Learner Centric Advanced Manufacturing Platform

INDUSTRY 4.0 TECHNOLOGY ABSORPTION THROUGH THE COLLABORATIVE LEARNING

PART 1: RESEARCH ON THE ROLE OF LEARNING FACTORIES IN VET EDUCATION

PART 2: MORPHOLOGY OF THE LCAMP COLLABORATIVE LEARNING FACTORY

PART 3: GUIDELINES FOR THE IMPLEMENTATION OF I4.0 TECHNOLOGIES IN VET LABS

WP6 Industry 4.0 technology absorption through the Collaborative

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Document description	This document is divided into three part that analyse the use of Learning Factories in Vocational Education and Training (VET) centres providing technical study programs related to Advanced Manufacturing and Industry 4.0, describes the main features of the Collaborative Learning Factory and provides set of guidelines for the implementation of i4.0 technologies in VET labs.
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CONTENT TABLE

1. PART 1: RESEARCH ON THE ROLE OF LEARNING FACTORIES IN VET EDUCATION

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GLOSSARY AND/OR ACRONYMS

AI - Artificial Intelligence
AM - Advanced Manufacturing
CLF Collaborative Learning Factory
CoVE - Centres of Vocational Excellence
EXAM4.0 Excellence Advanced Manufacturing 4.0
EC European Commission
EQF European Qualifications Framework
EU European Union
HE Higher Education
HVET Higher Vocational Education and Training
I4.0 Industry 4.0
IALF International Association of LFs
IoT Internet of Things
LCAMP Learner Centric Advanced Manufacturing Platform
LF Learning Factory
LF4.0 Learning Factories 4.0
OECD Organisation for Economic Cooperation and Development
SDLF 4.0 Scale-Down Learning Factories 4.0
SIF Smart Innovative Factory
TVET Technical and Vocational Education and Training
VET Vocational Education and Training

EXECUTIVE SUMMARY

This document analyses the use of Learning Factories in Vocational Education and Training (VET) centres providing technical study programs related to Advanced Manufacturing and Industry 4.0. The countries included in the study are France, Germany, Italy, Netherlands, Slovenia, Spain, Sweden, Türkiye, and Canada. .

Overview

The report examines the various approaches to the setting up of Learning Factories (LF) in VET centres, their different contexts, and the challenges they face in different countries. It also provides a brief overview of the current state of Learning Factories in each country, highlighting key trends and initiatives.

Learning Factories in VET centres

"Learning Factories are a practical way of teaching in a hands-on environment, specialized learning environments that replicate real-world industrial settings and provide hands-on learning experiences for students." (E. Abele, 2015). In recent years, the trend of creating LF in the educational field has emerged. This fact is due to the positive contributions that this type of work-based learning offers in learning environments. The benefits of LFs at university level are well documented in literature. The approach is likewise useful for VET study programs.

However, the use of LFs in VET is not very popular. The research carried out in 9 countries shows that with very few exceptions, the variation of LFs denominated Scale Down Learning Factories (SDLF) are the most common type of LFs used in VET. These modular sized LFs, normally commercially supplied with didactic purposes, use equipment with reduced size compared with industrial equipment. Those SDLF are equipped with state-of-the-art digital technologies used in Industry 4.0 environments but they work on elements with smaller dimensions. Their didactic function makes them appropriate to address not only technical competences but also transversal ones. On the other hand, the SDLF lack the potential of working in the manufacturing of real products for which life size are needed. In that respect, the pedagogical approaches of SDLFs are more limited.

The core LFs, meaning life size environment with industrial equipment and lay out, are not common in VET centres. This publication reports on the pilot Collaborative Learning Factory concept which was followed up by the LCAMP project and is being approached as a joint Learning Factory.

Main findings

The use of LFs in Vocational Education and Training Centres is less common that the SDLF. The research found 175 VET centres using such facilities, most of them in Germany (39%) followed by Spain (including Basque Country) 25%.

A general finding in all the studied regions is that different types of active methodologies are widely implemented in VET schools, usually including the participation of industry partners. The use of active methodologies is common, independently of the use of LFs or SDLFs. In certain cases, similar learning methods to LFs are being used but with different/alternative denominations. Indeed, in some of the studied countries the term Learning Factory does not appear to be commonly used.

For the competences addresses in SDLFs, study programs and configurations used in the countries studied have many agreements. Their applications are usually for advanced manufacturing and industry 4.0 related VET study programs where they mostly address technical competences. Programs such as industrial automation, robotics, mechatronics, maintenance, advanced manufacturing, mechanical engineering, manufacturing production, control engineering and similar are using those pieces of equipment. These SDLF give certain space to develop many transversal skills, although they are also more limited than life size LFs to create interdisciplinary environments where more options are available.

Potential of life size LFs in VET

The study concludes that training in advanced manufacturing carried out in real environments and using active teaching methodologies provides great benefits.

It, moreover, suggests that VET centres are working with active teaching methodologies and that, in some cases, they also work with SDLFs.

If we furthermore take into account that LFs work well at university level, we can infer that the implementation of LFs in VET makes sense as a means of reinforcing training in advanced manufacturing.

1. INTRODUCTION

2. Objectives

This report analyses the use of Learning Factories (LF) in Vocational Education and Training (VET) and Higher Vocational and Training (HVET) centres providing technical study programs (EQF 3-6) in the countries represented by the LCAMP consortium, which are France, Germany, Italy, Netherlands, Slovenia, Spain, Sweden, Türkiye and Canada.

The report examines the various approaches to the setting up of LFs in VET centres, their different contexts, and the challenges they face in different countries. It also provides a brief overview of the current state of LFs in each country, highlighting key trends and initiatives.

In section 2 a mapping of LFs in those countries is shown. The mapping covers the main characteristics of the analysed LFs and a general overview of the competences and skills commonly addressed by the analysed LFs.

3. Research Methodology

The report is based on studies and desk research carried out by the partners involved: Miguel Altuna, Tknika, DHBW; VSS, CMQ, DVC, CNG, MADE; KPDONE, Camosun.

The studied European regions or countries are; Basque Country, Spain, Baden Wurttemberg (Germany), Slovenia, France, The Netherlands, the Västra Götaland region (Sweden), Italy, Kocaeli (Türkiye).

The methodology used has been direct interviews and structured surveys in regional VET networks conducted by partner organizations. A total number of **163 VET centres** and **53 other organizations in 9 countries** were included in the analysis.

COUNTRIES/REGIONS	NUMBER OF VET CENTRES ADDRESSED	NUMBER OF VET CENTRE INCLUDED IN THE STUDY	NUMBER OF UNIVERSITIES, RTO, COMPETENCE CENTRES
Basque Country	16	12	4
France	45	2	0
Germany	68	68	28
Italy	Not applicable (1)	0	8
Netherlands	13	13	0
Slovenia	10	5	1
Spain	29	21	8
Sweden	11	1	0
Türkiye	23	23	0
Canada	18	18	4
TOTAL	**233**	**163**	**53**

(1) Only in Lobardy there are 900 VET centres and there is no official data available as to whether those VET centres are using LFs or not.

➢ *Table 1 Scope of the study*

The second source of information have been the suppliers of commercial SDLFs. The 2 main suppliers are SMC International Training and Festo Didactics. In this case, the information may not be accurate enough in some of the covered regions due to the difficulties in contacting the regional distributors.

Thirdly, we have relied on publications of the International Association of Learning Factories to reinforce the analysis.

4. IDENTICATION OF LFS IN VET CENTRES

5. Definition of a Learning Factory

“Learning Factories (LF) are a practical way of teaching in a hands-on environment, specialized learning environments that replicate real-world industrial settings and provide hands-on learning experiences for students. These LFs are designed to simulate industrial processes and allow students to apply the knowledge they have acquired in the classroom to a real-world environment. They are typically a simulated work environment, complete with tools, machines, and materials, where students can practice and apply the skills and knowledge they are learning in a real-world setting. They can also be used to introduce students to a particular industry or field, allowing them to gain a better understanding of the types of tasks, processes, and technologies associated with the field” (Abele E., 2015)

In a high-tech educational environment such as LFs, students can gain practical experience in a simulated industrial environment. They are equipped with advanced technology, including robots, computer-controlled machines, and other automated systems, which allow students to learn in a realistic and immersive way. The LF model has been shown to be effective in supporting the learning of technical and practical skills (E. Abele, 2015), as well as problem-solving and critical thinking.

In recent years, the trend of creating LF in the educational field has emerged. This fact is due to the positive contributions that this type of work-based learning offers in learning environments. In order to improve or acquire technical skills, self-explanatory and easy to use tools can be used in the area of work-based learning. On the one hand, these tools allow the employee to manage complex situations, while at the same time, making the process more efficient (Adolph, Tisch, & Metternich, 2014).

6. Types of Learning Factories

The reference model used in this report to describe the LFs is the Learning Factory Morphology given by the International Association of Learning Factories (IALF): *“A Learning Factory is a learning environment where processes and technologies are based on a real industrial site which allows a direct approach to product creation process (product development, manufacturing, quality-management, logistics). Learning factories are based on a didactical concept emphasizing experimental and problem-based learning. The continuous improvement philosophy is facilitated by own actions and interactive involvement of the participants.”* (Abele E., 2015) (IALF, 2021)

Under the IALF definition a lot of different configurations of LFs are possible. The IALF describes the variety of the LF concept diversity along seven dimensions as show in **Figure 1**. (Abele E., 2015) (Tisch, 2019)

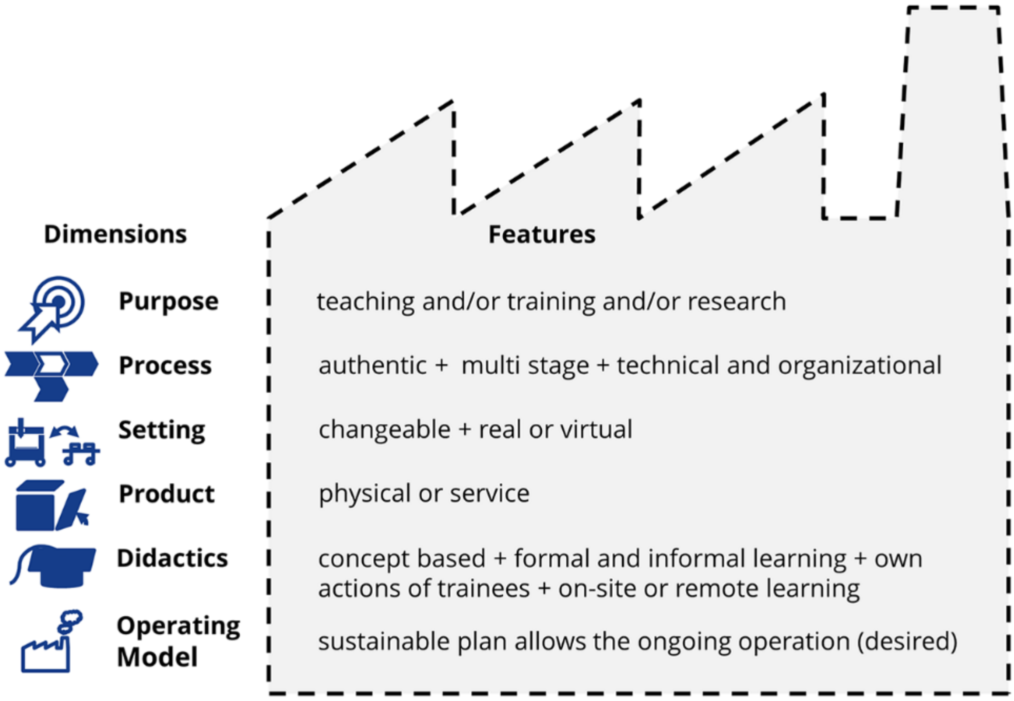

Figure 1 *Dimension of a LF Source: (Abele E., 2015)*

The description of those dimension makes it possible to compare LFs along the mentioned 7 dimensions.

- Operational model
- Purpose and targets
- Process
- Setting
- Product
- Didactics
- Metrics

For Each of the 7 dimensions there are multiple variants, therefore an exhaustive comparative analysis requires all those details for all the described LFs.

The target of the current study are LFs established in VET and HVET centres, study programs for students of EQF levels 3-6. In some cases, the purpose of the LFs covered in this study will also be ongoing worker training.

Taking as a reference the guidelines established by the IALF, the core concept of the LF consists of a realistic, **physical life-size factory environment** in which a physical product is created that learners can experience directly on site (Abele E., 2015). However, there can be some variations to that concept that are also considered as LFs, which are:

- Scale Down Learning Factories or model scale Learning Factories (SDLF)
- physical mobile LFs,
- low-cost LFs,
- digitally and virtually supported LFs
- producing LFs.

Considering the competences addressed in VET centres and taking into account the presence of SDLF in VET schools, we have included 2 main groups of LFs in this study:

- **Standard Learning factories:** Following the core concept of LFs: "a realistic, physical **life-size factory** environment in which a physical product is created that learners can experience directly on site (Abele E., 2015) Some examples are shown in **Figure 2** and **Figure 3**.
- **Scale Down LFs**, modular sized LFs, normally commercially supplied with didactic purposes. "Scaled or model scale LFs do not use original factory equipment but smaller equivalents, which should differ as little as possible from the original factory equipment except for the smaller dimensions" (Abele E., 2015). (Examples show in section 9.1).

Whatever the configuration of the LF is, they offer a prominent action oriented pedagogical approaches which are aligned with the competence building methods generally used in European VET systems. The pedagogical approaches enhancing experiential learning and project-based learning help to develop new ways to work simultaneously on job specific and transversal competences (OECD, 2021).

Figure 2 *The IIoT LF in TU Darmstadt. Source: TU Darmstadt*

Figure 3 *Smart Production Lab. Source: FH Johanneum*

7. Presence of LFs in VET centres

The reference model used in this report to describe the LFs is the Learning Factory Morphology given by the International Association of Learning Factories (IALF): *"A Learning Factory is a learning environment where processes and technologies are based on a real industrial site which allows a direct approach to product creation process (product development, manufacturing, quality-management, logistics). Learning factories are based on a didactical concept emphasizing experimental and problem-based learning. The continuous improvement philosophy is facilitated by own actions and interactive involvement of the participants."* (Abele E., 2015) (IALF, 2021)

Under the IALF definition a lot of different configurations of LFs are possible. The IALF describes the variety of the LF concept diversity along seven dimensions as show in **Figure 1**. (Abele E., 2015) (Tisch, 2019)

8. Competences and Skills

The competences and skills that can be trained in LFs are varied and cover a wide range of disciplines and industries. These can include technical skills such as automation, operating machinery, programming, robotics, as well as transversal skills like communication, teamwork, critical thinking and problem-solving.

One of the main advantages of LFs is that they provide an immersive and experiential learning environment, which can help to bridge the gap between theory and practice. By simulating real-world scenarios and challenges, learners can develop the confidence and competence needed to succeed in their chosen profession.

Furthermore, LFs can be tailored to meet the needs of different learners and industries, making them a flexible and adaptable approach to vocational and educational training. Whether someone is looking to develop a specific technical skill or to build their soft skills and professional competences, a LF can provide an effective and engaging learning experience. Furthermore, the LFs are configurations to fulfil users need which will determinate the purpose of the LF. Therefore, depending on the desired competences and skills the configuration of the LF may change.

Concerning the SDLF 4.0 for advanced manufacturing and industry 4.0 they are designed mostly to address technical competences of industry 4.0. Depending on the modules purchased and their set up, the competences will vary. In the case of Germany, the methodologies of the LFs aims to link competences of mechanical engineering, electrical engineering an IT with professional production management systems' competences.

Taking as example the stationary LF by SMC International Training (SMC International Training, 2023) the competences and skills obtained by learners would be the following.

- Technical skills: the assembly, testing, and maintenance of sensors and measurement systems. This includes the use of specialized tools and equipment, such as soldering irons, oscilloscopes, and multimeters. They could include 3D printing, CNC machining, and robotic assembly.
- Quality control: Learners can develop competences related to quality control processes and procedures. This includes the ability to identify defects and implement corrective actions to ensure that products meet the required specifications.
- Lean manufacturing: Learners can develop competences related to lean manufacturing principles and techniques. This includes the ability to identify and eliminate waste, optimize production processes, and improve efficiency.
- Collaboration and teamwork: Learners can develop competences related to collaboration and teamwork. This includes the ability to work effectively in a team environment, communicate with colleagues, and contribute to the achievement of common goals.
- Problem-solving: Learners can develop competences related to problem-solving. This includes the ability to identify and analyse problems, develop and evaluate alternative solutions, and implement effective solutions.

Another example of competences addressed by SDLFs can be found hereafter: the learning goals of the MPS 404-1 model by FESTO Didactics (Festo Didactics, 2023):

- Networking of multiple stations, controllers and I/O units with an MES-centred software environment via network-based protocols (OPC UA, IO-Link, PROFINET, TCP-IP, Node-RED).
- Programming of industrial touch panel and getting to know modern human-machine interfaces such as augmented reality and web interfaces.
- Getting to know RFID and network technology and intelligent sensors based on IO-Link.
- Getting to know new business models through IIoT retrofitting using webcam and small computers as well as application of algorithms from the field of machine learning.
- Manufacturing of customised products through Webshop-induced manufacturing orders.
- Vacuum and parallel gripper technology and conversion of production systems.

9. Collaborative Learning Factory

The Collaborative Learning Factory (CLF) is a concept that brings together the principles of collaborative learning and the structure of a factory-like environment to enhance the learning experience. It is a model that promotes active participation, teamwork, and practical application of knowledge. By combining hands-on activities with group collaboration, the CLF fosters a dynamic and engaging learning environment.

The key idea behind the CLF is to simulate real-world scenarios and challenges within an educational setting. It aims to bridge the gap between theoretical knowledge and practical skills by providing students with opportunities to work together, solve problems, and apply their learning in a realistic and meaningful way. The factory-like environment offers a structured framework that allows students to experience the entire process of a project, from conception to completion.

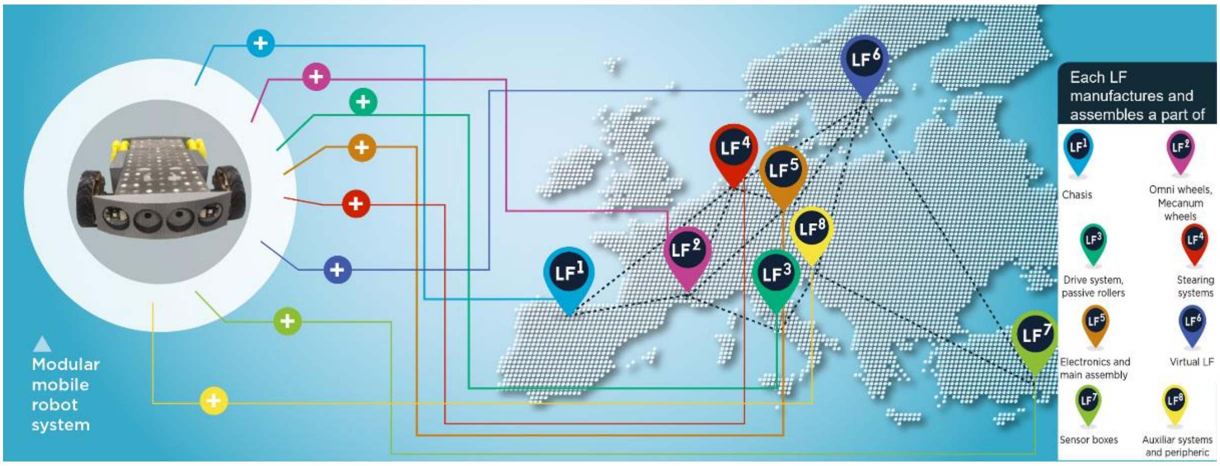

Figure 4 CLF, network of LFs Source: LCAMP

LFs or manufacturing labs to set up a common infrastructure to design, manufacture, and assemble products in collaboration The CLF is a part of the Learning Centric Advanced Manufacturing Platform (LCAMP), an international network of VET providers that have linked their regional autonomous (EXAM4.0, 2019). In the CLF, the product is subdivided into sub-products and each subproduct is produced in independent LFs located in different regions (see **Figure 4**). The final assembly of all the subproducts is carried out in CLF's final assembly line, located in a partner's lab (EXAM 4.0 (b), 2021) (EXAM4.0 (a), 2021).

This international consortium aims to enrich local independent LFs and/or manufacturing labs by fostering international collaboration. Currently 8 organizations, VET centres, a competence centre and a university of applied science are involved in the initiative.

10. International Association of Learning Factories

The International Association of Learning Factories (IALF) is a global organization dedicated to promoting and advancing the concept of LFs in education, research, and industry. Its mission is to foster collaboration, knowledge exchange, and innovation in order to enhance the effectiveness of LFs worldwide. The emphasis is in the relevance of improving technical skills and competences, as well as efficient capacity in newer processes. (IALF, 2021)

These are the LFs that are registered in the IALF.

EUROPE, MIDDLE EAST AND AFRICA	UNIVERSITY	LFs NAME
Austria	Vienna University of Technology	**Pilot Factory Industrie 4.0**
Greece	University of Patras	**LMS Learning Factory**
Germany	RWTH Aachen University	**DCC Aachen**
Germany	Braunschweig Institute of Technology	**Die Lernfabrik**
Germany	Reutlingen	**Werk150**
Hungary	Hungarian Academy of Sciences	**Centre of Excellence in Production Informatics and Control**
Germany	Ruhr University Bochum	**LPS Learning Factory**
Germany	Karlsruhe Institute of Technology	**Learning Factory Global Production**
Sweden	KTH Royal Institute of Technology	**XPRES real lab**
South Africa	Stellenbosch University	**Stellenbosch Learning Factory (SLF)**
Italy	Free University of Bolzano	**Smart Mini Factory**
Germany	Technische Universität Darmstadt	**Prozesslernfabrik - Center for industrial Productivity (CiP)**
Luxembourg	University of Luxembourg	**Operational Excellence Laboratory**
Austria	Graz University of Technology	**LEAD Factory**
Bosnia & Herzegovina	University of Mostar	**FSRE Learning Factory**
The Neatherlands	University of Twente	

Croatia	University of Split	**Lean Learning Factory**
Finland	Aalto University	**Aalto Factory of the Future**
Germany	Technical University of Munich	**Learning Factory for optimal machining (LOZ)**
AMERICAS	**UNIVERSITY**	**LFs NAME**
Canada	University of Alberta	**ALLFactory**
USA	Purdue University	**Intelligent Learning Factory (ILF)**
Canada	McMaster University	**SEPT Learning Factory**
Brazil	Universidade de São Paulo	**Fábrica do Futuro**
ASIA-PACIFIC	**UNIVERSITY**	**LFs NAME**
Malaysia	Universiti Malaysia Pahang	**FIM Smart Learning Factory**
Singapore	Agency for Science, Technology and Research	**Model Factory@SIMTech**
China	Tongji University	**LFF for 5G and AI Technology Application**

➢ ***Table 2*** *LFs registered in the International Association of Learning Factories (IALF)*

The Conference in LFs is organized every year in different places. (IALF, 2021)

11. FINDINGS

12. Overall Findings

The VET systems in the studied countries have some remarkable differences. Among those differences, the equipment and machinery in advanced manufacturing, mechatronics and robotics labs varies from region to region, even between regions in same member states. In regions where the investment in VET education is high, we can find very well-equipped labs with state-of-the-art machinery. The setting up of LFs, not only involves pedagogic challenges but also high investments are also needed. It is not surprising that those regions where VET schools are better equipped are also the regions where LFs, more precisely SDLFs, have been found.

A remarkable finding is that independently of the investments on equipment and therefore the presence of SDLFs, the active methodologies are well spread in all the VET systems; We have found examples of problem-based learnings, work-based learnings, training based on collaborations with companies and similar in all the studied regions.

Standard LFs with life size factory approaches are not commonly used as such among the studied VET centres.

However, the SDLF concept, also known as training systems for Industry 4.0 (SMC International Training, 2023) and Modular Production Systems (Festo Didactics, 2023) are becoming rather common in VET school. These modular pieces of equipment are commercially available and configurable. Users acquire the modules appropriate for their training purposes based on their investment capacity. It is possible to start for the simplest (and cheapest) 1-2 modules configuration and scale it up to 10-14 modules' set ups where rather high investments are needed.

The SDLF are usually designed to address technical competences of industry 4.0. The identified SLDF are use in study programs such as automation, industrial robotics, mechatronics and other Industry 4.0 related courses. Some examples of Industry 4.0 logistics have also been found. Usually there are not interdisciplinary training courses involved. That is, students in one program do not interact with students from another program.

In all the countries included in this research there are several VET schools where they have already implemented such equipment. This SDLF are also used in engineering studies at universities. **Table 3** shows the figures.

COUNTRIES/ REGIONS	NUMBER OF VET CENTRES INCLUDED IN THE STUDY	NUMBER OF LF FOUND (LIFE SIZE)	NUMBER OF SDLF FOUND	NUMBER OF LABS CLOSE TO LF CONCEPT (USING PBL, PIECED LFS, ACTIVE METHODOLOGIES ETC.	NUMBER OF LF IN UNIVERSITIES, RTOS (LIFE SIZE + SDLF)
Basque Country	31	2	14	31	4
France	45	0	2	Not included [1]	Not included
Germany	68	0	68	Not included	28
Italy	0	0	0	8	8
Netherlands	13	0	Not included	13	Not included
Slovenia	5	0	4	5	1
Spain	55	0	35	1 (Not exhaustive) [2]	5
Sweden	1	0	0	11	0
Türkiye	23	0	7	23	0
Canada	18	2	8	18	4

(1) Individualized study of the VET centres using active methodologies in their courses was not included.
(2) There could be more centres using active methodologies.

➢ ***Table 3*** *Number of SDLFs found in the studied EU regions.*

In the annexes 1-10 the detailed information per country is given.

13. Findings by countries

14. Overview

The results of the study show that the presence of LFs in the different countries is not homogeneous. **Figure 5** shows the distribution of the identified SDLF in VET centres and universities. The reasons for the differences are various:

- Difficulties to access to official data in some countries.
- The term Learning Factory, Scale Down Learning Factory or LF 4.0 are not widely used in all the regions to refer to the training equipment commercialized by SMC International Training and FESTO Didactics. It is possible that more VET centres have them but use another denomination.
- Different public policies and funding to invest in SDLFs.

Figure 5 *Identified centres with SDLFs, SDLF and LF in Universities and CLF partners in Europe. Source: Author's creation*

In the following sections the main conclusions of the regional analysis displayed. For the full regional analyses refer to annexes 9.2 to 9.10

15. Findings in France

The study has not yet found LFs in France. However, the research shows that project-based learning is quite common in France as it is implemented in every professional high school through the manufactured object initiative. For these project-based learning initiatives to be LFs, students would need to work on the entirety of the project from start to end and not only for a few steps of the project.

It is likely that despite our findings there are LFs in France. However, as they do not use that term, they are difficult to identify.

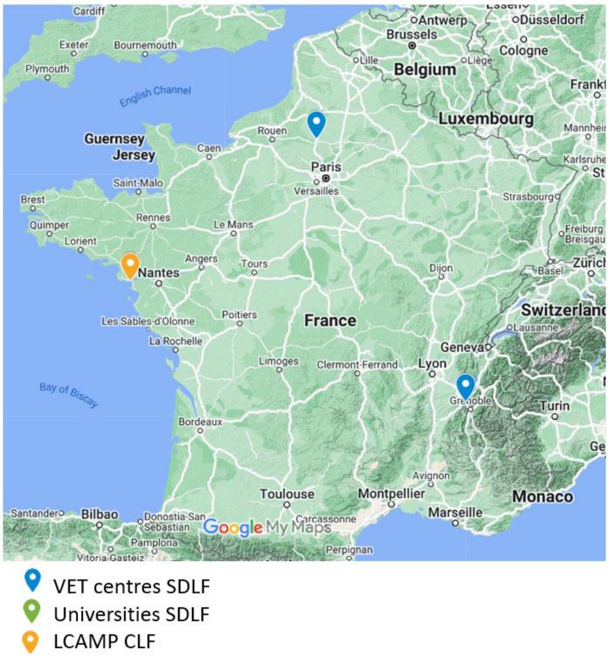

Figure 6 *Identified centres with ScLFs, SDLF in universities and CLF partners in France. Source: Author's creation*

Full report about France is available in the annex, section Error! Reference source not found.

16. Findings in Germany

The concept of SDLF is rather established at the VET centres level. There are specific regional policies and funding to foster such methodologies. In Baden Wurttemberg we have identified 68 VET centres with such equipment. In particular trainees in technical apprenticeships such as mechatronics, machining mechanics or industrial mechanics do receive instruction and application of new technologies in the LFs. Furthermore, various VET centres collaborate with other schools and universities of applied science e.g., teacher training colleges and universities, to train and prepare teachers and trainers for I4.0 and appliance of new technologies. In some LFs, trainees are given the opportunity to contribute to production in small projects in collaboration with industrial companies.

Concerning Life Size Learning Factories (LSLF), they are usually used in universities of applied sciences (Hoschule für angewandte Wissenschaften (HAW)). The concept of LSLF at HAWs usually includes a project-based approach. LSLF enable students to gain an insight into processes and further production processes in semester projects where among technical competences soft skills referring to team competences and acting in groups can be acquired. In fact, the concept of LF was developed in Darmstadt University (Abele E M. J., 2015)

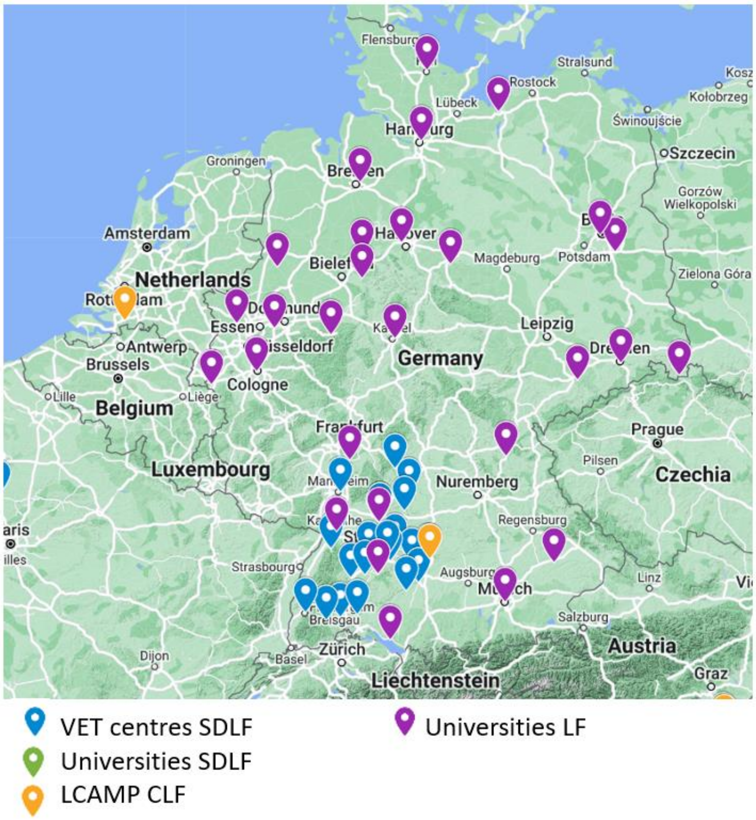

__Figure 7__ Identified centres with Scale Down LFs, LF in universities and CLF partners in Germany. Source: Author's creation

Full report about Germany is available in the annex, section Error! Reference source not found.**.**

17. Findings in Italy

The VET centres in Italy currently do not use LFs as a methodology for training in industry 4.0 related competences. No evidence has been found about the use of scale down LFs, although it is possible such pieces of equipment are already present in some HVET centres.

Concerning the Competence Centres spread in the national territory, they are pioneering at different level and speed Learning factories for training purposes, mostly for continuous training for industry and VET/HVET centres. Some LFs have a focus on creating technology knowledge, i.e., illustrating and showing how to use a digital technology in different industry rather than have a process perspective. This means there is not yet a widespread application of "connected LFs" aiming at upskilling digital competence of the manufacturing industry in a value chain perspective. The risk is that the highest technology focus might affect the practical approach or application into process manufacturing systems, thus making TFs difficult to adapt to different sector and leading to "technology silos".

However, MADE Competence Centre is the most advanced LF in Lombardy and Italy, pioneering the implementation of such approach also in international R&D project consortia (e.g., EIT Manufacturing).

Full report about Italy is available in the annex, section Error! Reference source not found.

18. Findings in the Netherlands

Although all VET centres have different Industry 4.0 facilities, they are focused on learning approaches and do not have defined products. All labs have their own unique approach based on the specific regional industries involved, but they have in common that all have a mix of the following elements: Access to state-of-the-art facilities, Project-based learning, Collaboration with industry partners, Entrepreneurship focus and Career guidance and support.

The centres have facilities and equipment to rather easy set up LF configurations. They are already using a very valuable features that enrich those labs as mentioned before. Based on this situation it is expected that most centres could set up a LF, with an entire production value chain to manufacture a product.

Full report about the Netherlands is available in the annex, section Error! Reference source not found.

19. Findings in Slovenia

In Slovenia we have not found VET schools with established LFs, following the definition of IALF in section 2.1. There is another initiative such as Inter-enterprise Training Centres, which has similar aims to LFs but whose methodology is rather different.

Full report about Slovenia is available in the annex, section Error! Reference source not found.

20. Findings in Spain

The use of life size LFs in Spain is not common. However, the SDLFs have emerged as a valuable approach to VET in Spain, particularly in the field of mechatronics and industrial automation and robotics.

The study identifies 27 VET centres out of the 214 centres in Spain (12%) using Industry 4.0 SDLFs. These figures are taken for the program *Industrial automation and robotics*. In the Basque Country 9 VET centres out 25 (36%) have stablished SDLF for Industry 4.0 for the same program. The establishment of the Spanish network of VET excellence centres would also foster this tendency. Currently 4%1 of those excellence centres operating in the mentioned fields are using SDLFs for Industry 4.0.

The term LF is not well known and there is certain confusion using it. LFs are, to a certain extent, linked to the modules commercialized by SMC International Training and FESTO Didactics whereas the core LF approach, using life size equipment is not widely known. 17% of the SDLF users do not use the term LF and they are not aware of the life size LF approaches.

Concerning the core LF approaches, the study identifies very few examples. The Collaborative Learning Factory (CLF) piloted in the EXAM4.0 initiative and currently followed up in LCAMP is one of those. In the Basque region CIFP Miguel Altuna LHII VET Centre established the Collaborative Learning CLF concept in their advanced manufacturing lab. Although the lay out of the equipment used in the LF is not exclusive, the disposition in manufacturing cells makes it possible to use life size equipment in the LF.

It is remarkable that the use of active methodologies is the standard in the Basque Country. VET centres work within the ETHAZI framework where the entire learning model is connected in a collaborative learning method based on challenges. The scheme used is very often close to the LF approach although this term is not commonly used. In other regions of Spain similar approaches are also becoming the norm.

The fact that frameworks such as ETHAZI are successfully implemented shows a clear strategy to foster methodologies where transversal skills are enriched. In that sense, the use of LFs, offers a wide range of possibilities to create new opportunities in this direction.

Figure 8 Identified centres with SDLFs, SDLF in universities and CLF partners in Spain. Source: Author's creation

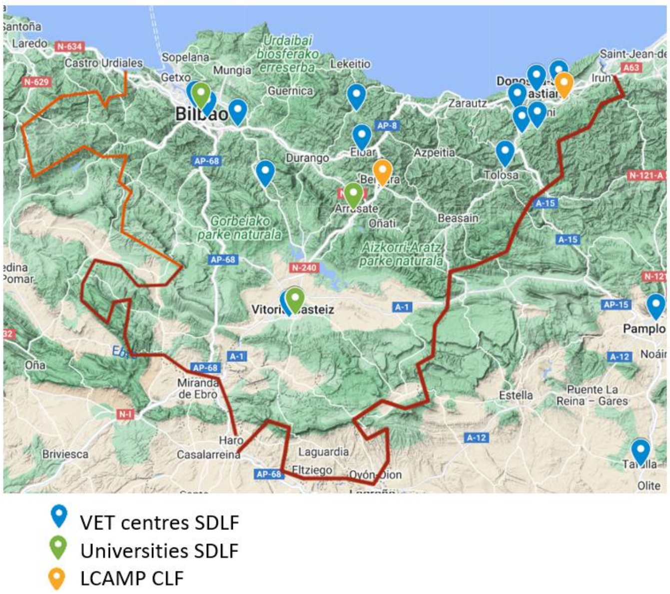

Figure 9 Identified centres with SDLFs in VET, SDLF in universities and CLF partners in the Basque Country. Source: Author's creation

Full report about Spain available i in the annex, section Error! Reference source not found.

21. Findings in Sweden

The conclusion of the research carried out in Sweden is that there are a variety of VET centers using LABS close to the LF concept. Life sized LF and SDLF are usually implemented in universities and HVET centres. Schools and companies are not eager to hand out too much information about equipment and educational methods. This may have been due to a lack of time and interest on their side.

On the other hand, there is a network of open innovation enviroment operating in Sweden with good examples of training facilities for life long learning on advanced manufacturing. The 12 organisations are public private partesrhip involving uninversities, researsh centres, large companies. Furthermore, some of those large companies have VET centres integrated. These open innovation enviroments operate LFs or SDLFs for their training and research activities.

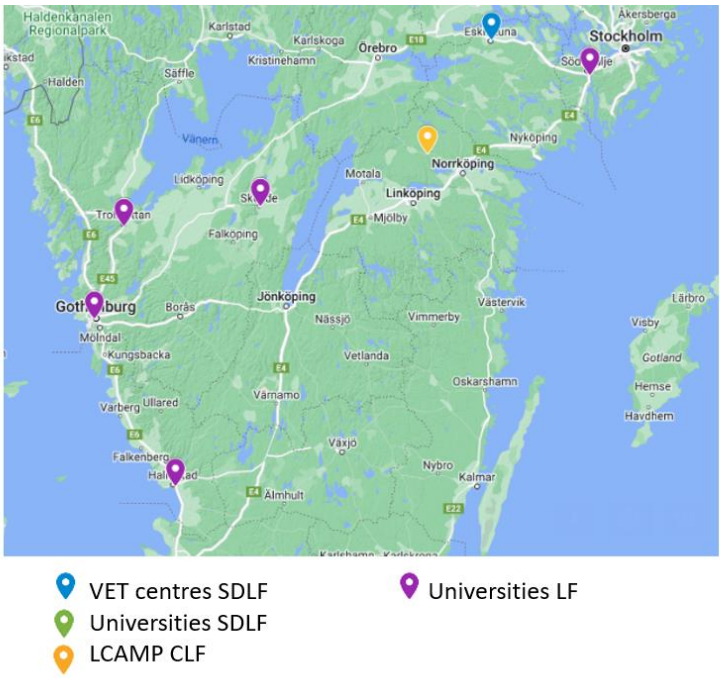

***Figure 10**: SDLF, CLF and LFs in Sweden. Source: Author's creation*

Full report about Sweden is available in the annex, section Error! Reference source not found.**.**

22. Findings in Türkiye

In Türkiye, the use of LFs for advanced production techniques courses in VET schools is limited to a small number of schools. However, in the Kocaeli region, only 12 out of 80 vocational high schools have training workshops/labs including pieced LFs where production can take place. These facilities do not simulate an entire factory but include specific sections such as production and packaging. 4 of these 12 VET schools have dedicated training classrooms where advanced manufacturing techniques, such as SDLFs can be taught. In the engineering departments of three universities located in Kocaeli, SDLFs are widely used for engineering education.

On the other hand, in Türkiye, various efforts have been made to enable businesses to benefit from lean production and digital transformation processes, including training personnel and interns. One such initiative is the establishment of the Applied SME Competence Centres (Model Factories) in collaboration between the Ministry of Industry and Technology of the Republic of Türkiye and the United Nations Development Programme (UNDP), which have the concept of standard LFs.

In some VET schools in Türkiye, SLDF have been established with the support of the central government and local development agencies at various levels. However, the general approach is to establish learning environments such as life-size factories or SDLFs (Model Factories) in industrial organizations, Industrial Zones (OIZ), or institutions coordinated by Industrial Chambers. This is because these training environments, which are established at high costs, have high sustainability costs such as basic maintenance, calibration, and renovation. Since it is not feasible for VET schools to consistently meet these costs, these training facilities eventually become idle. Therefore, Model Factories are established under the coordination of industrial institutions. The established model factories are associated with VET schools in the region.

The primary purpose of Model Factories is to provide training and consultancy services in lean transformation (aimed at improving operational efficiency) and digital transformation (implementing the principles of the Fourth Industrial Revolution) to small and medium-sized enterprises. Moreover, through the protocols established between Model Factories and VET schools, students enrolled in the 12th grade of VET schools can carry out their internship training in these facilities. Additionally, some courses are conducted in these facilities to enhance the practical skills and competences of VET schools.

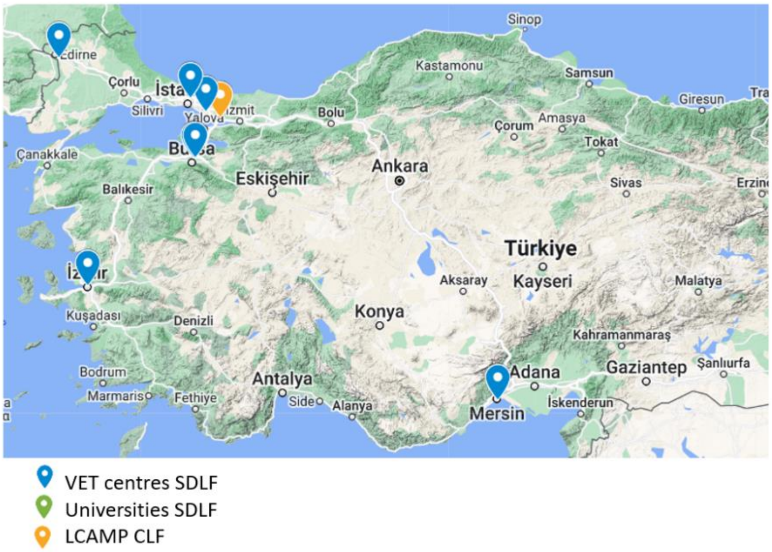

Figure 11 Identified centres with Scale Down LFs, SDLF in universities and CLF partners in Spain. Source: Author's creation

Full report about the Türkiye is available in the annex, section Error! Reference source not found.

23. *Findings in Canada*

The nature of Canada's development of LFs is intrinsically tied to the nature of federal and provincial educational funding and oversight. While a few Canadian universities have successfully drawn on federal and provincial funding to create fully realized LFs, most LF-like environments in the country are piecemeal, providing factory-like modules, often specialized to particular industries or methodologies, within academic contexts serving both educational and production goals. These modular facilities, organized across regional and national networks, provide students and industry professionals with applied research environments in which to develop their skills and learn upcoming industry standards.

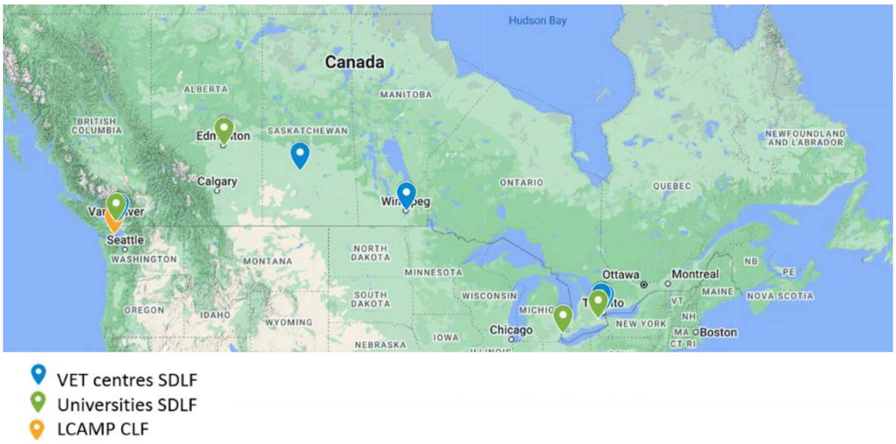

Figure 12 *Identified centres with Scale Down LFs, SDLF in universities and CLF partners in Canada. Source: Author's creation*

Full report about Canada is available in annexes, section Error! Reference source not found.

24. CONCLUSIONS

LFs in universities

LFs run in several universities in Europe as an approach to enhance skills and competences for advanced manufacturing and industry 4.0. Many of the features of the LFs, i.e., practical ways of teaching in hands on environments, replicas of real-world industrial settings, full value chains of manufacturing processes, opportunities to apply skills and knowledge in a real-world setting, make the LF concept very appropriate also for VET environments.

Furthermore, LFs with its understanding of links between technologies-tasks -jobs, an even the links between different stages in a production chain make it possible to directly address many transversal skills, to create interdisciplinary work scenarios and other attributes that are not always easy to reproduce in more traditional learning methodologies.

Outside Europe, the overview carried out in Canada shows that a few Canadian universities have also successfully created fully realized LFs.

SDLFs in VET centres

The study founds very few examples of life size LFs within the VET schools covered in EU countries and also in Canada.

The LF type of scenarios that are currently used in VET centres in the studied countries are the Scale Down Learning Factories (SDLF). These type of LFs are commercially available in modular configurations. They are normally turn-key solutions.

The use of SDLFs is not homogeneous in all the countries. In regions like Baden-Wurttemberg or the Basque Country many VET centres are equipped with SDLF 4.0. The public policies and funding opportunities in those regions are a decisive lever to spread such approaches. In other regions the presence of LFs or even SDLFs in not so obvious. Deeper research would be needed to find the reason behind that.

In any case, the competences, study programs and configurations worked out in the studied SDLFs have many concordances. Their applications are usually for advanced manufacturing and industry 4.0 related VET study programs where they mostly address technical competences. Programs such as industrial automation, robotics, mechatronics, maintenance, advanced manufacturing, mechanical engineering, manufacturing production, control engineering and similar are using those pieces of equipment. Concerning transversal skills, these SDLF give certain space to develop many transversal skills, although they are also more limited than life size LFs to create interdisciplinary environments where more options are available.

Likewise, in the studied VET centres, the results and impact of such SLDF in students' competences are very promising. Therefore, the SDLFs approach has very good acceptance in VET. Looking at the growth in the establishment of SDLF in the last 5 years, there is a trend to invest in such equipment.

Active methodologies in VET centres and Innovation Ecosystems

A general finding in all the studied regions is that different types of active methodologies are widely implemented in VET schools, usually including the participation of industry. The use of active methodologies is common, independently of the use of LFs. In certain cases, similar learning methods to those of LFs are being used but name differently. Some examples found in the study are: Manufactured object initiative and Technology platforms in France, Public Private partnerships in the Netherlands, Inter-enterprise Training Centres in Slovenia, Network of Vocational excellence in Spain, and ETHAZI framework in the Basque Country. Besides the active methodologies used, many of those VET schools are well equipped, using industry-like machinery for the trainings.

Other regional strategies found are the innovation ecosystems where the development of talent is included with upskilling/reskilling programs. In those ecosystems the collaboration with the regional education organizations either universities or VET centres is established. In the examples of the Competence centres for Industry 4.0 in Italy or the Model Factories in Türkiye they are using Teaching Factories approaches and active methodologies like LFs for the development of talent.

For the Canadian case, the idiosyncrasy of Canada is tied to the nature of federal and provincial educational funding and oversight: most LF-like environments in VET centres in the country are piecemeal, providing factory-like modules, often adapted to particular industries or methodologies.

The CLF defined in EXAM4.0 (EXAM4.0, 2019) and scaled up in LCAMP CoVE (LCAMP, 2022) is an example of the use of equipment of VET labs to establish LF schemes to enhance collaboration, interdisciplinary and other transversal skills.

All these active methodologies and innovation strategies are tightly related to the foundations of the LFs. The need to address simultaneously job-related skills, digital skills, personal and social skills make it necessary to look for appropriate methodologies to foster the development of the mentioned competences and skills.

Potential of life size LFs in VET

As we have seen throughout the document, training in advanced manufacturing carried out in real environments and using active teaching methodologies provides great benefits.

The study we have carried out shows us, moreover, that VET centres are working with active teaching methodologies and that, in some cases, they also operate with SDLFs.

If we add to this the fact that LFs work well at university level, we can infer that the implementation of LFs in VET makes sense as a means of reinforcing training in advanced manufacturing.

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Learner Centric Advanced Manufacturing Platform

3. PART 2: MORPHOLOGY OF THE LCAMP COLLABORATIVE LEARNING FACTORY

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GLOSSARY AND/OR ACRONYMS

AGV - Automated Guided Vehicles
AR - Augmented Reality
CLF - Collaborative Learning Factory
CoVE - Centres of Vocational Excellence
DFMA - Design Failure Mode & Effect Analysis
EXAM4.0 - Excellence Advanced Manufacturing 4.0
EQF - European Qualifications Framework
ERP - Enterprise resource planning
HVET - Higher Vocational Education and Training
I4.0 - Industry 4.0
I5.0 - Industry 5.0
IALF - International Association of Learning Factories
ICT - Information Communication Technology
IoT - Internet of Things
IT - Information Technologies
JBS - Job Breakdown Sheet
KPI - Key Performance Indicators
LCA - Life Cycle Assessment
LCAMP - Learner Centric Advanced Manufacturing Platform
LF - Learning Factory
MES - Manufacturing Execution System
MS - Maintenance Sheet
PCB - Printed circuit board
PCP - Process Control Plan
PFD - Process flow diagram
PFMA - Process failure mode and effect analysis tool
PLC - Programmable Logic Controller
PLM - Product lifecycle management
PPE - Personal protective equipment
QFD - Quality function deployment
QR - Quick Response
RFID - Radio Frequency Identification
ROS - Robot Operating System
SBC - Single-board computer
SIM - Short Interval Management
SME - Small and medium-sized enterprises
SS - Safety Sheet
STEM - Stands for science, technology, engineering, and math
SWOT - Strengths, weaknesses, opportunities, and threats
VET - Vocational Education and Training
VPN - Virtual Private Network
VR - Virtual Reality
WP - Work package

GLOSSARY

Advanced manufacturing technology, as the European Commission determines:

> Encompass the use of innovative technology to improve products or processes that drive innovation. It covers two types of technologies: process technology that is used to produce any of other advanced technologies, and process technology that is based on robotics, automation technology or computer-integrated manufacturing. For the former, such process technology typically relates to production apparatus, equipment and procedures for the manufacture of specific materials and components. For the latter, process technology includes measuring, control and testing devices for machines, machine tools and various areas of automated or IT-based manufacturing technology (European Commission, n.d.).

Advanced materials, as the European Commission determines:

> Lead both to new reduced cost substitutes to existing materials and to new higher added-value products and services. Advanced Materials offer major improvements in a wide variety of different fields, e.g. in aerospace, transport, building and health care. They facilitate recycling, lowering the carbon footprint and energy demand as well as limiting the need for raw materials that are scarce in Europe (European Commission, n.d.).

Artificial Intelligence (AI), as the European Commission determines:

> Is a term used to describe machines performing human-like cognitive functions (e.g. learning, understanding, reasoning or interacting). It comprises different forms of cognition and meaning understanding (e.g. Speech recognition, natural Language processing) and human interaction (e.g. signal sensing, smart control, simulators). In terms of its technology base AT is a very heterogeneous field. While some aspects like sensors, chips, robots as well as certain applications like autonomous driving, logistics or medical instruments refer to hardware components, a relevant part of AI is rooted in algorithms and software (European Commission, n.d.).

Augmented reality, as the European Commission determines:

> Devices overlay digital information or objects with a person's current view of reality. As such, the user is able to see his or her surroundings while also seeing the AR content. Virtual reality devices place end users into a completely new reality, obscuring the view of their existing reality. Augmented reality is enhanced by computer-generated perceptual information across multiple sensory, visual or auditory modalities. The user experience is closely interwoven with the physical world and is perceived as an immersive aspect of the real environment (European commission, n.d.).

Collaborative Learning Factory: International network of VET/ HVET providers that link their regional autonomous LFs or manufacturing labs to set up a common infrastructure to manufacture products and provide training in collaboration. Based on open innovation principles, in the Collaborative Learning Factory the common product is subdivided into sub-products. The development, manufacturing, and assembly process of each subproduct is leaded by an independent LF and shared with the network. The final assembly of all the subproducts is carried out in a final assembly line, located in a partner's lab. The structure allows for different types of participants as well as the collaboration in different stages of the value chain including:

- Co-design of product(s)
- Co definition of manufacturing processes
- Co-creation of digital workstations
    - Setting up and scaling up LFs, Integration of I4.0 technologies in existing LFs

- Creation of didactic materials and training contents
- Participation of students in joint projects involving any of the LFs: producing parts, modifying processes, tailoring product's features, sharing data
- Involvement of cooperative mobility actions as an option.

Centre of Vocational Excellence (CoVE): A multifunctional vocational education and training centre which, in addition to training, has an impact on the interaction with other actors and on the competitiveness of the region (considering competitiveness in the sense of beyond GDP) within its regional (and especially local) system.

Connectivity, as the European Commission determines:

> Refers to all those technologies and services that allow end-users to connect to a communication network. It encompasses an increasing volume of data, wireless and wired protocols and standards, and combinations within a single use case or location. *Standard connectivity* includes Fixed Voice and Mobile Voice telecom services to allow fixed or mobile voice communications, but also Fixed Data and Mobile Data services to have access and transfer data via a network. *Advanced connectivity* that is in the focus of the LCAMP project refers to the rise of Internet of Things scenarios, where connectivity technology boundaries expand beyond wired and cellular (e.g. 4G, 5G) services to Low Power Wide Area Network (LPWAN), Satellite, and Short Range Wireless technologies (e.g. Bluetooth, ZigBee) (European Commission, n.d.).

Industry 4.0: The application of digitalisation (Artificial Intelligence, Big Data, Internet of Things, Internet of Machines, etc.) and cutting-edge manufacturing developments (3D printing, Additive Manufacturing, High precision Machining, etc.) to manufacturing processes with the aim of increasing flexibility, productivity, and efficiency.

Industry 5.0, as the European Commission determines:

> Recognises the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process (European Commission, n.d.).

The Internet of Things (IoT), as the European Commission determines:

> Refers to the network of smart, interconnected devices and services that are capable of sensing or even listening to requests. IoT is an aggregation of endpoints that are uniquely identifiable and that communicate bi-directionally over a network using some form of automated connectivity. The Internet of Things relies on networked sensors to remotely connect, track and manage products, systems and grids. The Industrial Internet of Things (IIoT) – a subset of the larger Internet of Things – focuses on the specialized requirements of industrial applications, such as manufacturing, oil and gas, and utilities (European Commission, n.d.).

Knowledge: Lundvall classification of four types of economically relevant knowledge will be followed (Lundvall, 2016, pp. 112-115):

- Know-what: knowledge about facts that can be regarded as "information". Although, in general, the relevance of knowledge-what has diminished due to the easy access (in terms of effort and money) all have to large amounts of information through the internet, it is also true that knowledge-what can still be important for some professionals as doctors or lawyers. Examples of know-what can be the name of the first king of France, the temperature at which water boils, the number of inhabitants of a city, and many others.

- Know-why: scientific knowledge about principles and causes of natural, social or human phenomena. There are organisations, such as universities, specialised in the reproduction of this type of knowledge. Although it is true that, as indicated when discussing the science of such models of innovation, this type of knowledge is not as important as thought in the last century, it is also true that it has been, and still is, very important in some industries (chemical industry, electrical industry, electronical industry, and others).
- Know-how: skills to do things, practical knowledge. Although this type of knowledge has traditionally been related to production works and to manufacturing, it is also true that all endeavours involve a large extent of know-how: management, research, and even consumption.
- Know-who (where and when): to know key persons and to be connected with networks. This is one of the key elements for innovation when it is regarded as systemic, understood as a social system where different elements interact around knowledge.

Learning factory: The International Association of Learning Factories (IALF, 2021) defines a learning factory as:

> A learning environment where processes and technologies are based on a real industrial site which allows a direct approach to product creation process (product development, manufacturing, quality-management, logistics). Learning factories are based on a didactical concept emphasizing experimental and problem-based learning. The continuous improvement philosophy is facilitated by actions and the interactive involvement of the participants.

Robotics, as the European Commission determines:

> Is a technology that encompasses the design, building, implementation, and operation of robots. Robotics includes applications designed to conduct a specific task or series of tasks for commercial purposes. These robots may be stationary or mobile but are limited in function as defined by the intended application. Multipurpose robots are capable of performing a variety of functions and movements determined by a user that programs the robot for tasks, movement, range, and other functions and that may change the effector based on the required task. These robots function autonomously within the parameters of their programming to conduct tasks for commercial applications and may be fixed, "moveable," or mobile. Cognitive robots are capable of decision making and reason, which allows them to function within a complex environment (European Commission, n.d.).

Security, as the European Commission determines:

> Products are tools designed using a wide variety of technologies to enhance the security of an organization's networking infrastructure — including computers, information systems, internet communications, networks, transactions, personal devices, mainframe, and the cloud — as well as help provide advanced value-added services and capabilities. Cybersecurity products are utilized to provide confidentiality, integrity, privacy, and assurance. Through the use of security applications, organizations are able to provide security management, access control, authentication, malware protection, encryption, data loss prevention (DLP), intrusion detection and prevention (IDP), vulnerability assessment (VA), and perimeter defence, among other capabilities (European Union, n.d.).

Skills/Competences, as the European Commission determines:

- **Skills -** The ability to apply knowledge and use know-how to complete tasks and solve problems". They can be described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments) (European Commission, n.d.).

- **Competence “**means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development." They are described in terms of responsibility and autonomy” (European Commission, n.d.).

SME, as the European Commission determines:

> The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million (European Commission, n.d.).

Vocational Education and Training (VET): The LCAMP Alliance will adopt the definition of VET of the Council Recommendation on vocational education and training for sustainable competitiveness, social fairness and resilience: (The Council of the European Union, 2020, p. 4)

> Vocational education and training is to be understood as the education and training which aims to equip young people and adults with knowledge, skills and competences required in particular occupations or more broadly on the labour market. It may be provided in formal and in non-formal settings, at all levels of the European Qualifications Framework (EQF), including tertiary, if applicable.

EXECUTIVE SUMMARY

The deliverable "Morphology of the LCAMP Collaborative Learning Factory" (D6.1 part II) describes the main features of the physical learning scenario for advanced manufacturing education denominated *Collaborative Learning Factory*. The document is built upon three (3) pillars: the **pedagogical aspects** intrinsic to this learning environment, the necessary **technical and operational infrastructure** of the Collaborative Learning Factory and the **collaboration opportunities** for VET centres

The advanced manufacturing sector confronts multifaceted challenges with a concurrent demand for a skilled workforce capable of managing and adapting to rapid technological, environmental, organizational, and social changes.

In this context, skill ecosystems are becoming strategic, connecting relevant agents and redefining the skilling paradigms. Centres of Vocational Excellence (CoVEs) are at the forefront of Vocational Education and Training (VET) systems, fostering the connection of industry, education, and society while redeveloping the pedagogical approaches of education systems throughout the EU. What does it mean to redevelop pedagogical approaches? Traditionally, VET is characterised by its imminent practical character, based on the effectiveness of competence acquisition in action-based learning. Therefore, the challenge is how to create action-based learning environments aligned with the multifaceted challenges of the advanced manufacturing sector.

Immersed in the European Year of Skills, boosting the EU skills strategy, LCAMP is leading the design and creation of a **Collaborative Learning Factory (CLF)** for VET centres, an evolution of the classic Learning Factory concept widely used by many EU universities.

The Collaborate Learning Factory replicates authentic industrial processes in educational environments, i.e. in the labs of VET centres. The CLF is made up of existing and developing Learning Factories located in 7 geographically different VET centres, where each centre has a particular role for the manufacturing of a final common product. The interconnections within and between the distributed Learning Factories scaffold the operational arrangements of the whole CLF. This configuration allows:

1) practice-based learning with embedded I4.0 technologies for VET students
2) acquisition of job specific and transversal Advanced Manufacturing skills
3) enhancement of cooperation among VET organizations.

The 3 pillars that constitute the Collaborative Learning factory are: pedagogical aspects, technical and operational infrastructure, and collaboration opportunities.

Pedagogical aspects intrinsic to this learning environment

The CLF takes advantage of LF's benefits and adapts them to the key VET characteristics of hands-on training in a real environment, the simultaneous acquisition of job specific skills and transversal skills, the adaptation of courses to the needs of the VET students. Additionally, the CLF provides tools and applications that align learning amongst collaborators, yielding a collective understanding in support of student learning and teaching innovation. This includes clustering of advanced manufacturing courses in Industry 4.0 (I4.0) knowledge domains, as well as a clearly described unified competence framework.

Technical and operational infrastructure of the CLF

The CLF concept follows guidelines inspired by the design and implementation of real-world production lines, and is centred on four areas: product design, process engineering, supply chain, and manufacturing. The extensive range of outputs generated from those four areas serve as the baseline for creating the full CLF. The selected product for our model CLF is a mobile robot; workstations are established for the manufacture of components and assembly is accomplished using four dedicated primary digital workstations. As some workstations are geographically distributed, special attention has been given to the supply chain and logistics of manufacture. For initial fine-tuning of our first CLF, there will be two locations where the full production line is implemented. As the CLF is running as a smart factory, connectivity is key; this digital layer guaranties not only the correct coordination of decentralised production sites but also the implementation of I4.0 technologies. The digitalization of production lines gives opportunities to virtualize product and process via digital twins.

Collaboration opportunities for VET centres are a cornerstone of the LCAMP project

The CLF opens new perspectives and possibilities for international cooperation, spanning multiple dimensions that engage both educators and learners. It gives room to articulate collaborative activities in 4 levels: collaborative production of robots, cooperative development of CLF courses, collective participation in a virtual CLF, and unprecedented connectivity leading to enhanced mobility for students and staff. Central to this aspect is the potential for unique connections between partners that would otherwise have more limited opportunities for improving student learning; when multiple stakeholders are engaged in collaborative design, production, and training, it opens a world of opportunities that could not even be imagined in isolation.

1. INTRODUCTION

Work package 6 (WP6) of the Learner-Centric Advanced Manufacturing Platform (LCAMP) project, "*Industry 4.0 technology absorption through the Collaborative Learning Factory"* is devoted to the design and establishment of a **Collaborative Learning Factory (CLF)** for Advanced Manufacturing. The work is divided into three blocks: conceptualization, design, and execution. Conceptualization addresses research into Learning Factory (LF) environments for Vocational Education and Training (VET) centres. Findings are included in the previously-submitted report "D6.1part 1 Role of LF in VET Education" (LCAMP, 2023). This current document covers the second block of the roadmap, the design phase in "D6.1 part 2 Morphology of the LCAMP Collaborative Learning Factory".

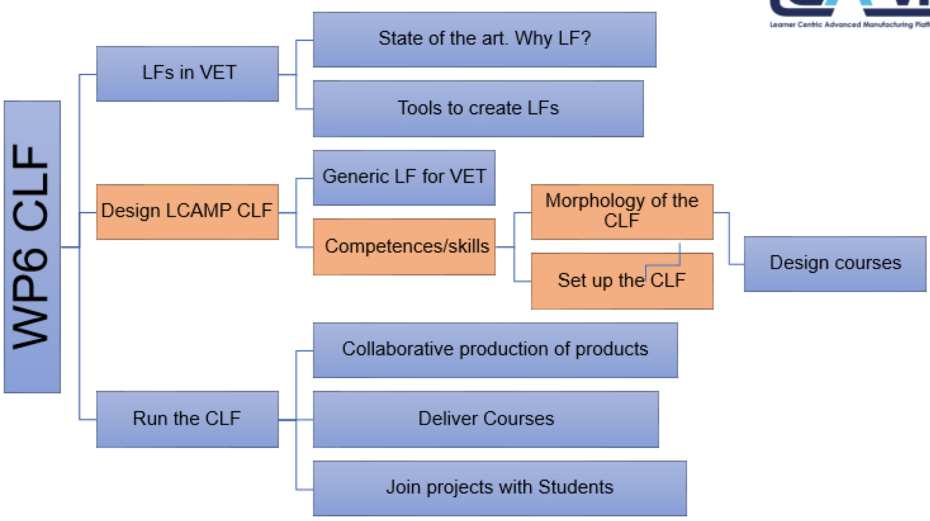


Figure 13. Basic scheme of the WP6.

This document is built upon three pillars: the **pedagogical aspects** intrinsic to a learning environment, the necessary **technical and operational infrastructure** of the CLF, and the opportunities for **collaboration among the VET centres** involved. The initiative is being implemented by 9 VET and High Vocational and Educational and Training (HVET) centres: CIFP MIGUEL ALTUNA (Basque Country), TKNIKA (Basque Country), DHBW (Germany), CMQ (France), MADE (Italy), CNG (Sweden), TSCMB (Slovenia), Camosun College (Canada) and GEBKIM VET (Turkey). The following companies are also participating in the creation of the CLF: Simumatik (Sweden) and Forcam (Germany).

1.1. HOW TO READ THIS DOCUMENT

This deliverable is the second step in the WP6 “Industry 4.0 technology absorption through the Collaborative Learning Factory”. It serves as a ‘reference document’ to set up and run the CLF.

- **Chapter 2** explores the didactics behind the CLF, presenting Advanced Manufacturing knowledge domains and proposing a competence framework.
- **Chapter 3** focuses on recent workplace changes brought about by digitalisation, with special emphasis on changes in production lines connected with characteristics of the CLF.
- **Chapter 4** provides guidelines on how to build a LF following industry patterns, from initial project outline through product design, process engineering, supply chain, and manufacturing process design.
- **Chapter 5** deals with CLF architecture, covering the main features and technical aspects of product, process, and digital infrastructure.
- **Chapter 6** deals with cooperation opportunities, the core collaboration activities of the project.
- **Chapter 7** provides a short summary of how the CLF will evolve.

Additional in-depth information is available in the annexes.

1.2. DEFINITION OF LEARNING FACTORY

Learning Factories facilitate a practical way of teaching, offering specialized learning environments that replicate industrial settings and provide hands-on learning experiences for students. They are designed to simulate industrial processes and allow students to apply the knowledge they have acquired in a practical, learning-centred milieu. (Abele, et al., Learning Factories for Research, Education, and Training, 2015).

The presence and development of LFs at the university level is covered extensively in the literature (Belinski, Peixe, Frederico, & Garza-Reyes, Organizational learning and industry 4.0: findings from a systematic literature review and research agenda., 2020) (Enke, et al., Industrie 4.0: competencies for a modern production system: a curriculum for learning factories., 2018) (Pittich, Tenberg, & Lensing, Learning factories for complex competence acquisition, 2020) but attention to LFs in VET is limited (Roll & Ifenthaler, Learning Factories 4.0 in technical vocational schools: can they foster competence development?., 2021) (Scheid, Learning Factories in Vocational Schools, 2018). Nevertheless,

> many of the features of the LFs, i.e., practical ways of teaching in hands on environments, replicas of real-world industrial settings, full value chains of manufacturing processes, opportunities to apply skills and knowledge in a real-world setting, make the LF concept very appropriate also for VET environments. (LCAMP, 2023).

Dimensions of a Learning Factory

The International Association of Learning Factories (IALF) describes LFs based on the six dimensions, proposed by Abele et al., (Abele E. , et al., 2015) and shown below in Figure 14 (IALF, 2021).

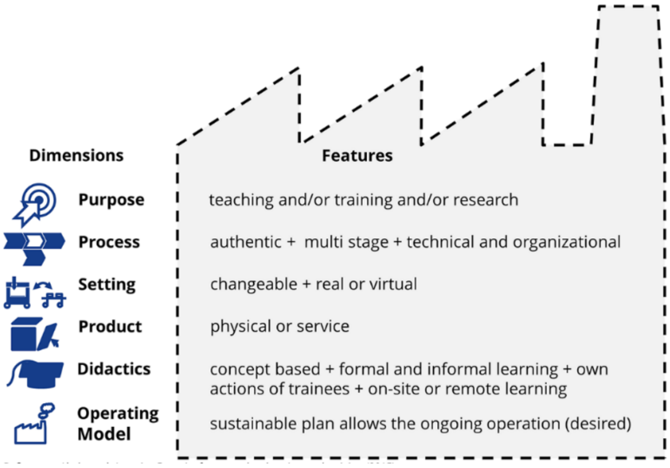


Figure 14. Dimension given by IALF to describe LFs. Source (Abele E. et al., 2015).

This structure begins with **purpose** and the learning foci of teaching, training, and research. Then comes the need for an authentic multi-staged **process** that both technical and organizational. The **setting** of the learning factory, whether physical or virtual, must be versatile and open to change. The **product**, while generally a physical deliverable, can also be some kind of service. As a site for both formal and informal learning, the **didactics** must be concept-based and action-based, although the work can be accomplished on-site of remotely. Finally, the **operational** model should strive for sustainability, with a plan that provides space and time and resources for ongoing operation in response to industry needs. What is not included in this model is metrics, and subsequent discussions of the learning factory have pointed out the necessity of including this as a seventh dimension for comprehension and comparability. This seven-dimension model is provided below in Table 4.

Table 4. Dimensions of a LF defined in the book Learning Factories: Concepts, Guidelines, Best-Practice Examples

Operational model	Outlines how managing entities effectively ensure the ongoing functionality of the LF, including financial, content-related and personal sustainability.
Targets and purpose	The fundamental objectives of LFs encompass educating students, training industrial staff, and conducting research related to production.
Process	The production processes illustrated within the LF are described in more detail.
Setting	Physical factory setting where learners can explore and engage in hands-on experimentation, whereas digital and virtual representations of the factory environment may also be acknowledged as alternatives to this. Furthermore, the factory setting can use either life-sized equipment, reproducing what is used in actual factories, or scaled-down factory equipment. The latter involves smaller models conceptually inspired by their life-sized equipment.
Product	The characteristics of the products that are going to be assemble in the LF.
Didactics	A fundamental element in understanding LF concepts, addressing the main objectives of education and training.

Metrics	Measurable aspects of LF concepts, including participant count per learning module, average duration of individual learning modules, and the available learning space.

While this seven-dimension model will be utilized for the CLF, the collaborative nature of our enterprise will require expansion to an eighth dimension.

1.3. DEFINITION OF COLLABORATIVE LEARNING FACTORY

LCAMP proposes to define the key features of shopfloor facilities (practical labs) in VET schools to effectively address the evolving demand for current skills triggered by the digital and green transformations, using the Collaborative Learning Factory (CLF) model. The CLF replicates contemporary industrial processes to manufacture a specific product for educational applications and environments (i.e. VET centre labs), but within a structure that is geographically distributed between seven VET centres, each centre playing a particular role in the manufacture of a shared final product. The interconnections amongst and between LFs scaffold the operational arrangements of the CLF. This configuration allows for the implementation of:

- Practice-based learning environments for VET students with embedded I4.0 technologies
- Acquisition of job specific and transverse skills for Advanced Manufacturing.
- Enhanced cooperation among international VET organizations.

Dimensions of the CLF

Following the seven dimensions provided in section 1.2, the CLF is characterized by the dimensions outlined in Table 5 which includes an additional 8th dimension to describe the collaborative aspects of the CLF.

Table 5. Dimensions of the LCAMP CLF

Dimension	Where to find the description of these dimensions
Operational model	LCAMP alliance (WP2 deliverables)
Targets and purpose	VET students, Workers, International collaboration
Process	Section 5.2
Setting	Section 5.2 and 5.3
Product	Section 5.1
Didactics	Section 2
Metrics	Section 1.5
Collaboration	Section 6

The distinctive element of the LCAMP CLF, compared with the standard LFs definitions, is its distributed geographical and organizational nature. This requires essential coordination, cooperation, and collaboration. Furthermore, the successful implementation of remote and collaborative work within this framework relies on the successful (EXAM 4.0, 2020).

1.4. EXPECTED RESULTS

The purpose of WP6 CLF encompasses the following results:

- **Creation** of a **collaborative work environment,** in which the value chain of goods production uses advanced manufacturing technologies. This environment takes shape both in a **physical space**, by the implementation of a tangible LFs in VET centres labs, and in a **virtual environment**, for those VET centres lacking physical resources.
- **Didactic open access educational materials and resources** are available to all LCAMP Alliance members, (LCAMP, 2023), and ultimately to the wider advanced manufacturing community, without restrictions, for their use and exploitation.
- Elaboration of a **Roadmap**, an action plan based on the experience acquired in the creation of the CLFs. This plan will serve as a guide for other institutions looking to replicate and establish their own CLFs, encouraging the dissemination and adoption of this educational approach.

Results achievement is monitored by a series of metrics that describe determinable quantitative measures, which are shown in section 5.4.

2. DIDACTICS OF COLLABORATIVE LEARNING FACTORY

The LCAMP CLF has been designed to expedite the development of competences related to Advanced Manufacturing by fostering an optimal learning environment. As a result, the full morphology of the CLF is closely intertwined with these competences. The didactic structure of LCAMP's CLF is therefore intrinsically linked to these competences, its complexity deriving from the need to accommodate both the acquisition of skills by students and the diversity of educational frameworks involved. Notably, the CLF encompasses remote laboratories across seven nations in various VET centres and universities. Educationally, the CLFs function at two distinct levels: **regionally**, where each VET centre customizes the CLF's attributes to align with local programs, curricula, and competences of their educational structures; and at the **consortium level**, which needs a unified approach to competences that are collaboratively fostered within the CLF, allowing for seamless integration into each educational entity's specific VET system (Ziarsolo, 2023).

The CLF enables courses delivered throughout the consortium, offering flexibility in delivery modes including synchronous, asynchronous, and multilingual options. At both regional and consortium levels, the didactics involve the development of **learning solutions** tailored to the predetermined competences in Advanced Manufacturing education. Further international consensus on these learning solutions is imperative for cohesive course descriptions. The framework for a common wording of the competences for advanced manufacturing is deployed in section 2.2.

Key aspects of these didactic solutions involve:

- Adapting and/or co-creating specific courses to be delivered in the regional LFs.
- Modularizing content to ensure integration into varying national qualifications systems.
- Defining appropriate delivery mechanisms within the LF environment based on content and audience, incorporating active learning methods, gamification, micro-learning, mobile learning, and virtual training.
- Establishing working methods for joint tasks among international students.

In defining the morphology of the CLF, the LCAMP consortium has identified relevant **knowledge areas** within the I4.0 that are pertinent to the target audience. The selected areas are listed in section below 2.1.

2.1. KNOWLEDGE DOMAINS INCLUDED IN THE COLLABORATIVE LEARNING FACTORY

As mentioned above, a LF implies a comprehensive learning environment enabling students to acquire competences throughout diverse knowledge domains. Among the landscape of I4.0, the LCAMP's consortium CLF has selected **specific technological domains** related to national qualifications systems from partners' organizations correlated with the findings of the LCAMP's Observatory (WP3) and VET-SME collaboration (WP7).

In this section the **domains addressed in the CLF** are listed.

The CLF covers a variety of areas. Notably, WP3 has conducted a thorough examination of job shifts within the advanced manufacturing sector in the participating countries, pinpointing the essential skills needed within the industry. Therefore, the courses will be carefully arranged to foster these critical competences. Moreover, the course selection is informed by the strategic aims and specific local circumstances of the partner institutions, ensuring that the educational offerings are pertinent and advantageous to the strategic LCAMP Alliance they serve.

Turning to the second point of emphasis, there is a recognized importance for a balance between non-technical and job-specific skills, as documented in (ETHAZI, 2016). Consequently, the course outline presented in WP5 elaborates on how a comprehensive skill set is developed, detailing the **content, learning methods, and innovative assessment strategies**. Importantly, given the unique opportunities presented by the CLF to address a variety of crucial non-technical (transversal) skills, the **delivery mechanisms** used to deploy the courses, are of vital importance.

The knowledge domains selected are the following:

- Mechanical engineering, smart manufacturing:
- Production management
- Process engineering
- Product-design
- Electronics
- Robotics
- Automation
- Manufacturing processes. Machining, additive manufacturing, assembly
- Logistics and supply-chain
- Sustainability
- Industry 4.0
- Industry 5.0
- IT Computer science

Annex 11.1 provides the LCAMP compilation of future proof qualifications related to the selected domains.

The straightforward correlation between the selected Knowledge Domains and the CLF Value Chain is depicted in Figure 3, illustrating four interconnected processes: Product Design, Process Engineering, Manufacturing, and Supply Chain. All of this is underpinned by digital infrastructure, where learning activities occur across various domains (see Annex 11.1).

The courses delivered within the CLF's educational activities will similarly be aligned to those knowledge domains (see annexe 11.4).

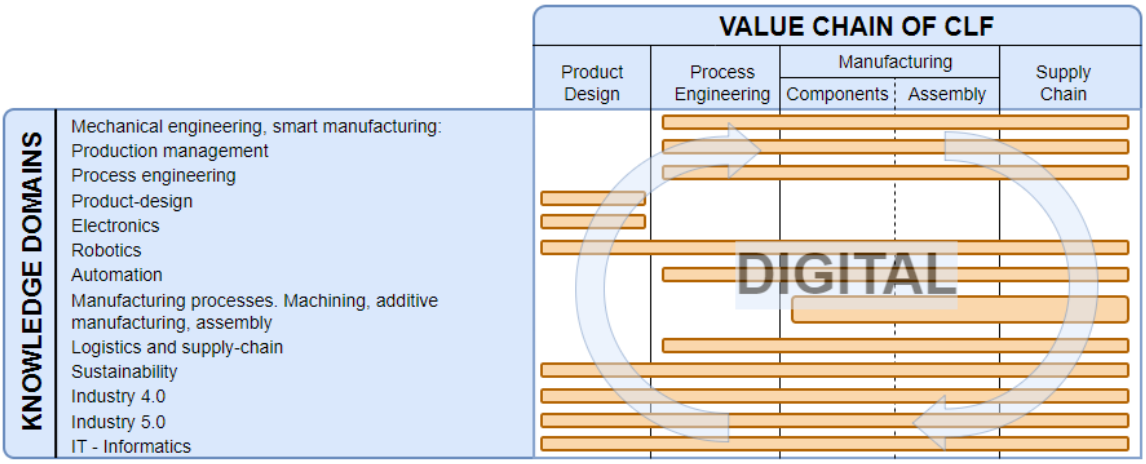


Figure 15. Cross-referencing knowledge domains with Value Chain of CLF processes.

2.2. COMPETENCE FRAMEWORK FOR ADVANCED MANUFACTURING

When defining courses within the CLF, a common educational approach and terminology are necessary, and this is where the LCAMP Competence Framework for Advanced Manufacturing, established in WP5, becomes relevant. This framework helps partners make informed decisions regarding specific technical and transversal skill sets, course content, delivery methods, and assessment methods for selected courses.

This framework proposes a merger with other existing competence frameworks, specifically the EXAM4.0 competence framework for advanced manufacturing (EXAM 4.0, 2020) and Beyond 4.0 (Clara R. Behrend, 2022). As the demands and requirements of the labour market evolve due to the impacts of several megatrends, the framework remains dynamic, reflecting the shifting demands of employers and the impacts of ongoing industrial transformation.

The framework, illustrated schematically in Figure 16, is organized into six categories of skills deemed essential for the future workforce in Advanced Manufacturing, further subdivided into subcategories. The categorization presents an initial set of job-specific skills related to tangible working tasks, typically technological skills, followed by four categories of transversal skills—digital, personal, social, and methodological skills. The sixth category is related to green skills.

Digital skills are further classified as advanced skills and basic/intermediate skills. Advanced digital skills are increasingly required in tasks related to IT and I4.0 applications, while many other occupations require basic or intermediate digital skills. In certain cases, those advanced digital skills can also be considered as job specific skills. In any case, the framework relies on the European Digital Competence Framework for Citizens (DigComp) (Vuorikari & Punie, 2022) to describe the entire set of digital skills.

Concerning non digital transversal skill sets, they have been classified as methodological, social, and personal skills. Finally, regarding skills referring to environmental sustainability, recycling economy, and resource conservation, they directly impact skills in all categories, as a mindset should be established for sustainable, resourceful, and responsible action. The LCAMP Competence Framework adopts the GreenComp framework (Bianchi, Pisiotis, & Cabrera Giraldez, GreenComp The European sustainability competence framework, 2022) which promotes learning on environmental sustainability in the European Union to describe green skills.

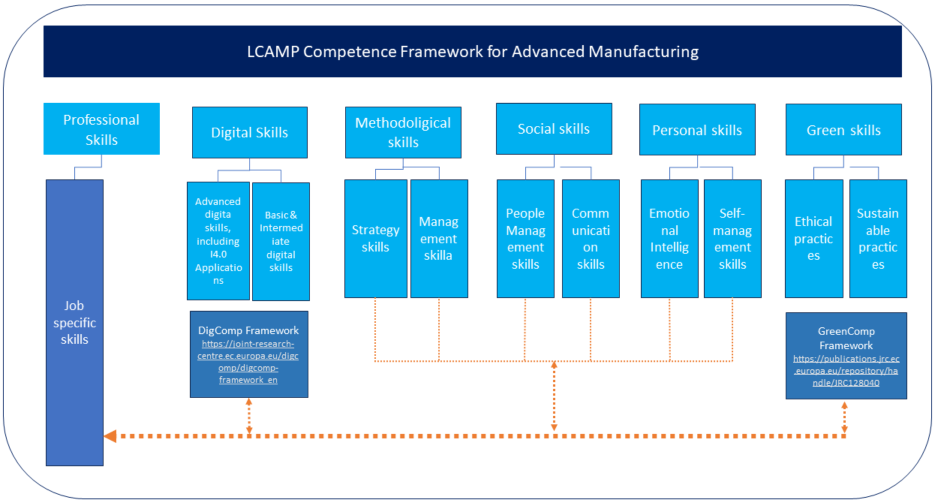


Figure 16. LCAMP's competence Framework for Advanced Manufacturing.

3. GENERIC DESCRIPTION OF DIGITAL WORKPLACES

3.1. DIGITAL WORKPLACE OVERVIEW

Digital workplace in the context of this report refers to–digitally transformed workplaces and shopfloors of manufacturing companies due to the integration of I4.0 technologies. The concept "transformation" also implies a substantial change of the functions of the workers in the shopfloor and the term "digital" refers to the use of new digital technologies and digital equipment. The digital workplace, and its implications, represents a significant feature of the CLF, as it is only through digital means that planning, design, execution, and assessment can occur amongst the partners participating in the LF-based collaborative activities. From collective intentions to shared software, cooperative design to planned execution, cooperative assembly to integrative critique, the CLF is a digital system, requiring a robust infrastructure to accommodate the needs of the individual partners and the aspirations of the pedagogical system.

3.2. HISTORY OF DIGITAL WORKPLACES

While both computers and telecommuting had their roots in the 1970s, the modern digital workplace was born in 1993, with the release of both America Online and Microsoft Outlook (Harvard Business Review, 2020). The introduction of email to the workplace created a groundwork for digital interaction, allowing employees to easily share files and correspondence electronically. The rapid spread of digital infrastructure led to the development of the Internet of Things (IoT), a term first introduced by Kevin Ashton in 1999. As processing power improved, the ability of an organization to collect and process data grew by leaps and bounds; at the same time, sensors were developed that could monitor a wide range of information in the real world. Through this combination, it became possible to remotely monitor and track everything from agricultural data to industrial robotics, making it possible for workers to oversee and adjust conditions in real-time, monitoring machinery from connected computers rather than needing to directly and manually operate equipment. Growth in digital infrastructure during this time also increased the speed with which data could travel between devices, which in turn allowed for a rapid expansion in the amount of data that could be safely stored and shared digitally.

The state of the digital workplace underwent a massive transformation due to the advent of the Covid-19 pandemic in 2020. As more adults began working from home, either full-time or on a hybrid basis, industrial infrastructure was established that simultaneously spurred an increase in inter-departmental and inter-organizational digital collaboration. A new infrastructure was developed in order to allow individuals to participate remotely, as well as to boost productivity and interconnectedness within working environments. Shop floor control data allows workers to monitor and process digital information directly to manufacturing or processing equipment, without difficult or complicated manual programming.

3.3. METHODS OF DIGITAL COLLABORATION

3.3.1. DIGITAL WORKPLACE COLLABORATION

A key aspect of the digital workplace is the ease with which it promotes digital collaboration both within and between organizations. The most direct method of collaboration is through shared information depositories. A proper data repository ensures that up-to-date and accurate data is available for anyone who needs it.

Many organizations rely on a virtual work environment to safeguard data, improve productivity, and manage workplace collaborations. Virtual work environments combine cloud storage and programs with remote desktop applications that allow workers to log into secure servers from any location, allowing employees to work from home or while on business or personal trips. These environments improve worker flexibility, with many employees being able to work remotely either partially or full time.

For production-focused organizations, remote automation can move beyond the digital process work, as discussed above, providing direct virtual access to human machine interfaces and industrial networks. This can allow workers to monitor and program complex automation tasks without having to go on-site and is especially valuable for remote monitoring of large-scale production processes.

In some cases, on-site workers interact with digital devices in their daily tasks, communications and collaborative processes with other actors within the organization. In other cases, on-site workers ensure that machines are loaded with the necessary components and reply to alerts, while remote workers focus on creating digital instructions for production processes and monitor progress on the factory floor. In the last case, production systems can even run while no human is present in the production zone, so long as someone is on call to respond to automated alerts.

3.3.2. DIGITAL COLLABORATION BETWEEN ORGANIZATIONS

The rise of the digital workplace allows for substantial improvement in digital collaborations, by providing a slate of tools to allow organizations to temporarily or permanently share information with one another as needed for critical projects. Staff or researchers can quickly take part in virtual conversations and open temporary shared workgroups and data repositories, allowing teams to coordinate their efforts and pool resources towards shared challenges. These collaborations provide a tremendous opportunity for researchers, designers, and engineers of all scopes. Different organizations have access to specialized monitoring and fabrication equipment that others may not be able to access, but which can be used remotely to combine efforts. In addition, teams of experts from multiple organizations can provide unique perspectives and experiences to each other, especially with highly trained specialists whose expertise may be difficult or impossible to reproduce at a host organization. Through remote access, virtual conferencing, and shared data repositories, experts in different cities, countries, or even continents can pool their efforts to develop unique approaches to solving complex challenges. In applied research situations, physical production can be managed by a single host organization while partnering experts adjust parameters and monitor results remotely, or provide their own machinery for simultaneous iteration, developing models and prototypes alongside other institutions and field-testing multiple designs simultaneously.

While there are many benefits to inter-organizational collaboration, the ease of doing so may paradoxically lead to unique challenges. IP rights are a particular concern, as without robust contracts, researchers may inadvertently create legal confusion as to who owns the results of shared research and development. Security concerns are also critically important. Data leakage and security breaches are another critical concern. With a large number of employees sharing data across multiple organizations, the chances of one person succumbing to a data hack or accidentally sharing unauthorized information increases, putting everyone at risk of having their data stolen or ransomed (Schumann, The Importance Of Protecting Collaboration Tools From Cyberattacks, 2022). Another challenge related to potential worsening of working conditions for many workers is algorithmic management," the use of software algorithms to automate organizational functions traditionally carried out by human managers" (Wood, A. J., Algorithmic Management: Consequences for Work Organization and Working Conditions, Seville: European Commission, 2021, JRC124874), which will only be made more prevalent by the growth of artificial intelligence. Finally, as the number of organizations involved in a collaboration grows, so do the number of competing standards of data storage, program usage, and best practices.

3.4. DIGITAL WORKPLACES CHALLENGES

The digital workplace, in its different forms, is changing all types of working environments. The digital workplace represents both a thrilling opportunity and a daunting challenge for many workforces. These challenges represent a new set of skills for the workforce. Through understanding its unique benefits and limitations, organizations have the potential to develop new processes and collaborative programs that will allow information to be researched and developed efficiently and effectively. Care must be taken to account for the potential pitfalls and vulnerabilities that accompany digital workplaces, and organizations will need to collaborate to ensure that the multitude of unique software and hardware options that have been developed are able to communicate effectively with one another. This is particularly significant for participants in the CLF.

4. GUIDELINES TO CREATE A LEARNING FACTORY

4.1. INITIAL PROJECT OUTLINE

If in the previous chapters, the core principles of the CLF have been established. Now the focus shifts to laying down the guidelines for the implementation of a LF. These guidelines are based on the design and implementation of a real-world production line (Kumar Agarwal & Kumar, Directions of Production Planning & Production Control System: Mathematical Evolution from the Flexibility Point of View, 2020). To achieve the right approach, four processes have been chosen, rather than attempting to incorporate a larger number of processes described in literature. This strategic decision aligns with the goal of tailoring the CLF to suit the specific adaptations necessary for developing the knowledge domain and competences outlined in Chapter 2.

Figure 17 shows in a simplified way the four processes chosen (green) and the main outputs coming from those processes (orange). The whole scheme constitutes the basis **for the conception** of the CLF, which is further developed.

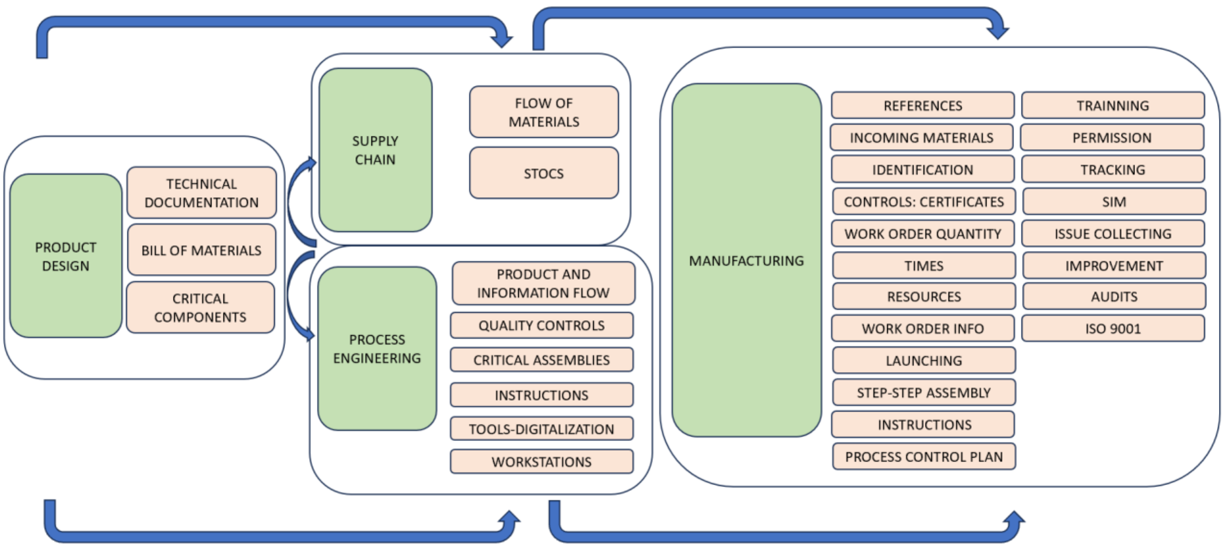


Figure 17. Conception of the LF. Own source.

Given the complexity of each process, the next level involves a more detailed breakdown into specific tasks to be addressed.

At this point, and before moving forward, the need to determine an **initial context** for the integration of technologies and **future developments arises** (see 5.2.10).

4.2. PRODUCT DESIGN PROCESS

In the product design process (see Figure 17), it is essential to focus on three key inputs, two of which are particularly critical:

- Customer specifications: These guide the creation of a product that effectively meets customer's needs. In the case of the CLF, the specifications must meet the requirements of identified knowledge, skills and competences
- Production process knowledge: This ensures that the product can be integrated into the manufacturing process, making production smoother and more efficient.

Additionally, there is a third important input, made even more significant by its growing influence: eco-design, or the consideration of environmental factors in the product design process (see 5.1.2).

After the product design phase, and the interactions with the stakeholders, comes the achievement of outputs (see Figure 17):

- Analysis of critical components: Identifying the critical components based on quality, safety, criteria-based purchasing, cybersecurity, sustainability, etc.
- Technical documentation: Providing the name, drawings, and specifications for each component of all the variants of the product and the product itself.
- Bill of materials (BOM): Identifying the corresponding list of components for each variant.

4.3. PROCESS ENGINEERING AND SUPPLY CHAIN DESIGN

After completing the outputs previously mentioned, or working on them concurrently if feasible, it is crucial to proceed with the following steps to reach a comprehensive grasp of the supply chain and process engineering implementation.

Outputs related to Supply Chain:

- Definition of the material flow (components, subassemblies, and the final product): This involves the details regarding how items move from the supplier to the factory, within the factory, and onward to the customer, as appropriate.

- Definition of the inventory: This entails the specification of the quantity and packaging of components, subassemblies, and the final product as they are transported from the supplier, within the facility, and to the customer.

Outputs related to Process Engineering:

- Definition of the product flow process: Also known as a Process Flow Diagram (PFD), this shows the step by step product progression, and is particularly valuable in defining the resources needed to manufacture and assemble the robot.
- Definition of the information flow process: This illustrates how information moves from the system to the workstations and vice versa. It includes the Manufacturing Execution

System (MES), Enterprise Resource Planning (ERP), instructions, drawings, technical information, and so on.

- Definition of both normative and non-normative quality controls: This involves consolidating various quality control measures and creating a Process Control Plan (PCP) to ensure that the process requirements are consistently satisfied.
- Analysis of critical assemblies: This is relevant to identify the root cause of the criticism from technological, safety, or quality perspectives, in order to implement action plans that prevent potential issues. The assessment can be carried out using a Process Failure Mode and Effect Analysis tool (PFMEA).
- First version of Safety Instructions: This initiates the project by producing a prototype from start to finish, while creating the initial version of the assembly or manufacturing process.
- First version of Assembly Instructions: This commences with the manufacturing and/or assembly of a single prototype from start to finish for the initial revision.
- First version of Quality Instructions: This first release of information includes the manufacturing and/or assembly of one prototype.
- Definition of the means of manufacture (tools, digitization level…): This involves specifying the required tools and methods for implementing each step of the manufacturing and/or assembly process, which include manual and digital tools, automation or semi-automation assembly, artificial vision systems, data collection methods, etc.
- Design of workstations: This entails physically designing the plant layout, including the arrangement of workstations and the location of elements such as parts, sub-assemblies, tools, machines, digital media, etc., while adhering to safety and ergonomic principles.

4.4. MANUFACTURING PROCESS DESIGN

The next stage is about the remaining fundamentals which are necessary to complete the manufacturing process.

Outputs related to materials (components, subassemblies, final product):

- Creation of manufacturing references to use in work orders.
- Definition of incoming material system that communicates with stock and work orders.
- Definition of each component, sub-assembly, and final product along with the type of identification (if necessary).
- Definition of supplier control and certification required in the case of critical materials.

Outputs related to production order:

- Definition of the work order quantity.
- Definition of production times.
- Definition of demand and analysis of human and other resources needed.
- Definition of how the production order reaches production and the information it carries.
- Definition of the standard information that must reach the operator, will be more detailed in case of critical assemblies.
- Establishment of how the launching of production is going to be accomplished.

Outputs related to workstations:

- Step-by-step assembly implementation, identifying assembly references, tools and other manufacturing means, and considering Lean Manufacturing methodologies.
- Generation of the manufacturing, assembly, safety, quality and environmental instructions.
- Generation of the maintenance instructions for the production line and/or workstations and for the maintenance section and sheets to be filled.
- Generation of the quality PCP sheet.
- Identification of hazardous products, sources, etc. derived from the production process and establish treatment according to environmental regulations.
- Identification of waste generated in production and consider waste management.

Outputs related to training:

- Identification and development of training for critical workstations.
- Access limitations for certain positions based on permissions generated by the operator's training.

Outputs related to production management:

- Establish the production total and partial tracking.
- Establish a Short Interval Management (SIM) production monitoring system.
- Establish a system for collecting safety, quality, production and feedback issues, incidents or/and accidents.
- Establish monitoring indicators and improvement plans.
- Establish health and safety, environmental and process control audits.
- Establish an ISO 9001 quality system.

5. ARCHITECTURE OF THE LCAMP'S COLLABORATIVE LEARNING FACTORY

Following the guidelines described in the previous chapter, the main features for the conception of the LCAMP's CLF are detailed. The proposed value chain for the CLF encompasses four processes: Product Design, Process Engineering, Manufacturing, and Supply Chain. All of these are interconnected by the digital infrastructure (see Figure 18).

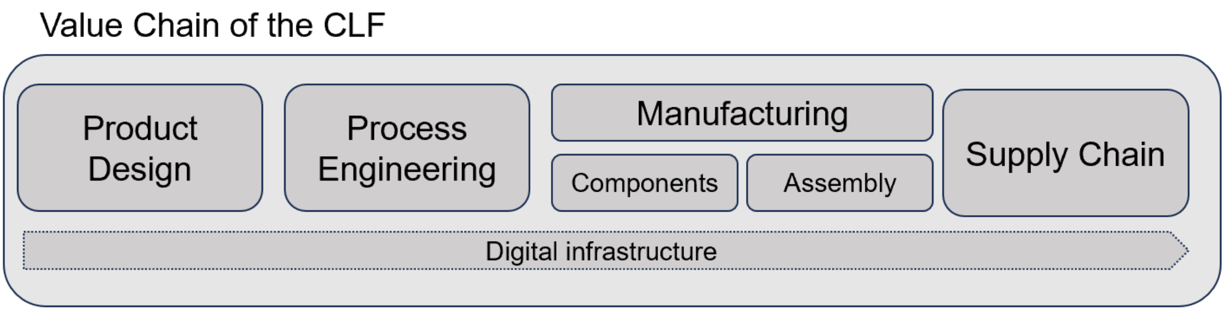


Figure 18. Value Chain of the CLF.

In Section 4 the four processes are described and complemented by the description of the metrics proposed to monitor the implementation in section 5.4.

5.1. PRODUCT DESIGN

Through this section, a comprehensive and current overview of the CLF robot will be provided by having a deep look at one of the building processes of the CLF value chain, namely, the product design. The characteristics and functions of the robot are explored in detail, as well as the eco-design principles that guide its sustainable development. Then the detailed information on the technical specifications that define the operation and performance of this robot are supplied and finally, an assessment of the robot's feasibility is conducted (Ziarsolo, Araiztegui, Irazabal, Errrasti, & Rupp, 2023)

5.1.1.FEATURES AND FUNCTIONALITIES

The product is an automatic robot that it is considered appropriate (explained in Chapter 4, as it meets the necessary specifications that allow the development of the CLF.

It is worth mentioning that the subject is equipped with sensors to make it intelligent and with communication tools to make it collaborative. The robot consists of two main plates, one upper and one lower, which make up the chassis. All components, such as the battery pack; motors and single-board computer (SBC) will be mounted on the bottom plate. On the upper plate it is possible to add additional elements, such as small robot arms or 360-degree cameras. There are two main versions of the robot:

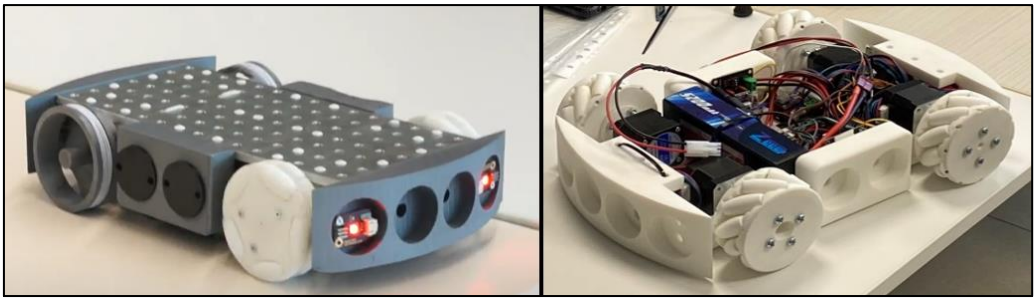
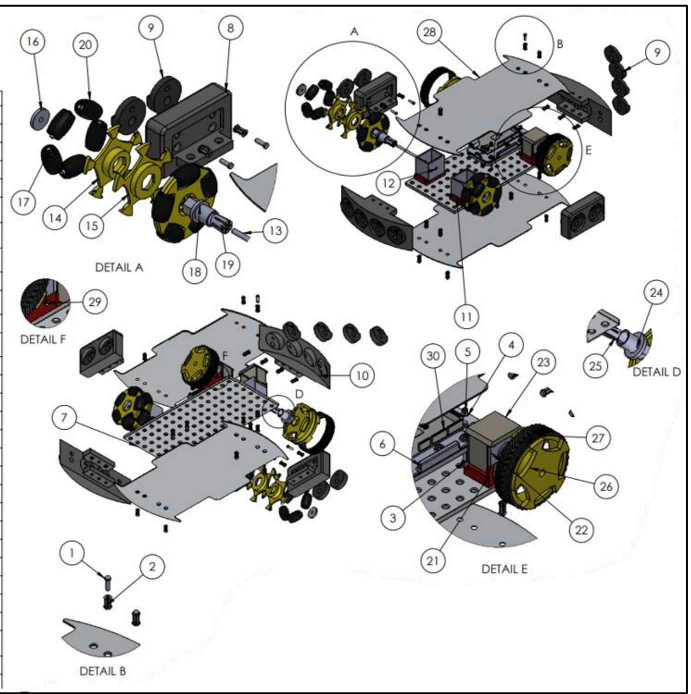


Figure 19. First and second prototypes.

- The first consists of 2 Omni wheels and 2 regular wheels, with only two motors for the two regular wheels as a differential drive robot.
- The second consists of four Mecanum wheels with one motor per wheel.

There is the potential capability of inserting different sensors for various fields of use or purposes. In addition, the robot is equipped with communication systems to exchange data and receive commands from the operator via Bluetooth or Wi-Fi.



N.°	NAME	QTY
1	Pin Clip	38
2	clipper 4_2	38
3	M3x12_DIN912	3
4	3.2_din125.2.2	3
5	M3_DIN934.2.3.1	3
6	Experimentier_Halter_Mega_02.05.2022	1
7	Main plate (plate with holes)	1
8	Small sensor box_05.10.21	2
9	Sensor.28.10.28	12
10	Curved_sensor_box.05.05.2022SLDPRT	2
11	Top.2_05.11.21	2
12	Wheel_shaft_holder.11.10.2021	2
13	Axis for wheel	2
14	Star 1 - 1	4
15	Star 1 - 2	4
16	Part3	2
17	Pin	20
18	Hub	2
19	Hub 2	2
20	Roller	20
21	Top_03.05.22	2
22	Stepmotor nema 17	2
23	Stepmotor holder	2
24	Hub 2.0 06.04.22	2
25	hub1.04.05.22	2
26	Wheel_04.05.2022	2
27	Tire 05.05.22	2
28	Cover plate.07.04.2022 bot	2
29	din_912-m3x0_5-6-10_9	4
30	Arduino	1

Figure 20. Explosion drawing of the first robot version.

5.1.2.ECO-DESIGN

Eco-design is a strategy to include environmental requirements into the process of development of new products. It can address of the seventeen Sustainable Development Goals set forth by the United Nations, as well as help reduce greenhouse gas emissions and slow down climate change (Schäfer & Löwer, Ecodesign—A Review of Reviews, 2020). Eco-design, as defined by the UNE 150301:2003 standard, is a new approach to product design. It involves considering environmental impacts at every stage of the product design and development process. The goal is to create products that have the least possible environmental impact throughout their entire lifecycle. (Sierra-Pérez, Domínguez, & Espinosa, El ecodiseño en el ámbito de la ingeniería del diseño (Ecodesign in design engineering), 2014).

Eco-design is characterized by three important aspects: it focuses on designing and developing products, it takes into account the entire lifecycle of the product, and it aims to reduce overall environmental impact. Implementing eco-design affects the entire organization and calls for a shift in mindset, moving away from disposable goods and towards a more sustainable business model (Schäfer & Löwer, Ecodesign—A Review of Reviews, 2020).

However, the most influential choices in a **product life cycle** occur during its design phase. The various interconnected stages of a product system, starting from the acquisition of raw materials or their extraction from natural resources to their eventual disposal, collectively form what is commonly referred to as the life cycle. This life cycle comprises the design phase, production phase, distribution phase, product usage phase, and the final stages of use. In the present case of the CLF, the design and production phases must be emphasised.

The most used eco-design preliminary analysis tool is the Life Cycle Assessment (LCA). Its foundation is the gathering of input and output data on energy, materials, emissions, and waste in the form of an inventory. After that, databases based on these inputs and outputs are used to evaluate any potential environmental effects and translate the data into eco-indicators which serve as a tool for comparing and evaluating product alternatives.

Additionally, these databases have been incorporated into computer-aided design programs like 3D design Solid Works, included in 3D Experience, enabling the model's environmental characteristics to be known throughout the various design stages (Sierra-Pérez, Domínguez, & Espinosa, El ecodiseño en el ámbito de la ingeniería del diseño (Ecodesign in design engineering), 2014).

In conclusion, the robot to be manufactured in this CLF includes the terms mentioned in eco-design and must therefore be analysed from an environmental point of view.

Considering that the design phase is key to reduce the environmental impact, the robot includes dismountable and non-disposable elements to be able to reproduce the assemblies using the same parts, without creating waste as far as the product is concerned and it can be stacked and sent as a single package.

It is worth mentioning that components and consumables are all in compliance with Restriction of Hazardous Substances (ROHS) and Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulations.

The CLF aims to encourage the training and participation of students, so that the goal is to carry out the LCA, supported by the data provided by the Product Lifecycle Management (PLM) tool, 3D Experience. From here, environmental impact reduction targets are established, and priority is given to the most polluting aspects and secondly to those which, although their impact is minor, can be resolved quickly and with hardly any investment.

This type of study deepens the knowledge of new technologies that seek the reduction of waste material and production time, and therefore energy consumption and improvements in logistics, including the circular economy. All this is translated as a reduction of greenhouse gas emissions.

5.1.3.TECHNICAL SPECIFICATIONS

In this section a detailed analysis of the technical specifications of the robot is conducted. These specifications are the routing sheet that describes the features, requirements, functions and appearance of a product.

The relevant specifications for a correct understanding of the robot are listed below:

- **Function**: The robot is an automatic vehicle with a variety of educational features. The main function of this robot is to adapt in a versatile and efficient way to a range of changing applications and scenarios. To ensure this, it must:
  - Provide an ideal learning environment to address and enhance the skills and competences needed in the field of advanced manufacturing.
  - Be of a suitable size to work with educational tools and technology. The robot has been designed in such a way that makes it appropriate for use in educational environments. This allows for practical and effective interaction with educational technology, facilitating the learning process in areas related to advanced manufacturing and automation.
  - Be modular for the creation of different versions. The different components of the robot can be assembled in different ways, allowing the creation of multiple versions adapted to specific needs. This makes it a versatile tool for applications in different fields.
  - Be dismountable for the reuse of parts. The ability to easily disassemble the robot is mandatory to promote the reuse of its components. This not only saves resources, but it also makes it easier to upgrade and maintain the robot, extending service life.
  - Be prepared for I4.0 technology integration. This robot has been designed with the flexibility required for the incorporation of I 4.0 technologies. Its ability to adapt to sensors, communication systems and advanced automation positions makes it a tool ready for current and future technological demands.
- **Dimensions**: The robot size is about 370mm x 250mm x 90mm depending on the configuration. It means that it is a quite compact product and big enough to include all the electronic components inside and able to be assembled with small, manufactured pieces. As a result, it makes for easy electronic and mechanical manual assembly and the foresight of the process automation.

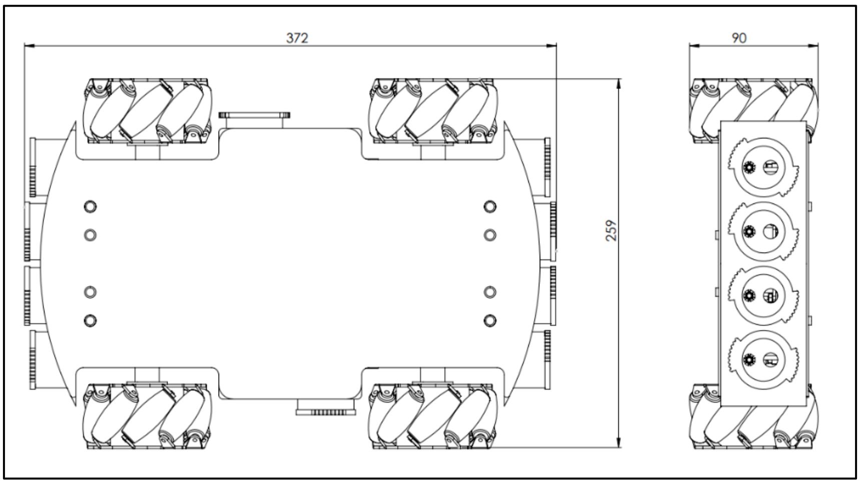


Figure 21. General measurements of one version of the robot.

- **Movements**: Due to the Mecanum and Omni wheels, the robot can move in all directions (in the horizontal plane):
  - Mecanum wheels: they provide greater versatility in multidirectional movements, including diagonal motions and rotation around its own axis.
  - Omni wheels: they are driven by the front regular wheels and are the optimal ones for agile lateral displacements and turning on themselves, skidding.
- **Power supply and electronic circuit:** The robot is powered by a three-cell LiPo battery with a nominal voltage of 11,1 V. A fuse is incorporated in the circuit to safeguard the entire electronics system. Next to the fuse, there is a switch, which enables the activation and deactivation of the electronics. The central component of the electronics is the microcontroller, more specifically, an Arduino microcontroller development board. The circuit possesses sufficient capability to receive signals from the intended sensors and offers ample connections to control all the power controllers for the electric motors. The DRV8825 power controllers are included to drive the stepper motors, which are adequately powerful for the 17HE15-1504S stepper motors used. Furthermore, the HC-05 Bluetooth (BT) module is used for wireless communication with mobile devices.

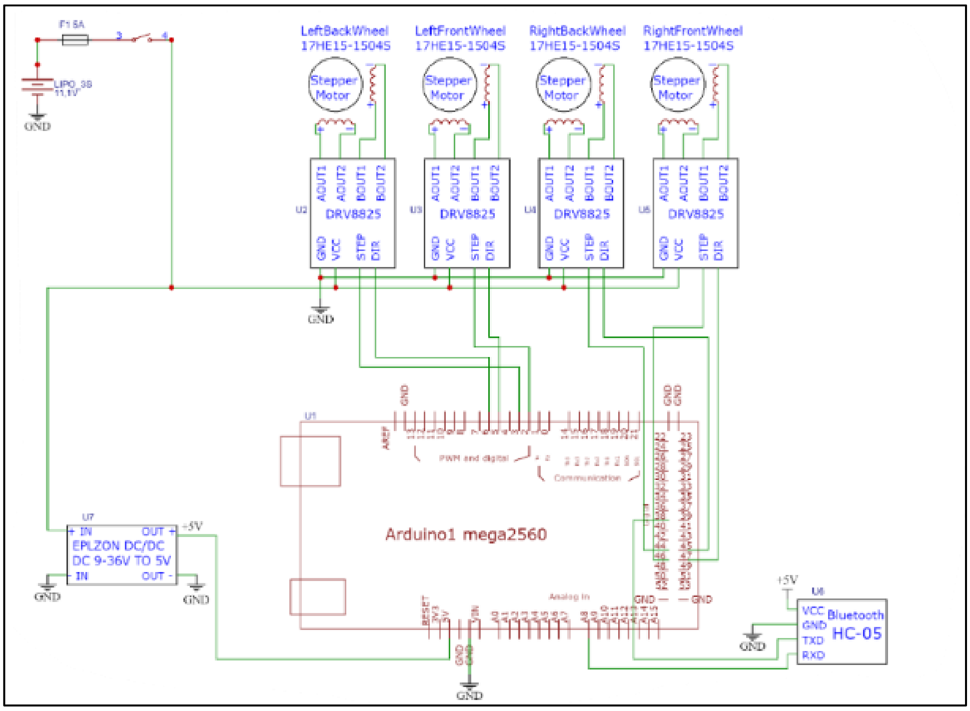


Figure 22.Electrical diagram of the robot

- **Signals and control:** The robot prototype is controlled by a Session Board Controller (SBC). An Arduino UNO R4 microcontroller development board is used for the very basic version and an Arduino Mega 2560 for more advanced control. In its basic version, the SBC is connected in BT (or Wi-Fi) to a Smartphone, to operate as a remote-controlled car, to move in space, being able to perform movements in all directions. The car includes up to 4 ultrasonic sensors to avoid collisions, thus the following aspects have to be considered:
    - The Arduino can be loaded by any other open user program and different sensors can be used. That is why the robot can be considered multifunctional.
    - The connection between the PC and the Arduino is through a USB cable. The robot has a lateral socket to connect the B type USB.
    - The robot communicates via BT with the remote controller – Smartphone. It is also able to switch to Wi-Fi.

  The preferred sensor communication protocol is I2C. Four-wire, SPI, Analog, PWM, IRQ and even CAN Bus (for different applications) cables are also being tested.

    - OPC-UA; Node Red; MQTT communications can be further developed on the robot for more advanced tasks.

  Later, in the evolution of the product to a higher technological robot, it is foreseen the use of:

    - STM32 discovery control, using micro-ROS on free-RTOS
    - Raspberry Pi Zero WH or Pi5 over Linux System with ROS
- **Materials**: The materials used in the first prototyping of the product are:
    - Aluminium for the three plates

- Plastic material such as PLA, ABS, Nylon or PETG for the remaining components.

  New materials will be used when building the robot following the principles of LCA analysis and in an attempt to maintain lightness without sacrificing robustness.

- **Manufacturing and assembly**: Considering the manufacturing of the parts, the main processes will be machining and 3D printing. On the other hand, digital workstations will be utilized for the assembly. The aim is for the process to be as automated and digital as possible to obtain and exploit data (see section 5.2).
- **Product documentation**: The documentation required for the robot is listed below (Cervera, 2018):
  - Design dossier
  - Technical data sheet
  - Engineering and manufacturing plans and structures (E-BOM, M-BOM) and commercial configuration system.
  - Labels
  - Installation, operation and maintenance manuals
  - Manufacturing guidelines and processes

  Note that all of them are related to design and manufacturing processes outputs (see Chapter 4).

5.1.4.VERIFICATION GUIDELINES

The implementation of the CLF includes a previous analysis of its feasibility, that is the awareness of the **knowledge, skills, and resources** to design the product and the whole process of implementing a LF.

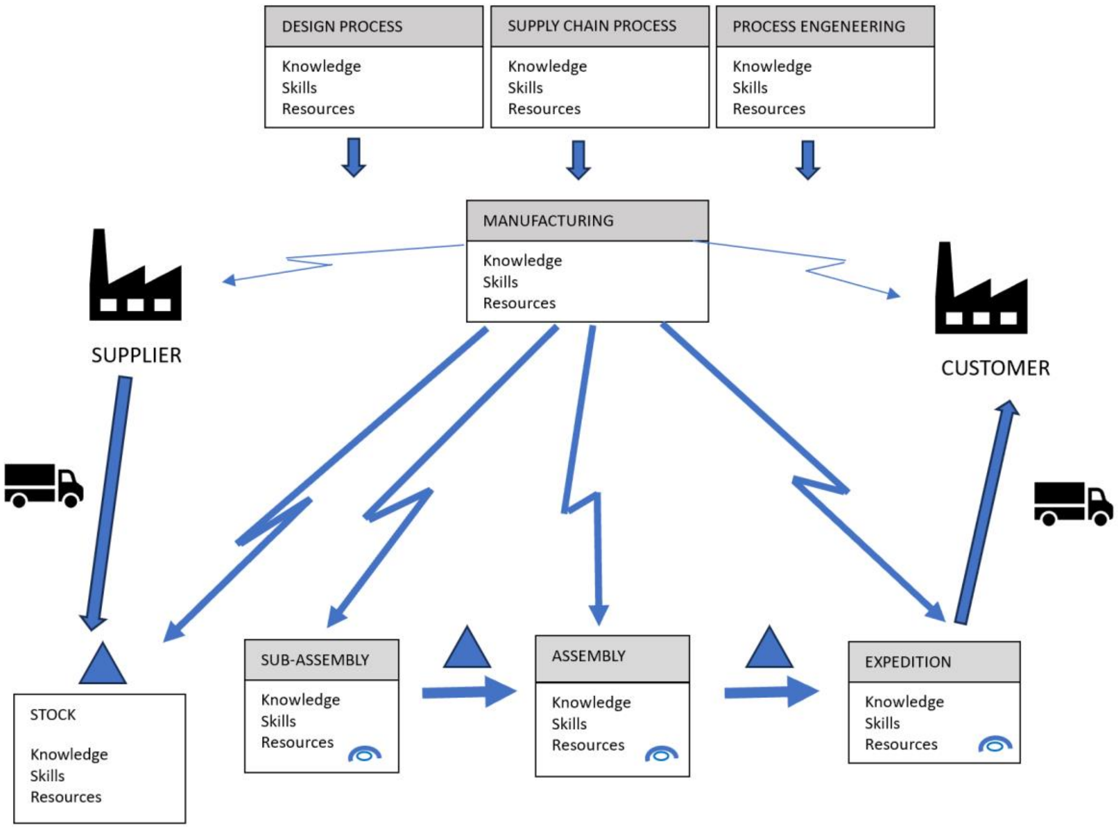


Figure 23. Feasibility analysis

First, and regarding the **product design**, part of the feasibility analysis involves the design process of the product itself. The **product design team** (partners of LCAMP consortium) must review whether they have the necessary skills, knowledge and means to develop the product and if not, to acquire them. It is recommended to use a DFMEA (Design Failure Mode & Effect Analysis) tool for the analysis.

Secondly, the analysis to be accomplished by **partners of LCAMP consortium**, comprises the competences, knowledge and means needed for **the previous design and implementation of the supply chain and manufacturing process.** It can be done by means of a SWOT (Strengths, Weaknesses, Opportunities, Threats, and Opportunities) tool and/or a Quality function deployment QFD with the house of quality finalized by a PFMEA tool.

Finally, **participants** (partners of LCAMP consortium) should go through the feasibility of **developing and delivering the learning courses** in their schools. It is recommended to be carried out using a SWOT analysis.

The analyses will give an overview of the strengths, weaknesses, and gaps in the development of the CLF and will allow focusing the efforts on the acquisition of knowledge and competences in the areas where they are lacking, to bring the project to a successful outcome.

5.2. PRODUCTION PROCESS DESIGN

Having covered the theoretical and conceptual foundations of manufacturing in the previous section, this chapter describes the practical application of these concepts in the CLF. It focuses on the specific implementation of the manufacturing processes, with an emphasis on the necessary technical documents, detailed job descriptions and the digital infrastructure that play a crucial role in production.

5.2.1.SHOPFLOOR CONFIGURATION

This section provides an overview of the layout for the fabrication of the LCAMP's product.

1. **Assembly process**

The initial configuration of the LCAMP's CLF Layout, in consideration of the product's inherent characteristics, comprises four primary digital workstations with the potential inclusion of an additional workstation for future deployment (see Figure 24). The core function of these workstations is teaching and learning while the fabrication and quality assurance of the robot are taking place.

The initial two workstations, *Sensor assembly workstation* and *Wheels assembly workstation*, operate independently and concurrently, each devoted to different assembly tasks. *Sensor Assembly workstation* focuses on installing sensors within the sensor housings, and *Wheels Assembly workstation* addresses the assembly of three types of wheels (Regular, Omni, and Mecanum). Subsequently, the components assembled in these initial workstations are carried by a circular conveyor system to *Chassis assembly workstation*, located within a circular conveyor system, where sequential assembly of mechanical parts onto the chassis occurs.

Following completion of mechanical assembly in *Chassis assembly workstation*, the chassis moves forward along the conveyor to *Final assembly workstation*. This workstation is responsible for the installation of all electronic components, affixing covers, and conducting a comprehensive quality control assessment prior to dispatch.

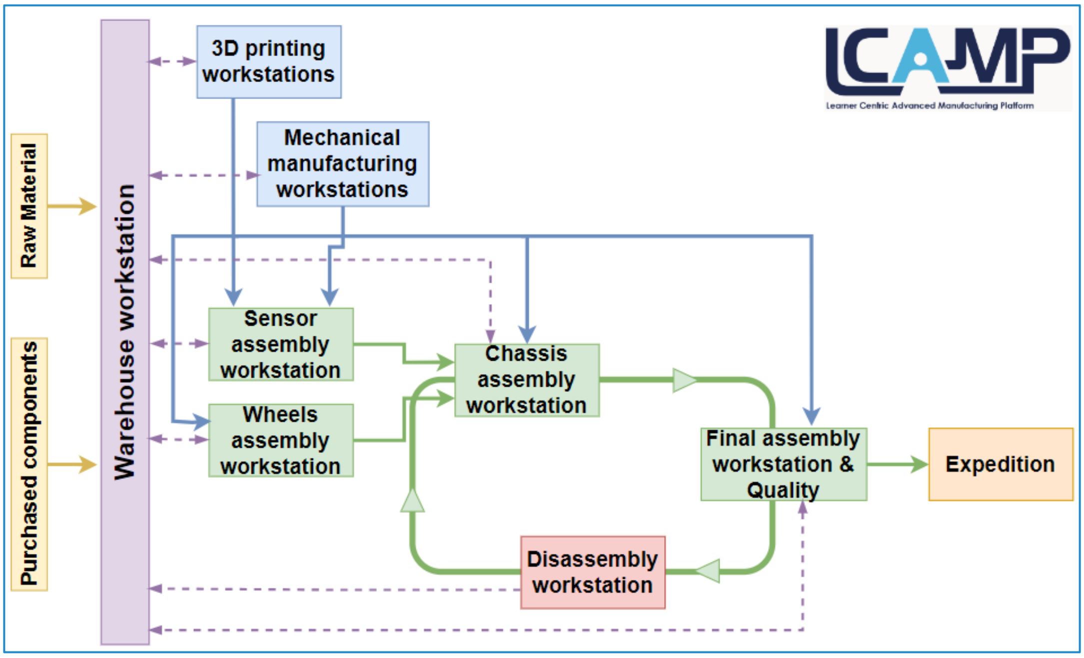


Figure 24. CLF manufacturing process

It is worth highlighting that the layout allows for the potential inclusion of *Disassembly workstation* within the conveyor system. This is envisioned as a workstation designed for disassembling robots that fail quality control inspections or are returned after their operational lifespan. The purpose of this dismantling process is to retrieve and reuse components that remain in optimal condition, aligning with sustainability objectives.

For a more detailed breakdown of individual workstation functionalities, please refer to the subsequent section. It is imperative to emphasize that both the manufacturing process and the workstation configurations must exhibit flexibility to accommodate potential redesigns or alterations to the product.

2. Components manufacturing

The production process for CLF product components will remain autonomous, irrespective of the diverse technological resources available at each centre. It is noteworthy that the technological capabilities of each centre are intimately correlated with the curriculum offerings and, consequently, the competencies addressed therein. Hence, a sense of reluctance exists towards centres to invest in technology that may not generate substantial value in the long term. Moreover, the diversification of technologies across centres engenders a spectrum of products characterized by distinct attributes, encompassing mechanical properties, materials, colours, and more.

Considering the attributes inherent to the participating centres, it is contemplated that there will be three options for procuring these components:

- **Mechanical Manufacturing:** Workstations may comprise conventional machinery, including CNC machines. While both types of machines can perform the tasks, it is advisable to use CNC machines or equipment capable of providing data input for the Manufacturing Execution System (MES). It is essential to bear in mind the objective of delivering added value within the scope of advanced manufacturing.

- **Additive Manufacturing:** Workstations will predominantly consist of different types of 3D printers, varying in print mode, materials, mechanical properties and other specifications.
- **Purchase:** Components that fall outside the purview of CLF's in-house manufacturing capabilities must be acquired. In this context, two options are feasible: firstly, the possibility of procuring certain components from other CLFs within the consortium, and secondly, the option to obtain commercial components from external vendors.

Every manufactured component must maintain a minimum inventory level to serve as a reservoir for subsequent workstation replenishment as required.

3. Warehouse(s)

Within a mechanical manufacturing process, it is imperative that all purchased or manufactured components, including raw materials and equipment, be stored within a designated storage facility. Ideally, this storage facility should feature intelligence or even semi-automatic/automatic operation, primarily for data acquisition to facilitate optimal functionality of the CLF. To this end, it must be meticulously designed to ensure operational efficiency and accurate inventory management. The following are some ideas of the features required for the warehouse.

Considering the design and layout, space should be optimised as much as possible and try to segment the storage areas, differentiating zones for raw materials, tools, semi-finished products and finished products.

On the other hand, when examining the storage system, it is advisable to incorporate mechanisms for product identification, such as barcodes, RFID or QR codes, at a minimum. This would open the option of incorporating data management technologies, such as inventory management software or integration into production systems.

Finally, on the one hand, the possibility of automating the process can be considered, incorporating robotics, implementing robotic systems or AGVs (Automated Guided Vehicles) to automate intra-warehouse movement. On the other hand, creating automatic data collection and access control through sensors and IoT (Internet of Things) devices can be investigated.

5.2.2.ASSOCIATED WORKING DOCUMENTS

The following section describes the templates to create the associate documents for each station of the CLF. The templates are available in annexe 11.5.

Job Breakdown Sheet (JBS): is a document used in the manufacturing and assembly of the CLF to provide a structured breakdown of tasks, steps, and responsibilities involved in a specific job or project. The JBS is an important component of the broader concept of Standard Work to improve efficiency.

This contains:

- Document details, which give information about the document such as process description and number of steps.
- Process symbols, which show Personal Protection Equipment (PPE) required, critical quality inspection, work-in-progress (WIP) quantity and quality symbols.
- Equipment list, which shows the tools and equipment required in the assembly of the CLF.
- Assembly steps that show all the steps of the assembly of the CLF, with images, descriptions, explanation, PPE and its explanation, and quality.

Safety Sheet (SS): is a crucial document that provides information about the safe handling and use of materials with the process of the CLF. It serves as a valuable resource to ensure the safety of workers and compliance within safety regulations.

This contains:

- Document details, which give information about the document such as workstation.
- Caution, which gives a short brief about the importance of following the Safety Instructions.
- Safety Instructions that show the steps, description of the work, explanation of the work and PPE.
- Symbols required to explain the PPEs used.

Process Control Plan (PCP): is a detailed document used in the manufacturing and assembly of the CLF. It is used to ensure the production of the CLF meets quality and performance standards. It is an essential part of quality management and process improvement methodologies.

It contains:

- Document details which provide information such as the work order, number of the product/ batch, project scope with a start and end date and number of steps.
- Process steps that show the sensors serial number, processes, quality inspection, name of the operator and notes to explain PPE symbols.

Maintenance Sheet (MS): is a document used to track and record maintenance activities, repairs, inspections, and other tasks related to equipment and machinery. The purpose of the MS is to ensure that maintenance is performed regularly, accurately, and in a well-documented manner, which helps maintain the reliability, safety, and performance of the assets.

This includes:

- Document details that provide information such as the purpose of the MS and the number of steps.
- Process steps, which show images of the maintenance steps, description of work, who's responsible for the work, frequency of the work and specifications.

Support material (training videos, maintenance videos, support videos).

All the templates that have been described are included in annex 11.5.

5.2.3. DESCRIPTION OF WHEELS ASSEMBLY WORKSTATION

The following table summarizes the main features of the wheel's assembly workstation:

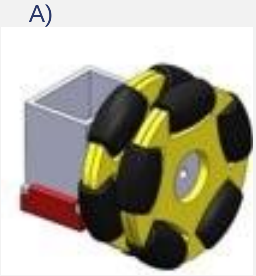
Name: Wheels assembly workstation
Didactic purpose: 1) Physical set up to address the following knowledge domains 1. Production management, 2. Lean manufacturing 3. Quality assurance 4. Assistance technologies 5. Ergonomics 6. Automation technologies 7. Digital workplace 2) Challenge based projects for students to enhance organizational aspects and decision-making activities.

Description: This digitised manual assembly station is set up to develop the correct assembly of the three types of wheels that the robot can carry now. Assistive technologies are optional and will be described later.
The variants of the product to be mounted depend not only on the **three types** of wheels but also on the **material** on which they are to be mounted and the **colour** in which they are to be mounted. The three types to assemble:

- **Omni wheel (A):** wheels with small discs (called rollers) around the circumference which are perpendicular to the turning direction. The effect is that the wheel can be driven with full force but will also slide laterally with great ease.
- **Regular wheel (B):** standard cylindrical shaped wheels with rubber on the outer edge for traction
- **Mecanum wheel (C):** The main difference between Omni and Mecanum is the direction the wheels on the outer edge are facing. Instead of being perpendicular to the main wheel, Mecanum wheels are made of conical-shaped wheels that face at a 45* angle from the main.

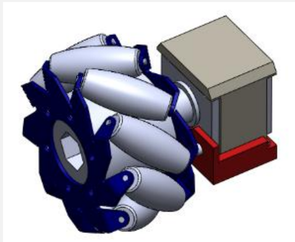
Sub product's picture:

A)



B)

C)



Works station's set up description	
Ergonomics	Standard mechanical assembly table
Assembly area	Workbench with a board with tray holders, necessary tools and a support for the instructions
Tools	Pliers
Measurements (approx.)	1 square metre. An ergonomic evaluation will be carried out to establish the configuration of the workstation.
Number of boxes (approx.)	10 numbered boxes (no colour) for: star1-1, star1-2, Part3, Pin, Hub, Hub2, Roller, Axis for wheel, Wheel shaft holder, Top) Size: 20-10cm Stored on the board according to the assembly order
Associated technologies / New trends	Paper instructions or using augmented reality (headset)

Tasks:

1. Check the minimum Stock is correct
2. Adjust the table or chair
3. Take the necessary tools
4. Check the instructions (per variant)
5. Use the AR headset for the instructions
6. Assemble the pieces with the instructions
7. Check the quality
8. Put the final assembly in the departure box

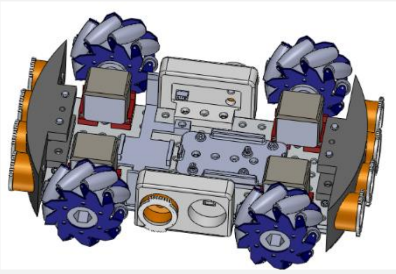
Associated documents:

1. Manufacturing Order(s)
2. Assembly instructions, Job Breakdown Sheet
    a. Omni Wheel Assembly
    b. Regular Wheel Assembly
    c. Mecanum Wheel Assembly
3. Quality instructions process Control Plan
4. Maintenance Standard

5. Safety Sheet
6. Support material (training videos, maintenance videos, support videos)
7. Bill of Materials
8. Drawings

5.2.4. DESCRIPTION OF CHASSIS ASSEMBLY WORKSTATION

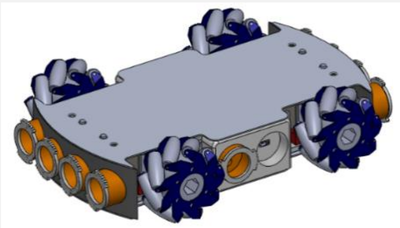
The following table summarizes the main features of the Chassis assembly workstation:

<table>
<tr><th colspan="3">Name: Chassis Assembly Workstation</th></tr>
<tr><td colspan="3">Didactic purpose:
1) Physical set-up to address the following knowledge domains
1. Production management,
2. Lean manufacturing
3. Quality assurance
4. Assistance technologies
5. Ergonomics
6. Automation technologies
7. Digital workplace
2) Challenge-based projects for students to enhance organizational aspects and decision-making activities</td></tr>
<tr><td colspan="2">Description: This digitized manual assembly station is set up to improve the accurate assembly of the robot's mechanical parts. The types of products that can be assembled include three types of wheels, a sensor box to be positioned on the robot's main body, a step motor holder, and other materials to be mounted on the main body.</td><td>Sub product's picture:
</td></tr>
<tr><td colspan="3">Works station's set up description</td></tr>
<tr><td>Ergonomics</td><td colspan="2">Standard mechanical assembly table</td></tr>
<tr><td>Assembly area</td><td colspan="2">The assembly table which workstation with necessary tools and a support for the instructions</td></tr>
<tr><td>Measurements (approx.)</td><td colspan="2">Two metres wide, one metre high, one metre wide</td></tr>
<tr><td>Number of boxes (approx.)</td><td colspan="2">12 boxes including main plate, wheel, stepper motor holder, curved sensor box, small sensor box, cover plate top, stepper motor Nema 17, clipper, hub, sensors, electronic cards etc.</td></tr>
<tr><td>Associated technologies</td><td colspan="2">Paper instructions or using augmented reality (headset)</td></tr>
<tr><td colspan="3">Tasks:
1. Check if the minimum stock is correct
2. Gather the necessary tools
3. Check the instructions (per variant)
4. Assemble the parts according to the instructions
5. Perform quality control at each step
6. Test and check the functionality of the product after assembly
7. Place the final assembly in the output box</td></tr>
</table>

8. Prepare the workstation for the next assembly 9. Make continuous improvements to increase workstation efficiency
Associated documents: 1. Manufacturing Order(s) 2. Assembly instructions 3. Technical drawing documents of the parts to be assembled 4. Instruction on assembly sequence 5. Quality instructions 6. Maintenance standard 7. Support material (training videos, maintenance videos, support videos)

5.2.5.DESCRIPTION OF FINAL ASSEMBLY WORKSTATION

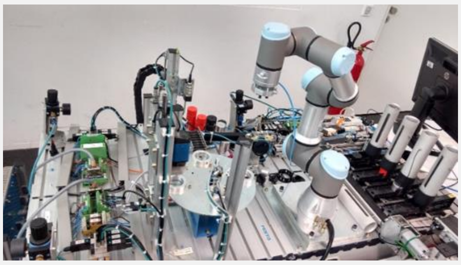
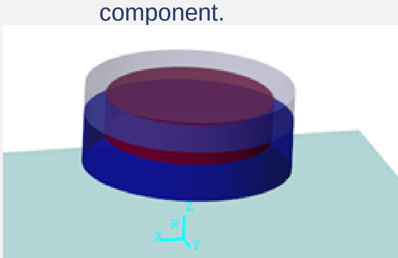
The following table summarizes the main features of the Final assembly workstation:

Name: Final assembly workstation	
Didactic purpose: 1) Physical set up to address the following knowledge domains 1. Production management 2. Lean manufacturing 3. Quality assurance 4. Assistance technologies 5. Ergonomics 6. Robotics and Automation technologies 7. Digital workplace 2) Challenge based projects for students to enhance organizational aspects and decision-making activities	
Description: Manual assembly of electronic components and wiring with assistance technologies (optional) Testing of final product	
Works station's set up description	
Ergonomics	An ergonomic evaluation will be carried out to establish the configuration of the work stations
Working area	Divided in 2 sections: • Assembly area: electronics and chassis assembly process • Testing area, validation assessments for the robot
Assembly area:	Workbench with a board with tray holders, necessary tools and a support for the instructions The materials are organized into two categories: wall materials and table materials
Measurements (approx.)	1 square meter
Tools	Screwdriver, soldering iron, scissors

Testing area:	Stand to lift the robot
Measurements (approx.)	1 square meter
Testing equipment	Multi-meter, oscilloscope, 12V Power supply Computer, with Arduino Workbench (or ST-Studio) and BT device
Number of boxes (colours, sizes, etc.) and layout	Wall materials (lightweight and non-fragile items) 12 numbered, 20-10cm sized boxes for: • Cables • Resistors • Capacitors • Switches • Terminals • Bluetooth Module HC-05 • I2C Multiplexer • DRV8825 Chip Table materials (heavier and fragile materials) 6 numbered, 20-40cm sized boxes for: • Batteries • Arduino • Ultrasonic Sensors All stored according to the assembly order
Associated technologies / New trends	1. Digital work instructions 2. AR 3. RFID/Barcode/QR More options: pick-to-light technology, robots, automated guided vehicles, and manipulators, motion monitoring
Tasks: 1. Check the minimum Stock is correct 2. Adjust the table or chair 3. Check the necessary tools are correct 4. Check the instructions (per variant) 5. Use the AR headset for the instructions 6. Assemble the electronic systems with the instructions 7. Check the product's quality 8. Put the final assembly in the departure box	
Associated documents: 1. Manufacturing Order(s) 2. Assembly instructions, Job Breakdown Sheet 3. Quality instructions process Control Plan 4. Maintenance standard 5. Safety Sheet 6. Support material (training videos, maintenance videos, support videos) 7. Bill of Materials 8. Drawings	

5.2.6.DESCRIPTION OF SENSOR BOX CELL

The following table summarizes the main features of the sensor box cell workstation:

Name: Sensor assembly workstation	
Didactic purpose: 1) Physical set-up to address the following knowledge domains 1. Production management, 2. Lean manufacturing 3. Quality management 4. Predictive Maintenance 5. Robotics and Automation technologies 6. Digital workplace (I4.0) 7. Sensor systems and test equipment	
Description: Automatic assembly of sensor components and wiring with assistance technologies (optional). Testing of Sensor assemblies	
Works station's set up description	
Measurements (approx.)	6m²
Working area	Aggrupation of didactic models to develop the task in a sequential automated way: 1. Based on the order, a part list for the sensors is generated. 2. The tooling for the specific order is set up in the assembly cell. 3. A wiring diagram is created, either in a student course or automatically 4. An assembly sequence for the MPS is generated. Starting from this sequence, the PLC and Robot programs are configured. 5. The storages in the assembly station are prepared by sequenced Parts.
Sensor mounting sequence:	1. Each sensor component consists of a base component, a Sensor PCB and a top component.  2. Each sensor component is plugged into one of the four sensor boxes. 3. After the assembly the sensor boxes are transferred to a test and calibration system
Sensor Modules:	Ultrasonic Sensor based on HC-SR04 Environmental Sensor based on BME280 Cam-Sensor Single Point Lidar Sensor
Actor Modules:	Light Module with white power-LED and RGB Led Power Switch Component with power switch and status LED

	USB-Connector and battery charger Sound Module with loudspeaker and amplifier
Associated technologies / New trends	MES, Configuration Management, Identification (RFID, Data Matrix-Code), Automation and Robotics, SCADA System, Data capture and calibration system, Industrial Communication.
Associated documents: 1. Product Sensor configuration(s) 2. Assembly instructions, Job Breakdown Sheet 3. Quality instructions process Control Plan 4. Operating Manual for the Work cell 5. Maintenance standard 6. Safety Sheet 7. Support material (training videos, maintenance videos, support videos) 8. Bill of Materials 9. Drawings	

5.2.7.DESCRIPTION OF WAREHOUSE WORKSTATION

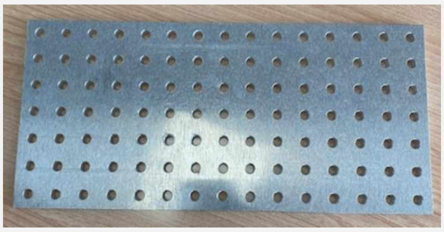
The following table summarizes the main features of the Warehouse workstation:

Name: Warehouse	
Didactic purpose: 1) Physical set up to address the following knowledge domains Production management, Lean manufacturing Quality assurance Assistance technologies Ergonomics Automation technologies 2) Challenge based projects for students to enhance organizational aspects and decision-making activities	
Description: Semi-automated or automated warehouse, where data is collected and raw materials, parts or semi-assemblies, and finished products are stored. It is the space allocated to regulate the flow of stock.	
Works station's set up description	
Ergonomics	Elements to consider movement and weight assessment; safe movement and compliance; hygiene standards; bins adapted to the activity; ergonomic picking equipment; space optimisation and racking savings; modular spaces within the warehouse; safe packaging; good lighting; personal equipment and essential safety equipment
Tools	The cutter, quick adhesive tape dispenser, weighing scales, roll holders and rollers for stretch film, strap tensioner, and final safety end cap, among others
Measurements (approx.)	About 20 square metres.
Number of boxes (approx.)	The number of boxes will depend on the type of manufacturing workstations, as the materials will change, and the number of Assembly workstations, due to the variety of by-products
Associated technologies / New trends	ERP, Warehouse Management System, RFID, QR, Barcode, Automation and Robotics, Data capture system, Material Handling technologies

Tasks: (list of tasks that a worker carries out in this workstation) Receiving, storing, and dispatching goods from a warehouse Unloading and sorting of goods Product quality control and order review Placing products in their respective locations within the warehouse Checking stock levels and stock replenishment of goods Order preparation Organising the dispatch of orders
Associated documents: Purchase order (issued by the company and sent to the supplier) Complete record of orders issued Requisition sheet for goods (between warehouses or between sections of the company) Delivery note (document received together with the goods) Receipt sheet (internal document with the purpose of recording the orders and goods received in the warehouse) Maintenance standard Safety Sheet Support material (training videos, maintenance videos, support videos)

5.2.8.DESCRIPTION OF MACHINING OF COMPONENTS WORKSTATIONS

The following table summarizes the main features of the Machining of components workstations:

<table>
<tr><th colspan="2">Name: Machining workstation</th></tr>
<tr><td colspan="2">Didactic purpose:
1) Physical set up to address the following knowledge domains
1. Smart manufacturing
2. Production management,
3. Lean manufacturing
4. Quality assurance
5. Assistance technologies
6. Ergonomics
7. Automation technologies
2) Challenge based projects for students to enhance organizational aspects and decision-making activities</td></tr>
<tr><td>Description: The machining workstations are multi-purpose machine tools that work by chip removal and perform various types of operations (turning, milling, drilling, boring, etc.) on the same metal part. The operator controls the machine and monitors the production of the parts automatically, based on a pre-established programme, by entering the machining data into the numerical control. Different parts will be produced here.</td><td>Sub product’s picture (example of a part):
</td></tr>
<tr><td colspan="2">Works station’s set up description</td></tr>
<tr><td>Ergonomics</td><td>The Final Risk will depend on the type of machine being worked on. The areas to be analysed include:
• Postural Level: All types of movements that the operator performs with the same body zone</td></tr>
</table>

	• Frequency: The number of movements that the operator performs with the same body zone within each postural level • Effort: The weight that the operator supports when performing a movement with the body zone within each Postural Level
Tools	The tools required will depend on the type of machine. However, the following groups can be identified: • Tools for set-up • Cutting tools • Measuring and checking tools
Measurements (approx.)	About 6 square metres
Number of boxes (approx.)	Depending on the parts to be manufactured on a particular machine. Approximately 3 boxes per production order
Associated technologies / New trends	HMI screens for displaying production information, RFID readers for user logging and MES systems are among the highlights
Tasks: 1. Prepare the workstation to produce the part, according to the data provided by the production department 2. Prepare the raw material 3. Select the necessary tools 4. Perform and supervise machining operations 5. Ensure the parts comply with the quality levels indicated in the technical specifications of the production orders	
Associated documents: 1. Manufacturing Order(s) 2. Job Breakdown Sheet 3. Quality instructions process Control Plan 4. Maintenance standard 5. Safety Sheet 6. Support material (training videos, maintenance videos, support videos) 7. Bill of Materials 8. Drawings	

5.2.9.DESCRIPTION OF 3D PRINTING WORKSTATIONS

The following table summarizes the main features of the 3D printing workstation:

Name: 3D printing workstation
Didactic purpose: 1) Physical set-up to address the following knowledge domains 1. Smart Manufacturing 2. Production management 2. Lean manufacturing 3. Quality assurance 4. Assistance technologies 5. Ergonomics 6. Automation technologies 2) Challenge-based projects for students to enhance organizational aspects and decision-making activities

<table>
<tr><td colspan="1">Description: 3D printing is an additive manufacturing process where objects are created by means of a succession of layers that are superimposed on top of the other until the desired part is achieved. Although the most used materials in this type of manufacturing are usually thermoplastic blends, they can be made with a wider variety of materials.
Among the advantages of this process are the reduction of waste, personalisation of parts and weight reduction</td><td>Sub product's picture (example of a part):
</td></tr>
<tr><td colspan="2">Works station's set up description:</td></tr>
<tr><td>Ergonomics</td><td>The Final Risk will depend on the type of machine being worked on. The areas to be analysed are:
• Postural level: All types of movements that the operator performs with the same body zone
• Frequency: The number of movements that the operator performs with the same body zone within each postural level
• Effort: The weight that the operator supports when performing a movement with the body zone within each Postural Level</td></tr>
<tr><td>Tools</td><td>The tools required will depend on the type of machine. However, the following groups can be identified:
• Tools for set-up: Blue painter's tape, alcohol, pliers, etc.
• Measuring and checking tools</td></tr>
<tr><td>Measurements (approx.)</td><td>About 2 square metres</td></tr>
<tr><td>Number of boxes (approx.)</td><td>Depending on the parts to be manufactured on that machine</td></tr>
<tr><td>Associated technologies / New trends</td><td>RFID readers for user logging and MES systems</td></tr>
<tr><td colspan="2">Tasks:
1. Import the file to be produced in STL format
2. Open the file with a laminating program
3. Export the file with the extension G-code
4. Load the file in the 3D printer
5. Pick up the part and post-process if needed</td></tr>
<tr><td colspan="2">Associated documents:
1. Manufacturing Order(s)
2. Job Breakdown Sheet
3. Quality instructions process Control Plan
4. Maintenance standard
5. Safety Sheet
6. Support material (training videos, maintenance videos, support videos)
7. Bill of Materials
8. Drawings</td></tr>
</table>

5.2.10. INDUSTRY 4.0 TECHNOLOGIES

In this section, an examination of the technologies that are incorporated into the CLF is shown. The starting point begins in June 2024, a crucial moment in the development of LCAMP as the first prototypes of the CLF are fully assembled. However, the project's endpoint will not be reached until June 2026, when the objectives set for the project, including the integration of I4.0 technologies into the CLF, are expected to be achieved.

This is not a random choice of technologies; each addition has been made with a well-defined purpose. The areas of knowledge plan for instruction, the current technologies mastered, the process design of the CLF and, not least, the product that will be created in this context: the robot. Throughout this section, the chosen technologies for this initiation will be analysed, and future additions that will contribute to the success of the CLF will be proposed.

Initial state in June 2024

- Assistive technologies - Digital workstation
- RFID, QR, Barcode
- AR
- COBOTS
- PLM
- MES
- Digital twin
- Networking technologies/ Virtual collaboration technologies
- Sensor technologies
- Drive Control
- Data analytics

Future developments

In the next 2 years, as the project's course is set towards its completion in June 2026, a list of future developments will be integrated.

- Integration of technology in the product (Robotic Operating System ROS, extra sensors with Sensor fusion and SLAM)
- Technologies to Reduction of environmental impact
- Life Cycle Assessment (LCA)
- Exoskeleton
- Artificial vision
- Automated Guided Vehicles AGV
- AI-Integration

5.3. DIGITAL INFRASTRUCTURE

According to the RAM I4.0 model (Plattform Industrie 4.0, 2018) there are three typical levels in the CLF.

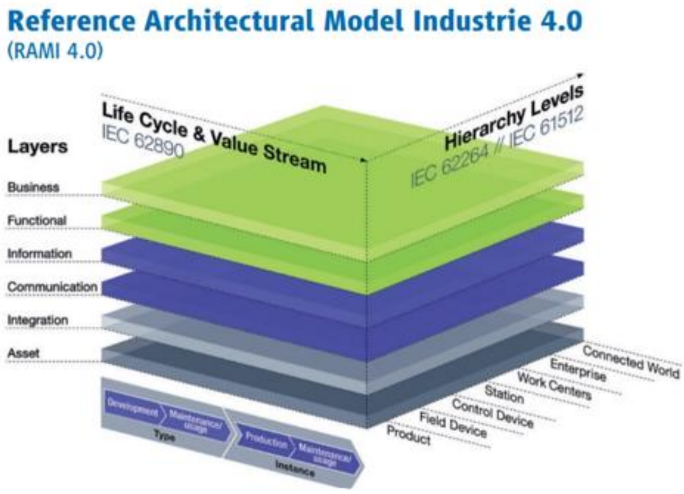


Figure 25. Architectural Model Industry 4.0. Source: Platform Industry 4.0.

The organization operates on three key levels: The Technical Level, which deals with assets and physical integration; the Operational Level, focused on communication and information; and the Management Level, where functional management and business-related tasks are prioritized.

Management Level
International digital Business
Operational Excellence

Operational Level
Lean Management, Production Order
MES-System, Supply-Chain, Life-Cycle Management

Technical Level
Industrial communication, Platform
Assembly Line, Automation, Product

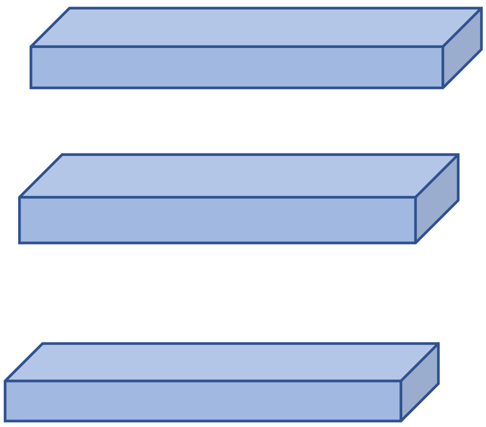


Figure 26. Levels according to RAM Industry 4.0 Model.

These three fundamental levels can be independently defined, each serving specific functions within the organization. The Technical Level involves distributed teams across different countries, enabling the execution of tasks related to assets and physical integration. At the Operational Level, activities can be carried out synchronously or asynchronously, using both the real factory and its digital twin, interconnected through the MES system. Management activities, on the other hand, can occur on-site or asynchronously, driven by CLF Data. Educational courses are structured accordingly, with the majority aligned with the Technical Level, falling within EQF 3-5. Some courses target the Operational Level, spanning EQF 5 and 6, while others are specifically designed for the Management Level at EQF Level 6.

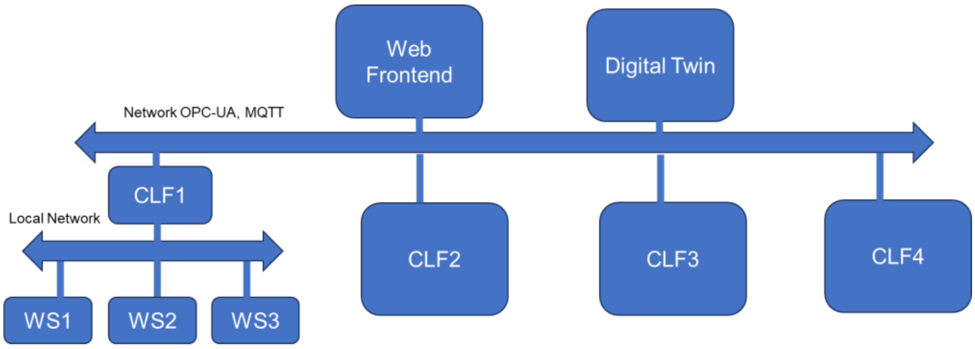


Figure 27. MES system of the CLF.

The MES system serves as the central nexus, linking all local CLFs. The digital twins emulate the connectivity of actual factories, ensuring that they function in a manner closely resembling real-world operations. Furthermore, a virtual LF has the capability to consolidate multiple local workstations into a sub-factory, enhancing operational efficiency and coordination.

5.3.1. DIGITAL TWIN OF THE CLF

The creation of digital twins for the CLF brings forth enhanced flexibility and accessibility for a spectrum of educational activities. Leveraging emulation technology, particularly that offered by the partner organization Simumatik (Simumatik, 2020), these Digital Twins will faithfully replicate both the mechatronic functionality and appearance of their physical counterparts. This digital emulation empowers both students and educators to engage in virtual work, reducing the exclusive reliance on physical equipment. The outcome is a substantial reduction in costs associated with materials, equipment, and space typically required for CLF-based education. This transition to digital representation stands to yield significant savings while expanding the range of educational possibilities.

The virtual production lines, currently in the preliminary stages of definition, will undergo a digital transformation into substations. Each substation will be equipped with its own PLC. The inputs and outputs will be interfaced with dedicated I/O cards featuring distinct mappings. This strategic approach empowers users to operate the system according to predefined manufacturing stages or reconfigure it to produce items in a customized sequence or to produce a different article. The substations can be manual stations to be used with assistive technologies such as VR or fully automated with machines and robots.

A standardized PLC will be integrated into the systems, including the MES. This integration will bolster the overall efficiency and coordination of the manufacturing process.

The primary advantage of these digital twin production lines lies in their capacity to foster collaboration among various VET centres. With one production line potentially situated in a different region or even country, users can remotely oversee and manage operations from their own computers. This not only enhances comprehension of the manufacturing stages but also exposes users to a diverse array of manufacturing solutions. Such remote accessibility broadens horizons, facilitating a more comprehensive understanding of the robot's production process and diverse manufacturing methodologies.

5.3.2.DIGITAL TWIN OF THE PRODUCT - VIRTUAL ROBOT

The morphology of the robot encompasses several key features and functionalities. It will be developed within the Simumatik Digital Twin Platform, an open emulation environment tailored for virtual commissioning (Simumatik, 2020). Emulation, in this context, refers to a system that replicates the behaviour of another system while remaining compatible with its inputs and outputs.

The platform's modelling framework is rooted in a component-based paradigm, where a system comprises one or more individual components.

The 3D model of the robot will be structured into distinct elements, comprising the base structure, top section, hole plate, and wheels (see Figure 28). This classification system will facilitate easy identification and comprehension of the specific elements that will constitute the robot. Furthermore, the robot will incorporate virtual motors, affording independent control over all four wheels, thereby enhancing its manoeuvrability and adaptability.

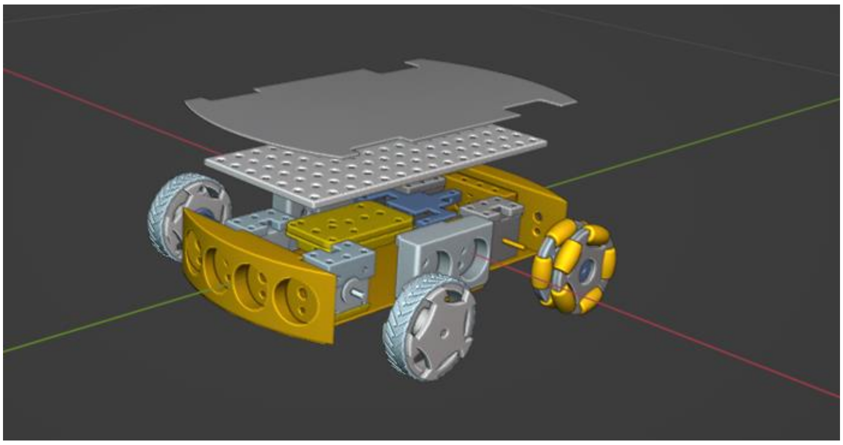


Figure 28. Parts of the virtual robot.

Furthermore, the robot will incorporate up to 10 sensors, as illustrated in Figure 28. This design allows the robot to be equipped with a hybrid combination of both analogue and digital sensor types. The virtualization of the sensors gives the possibility to test the sensors before incorporating them into the catalogue of the real robot. These sensors can be securely fixed to the robot's body, affording users the flexibility to adapt the configuration as needed.

Of course, the microcontroller is also virtualized. In fact, there are twins of more than one controller (Arduino, STM32, Raspberry Pi...), which gives the possibility to perform the tests and programming models before being incorporated into the physical model of the robot.

Two distinct iterations of the robot are under development: one equipped with a combination of regular and Omni wheels, and a second featuring solely Mecanum wheels. This modular approach ensures seamless interchangeability, providing users with exceptional convenience. Additionally, the robot will feature a hand controller, mirroring the functionality of the application used with the physical robot. This controller grants users the ability to navigate the robot within the virtual environment without the necessity for programming.

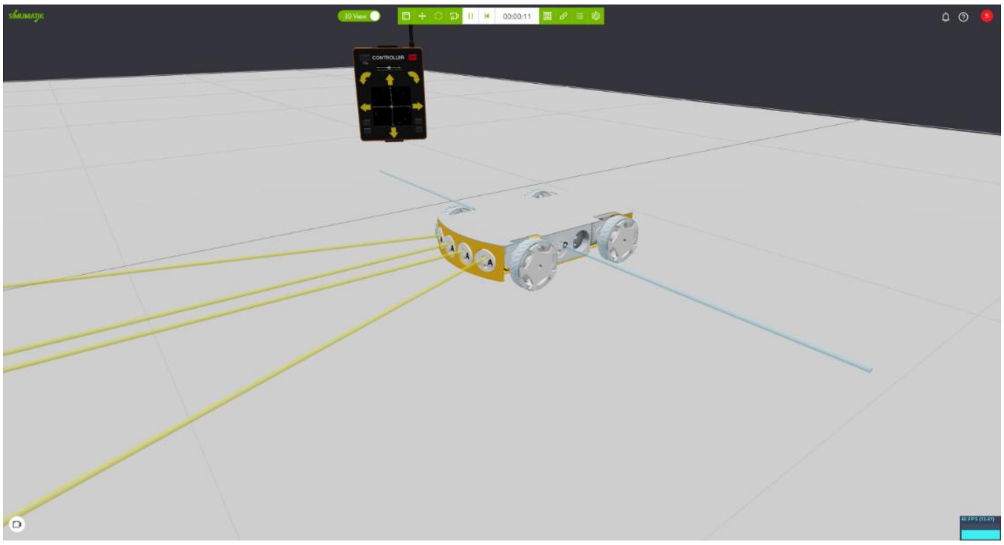


Figure 29. a virtual robot equipped with sensors and a hand controller

In conjunction with the robot, a range of dedicated spaces will be created within the digital twin environment. The underlying concept behind these spaces is to enable the robot's application domains to expand organically, free from the constraints of requiring additional equipment or physical area. These areas will be thoughtfully crafted to serve as dynamic hubs for interactive coding challenges, seamlessly integrated into various educational curricula, such as programming and control courses. The spectrum of robot control complexity will span from intricate algorithms to straightforward scripts, accommodating learners of all levels. Additionally, an exploration into the integration of lidar sensors for the robot is under way. These lidar sensors represent an advanced alternative to conventional sensors, promising to enhance the robot's capabilities significantly, targeting an AGV with the combination of ROS and odometry.

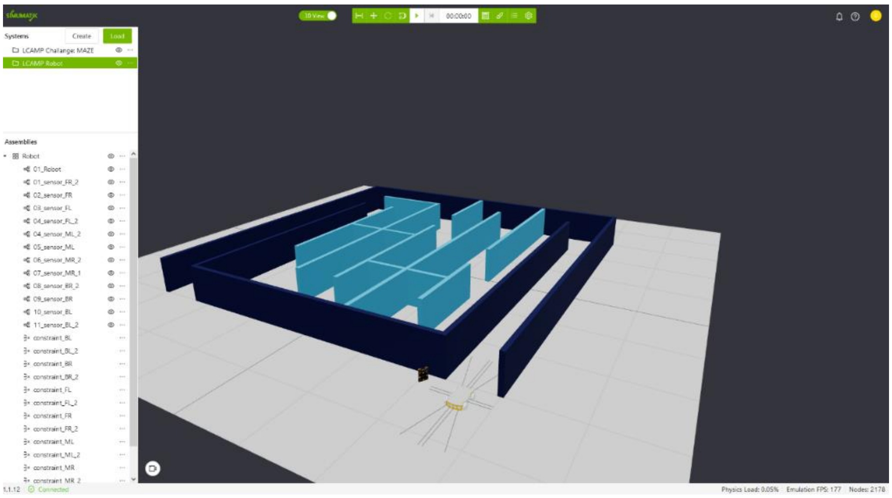


Figure 30. Example of the area for the robot

5.3.3.WORKSTATIONS AND MACHINE CONNECTION

The basic idea of CLF is collaboration and learning. For this purpose, a middleware must be integrated that uniformly processes the most diverse machine signals, with the most diverse semantics and different protocols, and makes them available for further processing in a standardized format.

Therefore, the machine message transformation tool **Force Edge** will be used (Aegilmez, 2021) It integrates a wide range of hardware devices (robots, sensors, etc.). From a communication perspective, the protocols and message formats can be simple +5V DC signal, proprietary line protocols or even high-level TCP-based protocols.

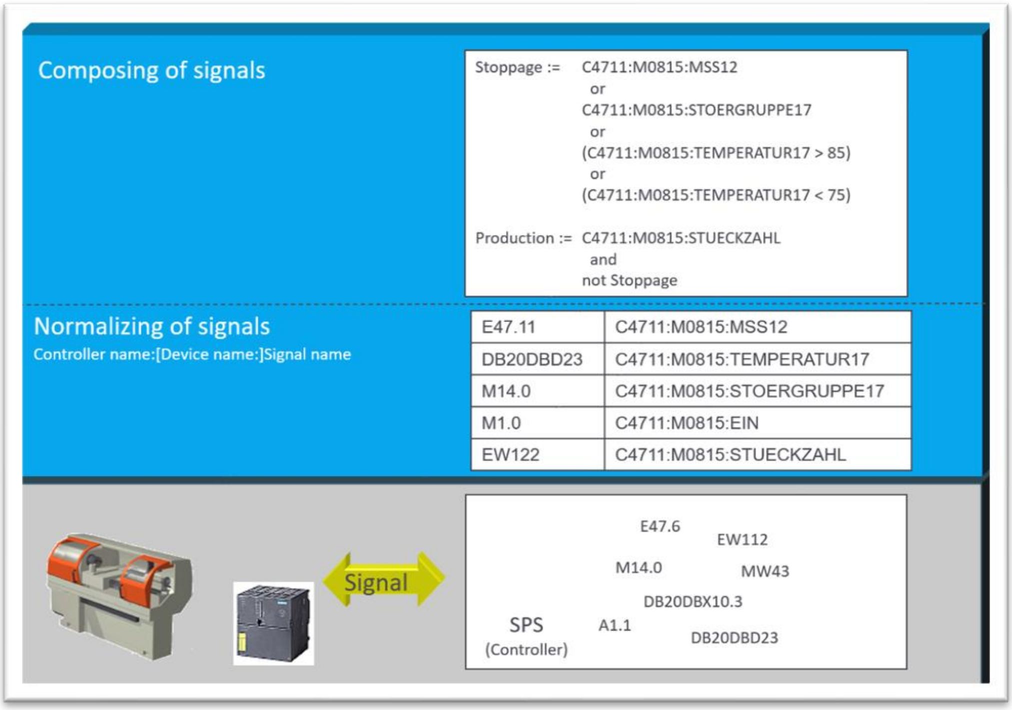


Figure 31. The transformation way from machine signal to manufacturing relevant information.

In the annexe 11.2 the features of the Forcam Force Edge solution are described.

5.4. MONITORING OF THE IMPLEMENTATION

In this section, the indicators, KPIs (Key Performance Indicators) and the monitoring of their evolution are established.

As detailed in section 1.4, there are a series of metrics whose fulfilment is related to the achievement of the expected results in WP6 CLF. Indicators are therefore created to measure these metrics. In the table below, the KPIs are listed, and the calculation or assessment criteria is explained:

Table 6. List of KPI's with their assessment criteria

KPI	How to calculate	Target
Number of I4.0 technologies	The number of I4.0 technologies/20	≥1
Quantity of collaborative product developments between project partner LFs	The quantity of collaborative product developments/8	≥1
Quantity of students from diverse countries working together in the CLF	The quantity of students/80	≥1
Creation of a digital twin for the CLF	Task performance degree/100	1
The establishment of pilot training courses	Number of pilot training courses/10	≥1
Implementation of collaborative courses between students from different countries	Number of courses/5	≥1
Establish pilot training courses tailored for workers	Number of pilot training courses/10	≥1
Level of satisfaction among Advanced Manufacturing VET/HVET students	Satisfaction Survey	≥8

As far as the monitoring of the evolution of the indicators is concerned, the main objective is clearly to ensure compliance with the series of metrics on time, but to achieve this, it is essential to analyse the evolution of the KPIs to know the causes that slow the progression, and in this case, collaborate with the partners in achieving the satisfactory implementation of the LF.

In addition, the project must follow the guidelines set by a roadmap that establishes not only the most important milestones for the implementation that will take place by June 2024, but will continue until the completion of the project in June 2026.

The fulfilment of the action plans needs to be evidenced by the corresponding deliverables included and defined in the roadmap and be related to the achievement of the targets set in the KPIs. This roadmap will start to be developed in December with the collaboration of the partners and will be established by January 2024.

It should be noted that once the LF has been set up, its journey will not end at this point, as its continuation will be supported by a system of continuous improvement, a method used to carry out continuous improvements. The LCAMP project envisages the development of this aspect in WP8.

6. COLLABORATION AMONG LEARNING FACTORIES

Collaboration among VET organizations is a key element of the LCAMP project. The CLF opens new perspectives for international cooperation, spanning multiple dimensions that engage both educators and learners.

The CLF gives room to develop collaborative activities in different stages of the value chain and for different types of participants. In the implementation phase, collaboration is taking place among the partners of the consortium, particularly researchers and teachers. In the operational phase, once the CLF is fully operative, a wider spectrum of users will have access to the CLF. In summary the following **target beneficiaries and users of the CLF** have been identified:

- VET centres from the LCAMP consortium. Directly responsible for the creation of the CLF, their collaboration is established as a part of LCAMP's tasks.
- VET centres from the LCAMP Alliance. As the first external users of the CLF, these early adopters will serve as proximal partners.

Four levels of collaboration are established:

- Robot production
- CLF course creation
- Virtual CLF
- Student and staff mobility

Additionally, LCAMP's Open Innovation Community (WP4) offers an even greater range of opportunities for interaction among VET centres.

6.1. COLLABORATIVE ROBOT PRODUCTION

The CLF has been created to produce a deliverable, specifically a robot, in conjunction with required theoretical knowledge, or didactic purposes. Robot production is embedded within a series of collaborative and coordinated learning activities involving VET students from different countries and regions, each contributing to specific tasks. This manufacturing process addresses competences described in section 2.1 through diverse experiential learning activities provided through courses, joint projects, and the CLF production line.

Information and data sharing: Interconnections between CLFs allow learners to share information and data internationally, including data about manufacturing activities as well as educational resources and materials.

Joint projects. Through joint projects and dedicated collaboration, students from different schools will have the opportunity to work together solving specific challenges including product design, lean manufacturing, and production management. The continuous improvement of the CLF allows for changes in the CLF value chain.

Competitions and challenge-based learning: The CLF environment, where replicas of the same workstations are available in different locations, allows the organization of competitions and challenges involving students from different geographical locations.

6.2. COURSES IN THE CLF

The CLF will deliver hands-on learning activities to enhance skills and knowledge for future Advanced Manufacturing professionals, and coordinate collaborative teaching and learning activities, primarily through formal courses. The cooperative nature of the CLF lends itself to offering joint courses for international or regional audiences, with a wide variety of delivery options including face to face, online (synchronous and asynchronous), blended delivery, and others. The preliminary list can be found in annex **Error! Reference source not found.**, but it will continue to grow with partner input and additional insights from WP3 and WP7, as well as the expansion of learning objectives from individual learning factories. The full description of the courses described in **Error! Reference source not found.** follows the common criteria developed in the work package devoted to Training for Advanced Manufacturing (WP5). Courses address the following criteria:

- Relatively short duration (10 to 30 hours or 1 to 3 ECTS).
- Offered as a part of an official national qualifications curriculum or as extracurricular courses tailored to the needs of a target audience (workers, undergraduate students, etc.).
- Delivered using the CLF, physically or virtually, albeit redesigned according to the learning objectives of each learning factory.

Delivered starting in the 3rd and 4th years of the LCAMP lifespan (2024-2026).

6.3. VIRTUAL CLF

The specific characteristics of the CLF will enable a broad variety of both learners and other users of the platform to collaborate internationally using the virtual version of the CLF. The digital infrastructure described in section 5.3 allows users to connect via the CLF or a virtual version of its features. Different solutions are available not only for members of the LCAMP consortium, but also for members of the LCAMP Alliance, including those who may not have CLF equipment available at their local VET schools. Examples of possible international collaboration using the virtual CLF include:

- Creating learning activities based on the digital twin of the product.
- Participating in collaborative simulations and virtual exercises in a controlled environment.
- Using the didactic materials of the virtual learning factories.

6.4. MOBILITY OF STUDENTS AND STAFF

Student and staff mobility constitutes a further direct cooperation opportunity inherent of the specific characteristics of the CLF. Learners and workers are open to engage in those locations where branches of the CLF are operating. Direct interaction and collaboration among international learners and workers constitute undoubtedly one of the crucial assets that the LCAMP CLF will take advantage of.

Erasmus + mobility programs, as they meet the previous features, are a good opportunity for such mobility measures:

- **Staff mobility** supported by Erasmus+: job Shadowing, Teaching or Training Assignments, Courses and Training.
- **Students' mobility** supported by Erasmus+: participation in VET Skills Competitions, Short-Term Learning Mobility of VET Learners, Long-Term Learning Mobility of VET Learners.

6.5. LCAMP'S ALLIANCE

The LCAMP Alliance, alongside its Open Innovation Community, stands as a pivotal gateway for external entities, particularly VET centres not yet affiliated with the consortium, to engage with and benefit from the activities of the CLF. It is critical to highlight the provision of **Open Educational Resources** (OER), a significant aspect of these initiatives. The CLF's growth entails the curation of didactic materials organized within four principal domains: The product to be manufactured (LCAMP robot).

- The manufacturing process, including fabrication and assembly.
- The digitalization of the CLF
- The virtual environments (CLF digital twin).

These domains collectively contribute to the wealth of resources, all of which will be made available through an accessible repository. The LCAMP platform, in this instance, provides a singular infrastructure facilitating universal access to this repository for all alliance members. This not only facilitates the replication of processes and products but also allows for modifications to create novel products or processes. Additionally, the community formed within the platform fosters direct interaction with the creators, thereby blurring the conventional demarcation between content creators and-users.

These efforts lead to several important benefits:

- Creation of a specific repository of I4.0 Open Educational Resources.
- Creation and enhancement of educational content, including didactic and methodological best practices.
- Promotion of materials distribution and reuse.
- Accelerated integration of enabling technologies in individual learning factories.

7. CONCLUSION AND OUTLOOKS

The CLF represents an ambitious and complex initiative, embracing **pedagogical objectives**, **technical and operational infrastructure**, and **VET centre collaboration**.

- **Pedagogical objectives** support the CLF addressing a wide range of knowledge domains from the Advanced Manufacturing landscape. Courses for diverse EQF levels clustered for those areas are proposed. Learning activities descriptions follow the taxonomy given on the LCAMP competence framework.
- **Technical and operational infrastructure** replicates existing industrial standards. Students manufacture a robot using geographically distributed process lines. The report details the architecture of the elements that constitute the set up and the approach for their digital connection and virtualization.
- **VET centre collaboration** is a distinctive characteristic of the proposal. The morphology provides details on collaborative opportunities, and the way that these collaborations will be articulated once the pilot is running.

7.1. CHALLENGES WITHIN THE LIFESPAN OF LCAMP

There are still quite a few open questions regarding the realization of the initiative, and the following challenges will be addressed before June of 2026.

- Enriching the scope of LCAMP collaboration, using collaboration mechanisms for specific actions.
- Expanding the competences map by identifying and addressing new skills needed within the Advanced Manufacturing industry.
- Opening the CLF concept to all interested VET centres; not only the operational aspects but also the technical ones must be addressed to facilitate engagement of additional VET centres.
- Attracting companies, especially SMEs from different EU countries, for their workforce training participation in the CLF.
- Incorporating future technological developments such as:
    - Automated Guided Vehicle (AGV) operations.
    - Environmental Impact Mitigation (EIM)
    - Life Cycle Assessment (LCA)
    - Machine Vision (MV) and other uses of Artificial Intelligence (AI)Robot Operating Systems (ROS)

7.2. SUCCESS FACTORS WITHIN THE LIFESPAN OF LCAMP

LCAMP relies on a variety of success factors, including:

- Achievement of KPIs articulated in section 5.4.
- Increase in the number of external VET centres involved.
- Use of the virtualized CLF.
- Use of the CLF facilities by teachers in VET centres.
- Addition of more content and technical features to the CLF.
- Development and delivery of micro-credentials for advanced manufacturing learners through the CLF.

7.3. SUSTAINABILITY

CLFs bring great potential to the VET community, but they also require attention to longevity and the ability of partners to maintain their commitments and good work outside the time frame of the initial project. Much of this work will be accomplished through the LCAMP Alliance. The LCAMP Alliance is the European reference network for knowledge generation and exchange, collaboration and service provision for VET centres, companies and other stakeholders working in the Advanced Manufacturing sector. The alliance aims at developing talent, reducing skills gaps in the industry, transferring knowledge and building a sustainable future of the Advanced Manufacturing community always punting the learners at the centre. VET providers of the Advanced Manufacturing sector from all over Europe can join the alliance and participate in the initiatives put forward. To assure continuity beyond the granting period, the LCAMP consortium has put in place several sustainability initiatives, including:

- Creating and expanding the LCAMP Alliance, described in WP2 (LCAMP, 2023).
- Strengthening the LCAMP Platform articulated in WP8.
- Establishing a stakeholders' engagement plan in WP9 (LCAMP, 2023).
- Developing collaboration projects through the Open Learning Community in WP4 (LCAMP, 2023).
- Increasing the number of courses linked to the CLF through WP3 and WP5.
- Promoting the good work and persistent impact of the LCAMP partners, individually and collectively.

Through the activities listed above, and others that will be developed in the coming years, LCAMP's accomplishments and the LCAMP Alliance will achieve a persistence and sustainability that contributes to the advanced manufacturing sectors of multiple countries and regions. This is further supported by internal enhancement through the development of tools and the establishment of innovative activities. Overall, the collective work of LCAMP partners, the LCAMP Alliance, and the industry partners engaged by each of participants will result in a robust network of learning and innovation that will persist for many years to come.

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9. INDEX OF FIGURES

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11. ANNEXES

When filling in the corresponding tables, the green colour will be used to indicate that in that section it corresponds to the checked box.

11.1. FUTURE PROOF QUALIFICATIONS RELATED TO THE KNOWLEDGE DOMAINS INCLUDED IN THE COLLABORATIVE LEARNING FACTORY

Lists future proof qualifications related to the selected domains that are offered in the partner's countries. Detailed information about those qualifications can be found in the document "Identification of Industry 4.0-Specific Qualifications and Job Profiles in Different Industry Sectors" elaborated in LCAMP.

Table 7. Future proof qualifications related to the selected knowledge domains included in the CLF.

Country	Related National Qualifications	Knowledge Domains												EQF level
		Mechanical engineering, smart manufacturing	Production management	Process engineering	Eco-design	Electronics	Robotics	Automatization	Manufacturing processes. Machining, additive	Logistic and supply chain	Sustainability	Industry 4.0	Computer science	
Basque Country	Production Scheduling in Mechanical Manufacturing													5
	Industrial Mechatronics													5
	Specialization Course in Smart Manufacturing													5
	Mechanical Manufacturing Design													5
	Automation & Industrial Robotics													5
	Electrotechnical & Automated Systems													5
	Electronic Maintenance													5
	Computer science and Telecommunication Systems													5
	Specialization Course in Collaborative Robotics													5
	Production Programming in Mechanical Manufacturing													5
	Machining													4
	Specialization Course in Smart Manufacturing													5
	Specialization Course in Artificial Intelligence and Big Data													5
	Specialization Course in additive manufacturing													5
	Specialization Course in Digitalisation of Industrial Maintenance													5

	Specialization Course in Cybersecurity in Operational Technology Environments	5
	Specialization Course in Installation and Maintenance of Systems Connected to the Internet (IoT)	5
France	**Maintenance of connected production systems**	**4**
	Mechanical engineering technician-training program	4
Germany	Mechanical engineering technician-training program	4
	General Industrial Engineering	6
	Specialization program in Production Engineering	7
	Mechanical Production Scheduling	5
	Design in Mechanical Manufacturing	5
	Mechanical Engineering Design and Development	6
	Automation & Industrial Robotics	5
	Production Programming in Mechanical Manufacturing	5
	Specialization program in Energy Management	7
	Specialization program in Virtual Engineering	7
	Specialization program Project Engineering	7
	Specialization program in Service Engineering	7
	Specialization program in Vehicle Technology and Electric Mobility	7
	Specialization program in Embedded Systems	7
	General Computer Science	6
	Specialization program in Information Technology	7
Slovenia	Mechatronics Operator	4
	Mechanical Engineering Technician	4
	Caregiver of process devices – Mechatronic	4
	Automotive Electrical and Electronic Systems	5
	Internet Of Things Developer	4
	Artificial Intelligence and Approach Techniques	6
	Ethical hacking, and cybercrime	5
	Data mining	5
	Bionics	5
	Bionics artificial intelligence	5
	Artificial intelligence and energy	5
	Micro technologies and energy	4
	Computing	5
	Programming	5

Italy	Digitalization of industrial process													4
	Developing innovative business models													4
	Life-cycle management (PLM) to virtual and augmented reality in the product development context													4
	Collaborative robotics													4
	Use of collaborative robotics in Health and safety fields													4
	Cyber-physical systems driven by Industrial IoT, cloud computing, data engineering and data analytics													4
	The potential of 3D printing or additive manufacturing as enabling technologies in Twinning													4
	Additive manufacturing													4
	How Automation, the Internet of Things and technological and managerial support combine to define 4.0 Logistics													4
	Overview of the building blocks of companies which are both digitized and sustainable.													4
	Internet of things: applications, networks and platforms													4
	Big Data analysis													4
	Cyber security applied to industrial context													4
Türkiye	Machinery													4
	Mechatronics engineering													4
	Computer Aided Design & 3D Printing													4
	Microcontrollers (Arduino) & Internet of Things													4
Canada	Mechanical Engineering													5
	Electrical Engineering (Marine & Industrial)													5
	Robotics and Automation													5
	ARM Microcontrollers & the Internet of Things													5

11.2. FEATURES OF THE FORCAM EDGE

Feature Summary

An EDGE solution is carefully designed to meet several critical requirements in the realm of industrial automation and machine communication. These essential arguments help ensure its effectiveness and adaptability in a modern industrial setting:

- **High Amount of Available PLC Plug-ins and Protocols for Machine Communication:** An EDGE solution must boast an extensive library of PLC plug-ins and support for diverse communication protocols. This diversity ensures that it can seamlessly connect and communicate with a wide range of industrial machines, regardless of their underlying technologies.
- **User-Friendly UI with an Integrated Wizard for a Guided Process for Machine Connection:** To simplify the machine connection process, a user-friendly interface with an integrated wizard is indispensable. This not only reduces the learning curve for operators but also streamlines the configuration of new machines.
- **Graphical Signal Composition for Building a Standardized Machine Event Model:** A graphical signal composition feature is vital for constructing a standardized machine event model. This allows for clear and consistent representation of machine data, making it easier to monitor and analyze machine performance.
- **Openness for 3rd-Party Systems via REST, OPC UA, MQTT, KAFKA, and NATS.io:** Interoperability is crucial in today's industrial landscape. An EDGE solution must provide open interfaces for third-party systems through widely accepted protocols like REST, OPC UA, MQTT, Kafka, and NATS.io, ensuring seamless integration with existing infrastructure.
- **Machine Repository to Build a Connectivity Library for Faster Connection of Machines:** A central machine repository is essential for building a connectivity library. This repository simplifies the process of connecting new machines by allowing operators to reuse established configurations and settings.
- **Bidirectional Communication Between OT and IT for Machine Data and NC-File Transfer:** An EDGE solution should facilitate bidirectional communication between Operational Technology (OT) and Information Technology (IT) systems. This enables efficient data transfer and analysis, as well as the exchange of NC (Numerical Control) files for manufacturing processes.
- **Scalable Architecture with a Central Configuration Instance:** Scalability is crucial to accommodate the evolving needs of an industrial environment. A scalable EDGE solution should support the addition of new machines and functionalities, while a central configuration instance ensures uniformity and ease of management across the system.

In summary, an ideal EDGE solution should possess these key features to ensure efficient, user-friendly, and adaptable communication between machines in an industrial setting. These arguments underscore the importance of a well-rounded solution that can meet the demands of today's industrial automation landscape.

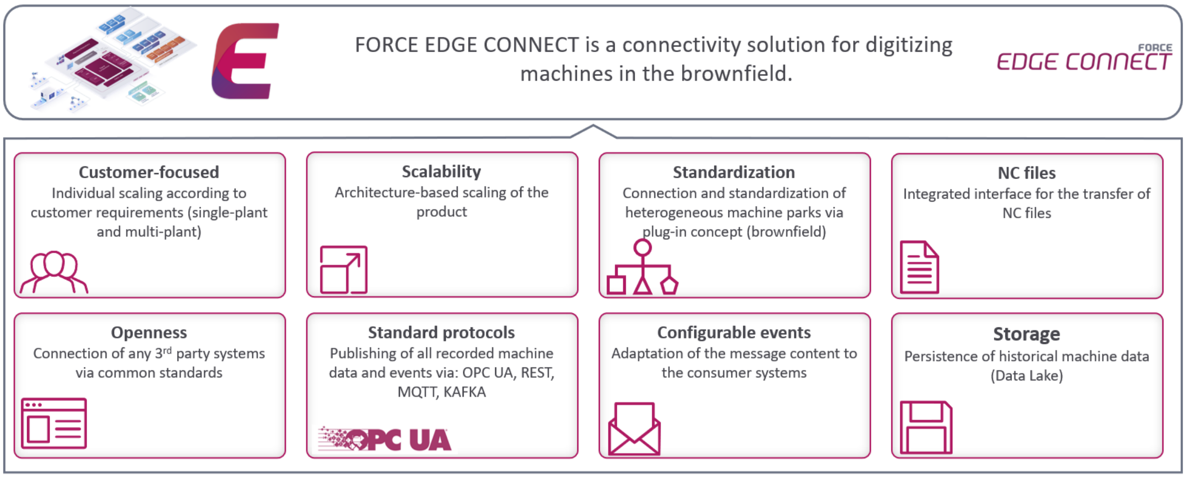


Figure 32. Summary of the FORCE EDGE features

A multi-level architecture is needed to implement this requirement. Machines and sensors have very different connection options. The well-known OPC-UA standard is only found in very few cases, which is why there is a universal data connection unit at the lowest level (South Bound Link) with an expandable plug-in concept for the integration of different protocols. From serial communication to control-specific protocols to OPC-UA, everything is possible or expandable. This is followed by a processing module (Signal Composition), which prepares the signals for further processing. In parallel, all input signals and the processed data are temporarily stored for a longer period of time. In this way, line interruptions in the direction of the "3rd party system" can be buffered or evaluation can be carried out directly on the EDGE data with reporting tools such as Grafana. In the direction of the "3rd party", the data is prepared in such a way that it can be transmitted using the protocols commonly used today. For further processing, reliance is placed on the open-source product Node-RED.

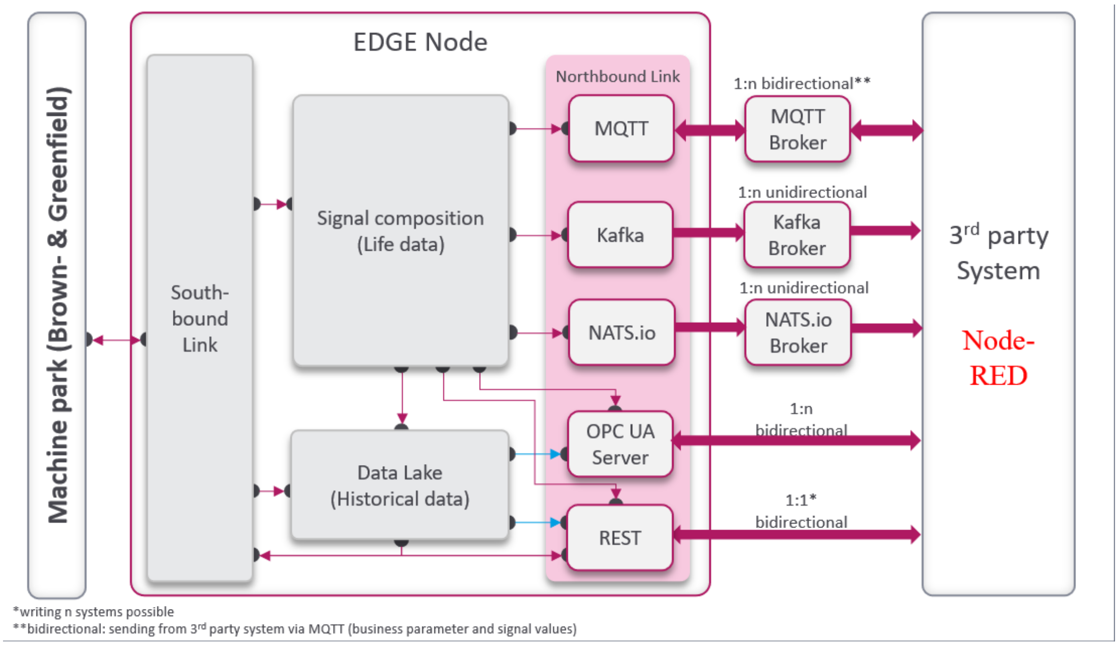


Figure 33. Architecture overview of FORCE EDGE

11.3. LCAMP COMPETENCE FRAMEWORK

The LCAMP Competence Framework for Advanced Manufacturing is organized into six categories of skills deemed essential for the future workforce in Advanced Manufacturing, which are further distinguished in subcategories, including the corresponding skills.

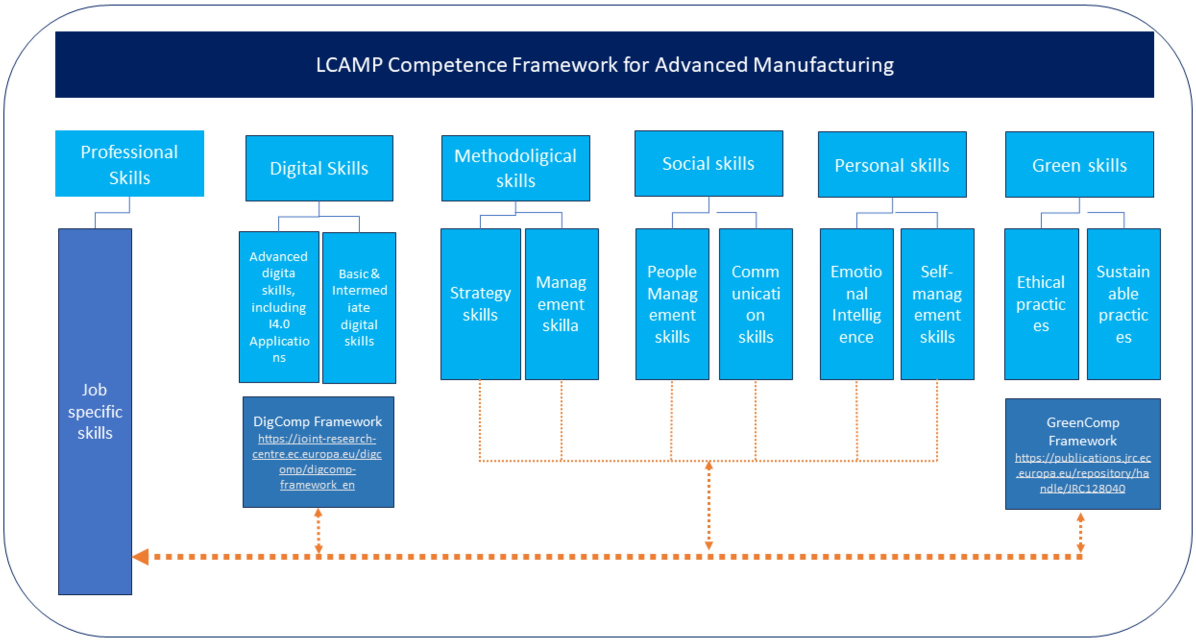


Figure 34. LCAMP's competence Framework for Advanced Manufacturing.

LCAMP's competence framework gathers the classical skills categories according to Heyse/Erpenbeck used in the educational landscape (Priffi, Knigge, Kienegger, & Kremar, 2017) i.e. professional skills, methodological skills, social skills and personal skills. For a better representation of the competences, LCAMP framework add digital skills and green skills categories. As the requirements and demands for employees depend on and change with the ongoing developments and transformational process, the competence framework will also adapt accordingly to display topical labour market needs. Furthermore, regarding the current twin transition in the economy, employee understanding, and possession of green skills show an increasing importance. Regarding this trend, skills referring to sustainability, the recycling economy, and resource conservations have direct impact on all the categories, as a mindset should be established for sustainable, resourceful and responsible action. The category of professional skills implies basic skills in STEM, as well as system analysis, interdisciplinary understanding of processes and organisations, competences in manufacturing, modelling and simulation, and equipment safety. With regard to Advanced Manufacturing, it is important for employees working in this sector to possess those basic and fundamental skills to be able to execute their primarily technical tasks. In addition, this category of the LCAMP-Competence Framework encompasses further technical skills.

Within the category of digital competences, there is a difference between competences referring to I4.0 applications and competences referring to data and information. The latter subcategory implies competences such as data management, data safety and security, cyber security, digital ethics, as well as data literacy. Moreover, this subcategory displays a variety of ancelary skills and subskills needed to be able to utilize a competence. Skills (e.g. programming, computing or handling ICT, human-machine interfaces and big data technologies) are clustered into the subcategory of I4.0 applications. Skills, and subskills of this category are predominantly highly job specific. Subskills referring to specific technological advancements are especially necessary for employees working in certain industry sectors, or with specific technologies in individual few companies. The content of this category has been complemented with the latest results of the DigComp model (Vuorikari, Kluzer, & Punie, DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes, 2022) which provides a common understanding of current digital competence demands for citizens.

The subcategories referring to methodological skills imply strategy and management. Skills such as customer orientation, health care, industrial hygiene, abstraction ability, complex problem solving, critical thinking, designing, planning, analytical as well as strategic or innovative thinking are clustered as strategic methodological skills. Furthermore, project, time, risk, and change management are all associated to management skills within the methodological category. Skills referring to management of intellectual property, personal or financial resources, deal negotiation, leadership, decision making, and conflict and quality management correspond to this subcategory.

Social Skills present the fourth category of the LCAMP-Competence Framework. This category implies skills referring to people management (e.g., teamwork, collaboration, and leadership), as well as those referring to communicating. Skills of the latter subcategory are related to all forms of interpersonal communication including digital interactions.

The fifth competence category is personal skills. Within this category the skills and skills are grouped into skills referring to emotional intelligence and self-management.

The skills implied in the first five categories (professional, digital, methodological, social, and personal), are expected to foster system as well as human resilience. The ongoing transformational process evokes continuous change and development. Employees and workers are required to adapt to the advancing changes and manage the developing requirements especially regarding the technical advances and innovations. In addition, the transformational process and twin transition also evoke changes in production processes and state or environmental regimentation. Therefore, the set of skills that define resilience will be crucial for the employees.

These categories of the LCAMP-Competence Framework have a human-centric approach, in which humans are at the centre of the problem-solving process. The Green Competences, on the other hand, comprise skills mainly from the current studies of the GreenComp (Bianchi, Pisiotis, & Cabrera Giraldez, GreenComp The European sustainability competence framework, 2022) framework, which promotes learning on environmental sustainability in the European Union. These green competences and skills related to sustainability are intended to help provide learners with an understanding of sustainability and environmental awareness. Ultimately, the majority of the skills in this category are also taught in other skill categories, such as: Problem solving, system thinking, critical thinking, adaptability or innovation, which refer to the category of methodological skills.

11.4. COURSES DELIVERED IN THE CLF

Table 8. Courses related to the selected knowledge domains included in the CLF

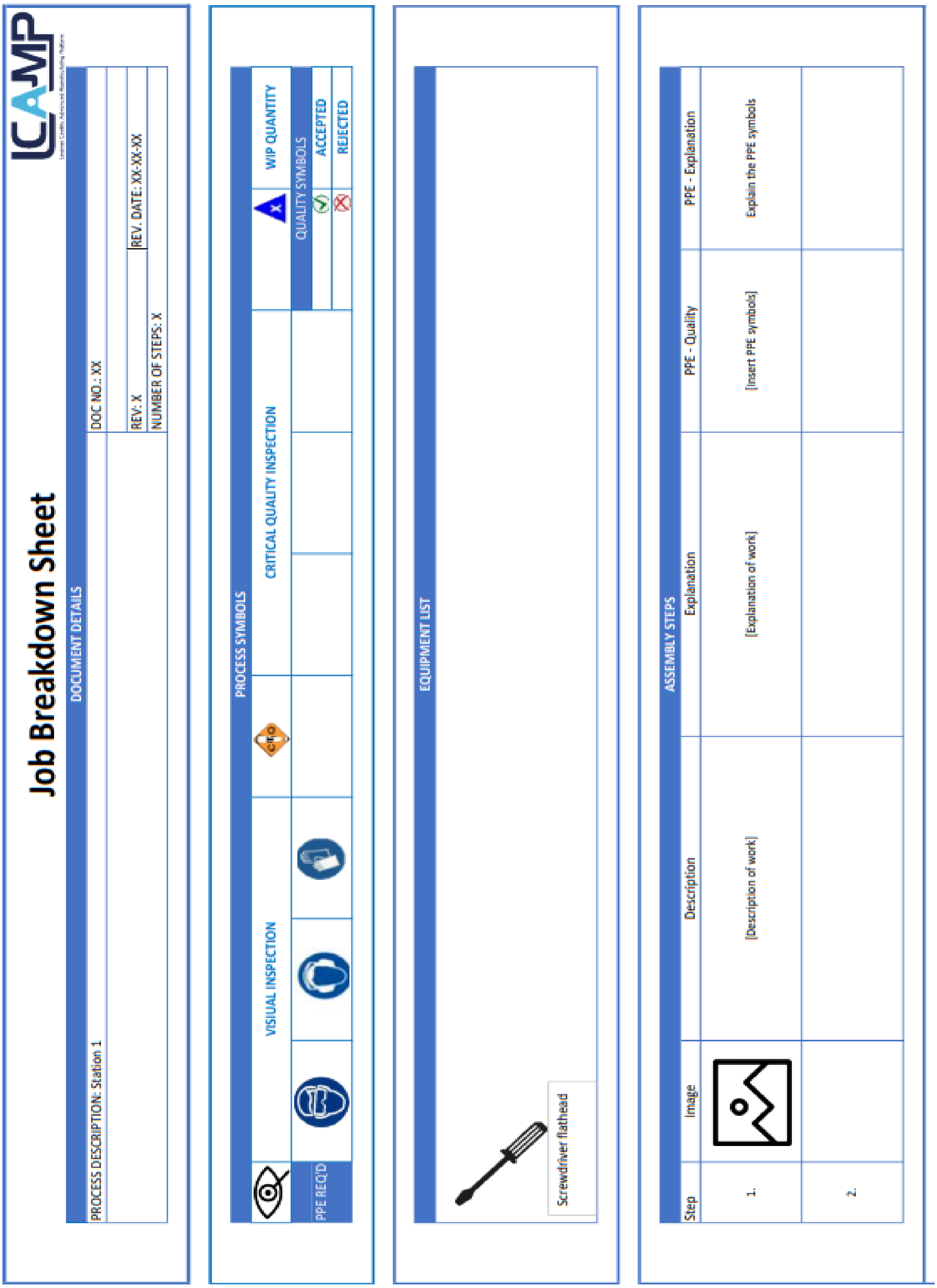
Country	Tittle of the Course	Mechanical engineering, smart manufacturing	Production management	Process engineering	Eco-design	Electronics	Robotics	Automatization	Manufacturing processes. Machining, additive manufacturing, assembly	Logistic and supply chain	Sustainability	Industry 4.0	Industry 5.0	Computer science	EQF level	Duration (Hours/ECTS)	Official curricular/ Extra curricular
Basque Country	PLM tools to redesign products in the CLF by means of Eco-design	■													5	20	E
	Production management in the CLF.		■												5	20	E
	Job analysis of a robot assembly tasks by Lean Manufacturing.			■											5	20	O
	Traceability of the critical elements in the assembly line			■											5	20	O
	Bases of the Life Cycle Assessment.				■										5	20	O
	Digital electronics with Arduino.					■									4	20	O
	Automation and robotics applied to the CLF						■								5	20	O
	Upgrading of the sensor assembly system by collaborative robot programming							■							5	20	E
	Augmented reality in the CLF							■							5	20	E
	Creation of digital instructions using augmented reality.											■			5	20	E
	Data analytics applied to the LF											■			5	20	O
	Decision making in LF environments.												■		5	20	O

France	Arduino programming														4	10-20	O
	Combinatorial logic														4	10-20	O
	IT numbering basis														4	10-20	O
	3D plastic printing														4	10-20	O
	Product lifecycle analysis														4	10-20	O
	Sustainable development awareness														4	10-20	O
	Digital conversion and analogy														4	10-20	O
	System design														4	10-20	O
	Production and management of a robot clamp														4	10-20	O
	Security														4	10-20	O
Germany	Lean, agile production management for CLF														6		
	Order management for highly varied distributed production														6		
	Sensor Systems with Arduino														6		
	ROS –Training –														6		
	Robotics Seminar														6		
	Autonomous configuration of assembly cells														6		
	Distributed Logistics														6		
	Resources efficient realization of a robot														6		
	Reduction of power loss in the manufacturing process														6		
	Production Controlling in distributed environment														6		
	Customer Value Management supported by CLFs														6		
	Risc- and Change management Seminar														6		

	Technical Communication Seminar		■												6		
Italy	Manufacturing 4.0	■													4	16	E
	Digital and sustainable factories		■												4	16	E
	Design 4.0				■										4	16	E
	Collaborative Robotics						■								4	16 - 32	E
	Health and Safety: Collaborative Robotics and 4.0 Factories						■								4	16	E
	Smart Connected Products							■							4	16	E
	Additive Manufacturing for Digital and Green Transition								■						4	16	E
	Manufacturing 4.0								■						4	16	E
	Intralogistics 4.0									■					4	8	E
	Green Factories										■				4	16	E
	Big Data and Business Intelligence										■				4	8	E
	Cyber and Industry Security										■				4	8	E
Türkiye	Exam 4.0 robot redesign course using Solid works program	■													4	16	O
	Course on manufacturing robot parts using 3D printer	■													4	16	E
	Computer-aided design 4.0				■										4	24	O
	Renewable Energy Integration				■										4	8	E
	Course on İnternet of things					■									4	24	O
	Using sensor systems with Arduino					■									4	36	O
	Ensure health and safety in manufacturing-								■						4	8	E
	Electronic card design and soldering techniques								■						4	24	O
	Industrial communications with PLC											■			4	12	O
Canada	Engineering Graphics & Modelling			■													
	Manufacturing Processes 3 and Quality Control					■									5	48	O
	Electricity and Machine					■									4	60	O
	Electronics for Mechanical						■	■							5	48	O

	Robotics & Automation														5	60	O
	Manufacturing Processes I														4	60	O
	Manufacturing Processes II														5	60	O
	Project Management and Social Responsibility														5	60	O
Slovenia	FANUC industrial robots programming														4	40	E
	Advanced 3D modelling in Creo Parametric 10														5	32	E
	3D modelling in Solidworks 2023														4	32	E
	PLK Automation basics														4	24	E
	CNC machine operator training														5	64	E
	Robotics & Automation														5	48	O
	Quality and reliability of processes														5	36	O
	Production preparation and management														5	54	O
	Computer aided manufacturing 4.0														5	48	O

11.5. TEMPLATES OF ASSOCIATED WORKING DOCUMENTS



Job Breakdown Sheet

DOCUMENT DETAILS		
PROCESS DESCRIPTION: Station 1	DOC NO.: XX	
	REV: X	REV. DATE: XX-XX-XX
	NUMBER OF STEPS: X	

PROCESS SYMBOLS			
PPE REQ'D	VISUAL INSPECTION	CRITICAL QUALITY INSPECTION	WIP QUANTITY
			QUALITY SYMBOLS: ACCEPTED, REJECTED

EQUIPMENT LIST
Screwdriver flathead

ASSEMBLY STEPS					
Step	Image	Description	Explanation	PPE - Quality	PPE - Explanation
1.		[Description of work]	[Explanation of work]	[Insert PPE symbols]	Explain the PPE symbols
2.					

- **Safety Sheet**

Safety Sheet

DOCUMENT DETAILS		
WORKSTATION: xx	DOC NO.: XX	
	REV: X	REV. DATE: XX-XX-XX

CAUTION
Welcome to this Safety Sheet. We prioritize safety in all our operations, and we are pleased to provide you this Safety Sheet to assist you in your work responibly. Please follow the safety instructions to elliminate the risks and please use the right PPE before you start your work.

SAFETY INSTRUCTIONS					
No.	Image	Description	Explanation	PPE	PPE - Explanation
1.		[Description of work]	[Explanation of work]	[Insert PPE symbols]	Explain the PPE symbols
2.					
3.					
4.					

- **Process Control Plan**

Process Control Plan

DOCUMENT DETAILS				
WORK ORDER: XX			DOC NO.: XX	
NUMBER OF THE PRODUCT/ BATCH: XX				
PROJECT SCOPE:	Start: ____________________	End: ____________________	REV: X	REV. DATE: XX-XX-XX
			NUMBER OF STEPS: X	

PROCESS STEPS					
Step	Serial Number	Process step	CTQ	Operator	Notes
1.		[Ex. clean the wheels]	[Quality inspection]	[Name of operator]	Explain the PPE symbols
2.					
3.					
4.					
5.					
6.					

- **Maintenance Sheet**

Maintenance Sheet

DOCUMENT DETAILS		
The purpose of this MS is to ensure that maintenance is performed regularly, accurately, and in a well-documented manner, which helps maintain the reliability, safety, and performance of the assets.	DOC NO.: XX	
	REV: X	REV. DATE: XX-XX-XX
	NUMBER OF STEPS: X	

PROCESS STEPS					
Step	Image	Description	Worker	Frequency	Specifications
1.		[Description of work]	[Who will do the work? Ex. operator]	[How often?]	
2.					
3.					
4.					
5.					
6.					

Learner Centric Advanced Manufacturing Platform

4. PART 3: GUIDELINES FOR THE IMPLEMENTATION OF I4.0 TECHNOLOGIES IN VET

Co-funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

GLOSSARY AND/OR ACRONYMS

ACRONYMS

AGV - Automated Guided Vehicles
AR - Augmented Reality
ARI - Automation and Industrial Robotics
BI - Business Intelligence
CBL - Challenged-Based Learning
CLF - Collaborative Learning Factory
CNC - Computer Numerical Control
CoVE – Centres of Vocational Excellence
EQF - European Qualifications Framework
ERP - Enterprise resource planning
FDM - Fused Deposition Modeling
HC-R-S - Human-centred, Resilient, and Sustainable
HVET High Vocational Education and Training
I4.0 - Industry 4.0
IALF - International Association of Learning Factories
ICS - Industrial Control Systems
IDS - Intrusion Detection Systems
IoT - Internet of Things
IPS - Intrusion Prevention Systems
ISA - International Society of Automation
IT - Information Technologies
KPI - Key Performance Indicators
LCAMP - Learner Centric Advanced Manufacturing Platform
LF - Learning Factory
LF-SAT - Learning Factory Self-Assessment Tools
MFA - Multi-Factor Authentication
MES - Manufacturing Execution System
MIR - Mobile Industrial Robot
OEE - Overall Equipment Effectiveness
OT - Operational Technology
PBL – Project Based Learning
PLC - Programmable Logic Controller
PLM - Product Lifecycle management
SLS - Selective Laser Sintering
VET - Vocational Education and Training
VPN - Virtual Private Network
VR - Virtual Reality
SAT - Self Assessment Tool
SOP Standard Operating Procedures
SWOT – Strengths, Weaknesses, Opportunities, and Threats
WP - Work Package

WS - Workstation

EXECUTIVE SUMMARY

This document presents a six-step guideline for incorporating Industry 4.0 (I4.0) technologies into vocational education and training (VET) environments, as demonstrated by the Learner-Centric Advanced Manufacturing Platform's (LCAMP) Collaborative Learning Factory (CLF). The guideline begins by identifying educational needs addressed by specific technologies, followed by a feasibility study. A phased implementation plan facilitates gradual deployment, emphasizing safety, compliance, cybersecurity protocols, and onboarding training for educators. It also prioritizes integrating these technologies into curricula to provide hands-on learning aligned with industry standards. The guideline concludes with recommendations for ongoing evaluation and continuous improvement. To support the guideline 12 Key use cases, such as augmented reality, automated workstations, and water jet cutting, showcase the practical application of these steps, demonstrating how CLF environments foster real-world skills through innovative, collaborative learning frameworks.

This document provides comprehensive guidelines for implementing I4.0 technologies in VET through the Learner-Centric Advanced Manufacturing Platform (LCAMP). LCAMP's key initiative, the CLF, aims to advance the teaching of advanced manufacturing by replicating industrial processes in VET centres using both physical and virtual environments. The CLF, a collaborative project among multiple VET centres, simulates real-world manufacturing scenarios to enable students to gain practical experience with cutting-edge technology.

The CLF framework is designed around practice-based learning that emphasizes job-specific and transversal skills essential for advanced manufacturing in the context of digital and green transformations. To facilitate this, LCAMP provides open-access educational resources and a roadmap for institutions seeking to replicate the CLF model. The CLF fosters collaboration across different institutions and integrates organizational models that focus on human-centred, resilient, and sustainable (HC-R-S) approaches.

A structured six-step guideline is outlined for integrating new technologies into learning factories, beginning with needs assessment and extending through technology selection, phased implementation, and continuous improvement. This guideline ensures a streamlined approach for VET institutions to adopt relevant I4.0 technologies, covering feasibility assessments, phased deployment, safety protocols, and training resources to support the technology's inclusion in educational programs.

Additionally, the document presents 12 specific use cases, such as augmented reality (AR) in assembly tasks, automated robotic workstations (WS), and water jet cutting, each demonstrating practical implementations and educational applications within the CLF framework. These cases showcase how I4.0 technologies enhance operational efficiency, facilitate collaborative learning, and align with industry standards. Through a mix of real and virtual environments, CLF enables international collaboration among students and instructors, preparing a skilled workforce capable of adapting to modern manufacturing challenges.

12. INTRODUCTION

Building a Learning Factory (LF) in a (higher) Vocational Education and Training (VET) centre is a major challenge. The purpose of the LF, its educational goals, target audience, structure, the manufacturing process it will replicate, the product, and the indicators all need to be defined (Abele E. , et al., 2015). Moreover, selecting the right technologies to incorporate in the LF is one of the most crucial decisions. These technologies, along with their applications and interactions with people, form the foundation of the LF experience.

The choice of technology will shape the entire operation of the LF. So, how should one select the appropriate technology? What criteria should a vocational education centre consider in making this decision? How can we prioritize factors such as didactic aspects and educational versatility, industry relevance, human-centred considerations, legal and administrative obligations, sustainability, cost and budget, space constraints, staff expertise, and other factors? Are all technologies equally suitable? And once the technology is chosen, how should it be implemented within the LF?

This report provides a comprehensive guideline for considering key factors in implementing technologies within the Learning Factories. The guide proposes a six-step pathway designed to assist practitioners in effectively absorbing I4.0 technologies. The guideline also draws on the experiences gathered through the development of the LCAMP Collaborative Learning Factory (CLF), where LCAMP partner organizations are incorporating I4.0 technologies into their Learning Factories according to a predefined framework (LCAMP, 2023).

By Industry 4.0 technologies, we mean technologies of these types:

- **Internet of Things (IoT):** A network of interconnected devices that collect and exchange data to improve operational efficiency and enable smart manufacturing.
- **Artificial Intelligence (AI) and Machine Learning (ML):** Advanced algorithms that analyze data, predict trends, and automate decision-making processes.
- **Big Data and Analytics:** Tools and methods for processing vast amounts of data generated in real time to optimize production and business strategies.
- **Cloud Computing:** Secure storage and on-demand access to data and applications over the internet, facilitating collaboration and scalability.
- **Augmented Reality (AR) and Virtual Reality (VR):** Immersive technologies used for training, product design, and enhancing operational workflows.
- **Robotics and Autonomous Systems:** Smart robots capable of performing tasks autonomously, improving precision and efficiency in manufacturing processes.
- **Cybersecurity:** Advanced measures to protect systems, networks, and data from cyber threats, ensuring safe operations.
- **Additive Manufacturing (3D Printing):** A transformative process of creating objects layer by layer from digital designs, enabling customized production and reducing waste.
- **Simulation and Digital Twins:** Virtual models that replicate physical assets, systems, or processes to optimize performance and predict failures.
- **Horizontal and Vertical System Integration:** Seamless connectivity between various systems across the supply chain, from factory floors to enterprise-level applications.
- **Edge Computing:** Processing data closer to its source for faster insights and reduced latency in critical applications.

- **Advanced Sensors and Smart Devices:** High-precision devices that monitor and control industrial processes in real time.
- **Blockchain:** A secure and transparent method for managing and verifying transactions, improving trust across supply chains.

In line with LCAMP's understanding of advanced manufacturing as the application of digitalisation and cutting-edge manufacturing developments (3D printing, Additive Manufacturing, High precision Machining, etc.) to manufacturing processes with the aim of increasing flexibility, productivity, and efficiency.

13. LCAMP COLLABORATIVE LEARNING FACTORY

Before diving on a technology absorption process it is worth adding a context to the activity. The proposed guideline is inspired by the LCAMP's CLF model.

LCAMP proposes the key features of shop floor facilities (practical labs) in VET schools to effectively address the evolving demand for current skills triggered by the digital and green transformations, using the CLF model (LCAMP, 2023). The CLF replicates contemporary industrial processes to manufacture a specific product for educational applications and environments (i.e. VET centre labs), but within a structure that is geographically distributed between seven VET centres, each centre playing a particular role in the manufacture of a final product. The interconnections amongst and between LFs scaffold the operational arrangements of the CLF. This configuration allows for the implementation of:

- Practice-based learning environments for VET students with embedded I4.0 technologies.
- Acquisition of professional[1] and transversal skills for Advanced Manufacturing.
- Enhanced cooperation among international VET organizations.

13.1. FEATURES OF THE CLF

The CLF model proposed in LCAMP (LCAMP, 2023) possesses the following characteristics:

- The entire **value chain** required for the production of products is replicated, with the physical environment, including machines, equipment, and resources, and set up within workshops. Additionally, the virtualization of the value chain may also be implemented as an optional component.
  The activities defined for the CLF value chain are gathered in 5 steps: 1. Product Design/ 2. Process Engineering/ 3. Manufacturing, Quality Control and Maintenance/ 4. Logistic/ 5. Virtualization
- It incorporates a **high degree of digitization**, taking inspiration from the smart factory concepts currently being developed within industry[2].

[1] According to the LCAMP competence framework, professional skills are related to all the skills under the subcategories of a) handling Production Principles; b) Competencies in STEM; c) Manufacturing; d) Additive Manufacturing; e) Simulation; f) Safety; g) Scientific work; h) Electrical engineering; i) Soldering / welding techniques; j) Human-machine interactions. Transversal refers to the skills included in the subcategories of a) Critical thinking; b) Problem-Solving; c) Analysing; d) Creativity/Innovation; e) Planning & Organising; f) Result-oriented; g) Willingness to Learn/Continuous Learning; h) Flexibility/Agility; i) Customer-oriented; j) Self-management; k) Decision Making; l) Responsibility; m) Communication; n) Cooperation/Teamwork; o) Diversity; p) Empathy

[2] We adopt a wide definition of technology. For us technology will mean (Bijker, 1994) • The knowledge required to handle a specific technology, or artifact, or a group of them. • The artifacts themselves, like a computer, a robot, or a pencil. • The reflection about the previous two, as in reflecting about I4.0, I5.0, digitalisation or advanced manufacturing.

- It is designed to **accommodate multiple technological disciplines** (either simultaneously or in sequence), necessitating the adaptation **of learning methodologies** accordingly.
- The model is conducive to fostering **collaboration** across various institutions, departments, and groups.
- Beyond digitization, the LF also facilitates the recreation of **organizational models found in companies**, with a focus on developing Human-centred, Resilient, and Sustainable aspects in line with the industry 5.0 paradigm (Oeij et al., 2023)

Whatever the configuration of the LF is, it offers a prominent action oriented pedagogical approach. The current study builds on the premise that most European countries are now actively using learning outcome (or competence) statements to define, review and refine their qualifications, VET curricula, and programmes (Cedefop, 2024)

The pedagogical approaches enhancing experiential learning[3] and Project-Based Learning (PBL) help to develop new ways to work simultaneously on job specific and transversal competences (OECD, 2021).

13.2. MATURITY MODEL FOR CLFS

The main characteristics that define a LF outlined in the previous section are difficult to assess. Moreover, VET schools may have different starting points for developing a LF model. It is worth remembering that the LF concept should align with each school's specific objectives. What works well for one institution may not necessarily be suitable for another, especially when making decisions about technology implementation.

To support technical education providers in creating or enhancing a LF, the LCAMP project has developed the **Learning Factory Self-Assessment Tool (LF-SAT)[4]** (LCAMP, n.d.) This tool provides tailored guidance based on each school's specific objectives and starting point, offering valuable insights to advance the implementation of their own LF. The LF-SAT is built upon 4 domains that represent the main characteristics of the Learning Factories:

- 1st domain: **learning methodologies**, in this domain the user asses to what extent active methodologies[5] are used in the learning activities and therefore in the LF.
- 2nd domain: technological disciplines or **technology fields** to implement in the LF. It delimitates what study programs are integrated in the LF, and by extension, what contents are planned to work out in the LF
- 3rd domain: the ability to recreate a **manufacturing value chain.** The value chain of a manufacturing process in advanced manufacturing involves a series of activities that transform raw materials into a finished product. The LCAMP CLF's value chain, the activities are clustered in 5 main steps: 1. Product design/ 2. Process Engineering/ 3.

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[3] UNESCO defines "experiential learning as "Experiential learning is a process that develops knowledge, skills and attitudes based on consciously thinking about an experience. Thus, it involves direct and active personal experience combined with reflection and feedback

[4] https://community.lcamp.eu/user-login/).

[5] Active learning is a method of learning in which students are actively or experientially involved in the learning process and where there are different levels of active learning, depending on student involvement (Bonwell & Eison, 1991). It is also defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing (Huang, 2020)

Manufacturing, Quality Control and Maintenance/ 4. Logistic/ 5. Virtualization. Indeed, these are the assessed items.

- 4th domain: **resources, equipment, level of digitization,** this assessment aims to measure the technical capacity to create a LF using the existing equipment and infrastructure available in the school.

As a result of the assessment process the user obtains a report detailing the readiness and progress in creating an LF. The report outlines school's or organization's current level across the four mentioned domains. The maturity levels range from initial stages called "basic level", an intermediate level called "ready level" to more advanced stages called "running level", where Learning Factories are already established.

Ultimately, the results of the LF-SAT provide valuable insights into a school's journey towards LF implementation highlighting specific areas where strategic focus could accelerate progress.

In recent years, numerous approaches to design learning factories and to assess their performance have been developed (Kreß, 2021). For already established LFs the International Association of Learning Factories (IALF) published the **Maturity Model for Learning Factories** (IALF, 2024) where concrete aspects about the functionalities of Learning Factories can be evaluated systematically. "Using the maturity model, it will be possible to evaluate and compare the maturity of Learning Factories not only in the field of lean production, but also for other thematic foci" (Enke J., 2017).

From another perspective, the Learning Factory Configuration Tool developed in the University of Twente (Frielinck, 2023) proposes a comprehensive tool to preserve the lifespan and educational value of a learning factory.

In the context of vocational training, Anselmann et al. have recently laid the groundwork for an exploratory descriptive study on LFs, with a particular focus on Baden-Württemberg (Anselmann, 2024). Their research underscores both the complexity of the analysis and the limitations faced. This study emphasizes the necessity for tools that can aid VET schools in the development and subsequent evaluation of LFs.

These tools are complementary and useful to obtain a clear picture of the context where a LF is being developed or used. When it comes to integrating technologies in those systems, they offer very valuable information to support the decision-making process.

14. GUIDELINES TO INCORPORATE TECHNOLOGY IN LFs

Integrating technology into manufacturing workshops in educational institutions requires a strategic and well-structured approach to maximize its impact. Proper guidelines are a support tool to ensure that technologies are implemented effectively, minimizing disruptions and optimizing outcomes.

This section presents a guideline to incorporate technologies in Learning Factories (LF), based on the experience that the LCAMP team gained during the creation of the LCAMP's CLF, enriched by selected use cases from bibliography. The guideline gathers insight from the educational context of the LFs and various industrial approaches for incorporating technologies into manufacturing processes. Additionally, human-centric aspects have gained significant importance in the development of the guideline due to their critical role in achieving a successful integration.

This report primarily focuses on how to incorporate new technologies in Learning Factory (LF) environments. Given that LFs can vary from one organization to another, it is recommended that each organization conduct a diagnosis of its specific situation before beginning the technology integration process. To support this, LCAMP provides the LF-SAT, enabling interested users to establish a baseline for starting the incorporation of new technologies.

The guideline consists of six basic steps, as follows.

14.1. IDENTIFICATION OF A NEED OR A PROBLEM TO SOLVE

The process begins with identifying a need, which can vary widely in nature. From an educational standpoint, this might include addressing a new skill or curriculum requirement, improving skill development, training individuals on specific technologies, meeting upskilling demands, or leveraging didactic opportunities presented by a particular technology. Additionally, the motivation to improve the features of the LF might also drive the integration of a specific technology.

Methods for identifying needs can come from a variety of sources, including outcomes from self-assessment processes like the previously mentioned LF-SAT, skill gap detection systems, data from monitoring systems (observatories), updates in official curricula, regional skills ecosystems, partnerships with industry, and more.

Finally, during the need's identification process, the following aspects should be taken into consideration (Mullen, 2011):

- Clearly establish the requirements and goals for integrating technology, such as improving skill development, enhancing simulation capabilities, or optimizing production processes for learning purposes.

- Align the technology with the overall educational and training objectives of the learning factory
- Evaluate the existing infrastructure to ensure compatibility with the new technology.
- Identify any necessary upgrades, such as connectivity improvements, software/hardware updates, or space modifications, to support the technology.
- Assess user needs, existing challenges, and process gaps.
- Involve stakeholders to understand expectations and constraints

14.2. TECHNOLOGY SELECTION AND FEASIBILITY STUDY

When analysing which needs the educational institutions aim to address through LF an initial filter has been applied to identify technologies that could be suitable. In this step, a more detailed examination is proposed, conducting a deeper analysis of the technologies deemed appropriate. For this purpose, the following criteria are suggested:

- Choose technologies that reflect real-world industry applications to create realistic learning environments.
- Conduct feasibility studies or pilot testing to validate the technology's effectiveness and fit.
- Ensure the technology is scalable, modular, and adaptable to accommodate future developments and expansions.
- Ensure that it is integrable into the existing infrastructure.
- Evaluate the virtualization capacity of the selected technology for its later integration in virtual environments (digital twins or others)
- Evaluate the collaboration options that the technology offers for co-work and collaboration activities with third parties.

14.3. DEVELOP A PHASED IMPLEMENTATION PLAN

Once the technologies are defined it is time to implement them into the LF. An appropriate planning of the implementation process is crucial to assure that the users will adopt naturally the choice made. In this step, a key factor is the human centric aspect of the technology adoption, to make the users participants of the implementation. The following criteria is recommended:

- Adapt the technology to align with user needs and workflows.
- Design user interfaces, features, and workflows that match user's requirements.
- Incorporate user feedback in the design process. Include users in the design team.
- Establish a timeline, milestones, and resources needed for deployment.
- Prepare risk mitigation strategies to handle potential challenges.
- Assign responsibilities to teams and individuals involved.
- Introduce technology gradually through pilot programs and limited deployment phases, establishing a timeline, milestones, and resources needed for deployment.
- Monitor each phase, gather feedback from participants, and refine the implementation process before scaling up.

- Prepare risk mitigation strategies to handle potential challenges.
- Ensure Safety and Compliance Standards
    - Follow safety protocols when integrating technologies to maintain a secure learning environment.
    - Comply with regulatory and educational standards related to the technology and its use within the learning factory.
    - Apply cyber security protocols to safeguard the integrity of equipment and networks.

14.4. TRAINING

A smooth adoption of a technology requires a training period for the users. In LF environments, there will be different types of user profiles, from developers to common users. Training processes must be tailored and adapted to each type of user.

- Offer comprehensive training programs to equip teachers/trainers with the skills to effectively use and teach the technology.
- Develop support materials (e.g., manuals, video tutorials, and interactive modules) to facilitate student learning and engagement.
- Provide training sessions, workshops, or e-learning modules for users.
- Develop user guides, Frequently Asked Questions (FAQs), and support resources.
- Offer hands-on practice and onboarding assistance for smooth adoption.

14.5. INTEGRATE TECHNOLOGY INTO CURRICULUM AND LEARNING ACTIVITIES

Generally, the final goal of the implementation of industry 4.0 technologies in LF is the upgrade of curriculums, always following the quality standards of each organization and national and/or regional regulations. The integration of the technology is reached by the creation of learning activities for the acquisition of the predefined set of skills linked to the use of the specific technology. The learning activities could be diverse in terms of learning methodology, contents, levels and duration.

- Design learning activities, projects, courses and simulations that incorporate technology to create hands-on, immersive learning experiences.
- Align these activities with industry standards and practices to ensure they are relevant and valuable for students.
- Define the assessment systems for the learning activities. The assessment should follow the quality standards of the organization and usually should include not only technical skills but also personal, social, digital and green skills. Moreover, the assessment system should be tailored for different types of users.

14.6. EVALUATION AND CONTINUOUS IMPROVEMENT

- Assess effectiveness and refine the integration process.
- Collect data on technology usage, efficiency, and user satisfaction.
    - Analyse performance metrics and compare them with initial goals.
    - Collect feedback from instructors and students to identify areas for improvement and continuously update the technology's integration.
- Plan for periodic updates and future technology enhancements to keep the LF up-to-date with industry advancements.

15. INTEGRATED TECHNOLOGIES, USE CASES

This section provides a comprehensive analysis of all the technologies that have been integrated into the CLF, exploring in detail their functions, modes of installation and contributions to the collaborative learning and production environment.

The CLF, conceived as a dynamic ecosystem that promotes collaboration and knowledge sharing, has been equipped with a wide range of technologies ranging from assistance technologies to advanced manufacturing systems. Each of these technologies plays a crucial role in the operation and continuous improvement of processes within the CLF.

12 use cases about technology implementation carried out by LCAMP partners in their own LFs are described hereafter. The focus is on describing in depth the specific functions of each technology, including their ability to improve operational efficiency and their role in facilitating communication and collaboration between participants. The integration of these technologies in the CLF has followed the guidelines proposed in section 3.

This detailed analysis provides a fuller understanding of how the technologies embedded in the CLF are transforming the way learning and collaborative production are conducted, and how they are contributing to the ongoing evolution of this innovative approach to manufacturing and knowledge.

15.1. USE CASE 1: ASSISTANCE TECHNOLOGIES BASED ON AR

USE CASE	**Assistance technologies based on AR**
Author:	Miguel Altuna LHII, Basque Country
Description	The assistance technologies for advanced manufacturing are designed to enhance productivity, quality, and efficiency in manufacturing processes. In particular, the LCAMP CLF is using AR as assistance technology to support user (either students or workers) in performing complex tasks more accurately and efficiently. This AR-based system overlay digital information onto the physical environment in real time, enhancing the user's ability to perform tasks, monitor processes, and make decisions. The system integrated guide users through the assembly processes by displaying step-by-step instructions directly in their field of view. This reduces errors and training time. (see Figure 35) Furthermore, the system is equipped with artificial vision cameras to assist in quality control tasks by checking deviations from the standard instructions on the CLF product. Last but not least the ergonomic aspects of the WSs are improved.
Location	• Miguel Altuna LHII – Basque Country • Tknika - Basque Country • DHBW- Heidenheim- Germany • CMQ- France

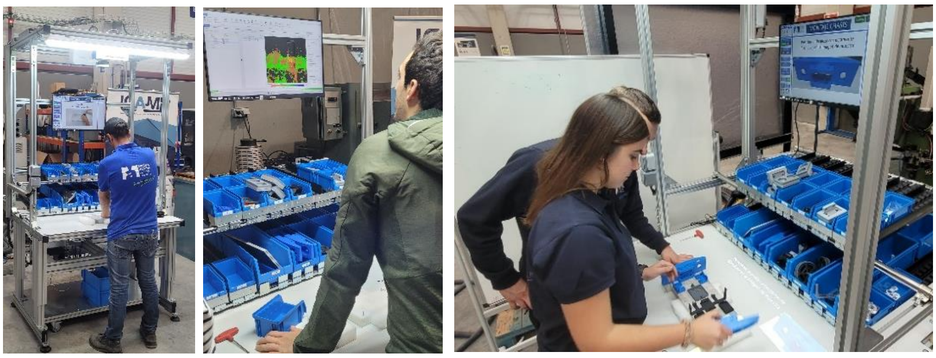


Figure 35 WS from Miguel Altuna LHII's LF equipped with the ARKITE system

#1. Identification of a need or a problem to solve,	
Purpose (technical)	The aim of this system is to digitalize to same extend the manual assembly WSs of the LF to get digital signals from them, assuring assembly quality and allowing traceability of the process. The purpose is to improve productivity, quality, and operational efficiency in manufacturing.
Purpose (didactic)	The purpose is to learn, trial and afterwards create learning contents about concrete digital solutions used in industry to improve productivity, quality, and operational efficiency in manufacturing. Besides that, we aim to research human centric aspects in manual assembly tasks and to raise the awareness of students on human centric practices. As a result, we aim to integrate learning activities into the following programs • PM, Mechatronics, Automation and industrial robotics (ARI), Smart manufacturing (Miguel Altuna LHII)
#2. Technology Selection and Feasibility Study	
	The selected technology, called ARKITE (ARKITE, n.d.) is a real-world industry application used in several industries where manual assembly operations are difficult to automatize and operators carry out manual tasks. **Technology's effectiveness and fit**. The selected system uses a 3D sensor and infrared sensor technologies for detections supported by the AR projection functionalities. Other object recognition technologies have been evaluated without achieving such satisfactory results (Raj, 2024),for different reason (process, service, technology, conditions). **Adapt the technology to align with user needs and workflows** This system enhances the Learning Experience of users by transform abstract concepts of lean manufacturing into interactive, 3D visualizations, making them easier for students to understand. It turns theoretical lessons into immersive experiences. The selected AR solution allows the tailored configuration for different users, work modes for training, allow to determinate the degree of assistance needed depending on the user's experience. It's also configurable considering physical aspects laterality, posture and movement, distribution of elements and lay out, tool's distribution and others. At the same time, the flexibility offered by system allows it to be reconfigured for the assembly of a variety of products. This aspect is important, as the system can be used in parallel for several assembly processes either within the LCAMP CLF or in other activities. In Miguel Altuna LHII's case the language and instruction's modes were adapted to the target user's needs. **Scalability**

Once LCAMP is finished, the AR system offers the possibility to continue working on a number of other projects, depending on the predominant technological fields of the universities using them. Undoubtedly, one area of study that will prevail is the digitisation of workplaces and manufacturing processes, the communication systems needed, the maintenance of such environments and its cybersecurity. Besides that, an important study field is related with the integration and use of digital technology by people in the shopfloor, the so call human technology integration, covering aspects like ergonomics, wellbeing, empowerment, participation. The system allows the inclusion of such elements in student projects, enriching this type of increasingly relevant competences.

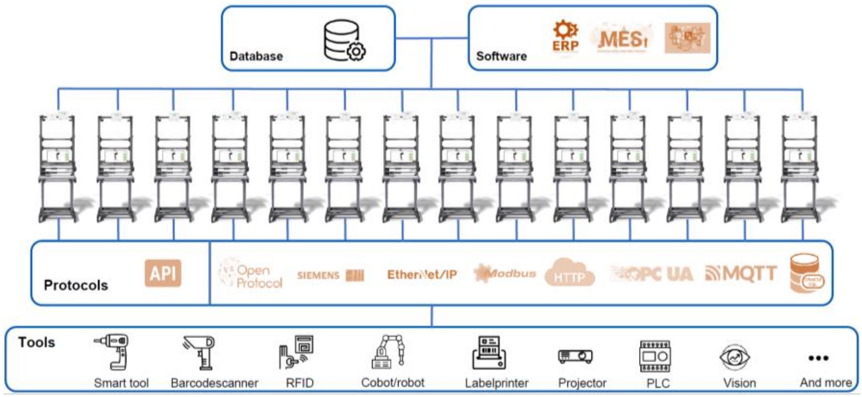


Figure 36 Communication options for the ARKITE system

Evaluate the virtualization

The AR system gathers signals collected during manual assembly and stores them in a database. This data is later used by other devices for purposes such as process analysis or visualization, for instance, in the creation of digital twins.

Collaboration opportunities

Within the LCAMP consortium, the integrated AR system will be used in 4 partners' LF. Therefore, the setup of assembly instructions are fully shareable among the 4 partners. The work made in 1 lab is automatically transferable to the others with slight adjustments. This feature allows big collaboration opportunities. Students from different countries can work together in projects and to share their set up.

The use of alternative systems would difficult such collaboration. The results of the market research carried out show that the communication (data exchange) between different systems would be possible. However, the sharing of full set ups and configurations would not be possible. Furthermore, the testing feature of Arkite is not possible in other analysed alternatives, therefore technological solution would not be so complete

#3. Develop a Phased Implementation Plan

Implementation and testing

The implementation of the AR system has been carried out as follows:

First, the system was delivered by the supplier, who also performed the equipment calibration. A group of 3 teachers from the school received an initial training to understand the system's details. The designated teachers team oversaw and validated the setup. For this purpose, in addition to set up the assembling of the LCAMP CLF product, the teachers did also program other sub-assemblies used in the school for learning porpoises.

Communication campaign, users' needs

Once the system is validated and ready, in parallel of the progression in its use, a communication plan was performed to inform the potential users (teachers) of the systems of the didactic opportunities that the system brings to them. Besides that, the communication campaign serves to open a channel to understand the needs of the potential users and to align the system with their needs and workflows.

Pilot training, roll out technology in small team

As a results of the communication campaign, two more teachers joined the core team to roll up the technology. The adaptation of the system to the users needs include:

- Adapt user interface by translating it into Basque language and adding requested features
- Include users in the design team and incorporate their feedback in the design process.

A training is planned for November 2024 with the participation of 10 teachers of Miguel Altuna LHII.

Gradual expansion. Support team. (in progress)

The teachers attending the first internal training are the responsible of the gradual expansion at Miguel Altuna LHII.

The use of the system is planned for 3 more programs during the scholar year 2024-25.

The systems will be available not only as a part of the CLF but also independently for external PBL activities in other to maximize its use.

Ensure Safety and Compliance Standards

The systems was set up following a safety plan provided by the supplier. The specific safety plan of the system will be included in the general safety plan of the advanced manufacturing workshop at Miguel Altuna LHII.

A similar protocol will be applied for the Cybersecurity plan (in progress)

#4. Training

The training for the implementation team was place at October 1-2-3-4, 2024 at Miguel Altuna LHII. Teachers from Miguel Altuna LHII and Tknika took part on the sessions, provided by the supplier.

The first onboarding course for further teachers is planned for November 2024.

Another training session for LCAMP partners will be delivered in January 2025

Figure 37 Training session for teachers (2024 October 2nd)

#5. Integrate Technology into Curriculum and Learning Activities

At Miguel Altuna LHII, learning activities are structured around the Challenge-Based Learning (CBL) methodology, embedded within the Ethazi pedagogical framework. Consequently, the integration of the AR system into the curriculum is achieved through two approaches: embedding AR-based tasks within existing CBL projects or developing new CBL projects specifically focused on utilizing AR technology. The choice of approach will depend on the specific requirements of each study program.

The roll out of the technology implies the adaptation or creation of CBL projects.

Courses foreseen for the WS

- Programming of AR assistance systems
- Lean Manufacturing.
- Production management.
- Projects management in LF environments.
- Maintenance of automated lines.

Assessment methods

Upon the conclusion of the pilot period, the courses developed for this WS will be incorporated into the quality system of Miguel Altuna LHII. This quality procedure encompasses the student

	evaluation system, which will also apply to the learning activities conducted within the AR system Finally, for the assessment of activities integrated within the CLF, the LCAMP skills framework (LCAMP, 2023) will serve as a unifying mechanism, in addition to the assessment methods employed by individual schools. This framework encompasses not only technical skills but also transversal skills, digital skills, and green skills, thereby facilitating the development of a common assessment method. This task is currently ongoing and is expected to be completed by November 2024
#6. Evaluation and Continuous Improvement	
In progress	

15.2. USE CASE 2: AUTOMATED ASSEMBLY WS: SENSOR BOX WS

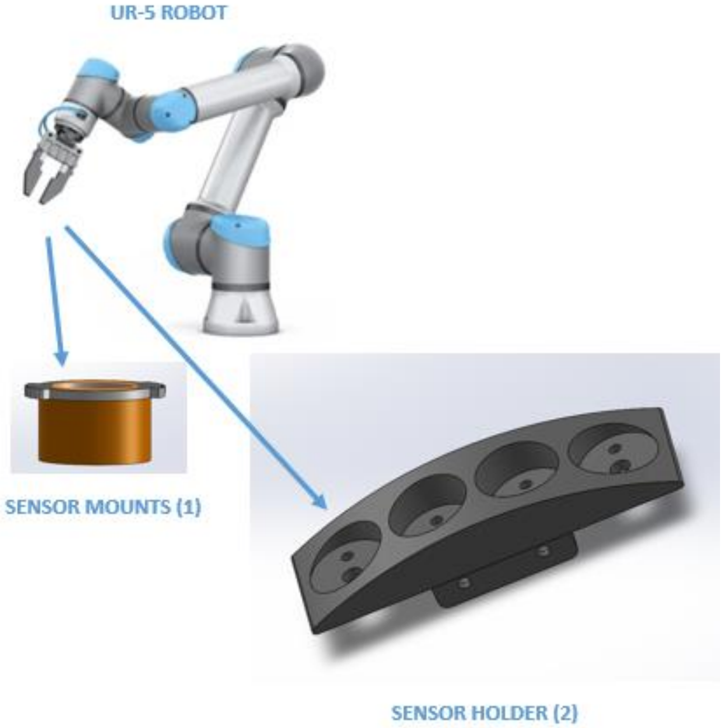
USE CASE	**Automated Assembly WS: Sensor Box WS**
Author	Miguel Altuna LHII, Basque Country
Description	The automated assembly WS known as the Sensor Box WS is part of LCAMP's Learning Factory, where sensor mounts (1) are assembled onto the Sensor Holder (2) components on the front and rear parts of the LCAMP Robot. See Fig 4. Assembly is carried out automatically by a UR5 collaborative robot. The WS features a system for detecting and sorting defective parts. 

	Figure 38 Schematic process for mounting the sensor mounts on the sensor holder. This station not only enhances the operational efficiency of the LF but also provides a comprehensive educational platform for developing automation skills within a practical, interdisciplinary learning environment. When integrating these technologies into the CLF, the steps outlined in Section 3 of this guide were followed. The WS Sensor Box automated assembly WS consists of a Siemens S7-1500 PLC, a Cognex artificial vision camera, a UR-5 collaborative robot, and an AMR mobile robot (MIR), ensuring a high degree of automation, precision in part classification, and resource optimization.
Location	• Miguel Altuna LHII – Basque Country

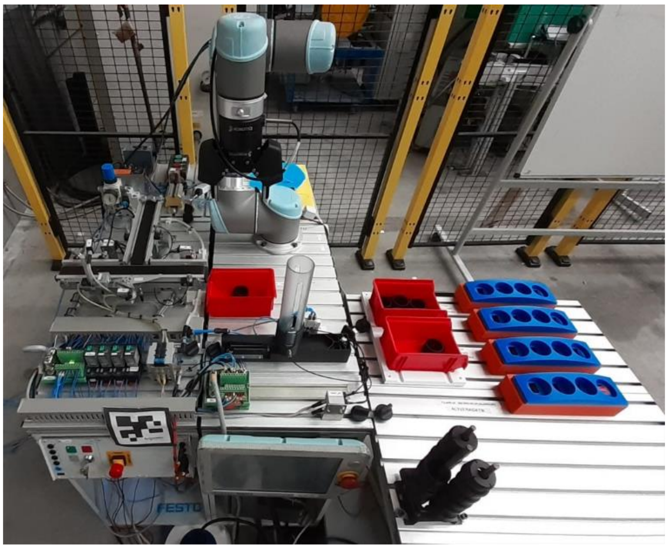


Figure 39 Automated Assembly WS: Sensor Box WS at Miguel Altuna LHII

#1. Identification of a need or a problem to solve,	
Purpose (technical)	The objective of this system is to automate the assembly of an LCAMP robot subsystem, specifically the sensor box, eliminating the need for manual assembly. This automation is achieved through the integration of a collaborative robot, guided by a machine vision camera and controlled by a PLC. Additionally, various components are transported using a mobile robot. This setup improves efficiency in part classification and handling, ensuring product quality. Furthermore, the flow and quality of processed parts are monitored and recorded to ensure traceability and control.
Purpose (didactic)	The system provides hands-on experience in programming and setting up an automated system, promoting real-world problem-solving and collaborative work. The intended learning outcomes align with the following vocational training programs: • Industrial Mechatronics: Combining mechanics, electronics, and computing to design and maintain automated systems. • Automation and Robotics Industries (ARI): Integrating automated systems and programming PLCs and robots. • Smart manufacturing: Integration of automated systems in smart manufacturing production lines.
#2. Technology Selection and Feasibility Study	

	To implement this WS in LCAMP's CLF, the Siemens S7-1500 PLC, Cognex machine vision camera, UR-5 collaborative robot, and AMR (MIR) mobile robot were selected. These components ensure a high degree of automation, precision in part classification, and resource optimization.
	Justification for Material Selection
	• Siemens S7-1500 PLC: Selected for its reliability, flexibility, and integration capabilities with other systems. It is widely used in industry, making it ideal for learning with real-world technology.
	• Cognex Machine Vision Camera: Chosen for its high precision and ability to perform detailed inspections. Its In-Sight software allows for easy programming and adjustments.
	• UR-5 Collaborative Robot: Known for its safety features and ease of programming. It is ideal for close collaboration with humans and handling delicate parts.
	• AMR Mobile Robot (MIR): Selected for its autonomous mobility and efficient material transport capabilities, improving internal logistics.
	Feasibility Study
	Technical aspects:
	Compatibility: The selected components are compatible with each other, facilitating integration and centralized control.
	Reliability: All components come from recognized manufacturers, ensuring a high level of reliability and technical support**.**
	• **Economic Aspects**
	  • **Initial Cost:** The initial investment may be high, but it is justified by the durability of the components and the reduction in operational costs in the long term.
	• **Didactical aspects**
	  • **Educational relevance:** The selected material is extensively used in the companies of the region, so it is expected that its didacticization will have relevant use also in parallel courses outside the LF.
	  • **Versatility**: They enable the teaching of multiple disciplines, ranging from PLC and robot programming to the implementation of machine vision systems and automated logistics**.**
	Improvement Options / Potential Future Implementations
	• Expansion of Artificial Vision System: Upgrade the artificial vision camera to one with higher resolution, or add additional cameras to provide various inspection angles.
	• Additional Robots: Add more collaborative or mobile robots to optimize the handling and transport of parts.
	• Internet of Things (IoT) Integration: Connect all components to an IoT platform for real-time monitoring and cloud-based data analysis.
	• Predictive Maintenance: Integrate sensors and software to predict failures and schedule equipment maintenance.
	• Remote Control and Monitoring: Develop a remote interface to control and monitor the station from any location.
	• Modular Expansion: Design the station to allow for easy addition of new functions and equipment as needs evolve.
	System Virtualization
	This station has been virtualized using the Simumatik platform to replicate the physical system created. This approach facilitates testing and simulations prior to real implementation, reducing costs and risks, while enhancing the system's flexibility and scalability.
	Simumatik is the emulation platform that provides a flexible digital environment for building and exploring physical, electrical, pneumatic, and mechatronic systems. It allows users to program robots and PLCs in a virtual world, creating "digital twins" that can later be transferred to real systems.
	Collaboration opportunities
	The physical setup, utilizing standard equipment, facilitates collaborative work with external stakeholders. Additionally, the virtual setup built on Simumatiks allows for

collaboration with partners who do not have the physical setup of the system. The anticipated collaboration opportunities include:
The foreseeing collaboration opportunities include:

- Sharing of didactic material
- Join projects among international students
- Hosting of international students in mobility activities

#3. Develop a Phased Implementation Plan

1. **Planning and Preparation:** With the technical and instructional goals of the LCAMP CLF in mind, this WS was designed to support learning activities for students in *ARI*. The implementation was led by one teacher from the ARI group, with a team that included two teachers and the CLF coordinator.
2. **Acquisition of Equipment and Software:** The team selected equipment commonly used in the ARI lab to be integrated into the CLF: a Siemens S7-1500 PLC, a Cognex camera, a UR-5 robot, and an AMR robot. They configured the necessary software for each component to ensure compatibility.
3. **Integration and Initial Configuration:** The team installed and connected all components, then programmed and the PLCs and robots, test each component separately, and conduct integrated tests to ensure the overall functionality of all the system.
4. **Development and Testing:** After the first testing a pilot activity was carried out in May 2024. An interdisciplinary pilot course was conducted in May 2024. 15 students from 6 study programs participated in a 50 hours PBL activity using all the equipment of the station.

Figure 40 Students from Miguel Altuna LHII

5. **Implementation and Monitoring:** Following the first pilot experience, the use of the station has been scheduled for inter-cycle activities throughout the 2024-2025 academic year. The assessment and monitoring system designed for the pilot experience will be reused in future editions, with relevant improvements added.
6. **Integration in the LCAMP CLF:** The Sensor Box WS is the first assembly station in the LCAMP CLF. The assembly line consists in 2 more assembly WSs. The components assembled in the Sensor Box WS are then feed to the WS01 Chassis assembly where the CLF's main products mechanic components are assembled. I part under the guidance of ARKITE. The electronic part will be carried out at a third WS. The tan

	7. **Preventive and Corrective Maintenance:** A preventive and corrective maintenance plan is stablished to maintain the system operative.
#4. Training	
	Teachers from the automation department are already familiarized with the equipment integrated in the WS. There is an onboarding training material for new users as well as instructions on the operation and maintenance of the system. This learning material is adapted and used also with students. **1.** Introduction to LCAMP's CLF: Overview of the product and to the entire process. **2.** Function and scope of the system assembled in the sensor box WS. **3.** Set up of the sensor box WS. Programming and configuration of the Siemens S7-1500 PLC, Cognex camera, UR-5 robot, and AMR robot. **4.** Operations in the sensor box WS. Production, quality control and intra logistics. Scale up options. **5.** Digital twin of the sensor box WS: Use of Simumatik for preliminary testing. **6.** Maintenance protocol
#5. Integrate Technology into Curriculum and Learning Activities	
	At Miguel Altuna LHII, learning activities are structured around the CBL methodology, embedded within the Ethazi pedagogical framework. Consequently, the integration of the Sensor box WS system into the curriculum is achieved through two approaches: embedding related tasks within existing CBL projects or developing new CBL projects specifically focused on utilizing technologies from this WS. The choice of approach will depend on the specific requirements of the involved study program. The roll out of the technology implies the adaptation or creation of CBL projects. To ensure the effective implementation of the technology in CBL activities, a series of courses has been developed, focused on the equipment included in the system. The following is a list of these courses. 1. Programming and configuration of the Siemens S7-1500 PLC (40h) and the UR-5 robot. (20h) EQF 5 2. Integration and use of the Cognex camera and its In-Sight software. EQF 5 (20h) EQF 5 3. Logistic automation with AMR (MIR) robots to optimize transport routes in simulated factories (30h) EQF 5 4. Integration of PLC, robots and vision cameras. (20h) EQF 5 5. Predictive maintenance techniques and fault diagnosis using data obtained from the integrated systems. (30h) EQF 5 6. Managing interdisciplinary projects to design and improve automated systems through collaboration across mechanics, electronics, and programming. (40h) EQF5 **Assessment methods** Upon the conclusion of the pilot period, the courses developed for the Sensor Box WS will be incorporated into the quality system of Miguel Altuna LHII. This quality procedure encompasses the student evaluation system, which will also apply to the learning activities conducted within the Sensor Box WS. For learning activities conducted within CBL projects, the current established assessment method will be prioritized. The introduction of new tasks into existing CBL projects will necessitate an update of the Key Performance Indicators (KPIs) used for evaluation. The Ethazi framework includes assessment of technical and transversal skills. Finally, for the assessment of activities integrated within the CLF, the LCAMP skills framework (LCAMP, 2023) will serve as a unifying mechanism, in addition to the assessment methods employed by individual schools. This framework encompasses not only technical skills but also transversal skills, digital skills, and green skills, thereby facilitating the development of a common assessment method. This task is currently ongoing and is expected to be completed by November 2024.
#6. Evaluation and Continuous Improvement	

	To assess the operability of the Sensor Box, a combination of surveys, interviews, direct observation and analysis of usage data is carried out. These techniques allow us to collect and analyse data on user satisfaction (both student and teacher), ease of use, and system performance. KPIs include student satisfaction, achievement of objectives and difficulty level. This comprehensive approach ensures a thorough understanding of the system´s effectiveness and areas for improvement.

15.3. USE CASE 3 : DIGITAL TWIN

USE CASE	**Use Case: Digital Twin of part of the Sensor Box Workstation (WS)**
Author	**Simumatik Sweden**
Description	A Part of the Sensor Box WSs was developed on the Simumatik Platform. This digital twin mirrors part of the automated assembly process, where sensor mounts are sorted in the conveyor system. This simulation replicates the actions performed by a UR5 collaborative robot, and the conveyor system The system is using a generic PLC that can be connected to a various amount of PLC, brands including Siemens, Codesys, Allen Bradley and more. The robot, UR5, can also be connected to RoboDK and UR-Sim. The Festo conveyor system replicates the physical, electrical and the pneumatic characteristics, allows users to interact with the system as they would with the physical station.
Location	• Available at the Simumatik Platform.

Figure 41 Automated Assembly WS: Sensor Box WS in Simumatik

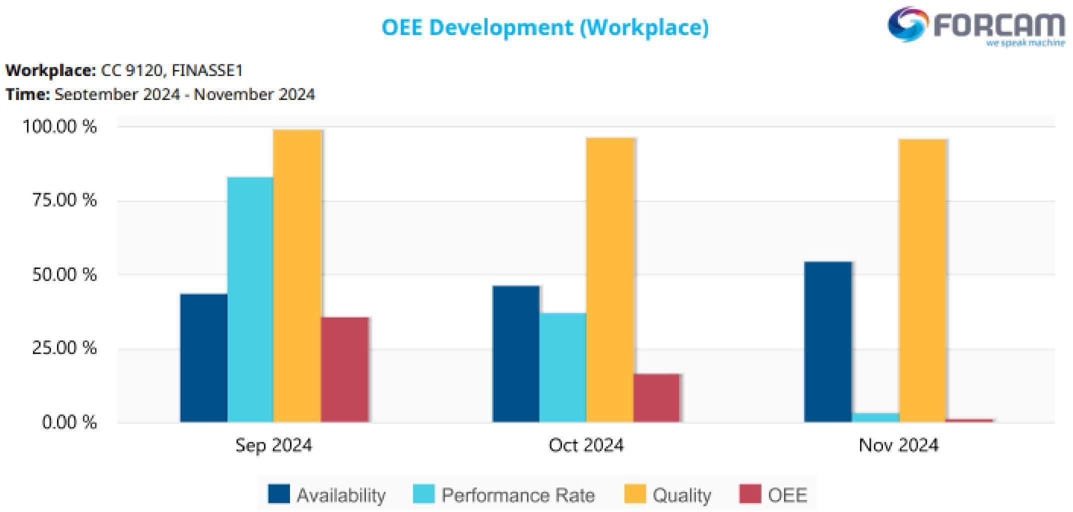
#1. Identification of a need or a problem to solve,	
Purpose (technical)	The purpose of this digital twin system is to model the automated assembly workflow for the sensor box within an LCAMP robot subsystem. By providing a virtual alternative to physical prototypes and hands-on assembly trials, the digital twin minimizes the need for real-world testing. In this simulated setting, the operations of a collaborative robot, guided by a programmable logic controller (PLC), are recreated to mirror actual automation processes.
Purpose (didactic)	As a didactic tool, the digital twin offers hands-on experience with an industrial automation system in a safe, flexible virtual environment. Students and instructors can engage in programming and troubleshooting without impacting physical hardware. This platform supports learning in: • Industrial Mechatronics: Automation system design, maintenance, and programming. • ARI: PLC and robot programming. • Smart Manufacturing: Process optimization and integration with smart manufacturing systems.
#2. Technology Selection and Feasibility Study	

	Strengths, Weaknesses, Opportunities, and Threars (SWOT) analysis of the use of waterjet cutting technologies in teaching: **Strengths** • **Cost-Effectiveness**: Virtual simulation via Simumatik is significantly more affordable than purchasing real hardware, making it an attractive option for educational institutions. • Remote access enables students to engage with the system even if they cannot physically access the equipment. • **Collaborative and Remote Accessibility:** Facilitates global collaboration and joint projects by allowing students from different institutions to work together in virtual environments, promoting international mobility and exchange programs. • **Integration and Flexibility:** The system is adaptable, with the ability to connect to various PLC brands (Siemens, Codesys, Allen Bradley, etc.) and robot simulators like RoboDK and UR-Sim, enhancing flexibility for different use cases and preferences. **Weaknesses** • **Limited Physical Interaction:** While the digital twin provides a simulation environment, it lacks the tactile interaction and real-world sensory feedback that physical systems offer. This might limit the ability to learn certain hands-on aspects of assembly and troubleshooting. **Opportunities** • **Further Development and Innovation:** This technology facilitates cooperative efforts in the fields of engineering, science, and information technology, contributing to the cultivation of diverse skill sets. (Gruyter, 2019) • **Augmented and Virtual Reality (AR/VR) Expansion**: Leveraging existing AR and VR capabilities within the digital twin can deepen the immersive training experience. By using VR headsets to interact with the simulated environment, learners can engage with complex processes in a realistic, hands-on manner, boosting engagement, practical understanding, and knowledge retention. • **Remote Learning and Upskilling**: Given the increasing demand for online learning, this digital twin platform could be marketed as a remote training solution for professionals seeking to upskill in ARI. **Threats** • **Reduced Industry Adoption of Virtual Training:** If industries prioritize physical, hands-on training over virtual simulations, there may be a risk of decreased demand for this kind of virtual tool, especially if tactile learning remains essential for certain skills. **Improvement Options / Potential Future Implementations** • **Camera Equipment Development:** Integrate existing 3D cameras within the Simumatik platform and connect them with Cognex Machine Vision software. This requires replacing the physical camera in the lab with a model that includes an integrated simulator. • **AGV and Additional Structure Development:** Development of AGV (Automated Guided Vehicles) and missing structures: Develop rest of the equipment to get a validated state in comparison with the physical system.
#3. Develop a Phased Implementation Plan	
	1. **Planning and Preparation:** Effective implementation of a digital twin platform requires preparation, particularly for teachers who need to become proficient with the software. Simumatik offers an online learning platform, the Simumatik Academy, which provides structured courses and resources for educators to develop the necessary skills to manage and teach with the software confidently. 2. **Integrating Additional Software:** Decide on complementary software to enhance Simumatik's connectivity and functionality. For example, Codesys, which offers a free trial version with soft PLC capabilities, can be used for PLC integration. Similarly, for robotic control, URSim is a free software option that can simulate robot programming, enabling students to gain hands-on experience with robotics. 3. **Pilot Project for Hands-On Learning:** Once educators are trained and familiar with Simumatik, initiate a pilot project with students to test the platform's integration into the curriculum. Simumatik provides "Getting Started" courses, which can be

	assigned to students as a preliminary exercise. This allows students to become comfortable with the software before they begin hands-on work in the virtual lab. 4. **Continuous Improvement:** Establish a process for ongoing development of the virtual lab and training materials. Regular updates based on student feedback and industry trends will help keep the curriculum relevant and maximize the educational benefits of the digital twin platform.
#4. Training	
	The training has not yet taken place, but the first session is scheduled for next semester at Miguel Altuna LHI
#5. Integrate Technology into Curriculum and Learning Activities	
	Despite the limitations associated with digital twin technology, the application of learning activities, as proposed in Chapter 4.2, remains feasible, albeit with some restrictions related to vision cameras and AGV's.
#6. Evaluation and Continuous Improvement	
	To assess the operability of the Digital Twin, a combination of simulations, data analysis, user feedback, and system diagnostics is employed. These methods allow us to gather and evaluate information on system reliability, user interaction quality (from both operators and end-users), and the fidelity of the digital model in mirroring real-world conditions. KPIs include user satisfaction, accuracy of simulations, and efficiency in achieving operational goals.

15.4. USE CASE 4. MANUFACTURING EXECUTION SYSTEM

USE CASE	**Manufacturing Execution System (MES)**
Author	Miguel Altuna LHII, Basque Country
Description	In today´s competitive environment, manufacturing companies face constant challenges to improve efficiency, reduce costs, and maintain high-quality standards. The adoption of a Manufacturing Execution System (MES) has become a strategic solution to achieve these objectives. An MES provides real-time visibility into production operations, facilitating decision-making and process optimization.
Location	• Miguel Altuna LHII – Basque Country



Date	Sep 2024	Oct 2024	Nov 2024
Availability	43.46%	46.4%	54.71%
Performance Rate	83.11%	37.27%	3.07%
Quality	99.19%	96.32%	95.67%
OEE	35.83%	16.66%	1.61%

1

Figure 10 Screenshot taken from FORCAM

#1. Identification of a need or a problem to solve,	
Purpose (technical)	A MES in a LF facilitates system integration and real-time data collection, optimizes processes, ensures complete traceability, provides practical training, allows for strategy simulation and modelling, and efficiently manages resources, thereby improving production efficiency and quality while offering a valuable educational environment.
Purpose (didactic)	The educational objective of a MES in a LF is to provide a practical learning environment where students and professionals can acquire knowledge and skills in the management and optimization of manufacturing processes, develop technical skills, improve data-driven decision-making, and foster continuous innovation and improvement.

#2. Technology Selection and Feasibility Study

FORCAM has been chosen as the MES for the Learning Factory for several key reason:

1. **Integration and flexibility:** FORCAM offers us versatile solutions that adapt to different production and educational needs, allowing perfect integration with existing infrastructure.
2. **Advanced Data Analysis Capabilities:** It provides robust tools for real-time data collection and analysis, essential for optimizing processes and improving operational efficiency.
3. **Educational experience:** Its solutions are designed to provide practical educational experiences, enabling students and professionals to learn how to manage and optimize manufacturing processes in a controlled environment.
4. **Continuous Improvement and Traceability:** It facilities continuous improvement by enabling complete traceability and offering detailed analyses that help quickly identify and correct issues.

	5. **Innovation and Support:** Its innovative strategies and robust technical support ensure that the Learning Factory stays at the leading edge of manufacturing technology.
#3. Develop a Phased Implementation Plan	
	1. **Planning and Preparation:** To implement the FORCAM MES, educators should first complete training using available resources to become proficient with the software. 2. **Pilot Project for Hands-On Learning:** After training, initiate a pilot project with students to apply the MES system in real world scenarios, using introductory courses to help students get started. 3. **Continuous improvement:** Continuously update the curriculum and training materials based on student feedback and industry trends to ensure the learning experience stays relevant and effective.
#4. Training	
	Teachers from de automation department are already familiarized with the equipment integrated in the WS. There is onboarding training material for new users and students, including instructions on the operation and maintenance of the system. 1. **Introduction and Scope:** Overview of the MES and its application. 2. **Setup:** Instructions for initial configuration and integration with existing systems. 3. **Operations:** Supervision of production, quality control, and intra-logistics management. 4. **Maintenance:** Maintenance protocols and technical support.
#5. Integrate Technology into Curriculum and Learning Activities	
	In process
#6. Evaluation and Continuous Improvement	
	In process

15.5. USE CASE 5: OT CYBERSECURITY

USE CASE	**Operational Technology (OT) Cybersecurity**
Author	Zubiri Manteo BHI Basque Country
Description	This use case describes the protocol to assure OT cybersecurity in the regional LF's. The protocol aims to create a secure network to connect the regional LF's into an international CLF. The applicable protocol for OT cybersecurity is not strictly the implementation of a technology but the integration of certain elements and the setting up of security practices. The International Society of Automation (ISA) defines OT cybersecurity as the practice of protecting Industrial Control Systems (ICS) and cyber-physical systems from cyber threats. This involves implementing security measures to prevent unauthorized access, manipulation, and disruption of these critical systems, ensuring the safe and reliable operation of industrial processes. (ISA, 2024)
Location	Miguel Altuna LHII
#1. Identification of a need or a problem to solve,	

Purpose (technical)	To understand and apply the appropriate cybersecurity protocols to create secure IT and OT networks in the CLFs. The protocol describes the network configuration and elements that should be used to that aim.
Purpose (didactic)	For students of ITC and Cybersecurity in Operation Technology Environments Specialty, the purpose is to design and integrate cybersecure networks in industrial environments. Mitigating penetration risks and external threats. Configuring network devices with this objective. For Mechatronics, Manufacturing, Robotics, Maintenance related learning programs the aim is to integrate cybersecurity protocols and practices in their curriculums.

#2. Technology Selection and Feasibility Study

This section shows the different measures and practices to create secure environments in operational facilities, normally production lines, shopfloors, labs and LFs:

Consider security from the design phase of the network and industrial line

- **Segment** networks according to needs**:**
  - Logical segmentation (VLAN, Layer 3 switch ACLs)
  - Physical segmentation to separate IT and OT (Firewall)
- **General Policies:**
  - Least privilege, minimize attack surface
  - Restrictive access policies, especially concerning communication with the OT network

IT network:

- Logically segment IT network's subnets (VLANs).
- Fortify the domain controller and servers.
- Protect domain endpoints (PCs, laptops, etc.): Antivirus, EDR, etc.
- Update policies (WSUS).

OT network:

- **Monitor** network activity**:**
  - Implement an Intrusion Detection System (IDS) or an IPS Intrusion Prevention System (IPS).
  - Set up and properly configure a SIEM (Security Information and Event Management) system.
- **Remote access** to the OT network **(VPN):**
  - Properly configure remote access (e.g., to access TIA Portal ensure connection is on the same network).
  - Enable Multi-Factor Authentication (MFA).
- Restrict USB connection capabilities on devices and establish usage policies.
- Place additional protection devices between vulnerable devices (those with outdated or unpatchable operating systems) and the network.
- Protect OT network servers (such as those with MES, OPC-UA, etc.)
- **Regularly scan the network** to detect new devices and analyse vulnerabilities in known devices' systems and services (Nozomi).
- **Incident response plan.**
- **Provide proper training** to all individuals interacting with the Learning Factory and communicate risks.

Physical Security:

- This section has been left out of the current analysis. Elements in this section include:
  - Ensuring power supply (UPS/SAI, generators, etc.).
  - Controlling physical access to elements that make up the network infrastructure (access restrictions, video surveillance, etc.).
  - And so on.

#3. Develop a Phased Implementation Plan

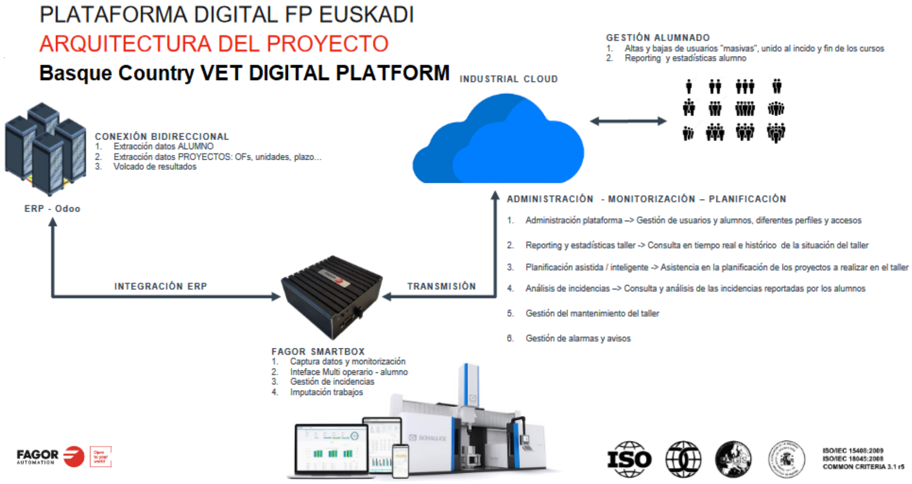
	The first action on the Cybersecurity protocol that is “Consider security from the design phase of the network and industrial line” does not apply as far as the LF networks are already designed. Therefore, the implementation plan begins studying the existing networks by means of cybersecurity protocols. Partners are individually applying the protocol in their LFs. At this stage (December 2024) the stablishment of the protocols are in progress in all the labs.
#4. Training	
	Training on cybersecurity for IT and maintenance staff. Awareness-raising campaigns among teachers and labs managers
#5. Integrate Technology into Curriculum and Learning Activities	
	At Miguel Altuna LHII, learning activities are structured around the CBL methodology, embedded within the Ethazi pedagogical framework. Consequently, the integration of the AR system into the curriculum is achieved through two approaches: embedding AR-based tasks within existing CBL projects or developing new CBL projects specifically focused on utilizing AR technology. The choice of approach will depend on the specific requirements of each study program. The roll out of the technology implies the adaptation or creation of CBL projects. **Best Practices for Configuring Network Devices for Cybersecurity** **1.Implement Strong Access Controls** Ensure all network devices, such as firewalls, PLCs, and monitoring systems like Nozomi, are protected with strong, unique passwords and MFA wherever possible. Limit access based on the principle of least privilege to reduce exposure to unauthorized users. **2.Keep Firmware and Software Updated** Regularly update the firmware and software of your network devices to protect against vulnerabilities. Use vendor-recommended patches and updates, and establish a process for applying them promptly. **3.Network Segmentation and Zoning** Use network segmentation to isolate critical systems, such as PLCs, from less secure or public-facing networks. Deploy firewalls to control and monitor traffic between these segments, minimizing the risk of lateral movement during an attack. **4.Enable Logging and Monitoring** Configure all devices to log activities and send these logs to a centralized monitoring solution, like a Security Information and Event Management (SIEM) system. Leverage tools such as Nozomi for real-time visibility and anomaly detection within industrial and operational environments. **5.Disable Unused Services and Ports** Reduce the attack surface of your devices by disabling unused ports, protocols, and services. Conduct regular audits to ensure that only necessary features are enabled and properly configured.
#6. Evaluation and Continuous Improvement	
	In progress

15.6. USE CASE 6. INDUSTRIAL BUSINESS INTELLIGENCE PLATFORM

USE CASE	**INDUSTRIAL BUSINESS INTELLIGENCE (BI) PLATFORM**
Author	Tolosaldea LHII, Basque Country
Description	“An Industrial BI Platform is a specialized tool designed to help businesses in industrial sectors collect, analyze, and visualize data to make informed decisions. These platforms integrate data from various sources, such as manufacturing equipment, provide real-time analytics to monitor production processes. They offer custom dashboards for visualizing KPI, enable predictive maintenance by analysing historical data, and enhance decision-making by providing comprehensive data insights, ultimately improving efficiency and reducing cost”. (Pauli, 2021) In this use case the implementation of the platform **Fagor Digital Suite** (Fagor Automation, 2024) in learning environment (VET) is described. The aim is to offers real-time problem-solving aligned with real-world industrial processes, providing the students skills in production monitoring, quality assurance, data analysis. The selected Industrial BI platform**,** is modular, scalable, and targeted for I4.0 environments, serving both industrial and educational needs in digital manufacturing setup. Additionally, when implementing this platform in a VET environment, the focus is on the learning process rather than solely on improving efficiency. The goal is to execute the teaching-learning process based on Project Based Learning (PBL) methodology but following I4.0 standards. So, when the execution phase of the PBL comes, the platform is used to translate machining operations and maintenance tasks into work orders, to manage, monitor and analyse the processes/machines. To achieve this goal, 30 conventional machines (18 lathes and 12 milling machines) have been connected via a PLC and 6 CNC machines to the Fagor Digital Suite platform. This platform is not only designed and managed in the workshop itself but also from the classroom.
Location	Tolosaldea LHII – Basque Country

Figure 42 Workshop from Tolosaldea LHII connected to Fagor Digital Suite platform

#1. Identification of a need or a problem to solve,	
Purpose (technical)	Enhance manufacturing efficiency, minimize downtime, and ensure product quality with real-time machine monitoring, optimized production scheduling, and predictive/corrective maintenance. Close the gap between production and educational environments, transforming PBL challenges into work orders.
Purpose (didactic)	Aims to provide students and trainees experience in real-world manufacturing challenges. By using the platform learners gain skills in monitoring machine performance, optimizing workflows, applying quality control measures, and conducting data-driven decision-making.

	• Integrate learning activities into the following programs: • Production by machining • Mechatronics • Management of computer systems on network
#2. Technology Selection and Feasibility Study	
	Implementing an Industrial BI platform in VET requires a focused Technology Selection and Feasibility Study. In this case the process has been as follows: The selected industry-relevant technologies, aimed at mirroring real-world applications to enhance learning, include CAD/CAM, CNC machining, and conventional machining processes. The technologies selected represent accurately those used in industry settings, offering students a realistic training environment. This makes the transition from education to the workforce smoother and gives students relevant, job-ready skills. Collaborate with industry professionals to confirm that these tools meet current market requirements. 1. **Feasibility and Pilot Testing.** Conduct small-scale tests to validate the suite's effectiveness within the educational setting. That pilot projects in select VET courses, closely monitoring performance indicators like student engagement, learning outcomes, technical compatibility, and instructor satisfaction. These metrics will provide insights into the suite's overall impact and inform adjustments before broader deployment. 2. **Adapt to User Needs.** Customize the suite to align with existing workflows, ensuring relevance for both students and instructors. Map the VET curriculum to the suite's capabilities, identifying which features support targeted learning goals. Modify simulation tools or PBL applications to replicate scenarios that students will encounter in their specific vocational fields. 3. **Design for Usability**. Involve users in designing intuitive workflows, ensuring ease of use. Because, well-structured workflows are crucial for both student engagement and instructor effectiveness. Assemble a design/driving team with a cross-section of users, including students, instructors, and technical experts. Together, create workflows that support course flow and make key features easily accessible. 4. **User Feedback**. Establish a feedback loop with students and educators to refine the suite workflow. Including students and educators directly in the design team ensures the suite evolves based on real-world needs. 5. **Scalability and Modularity**. Ensure components/connections are adaptable for future expansions and industry updates. Select modular elements within the suite, ensuring they can be adapted to integrate new technologies or address emerging skills.  *Figure 43 Digital architecture of the platform* 6. **Integration:** Confirm compatibility with current systems, including LMS and hardware. Assess compatibility with the institution's IT systems. Configure the suite as needed to ensure it aligns with the current infrastructure and work with the supplier's team to troubleshoot any integration issues that arise during pilot testing.

7. **Virtualization evaluation:** Evaluate all aspects of implementation to promote continuous improvement, such as, virtualization capacity of the selected technology for its later integration in virtual environments.
8. **Collaboration:** Enable features supporting teamwork and remote access. Evaluate collaboration tools within the suite, such as shared virtual workspaces, group simulation projects, or feedback systems for remote learning.

#3. Develop a Phased Implementation Plan

The Phased Implementation Plan for the Industrial BI platform in a VET setting has been streamlined as follows:

1. **Preparation and Planning**. Set up the multidisciplinary team to drive and design the implementation process together with the supplier Define goals, timelines, and scope.
2. **Configure the workshop network.** Ensure compatibility with the school's current IT and its possible extensions and updates to future developments.
3. **Connect the machines** to the platform and check the integration and connectivity of the entire system.
4. **Training of the driving team** simulation of real cases of the learning process and execution in the workshop
5. Establish a **work methodology** and set a schedule for milestone comparison and progress tracking between the driving team and the supplier's team.
6. **Design the workflow** to be developed both in the software and during the execution phase in the workshop. The focus will mainly be on two areas:
   - Workshop management: maintenance, machine availability, work order scheduling…
   - Management of the learning process vs. production

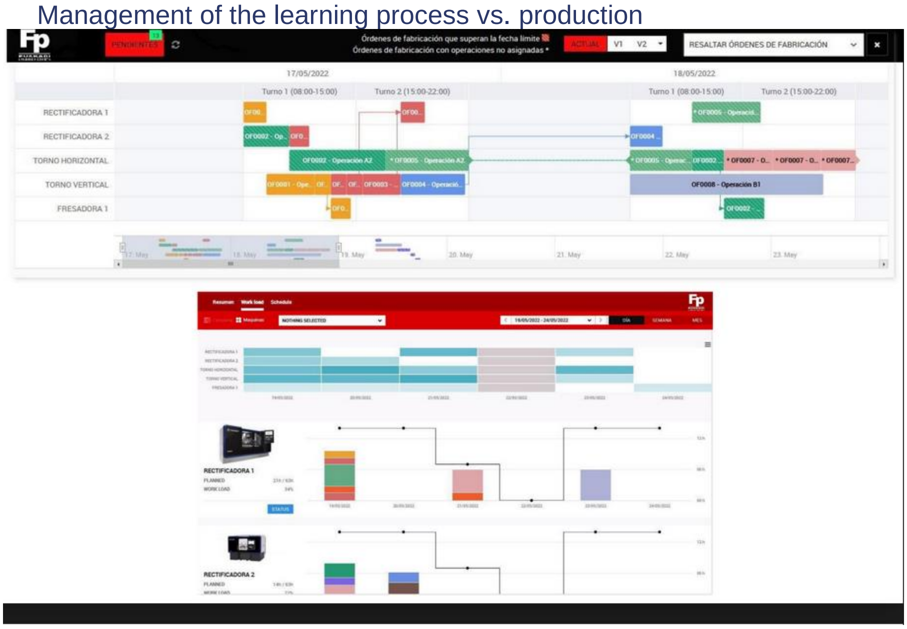


Figure 44 workshop scheduling and machine tracking dashboard

7. **Pilot Testing**. Deploy a small-scale test of core features, gathering feedback from teachers and students. Make necessary adjustments based on the feedback.
8. Implement all necessary **management inputs** in the software.
   - Machines
   - Users and their roles
   - Maintenance planning
   - Manufacturing order management and their allocation…
9. Interface and data visualization design. Configure screens and data reports for:

- Machine. Overall Equipment Effectiveness (OEE), production backlog, incidents, and maintenance logs.
- Operator/student tracking. Efficiency, training progress, and incident handling
- Manufacturing order. PBL, order status, resource allocation, time tracking.

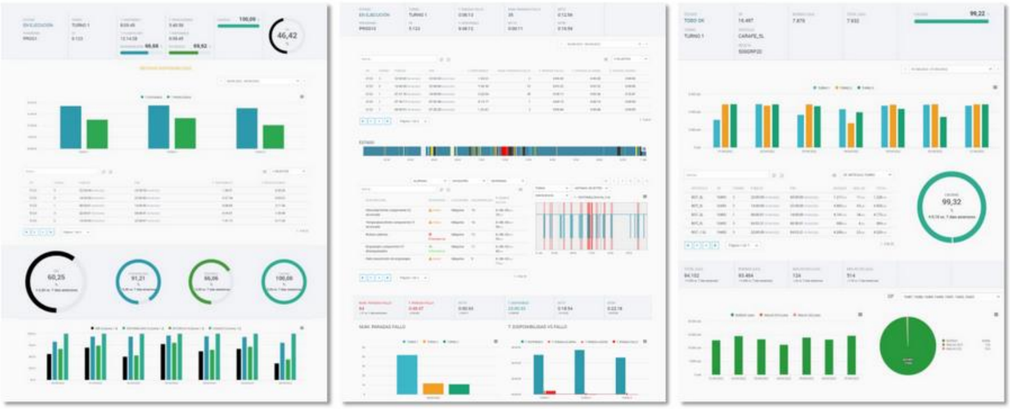


Figure 45 Data analysis dashboard

10. **Validation and comparison** by both teachers and students, as well as the supplier team, to solve any integration problems that may arise during the pilot tests and/or their redesign.
11. **Staff Training and Curriculum Integration**. Provide training on core functions, focusing primarily on workflow. Develop teaching materials and create learning modules aligned with PBL standards.
12. **Full Deployment.** Integrate the suite across relevant modules and introduce students to real-world exercises, such as monitoring and optimizing production.
13. **Continuous Monitoring and Feedback**. Collect feedback from users, assess learning outcomes, and make updates to enhance usability and learning impact.
14. **Evaluation and Documentation.** Evaluate the overall impact, document best practices, and compile teaching materials for long-term use.

#4. Training

The developed training process has been as follows:

1. Initial training of the driving team in both the software and the system architecture
2. Initial training for the teacher pilot group by the driving group and Fagor
3. Periodic meetings of the driving group and supplier to develop the design and creation of the workflows for their adaptation to the teaching-learning process
4. Training-dissemination in the use and management of the system for the teacher pilot group
5. Training and instruction in the workflow both in the classroom and on the students' machines
6. Production of training pills for teachers and students with practical exercises on platform management

#5. Integrate Technology into Curriculum and Learning Activities

In process

#6. Evaluation and Continuous Improvement

In process

15.7. USE CASE 7. CNC

USE CASE	**CNC machines**
Author	Campus Des Metiers et Des Qualificatications D'Excellence France
Description	The use of CNC (Computer Numerical Control) technology in the manufacturing sector is based on the computer control of machine tools to perform precision operations such as milling, turning, drilling and cutting. These machines are programmed to perform specific movements and actions, enabling them to reproduce complex shapes and meet exact design specifications (Gavin, 2023). In the CLF, CNC technology is used with: **Water jet cutting**: CNC waterjet cutting uses a high-pressure water jet to cut hard materials without heat, thus avoiding deformation. It is precise, versatile and environmentally friendly, with little waste. **Laser cutting**: CNC laser cutting uses a concentrated laser light to cut materials with great precision. The process provides clean edges and reduces the need for finishing, while being fast and efficient for a wide range of materials, including metals and plastics. **Wire cutting**: CNC wire cutting, or wire electrical discharge machining, uses a conductive metal wire to make precise cuts in conductive materials such as metals. An electric discharge is created between the wire and the workpiece, eroding the material and cutting it along a pre-determined line. **Contouring on milling machines:** Contouring on a milling machine consists of machining the external or internal contours of a part using a milling cutter, generally following a predefined line. **And others**.
Location	• CMQE France • Miguel Altuna LHII – Basque Country • DHBW- Heidenheim- Germany • Curt Nicolins Gymnasiet – Sweden

Figure 46 Mikron UCP 600 Vario (Machining) from CMQE If CLF equipped with the CNC technology

#1. Identification of a need or a problem to solve,	
Purpose (technical)	The use of CNC technology enables high precision and repeatability to be achieved in the manufacture of simple or complex parts. This reduces human error and ensures that products meet specifications. The large choice of processes helps to choose the most appropriate methods for manufacturing parts. They also offer the flexibility needed to adjust parameters and choose the right tools. Different techniques can be tested to find the most efficient. The purpose is to improve productivity, quality, and operational efficiency in manufacturing. (Polygenis, 2024) Some components of the CLF product are suitable to be manufactured by means of CNC machining. By incorporating CNC machining into the CLF manufacturing process, the aim is to add the benefits that this technology provides from a systems perspective, encompassing the process as a whole.
Purpose (didactic)	CNC technology use in the CLF enables: • To master CNC programming for various processes to improve precision, quality and productivity. • To be able to compare different CNC processes (cost savings, time savings, etc.). • To use programming software to operate the machine. • To use the digital chain, from CAD and CAM to manufacturing.
#2. Technology Selection and Feasibility Study	
	CNC Technology selection **Improve precision**: Enables parts to be produced to close tolerances. **Increase repeatability**: Guarantees consistent quality for every part produced. **Reduce human error**: Automates processes to minimise the risk of error. **Save time**: Accelerate production through fast, efficient execution. **Offer manufacturing flexibility**: Enables the production of parts with varied and complex shapes. **Make learning more relevant**: Aligns students' skills with current industry practices **CNC Feasibility study** **Needs analysis**: The CNC technology on machines meets the production requirements, offering precision and cutting complexity adapted to the different sizes of parts. It can also machine a variety of materials. **Cost assessment**: Purchase, installation and maintenance costs are significant, but can be offset by the machine's durability. **Performance testing**: CNC technology enables parts to be produced with great precision and uniformity, guaranteeing a quality finish for each series. **Comparison of options**: CNC technology can be used with a variety of machines, giving a large choice of production processes. **Impact on learning**: CNC technology enables students to familiarise themselves with programming and precision machining, skills that are directly applicable in the workplace. The integration of this machine enriches practical and technical learning. Infrastructure assessment: The workspace, safety devices and electrical resources are compatible with the requirements of the machine in the CLF workshops.
#3. Develop a Phased Implementation Plan	
	To ensure optimal integration of CNC technology: • Definition of objectives and requirements • Identify the pedagogical and technical objectives to be achieved with the CNC machine (precision, types of parts, materials). • Determine the skills to be developed by the students (programming, machining, CAD/CAM design). • Draw up an overall budget, including acquisition, training and maintenance costs. **To select the CNC machine:**

	• Research and compare available machines according to defined needs (capacity, precision, material compatibility). **To prepare the infrastructure:** • Adapt the workspace to accommodate the machine (ventilation, materials storage space, safety). • Check that the electrical installations are appropriate for the specific requirements (power, connectivity). • Install safety devices to protect users. • Staff training • Train teachers and technicians in the use of the machine, CNC programming and associated CAD/CAM software. • Organise practical sessions to familiarise staff with basic maintenance and troubleshooting. • Ensure that staff are trained in safety standards for the use of CNC equipment. **To integrate the technology into the training programme:** • Design CNC-related training modules for students, covering programming, materials handling and machine operation. • Integrate the digital chain (from CAD to manufacturing) for complete and realistic learning of industrial processes. **Test and adjustment phase:** • Carry out tests to validate that the machine meets the educational and technical requirements. • Adjust the cutting parameters, speed and processes to optimise the quality and precision of the parts. • Gather feedback from teachers and technicians to fine-tune use and correct any bottlenecks. **To integrate the students:** • Organise practical sessions to introduce students to the use of the CNC machine and associated software. • Involve students in practical projects to enable them to develop their skills in real-life conditions. • Monitor progress and adjust teaching modules if necessary.
#4. Training	
	Students and teachers working with the LCAMP CLF CNC technology will first receive an introduction to the LCAMP project and the concept of the CLF. This will enable them to become fully aware of the European and collaborative scope of their activities. The technology will be gradually integrated into the CLF. First, the CLF implementation team will be trained, then integration and training of teachers and finally integration and training of students.
#5. Integrate Technology into Curriculum and Learning Activities	
	The students who are working with CNC technology in the CLF at CMQE If (France) are students in: • Vocational Baccalaureate (EQF 4) **Technician in mechanical product manufacturing** and Higher Technical certificate (EQF 5) **Design of product manufacturing processes.** Use of CNC technology with water jet cutting machine, wire cutting machine, milling machine. • Technological Baccalaureate (EQF 4) **Science and Technology for Industry and Sustainable Development.** Use of CNC technology with laser cutting machine.
#6. Evaluation and Continuous Improvement	
In process	

15.8. USE CASE 8: WATER JET CUTTING

USE CASE	**Water Jet Cutting**
Author	Baden-Württemberg Cooperative State University Heidenheim site, Germany
Description	Waterjet cutting offers many technical and economic advantages: **Versatility and precision:** The process can be used to cut almost any material, from metals and plastics to glass and ceramics, without thermal influence. This means there are no heat-affected zones, which is particularly advantageous for temperature-sensitive materials. **Cost savings:** As no special tools are required for different materials, there is no need for tool changes and the associated costs. In addition, the narrow kerf width reduces material loss and enables efficient material utilization. **Environmentally friendly:** The process produces no harmful emissions and minimizes waste, resulting in a lower environmental impact. **Energy efficiency:** Energy consumption is moderate compared to other cutting processes, reducing operating costs and increasing profitability. Overall, waterjet cutting is an efficient and cost-effective technology that is used in a wide range of industries due to its flexibility and precision.
Location	Baden-Württemberg Cooperative State University Heidenheim site

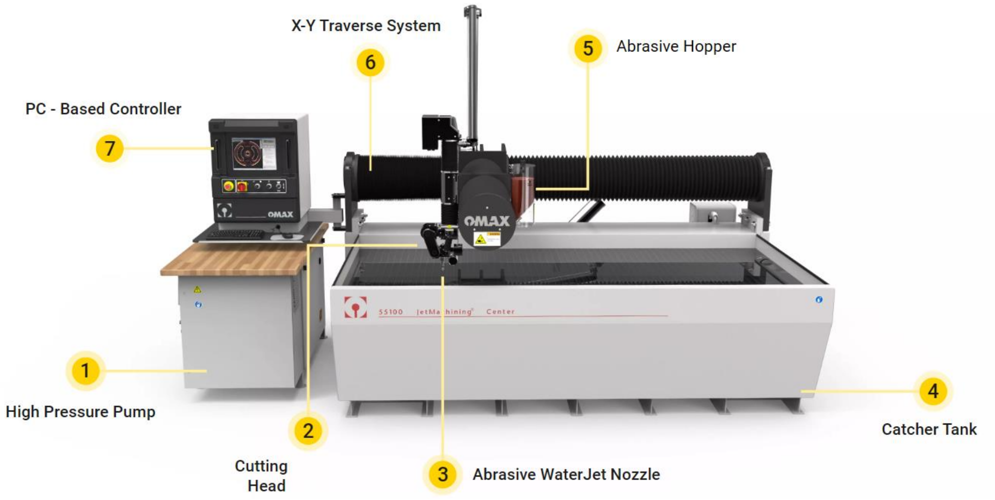


Figure 47 - OMAX JetMachining Center. (OMAX, 2024)

Figure 48 - OMAX 2652 JetMachining' at the Duale Hochschule Baden-Württemberg in Heidenheim.

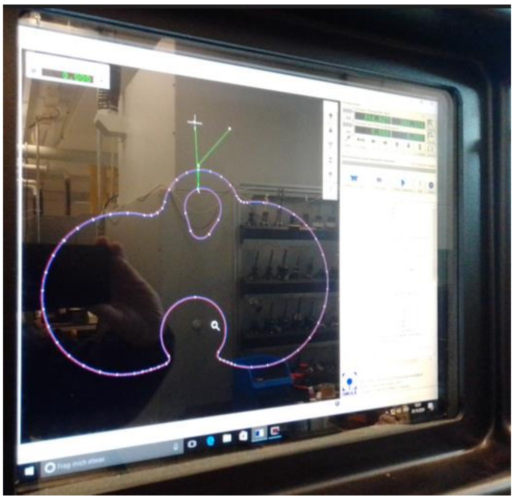


Figure 49 - Programming of the cutting contour on the PC-based control system

#1. Identification of a need or a problem to solve,

Purpose (technical)	In advanced manufacturing and I4.0, waterjet cutting is a highly accurate and versatile process, particularly characterized by its flexible and precise material processing. It is ideal for cutting complex and multi-layered materials without thermal effects, enabling precise processing of metals, glass, and composites. In addition, waterjet cutting can be seamlessly integrated into automated production processes and supports real-time data integration, meeting the demands of networked and flexible smart factories. Thanks to its resource-saving approach - with low energy consumption and no toxic emissions - it contributes to sustainability in production and is ideally suited to green strategies, which are becoming increasingly important in I4.0.
Purpose (didactic)	In university teaching, the didactic objectives between waterjet cutting, advanced manufacturing, and I4.0 can be developed in a variety of ways. Interdisciplinary learning enables students to understand the link between traditional manufacturing techniques and modern advanced manufacturing methods, which promotes a comprehensive understanding of the requirements of I4.0. Practical applications, such as laboratory exercises in waterjet cutting, provide students with the opportunity to directly experience the principles of material processing and separation and to simulate real industrial applications. The technological integration of waterjet cutting with advanced manufacturing technologies and digital systems helps students understand the connection between physical and digital systems, including the use of IoT, data analytics, and automation. Students will also develop their problem-solving skills by analysing and optimizing waterjet cutting processes, investigating process parameters, and implementing efficiency improvements and quality control. Another important aspect is the discussion of the efficiency and sustainability of waterjet cutting compared to other manufacturing methods, creating an awareness of environmentally friendly practices, which is important in I4.0. Encouraging innovation through the development of new applications and improvements in waterjet cutting can strengthen students' ability to innovate, for example through research projects or competitions. Finally, data analytics and data management play a central role by making students aware of the importance of data in modern manufacturing, an essential part of I4.0. By combining these approaches, universities can best prepare their students for the challenges and opportunities of modern manufacturing.
#2. Technology Selection and Feasibility Study	
	SWOT analysis of the use of waterjet cutting technologies in teaching: **Strengths** - **High level of precision and versatility**: The versatility of waterjet cutting makes it particularly suitable for handling diverse material categories, providing students with a comprehensive knowledge of materials. (OMAX, 2024) - **Hands-on learning in advanced manufacturing**: The integration of this technology enables hands-on learning that meets the demands of I4.0 (Schneidforum: Vorteile und Nachteile des Wasserstrahlschneidens., 2024) - **Sustainability and Resource Efficiency**: Through the reduction of material waste and the avoidance of toxic emissions, waterjet cutting serves as a sustainable technology, highlighting environmental consciousness within educational frameworks. (RUNSOM, 2024) - **Compatibility with automation**: Waterjet cutting technologies can be integrated into automated production lines, giving students an understanding of interconnected production processes. (Aller-Weser Wasserstrahlschneidetechnik, 2024) **Weaknesses** - **High initial cost**: The procurement and upkeep of modern waterjet cutting equipment require substantial expenditure. (Schneidforum: Vorteile und Nachteile des Wasserstrahlschneidens., 2024) - **Technical complexity for beginners**: in-depth prior knowledge required. (RUNSOM, 2024) - **Time-consuming training required**: Proficiency in machine handling, routine maintenance, and adherence to safety standards is necessary. (OMAX, 2024)

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Space and infrastructure requirements: Waterjet cutting machines require significant space. (Aller-Weser Wasserstrahlschneidetechnik, 2024)

Opportunities

Expansion of interdisciplinary skills: This technology facilitates cooperative efforts in the fields of engineering, science, and information technology, contributing to the cultivation of diverse skill sets. (Gruyter, 2019)
Promoting sustainable production methods: Integrating this approach enhances recognition of eco-friendly production technologies. (RUNSOM, 2024)
Environmental: water treatment linked (filtration/sedimentation/recycling) (Aller-Weser Wasserstrahlschneidetechnik, 2024)
Virtual learning environments: The application of simulation software for virtual planning and process optimization helps to decrease costs while improving safety in the technology's operation. (OMAX, 2024)

Threats

Rapid technological progress: Technology is evolving rapidly, which means that purchased machines may quickly become obsolete and require new investment. (Gruyter, 2019)
Safety risks associated with improper use: Adherence to stringent safety protocols is essential in waterjet cutting, as operational errors may result in severe accidents. (De Gruyter).
Resource consumption: The substantial water usage may lead to significant environmental and logistical concerns. (RUNSOM, 2024)
Limited flexibility due to infrastructure requirements: Incorporating waterjet cutting technology into established laboratory setups commonly demands adjustments to the water and power supply systems. (Aller-Weser Wasserstrahlschneidetechnik, 2024)

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<tr><td colspan="2">#3. Develop a Phased Implementation Plan</td></tr>
<tr><td></td><td>When selecting and purchasing a waterjet cutting system for a university laboratory, it is crucial to define the specific application requirements: What materials and workpieces will be cut, and is abrasive or clean waterjet cutting required? The technical specifications, such as cutting thickness, pressure capacity, and CNC control, must match the variety of cutting tasks required and be intuitive for students to operate. Seamless automation and software integration allow direct implementation of digital designs and networking with existing CAD/CAM systems, optimizing laboratory operations and teaching methods.
Safety is essential: emergency stop functions, protective covers, and a user-friendly interface offer protection and ease of use. Sustainability is achieved through water treatment and recirculation systems that minimize water consumption and abrasive waste, thereby reducing running costs. The modularity of the system allows for future expansion, such as retrofitting sensors and automation components for new projects. Life cycle cost-benefit analysis and a reliable supplier with good service and support will ensure long-term operational reliability and cost-effectiveness of the system in the laboratory environment.</td></tr>
<tr><td colspan="2">#4. Training</td></tr>
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Economic & Technical Fundamentals
Energy & Environmental Management
Quality Management
Health and Safety Management
Laboratory exercises
Development towards a micro-credential in planning

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<tr><td colspan="2">#5. Integrate Technology into Curriculum and Learning Activities</td></tr>
<tr><td></td><td>In process</td></tr>
<tr><td colspan="2">#6. Evaluation and Continuous Improvement</td></tr>
</table>

	In process

15.9. USE CASE 9. 3D PRINTING

USE CASE	**3D Printing**
Author	**Curt Nicolin Gymnasiet, Sweden**
Description	The 3D printing technology selected for the LCAMP CLF includes both Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) printers, specifically the EOS Formiga P110. FDM printing is utilized due to its accessibility, cost-effectiveness, and the wide range of material options available. This method allows for rapid prototyping and the production of functional parts using various thermoplastics, making it ideal for diverse applications within the CLF. On the other hand, the SLS printer, an advanced solution, is chosen for its ability to produce high-precision and durable parts. The EOS Formiga P110 leverages laser sintering to fuse powdered material layer by layer, resulting in intricate and accurate components that meet stringent specifications. This capability is crucial for applications requiring tight tolerances and robust components. By integrating both FDM and SLS technologies, the CLF can optimize learning and production activities, ensuring that printed components are reliable, high-quality, and suitable for a wide range of uses. The combination of these technologies allows for the creation of complex geometries and functional prototypes, essential during the development and testing phases of our projects.
Location	CNG – (FDM & SLS) CMQ MIGUEL ALTUNA LHII DHBW MADE GEBKIM

Figure 50 - SLS Printer from CNG. Figure 2 FDM Printer from CNG

#1. Identification of a need or a problem to solve,	
Purpose (technical)	The aim of this system is to integrate 3D printing technologies into the LCAMP CLF to enhance production efficiency and ensure high-quality, traceable manufacturing processes. The accessibility and ease of use of 3D printing make it convenient for many to adopt and start using effectively.

Purpose (didactic)	Research the educational aspects of 3D printing technology and its applications. Integrate learning activities into the following programs: • CAD, DfAM (Design for Additive Manufacturing), Smart manufacturing
#2. Technology Selection and Feasibility Study	
	The 3D printing technology selected for the LCAMP CLF is tailored to meet diverse user needs and workflows. Both FDM and SLS printers offer flexibility in terms of material choice, precision, and production speed. This adaptability ensures that the technology can be configured for various skill levels and project requirements, from rapid prototyping to the production of high-precision components. Flexibility and Reconfiguration The flexibility of the 3D printing system allows it to be reconfigured for different manufacturing tasks. This is crucial for the CLF, as it enables the production of a wide range of components and prototypes. The system can be used in parallel for multiple projects, enhancing its utility within the CLF and other related activities. Customization for User Needs In the case of the LCAMP CLF, the 3D printing system is customized to meet the specific needs of the users. This includes adjustments in the printing parameters, material selection, and post-processing techniques to ensure the highest quality output. The system's user-friendly interface and accessibility make it easy for operators to learn and use effectively. Scalability

	Once the LCAMP project is completed, the 3D printing system offers the potential to be utilized in various other projects. This includes ongoing research in digital manufacturing, process optimization, and the integration of new materials and technologies. The scalability of the 3D printing system ensures that it can continue to contribute to innovative manufacturing solutions and educational programs. Why was 3D Printing chosen for the CLF in the LCAMP project? 3D printing was chosen for the CLF due to its accessibility and suitability for rapid prototyping. This technology is relatively user-friendly and easy to get started with, allowing for the efficient production of high-quality prototypes and components, making it ideal for diverse applications within the CLF. Ensure that it is integrable into the existing infrastructure. The 3D printing technology is easily integrable into the existing infrastructure, ensuring seamless adoption and minimal disruption to current workflows. Its compatibility with existing systems allows for a smooth transition and efficient implementation within the CLF. Evaluate the virtualization The virtualization of 3D printing technology within the LCAMP CLF allows for comprehensive simulation and optimization of manufacturing processes. By creating digital twins of the 3D printers and their operations, we can test and refine production workflows in a virtual environment before physical implementation. This approach not only enhances efficiency and reduces errors but also enables predictive maintenance and real-time monitoring. The ability to simulate different scenarios and material behaviors virtually ensures that we can achieve the highest quality outputs while minimizing resource usage and downtime. Virtualization thus plays a crucial role in integrating 3D printing seamlessly into our existing infrastructure and advancing our manufacturing capabilities. Collaboration opportunities Within the LCAMP consortium, the integration of 3D printing technology opens up significant collaboration opportunities among partners. The flexibility and accessibility of both FDM and SLS printers allow for seamless sharing of designs and manufacturing tasks. For instance, one partner can design a component, another can print it, and a third can handle the assembly. This distributed approach not only enhances efficiency but also leverages the unique strengths and capabilities of each partner. The ability to share digital files and printing parameters ensures that work done in one lab can be easily replicated and adjusted in another, fostering a collaborative environment where knowledge and resources are shared. This setup enables students and researchers from different countries to work together on projects, exchanging ideas and refining processes in real-time. Alternative systems might complicate such collaboration due to compatibility issues and the inability to share complete setups and configurations. The 3D printing technology we have chosen supports robust data exchange and maintains the integrity of designs across different platforms. This ensures that the collaborative efforts are not hindered by technological limitations, making the 3D printing solution an ideal choice for the LCAMP consortium.
#3. Develop a Phased Implementation Plan	
	Develop a Phased Implementation Plan **To ensure optimal integration of 3D printing technology:** • Definition of objectives and requirements • Identify the pedagogical and technical objectives to be achieved with the 3D printers (precision, types of parts, materials). • Determine the skills to be developed by the students (3D modeling, printing techniques, material science). • Draw up an overall budget, including acquisition, training, and maintenance costs. **To select the 3D printers**

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Research and compare available printers according to defined needs (capacity, precision, material compatibility).
Choose both FDM and SLS printers to cover a wide range of applications.

To prepare the infrastructure

Adapt the workspace to accommodate the printers (ventilation, materials storage space, safety).
Check that the electrical installations are appropriate for the specific requirements (power, connectivity).
Install safety devices to protect users.

Staff training

Train teachers and technicians in the use of the printers, 3D modeling software, and associated technologies.
Organize practical sessions to familiarize staff with basic maintenance and troubleshooting.
Ensure that staff are trained in safety standards for the use of 3D printing equipment.

To integrate the technology into the training .program

Design 3D printing-related training modules for students, covering 3D modeling, materials handling, and printer operation.
Integrate the digital chain (from CAD to manufacturing) for complete and realistic learning of industrial processes.

Test and adjustment phase

Carry out tests to validate that the printers meet the educational and technical requirements.
Adjust the printing parameters, speed, and processes to optimize the quality and precision of the parts.
Gather feedback from teachers and technicians to fine-tune use and correct any bottlenecks.

To integrate the students

Organize practical sessions to introduce students to the use of the 3D printers and associated software.
Involve students in practical projects to enable them to develop their skills in real-life conditions.
Monitor progress and adjust teaching modules if necessary.

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<tr><td colspan="2">#4. Training</td></tr>
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Students and teachers working with the LCAMP CLF 3D printing technology will first receive an introduction to the LCAMP project and the concept of the CLF. This will enable them to become fully aware of the European and collaborative scope of their activities.
The technology will be gradually integrated into the CLF. First, the CLF implementation team will be trained, followed by the integration and training of teachers, and finally the integration and training of students.
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<tr><td colspan="2">#5. Integrate Technology into Curriculum and Learning Activities</td></tr>
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The students who are working with 3Dm Printing technology in the CLF at CNG in (Sweden) are students in:

Vocational Baccalaureate: Production technology (EQF4), Production technology (EQF5), Design and product development (EQF4), Design and product development (EQF5)
Technological Baccalaureate: Science technology (EQF4)

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<tr><td colspan="2">#6. Evaluation and Continuous Improvement</td></tr>
</table>

In progress

15.10. USE CASE 10. MANUAL ASSEMBLY LINE

USE CASE	**Manual Assembly Line**
Author	**GEBKIM VET, T**urkey
Description	The manual assembly line is a training environment replicating the assembly processes found in manufacturing industries. It consists of workstations where students perform assembly tasks step by step, learning how to follow standard operating procedures (SOPs), use tools, and ensure quality control. This assembly line is flexible and modular, allowing different assembly products and varying levels of complexity to be introduced. The objective of this assembly line is to provide hands-on learning opportunities, bridging the gap between theoretical knowledge and practical industrial skills. The manual assembly line will simulate real-world industrial processes, offering students an immersive learning experience in line with modern manufacturing practices.
Location	GEBKİM VET, Turkey
 *Figure 51– Manual Assembly Line GEBKİM VET and - Computer Laboratory GEBKIM VET*	
#1. Identification of a need or a problem to solve,	
Purpose (technical)	From a technical perspective, the manual assembly line provides a realistic simulation of industrial assembly processes. It is designed to: • Teach the use of various tools and equipment commonly found in manufacturing. • Develop skills in quality control, troubleshooting, and process optimization. • Ensure students gain a deep understanding of workflow, time management, and productivity in assembly line environments. • Familiarize students with industrial safety standards and ergonomic practices to prevent workplace injuries.
Purpose (didactic)	Didactically, the manual assembly line serves to: • Engage students in experiential learning, where theoretical knowledge is applied in a hands-on environment.

	• Foster problem-solving skills by simulating common challenges in production lines. • Enhance teamwork and communication as students work in groups to complete assembly tasks. • Build competencies in quality management, lean manufacturing techniques, and continuous improvement processes. Allow for individualized learning, where students can advance at their own pace through varying levels of task complexity.
#2. Technology Selection and Feasibility Study	
	The selection of technology for the manual assembly line involved a careful assessment of the following factors: • **Relevance:** Manual tools and assembly methods that reflect current industry practices. • **Flexibility:** Modular workstation that can be adapted for different product assemblies. • **Safety:** Ergonomically designed stations and the inclusion of safety protocols to mirror real-world standards. • **Cost-effectiveness:** Affordable equipment that offers durability for long-term use while being accessible for educational budgets. • **Maintenance:** Equipment that is easy to maintain and repair to minimize downtime during training. A feasibility study was conducted to determine the following: • **Technology Compatibility:** Manual assembly tools and equipment selected are compatible with future upgrades, such as automation or digital integration. • **Cost-benefit Analysis:** The investment in the assembly line provides long-term value by enhancing student learning outcomes and employability. **Threats/Disadvantages** - Manual assembly lines and potential workstations require additional physical space. - The technological infrastructure requirements for the development of the system require additional costs. **Development Options / Potential Future Applications** Potential future development options include; -Predictive Maintenance: Integrate sensors and software to predict failures and plan equipment maintenance. -Remote Control and Monitoring: Develop a remote interface to control and monitor the station from anywhere. -Modular Expansion: Design the station to allow easy addition of new functions and equipment as needs evolve. **Collaboration opportunities** In the future, agreements can be made with industrial partners so that their workstations can be used by teachers and students. Thus, industrial automation systems such as robotics and CNC can be utilized without physical space and budget problems.
#3. Develop a Phased Implementation Plan	
	The phased implementation plan for the manual assembly line in the learning factory is as follows: **Phase 1: Planning and Design** • Define learning objectives aligned with industry standards. • Design the layout of the manual assembly line, specifying the workstation and required equipment. • Prepare safety protocols and instructional materials.

	Phase 2: Procurement and Setup • Purchase necessary tools, equipment, and materials. • Install and configure workstation and monitoring system(computer) in the learning factory. • Conduct safety checks and testing to ensure all equipment meets operational standards. **Phase 3: Curriculum Development** • Integrate manual assembly line training into the VET curriculum. • Develop instructional guides, assessment rubrics, and supporting materials for teachers and students. • Plan for various learning modules, from basic assembly tasks to advanced troubleshooting. **Phase 4: Pilot Program and Evaluation** • Conduct a pilot program with a selected group of students to evaluate the effectiveness of the assembly line. • Gather feedback from students and instructors to refine the learning activities and processes. • Make necessary adjustments to equipment, curriculum, and teaching methods. **Phase 5: Full-scale Implementation** • Launch the manual assembly line as a core component of the VET program. • Regularly evaluate and update the assembly line setup, tools, and curriculum based on evolving industry trends and feedback.
#4. Training	

	A comprehensive training program within the scope of LCAMP Project will be established to ensure both instructors and students can fully utilize the manual assembly line:
	• **Instructor Training:**
	  ◦ Best practices for teaching in a hands-on, industrial environment.
	  ◦ Guidelines for student assessment, safety management, and feedback delivery.
	• **Student Training:**
	  ◦ Introductory sessions covering safety protocols, tool use, and assembly procedures.
	  ◦ Progressive skill-building exercises, starting from simple tasks and advancing to more complex assembly operations.

#5. Integrate Technology into Curriculum and Learning Activities	
	To fully leverage the potential of the manual assembly line, it must be tightly integrated into the curriculum: • Learning Modules: Assembly line tasks will be broken down into structured learning modules focusing on specific skills such as tool use, workflow management, and quality control. • Cross-disciplinary Projects: Collaboration across various subjects (such as mechanical technology and industrial design) to promote a comprehensive understanding of the manufacturing process. • Case Studies: Real-world case studies will be introduced to simulate troubleshooting scenarios, improving critical thinking and problem-solving skills. • Assessment and Feedback: Continuous formative assessments will track student progress, with feedback provided to support ongoing improvement.
#6. Evaluation and Continuous Improvement	
In progress	

15.11. USE CASE 11. PLM

USE CASE	**Product lifecycle management (PLM)**
Author	Tehniški šolski center Maribor Slovenia
Description	Product Lifecycle Management (PLM) is an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment, and maintenance - culminating in the product's removal from service and final disposition. By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of lean thinking. (Grieves, 2005) LCAMP CLF is using Dassault Systèmes 3DEXPERIENCE cloud platform as primary 3D CAD modelling environment, also same platform is used as a PLM solution with Enovia Collaborative Lifecycle app, so LCAMP members can: • Collaborate seamlessly no matter the location • Increase creativity using virtual twin CLF • Leverage a holistic and real-time view into processes.
Location	Tehniški šolski center Maribor, Slovenia

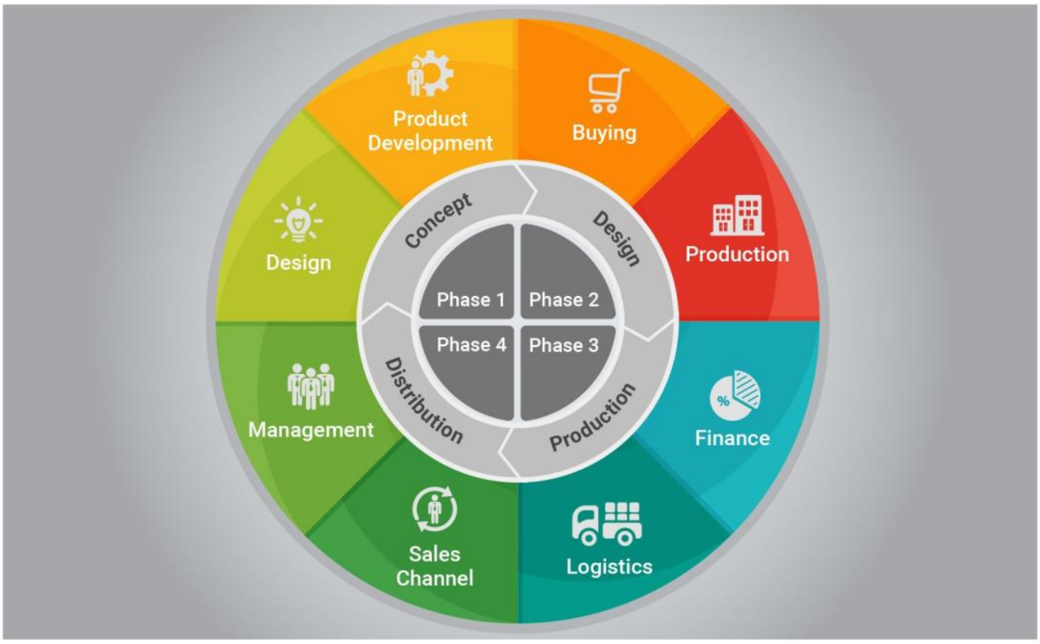


Figure 52 Screenshot taken from https://www.surefront.com/blog/product-lifecycle-management-plm-software-6-things-you-need-to-know

#1. Identification of a need or a problem to solve

Purpose (technical)	The purpose of using 3DEXPERIENCE PLM is to enhance assembly of LCAMP robot subsystem by simulating real-world product development scenarios and managing complex data – in LCAMP case all assembly parts and documentation for robot. 3DEXPERIENCE PLM enhances collaboration between LCAMP members and in case of CLF students, mimicking

	industry teamwork and help optimize processes for part structure efficiency. PLM ensures compliance with industry standards and teaches the importance of regulatory adherence. It also allows students to perform lifecycle analysis, promoting sustainable practices. Idea of implementing PLM to VET is to equip students with essential technical skills for their careers.
Purpose (didactic)	Product Lifecycle Management (PLM) primary didactic purpose is to equip students with a comprehensive understanding of the entire product lifecycle, from conceptualization to end-of-life. By integrating PLM into engineering and manufacturing curricula, educational institutions can deliver skilled engineers, capable of driving innovation, improving product quality, and optimizing manufacturing processes. Using PLM in VET enhances active, hands-on learning and helps students develop both technical and soft skills. It aligns the curriculum with current industry standards, making training more relevant. PLM supports differentiated instruction to meet diverse learning needs. It also facilitates continuous assessment and feedback for ongoing improvement.
#2. Technology Selection and Feasibility Study	
	Implementing a Product Lifecycle Management (PLM) system into LCAMP CLF can significantly enhance the it's capabilities by providing a centralized platform for managing product data, processes, and collaboration. PLM is designed to scale to meet the needs of VET of all sizes, from schools with few hundred student to colleges with several thousand students. It can be configured to support a wide range of workflows and processes, making it adaptable to different learning scenarios The 3DEXPERIENCE platform simplifies the lifecycle of the supporting design data with the Collaborative Lifecycle app. This enables users to release, revise, branch, move and delete data directly from web browser. Users can protect completed design data by changing its maturity state - additional states are available to make objects private when working in a shared collaborative space. Object's flag is frozen if the release is pending decisions from other stakeholders, or make the object obsolete, if it is no longer needed, or if it has been replaced by a new version. Revisions capture improvements to existing designs, users can increment the revision of an object by clicking "new revision". This automatically creates a reference between the revisions and the app makes this visual, so users can easily understand the history of an object. In many cases you have multiple design candidates for the next revision. Users create branches for this scenario, again the references are automatically created and visualized in the app. New revisions may also be created from these branches by clicking "new revision from" and picking the desired object. To clean up the history and remove unwanted versions users can pick the objects of interest and click delete. For assemblies users can enable the "whole structure option" if they want to delete all of the child components as well. For scenarios where users want to move data to a different collaborative space or assign another user as the owner, use transfer ownership and define the desired destinations. When it comes to moving, deleting, branching, revising and releasing product design data, you can do all of this from your internet browser with one app on the 3DEXPEREIENCE platform. The 3DEXPEREIENCE platform can store documents to give them the same security as all other data stored in the platform. In addition to this, these documents can then be linked directly to other data. Documents in the platform are revision controlled and can be placed under change control, giving the same level of functionality to your documents as users CAD data. 3DEXPERIENCE uses a Unified Product Structure which brings together all elements of a design such as mechanical, electrical, PCB, Software, etc. into one 'BOM'. This unified BOM can then be used by many other areas of the platform, for example Variants and Options can be applied to the whole BOM structure as a single BOM rather than over multiple BOM's.
#3. Develop a Phased Implementation Plan	
	It was important to perform an initial assessment of all possible phases of the project when using 3DEXPERIENCE implementation within LCAMP stakeholders. This involves

mapping project requirements to available functionality and determining if any customizations are required.

The LCAMP team had to consider licensing requirements which took more time and effort as previously planned. Right from the start, the project team had to plan for a data migration step from previous project where whole robot was designed in Solidworks to perform data migration into 3DEXPERIENCE platform.

During the data migration, the data had to be cleaned-up to eliminate:

- Duplicated part numbers per file
- Duplicated file names
- Duplicated files with different names
- Missing or incorrect file attributes
- Missing or incorrect file associations or links
- File revision not current
- Non-current parts in current assemblies
- Non-compliance revision/versioning scheme
- Missing mandatory attributes in source system

With proper planning and testing, implementing and migrating data to 3DEXPERIENCE can go smoothly. The better prepared you are ahead of time, understanding requirements, data sets, limitations and the technology being used, the better the 3DEXPERIENCE implementation will run. It is important to set the right expectations among users, knowing that most implementation and data migration projects are accomplished in a relatively straightforward manner.

#4. Training

The training of 3DEXPERIENCE PLM solutions will be performed by TKNIKA.

PLM Training for Teachers in LCAMP CLF:

1. Assessment of user’s needs:

- Identify Core Competencies: Determine the essential PLM skills teachers need to effectively guide students. This might include basic navigation, data management, workflow creation, and collaboration tools.
- Assess Current Knowledge: Evaluate teachers' existing knowledge of PLM and digital tools. This will help tailor the training to their specific needs.
- Identify Training Goals: Clearly define the objectives of the training, such as improving teaching methods, enhancing learning experiences and innovation.

2. Develop a Comprehensive Training Plan:

- Modular Approach: Break down the training into manageable modules, covering topics like:
    - Introduction to PLM concepts
    - Navigating the 3DEXPERIENCE interface
    - Creating and managing product structures
    - Working with workflows and tasks
    - Collaborating with team members
    - Integrating with other tools (CAD, CAM, etc.)
    - Data management and security
- Hands-on Practice: Incorporate practical exercises and simulations to reinforce learning.
- LCAMP Project Integration: Use LCAMP robot assembly to demonstrate how PLM can be applied in CLF settings.

3. Choose Effective Training Methods:

- Blended Learning: Combine various delivery methods, such as:
    - Instructor-led training: In-person sessions for interactive discussions and demonstrations.
    - Self-paced online learning: Provide access to online tutorials, videos, and documentation for flexible learning.
    - Hands-on workshops: Practical sessions to practice PLM skills in a collaborative environment.

	- Mentorship and Coaching: Assign experienced PLM users as mentors to provide guidance and support. - Community Building: build a community of practice among teachers to share experiences and best practices. 4. