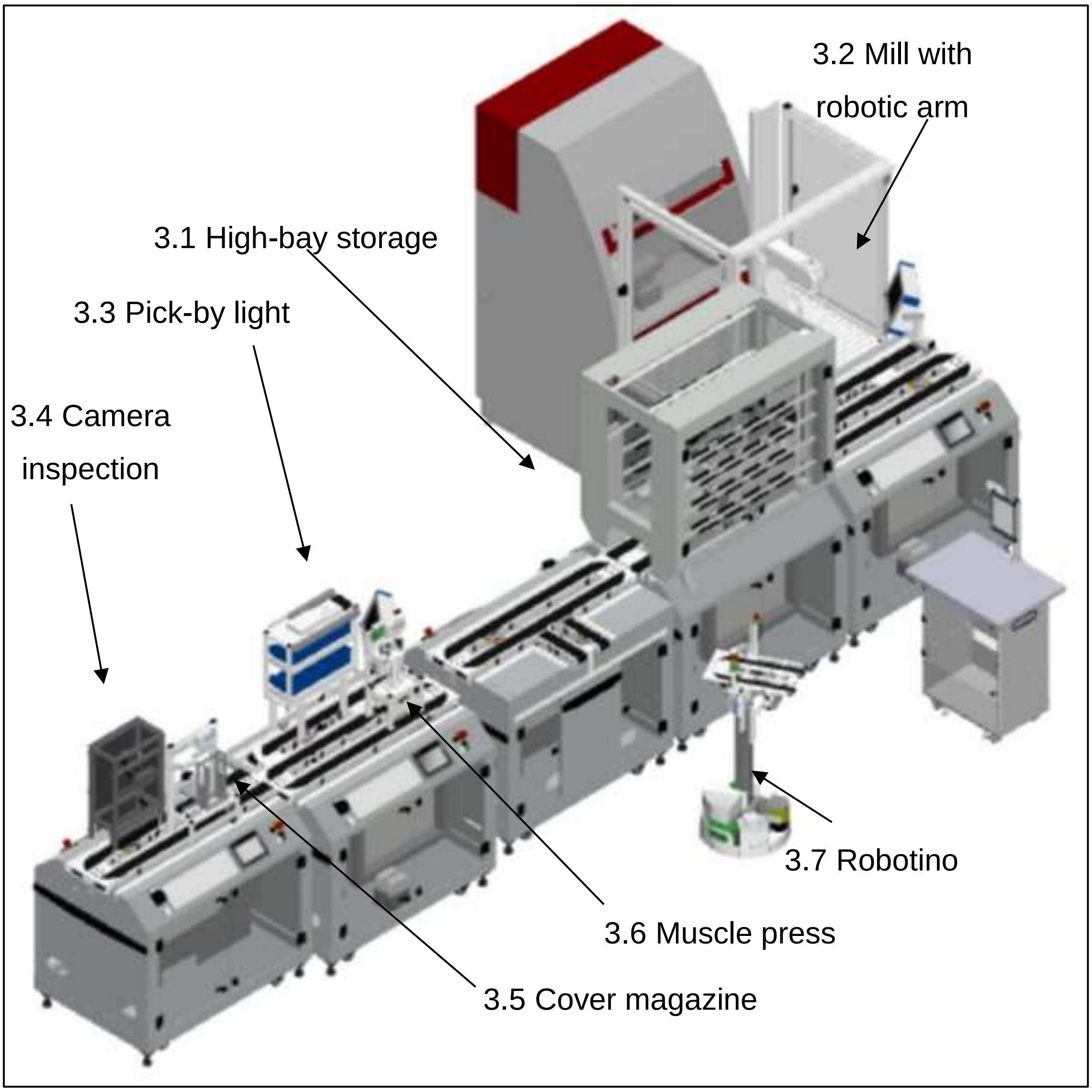

Figure 4. Smart Factory set up in the Kosmos Lab

The workpieces in the Smart Factory are placed in the slots on the pallets shown in Figure 5, those are provided by Festo. On the base of the pallet two holes are drilled for the docking on the conveyers and in the High-bay storage. The exact drawings and dimensions are displayed in Appendix 1. A grip spot for the forklifting arms are the pins mounted along the long side edge of the pallet. The size restriction of the workpieces operated in the module is 60 x 114 mm.

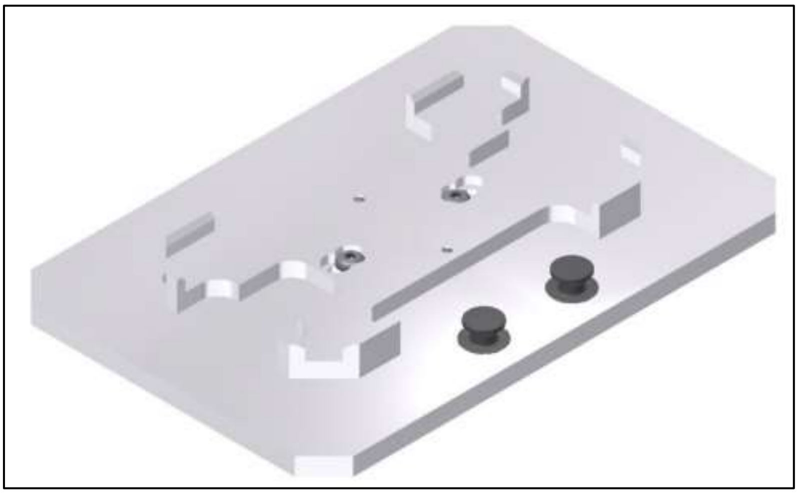

Figure 5. Pallet provided in the Festo kit (Schober 2017, 11)

To transport the pallets along the assembly line the conveyers displayed in Figure 6 are used. The operation information and data of the workpieces are stored in the built-in RFID tags.

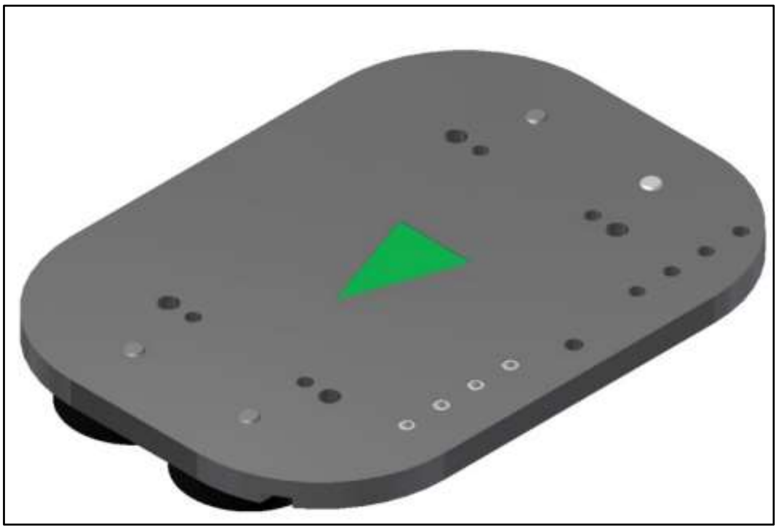

Figure 6. Conveyer provided in the Festo kit (Schober 2017, 11)

3.1 CP Factory High-bay storage

The pallet Automated Storage and Retrieval System (ASRS) comprises a 1200mm long, two-lane conveyor line, firmly connected to the storage unit. The conveyors are 80mm wide and used for transporting boards on carriers. These carriers come equipped with a read/write ID-system, which is a crucial component of the Cyber-Physical (CP) Factory System. The ID-system stores vital data related to the workpiece being transported, and this information is conveyed to every operating position along with the carrier. The ASRS for pallets has only one operating side, and it is inaccessible from the back. (Schober 2017, 14.)

To detect the presence of shelves, a through-beam sensor is employed. This sensor system uses flexible fiber optic cables that are attached to a fiber optic unit operating with visible infrared light. When a workpiece is placed on a shelf, it interrupts the through-beam sensor, and the shelf is identified as occupied. (Schober 2017, 54.)

Table 1. Datasheet of the Festo CP Factory High-bay storage (CP-F-ASRS32) (Schober 2017, 1)

Operating voltage	230/400 VAC
Operating pressure	6 bar
Storage robot gripper	Parallel pneumatic gripper
Number of shelf positions	32
Transport belts	2 move in opposite directions
Data transmission	RFID
Shelf detection	Beam sensors
Dimensions (HxWxD)	1800 x 1200 x 800 mm

3.2 CP Factory mill with loading robot

The milling process is supported by a feeding system, comprising a basic module bypass, a loading cell with a robot, and a Computer Numeric Control (CNC) machine. The conveyor belts have dimensions of 80mm in width and 1200mm in length, allowing carriers with workpieces to be transferred and processed for extended periods. This capability provides the bypass ideal for applications that demand longer processing times. Importantly, the workpiece flow remains unaffected by the bypass line. The system is equipped with read/write ID-system carriers that serve as a vital component of the CP Factory System. These carriers store current workpiece data, enabling essential process information to be transported and readily available at every station. (Schober & Weiss 2018, 16.)

The main element of the bypass module is an aluminium plate affixed to a base frame that houses a 6-axis robot and its peripheral equipment. The robot manages all processes within the module, while a CNC machine is mounted on the same frame for workpiece machining. The station's core function is to equip the CNC machine with workpieces and process them according to the CNC machine's requirements, which it executes with precision and efficiency. (Schober & Weiss 2018, 16.)

Table 2. Datasheet for CP Factory mill with loading robot (CP-F-FEEDROBM) (Schober & Weiss 2018, 1)

Operating voltage	230/400 VAC
Operating pressure	6 bar
Loading robot	6 axis
Max load	4kg
CNC mill (X/Y/Z)	190 / 140 / 260 mm
Data transmission	RFID
Carrier detection	4 optoelectrical sensors
Dimensions (HxWxD)	1800 x 1200 x 2700 mm

3.3 PickByLight station

The application module is designed to provide a range of workpieces which are accommodated in distinct boxes, each of which is fitted with a light module. The flashing pattern of these light modules varies depending on the order, indicating to the user the number of workpieces that should be retrieved from the corresponding box and their sequence. Upon entering the application module, the carrier is detected by a beam sensor and brought to a stop. The indicator lights then activate in accordance with the preconfigured data, and the user proceeds to assemble the workpiece accordingly. After completing the assembly, the carrier is released from the application module. (Schober & Weiss 2019d, 24.)

Table 3. Datasheet for PickByLight (CP-AM-iPICK) (Schober & Weiss 2019d, 1)

Operating voltage	24VDC
Function	Provide order for assembly
Workpiece detection	Beam sensor
Number of storage bins	8
Dimensions (HxWxD)	650 x 480 x 245 mm

3.4 Camera inspection station

The camera inspection module of the application is designed to inspect the condition of the workpiece on a board. When a carrier encounters the module, it comes to stop. A picture is taken by the camera, and the software executes the selected program to compare the picture with the desired condition. After processing the result, the carrier with the workpiece is allowed to leave the module. (Schober & Weiss 2019a, 24.)

Table 4. Datasheet for Camera inspection (CP-AM-CAM) (Schober & Weiss 2019a, 1)

	Operating voltage	24VDC
	Function	Camera inspection
	Measuring	Range, Dimension, Position
	System compares to	Desired condition
	Dimensions (HxWxD)	650 x 350 x 195 mm

3.5 Cover Magazine

The application module supplies a carrier with either a front or a back cover. Once the carrier passes through a beam sensor, it is detected and brought to a stop. Subsequently, sensors inspect the condition of the carrier, and there are three conditions. Either there is now workpiece available, the back cover is on the pallet or the front cover is on the pallet. The systems differ in these three stages and applies a cover if the workpiece requires it. The information if a cover is required is stored on the RFID tag of the carrying device. (Schober & Weiss 2019b, 24.)

Table 5. Datasheet for Magazine (CP-AM-MAG) (Schober & Weiss 2019b, 1)

	Operating voltage	24VDC
	Function	Feeds workpiece with cover
	Workpiece detection	Beam-sensor
	Magazine capacity	10
	Dimensions (HxWxD)	525 x 340 x 185 mm

3.6 Muscle Press

As the workpieces enter the application module, beam sensor recognizes them and halts the carrier's movement. Using the strength of its muscles, the module compresses both the front and back covers. The applied force and duration of the operation is adjustable. The Force can operate from 5–100 N and the adjustment can be made in steps of 10 N. For the duration of the applied force the time is adjustable in the range of 0-30 sec. Once the pressing is complete, the carrier exits the application module, completing the process. (Schober & Weiss 2019c, 24.)

Table 6. Datasheet for Muscle Press (CP-AM-MPRESS) (Schober & Weiss 2019c, 1)

	Operating voltage	24VDC
	Function	Applies pressure on cover
	Workpiece detection	Beam-sensor
	Force applied	5 - 100 N
	Dimensions (HxWxD)	210 x 247 x 290 mm

3.7 Robotino

Festo Robotino 4 is a mobile robot platform designed for education, research, and industrial applications. It has a modular design, allowing users to add or remove components to suit their specific needs.

The tower is an extension module that can be attached to the Robotino 4 to increase its functionality. It includes a manipulator arm, a gripper, and various sensors, such as a 3D camera and a laser scanner. With the tower, Robotino 4 can perform tasks such as object recognition, grasping, manipulation, and navigation in complex environments. It can also be programmed to perform tasks such as sorting, assembly, and inspection in industrial settings.

Additionally, the Robotino 4 has an open software architecture that allows users to program it using various programming languages and tools. This flexibility makes it a popular choice for educational institutions and research labs, where students and researchers can learn about robotics and develop new applications. (Deppe, Ersoy & Tsakas 2019, 52.)

Table 7. Datasheet for Robotino 4 (Deppe, Ersoy & Tsakas 2019, 45)

	Motor	3 x DC; max. 3600 rpm
	Wheels	3 x opmidirectional
	Payload	30 kg (centered)
	Height	Adjustable
	Diameter	450 mm

4 METHODOLOGY

In order to obtain expert opinions regarding the design of the carrying device for study-related purposes, the commissioner, who is an expert in the Festo environment, will be consulted. With his extensive experience in this field, he is well-versed in the specific requirements for such carrying devices. Additionally, if any metal processing tools are required during the manufacturing process, the person in charge of those tools will be available to provide assistance as needed. By leveraging the expertise of these individuals, this study aims to ensure that the carrying device is designed and manufactured to the highest standards of quality and functionality.

To ensure a thorough understanding of the process involved in designing a product, from prototyping to implementation in digital manufacturing, a comprehensive literature review has been conducted. This review covers the basics of digital manufacturing, including its key components, to provide a better understanding of the overall process. Additionally, the fundamentals of Manufacturing Execution Systems are explained to assist in the design of a process flow chart and its integration with the associated device. As prototyping is a vital aspect of this thesis, the literature review explores additive manufacturing in detail. By exploring these essential topics, this study aims to establish a solid foundation of knowledge to guide the development and implementation of the carrying device.

To gain a better understanding of the proposed products and ideas, each concept is modelled using Computer-Aided Design software, specifically Autodesk Inventor. Before proceeding with the prototype process, careful consideration is given to the advantages and challenges of each design idea in order to minimize the number of subsequent prints required. The drawings and associated inspections of the designs are also thoroughly described to ensure the highest level of accuracy and precision.

Additive manufacturing is utilized in the creation of the prototypes, as it allows for a rapid transformation of a digital model into a physical object. The prototypes are subjected to testing to assess their compatibility with the existing components of the Festo Smart Factory, based on the testing standards displayed in Table 8. To consider a statement true the process must be successfully processed five times. If any issues or incompatibilities are identified, the necessary adjustments are made to the digital model before the manufacturing process is repeated. By utilizing this repetitious approach, this study aims to ensure that the final carrying device design is both functional and compatible with the Festo Smart Factory.

Table 8. Methodology on testing suitability of the carrying device.

x if statement is true	**Size restrictions met**	**Component identifies device**	**Component operates device**
CP Factory High-bay storage			
CP Factory mill with robotic arm			
Pick by light Module			
Camera inspection			
Cover Magazine			
Muscle press			
Robotino			

Assuming that the final carrying device design is compatible with the components of the Festo Smart Factory, it can be manufactured in the desired quantity by the Lapland University of Applied Sciences (UAS). The necessary drawings and associated files required for reproduction are then provided to the University. By completing this process, this study aims to create a functional and reliable carrying device that can be utilized for study-related purposes by the teachers and students of the Lapland UAS.

5 DESIGN

The current pallet used in the Festo Smart Factory is capable of carrying and operating workpieces with dimensions of 60 x 114 mm. However, in order to allow teachers and students of Lapland UAS to work with a wider range of products within the Smart Factory, a new pallet design is needed to accommodate larger sized products. Additionally, to maximize the pallet's usage, it should still be able to carry the currently used workpieces along with the larger products, therefore be adjustable. The new pallet is intended to be manufactured by an additive manufacturing method.

5.1 Conceptual Design

To establish the criteria and parameters for the adjustable pallet, the original pallet from the Festo training kit was measured and all necessary dimensions were recorded for manufacturing. Using this information, the base of the pallet (see Appendix 1), the workpiece holder (see Appendix 2), and the pin (see Appendix 3) were designed using CAD software, Autodesk Inventor 2021. Drawings of each individual part are provided in their respective appendices, along with an assembly drawing of the completed pallet (see Appendix 4).

In order to determine size restrictions within the Festo Smart Factory, measurements were taken at each station and application on the assembly line. A table containing the limitations for the workpiece and pallet in each module is provided in Appendix 9.

5.1.1 Device criteria and parameters

When designing the new pallet to facilitate workpieces in the Smart Factory, two important features must be considered. Firstly, the dimensioned holes shown in Figure 7 must be placed precisely in the indicated position to ensure a seamless connection with the conveyor and the high-bay storage. The diameter of the hole is 6.2 mm with a chamfer on the bottom edge of 1.8 mm. For the pneumatic grippers in the ASRS and the CNC mill station, pins are placed in the holes marked in red on the long edge of the pallet. The diameter for the pins is 13.3 mm and there is a 1 mm deep drill from the bottom side with a diameter of 15 mm.

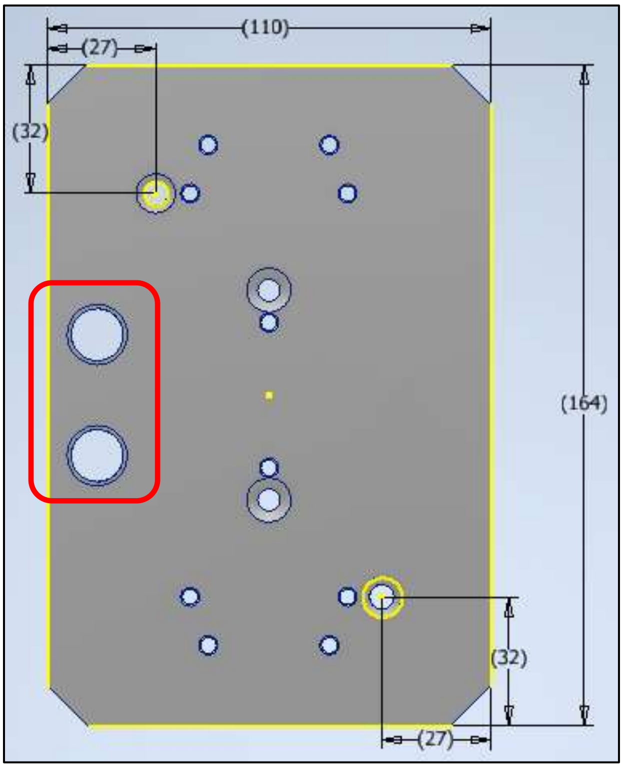

Figure 7. Model Base pallet (Festo)

The ASRS uses a trough beam sensor to detect the presence of pallets in each shelf. For this purpose, the pallets provided by Festo are equipped with reflecting stickers placed on the corners of the pallet as shown in Figure 8. The stickers reflect the emitted infrared light by the fibre optic device.

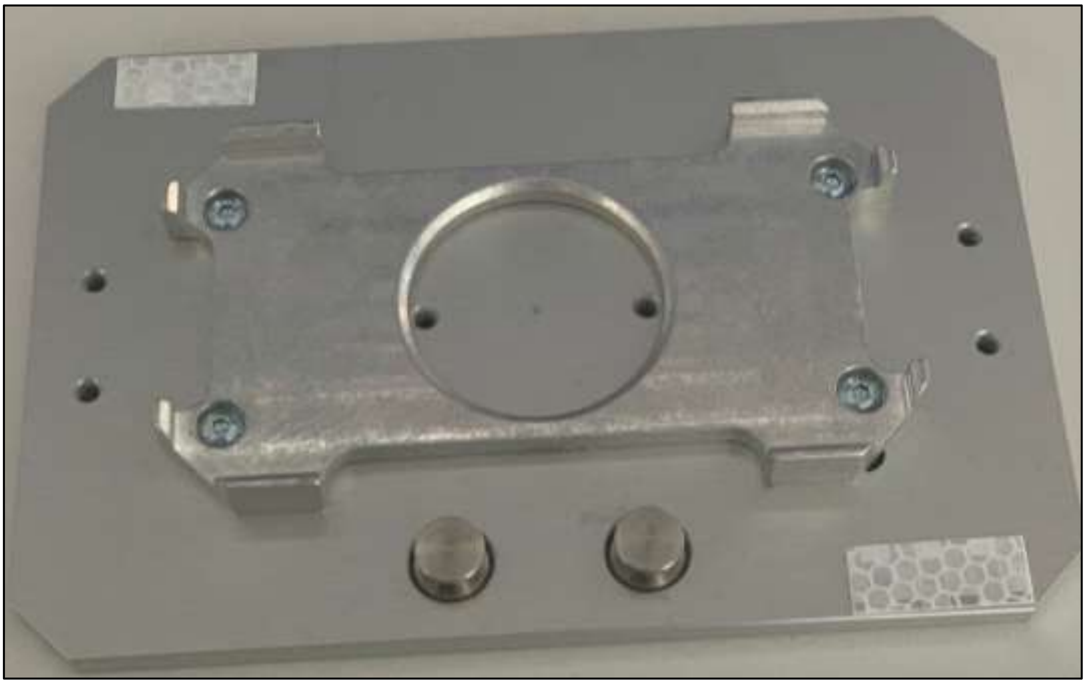

Figure 8. Pallet (Festo)

5.2 Workpiece size limitations

The pallet base is a crucial module in the Smart Factory that directly connects and is scanned with the factory devices. Due to its importance, it doesn't offer many options for changes. Additionally, the size of the operated workpiece is mainly limited by the pallet's dimensions, as it is stored and transported on top of it. To ensure efficient transportation and operation of the workpiece, each Smart Factory component has specific height, width, and length restrictions, which are listed in Appendix 9.

5.2.1 Height

The workpiece is not limited by the pallet, for this purpose each height limitation of the list is compared. The comparison shows the maximum size for the transportation of the workpiece is 20 mm, which is the transportation size limitations in the application of the Cover Magazine and Muscle Press.

Regarding the operation limitation of the workpiece, the Cover Magazine limits the size of the workpiece to 6 mm, this is just for the Workpiece stored in the magazine. After the addition of the cover piece the assembled workpiece can be up to 20 mm high.

5.2.2 Width

The width of the workpiece is currently limited to 60 mm due to the composition of the pallet. The placement of the pins requires the workpiece to be in an exact position and extending it in this direction would interfere with the grippers. On the other hand, extending it in the opposite direction would cause an imbalance in the pallet, which could lead to issues in the ASRS or during transportation on the conveyors.

5.2.3 Length

The length is the only dimension that is possible to extend. To avoid any problems or conflicts with other conveyors and applications on the line, the length of the workpiece should not exceed the length of the pallet. Since the pallet's length is 164 mm, there should be approximately 5 mm of space on each side of the workpiece holder, allowing for a maximum length of 154 mm for the new workpiece.

5.3 Detailed design

In the new design, the dimensions of the base of the pallet remain unchanged as it serves as a direct connection to the existing Smart Factory environment. The optimized dimensions of the base ensure seamless operation and easy detection by the system.

To make the pallet compatible with workpieces of varying lengths, the workpiece holder on the base offers adjustable features. The new design includes movable length borders, while the width borders remain fixed to accommodate different workpiece sizes. The length borders are designed to slide between the width borders, making them adjustable. However, the mounting of the length adjustable rails needs to be carefully considered since it is not possible to create a durable thread in the additive-manufactured structure. To mount the rails, holes are made along the base, with a recess in the form of a nut at the bottom of the pallet to secure the movable rail with a screw. This ensures that the rails remain fixed in place and do not move around during use.

Additive manufacturing is utilized to produce the base of the pallet with the width borders in a single piece, thus reducing the number of parts needed for assembly. This approach streamlines the manufacturing process and enhances consistency in the final product.

5.4 Modelling

The pallet design process was carried out using Autodesk Inventor 2021 CAD software. As the pallet needed to be produced using additive manufacturing, the device was optimized for this method of production. Additive manufacturing was chosen for its efficiency in saving both time and resources, as compared to the traditional method of manufacturing pallets using aluminium.

One advantage of additive manufacturing is that it enables the modelling of unconventional shapes and geometries, which can be challenging or not possible to manufacture by conventional methods. Additionally, additive manufacturing can reduce waste by using only the necessary amount of material required for the final product, as opposed to traditional manufacturing methods that often result in excess material being discarded. This can lead to significant resource and cost savings in the long run.

The name of the project, including all its representative parts and assemblies, is called "Length Adjustable" (LA). To aid in the modelling process, the parts have been named as follows for better understanding.

LA-1001	Pallet base
LA-1002	Adjustable rails
LA-1003	Pins
LA-001	Pallet assembly

5.4.1 LA-1001 Pallet Base

The base of the pallet was modelled to have the exact same dimensions as the one provided by Festo. The placement of the holes for the pins and the holes for docking in the ASRS and conveyors remained unchanged to ensure compatibility with the system, as they are the direct connection spots with the Smart Factory.

The changes compared to the pallet provided by Festo are the width borders of the workpiece holder, which are directly attached to the base of the pallet. This change was made possible by additive manufacturing, making the assembly of the completed pallet easier. The width borders are equipped with chamfers measuring 1,5 mm x 45°, ensuring the workpiece is placed frictionlessly.

A recess with a width of 30mm was implemented between the width borders to facilitate the assembly of adjustable rails with the length borders. Along the recess, holes with a diameter of 3.2mm and a distance between middle points of 10mm and a width of 20mm were placed to connect with the adjustable rails using screws. The alignment of the holes enables the adjustable rail to be attached in 3 different positions. Recesses in the form of an M3 nut were made on the bottom side of the plate at the spot of the holes to make a thread connection for the screw. This was done because it is not possible to insert a durable thread in additive manufactured structures. The model and features described above are displayed in Figure 9.

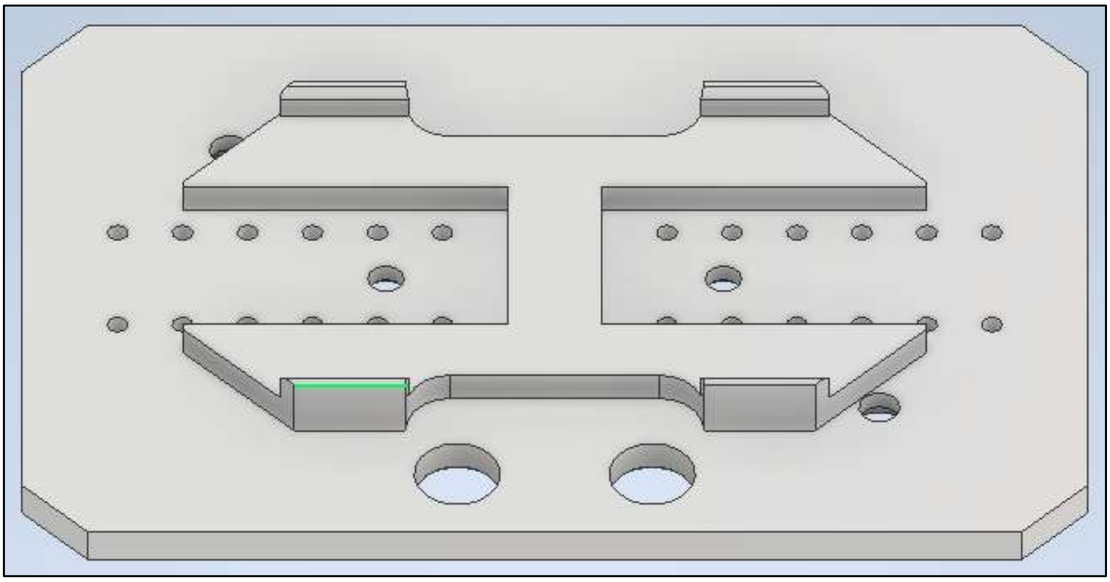

Figure 9. LA-1001 model via Autodesk Inventor

5.4.2 LA-1002 Adjustable Rail

In order to enable length adjustment in the new design, it was required to move the length border along the pallet. For this purpose, an adjustable rail was designed to move along the base of the pallet and between the recesses made in the width borders.

The border used to hold the workpiece in place is 5 mm high and features a chamfer measuring 1.5 mm x 45°. The rail itself has dimensions of 30 mm x 52.7 mm x 5 mm, with holes that facilitate screws measuring 3.2 mm in diameter and featuring a chamfer with dimensions of 2.5 mm x 45°. The chamfers prevent the screws from interfering with the workpiece placed on top.

To ensure a frictionless insertion into the recesses made in the width borders, the front edges of the rail are modelled with a chamfer measuring 1 mm x 45°.

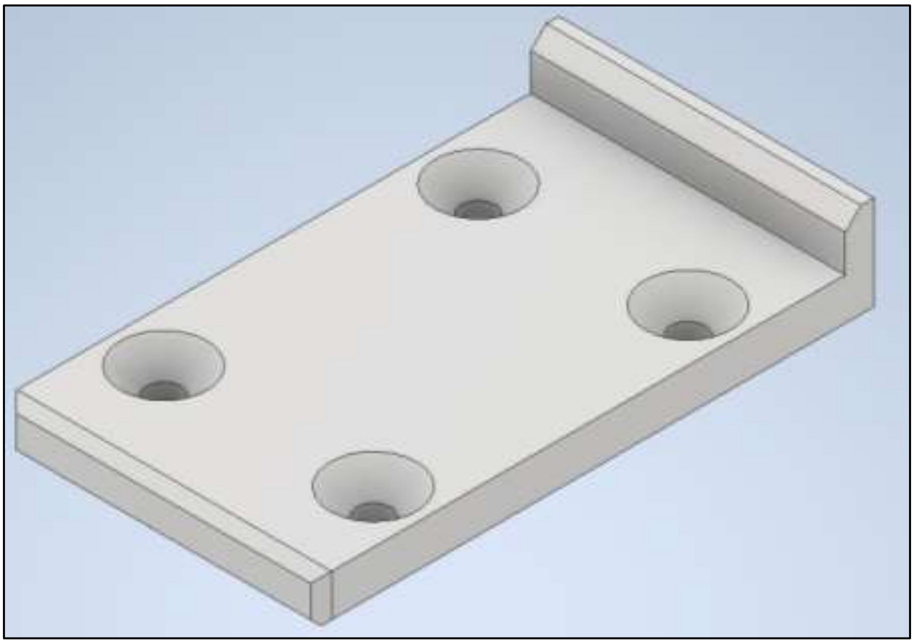

Figure 10. LA-1002 model via Autodesk Inventor

5.4.3 LA-1003 Pins

The top of the new designed pin needs to be exact as the original one provided by Festo, because the placement of the grippers cannot be adjusted. The top diameter is 10,6 mm, the thin diameter is 6,6 mm and is connected with a 2 mm x 45° chamfer. This is the area of the pin which is directly connected to the grippers in the operation. The bottom two rounds are inserted in the base of the pallet, therefore giving room for adjustments if necessary. The described model is displayed in Figure 11.

