THE EXCELLENT ADVANCED MANUFACTURING 4.0

Evidence on performance: Recorded data

Piloting the Advanced Manufacturing workshop 4.0

04

Co-funded by the
Erasmus+ Programme
of the European Union

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

EXAM 4.0 partners:
TKNIKA – Basque VET Applied Research Centre, CIFP Miguel Altuna, DHBW Heilbronn – Duale Hochschule Baden-Württemberg, Curt Nicolin High School, Da Vinci College, AFM – Spanish Association of Machine Tool Industries, 10XL, and EARLALL – European Association of Regional & Local Authorities for Lifelong Learning.

TABLE OF CONTENTS

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Table of figures

Table of figures

Table of figures

Table of figures

Table of figures

Acronyms and Abbreviations

AGV	Automated guided vehicle
AM	Advanced Manufacturing
AR	Augmented Reality
CAD	Computer-aided design
CLF	Collaborative Learning Factory
CNG	Curt Nicolin Gymnasiet
DHBW	Duale Hochschule Baden-Württemberg / Baden-Wuerttemberg Cooperative State University
ERP	Enterprise Resource Planning
HVET	Higher Vocational Education and Training
IIoT	Industrial internet of things
IT	Information Technology
KET	Key enabling technology
LF	Learning factory
MOM	Manufacturing Operations Management
M2M	Machine to Machine
PLM	Product Lifecycle Management
RFID	Radio Frequency Identification
TPE	Thermoplastic elastomers
VET	Vocational Education and Training
VR	Virtual Reality

0 Abstract

This is a report with detailed information evidencing the contribution and information from all partners piloting the EXAM4.0. It contains relevant aspects to the project: evidence of the planning and implementation of the process, main activities, incidents occurred, results obtained, lessons learned. Tables, pictures, videos are available directly in the document or indirectly by links.

1 Introduction

This document details the evidence collected in the performance of the EXAM 4.0 pilot Workshop, providing the data recorded to allow the internal audit of the initiative and verification by the group of experts. The document details the two lines of action that have been followed by the consortium. On the one hand, the technologies and applications in Industry 4.0 that have been purchased or installed during the development of the project. On the other hand, the process of creating the CLF value chain. At the end of the document, the incidents that have existed, the results obtained and the conclusions drawn are summarized.

2 Implementation of Industry 4.0 technologies

One of the main activities of the work package has been the creation of a Collaborative Learning Factory (hereafter CLF) as a testing scenario. During the project, different technologies of Industry 4.0 (i4.0) and different ways of working with these technologies have been analyzed and all this has resulted in the CLF. In the development of the CLF, these technologies, according to their utility, have been distributed in the different parts of the value chain and each VET / HVET has incorporated some of them for the correct operation of the CLF. This section states the key technologies that have been implemented in each VET / HVET of each consortium partner.

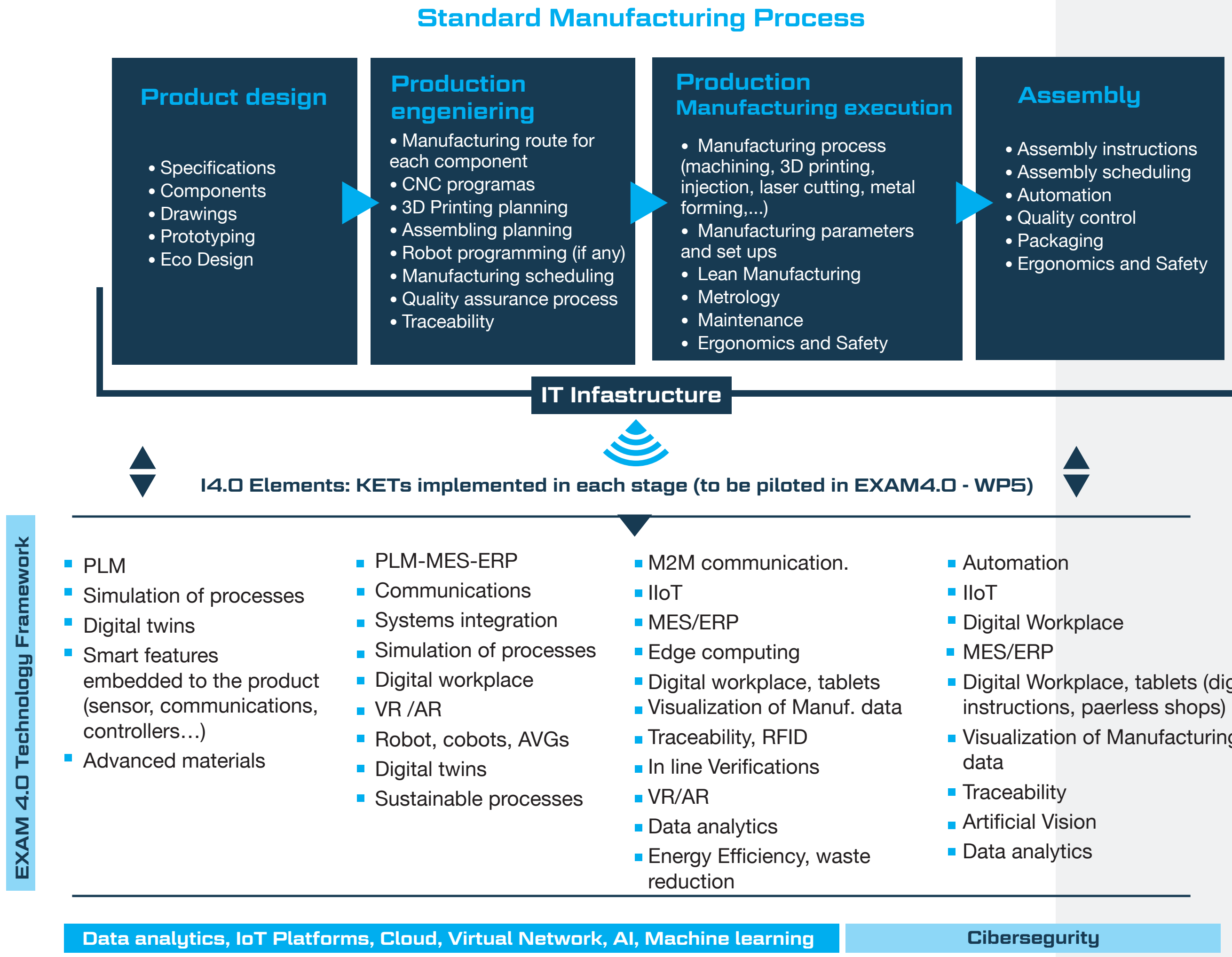


Figure 1: EXAM 4.0 Collaborative Learning Factory (CLF) process and technologies. Source: Authors' creation

In the next section we will describe the way each partner institution has tested and piloted different I4.0 technologies while they were carrying out the CLF.

2.1 Curt Nicolin Gymnasiet

Advanced VR technology and a new 3D-printer were implemented at CNG during the project. The printer uses carbon fiber, resulting in more valuable prints. This printer also works rapidly which is beneficial for prototyping. The new 3D-printer will serve the purpose of prototyping and producing components for the EXAM robot.

Figure 2: Implemented technologies at Curt Nicolin Gymnasiet. Source: Curt Nicolin Gymnasiet

VIRTUAL REALITY / AUGMENTED REALITY

Virtual Reality/Augmented Reality will be used at Curt Nicolin Gymnasiet to create a Digital Twin. Augmented Reality was also used to support a paperless production during the process, hence drawings were displayed digitally in AR as well as being a tool to improve the communication and exchange of information between the partners.

AUGMENTED REALITY	Curt Nicolin Gymnasiet has implemented Augmented Reality as an educational method, this is done in the form of the Microsoft HoloLens 2. Microsoft's Dynamics 365 applications such as Remote Assist and Dynamics guides have been used with the aim to improve education. This software is currently being evaluated at the school and will certainly be used in future education.
REMOTE ASSIST	This application is beneficial to get remote assistance by an expert. The person using the HoloLens calls the expert on Microsoft Teams through Remote assist when needed. The HoloLens has an integrated camera at the front of the headset and the expert will therefore see the same things as the person wearing the headset (first person). The headset also has an integrated microphone and audio, making it hands-free. The expert can put additional objects that will appear in the view of the headset for the user, thus appearing in real time and extending the reality for the user.
DYNAMICS GUIDES	Dynamics guides are used to give visual descriptions via HoloLens. They extend the reality for the user and give visual instructions in the form of darts, circles, text, etc. Visual learning and on-site training are often a good way of learning.

Curt Nicolin Gymnasiet is also implementing key enabling technologies to be able to organize meetings with local SMEs customers. We are developing something we call a "Nod", a physical space where local companies can virtually meet their customers. In this way companies and partners can physically meet their customers virtually to discuss products, designs and general approaches without having to travel and meet their customers overseas. Companies have realized the power of digitalization, there is no time to hesitate. At Curt Nicolin Gymnasiet we are taking digitalization, virtualization further to ensure that our partners keep up with the market. This could be a beneficial tool for the EXAM 4.0 platform partners.

3D PRINTING

Curt Nicolin Gymnasiet optimized and updated the 3D-printer for it to be adapted to Industry 4.0 requirements and to make it a valuable tool for the EXAM 4.0 project. The 3D-printer can send signals to a PLC-system and a collaborative robot is programmed to collect the 3D-printed parts from the printer when it is finished. This process is not completely ready for automatic production, but it will soon be.

Figure 3: Implemented technologies at Curt Nicolin Gymnasiet.
Source: Curt Nicolin Gymnasiet

The 3D-printer is also connected to the internet and has an integrated camera, making it possible to control it remotely. This is very useful when the staff are working from home, for example during the Covid-19 pandemic. The robot is programmed to both start the printing and empty the machine as well as to change the building plate, this is all possible to maneuver from the distance. This printer is used in an educational environment, therefore there are almost never any classified parts that are produced, it is therefore possible to send the files over the Internet without the risk of losing secret information. However, the ethernet cable can easily be removed if the parts are classified. In that case, the printer needs to be started manually and the files must be exported with a SD-card (memory-card).

2.2. CIFP Miguel Altuna LHII

The section in which Miguel Altuna has worked the most has been the manufacturing part. That is why the technologies that have been applied have been focused on it. At Miguel Altuna we have tested the following technologies: M2M communication, tools control & traceability, Cobots at production and AVGs at production and Virtual Desktops.

M2M COMMUNICATION.

M2M refers to technologies that enable the automated exchange of information between machines in the advanced manufacturing labs at Miguel Altuna. Through the implementation of advanced communication technology, integrated sensors and data monitoring systems, it is possible to transmit meaningful information from the entire lab, forming the interface between the physical and virtual world. Through the implementation of PLCs in conventional machines, data transfer systems, traceability systems for both people and tools, it has been possible to implement an efficient student management system.

M2M communications allows the set-up of Digital workplaces for students.

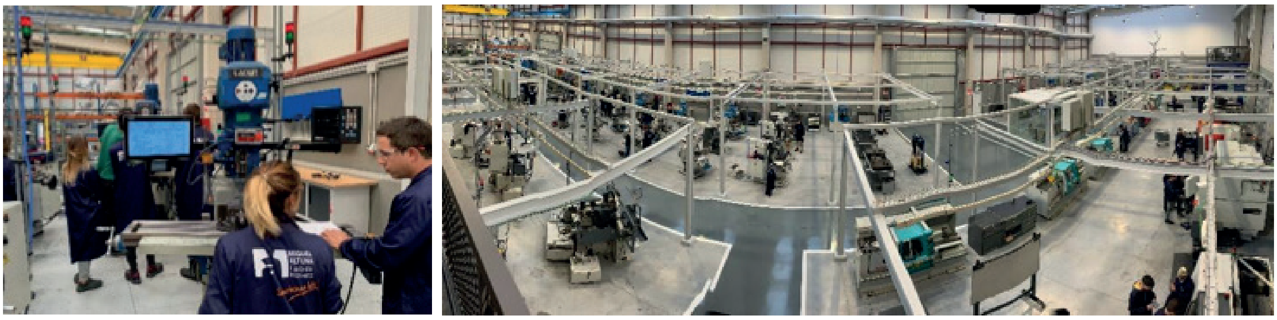


Figure 4: RFID card, Tools with RFID and RFID readers at Miguel Altuna. Source: Miguel Altuna

TOOL CONTROL & TRACEABILITY

Students and staff at Miguel Altuna are using RFID lectors to assure tool control. By using two different types of RFID systems, it is possible to control both machine booking and tools used.

The identification of people is possible by using different login points. All the equipment and machines of the lab are ready for RFID reservation.

Figure 5: RFID card, Tools with RFID and RFID readers at Miguel Altuna. Source: Miguel Altuna

We have developed our own IT applications to manage the tool-control system and traceability. All the data is stored in our servers. For Data analytics Microsoft Power BI solution is used.

COBOTS AT PRODUCTION

Cobots are used in mechanical manufacturing for different purposes. Cobots are user-friendly robots, easy to program and do not require specific protective measures. We have tried them in different applications in the labs since they can be easily transported from one phase of the process to another. Application has been: Feeding of parts to the CNC machines; handling of parts in assembly stations. Integration of Cobot with other elements (AVGs, smart access tools, scanners for inverse engineering, vision cameras).

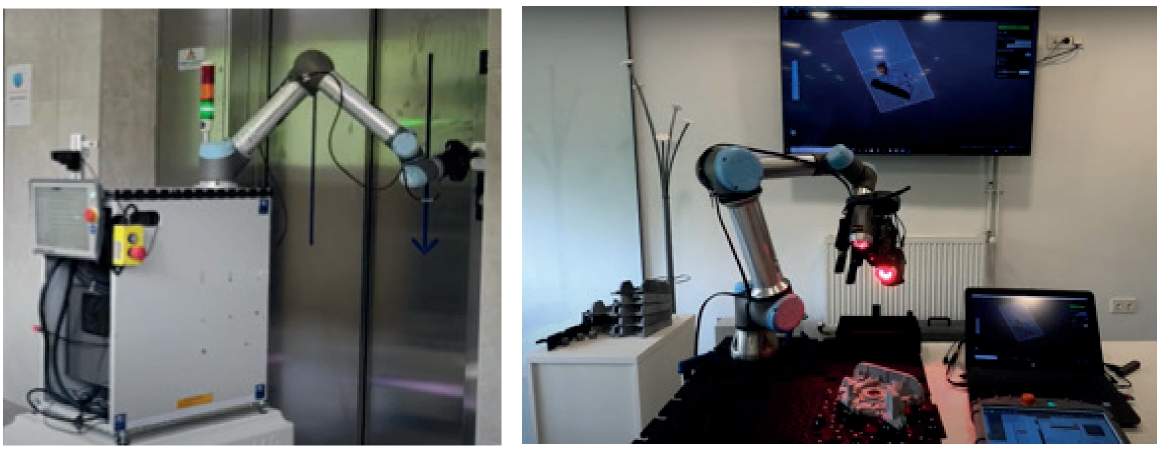


Figure 6: Cobots at Miguel Altuna. Source: Miguel Altuna

AVGS AT PRODUCTION

An Automated Guided Vehicle or Automatic Guided Vehicle (AGV) has been placed in the manufacturing lab. The AVG used is a Mobile Industrial Robot (MIR)-100.

The MIR moves autonomously within the lab. Thanks to a positioning system and a set of sensors. The positioning is based on CAD files of the building that are directly loaded to the robot. Some fine tuning is made by a web-based interface programming (no prior programming experience is required). The robot's mission can be easily adapted using a smartphone, tablet or computer connected to the network.

Concerning the movements around the lab, with built-in sensors and cameras and sophisticated software, the MiR100 identifies its surroundings and takes the most efficient route to its destination, safely avoiding obstacles and people. No inflexible wires or sensors have been installed to alter the lab's facilities.

The MIR100 also communicates with UR cobots placed both on the top of the MIR or in a nearby workplace.

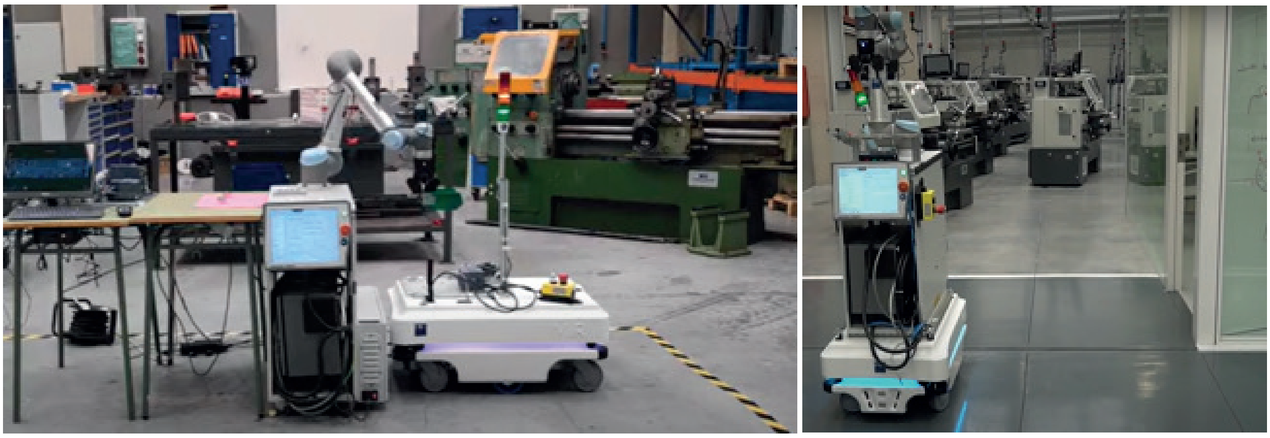


Figure 7: AGV robots at Miguel Altuna. Source: Miguel Altuna

VIRTUAL DESKTOPS

Virtual desktop services are in place at Miguel Altuna. Hosted on a local server, virtual desktops have been set up for students and staff. Virtual desktops are preconfigured images of operating systems and applications in which the desktop environment is separate from the physical device used to access it. Users can access their virtual desktops remotely and with any device.

During the piloting stage, the server was set up and all the installations and infrastructure were made to have the virtual desktops operative. We have defined different desktops for different users, and we have installed the relevant applications, with their respective license numbers.

Applications (software) may have a different number of users, so the virtual desktop's partitions have been prepared for this purpose.

2.3. Da Vinci

Like in industry, Da Vinci has its own Maker Space, which is part of Davinci's CLF, located near the IOT/3D print lab. We have a 3D printer booth, in which printers are fed with filament. Filament can be made of a variety of materials, like PET, PLA, Nylon, even concrete or aluminum.

Figure 8: 3D-printer booth. Source: Da Vinci

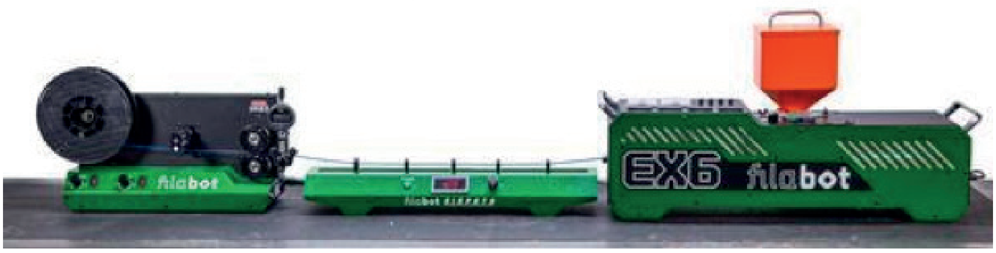


Figure 9: The Filabot machine transforms pellets into filament for 3D printers. Source: Da Vinci

2.4. DHBW

ROBOTS

The DHBW on Campus Heidenheim has a Focus in Robotics and Structural Analysis. In two labs we have a collection of Industrial Robots, Collaborative Robots and some mobile Robots.

Figure 10: Robots at DHBW. Source: DHBW

COLLABORATIVE ROBOT

The 7-Axis Sawyer Robot is a collaborative Robot with a simple Icon based programming Interface. Pick and place Tasks could easily be taught. It has no high safety requirements in operating with students. The web Interface and the plugged-in camera make it possible to integrate the robot into a CPS system and especially into our CLF.

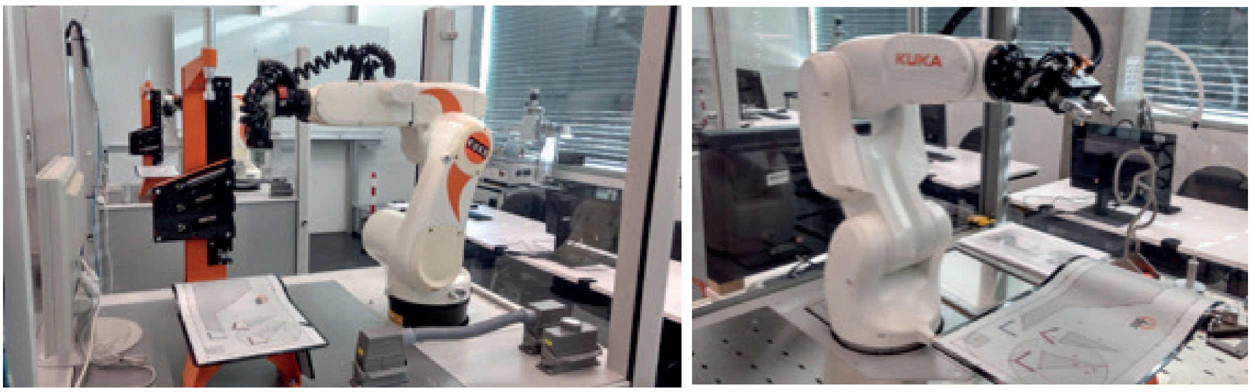


Figure 11: Kuka KR5-Six R650 and kuka Agilus KR 6 R700. Source: DHBW

The 3 industrial Robot Training-cells were updated with a new Kuka Agilus Robot. These cells are used for the Robotics lab which includes teaching and safety issues.

Figure 12: Cobots. Source; DHBW

UR 5 ROBOT

A collaborative robot for projects and Teaching students. The Robot is based on a Trolly to be very flexible. It could be used in each classroom.

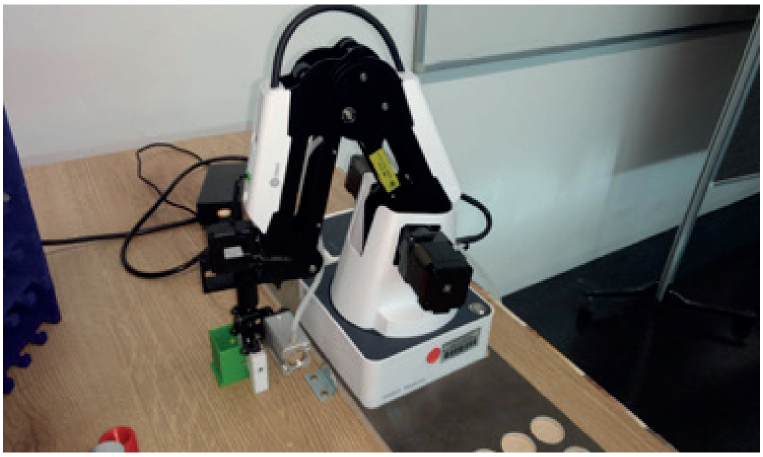


Figure 13: Dobot Magician assembling the EXAM robot. Source: DHBW

DOBOT MAGICIAN.

A simple small robot for education and projects. It has a very simple programming API and could be easily integrated in IOT projects.

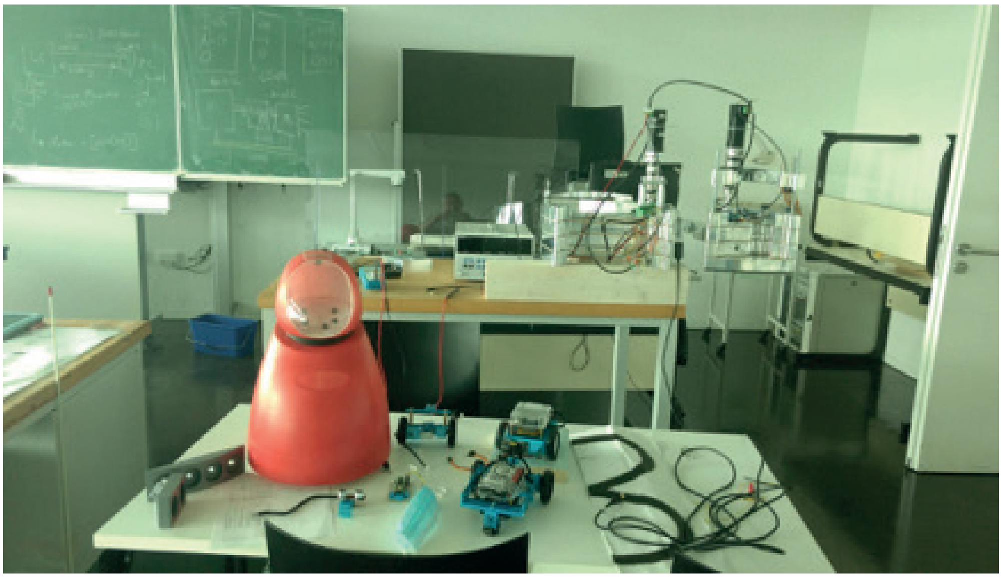


Figure 14: Mobile Robots based on Makeblock ranger. Source: DHBW

A very simple platform for mobile robots to take the first steps in mobile robotics using several sensor systems. The cobots use the Arduino platform and have Bluetooth communication, which enables them to be integrated in IOT Projects.

MODULAR PRODUCTION SYSTEM AS STARTUP FOR CLF

A simple small robot for education and projects. It has a very simple programming API and could be easily integrated in IOT projects.

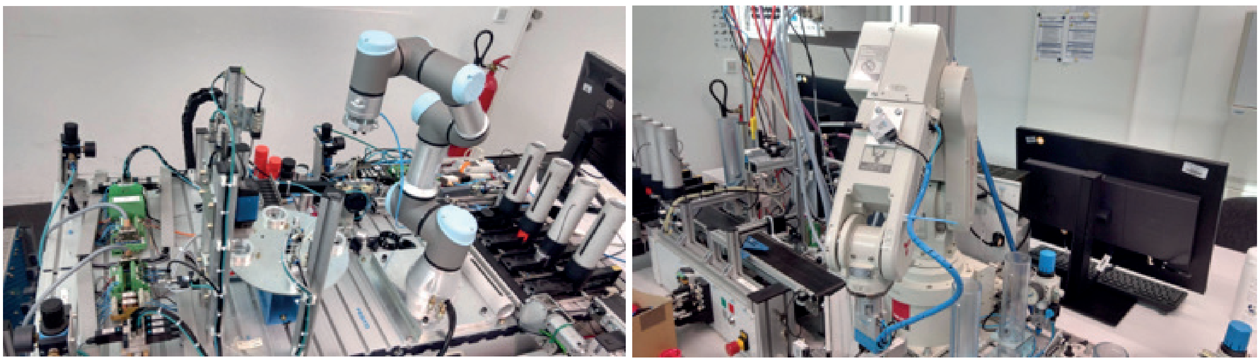


Figure 15: Festo Modular production system with UR3 robot and Mitsubishi Robot RV-2SD. Source: DHBW

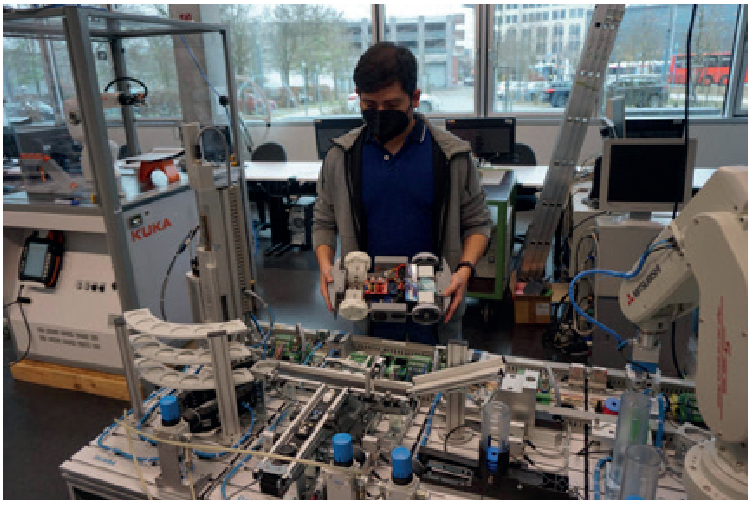


Figure 16: Modular production system as part of the CLF. Source: DHBW

The drive systems should be preassembled in this modular system. Starting from an order for a special configuration, different types of drives like Stepper Motors or DC- as well as BLDC-Motors could be combined with simple Wheels with or without steering and suspension. Omni Wheels or Mecanum Wheels with a diameter up to 80mm could be used and assembled in the CLF.

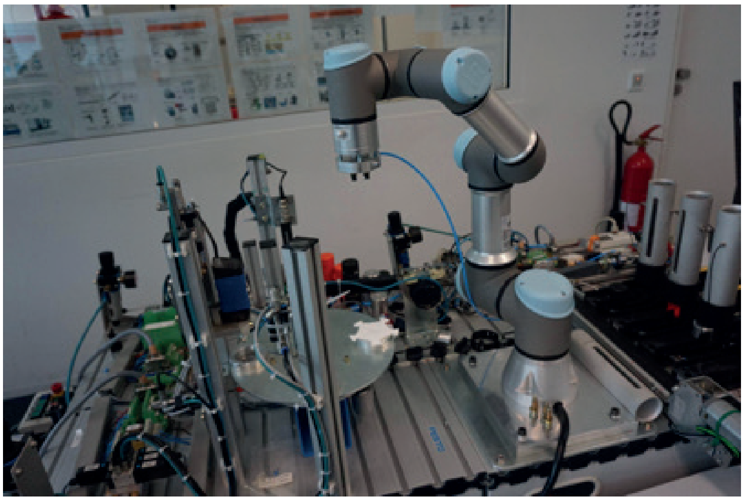


Figure 17: Modular production system from Festo with UR3 Robot.
Source: DHBW

It is possible to pre assemble smaller components in this equipment. Especially flexible and modular assembly of Sensor systems will be performed.

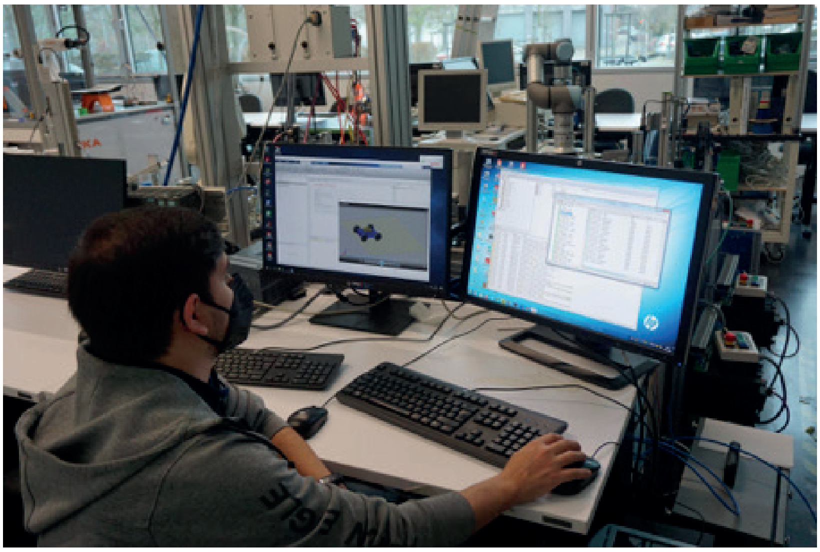


Figure 18: Web connection with OPC server and MES layer for the MPS system. Source: DHBW

The central System contains the Wonderware Intouch Software as a SCADA System. I adUA server and support the MQTT-Protocol with a coupled Thingsboard-IO server.

Product automation will be used during the assembly of the robot, to automate the process.

RESEARCH LAB

Structural Analysis and Reverse Engineering.

Figure 19: 3D scanning cell for reverse engineering. Source; DHBW

In the lab for research projects several technologies for reverse engineering and structural analysis were combined.

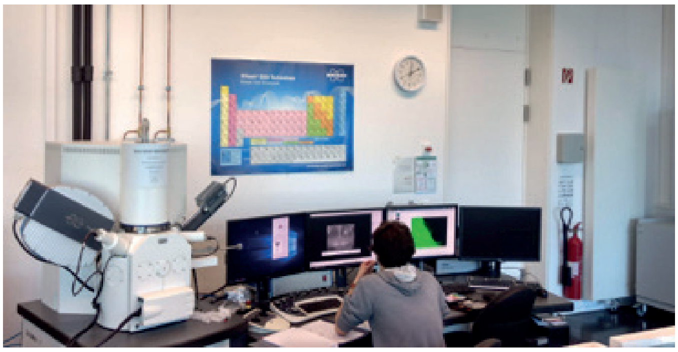


Figure 20: Rater electron microscope Zeiss, Brucker. Source: DHBW

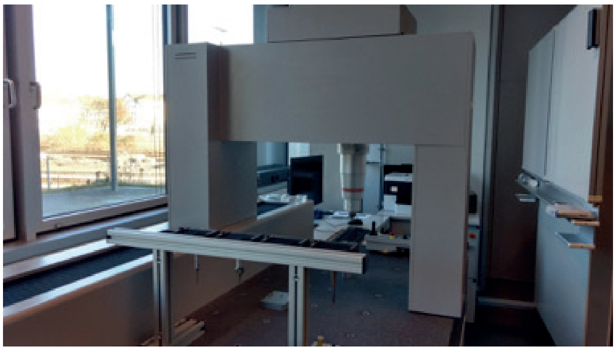


Figure 21: Coordinate measuring machine Zeiss UMC500. Source: DHBW

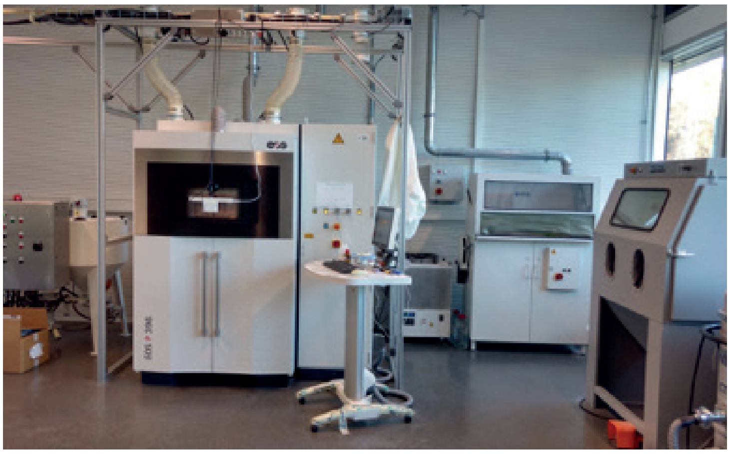


Figure 22: 3D printer EOS P 396 Lasersinter. Source: DHBW

This machine will be used for quality control of the components built in the CLF. The Control software Calypso will also be integrated in our CLF.

Most of the parts for the EXAM Robot could be manufactured in this System.

2.5. TKNIKA

IOT

In technology, IoT is being worked on from different points of view. On the one hand, in I4.0 Lab we have incorporated SMC s SIF-400 Learning Factory. SIFMES-400 allows the user to control and manage the SIF-400 system by storing and monitoring all process data. In the connected company, customers, manufacturers, and suppliers are communicated and connected thanks to some of the functionalities of this software (SMCtraining, 2021).

Figure 23: Didactic equipment from SMC for industry 4.0 SIF-400. Source: Tknika

It is structured in four blocks:

- **Management:** production orders, planner, launcher, inventory, logistics, customers, maintenance, database, and data analysis...
- **Movements:** physical layout, logical layout, system reset and traceability of movements...
- **Visualization:** system status and alarms: maintenance, energy, analysis and statistical process control...
- **Administration:** Database, role, and disturbance management (Instructor)...

This software represents a major step forward in digitalization and smart manufacturing due to the fundamental role played by this technology in the new industrial reality.

On the other hand, an IIoT gateway (Hardware & Software) has been developed allowing us to communicate with any industrial controller that speaks OPC UA, Modbus or S7 protocol. The gateway, called IoM2040, has been developed based on a Raspberry Pi 4, and a software package, called IoMBian (Raspbian Lite, Node RED, Mosquitto, MQTT client, Monit, Samba, etc). Everything has been designed to be easy to implement. More information about these projects can be found in the following links:

- **IoMBian**: https://github.com/Tknika/iombian
- **IoM2040**: https://github.com/Tknika/iom2040

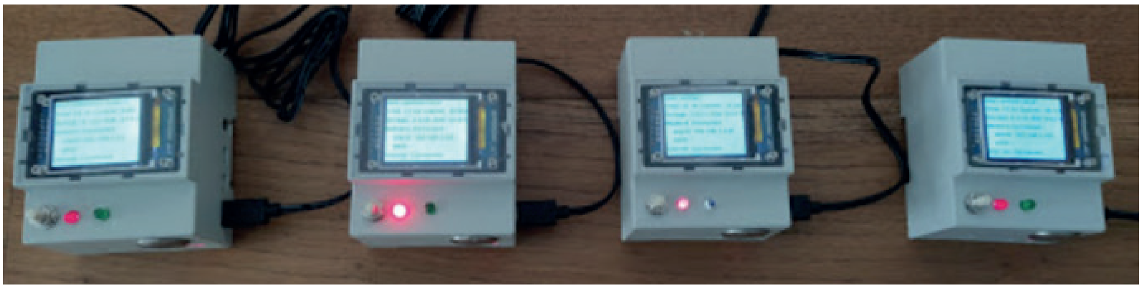


Figure 24: IoMBian and IoM2040. Source: Tknika

DATA ANALYTICS

In the data analysis part, an IoT platform has been deployed in the cloud to provide service to the different CLFs. For that purpose, Tknika is testing the IoT platform Thingsboard. ThingsBoard is an open-source IoT platform for data collection, processing, visualization, and device management. It enables device connectivity via industry standard IoT protocols - MQTT, CoAP and HTTP and supports both cloud and on-premises deployments.

In our IoT lab, which is a scaled learning factory environment, ThingsBoard platform provides services such as:

- Provide devices, assets, and customers, and define relations between them.
- Collect and visualize data from devices and assets.
- Analyze incoming telemetry and trigger alarms with complex event processing.
- Control devices using remote procedure calls (RPC).
- Build workflows based on a device life-cycle event, REST API event, RPC request, etc.

- Design dynamic and responsive dashboards and present device or asset telemetry and insights to the customers.
- Enable use-case specific features using customizable rule chains.
- Push device data to other systems.

Figure 25: Data analytics dashboards. Source: Tknika

VIRTUAL REALITY & AUGMENTED REALITY

Different VR solutions have been tested. We are testing Immersive technologies and its potentialities. There are several applications in advanced manufacturing where this technology can be applied.

Figure 26: Student in learning in Virtual Reality. Source: Miguel Altuna

Demonstration of VR immersive room to young students within the STEM Open Day activities at Miguel Altuna's facilities.

Among the integrated software and hardware that Tknika uses the following tools and devices can be found:

- **Soldamatic:** for welding simulations. Soldamatic IE is applying new technologies like AR/VR to enhance the learning process and use real welding equipment to develop skills and muscle memory. It applies gamification to improve the motivation of trainees, personalized learning to adapt to their personal needs and green & safe technology to reduce the risks and pollution.

Figure 27: Welding VR in Tknika. Source: Tknika

- **SimSpray:** for painting simulations. It is a VR spray painting and coatings system used by industries and schools worldwide to enhance their training programs. SimSpray is easy to use and helps your programs train quicker, safer, and more cost-effectively

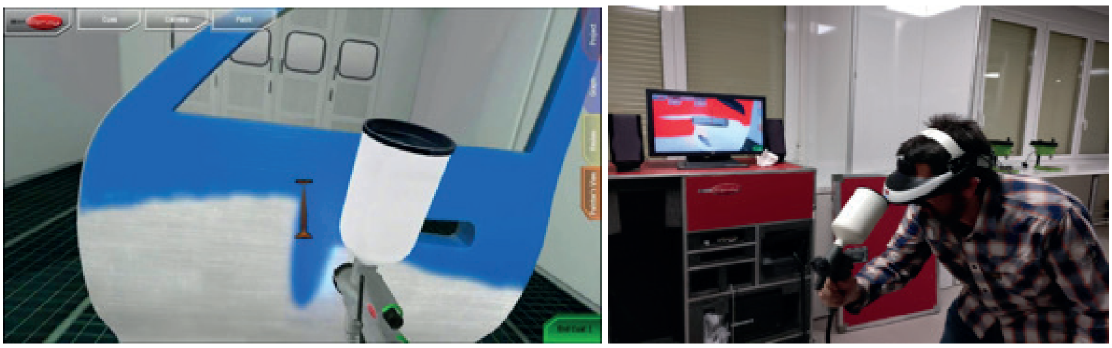


Figure 28: Painting VR in Tknika. Source: Tknika

- **Innvison and InnXr:** for VR meetings in different cities. It helps to meet the needs of the customers through 3D content development for virtual and immersive reality
- **Some HMD:** Oculus quest2, HTC vive, Oculus Rift and others

Figure 29: VR equipment. Source: Tknika

- **Some AR and XR headsets:** Microsoft HoloLens 1 and 2

Figure 30: Microsoft HoloLens AR Equipment. Source: Tknika

- **Unity**: as a development IDE. Unity is a multiplatform engine for video game development. In other words, it allows you to develop games for different consoles and devices from the same base, without having to create it from scratch for each platform.

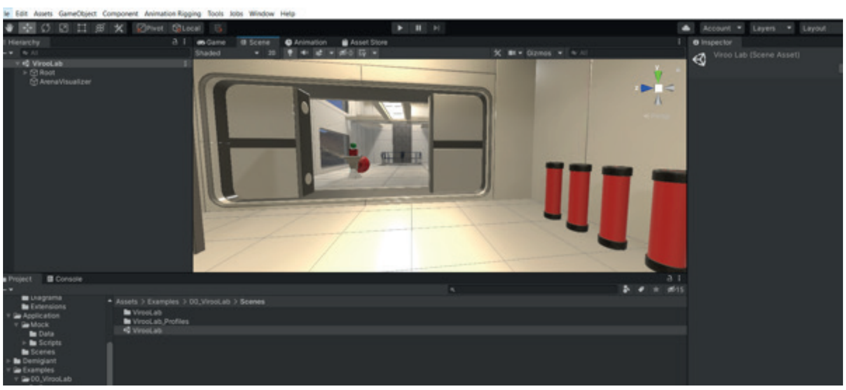


Figure 31: Space for VR designed in Unity. Source: Miguel Altuna

Being able to compile for different platforms, it allows creating video games enabled for web, mobiles, consoles, smart TVs, and even virtual and augmented reality devices.

- **Blender:** as modeling, sculpting and animation software
- **Motion captor:** for body tracking and movement capture

REVERSE ENGINEERING

Reverse engineering has been introduced in Tknika´s IKASLAB together with Additive Manufacturing technologies, as both technologies share common advantages and combine perfectly in certain applications.

Digitalization and replication of work pieces on complex surfaces, fast prototyping: these processes and features need the combination of both technologies to develop projects properly.

Figure 32: I4.0 corner in Tknika. Source: Tknika

In the figure above Tknika's scanning corner can be seen. It is part of the IKASLAB Project's laboratory. Scanners from left to right: Creaform Go!Scan Spark, Creaform Handyscan 700 and Solutionix Rexcan CS+. All those scanners can be used by students from Basque VET System.

The software's used in Tknika are:

- **Ezscan:** scanning and processing of cloud of points for Solutionix Rexcan CS+ scanner.
- **VX Elements:** scanning and processing of cloud of points for all Creaform scanners. It Comes together with VX Model to develop a reverse engineering process and VX Inspect, which allows contrasting a reference model part.

- **Polyworks:** advanced industrial inspection software that combined with a handheld scanner can help in part inspection after or during a manufacturing process.

- **Geomagic Design X:** complete reconstruction of geometries beginning from a scanned part.

CYBERSECURITY

Tknika's Cybersecurity Factory Lab has been working on different scenarios.

On the one hand, there are the IT related scenarios, which consist of an IT zone and a honeypot. In the IT zone, there is a rack with firewalls, switches and 3 PCs used to research the vulnerability of IT systems, to train in the creation and development of secure IT systems. The honeypot zone is to do research on what types of attacks an exposed device can get, where they come from, and how to mitigate them.

Besides those specific branches, the basics and good usage of the Internet can be taught in any HVET/VET cycle to avoid information loss, ransomware, virus, malware…

To achieve all of this, different software is used, such as:

- Proxmox Virtual environment
- VMWare
- VirtualBox
- Modern Honey Network
- Visual Studio 2019
- PaloAlto Academy
- Wireshark
- Kali

On the other hand, we have the industry and automation related scenarios, the Omrom PLC area and the Siemens PLCs area.

Main lines of action planned for the next year are the following:

- Development and implementation of a CyberRange space.
- Social engineering
- Secure remote accesses
- Secure coding
- SIEM Tools

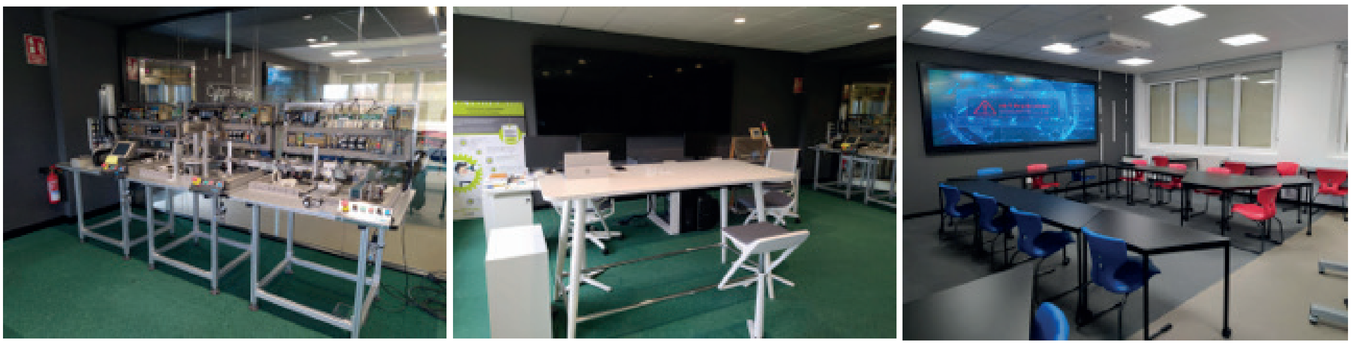


Figure 33: Cybersecurity facilities at Tknika. Source: Tknika

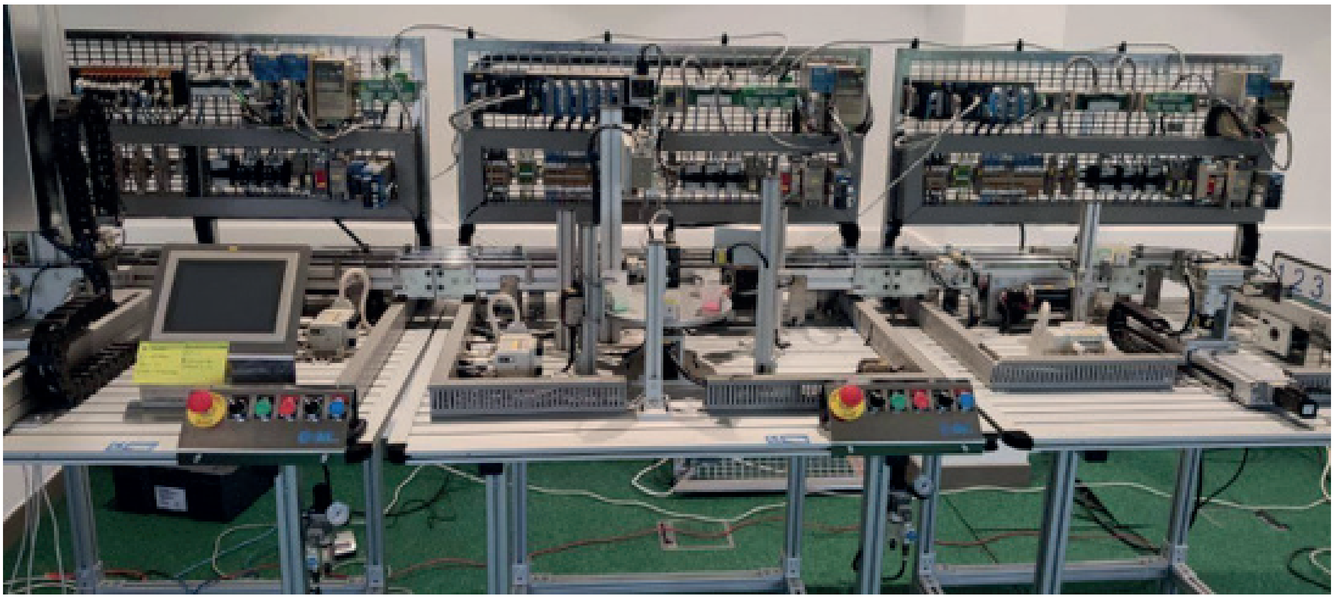


Figure 34: Omrom PLC area. Source: Tknika

Usually automation elements were isolated, but Industry 4.0 and remote assistance, among other factors, have forced these systems to be connected to the network. Due to the lack of updating the automated systems, industry and automation related students should/must be aware of the danger and take action to protect them.

Overall, all IT systems must be protected. Not only the ones that are in offices or server rooms but also in industrial machines HMI or Scadas.

In order to achieve all this, different software is used, such as:

- TIA Portal
- Cx One

DIGITAL TWINS

One of the objectives of the Tknika digital twin lab is to create a digital twin of the workshop equipment to allow the total simulation of a real production process. The SIF-400 teaching team is working on this aspect, a SMC model that emulates a highly automated smart factory, including technologies related to Industry 4.0, advanced manufacturing concepts and the reality of the connected company.

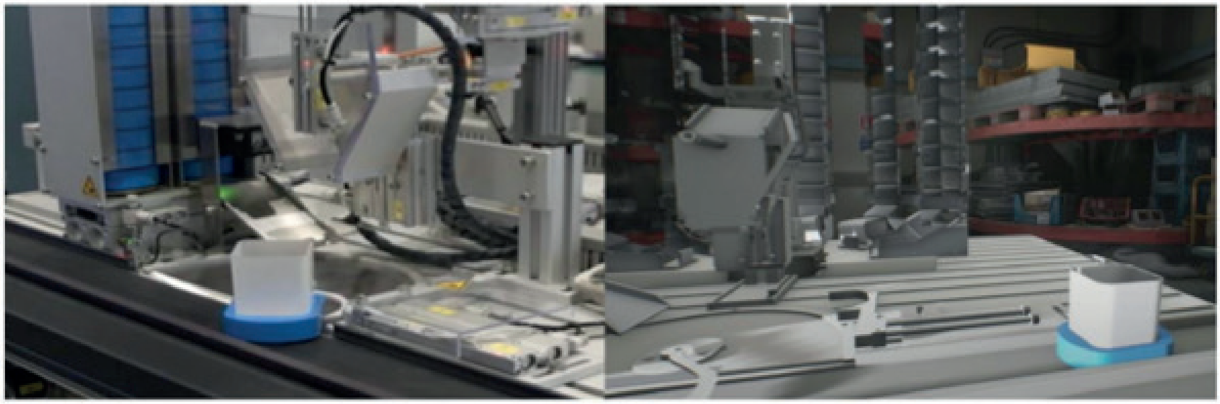


Figure 35: In the left the real machine and in the right the digital twin of the SMC SIF400 machine. Source: Tknika

3 EXAM 4.0 Collaborative Learning Factory

The EXAM 4.0 partners combined the labs from each center to create a collaborative learning factory. This learning factory is to be used for three main purposes.

1. To provide an industry 4.0 learning environment usable by future partners of the platform.
2. To pilot the implementation of advanced manufacturing key enabling technologies.
3. Enhance the collaboration among labs in different locations through the production of a common product. To show the concept of the CLF by producing the EXAM robot.

Each center implemented a certain number of technologies in their lab, ensuring that all relevant technologies were covered. All centers also contributed to the production of the EXAM robot that was created within the CLF. The partners had a collaborative approach, combining the labs from the different centers into one Collaborative Learning Factory. With assistance from the implemented technologies each partner contributed to the CLF and production of the robot with their core business, but also supported the other activities in the production chain. The CLF approach ensures quality exchange of data and information between the partners, making it a high-end education environment.

3.1. Product Design

To implement all the technologies and work throughout the value chain, it was necessary to develop and produce a common product. The product to be produced in a LF is an important decision, as it must provide space for the students to develop a certain number of competences during its production cycle.

The product chosen is a Mobile Robot System. The robot will be equipped with electronics and a series of sensors to ensure its autonomous mobility and control. Physically, the mobile robot must be suitable to be divided into sub-assemblies to distribute the manufacturing tasks in different labs and the final assembly at a specific location. The selected subsystems are the following: Drive systems. Chassis. Steering systems, electronics and sensors, control application, and communications.

The product design covers mainly the functional aspects leaving the aesthetic part as of minor importance. As for the customizable side, the product may be customized to a certain extent. To achieve it, the available motion systems will be Omni wheels, mecanum wheels and standard wheels. Some color options will be available for 3D printed components.

Among the functionalities, we have foreseen that the mobile robot can support a certain load to place elements such as cobots, cameras, part containers etc. on top of it in the future. So those mechanical specifications must also be considered.

The size of the robot will also be limited. As some partners will use their current automation LF to assemble some sub components of the robots, the maximum size of those sub-assembles are limited by the specifications of those LFs.

For the design phase, instead of distributing tasks among the partners and assigning the complete product design to one of them, we have decided to carry out all phases collaboratively including design. In this way, we could make the simile with a company, where we would work from the design phase, process engineering, manufacturing and its subsequent assembly and shipment. Having to work the entire product would give us information to see what IT we would need within our process engineering. This approach has forced us to implement collaborative design tools. We have analyzed product life management tools among others.

To start with the design phase, after different meetings and analyzing the characteristics (size, functions ...) that our robot had to have, a team responsible for the design was created. The role of this team would be to collect feedback from the consortium and materialize the specifications of the robot.

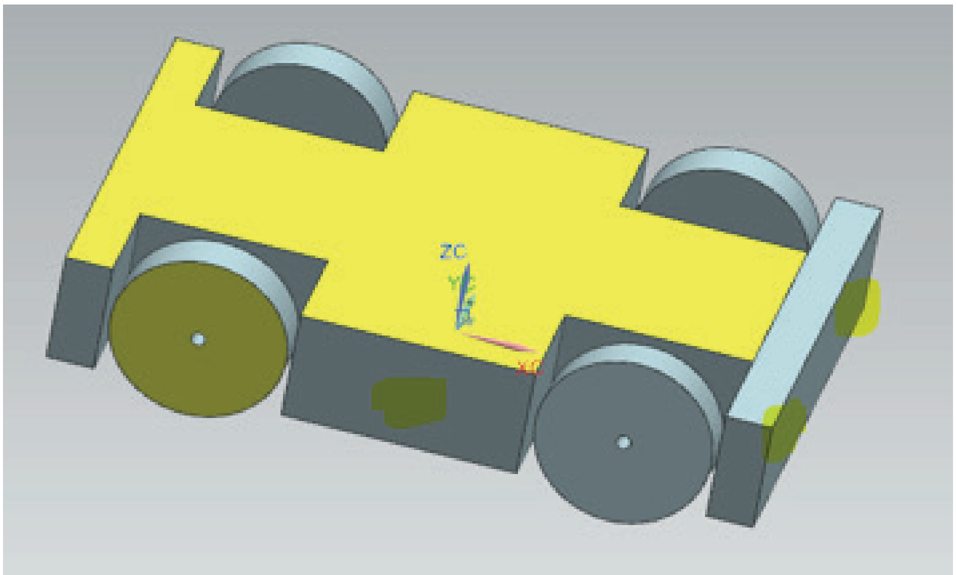


Figure 36: First appearance of the robot. Source: Curt Nicolin Gymnasiet

Numerous meetings were held by the technical experts' group regarding the design of the robot. The main topics that were discussed during the meetings were the appearance of the robot, the dimensions of all included components and the placements.

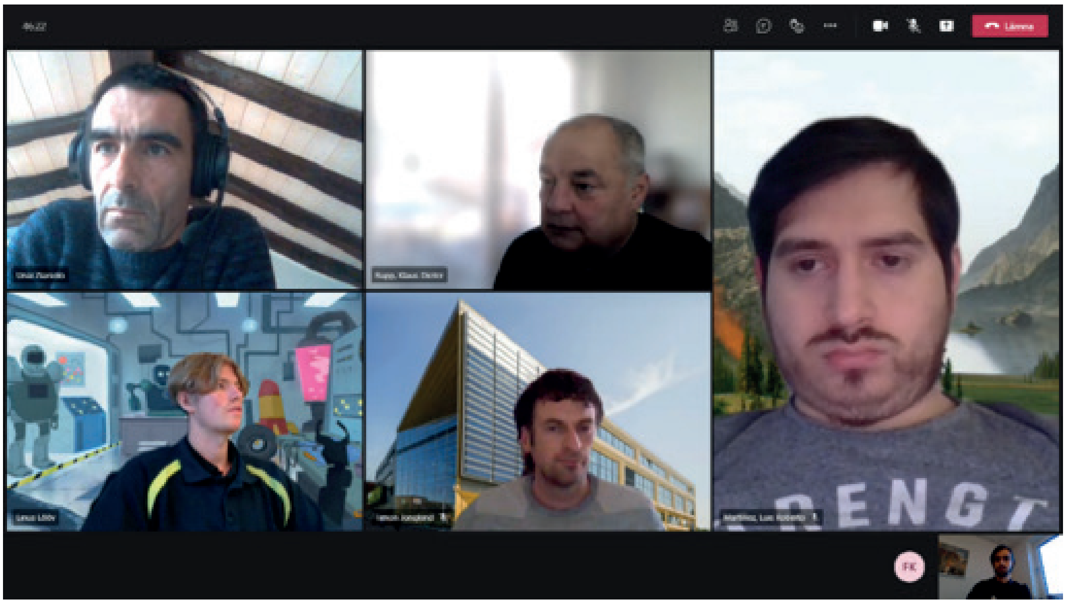


Figure 37: Design technical group meeting. Source: Exam4.0

EXAM ROBOT STEERING

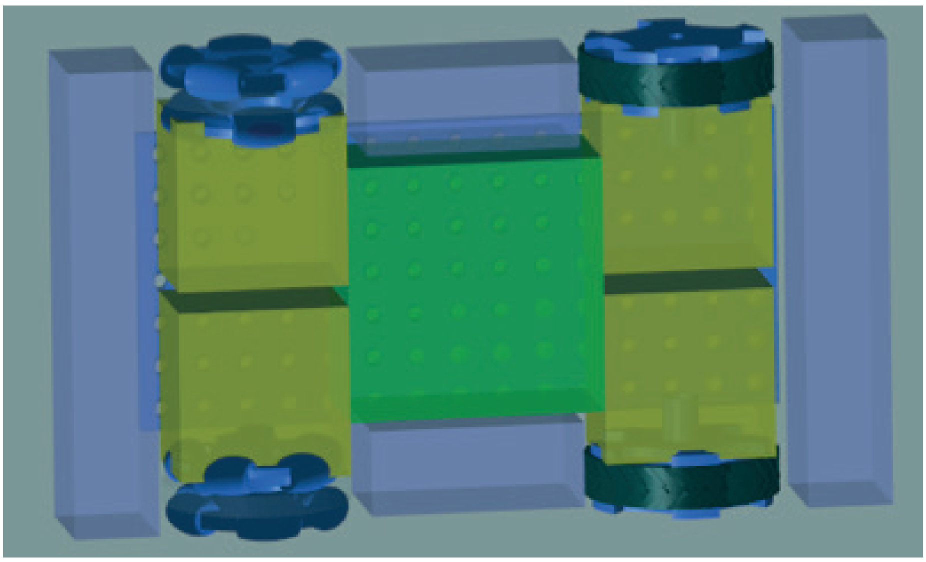


Figure 38: Concept of modular mobile robot. Source: DHBW

The modular mobile Robot consists of a few basic subsystems. There is space for 4 Drive-Systems and 4 Sensory Boxes. On top is the Base-Plate and in the center the Controller. The Sensor Boxes contain two or four Sensor-Devices or Display Elements. The Drive-System contains the Motor, the Motor controller and additional the Steering- or Suspension-Module.

Figure 39: EXAM Robot with controller and battery. Source: DHBW

In the Robot, different Controllers could be used: An Arduino compatible Controller, ESP32 Controller-series or even a Raspberry Pi Compatible Controller. It has a Bluetooth and a WLan interface to be integrated in an IOT system.

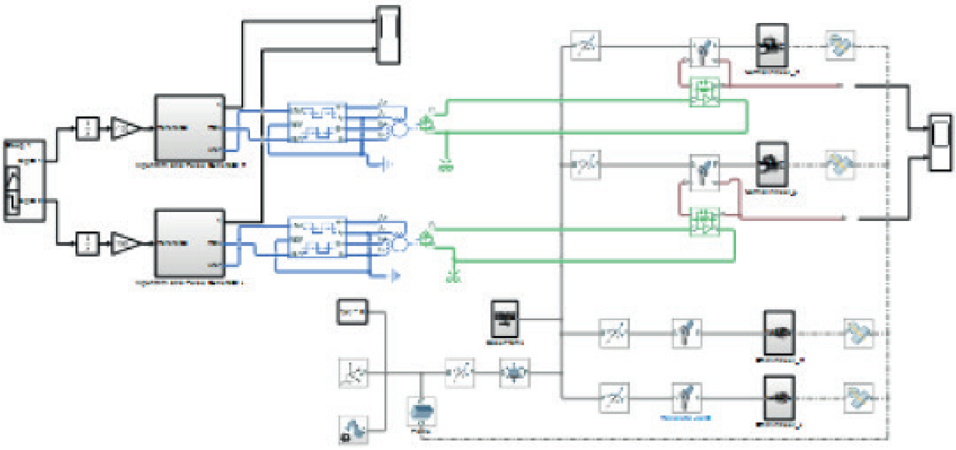


Figure 40: Simulation of EXAM4.0 Robot. Source: DHBW

Figure 41: EXAM robot with Dobot magician on top as an application for picking objects. Source: DHBW

The Exam Robot is a modular mobile Robot with a very big number of possible configurations. The design could be changed within student projects. It could be used as a base for numerous Applications.

OTHER DESIGN ASPECTS

Besides the key elements of the mobile robot (drive systems, chassis, steering system, electronics), we have also taken into account other aspects that guarantee the possibility of automating the assembly of the subsets. Aspects such as the joining elements, avoiding the use of elements such as screws, nuts, etc. that would complicate their automated assembly.

After an analysis and discussion on different commercial joining methods, we selected a component with a clip function to join the components to the robot frame or to each other.

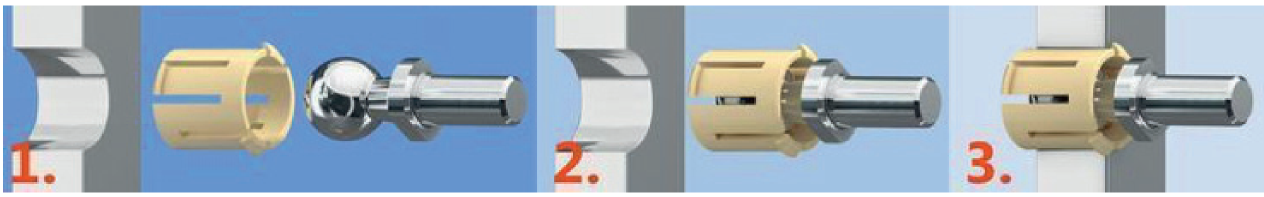


Figure 42: Clip function. Source: DHBW

After a few last meetings and knowing the method with which the joints were to be made, two final designs were created.

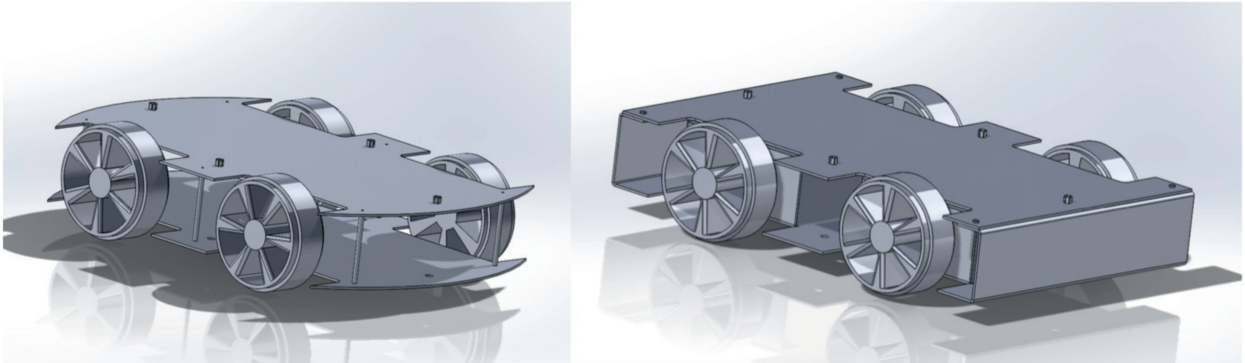


Figure 43: The 2 final design of the robots. Source: Curt Nicolin Gymnasiet

The two different designs were created by Curt Nicolin Gymnasiet and presented to the group. The technical experts' group decided on the appearance of the first robot, that is, the one on the left in the picture above.

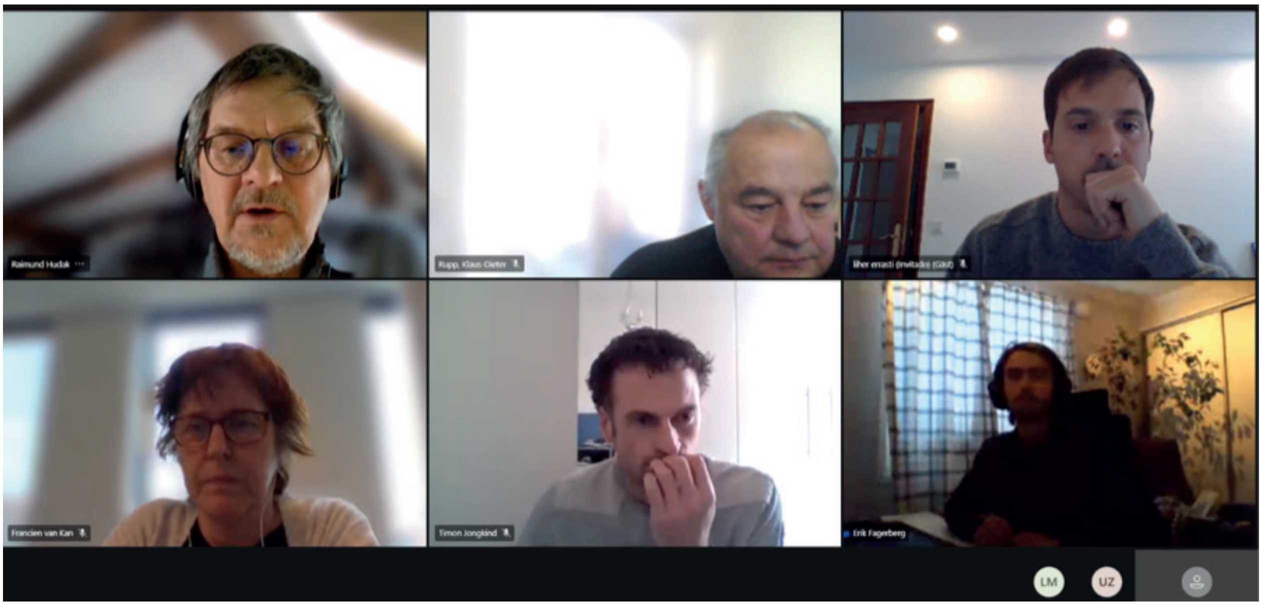


Figure 44: A meeting regarding dimensions. Source: Exam4.0

This picture is from a meeting where the design was more comprehensively discussed. The dimensions of the components for the robot were decided. Though they could be changed during the process, these were the guidelines to work on.

Dimensions decided:

- **Frame top:** 350x200x5
- **Frame bottom:** 350x200x1.5
- **Wheel:** D85x28
- **Sensor box:** 200x25x60
- **Small sensor box:** 100x25x60
- **Controller:** 120x100x40
- **Akku battery:** 137x35x47

The tyres for the wheels were also a topic of discussion. It was decided that these tyres should be produced in one of the partners' LAB and not purchased. There were two different methods suggested. One method was to use a 3D-printer, with a suitable material, to print the tyres. The other method was to use a regular 3D-printer and print a mould that would be used to cast the tyres.

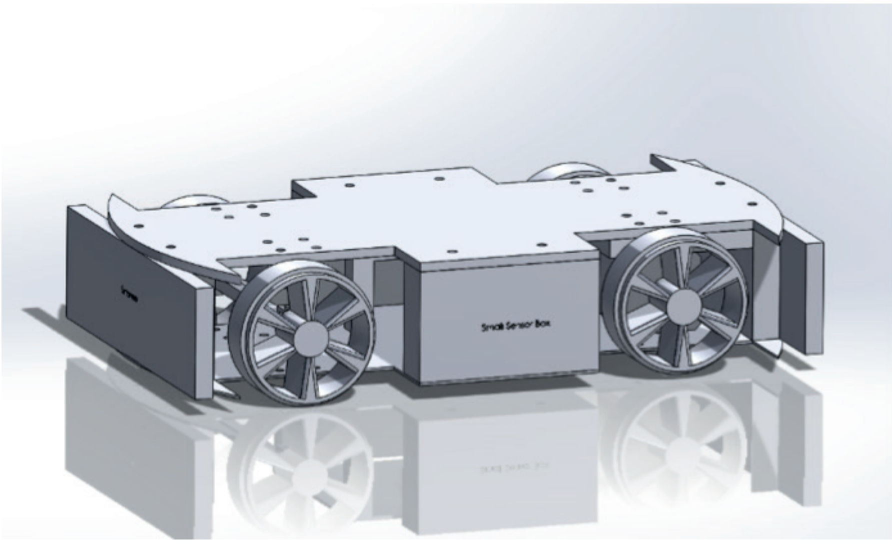


Figure 45: Design of robot. Source: Curt Nicolin Gymnasiet

This picture shows the first design of the robot that includes sensor boxes, batteries, and the controller. The sensor boxes at the front and back are optimized to have space for the steering of the wheels. The plate at the top and bottom are also adjusted to leave more space for the wheels. The stepper motors are lowered 10 millimeters from the top plate, an additional component is added for this purpose, for the wheels to reach the ground with the current height and design of the robot. The part that will have the function to lower the stepper motors 10 mm will be produced by using additive manufacturing.

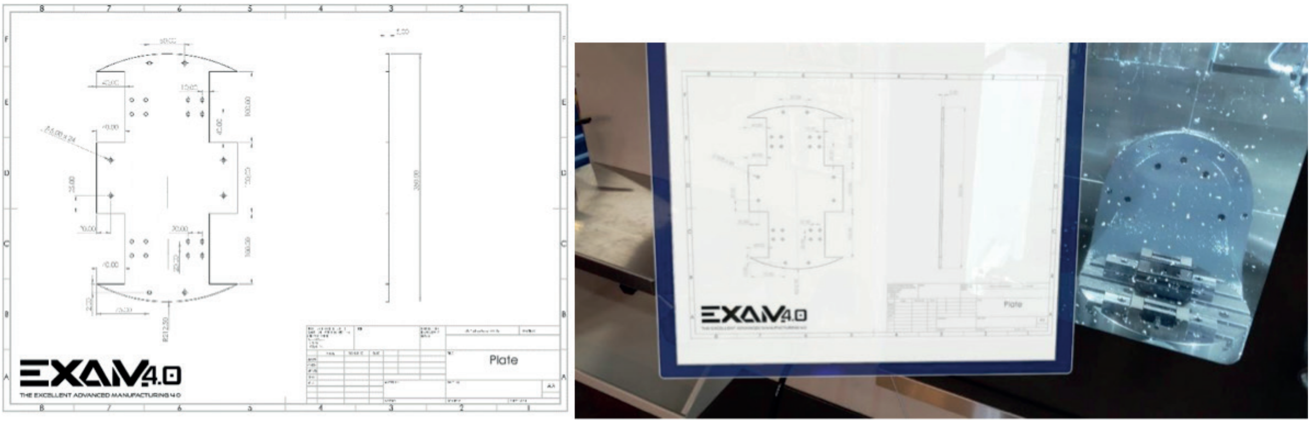


Figure 46: Regular and AR drawing of components for the robot. Source: Curt Nicolin Gymnasiet

Curt Nicolin Gymnasiet created drawings of the parts that will be manufactured in the partners' LABs. These drawings will be used in the production stage, especially during the production of the machined parts. The drawing to the right is displayed in Augmented Reality, through a HoloLens 2 headset. This method contributes to a paperless production during the production process and is part of the implementation of key technologies.

After that a small meeting was held among the technical experts. The topics of the meeting were the steering of the robot and how the different components would be connected to each other during the assembly. DHBW presented different steering options, based on a presentation made by students at Da Vinci College.

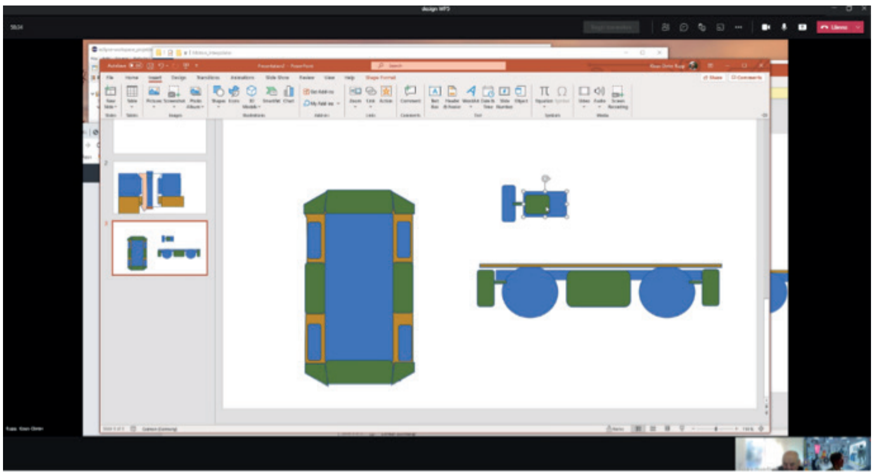


Figure 47: Technical meeting regarding steering. Source: Exam4.0

It was decided that Omni wheels would be used for the steering of the robot. Two wheels are used for this purpose, placed at the front of the robot, attached to a regular axis. The EXAM Omni wheels were designed in CAD, adapted for 3D-printing, by students at Curt Nicolin Gymnasiet. The first prototype was 3D-printed at Curt Nicolin Gymnasiet. It consists of 6 different parts, thus 4 different "stars" as well as pins and rollers.

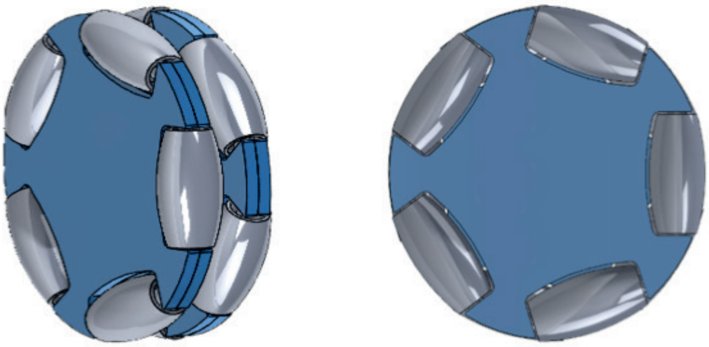
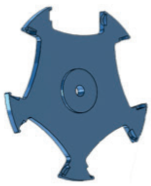
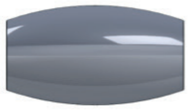


Figure 48: Omni wheels. Source: Curt Nicolin Gymnasiet

In the follow chart we can see the parts of the Omni wheel

Parts included in the EXAM Omni wheel					
Star 1	**Star 2**	**Star 3**	**Star 4**	**Pin**	**Roller**
					

Once the design was done, a fast prototyping was made. The 3D-printer, implemented because of EXAM 4.0, served the purpose of producing prototype parts for the EXAM Robot. The prototype showed that some changes in the design of the stars were necessary.

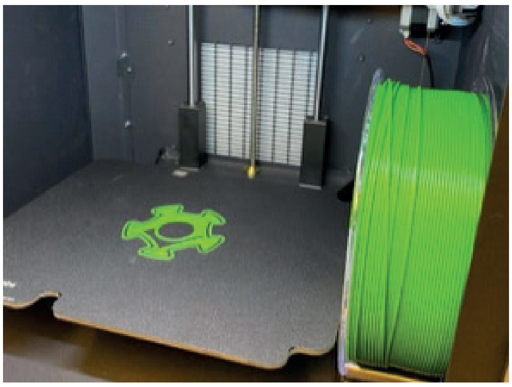


Figure 49: Prototyping Omni wheel. Source: Curt Nicolin Gymnasiet

The next part was how to hold all the parts and for that a main plate was designed. The main plate holds all the components of the robot, accordingly all of the components of the robot are supposed to be attached to this plate.

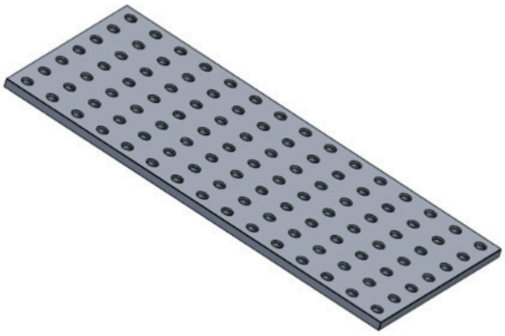


Figure 50: : Main plate. Source: Curt Nicolin Gymnasiet

A fast manufacturing of the main plate was done by Miguel Altuna via CNC milling. During the design it was decided that the Main plate would be 8 millimeters thick in order to hold all the components. The first production of the Main plate showed that 8 millimeters was a bit too much, thus it was too heavy. It was therefore decided to change the thickness to 6 millimeters.

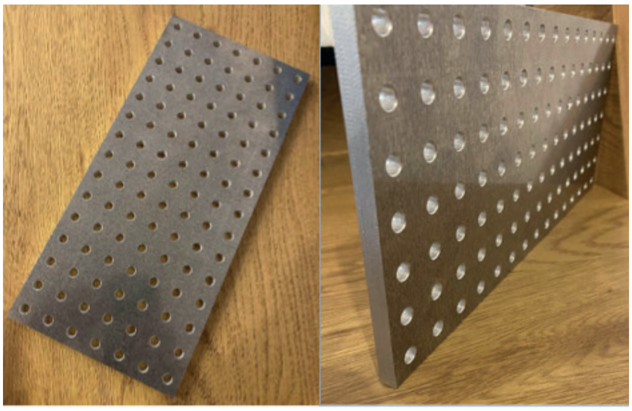


Figure 51: First produced main plate. Source: Miguel Altuna

These components will be attached to the main plate with the component "clipper", to simplify the assembling of the Robot. The main plate is designed with multiple holes to have a large changeability in the robot, making it easy to change the placements of different components.

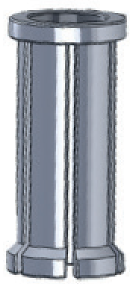


Figure 52: Clipper. Source: Curt Nicolin Gymnasiet

The clipper was designed to have a tool to connect all components to the main plate. A prototype was 3D-printed at Curt Nicolin Gymnasiet and tested to see how it worked.

The clipper was redesigned to be more functional in the assembly of the robot. A chamfer was added at the bottom of the clipper for another robot to be able to push the clipper into a hole of the Main plate and the other components, making the assembling process automatic.

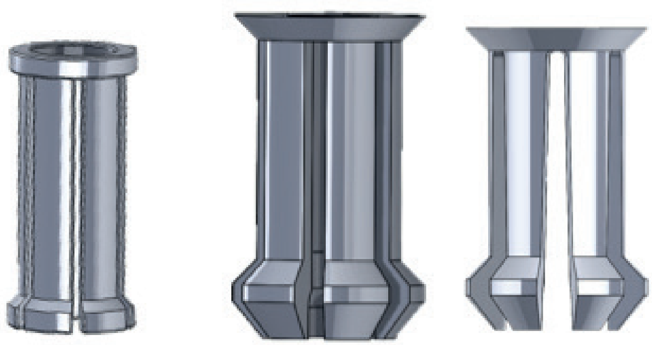


Figure 53: From the left to the right evolution of the pin. Source: Curt Nicolin Gymnasiet

The clipper was once again re-designed to be even more functional in the assembling process. A draft was added on each “pin”, making it wide at one end and smaller at the other. This made the clipper more flexible, thus able to fit into holes of other components more easily.

The Pin for clippers ensures that it does not slip out of the holes it is attached to. Once the pin is removed it is possible to de-attach the clipper from the part it is attached to.

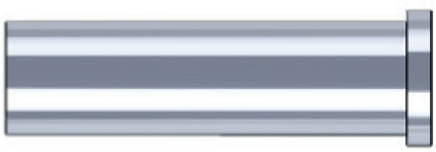


Figure 54: Pin for clipper. Source: Curt Nicolin Gymnasiet

On the other hand, in addition to having the Omni wheels that will serve to turn, some wheels are needed to propel the robot. The design of the regular wheels, which are used to drive the robot, was redesigned to match the design of the omni wheels. The new design has the appearance of a star, like the omnidirectional wheel. A gutter is implemented in the wheel to keep the tyres in place.

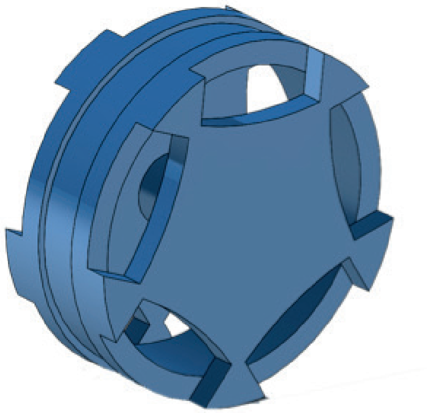


Figure 55: Regular wheel. Source: Curt Nicolin Gymnasiet

The wheels used for the drives are supposed to have tyres in order to have a better grip and give better driving power. A question within the technical expert group was how these tyres would be produced. Two methods were presented; to 3D-print a mould used to cast the tires or 3D-print the tyres with a soft material, like TPE. Miguel Altuna printed the prototype tyres with TPE, and the result was good. It was therefore decided that it was the best method for producing the tyres.

Figure 56: First tyres printed in Miguel Altuna. Source: Miguel Altuna

When the method for manufacturing was decided it was time to determine the definite design of the tyre. Students at Curt Nicolin Gymnasiet got the task to design tyres for the wheels. The picture shows the design that the group decided on. The new tyres had tracks in order to have better traction and help the driving of the robot, it also looked more aesthetic.

Figure 57: Tire with tracks. Source: Curt Nicolin Gymnasiet

The new tyres were printed with the same material as the first ones, TPE, and the result was good.

Figure 58: New tires printed in Miguel Altuna. Source: Miguel Altuna

Stepper motors, Nema 17, **are used as drives** for these wheels in the EXAM 4.0 robot. Different drive options could be used in the future when more robots are produced. The changeable dimensions of the robot are therefore essential, to make sure that different driving options are possible without changing the whole appearance and design of the robot.

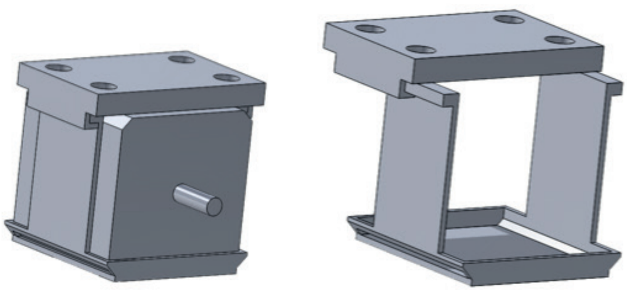


Figure 59: Step motor with the holder and the Holder assembly. Source: Curt Nicolin Gymnasiet

One big challenge was the question “how could the Nema stepper motors be attached to the main plate”. The students at Curt Nicolin Gymnasiet therefore designed a holder for this purpose. One challenge was also that the robot should have the possibility of change. A component we decided to call “Top” was therefore invented to connect the stepper motor to the main plate. The Top slides on and off the holder and the four holes on the slider connect to the main plate with the clippers.

The Stepper motors had a cable placed in the middle of the top side. The Top component for the stepper motor Holder was therefore re-designed. A square of material was subtracted for the cable to fit.

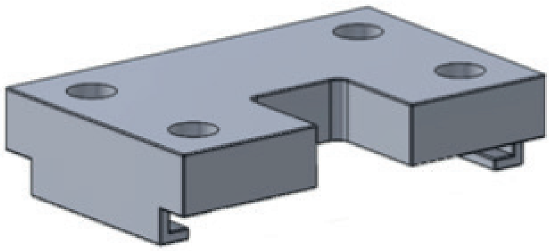


Figure 60: Developed Top. Source: Curt Nicolin Gymnasiet

The Omni wheels will not be mounted to a stepper motor, but instead fixed to an axis. The axis will rotate freely. The axis house is designed to look similar to the stepper motor. Two spacers are used to keep the axis in place.

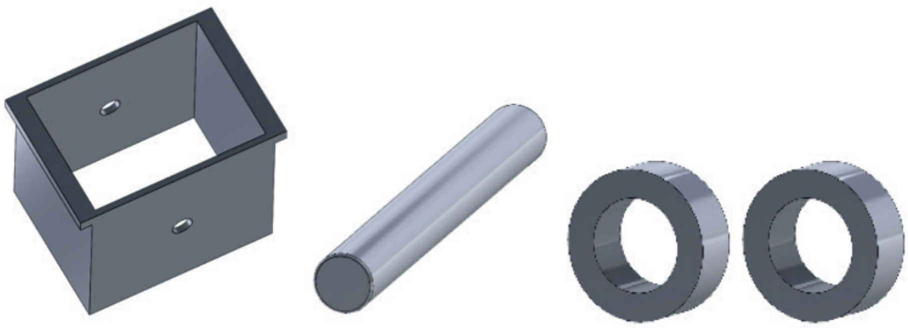


Figure 61: Axis house. Source: Curt Nicolin Gymnasiet

Curt Nicolin Gymnasiet purchased the stepper motors to make sure that the correct dimensions were used for the holder.

After that, two different sensor boxes were created for the robot. The curved one is placed at the front and the other at the back of the robot. The small sensor box is placed to the left and right side of the robot. These boxes ensure the ability to have 12 sensors or actors on the robot and hold these in place.

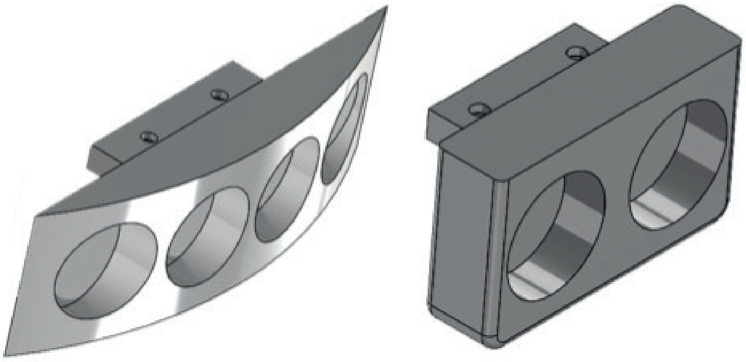


Figure 62: Curved and small sensor box. Source: Curt Nicolin Gymnasiet

Finally, another meeting was held regarding the design among the technical experts. In this meeting the production process started. Here, the final CAD of the robot was presented.

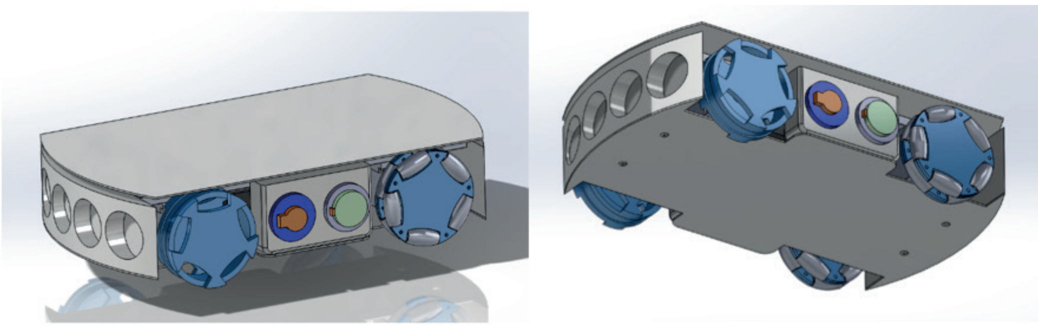


Figure 63: Final design of robot. Source: Curt Nicolin Gymnasiet

After this meeting it was decided which components each partner should manufacture. It was also decided that the assembly would be made in Germany.

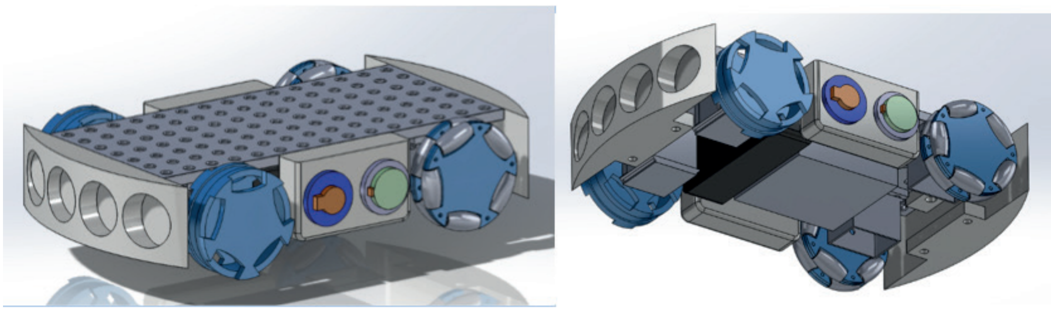


Figure 64: The robot without cover plates. Source: Curt Nicolin Gymnasiet

3.2. Process Engineering

Although the idea that the CLF has a more complex information exchange structure, the first pilot has been carried out in a more basic way. In principle, two partners in charge of the design part, have collaborated with each other to create the design of all the components that have been validated in different meetings by all the partners.

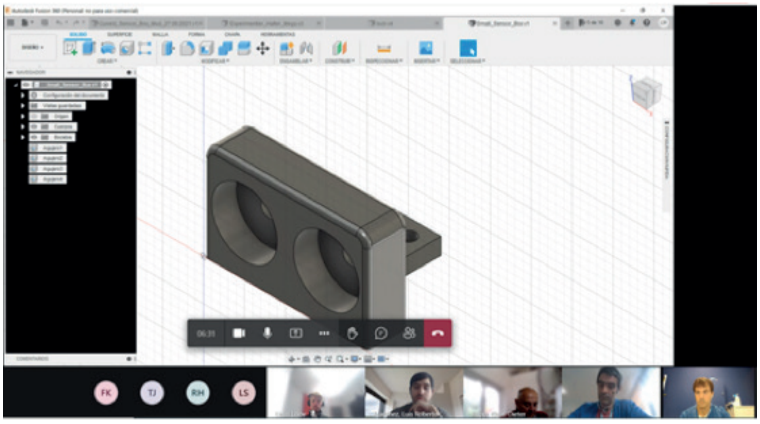


Figure 65: Validating parts of the robot with the consortium. Source: Exam4.0

The design partner has distributed drawings and files for all parts to all other manufacturing partners. Each partner received information on the parts they were supposed to produce, more on this in the next section. After production, each partner sent their parts to the partner in charge of assembling the robot. The assembly process began, and every component-related error found by the assembly partner was sent back to the design partner to start the process all over. All parts were approved after some redefinitions and the robot was terminated.

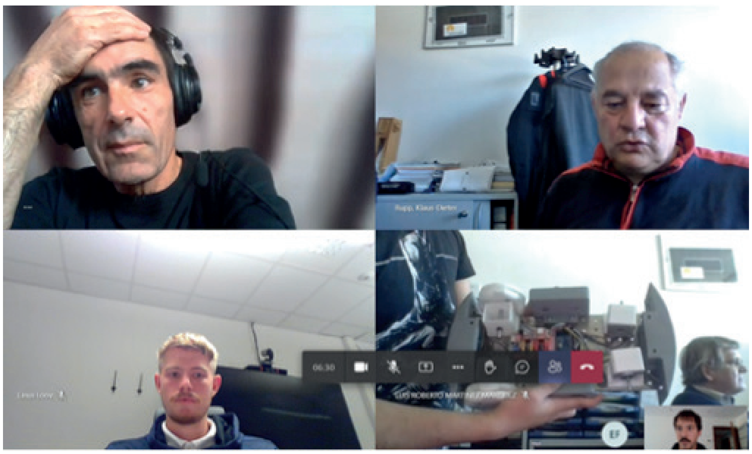


Figure 66: Fixing errors with the consortium. Source: Exam4.0

Although this has been done to check the type of communications that exist between laboratories and to finish the first robot on time, the CLF is expected to operate accordingly to Industry 4.0 in the near future and the technologies embedded in the laboratories will be interconnected. To do this, we have designed a digital process that meets one of the objectives of the CLF: transferring data between laboratories. It is essential to learn how we should structure a digitized laboratory, as shown in the following image. From the base, the factory part, we would have technologies and machines that connected with sensors would transfer data through a PLC to a MES. This MONTH would be connected to the technical office part through a PLM and the latter to the administrative part through an ERP / SMC / CRM. All this data would be transferred to the cloud to be subsequently processed, always taking cybersecurity into account. This structure is already implemented to certain extent in some of the participants' labs. The complexity arises when we connect the remote labs. It is necessary to design and agree on a common IT architecture to ensure data transfer. During EXAM4.0 we have been studying different solutions and their pros and cons. There are certain elements that must be common, so we need to arrive to a consensus for their selection.

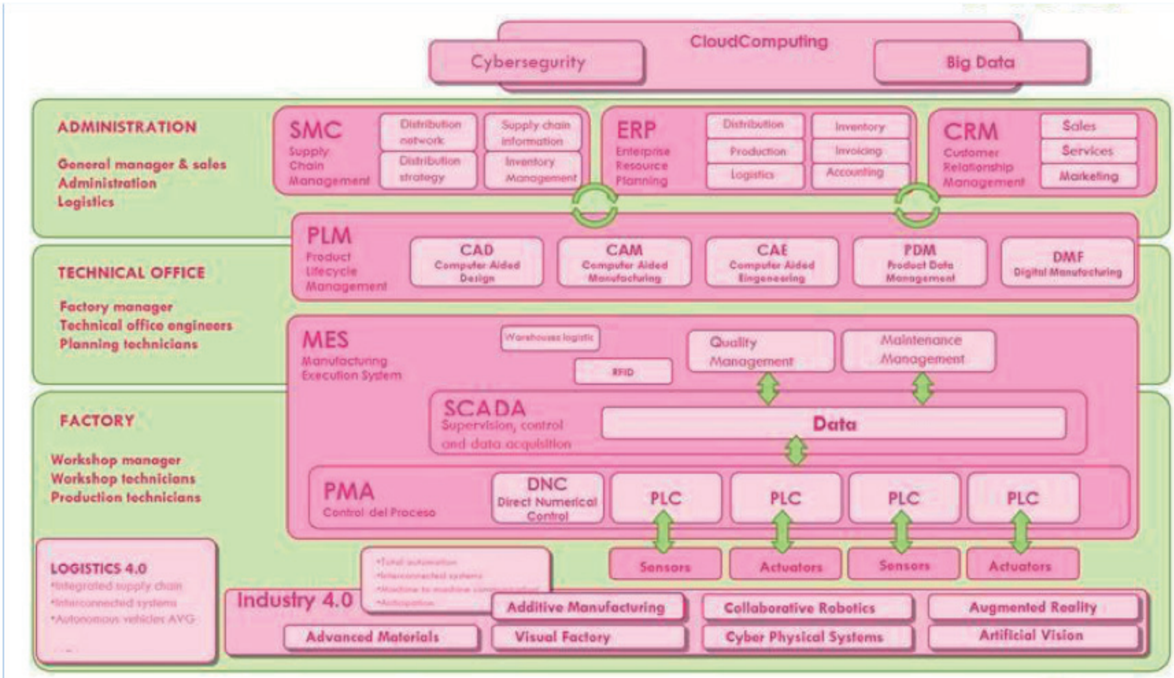


Figure 67: Structure of a connected factory. Source: Ibermática

To be able to unite the labs and share the data from the different processes in it, we need to create a common process but one that gives some flexibility so that each of the labs can use their independent processes. The following diagram shows possible solutions of a production process.

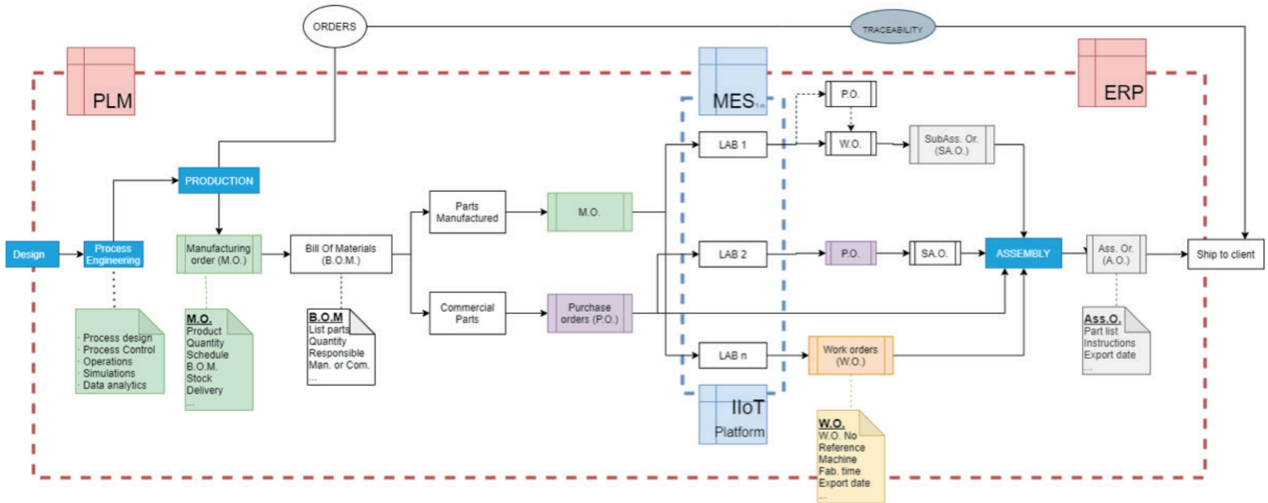


Figure 68: Possible diagram of the operation of the ERP-PLM-MES system of the CLF. Source: EXAM4.0

As can be seen in the image above, first, we must analyze what type of system each of the labs is using currently. Enterprise resource planning (ERP), product lifecycle management (PLM) manufacturing execution systems (MES); IIoT platform, Cloud solutions among others. ERP, PLM and MES have traditionally been three very distinct pillars of the manufacturing technology puzzle. But in today's world—where timely product delivery and top-notch quality are the hallmarks of success—those individual pieces are coming together to create a foundation for a modern-day interpretation of lean manufacturing (AutomationWorld, 2021).

A PLM solution could potentially be implemented in the consortium to enhance the collaboration. Using a PLM solution successfully, could result in more innovations and higher efficiency at consortium level (Rudeck, 2021). During the lifespan of EXAM4.0 we have checked two business management platforms where PLM solutions are embedded: 3D experience (Dassault Systems) and Teamcentre (by Siemens). So far, we have not implemented a common PLM system at consortium level. However, individual partners of the consortium do have licenses for different PLM systems at their VET/HVET center. After finalizing the study of the Business Management platform available in the market the consortium will decide on the common solution for the EXAM4.0 CLF.

With all this in mind, first of all, to cover the design phase and future modifications a joint PLM is needed. In this way, it will be possible to manage the useful life and the digital concept of the product to be developed, from the conception of the idea to its recycling, through its design, manufacture, or distribution / sale. The PLM would be in charge of collecting the CAD of the products, their different versions, the BOM (Bill Of Materials) and their manufacturing processes.

BOM	EXAM4.0 THE EXCELLENT ADVANCED MANUFACTURING 4.0

Product:
Code:
Plant:
Number of version:

Material	Documents	General

Code	Component	Subcopm. L1	Subcopm. L2	Description	Quantity	Material	Plant

Figure 69: Possible BOM for EXAM4.0. Source: EXAM4.0

As can be seen in the image above, first, we must analyze what type of system each of the labs is using currently. Enterprise resource planning (ERP), product lifecycle management (PLM) manufacturing execution systems (MES); IIoT platform, Cloud solutions among others. ERP, PLM and MES have traditionally been three very distinct pillars of the manufacturing technology puzzle. But in today's world—where timely product delivery and top-notch quality are the hallmarks of success—those individual pieces are coming together to create a foundation for a modern-day interpretation of lean manufacturing (AutomationWorld, 2021).

A PLM solution could potentially be implemented in the consortium to enhance the collaboration. Using a PLM solution successfully, could result in more innovations and higher efficiency at consortium level (Rudeck, 2021). During the lifespan of EXAM4.0 we have checked two business management platforms where PLM solutions are embedded: 3D experience (Dassault Systems) and Teamcentre (by Siemens). So far, we have not implemented a common PLM system at consortium level. However, individual partners of the consortium do have licenses for different PLM systems at their VET/HVET center. After finalizing the study of the Business Management platform available in the market the consortium will decide on the common solution for the EXAM4.0 CLF.

With all this in mind, first of all, to cover the design phase and future modifications a joint PLM is needed. In this way, it will be possible to manage the useful life and the digital concept of the product to be developed, from the conception of the idea to its recycling, through its design, manufacture, or distribution / sale. The PLM would be in charge of collecting the CAD of the products, their different versions, the BOM (Bill Of Materials) and their manufacturing processes.

Additionally, physical machinery can be connected to software through sensors that constantly monitor performance. This allows teachers and students to have a better understanding of the operational performance of the process.

Taking all this into account, when operating the entire system, it would work as follows:

First, there must be a platform where orders can be made. Initially, it is not contemplated that the orders can be customizable, but it could be in the second stage. In this way, the platform or space that is going to be designed to place the orders will have to take this into account.

This order will have to reach our ERP, which will have to consider the supply chain, the warehouse, the production, as well as other data related to the production process. As commented before, it will control the delivery times, traceability, machine availability …

Next, we need the ERP-PLM connection. For this purpose, it is necessary to collect the information from the PLM, where it will collect the BOM of the product and distribute the work to the different labs considering the information it collects from the MES.

The functionality of the MES / ERP that should be in each lab can be categorized into three main blocks: track and trace capabilities; process management; and simulation and predictive analytics. These blocks would be translated into the operations that appear in the image below.

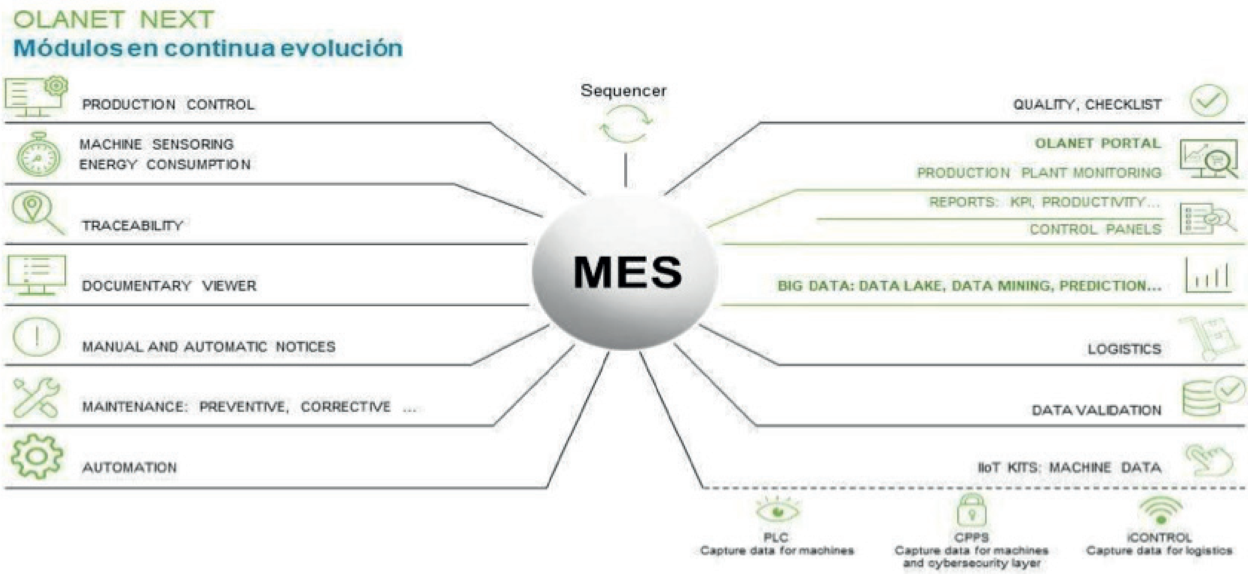


Figure 70: Example of the characteristics of a MES system.
Source: https://ibermaticaindustria.com/solucion-olanetenntte/

As can be seen in the image above, a complete MES system has many features, which in addition to being difficult to install, are very expensive. That is why it will be necessary to decide which of the functions are necessary and which are optional for the workshops that are within the CLF. Some of those important features can be control of manufacturing time and product quality.

Once the parts and sub-assemblies are completed, the MES systems, in addition to the data they have collected, will have to notify the ERP so that it can proceed to give the shipping and assembly orders.

Finally, once assembled, the notice will have to be given to proceed with the customer's shipment. The ERP system will take care of the customer management and will collect the non-conformities to improve the process or product.

3.3. Manufacturing

Each partner manufactured the different components for the robot. This was done with different methods and machines such as CNC-machines and laser cutting, but most of the components were 3D-printed

3.3.1. CIFP Miguel Altuna LHII

Miguel Altuna produced the machined parts for the robot, such as the new 6mm main plate and the cover plates for the bottom and top side of the robot.

Figure 71: All plates produced for the robot. Source: Miguel Altuna

The process of manufacturing the main plate, with a lot of holes, was performed with CNC by students at Miguel Altuna.

Figure 72: Student producing the main plate in a CNC milling machine. Source: Miguel Altuna

The production of one of the cover plates (the one on the right) was rather difficult. One of the ideas with the robot was to mount all components on the main plate with the Clipper; the Clipper is designed and produced by the CLF. It was necessary to add bushings with internal holes onto the cover plate in order to make it possible to mount this cover plate to the main plate. The cylinders were produced by CNC-turning and then welded onto the plate.

Figure 73: Student producing the bushes in a CNC lathe machine. Source: Miguel Altuna

3.3.2. Curt Nicolin Gymnasiet

The production of one of the cover plates (the one on the right) was rather difficult. One of the ideas with the robot was to mount all components on the main plate with the Clipper; the Clipper is designed and produced by the CLF. It was necessary to add bushings with internal holes onto the cover plate in order to make it possible to mount this cover plate to the main plate. The cylinders were produced by CNC-turning and then welded onto the plate.

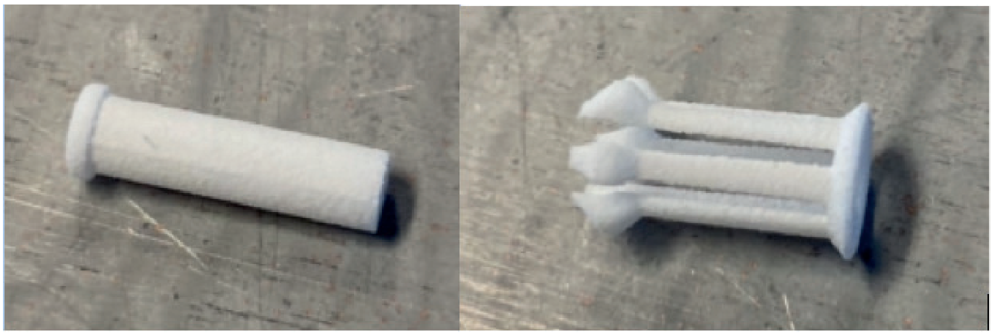


Figure 74: Printed clipper and pin for clipper. Source: Curt Nicolin Gymnasiet

Curt Nicolin Gymnasiet printed the latest version of the clipper as well as the pins in a large quantity. The Clipper is a complicated component which was required to be re-designed multiple times to be able to hold the load of the heaviest components. This component is very small, about 11 mm tall. The features that are very thin make it difficult to print these parts in normal FFF-printers (thread is too wide and tolerances are not good enough). Because of that, these parts were printed in a SLM/LSM-machine.

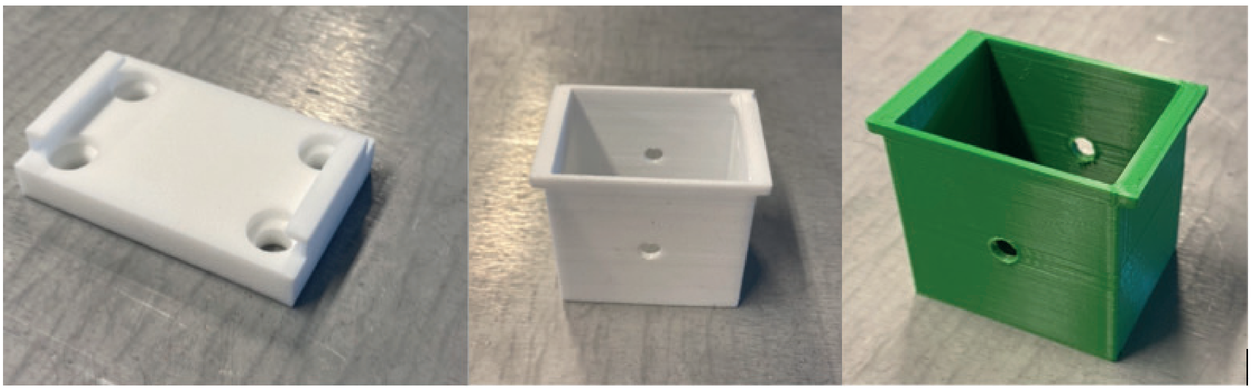


Figure 75: Various printed parts. Source: Curt Nicolin Gymnasiet

The “Top” part was printed in the EOS formiga p110, because of the slide function that requires good tolerances. The “Axis house” was originally printed in the EOS formiga p110. The first print showed that some dimension changes were necessary. The “Axis house” did therefore need to be re-printed in the last minutes, Curt Nicolin Gymnasiet decided to print this part in their new ZYYX-printer which works very rapidly, this was necessary in order to get the part produced and shipped on time.

Figure 76: Spacers. Source: Curt Nicoling Gymnasiet

The “spacer” was originally intended to be manufactured in steel, using a saw and drill. There were, however, some problems with the saw that resulted in not perfectly manufactured spacers. It was therefore decided to print the spacers with the EOS Formiga p110 as well to get the best results.

Figure 78. Axis

The “Axis” was manufactured by using a metal saw and a grinding machine.

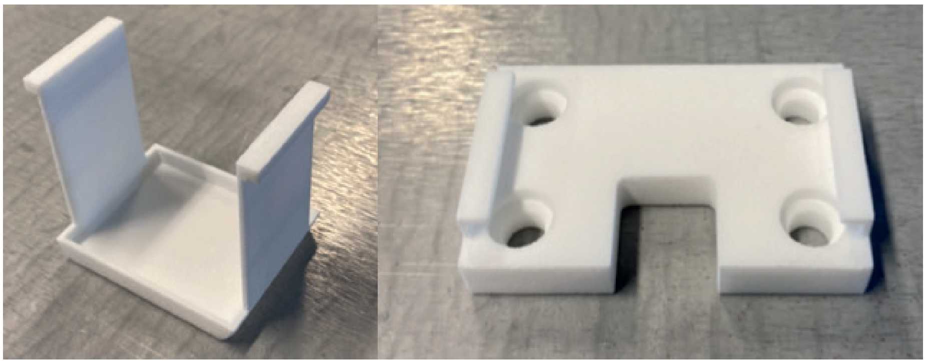


Figure 77: Printed holder for step motor. Source: Curt Nicolin Gymnasiet

Both the Holder for the stepper motor and the re-designed top part were printed in the EOS Formiga p110 with a good result. These parts were also printed in this machine because of the tolerances.

Figure 78: Printed parts for the omni wheel. Source: Curt Nicolin Gymnasiet

The EOS Formiga P110 provides parts with nylon material that is of high quality. All parts for the EXAM Omni wheel were therefore printed with this machine and material.

3.3.3. Da Vinci College

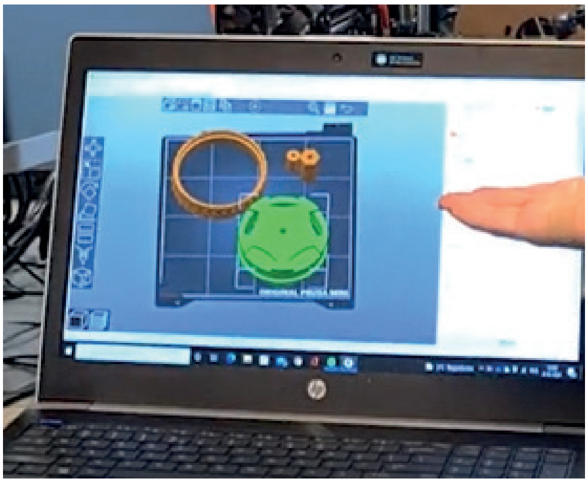


Figure 79: Starting a new print with wheel and tire . Source: Da Vinci College

Da Vinci College printed the regular wheels for the robot as well as the tyres and sent them to DHBW to be assembled. The regular wheels were printed in an FFF-printer in Da Vinci College's 3D-printing lab. The tyres were printed with a soft plastic material, such as PU, soft PVC, TPR.

3.3.4. DHBW

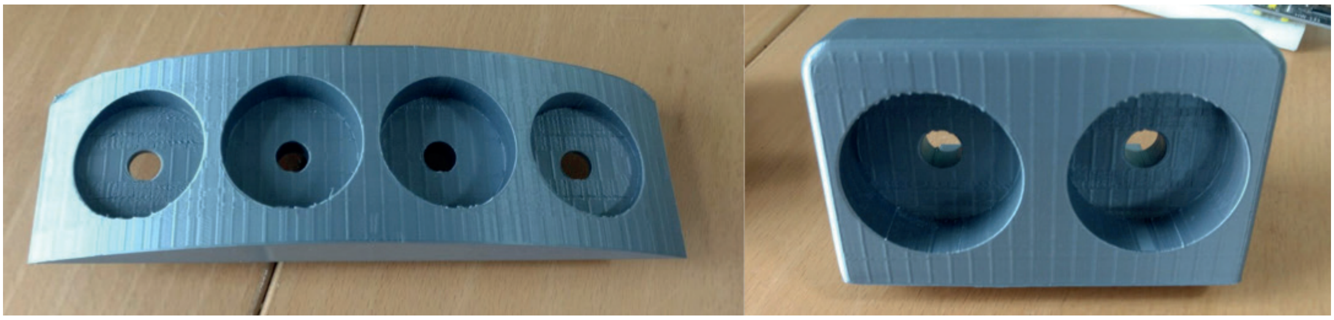


Figure 80: Produced sensor boxes. Source: DHBW

DHBW oversees the sensors, so it was therefore a natural decision for them to produce the sensor boxes as well. The sensor boxes were designed in close correlation between Curt Nicolin Gymnasiet who oversaw the design and DHBW who oversaw the assembling. DHBW had the co-lead on the design and had the highest knowledge of the specifications of the robot when it comes to sensors, cables, battery etc. The sensor boxes were printed at DHBW with a 3D-Printer. The surface of the components is not great. However, the surface smoothness of the sensor boxes did just fine for the first robot. The parts were printed with the purpose of a fast production in order to start the assembling process. Other production methods might be relevant in the future if the robot is to be produced in larger quantities. That is because these components are large and require a lot of material, thus additive manufacturing is not a beneficial production method for these components.

Almost all the components were re-designed, and therefore manufactured again. Every partner used the same production method when producing these different components. The students were however more comprehensively involved in the production the second time.

3.4. Product's assembly

As we have commented previously, the assembly of the robot has been done in DHBW, Germany. To do this, the assembly plans were created before. Meanwhile, the partners were sending the produced parts there.

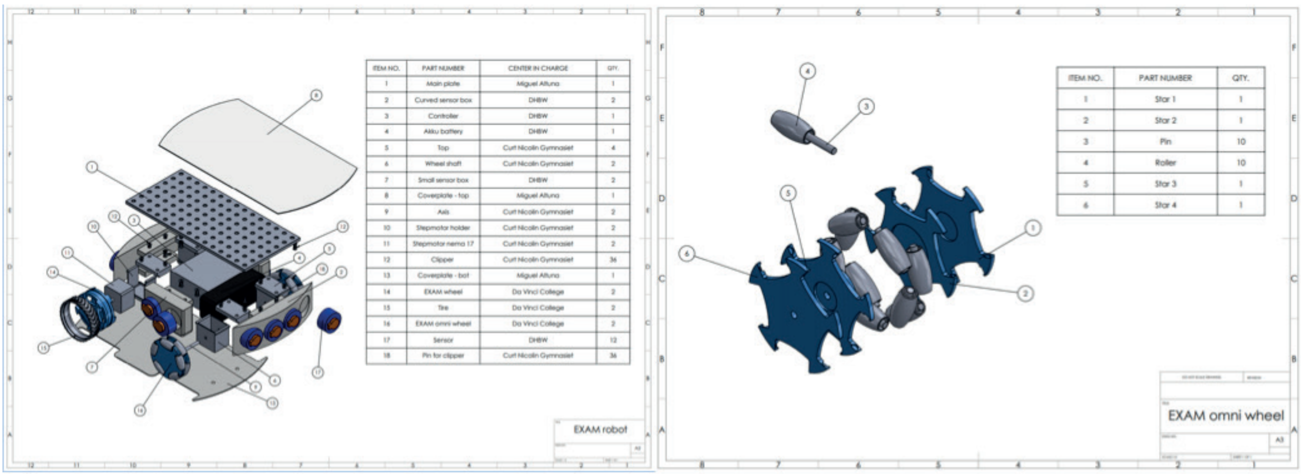


Figure 81: Assembly drawings of the EXAM robot as well as the omni wheels. Source: Curt Nicolin Gymnasiet

The first components that arrived at DHBW were the Main plate and Cover plates. These pictures show the start of the assembly at DHBW.

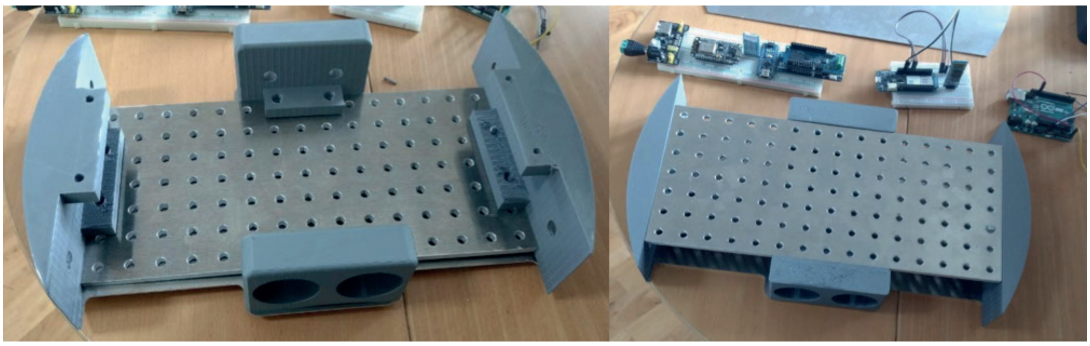


Figure 82: Beginning of the assembly. Source: DHBW

The parts from Curt Nicolin Gymnasiet were the second to arrive at DHBW. The actual assembly of the robot could begin when these parts arrived. The clippers were one of the parts that was delivered in this shipment, making it possible to start connecting and mounting different components together.

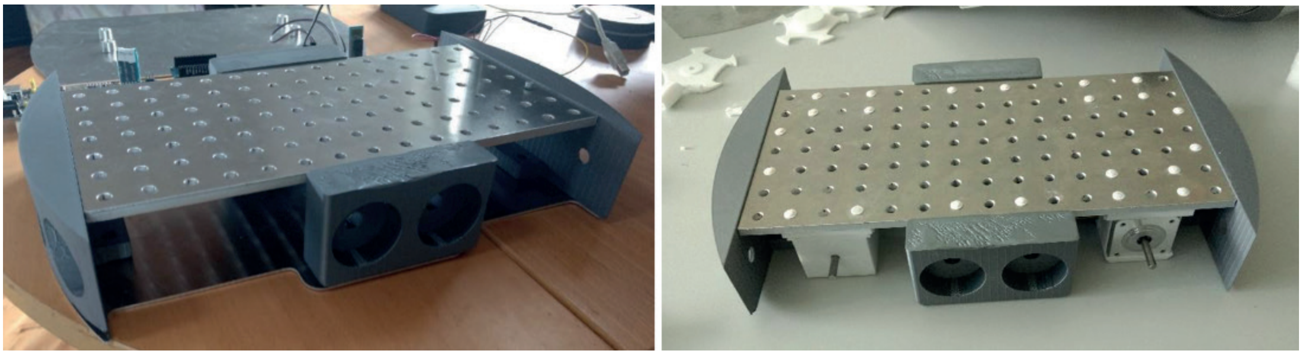


Figure 83: Assembly with Curt Nicolin Gymnasiet parts. Source: DHBW

The stepper motors and the other components for the steering of the robot were also delivered in this shipment. This picture shows the stepper motors being connected to the controller.

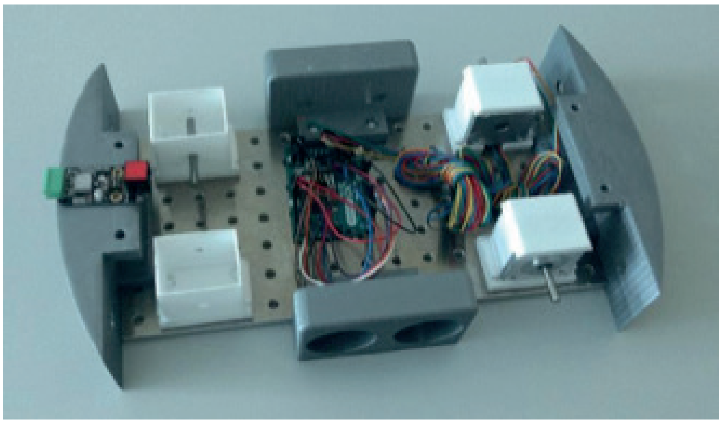


Figure 84: The electronic part of the assembly. Source: DHBW

At this point the parts from Da Vinci College had not yet arrived. DHBW had, however, printed provisional wheels for the stepper motors (the grey wheels) that were used until the actual wheels arrived.

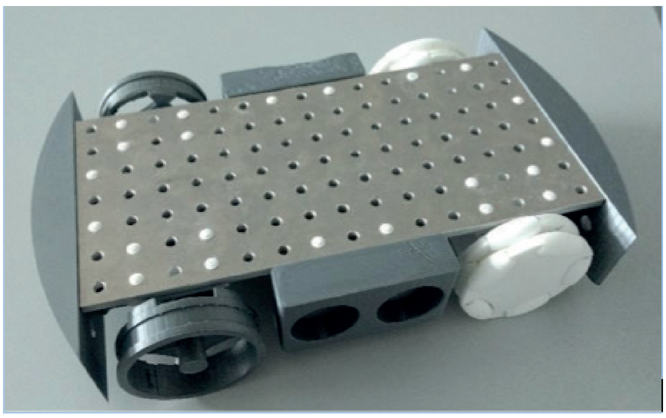


Figure 85: Assembly with provisional wheels. Source: DHBW

In the picture below the small sensor box that is connected to the main plate with the clipper and the pin for the clipper are shown. The clipper is beneficial because no glue is required during the assembling. The clipper makes it easy to change the parts of the robot as well as changing the placement.

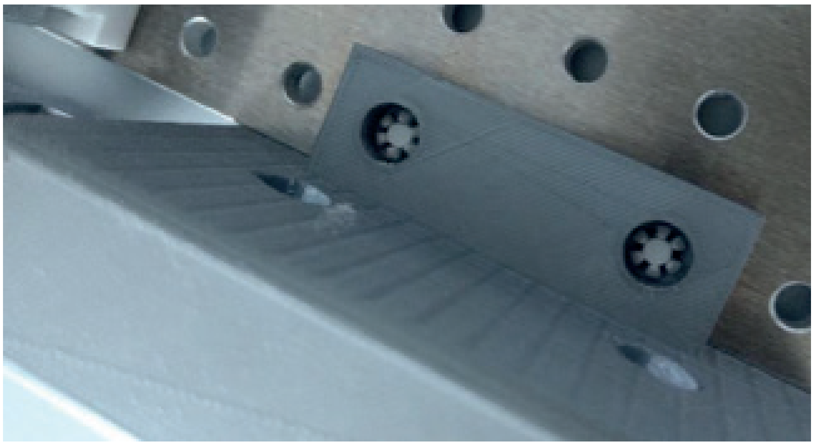


Figure 86: Union with clippers. Source: DHBW

The assembly process took place at DHBW and they used different robotics and automation processes for this task. The students also had the opportunity to participate in the assembly process.

Figure 87: Assembling with the robot while the student is helping. Source: DHBW

The assembling of the parts resulted in the acknowledgement of more changes of the parts, thus the components for the robot were not good enough. The process therefore had to start over. Multiple parts were re-designed, produced and then once again assembled into the final robot.

The first part that needed changes were the Omni Wheels. The wheels were re-designed to have a better roll.

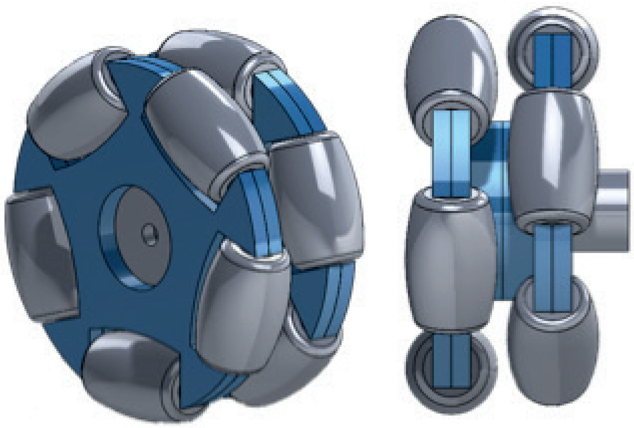


Figure 88: New Omni wheel. Source: Curt Nicolin Gymnasiet

The wheels were also changed to implement a hub into the wheel, this hub will be the standard for all wheels of the EXAM robot. The hub is a component used to attach the wheels to the axis.

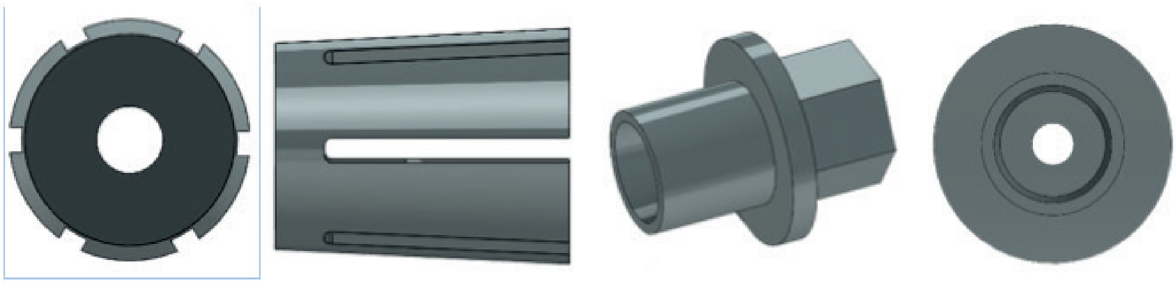


Figure 89: The hub. Source: Curt Nicolin Gymnasiet

The holder for the stepper motors did now work as envisioned either. The motors did not stay in place in the holder when the motor was driving. The top part was therefore re-redesigned. With the new design, it is possible to mount the stepper motors with screws.

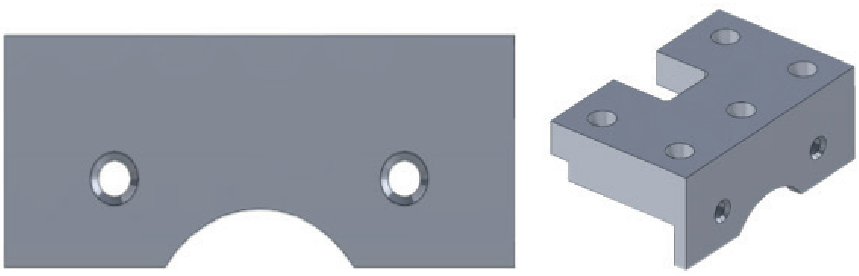


Figure 90: New top. Source: Curt Nicolin Gymnasiet

And the last change were the sensor boxes. The sensor boxes were optimized to have holes for the cables of the sensor, we also added holes to attach the sensors with the clipper.

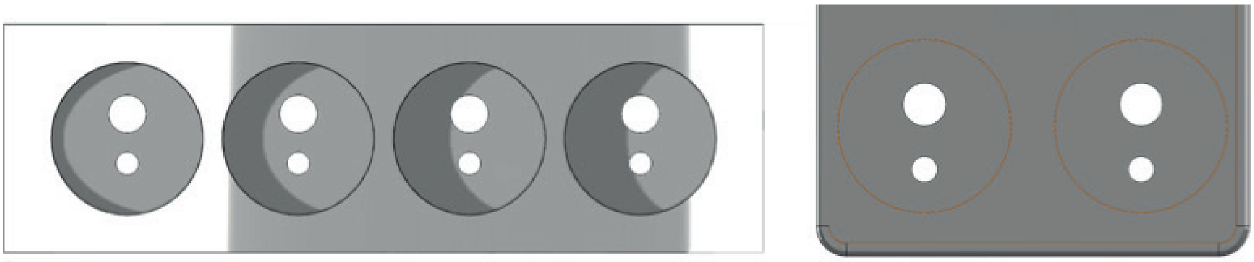


Figure 91: New sensor boxes. Source: Curt Nicolin Gymnasiet

All the new parts have been produced in the labs participating in the CLF. The project and the CLF are still ongoing and the final version of the robot, with all the developed and updated components, is currently being assembled in the Learning Factory at DHBW.

EXAM ROBOT STEERING

The assembly process for the first prototype was manual. Once the elements were fixed and tested, we validated the functional aspects of the robot.

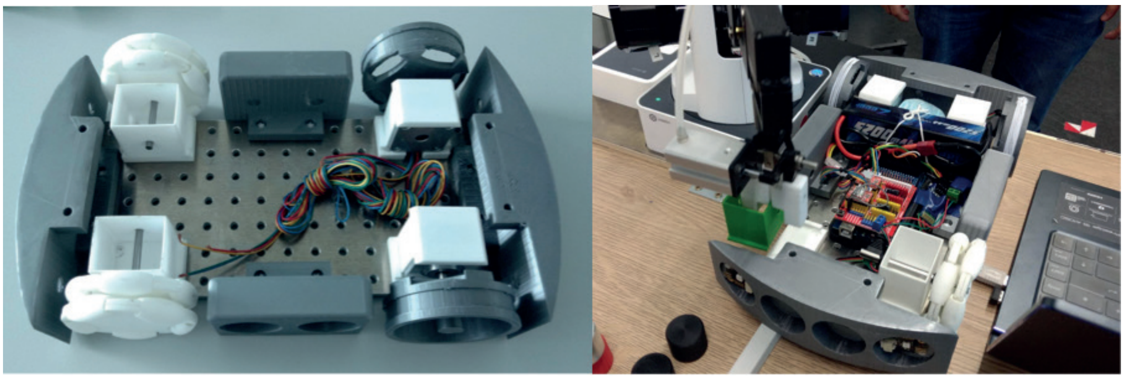


Figure 92: EXAM Robot with controller and battery

In the Exam robot it's possible to plug another controller, it could be an Arduino compatible controller, ESP32 Controller-series or even a Raspberry Pi, some of the boards would need a expansion shield for the inputs and outputs and a driver shield, in the previous figure we have a red board in the middle of the robot that's our driver module and is compatible for

Arduino Uno, Mega and Leonardo. In case we use an esp32 we would need to have another module that is compatible. The big difference between the Arduino (not including MKR and IOT NANO) and the ESP32 is that ESP32 has an onboard Wi-Fi and Bluetooth, Arduino doesn't have it included and it's necessary to add a Wi-Fi/Bluetooth module in case you want to use this communication.

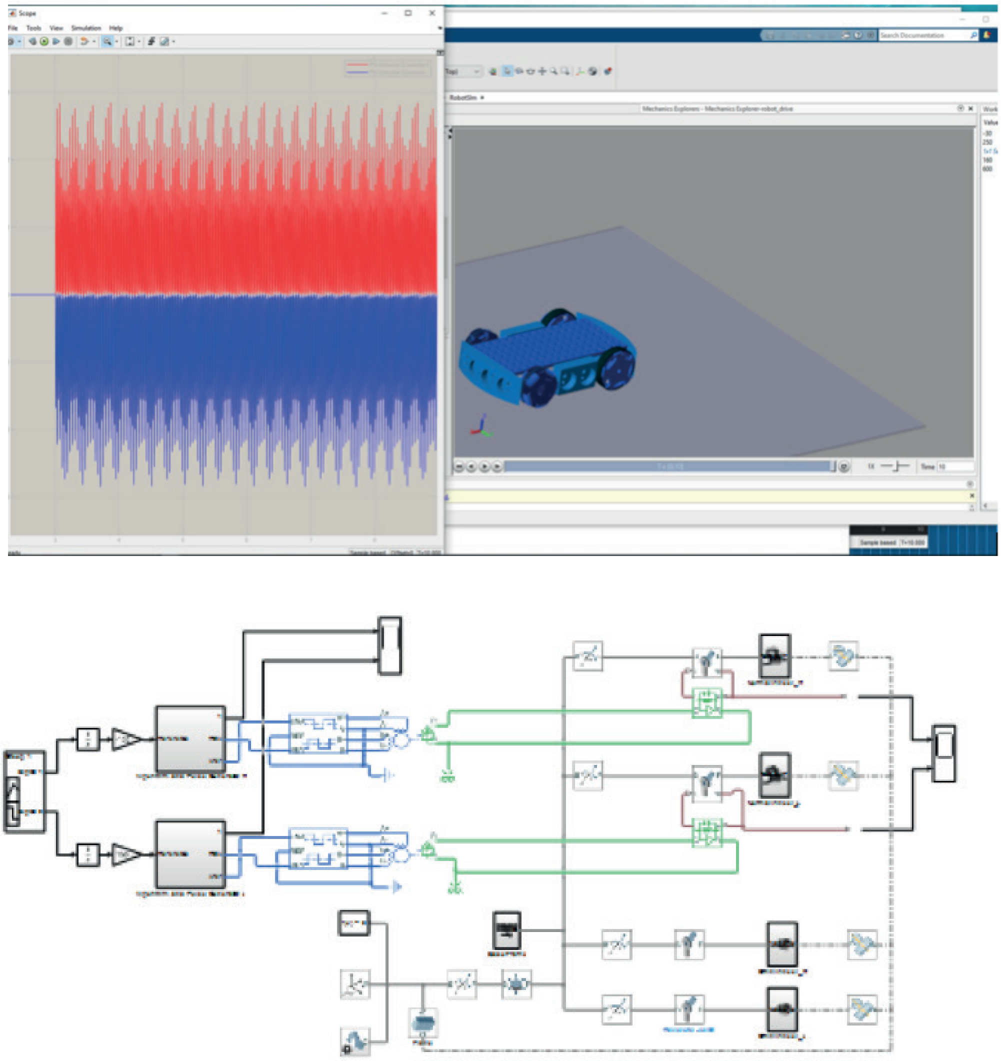


Figure 93: Simulation of EXAM4.0 Robot. Source: DHBW

Before assembling, DHBW's staff simulated the model. The simulation model is used to find the right specification for the system. Different models for the specific domains were set up to get answers for mechanical, electrical and control issues. The simulation is a first piloting step to a Digital Twin of the Robot. For sharing contents with the Robot, the Simulation of the whole system or only specific components like hardware in the loop or software in the loop simulations will be added to the product from the CLF.

Figure 94: EXAM robot with Dobot magician on top as an application for picking objects. Source: DHBW

At this point, the Exam Robot is a modular mobile Robot with a very big number of possible configurations. The design could be changed within student projects. It could be used as a base for numerous Applications. In a student project we tested the system with a Dobot magician. The Robot could be connected via USB to the Exam Robot Controller. Together with a camera combined with a Raspberry Pi4 it can perform autonomous missions with IOT integration.

3.5. Testing

In the first state of the EXAM robot, we decided to validate the components that we design but we saw some problems at the moment we assembled the Components to the frame therefore, we changed the 3D Model, we made some modifications until we reached a point we were satisfied with the functionality.

During the time we changed the 3D Designs we tested several sensors independently from the Exam robot frame, the sensor we used in our teste were humidity Sensor, IR Sensor, Speaker Module, Light Module, Ultrasonic Sensor and more. we have test codes for each of the sensors in case students want to learn more about the interaction between the sensors and the controller and we plan to get the specification of the sensor with a test code, a small documentation from our side and in case is needed a library for the supported controller that could be ESP32, ESP8266, Arduino, Teensy.

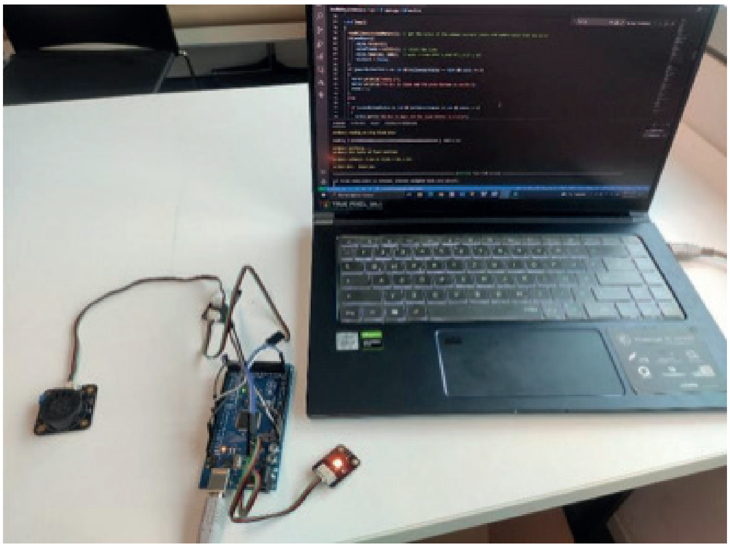


Figure 95: Testing the codes. Source: DHBW

The testing regarding the steering was not completely possible until the final wheels arrived with the new HUB, now we are in a state that we can develop a smooth steering system including some sensors in the Exam robot to have a fully functional robot.

In our current state it is possible to send commands via Bluetooth (Cell phone/Computer) to the EXAM robot and change the movements, also to control the Lights in the vehicle independently if it's needed, the use of Wi-Fi is already tested and is possible to change the code remotely over the Network using Wi-Fi.

For Programming the controller, we use two IDE (Integrated development environment)

- Arduino IDE
- Visual Code Studio (Platform IO Plug)

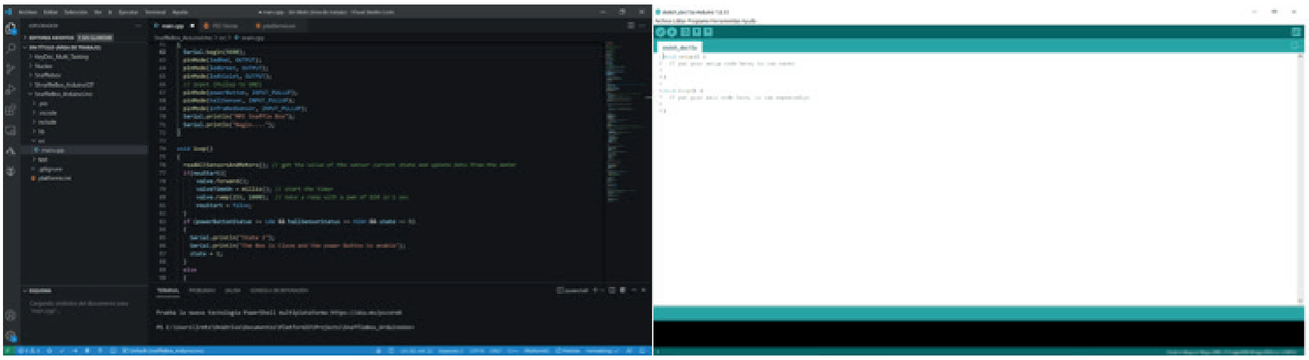


Figure 96: Visual Code Studio IDE and Arduino IDE. Source: DHBW

4 Incidents occurred

One of the big goals was to involve students in the process. The consortium is developing a CLF and producing a product, which would be very beneficial for students. One factor that made this difficult was Covid-19. Most schools had no or a limited number of students at school. This resulted in a lot of problems and long waiting periods to see if the situation would get any better, which did not.

There were a lot of changes in the design that came in bad timing and took extra time. An example was that Curt Nicolin Gymnasiet printed all clippers and got ready to send them, but in the meeting the next day the group decided to change the design. The school had just closed for the summer which resulted in problems delivering the components on time. This was a result of poor communication or miss understanding.

Another issue was the shipment. The different components of the robot were produced at different locations, in different countries, which meant that the components had to be transported in order to be assembled. One delivery of components got lost during the transportation, it did also take a long time to track the package before realizing it was gone. The centre in charge of the assembling had to produce the parts. This last minute solution resulted in an inferior prototype of the robot and a delay in the production process.

5 Results obtained

Throughout this document, we have detailed the process of creating a model of Advanced Manufacturing labs for VET that we have called CLF.

Through the implementation of the CLF, we have sought to align the technological trends set out in the EXAM 4.0 framework (EXAM4.0, 2020) with the proposed competence framework for advanced manufacturing (EXAM4.0, 2020)

The core piloting process has been carried out jointly in the labs of the five institutions that make up the consortium (Tknika, Miguel Altuna, DHBW, DVC and CNG). We have also counted on the very valuable contribution of the 3 Basque affiliate partner VET centres (Bidasoa, IMH, Usurbil).

As a result of the piloting process, we have set up and run the EXAM 4.0 Collaborative Learning Factory (CLF). As described in previous sections, we have been able to produce a mobile robot in a collaborative way establishing what the CLF value chain entails. We have tested different enabling technologies and how to approach training sessions about them. However, the most important achievement has not been to build such a prototype, but to lay the foundations for the structure and operation of a distributed learning factory.

We have structured the results of the piloting process in the following documents:

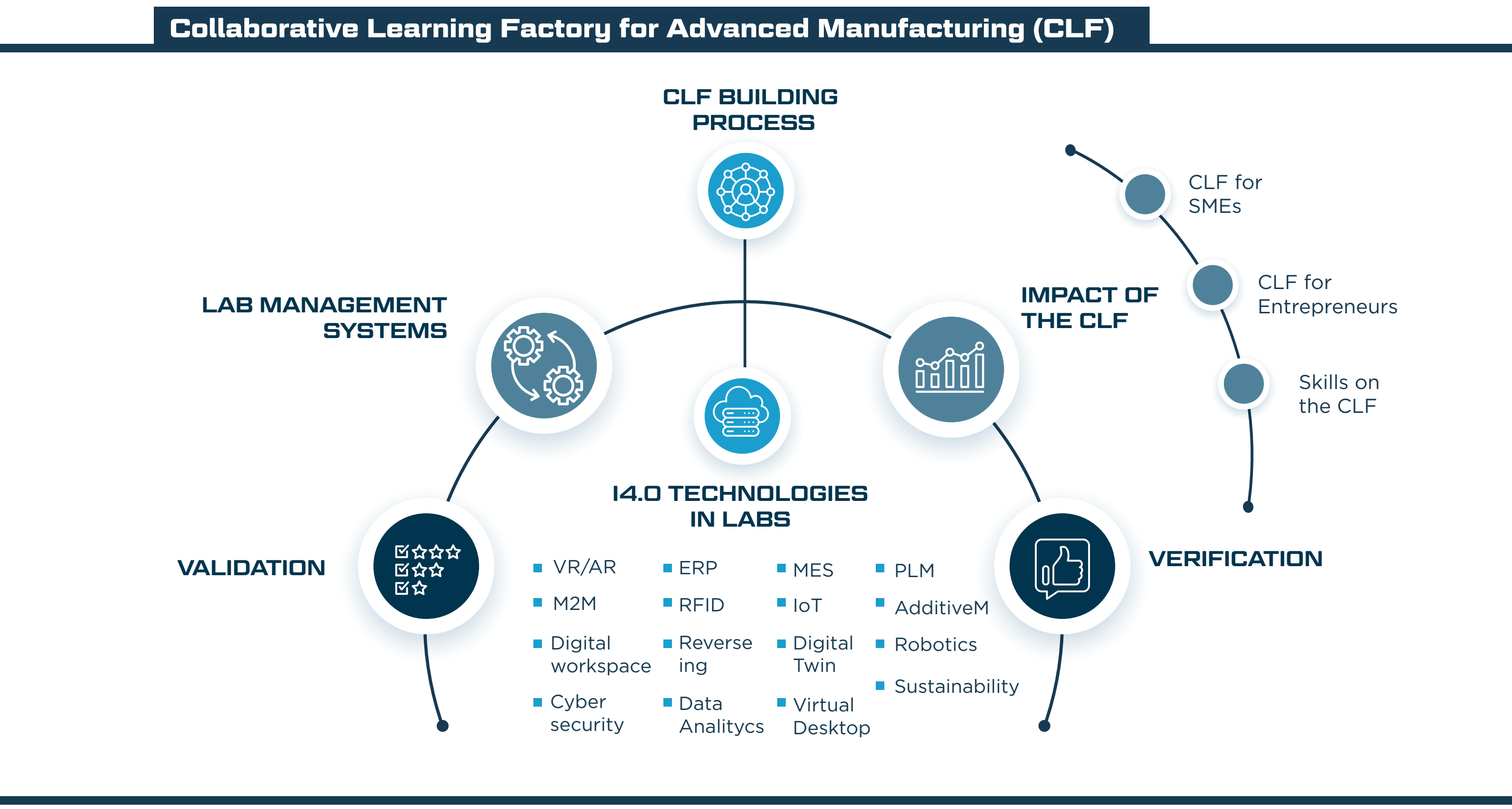


Figure 97: Result of Labs for Advanced Manufacturing - CLF. Source: Exam4.0

01. VALIDATION REPORT (PUBLIC)	Validation of the AM lab concept by EXAM4.0 stakeholders. (EXAM4.0, 2021)
02. LABS MANAGEMENT SYSTEMS (PUBLIC)	We describe the management solution we have studied and tested in partner's labs and in the EXAM4.0 CLF. In an industry 4.0 context, the ERP solutions together with MES and PLM integration have become a central element. (EXAM4.0, 2021)
03. AM LABS RUNNING (PUBLIC)	It describes the conceptual design of the CLF. It also includes details about the piloting process of 16 industry 4.0 technologies imple-mented in our labs and the relations among them. (EXAM4.0, 2021)
04. AM LABS RUNNING (PUBLIC)	It describes the process of implementing the CLF and producing the mobile robot. (this document)
05. EQUIPMENT UPDA-TED (CONFIDENTIAL)	It describes the equipment and methodology update carried out by partners institutions as a result (or influenced by) their participation on the project.
06. PROTOCOL OF EXPLOITATION OF CLF BY SMES (PUBLIC)	It describes how the CLF could support SMEs and its potential impact (EXAM4,0, 2021)
07. PROTOCOL OF EXPLOITATION OF CLF BY ENTREPRENEURS (PUBLIC)	It describes how the CLF could support entrepreneurs and its potential impact (EXAM4,0, 2021
08. SKILLS ACQUIRED BY THE STUDENTS TAKING PART IN THE PILOTING (PUBLIC)	It describes the impact of the piloting process on students and potential impact on their competences (EXAM4.0, 2021)
09. VERIFICATION REPORT (PUBLIC)	EXAM4.0 stakeholders validate and evaluate the overall piloting process and it impacts

Concerning the results on the technological side, we have also described the way we have worked with 16 Industry 4.0 enabling technologies collected in as many documents. (EXAM4.0, 2021)

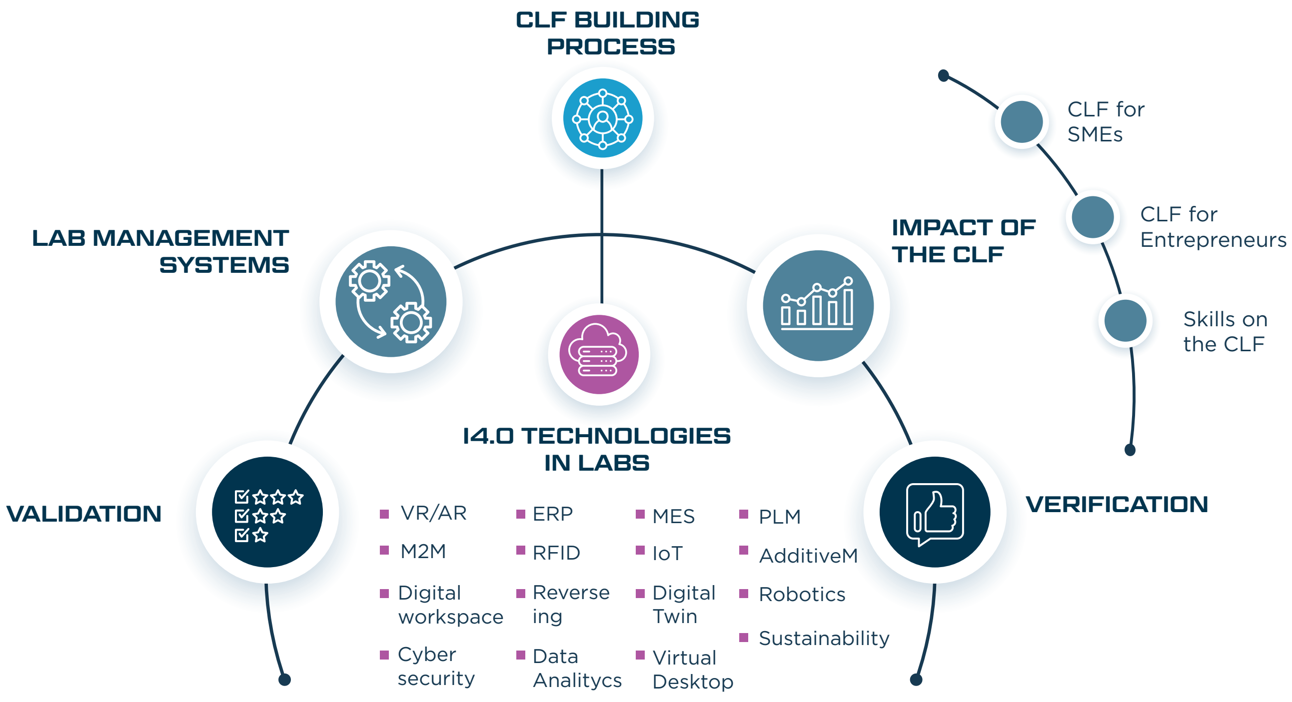


Figure 98: I4.0 technologies in labs. Source: Exam4.0

For each of them, we have described their implementation in the CLF, the competences worked on and the collaboration options they offer.

PARTICIPATION OF STUDENTS

EXAM's development has been strongly marked by the COVID 19 pandemic, which has hit it hard. The part where it has had the most impact has been the participation of students in the CLF. Many tasks have had to be modified and, in most cases, the most affected group has been students for obvious reasons. Even so, and despite the low participation, we have had the opportunity to develop the competence part of the CLF.

Although to a lesser extent than anticipated, students at different centers have been part of a real-life production process, from idea to final product. The students contributed to the design and production of the components as well as the assembling of the robot. The process of designing and making drawings, which were made with CAD, are different when it comes to components designed for real production compared to educational projects. However, student involvement could have been better if it had not been for Covid-19, which obviously brought along some pedagogical difficulties. If it had not been for the restrictions, the learning outcomes for the students would have been even better.

FINAL REMARKS

The CLF is a result of the project. The consortium now has a fully functional Collaborative Learning Factory, with significant data and information exchange.

The CLF did in turn result in a fully functional robot. It is a result of the process of the CLF and is, as aforementioned, created by staff of the consortium and students from the institutions. The robot is controlled with a Raspberry Pi4 and an application was created to steer the robot. Another result of the project and the CLF is the implementation of KETs. They have been implemented in relation to the project or to be able to cover and improve all essential aspects of the CLF. The institutions of the consortium are therefore, because of the project, provided with state-of-the-art technologies such as 3D-printers, robotics, technological systems and, as aforementioned, simulation technologies such as AR. These new technologies are large assets for the EXAM platform as well as the CLF.

Therefore, the main result is that we have laid the foundations of the structure and operation of a distributed learning factory, probably the first collaborative learning factory in Europe.

6 Lesson learned and future challenges

During the EXAM 4.0 project, we realized that we had underestimated the potential risks that could occur setting up a complex initiative such as the CLF. To avoid eventual risks in an early stage we carried out a risk identification. This identification took place once every month.

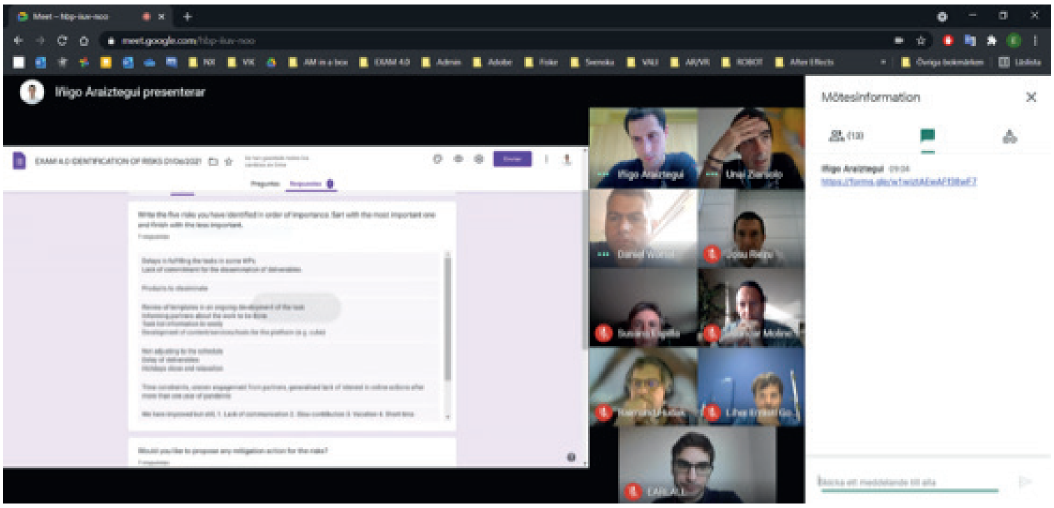


Figure 99: Consortium risk identification. Source: Exam4.0

LESSONS LEARNED WITHIN WP5

The CLF helped the consortium to be better at collaborating and communicating. It was necessary for the consortium to have several meetings during the process of creating the EXAM robot. There were a lot of aspects to cover during the process such as the actual manufacturing of the robot but also all other additional aspects, such as documentation. A lesson learned during this process was that context is often understood in different ways by different partners during meetings or emails. It is therefore important to make sure that everybody is on the same track and to be extremely clear when explaining things or when making decisions. The communicative misunderstanding within the Collaborative Learning Factory led to some delays in the process of producing the EXAM robot. These communications errors have now been considered and this aspect is to be improved in future pilots. The main conclusion regarding communication errors is that the best channel is a digital meeting where participants see each other and the presenter is sharing his/her screen.

The first pilot of the CLF, creating the robot, was an examination to see the possible benefits of piloting such a learning environment. Students were involved in this pilot, by designing and producing components for the product, they will however be more comprehensively involved in future collaborations. The consortium learned from this pilot and will use this knowledge to make the CLF a self-propelled learning method suitable for education. All required data for the EXAM robot is produced during the first pilot. The process of creating more EXAM robots will therefore be more automatic, thus easier, and more beneficial to involve students during the entire process.

Of all the unplanned events that have occurred during the life of the project, we have highlighted for this report those that we consider relevant and should be considered to ensure the sustainability of the CLF.

FUTURE CHALLENGES

In the following table we have included as a conclusion dome risk and challenges we consider relevant for future activities of the CLF and even for future projects. We also propose potential solutions or measures to face those challenges.

LESSONS LEARNED AND CHALLENGES FOR THE CLF	
RISKS/CHALLENGES	**SOLUTIONS/MEASURES/FUTURE ACTIONS**
Delays in contributions. **Tasks not finished.**	Set up "Work monitoring tool" and "track and trace tool" Once the IT infrastructure is in place for the connected CLF, a track and trace system must be implemented. This system allows the monitoring of detailed information on the tasks, the manufacturing state of each component, the expected delivery date, etc. In case of incidents, the system must indicate new delivery dates with the consequent reorganization of the entire production chain. As it happens in industry, certain penalty measures could be adopted for the responsible of tasks.

RISKS/CHALLENGES	SOLUTIONS/MEASURES/FUTURE ACTIONS
The technical complexity of certain I4.0 implementations or certain activities are underestimated.	• Use of synergies between training centers. • Create an "internal support or consultancy service" to advise and guide the implementation of technologies from the most experienced centres. It is foreseen that the EXAM4.0 platform will offer this type of service to any VET centre that requires it, so this internal service would be the seed to create a contrasted service.
Problems for the integration of I4.0 solutions among partners. Heterogeneity of suppliers, software and solutions.	**Standardization of processes.** • The manufacturing processes of each partner involved in the CLF must have an important level of standardization to ensure proper communication. Furthermore, the processes are linked to common training programs, so standardization is doubly important. The minimum standards foreseen will be set out in templates. The idea of modularity is important to generate flexible and scalable processes. • The distributed LF implied by the CLF requires a minimum consensus on some of the jointly used solutions. Partners who participate directly in the CLF by linking their processes to the CLF must agree on the common applications to be used. It is very likely that in the future centres with third party applications will want to join the CLF, so it is necessary to work with our solution providers to have a flexible and compatible system.

RISKS/CHALLENGES	SOLUTIONS/MEASURES/FUTURE ACTIONS
High investment needed to set up advanced manufacturing labs.	We will promote the Virtualization of processes to reduce the investments to participate in CLFs and to have access to the training courses that take place there. A solution will be to create the digital twins of the individual LFs and data and information sharing to put in place courses without having the physical equipment. We will also promote the use of virtual desktops to facilitate the access to solutions without the need of powerful computers These actions will led us to the democratization of AM training.
Differences in education systems	We will continue using European standards (EQF) to identify the levels of training put into practice. As a complement, as a group we will work on a generic level and it will be the responsibility of each organization to adapt the contents to the particularities of their educational systems. All the developments carried out in the CLF should be useful for any EU educational systems,
Operational Misunderstandings and terminology issues. Multicultural /Multilingual issues: It may happen that the interpretation of certain tasks is different in each partner country. Indeed, even if the same terminology is used, its interpretation is not identical in all countries. These differences can lead to errors, delays and even conflicts.	One of the strengths of the CLF is its international co-creation. Multiculturalism and multilingualism are understood as an opportunity for learning and mutual enrichment rather than as an obstacle. Of course, it is necessary to put tools in place to facilitate the process and avoid misunderstandings. The elaboration of a Diversity plan will help to better understand the members of the working groups when international students are working together in the same project. A glossary will gather some key terms that are important to be identically interpreted in order to avoid misunderstandings. The definition of the terms will be individually discussed and agreed among the group members.

RISKS/CHALLENGES	SOLUTIONS/MEASURES/FUTURE ACTIONS
Lack of Involvement of collaborative units' staff	A key aspect is to create a high Culture of digitalization among the staff/ among the participants. Without motivation and involvement of people the CLF will never run properly. So, it is very important to make an effort to take care of these aspects. All the participant organizations will have a list of actions that they can implement in their organizations to enhance this culture.
Lack of visibility of the results and progress	We will use agile development methodology to set up new courses, new technological implementation or other tasks to be developed among members. Among other features, we will use sprint tasks with precise deliverables and indicators.

7 References

AutomationWorld. (2021.eko Dicemberk 12). Retrieved from https://www.automationworld.com/products/software/article/13314943/plm-mes-erp-closedloop-product-lifecycle

Enisa. (2021.eko Dicemberk 10). Retrieved from https://www.enisa.europa.eu/topics/iot-and-smart-infrastructures

EXAM4,0. (2021). 6 Protocol of exploitation of CLF by SMEs. Retrieved from https://examhub.eu/proposals-for-advanced-manufacturing-4-0-labs/

EXAM4,0. (2021). 7 Protocol of exploitation of CLF by Entrepreneurs. Retrieved from https://examhub.eu/proposals-for-advanced-manufacturing-4-0-labs/

EXAM4.0. (2020). EXAM4.0. The Advanced Manufacturing 4.0 technology framework. Retrieved from: https://examhub.eu/wp-content/uploads/2021/04/WP_4_2.pdf

EXAM4.0. (2020). EXAM4.0 COMPETENCE Framework. "Methodologies for analysing and anticipating skills need in the Advanced Manufacturing sector".Retrieved from https://examhub.eu/wp-content/uploads/2021/04/WP_2_3.pdf

EXAM4.0. (2021). 03 Advance Manufacturing labs running. Retrieved from https://examhub.eu/wp-content/uploads/2021/12/3AdvancedManufacturingLabs_running.pdf

EXAM4.0. (2021). 1 Labs for Advanced Manufacturing. Validation report. Retrieved from https://examhub.eu/validation-report/

EXAM4.0. (2021). 2 The ERP, Enterprise Resource Planning Adapted to the Project Needs. Retrieved from https://examhub.eu/the-erp-enterprise-resource-planning-adapted-to-the-project-needs/

EXAM4.0. (2021). 8 Report on skills acquired by the students taking part in the piloting. Retrieved from https://examhub.eu/proposals-for-advanced-manufacturing-4-0-labs/

Forcam gmbh. (2021). Modular IIoT solution FORCAM FORCE IIOT.Retrieved from https://forcam.com/en/

Rudeck, E. (2021.eko Dicemberk 13). Retrieved from https://www.concurrent-engineering.co.uk/blog/bid/99442/why-companies-need-a-plm-system

ThingsBoard, Inc. (2021). Thingborad IoT platform. Retrieved from https://thingsboard.io/

Zemsania. (2021.eko November 25). Retrieved from https://zemsaniaglobalgroup.com/3-claves-para-la-convergencia-it-ot-big-data-iot-y-cloud/

EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0