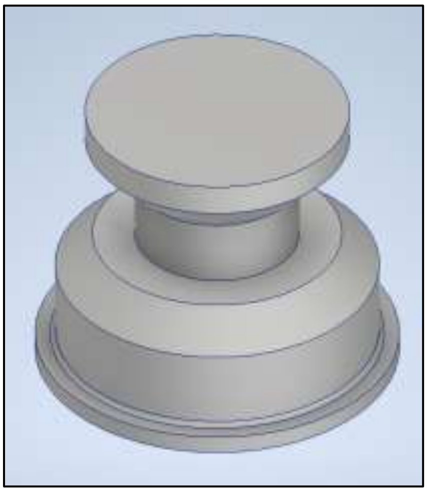

Figure 11. LA-1003 model via Autodesk Inventor

5.5 Drawings

To manufacture the modelled parts and assemble them into a completed pallet, representative drawings are created to determine the exact dimensions needed. General tolerance ISO 2678-m has been selected for manufacturing, as the accuracy of the fitting and compatibility of the parts depend on it. For reference, detailed drawings of each part and assembly can be found in the appendix as follows:

Appendix 5 (2). Pallet base, LA-1001

Appendix 6. Adjustable rail, LA-1002

Appendix 7. Pin, LA-1003

Appendix 8. Pallet, Assembly LA-001

6 PROTOTYPE DEVELOPMENT

The project requires the new pallet for the Smart Factory to be manufactured primarily using additive methods, with traditional manufacturing methods used only as necessary. During the testing of the first prototype (designated 7.2), all parts of the pallet were additively manufactured, except for the screws and nuts required to attach the rails to the base.

As the testing process progressed, modifications were made to the design to improve its functionality. The material used for the pins was changed from PLA to aluminium to minimize surface damage, and a stainless-steel support plate was added to enhance the pin's strength. Further details regarding these adjustments can be found in section 6.2.

6.1 Initial design manufacturing

To prepare for the 3D printing process, each representative model was saved as a Standard Transformation Language (STL) file, enabling compatibility with the slicing software. Ultimaker Cura was utilized for slicing, where printing attributes were selected based on the required features. The software generated a representative G-code to be used for the printing process.

Before each print, glue was applied to the printing bed to enhance the connection between the bed and the first layer of the print. Afterward, warm water was used to clean the bottom of each print. If a print was generated with a support structure, it was manually treated to remove the support.

6.1.1 Pallet

LA-1001-PLA-30% infill:

To prepare the model for printing, the Cura software was utilized to slice it. In this prototype, the pallet was positioned flat on the printing bed to achieve a level surface. The infill density was set to 30% with a triangle pattern. To guarantee precise recesses on the bottom for the placement of nuts and pins, a breakaway support structure was implemented. This support structure allows for precise printing at a 90° angle without directly attaching to the material underneath the layer. The slicing process is illustrated in Figure 12 and the testing of this specific pallet is discussed in section 7.2.

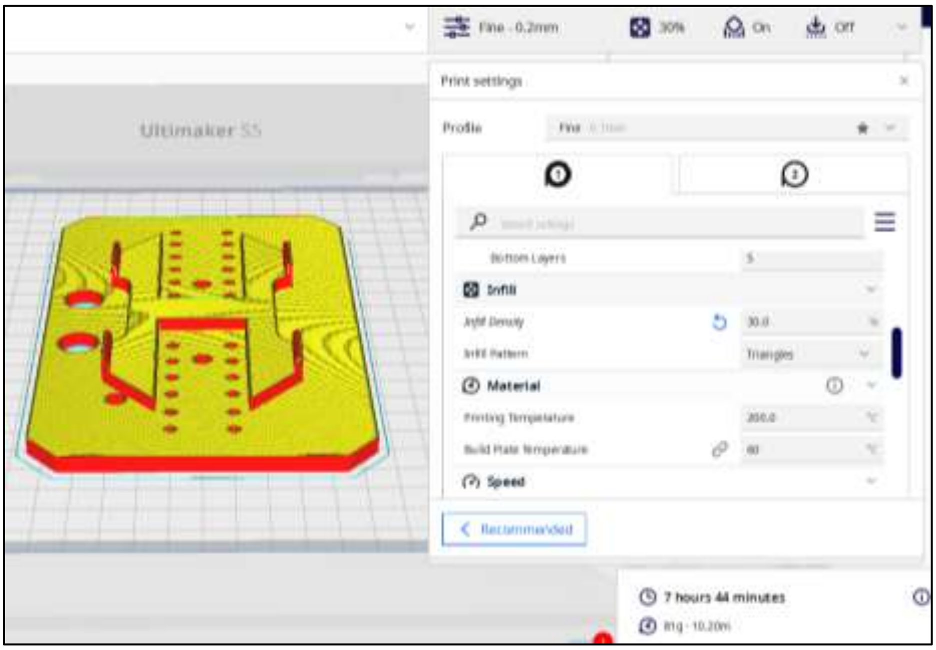

Figure 12. Slicing LA-1001 30% infill

6.1.2 Adjustable rails

The rails were manufactured using additive manufacturing, with the representative model sliced and laid flat on the printing bed for the process. To adjust the infill density, a pattern of triangles was selected at 30%. As two rails are needed for the assembly, they can be sliced in a single print, placed next to each other. As the overhang angle of the chamfer on the bottom was 45°, it was not necessary to create a support structure.

6.1.3 Pin

The initial pin was additively manufactured, as it serves as the direct connection between the grippers and the pallet, and thus must bear the entire weight of the device. To produce a highly robust and accurate print, the infill density was set to 100% with a concentric pattern and a print speed of 30 mm/s. The results of testing with this pin are outlined in section 7.2.

6.2 Assembling

The assembly of the completed pallet begins by inserting the pins into the base through pressure fitting. The rails are then slid between the recesses of the width borders and can be mounted in three different positions, allowing for adjustments in the carried workpiece size. The rails are mounted by inserting 4x M3 countersunk screws on the top of the rail and tightening them with 4x M3 nuts placed on the bottom of the base.

6.3 Iterations and adjustments

During testing of the device for compatibility with the Smart Factory, errors were encountered. To rectify these issues, adjustments were made to the design and manufacturing processes, which are described in the following chapters.

6.3.1 Pallet

Adjustments to the pallet were necessary to increase the stability of the pin in the base. Two adjustments are described in the following chapter. In the second adjustment, the design of the pallet was modified and renamed as "LA supported (s)" to facilitate better understanding of the drawing files.

LA-1001-PLA-100% infill:

After analysing the test results of the pallet's base with 30% infill density, it was observed that the construction required reinforcement to prevent pin displacement. The pallet was again placed flat on the print bed during slicing, and a support structure was added to the bottom for accurate printing of the recesses. The modified pallet was tested, and the details are outlined in section 7.3.

To avoid increasing the infill density of the workpiece holder's width borders, two different infill densities were used for printing. The base holding the pins required extra reinforcement, which was achieved by generating a support blocker in the slicer to cover the pallet's base. The mesh type of the support blocker was then changed to "Modify settings for overlaps," allowing fine-tuning of the part's characteristics covered by the support blocker.

Figure 13 illustrates the settings for the parts covered by the support blocker on the left side, while the settings for the overall print are shown on the right side.

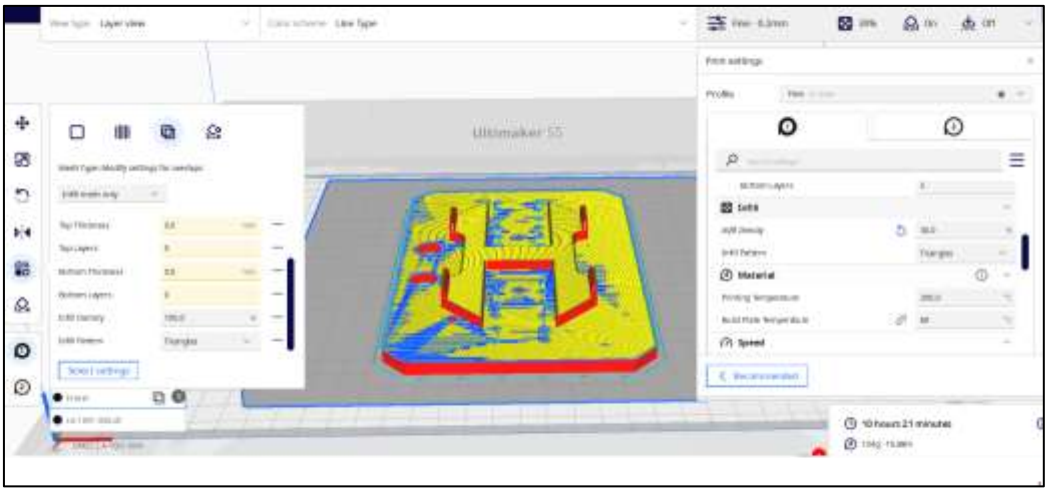

Figure 13. Slicing LA-100% infill

LAs-1001-100% infill- (Stainless steel supported)

After reviewing the results of the test in section 7.3, it was concluded that the base of the pallet requires additional support material to prevent displacement of the pins. However, it was also determined that the diameter of the pallet must remain unchanged to allow the grippers to attach to the pins without any issues.

To address this issue, a recess was added to the middle of the base of the pallet to accommodate a stainless-steel plate. This modification is illustrated in Figure 14 and the detailed dimensions can be found in Appendix 10. Additionally, the drawing of the assembled LAs pallet is provided in Appendix 13.

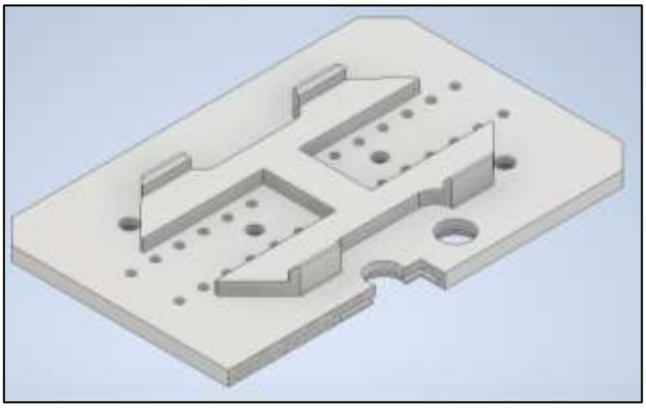

Figure 14. LAs-1001 model via Autodesk Inventor

To create the plate for the recess, a 1.5 mm thick stainless-steel plate was cut using plasma cutting to achieve an accurate outline. The holes were then drilled by hand, starting with a 2 mm drill, and increasing by 1 mm up to 13 mm for maximum precision. The drawing for the plate can be found in Appendix 12.

For the slicing of this part, a 100% infill density with a triangle pattern was chosen. To ensure better stability, the stainless-steel sheet was inserted inside the print. This required pausing the print at a specific layer, which involved modifying the G-code. The steps for this are shown in Figure 15 The "Add script" button was clicked, and "Pause at height" was selected from the drop-down menu. The pause needed to be set for the 12th layer, and the appropriate mode needed to be selected depending on the printer's firmware.

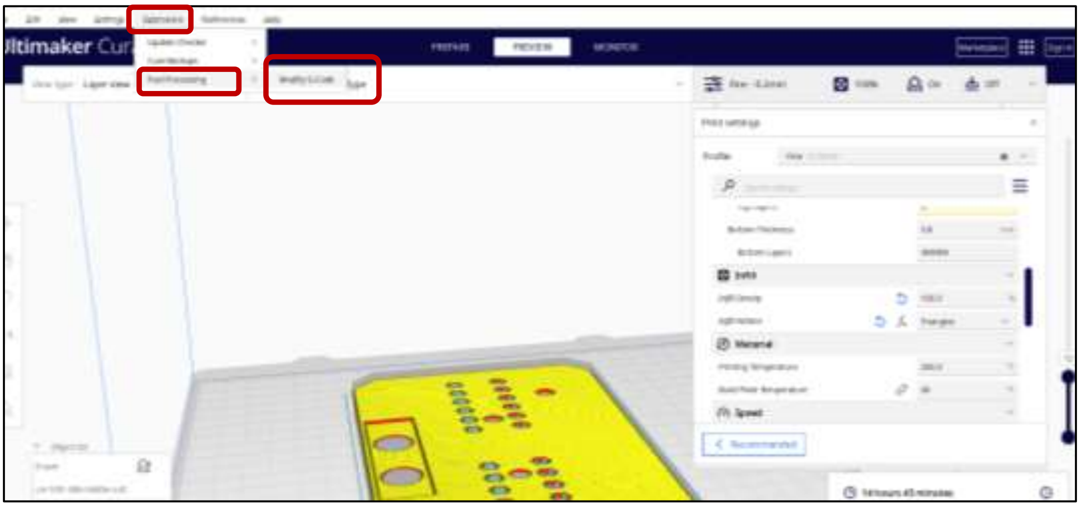

Figure 15.Slicing LAs-1001 via Ultimaker Cura

After the print was started, a pause occurred on the 12th layer as planned. The stainless-steel sheet was then inserted into the designed recess. To ensure a better connection between the filament and the metal surface, glue was applied. Once the sheet was placed correctly, the printing process was resumed. This step is displayed in Figure 16.

Figure 16. Stainless-steel sheet placement in the print

6.3.2 Pin

After examining the additive manufactured pin used in test 7.2 , it was found that the surface of the pin had been damaged. In order to improve the durability of the pin, it was machined on a lathe from aluminium. The dimensions of the pin were also modified, with the chamfer used to facilitate insertion into the pallet being reduced from 2 mm x 45° to 0.5 mm x 45°. This was done to increase the contact surface between the pin and the pallet, thereby reducing the pressure applied to the pin and minimizing the risk of displacement. The adjustments are illustrated in Figure 17, with the original design on the left and the modified chamfer dimensions on the right. The precise dimensions are included in Appendix 11.

Figure 17. Original Festo pin design (left) dimension adjusted pin (right)

7 IMPLEMENTATION IN THE SMART FACTORY

7.1 Process creation via MES4

To test the compatibility of the new pallet with the Smart Factory components, a work process must be created through the MES4 software. For testing, two different work processes were created. The first is designed to test the compatibility of the pallet with the ASRS and conveyor, and the process and representative creation is described in section 7.1.1. Once the first process is completed successfully five times and the operation of the ASRS and pallet is considered reliable, the second process is conducted to test the compatibility of the pallet with the applications. This process is described in section 7.1.2.

To add the new pallet to the MES4 database, a new part must be created with the part number "35". Additionally, the part needs to be enabled in "Other Settings" as a pallet for the ASRS. The necessary steps are displayed in Figure 18.

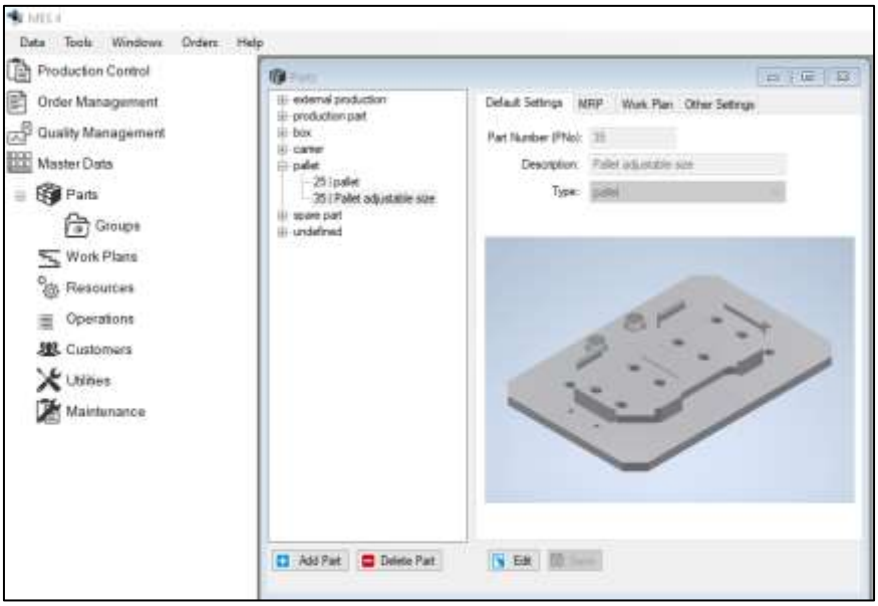

Figure 18. LA pallet creation in MES4

When the pallet is placed in a free shelf of the ASRS, the position of the pallet needs to be entered in MES4. “Production Control” -> ”Buffers” -> choose right spot and change from “0-nothing” to “35-Pallet adjustable size”.

7.1.1 MES4 Work plan 1

To test the connection between the ASRS grippers and the pallet pins, a three-step work plan has been created. In the first step, the grippers release the pallet from the shelf and place it on a free conveyor, which then heads towards the Pick-by Light station. At this station, the pallet is manually examined, and upon approval, the step is completed. During the journey towards the ASRS, the pallet passes through several checkpoints, including camera inspection, cover magazine, and muscle press, to ensure that the size restrictions are met and that the device can pass through the applications smoothly. Once the conveyor reaches the ASRS, the grippers pick up the pallet and place it back in a free shelf.

This representative work plan is identified by the work plan number "9013" and is named "Test-Pallet Take-In Part."The work plan is displayed in Figure 19.

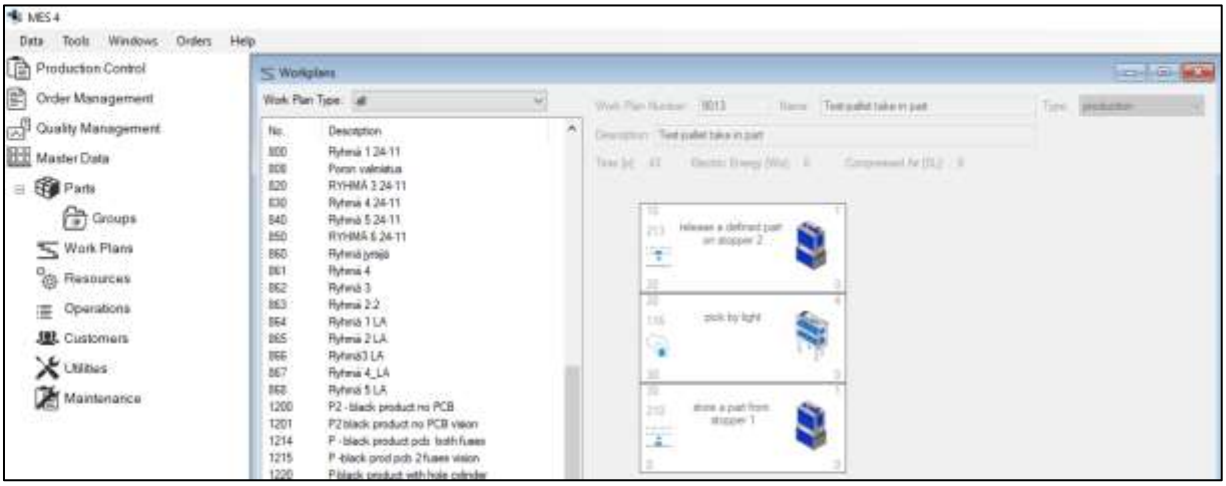

Figure 19.Work plan 1 via MES4

7.1.2 MES4 Work plan 2

The second work plan was designed to test the compatibility of the new pallet with the main applications in the Kosmos Lab's Smart Factory. However, due to memory limitations in the database, the Camera Inspection and CNC-mill could not be included in the work plan. To test the compatibility of the robotic arm of the CNC-mill with the workpiece, it was controlled manually. The Robotino 4 is currently out of order, therefore it could not be included in the tests. The work plan includes the ASRS, Pick-by light module, Cover Magazine, and Muscle Press to evaluate the compatibility of the pallet with these applications. The workflow for this work plan is illustrated in Figure 20.

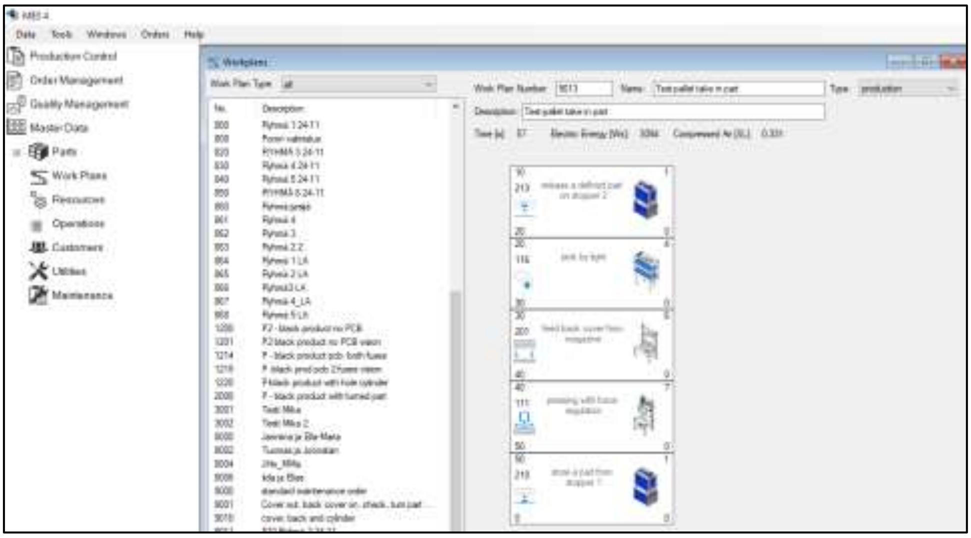

Figure 20. Work plan 2 via MES4

7.2 Test run LA-PLA-30% infill with PLA pins

In the following the test the MES4 Work plan 1 was used. The test run involved using a Length Adjustable pallet printed with PLA and an infill density of 30%. The Pins used in the test were also printed with PLA, but with a concentric infill pattern and 100% infill density, the device is shown in Figure 21. The purpose of the test was to determine whether the pallet could be detected in the ASRS and whether the pins were correctly positioned to enable the grippers to attach to the pallet. Additionally, the Pick-by-light application was integrated into the process to investigate the compatibility of the pallet with the conveyors.

Figure 21. LA pallet-PLA-30% infill with PLA pins

The results of the test are shown in Table 9. The fibre optic device of the ASRS was able to identify the presence of the pallet on the shelf. The grippers were able to connect to the pallet via the pins and place it on the conveyors. The pallet's transportation through every station met the size restrictions of each application in the work process. The successful operation of the ASRS could not be repeated in the test. The grippers did not release the pallet in the storing operation.

Table 9. Testing result LA pallet-PLA-30% infill with PLA-pins

LA-PLA-30%infill (PLA-Pins)			
x if statemtent is true	**Size restritcions met**	**Component identifies device**	**Component opperates device**
CP Factory High-bay storage	x	x	
CP Factory mill with robotic arm			
Pick by light Module	x	x	x
Camera inspection	x		
Cover Magazine	x		
Muscle press	x		
Robotino			

7.2.1 Error

To ensure the durability of the pallet, the test was repeated. However, during the third run of the work process, the grippers in the ASRS did not release while putting the pallet back on the shelf, causing the Smart Factory to come to a halt.

An error call was made for Y-axis calibration, as the grippers were unable to release. To resolve the error, the ASRS had to be changed to Default mode. In the Setup menu, the grippers could be operated manually. The process is visualized in Figure 22. Once the grippers were released and had returned to their home position, the ASRS could be put back into MES4 mode to operate automatically.

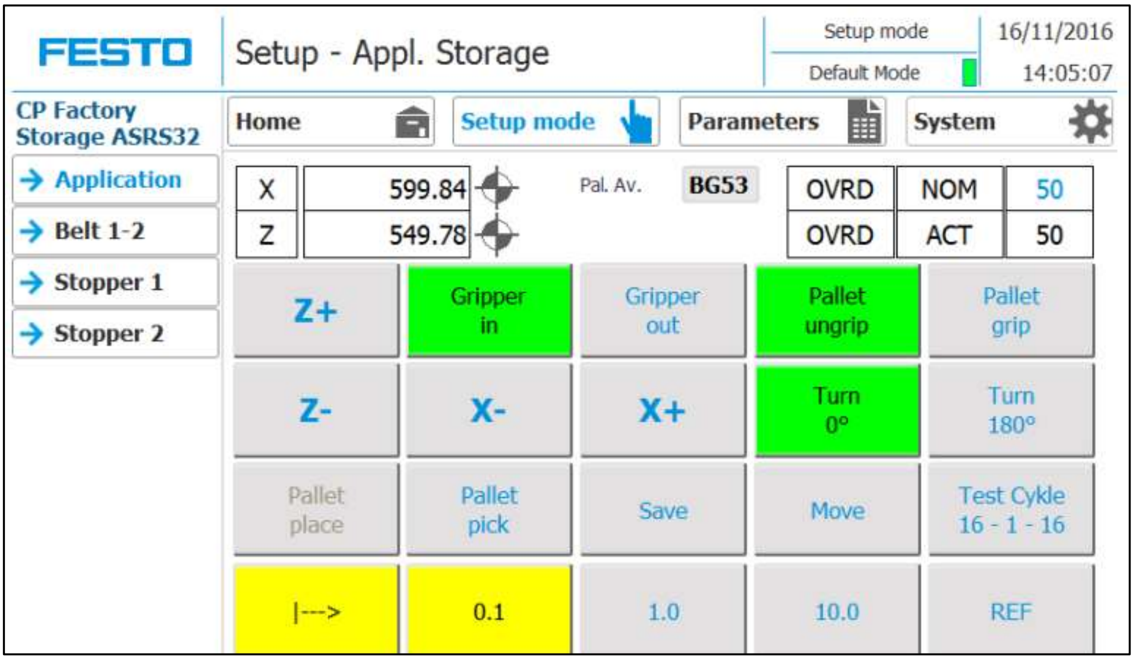

Figure 22. Interface of the Smart Factory to operate manually

After the pallet was removed from the Smart Factory, it was examined and found to have a slight displacement of the pins and damages on the surface of the pins. It was evident that the applied pressure of the grippers was too high to operate with pins manufactured from PLA.

7.3 Test run LA-PLA-100% infill with Aluminium pins

In the following test the MES4 Work plan 1 were used. The test run was conducted using a pallet made of PLA with an infill density of 100%, while the pins used in the test were made of aluminium. The pallet is shown in Figure 23. The purpose of the test was twofold: first, to determine whether increasing the infill density would solve the pin displacement issue, and second, to test the aluminium surface of the pins for resistance to damage caused by the grippers.

Figure 23. LA pallet-PLA-100% infill with Aluminium pins

The results of the test are shown in Table 10. In this test the ASRS detected the presence of the pallet. The grippers connected to the pins, in the first step of the process and released it on the conveyer. On the way the Pick-by light application worked with the device. In the storing operation the grippers did not manage to put the pallet back to storing shelf.

Table 10. Testing result LA pallet-PLA-100% infill with Aluminium pins

LA-PLA-100%infill (Aluminium-Pins)			
x if statemtent is true	Size restritcions met	Component identifies device	Component opperates device
CP Factory High-bay storage	x	x	
CP Factory mill with robotic arm	x		
Pick by light Module	x	x	x
Camera inspection	x		
Cover Magazine	x		
Muscle press	x		
Robotino			

7.3.1 Error

In this configuration of the pallet, the exact same error occurred as in the error described in Test run LA-PLA-30% infill with PLA pins. The grippers got stuck in the same position, while not being able to release the pallet on the shelf. The error notification and resolve steps are explained and shown in 7.2.1.

7.4 Test run LAs-PLA-100% infill with Aluminium Pins

In the following test the MES4 Work plan 1and MES4 Work plan 2 were used. The test runs were conducted using a pallet made out of PLA with 100% infill with an inserted stainless-steel sheet and aluminium pins. The used device is shown in Figure 24, the inserted sheet is placed inside of the print. The purpose of the test was to determine if the metal support prevents the pins from displacement.

Figure 24. LAs-PLA-100% infill with Aluminium pins

The test results are presented in Table 11. The pallet was identified and functioned smoothly in every application across the Smart Factory. However, the Camera inspection operation could not be tested due to memory space limitations in the database, which prevented additional work plans for the application. The CNC mill with the robotic arm was tested by manual control since the Robotino is currently not operational, and its compatibility with the application could not be tested.

Table 11. Testing result LAs pallet-100% infill with Aluminium pins

LAs-PLA-100%infill with support metal sheet (Aluminium-Pins)			
x if statemtent is true	Size restritcions met	Component identifies device	Component opperates device
CP Factory High-bay storage	x	x	x
CP Factory mill with robotic arm	x	x	x
Pick by light Module	x	x	x
Camera inspection	x	x	
Cover Magazine	x	x	x
Muscle press	x	x	x
Robotino			

7.4.1 Error

During the testing of the Cover magazine, a sensor was unable to detect the presence of the bottom workpiece on the pallet, and the interface displayed an error code "-BG7" indicating a sensor issue. Upon removal of the pallet from the application, the sensor was examined, and it was discovered that the converter was not transforming the analog signal into a digital signal. The faulty converter, shown in Figure 25 was replaced by a new one, and the fiber optic cables, and electricity wires were properly connected. After resetting the Smart Factory, the sensor and the Cover magazine were able to work smoothly with the workpiece.

Figure 25. Fibre optic sensor converter

8 DISCUSSION

In conclusion, the testing of the additive manufactured pallet for compatibility with the Festo Smart Factory in the Kosmos Lab at the Lapland UAS has revealed that it is not feasible to completely manufacture a pallet solely from additive manufacturing materials that fulfils the strength requirements of this particular Smart Factory. However, it has been demonstrated that implementing minor metal features into the design, such as a stainless-steel support sheet and aluminium pins, can increase the strength and durability of the pallet while reducing the number of metal components in the device.

Therefore, a hybrid approach combining additive manufacturing and traditional manufacturing techniques may be the most practical solution for developing pallets that are compatible with the Smart Factory. The research also suggests that further investigation into additional combinations of materials and manufacturing techniques is needed to enhance the performance and cost-effectiveness of pallets in the Smart Factory.

Moreover, the thesis reveals that the hybrid base of the pallet is compatible with the Festo Smart Factory training kit, and the workpiece holders can be adjusted to accommodate other desired shapes of the operated workpiece.

While the findings suggest that it is not possible to completely replace metal pallets with additive manufacturing in this specific Smart Factory, integrating minor metal features into the design can help to reduce the use of metal resources in production. Additionally, exploring the feasibility of manufacturing these pallets using Polyethylene terephthalate glycol (PETG) or Acrylnitril butadien styrol (ABS) could be a potential avenue for further exploration, as it may offer greater long-term durability than PLA.

Finally, it is important to note that the economic impact of replacing metal structures with mainly PLA was not explored in this research, which could be a potential research question for future studies to investigate the financial effects of replacing metal structures with additive manufactured devices.

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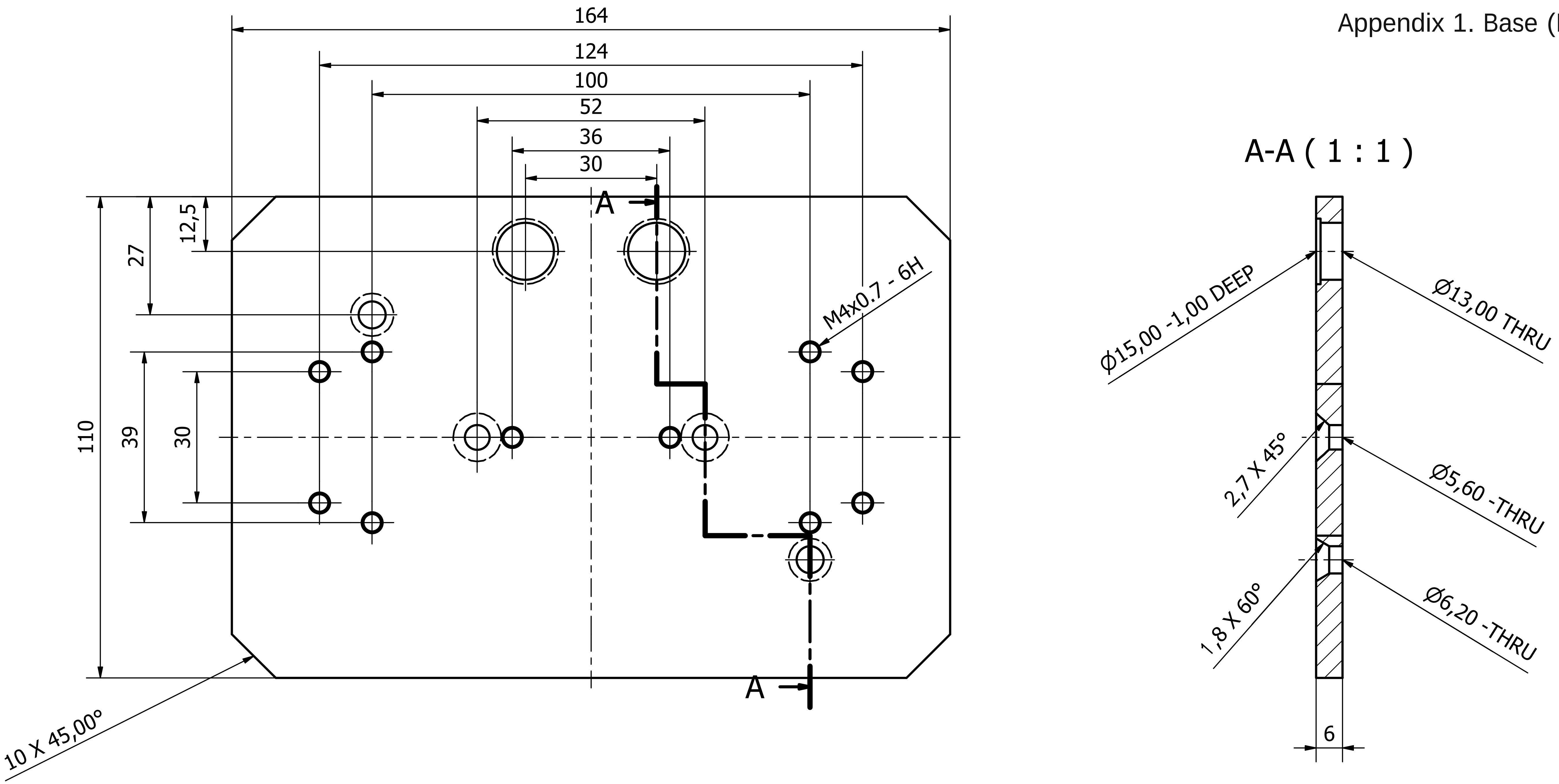
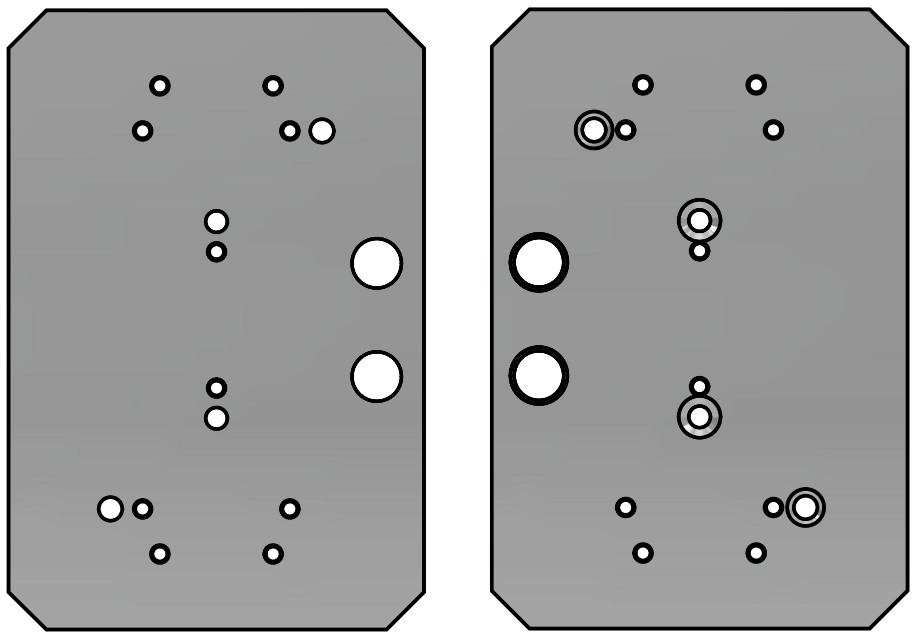
10 APPENDICES

Appendix 1.	Base (Festo), Drawing OG-1001
Appendix 2.	Workpiece holder (Festo), Drawing OG-1002
Appendix 3.	Pin (Festo), Drawing OG-1003
Appendix 4.	Pallet (Festo), Drawing OG-001
Appendix 5 (2).	Pallet base, Drawing LA-1001
Appendix 6.	Adjustable rail, Drawing LA-1002
Appendix 7.	Pin, LA-1003
Appendix 8.	Pallet, Drawing LA-001
Appendix 9.	Size limitations Festo stations
Appendix 10 (2).	Pallet base supported, Drawing LAs-1001
Appendix 11.	Pin adjusted, Drawing LAs-1003
Appendix 12.	Support metal sheet, Drawing LAs-1004
Appendix13.	Supported Pallet, Drawing LAs-001

Appendix 1. Base (Festo)

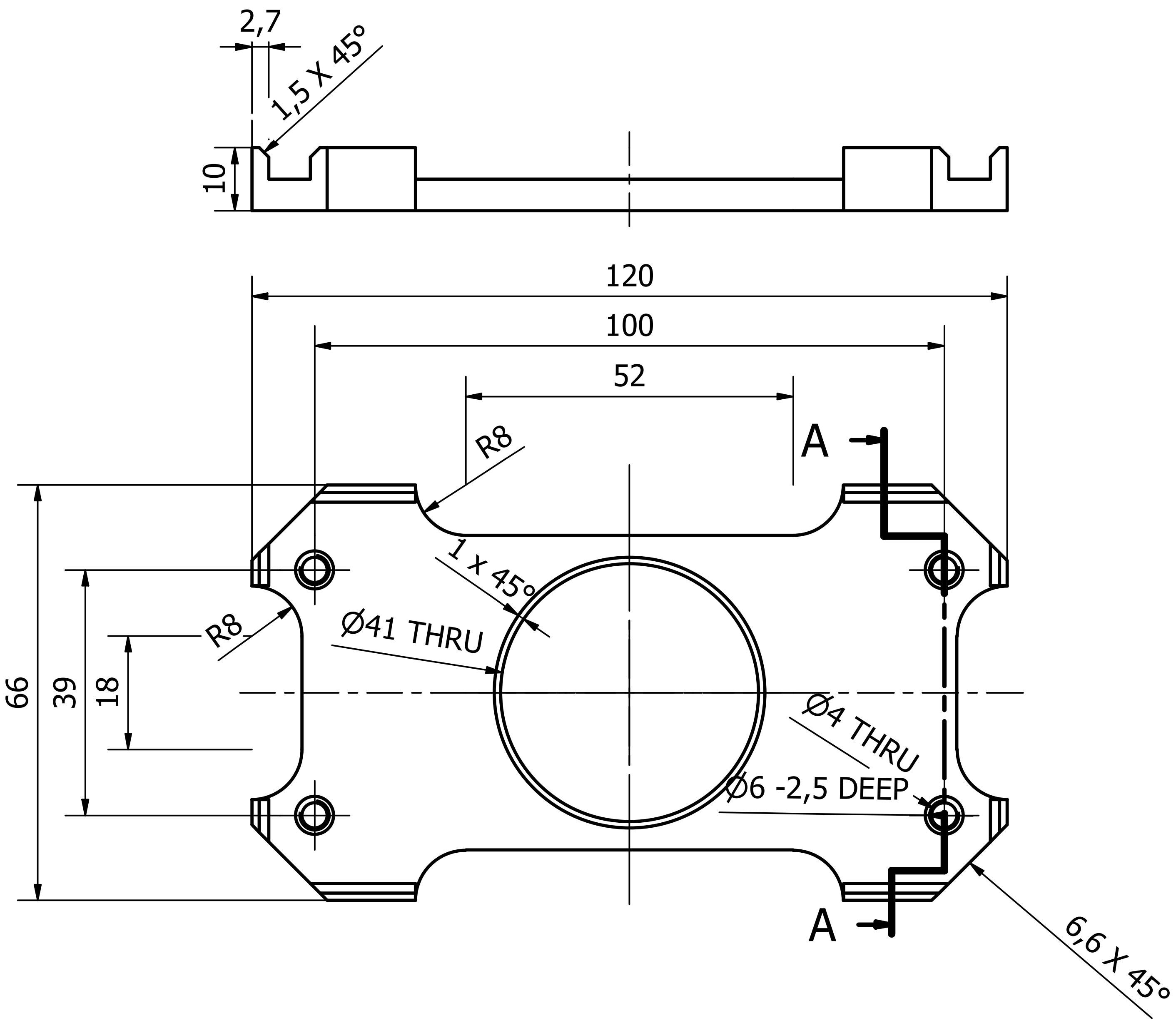




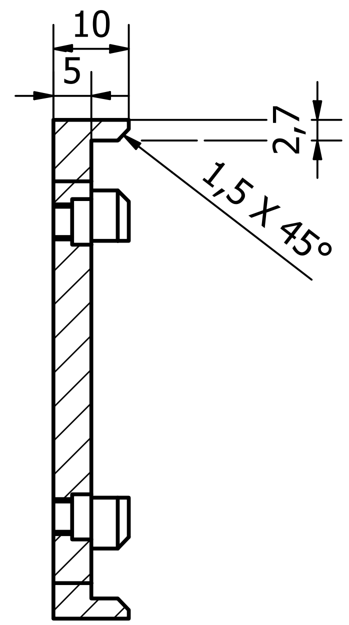
1	Base	Aluminium 6061	OG-1001	1	0,3 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

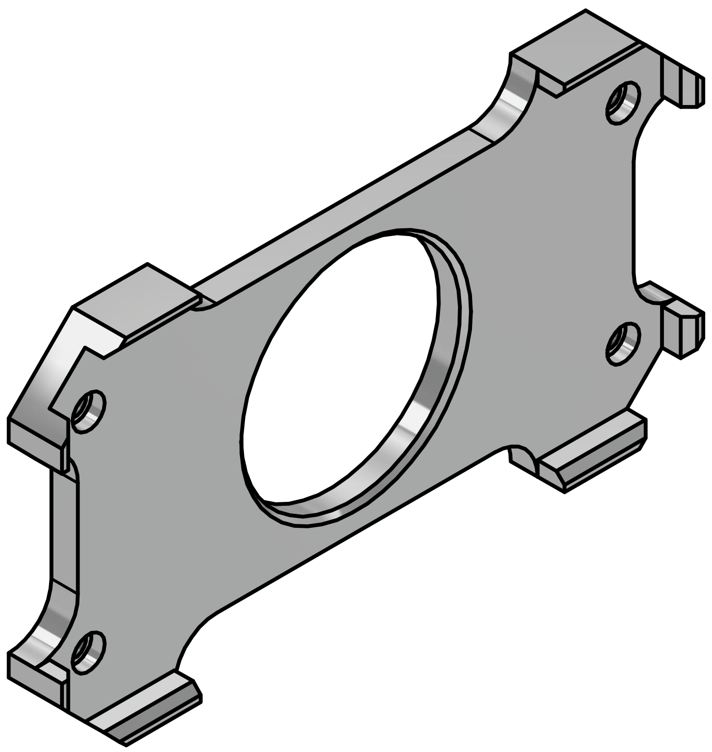
Suun	SSz	04.04.2023	Mittakaava	Tuote	Liittyy OG-001
Piirt	SSz	04.04.2023	1:1	Yleistoleranssit ISO 2768-m	Osan nimi Pallet (Festo)
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa 0,280 kg					Osan numero OG-1001

Appendix 2. Workpiece holder (Festo)



A-A (1 : 1)

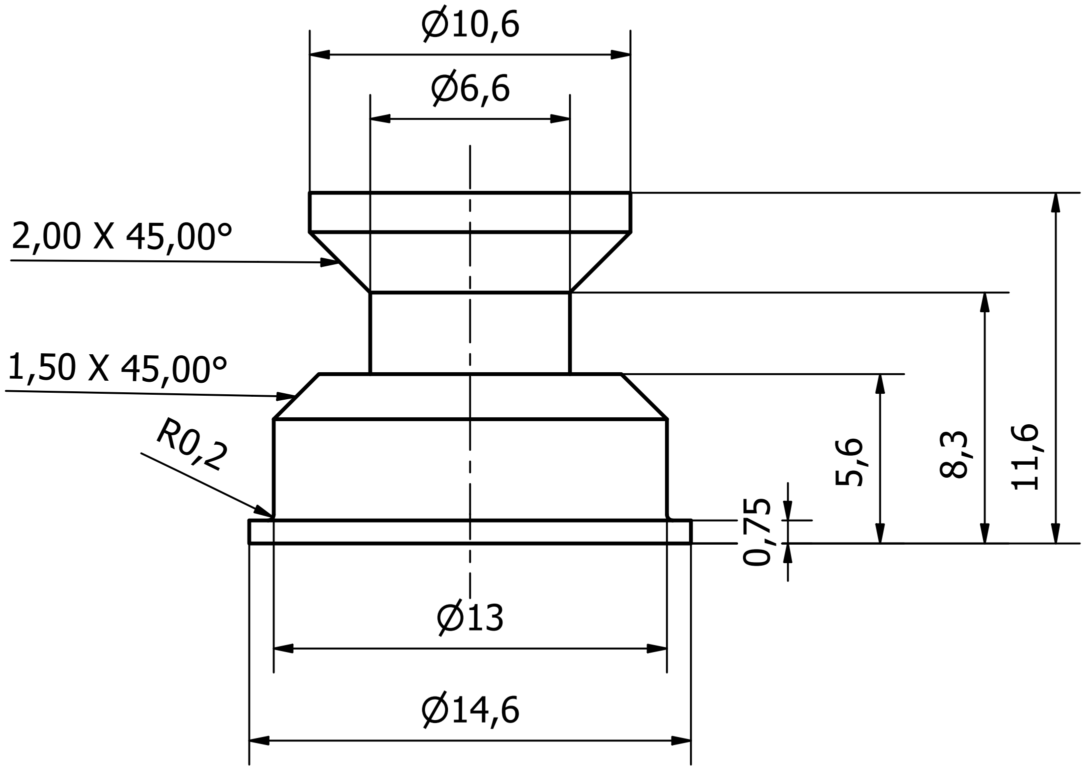


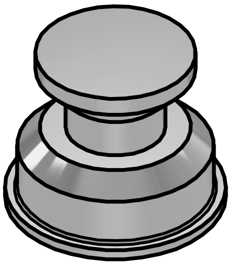


1	Workpiece holder	Aluminium 6061	OG-1002	1	0,1 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	12.04.2023	Mittakaava	Tuote	Liittyy OG-001
Piirt	SSz	12.04.2023	1:1	Yleistoleranssit ISO 2768-m	Osan nimi Pallet (Festo)
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa 0,066 kg					Osan numero OG-1002

Appendix 3. Pin (Festo)

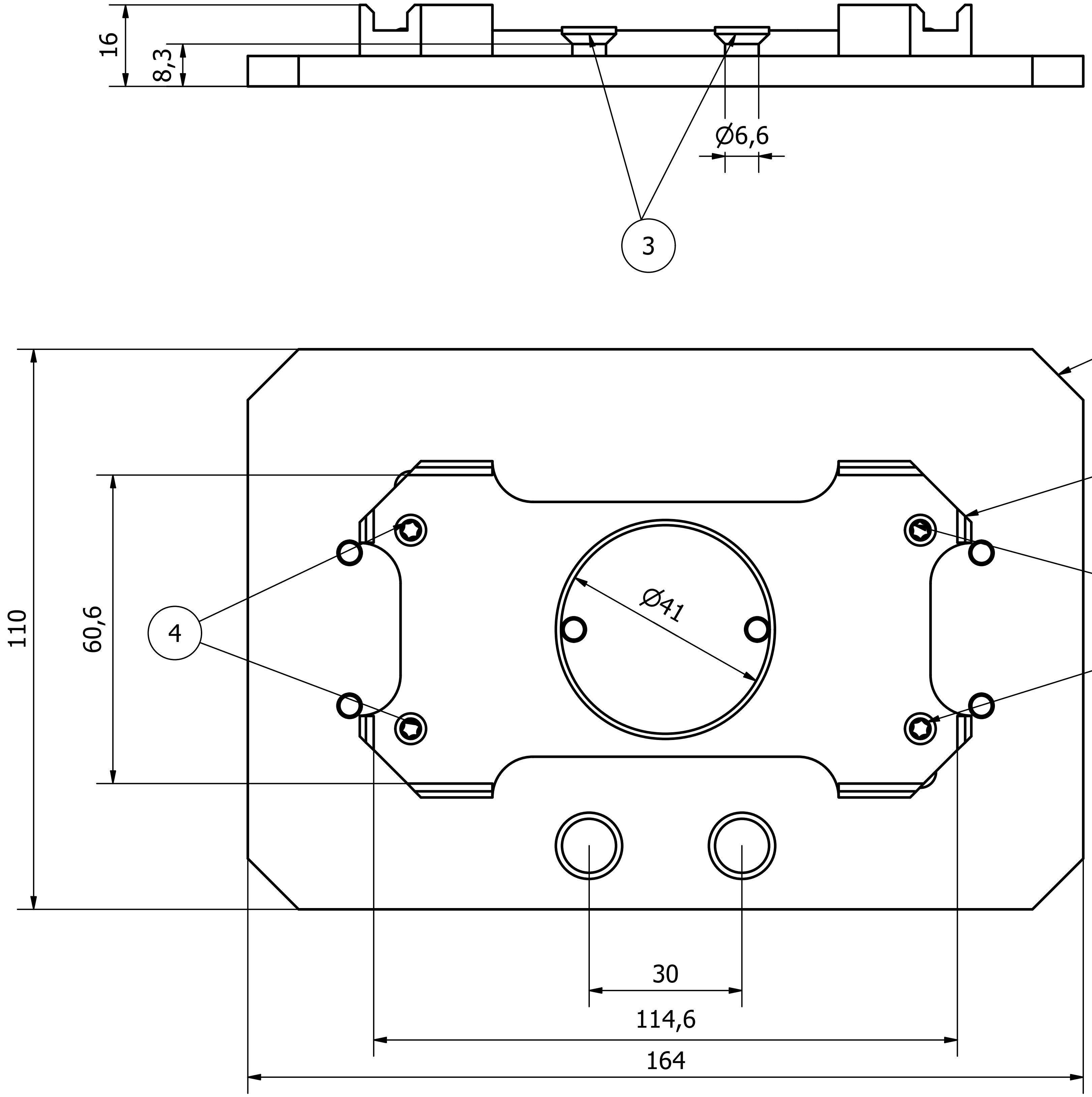




1	Pin	Aluminium 6061	Pin	1	0 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	21.03.2023	Mittakaava	Tuote	Liittyy LA-001
Piirt	SSz	21.03.2023	4:1	Yleistoleranssit ISO 2768-m	Osan nimi Adjustable Pallet
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa 0,003 kg					Osan numero OG-1003

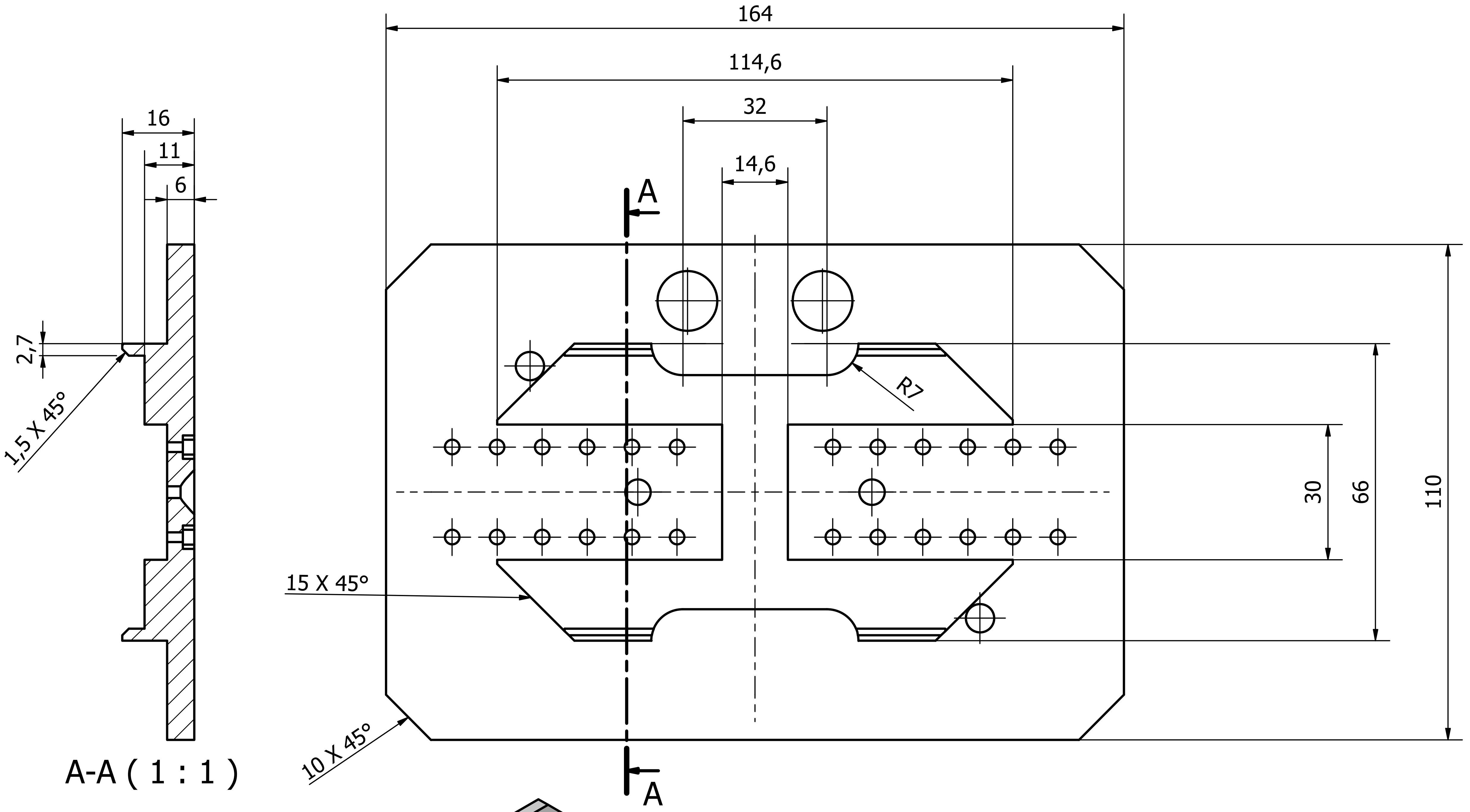
Appendix 4. Pallet (Festo)

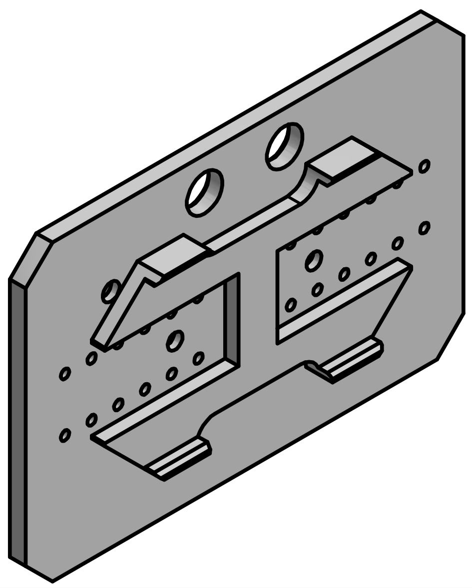


Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino
4	Hexalobular socket pan head screws		GB/T 2672-2004	4	0 kg
3	Pin (Festo)		OG-1003	2	0 kg
2	Workpiece holder (Festo)		OG-1002	1	0,1 kg
1	Base (Festo)		OG-1001	1	0,3 kg

Suun	SSz	13.04.2023	Mittakaava	Tuote	Liittyy
Piirt	SSz	13.04.2023	1:1	Yleistoleranssit: ISO 2768-m	Osan nimi: Pallet (Festo)
Tark					
Hyv					
Mikrofilm. pvm.				Yritys: Lapin AMK	Revisio / Sivu: 1
Osan massa: N/A					Osan numero: OG-001

Appendix 5 1(2). Pallet base



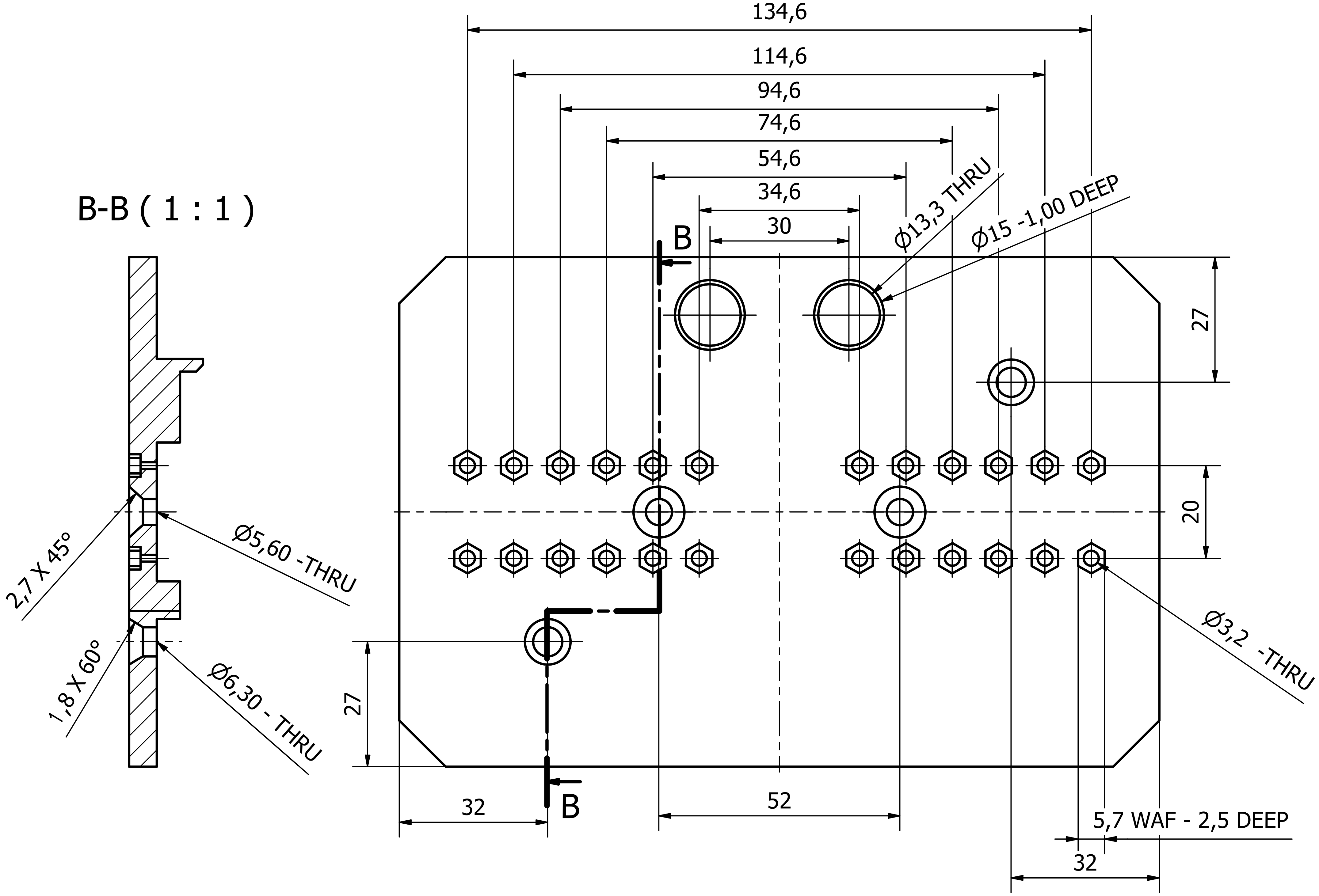


Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino
1	Pallet base	Polylactic acid (PLA)	LA-1001	1	0,2 kg

Suun	SSz	12.04.2023
Piirt	SSz	12.04.2023
Tark		
Hyv		

Mittakaava	1:1
Tuote	
Yleistoleranssit	ISO 2768-m
Liittyy	LA-001
Osan nimi	Adjustable Pallet
Mikrofilm. pvm.	
Yritys	Lapin AMK
Revisio	
Sivu	1/2
Osan numero	LA-1001
Osan massa	0,154 kg

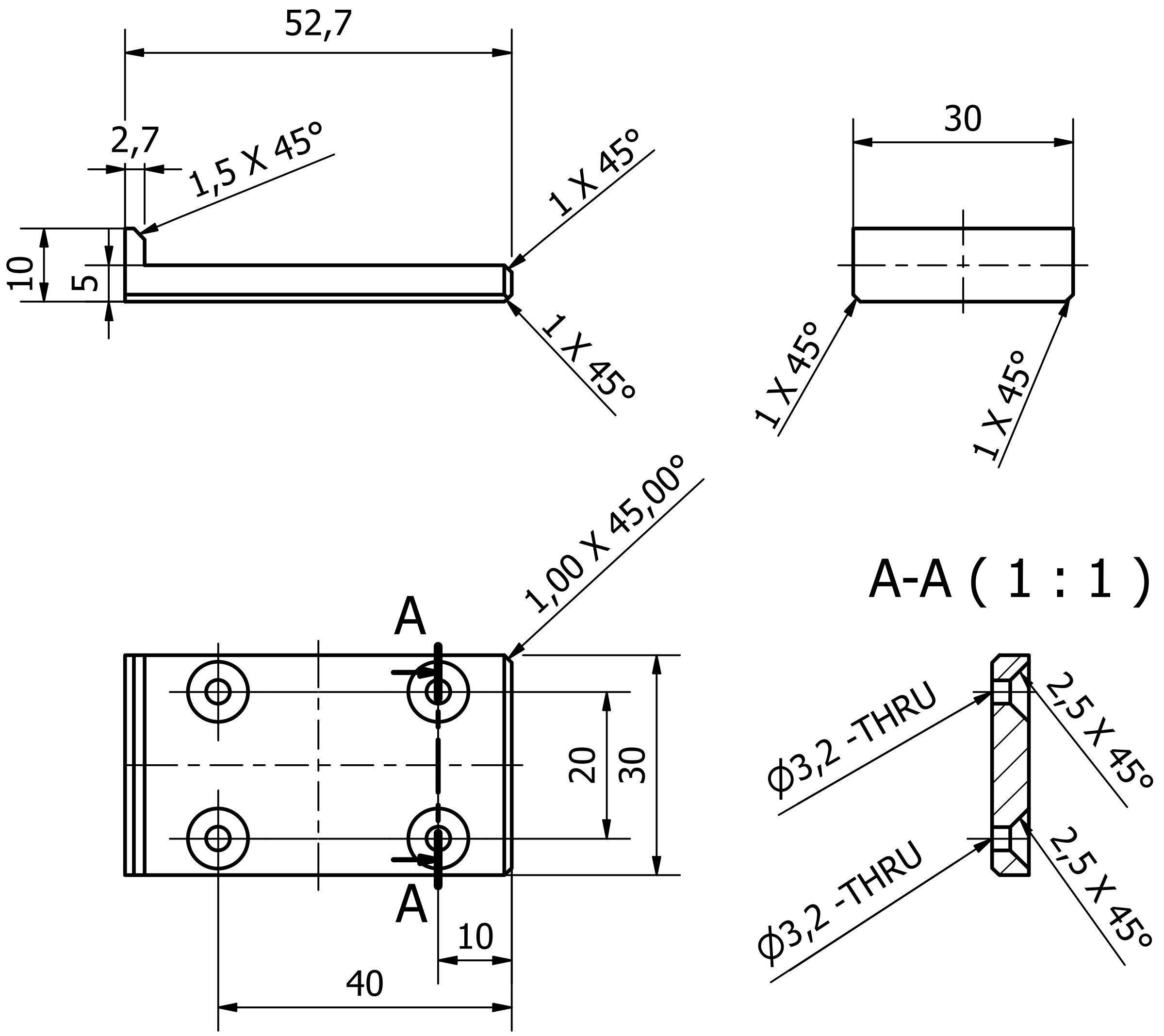
Appendix 5 2(2). Pallet base



This View is rotated 180° with respect to the worpiece on page 1

Suun	SSz	12.04.2023	Mittakaava	Tuote	Liittyy LA-001
Piirt	SSz	12.04.2023	1:1	Yleistoleranssit ISO 2768-m	Osan nimi Adjustable Pallet
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 2/2
Osan massa 0,154 kg					Osan numero LA-1001

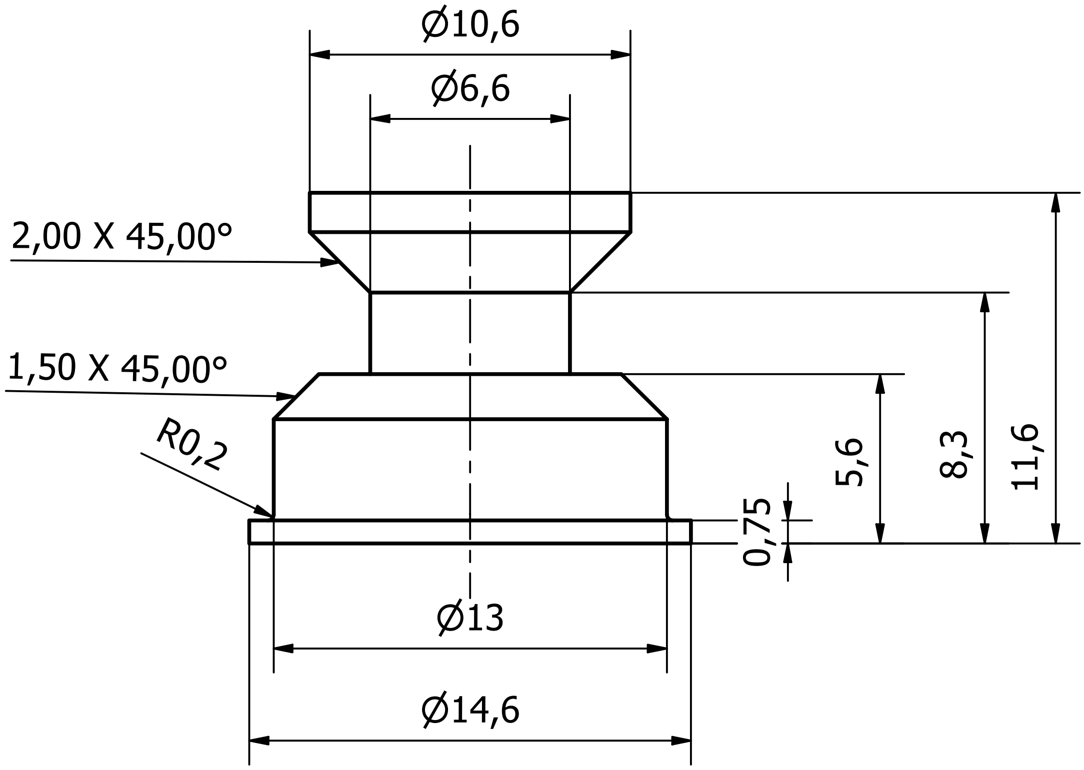
Appendix 6. Adjustable rail

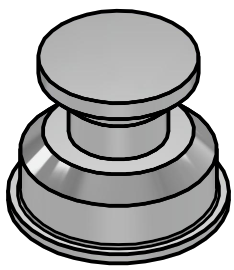


1	Adjustable rail	Polylactic acid (PLA)	LA-1002	1	0 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	13.04.2023	Mittakaava	Tuote	Liittyy LA-001
Piirt	SSz	13.04.2023	1:1	Yleistoleranssit ISO 2768-m	Osan nimi Adjustable Pallet
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa N/A					Osan numero LA-1002

Appendix 7. Pin

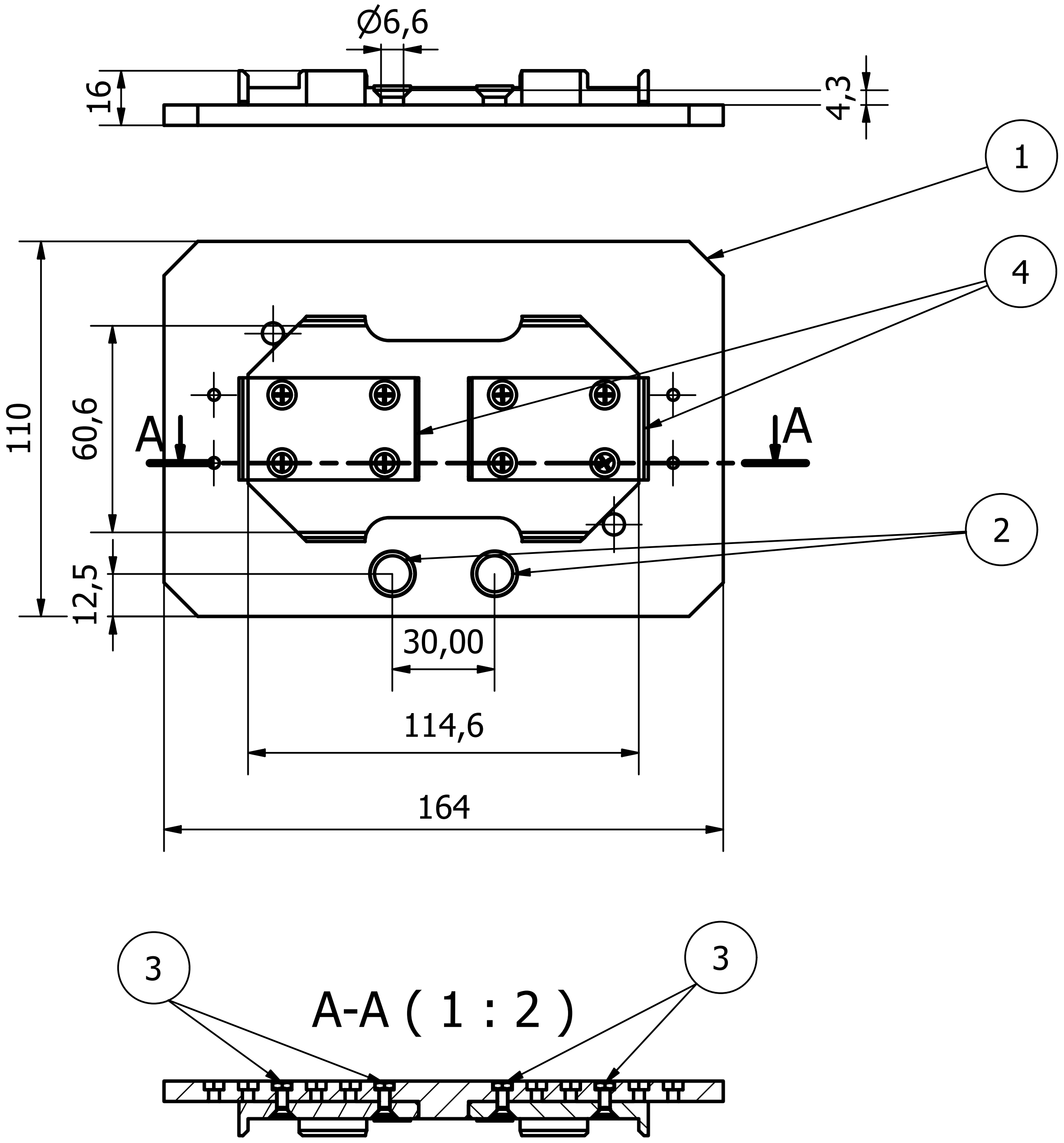


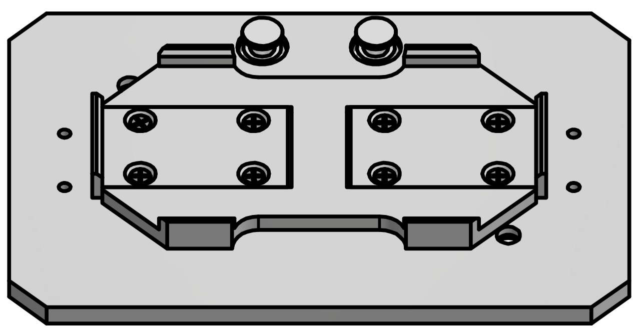


1	Pin	Aluminium 6061	Pin	1	0 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

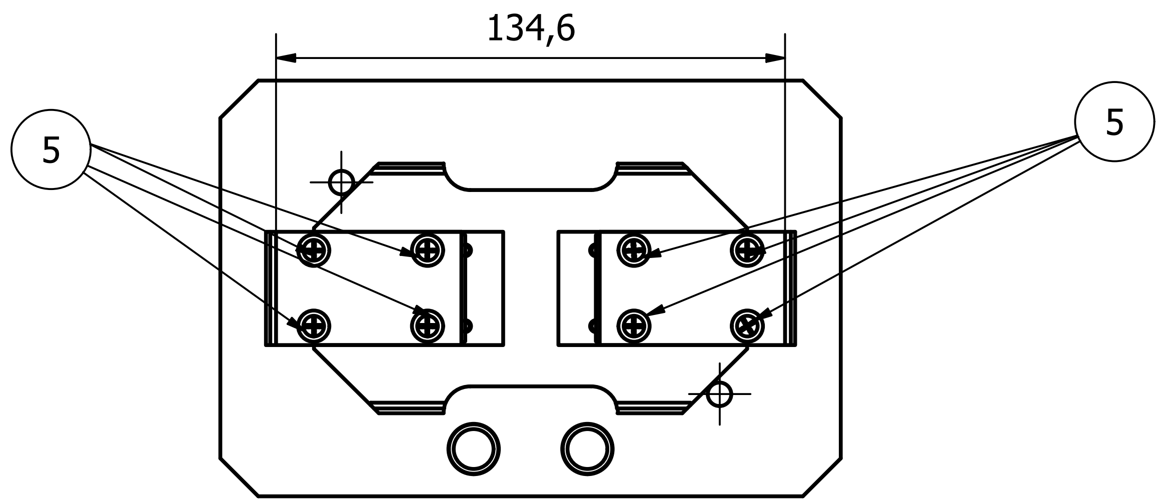
Suun	SSz	21.03.2023	Mittakaava 4:1	Tuote	Liittyy LA-001
Piirt	SSz	21.03.2023		Yleistoleranssit ISO 2768-m	Osan nimi Adjustable Pallet
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa 0,003 kg					Osan numero LA-1003

Appendix 8. Pallet

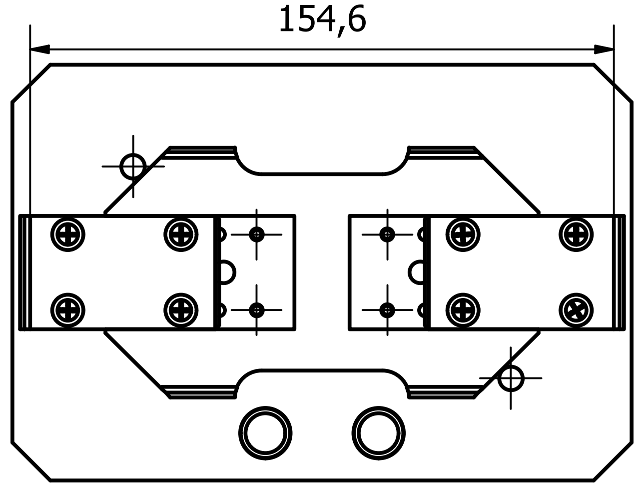




Pos 1



Pos 2



Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino
5	Countersunk flat head screws (common head style) with type H or type Z cross recess.		BS EN ISO 7046-2 H	8	0 kg
4	Adjustable rail		LA-1002	2	0 kg
3	Hexagon nuts, style 1 - Product grades A and B		ISO 4032	8	0 kg
2	Pin		LA-1003	2	0 kg
1	Pallet base		LA-1001	1	0,2 kg

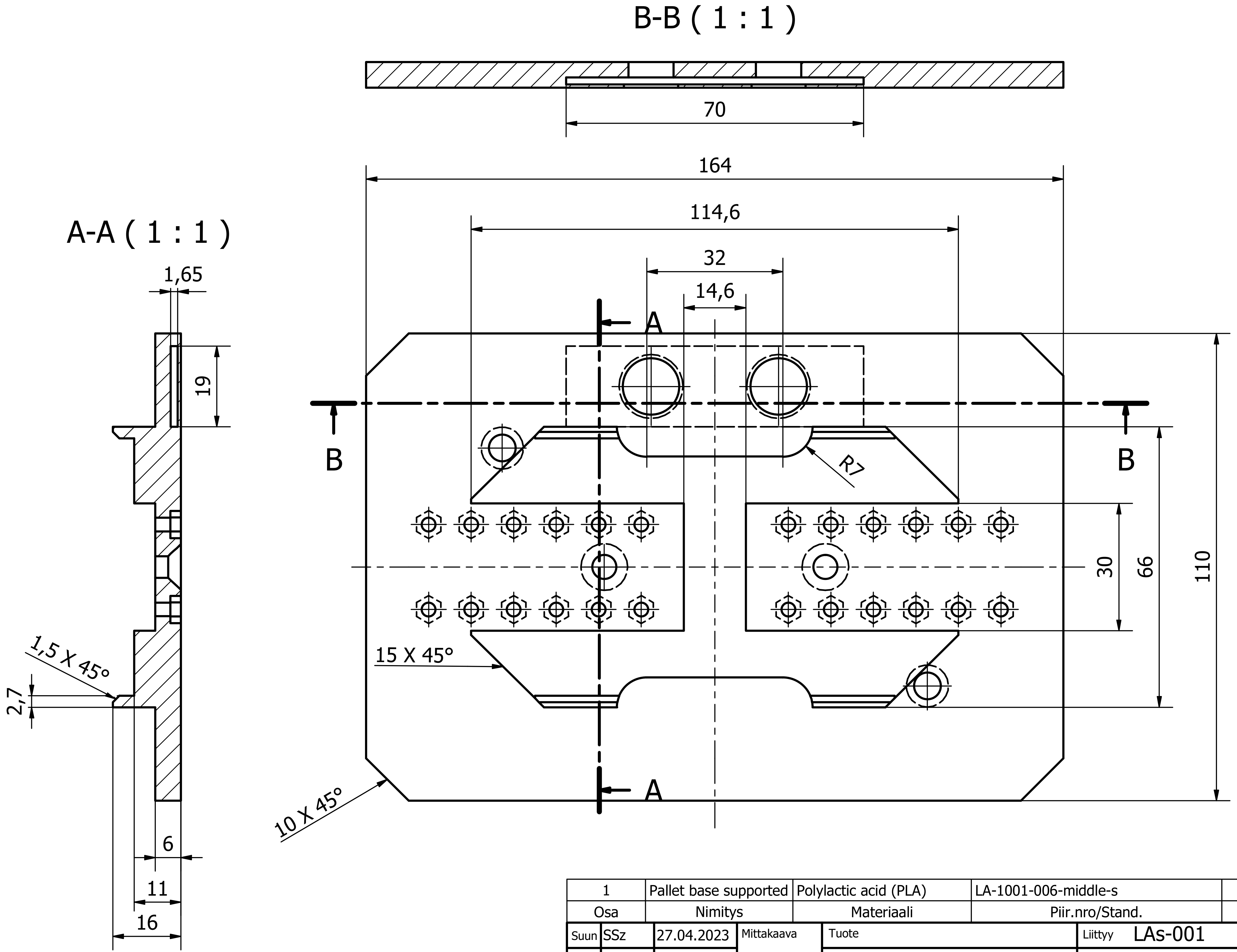
Suun	SSz	13.04.2023	Mittakaava: 2:1	Tuote
Piirt	SSz	13.04.2023		Yleistoleranssit: ISO 2768-m
Tark				
Hyv				

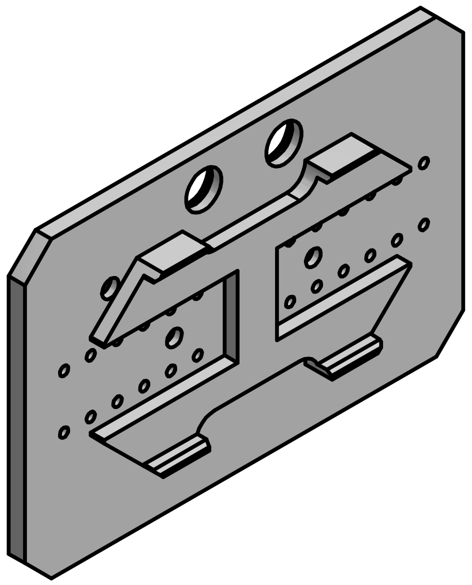
Liittyy	
Osan nimi	Adjustable Pallet
Mikrofilm. pvm.	
Yritys	Lapin AMK
Revisio	
Sivu	1
Osan massa	N/A
Osan numero	LA-001

Appendix 9. Size limitations Festo stations

Station	Device	Purpose	H x W x L
High-bay storage	Workpiece	transportation	30 x 73 x 154 mm
		operation	30 x 60 x 154 mm
	Pallet	transportation	13 x 127 x 180 mm
		operation	6 x 110 x 180 mm
CNC-mill with robotic arm	Workpiece	transportation	30 x 73 x 154 mm
		operation	30 x 60 x 114 mm
	Pallet	transportation	13 x 127 x 180 mm
		operation	13 x 110 x 180 mm
Pick-by Light	Workpiece	transportation	150 x 60 x 154 mm
		operation	80 x 60 x 154 mm
	Pallet	transportation	15 x 135 x 200 mm
		operation	15 x 135 x 200 mm
Camera inspection	Workpiece	transportation	100 x 135 x 154 mm
		operation	20 x 60 x 154 mm
	Pallet	transportation	13 x 135 x 200 mm
		operation	13 x 135 x 200 mm
Cover magazine	Workpiece	transportation	20 x 60 x 200 mm
		operation	6 x 60 x 114 mm
	Pallet	transportation	13 x 135 x 200 mm
		operation	13 x 135 x 200 mm
Muscle press	Workpiece	transportation	20 x 73 x 200 mm
		operation	20 x 73 x 200 mm
	Pallet	transportation	6 x 116 x 200 mm
		operation	6 x 116 x 200 mm
Robotino	Workpiece	transportation	150 x 60 x 154 mm
		operation	150 x 60 x 154 mm
	Pallet	transportation	15 x 135 x 200 mm
		operation	15 x 135 x 200 mm

Appendix 10 1(2). Pallet base supported

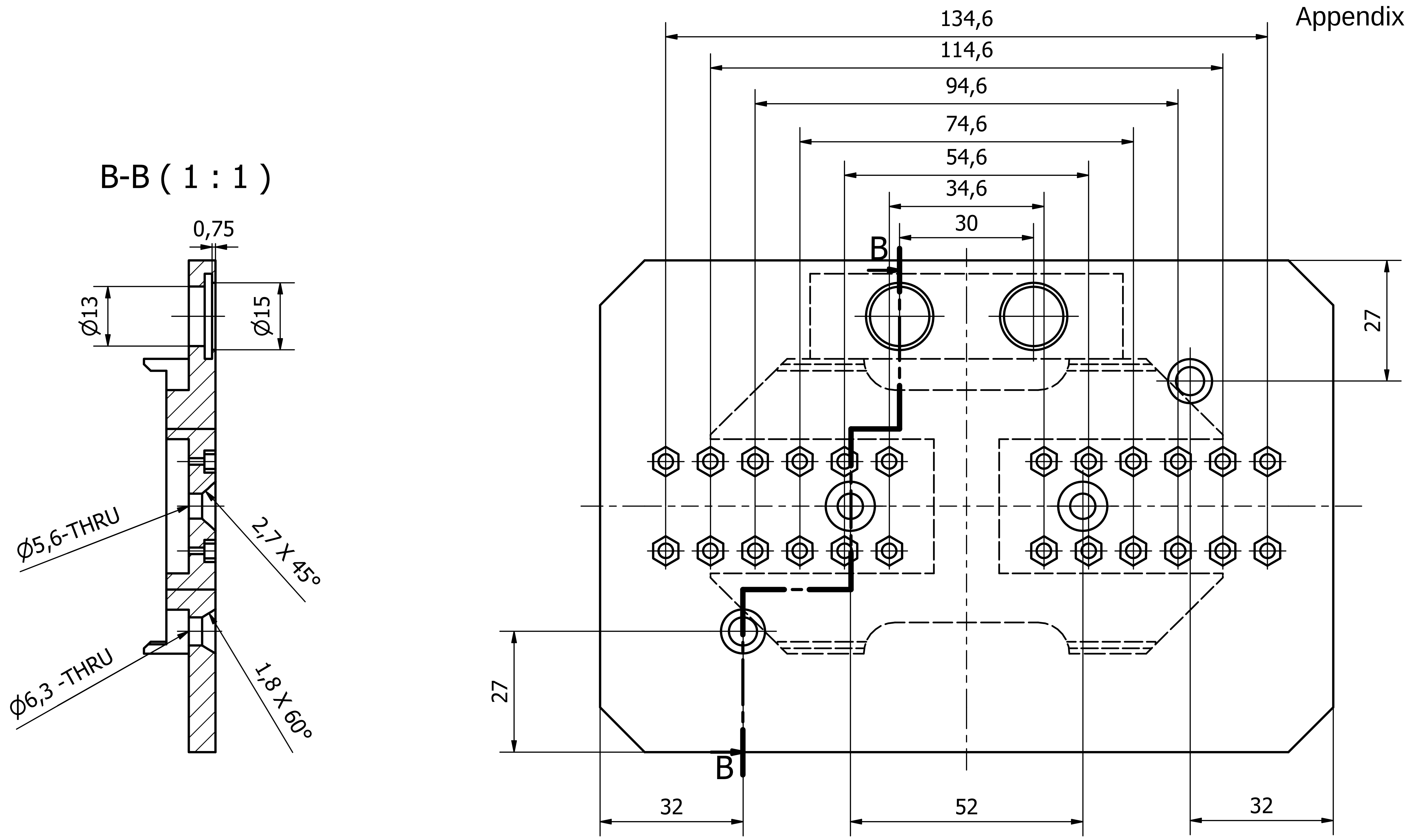




1	Pallet base supported	Polylactic acid (PLA)	LA-1001-006-middle-s	1	0,2 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	27.04.2023	Mittakaava: 1:1	Tuote	Liittyy: LAs-001
Piirt	SSz	27.04.2023		Yleistoleranssit: ISO 2768-m	Osan nimi: Pallet base supported
Tark					
Hyv					
Mikrofilm. pvm.				Yritys: Lapin AMK	Revisio / Sivu: 1/2
Osan massa: 0,152 kg					Osan numero: LAs-1001

Appendix 10 2(2). Pallet base supported

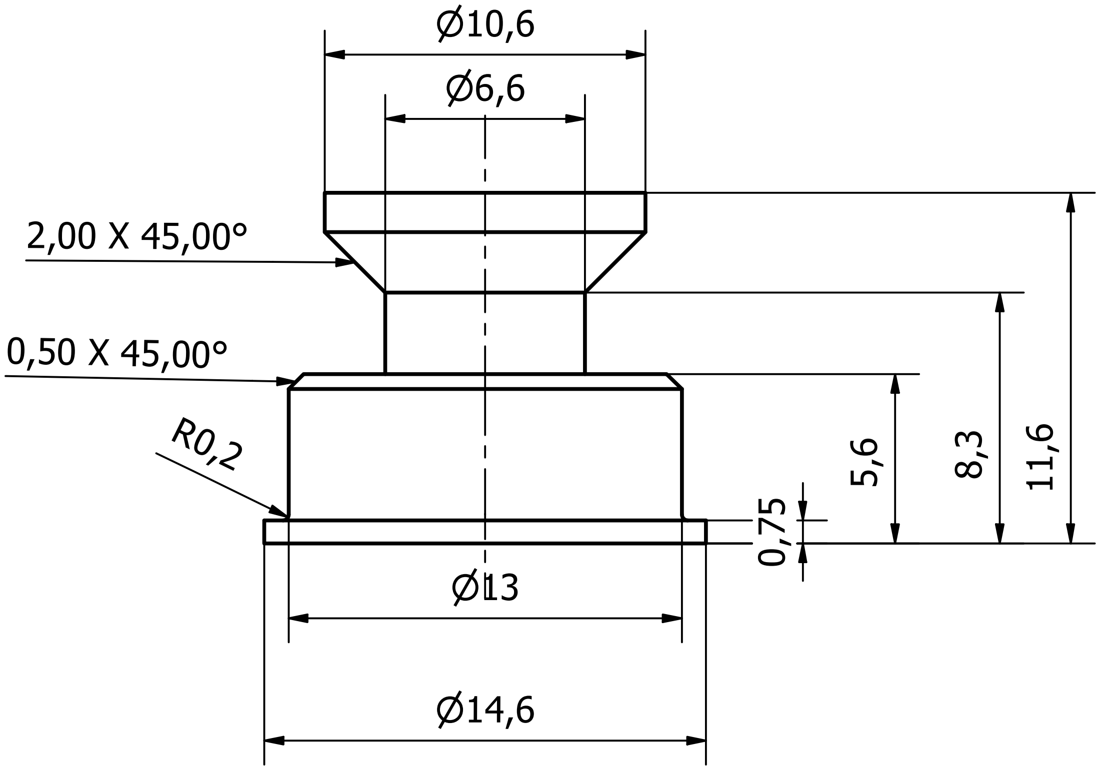


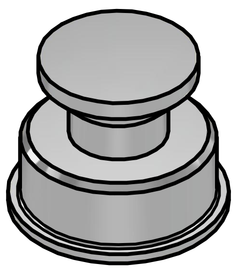
1	Pallet base supported	Polylactic acid (PLA)	LA-1001-006-middle-s	1	0,2 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	27.04.2023	Mittakaava	Tuote	Liittyy	LAs-001
Piirt	SSz	27.04.2023	1:1	Yleistoleranssit ISO 2768-m	Osan nimi	Pallet base supported
Tark						
Hyv						
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio	Sivu 2/2
Osan massa 0,152 kg					Osan numero	LAs-1001

The View is rotated 180° with respect to the workpiece on page 1

Appendix 11. Pin adjusted

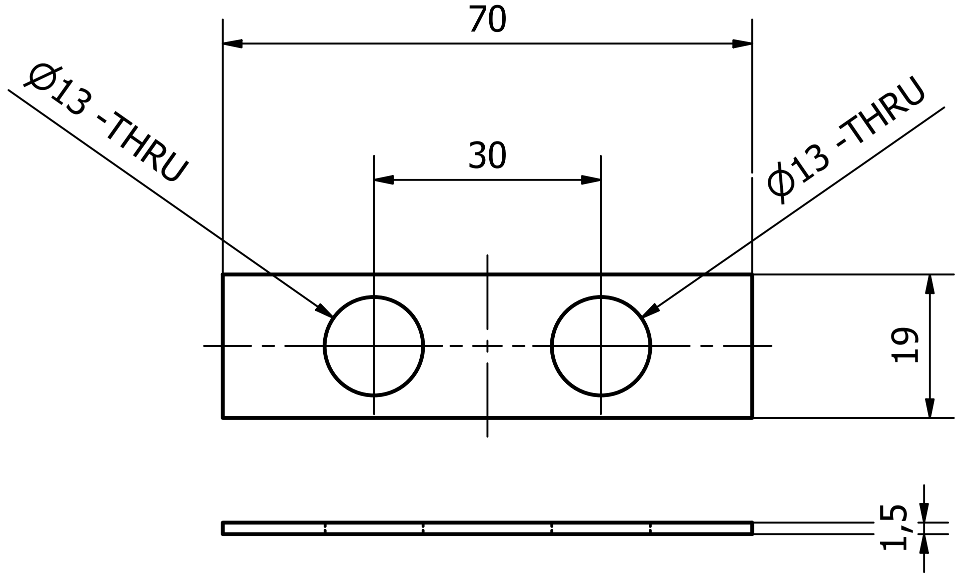


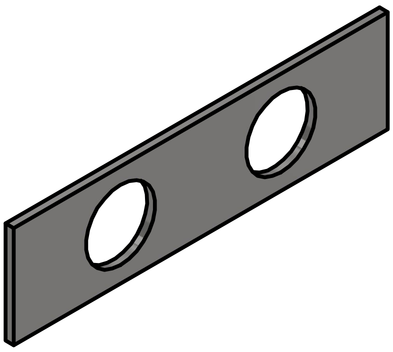


Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino
1	Pin	Aluminium 6061	Pin	1	0 kg

Suun	SSz	21.03.2023	Mittakaava: 4:1	Tuote	Liittyy: LAs-001
Piirt	SSz	21.03.2023		Yleistoleranssit: ISO 2768-m	Osan nimi: Adjustable Pallet
Tark					
Hyv					
Mikrofilm. pvm.				Yritys: Lapin AMK	Revisio / Sivu: 1
Osan massa: 0,003 kg					Osan numero: LAs-1003

Appendix 12. Support metal sheet

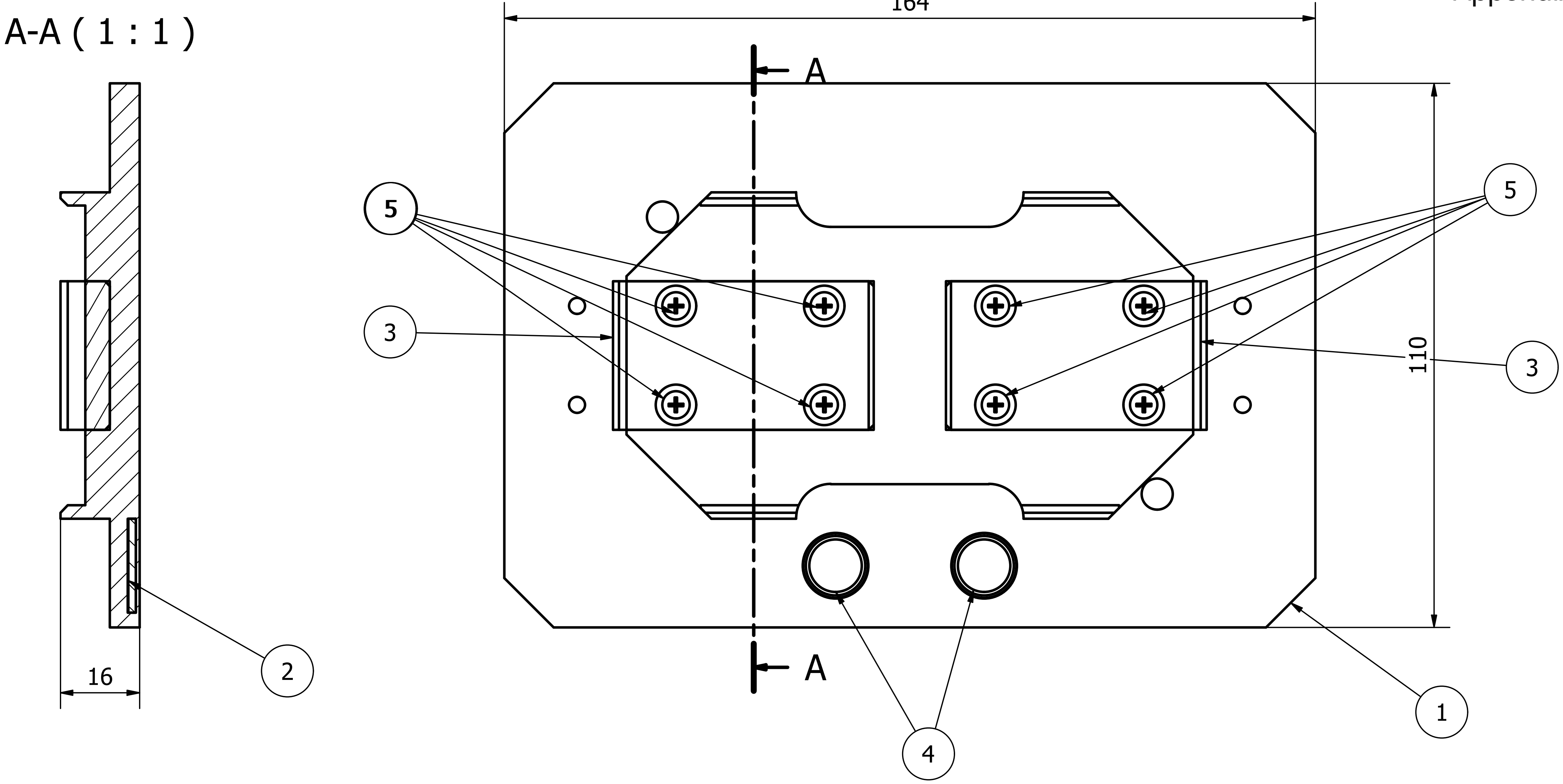




1	Support-sheet	Stainless-steel	LAs-1004	1	0 kg
Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino

Suun	SSz	03.01.2018	Mittakaava	Tuote	Liittyy LAs-001
Piirt	SSz	03.01.2018		Yleistoleranssit ISO 2768-m	Osan nimi Pallet base supported
Tark					
Hyv					
Mikrofilm. pvm.				Yritys Lapin AMK	Revisio / Sivu 1
Osan massa N/A					Osan numero LAs-1004

Appendix 13. Supported pallet



Osa	Nimitys	Materiaali	Piir.nro/Stand.	Kpl	Paino
6	Hexagon nuts, style 1 - Product grades A and B		ISO 4032	8	0 kg
5	Countersunk flat head screws (common head style) with type H or type Z cross recess.		BS EN ISO 7046-2 Z	8	0 kg
4	Pins	Aluminium	LAs-1003	2	0 kg
3	Adjustable rails	Polylactic acid	LA-1002	2	0 kg
2	Support sheet	Stainless-steel	LAs-1004	1	0 kg
1	Pallet base supported	Polylactic acid	LAs-1001	1	0,2 kg

Suun	SSz	30.04.2023	Mittakaava: 1:1	Tuote	Liittyy
Piirt	SSz	30.04.2023		Yleistoleranssit: ISO 2768-m	Osan nimi: Base pallet supported
Tark					
Hyv					
Mikrofilm. pvm.				Yritys: Lapin AMK	Revisio / Sivu: 1
Osan massa: 0,199 kg					Osan numero: LAs-001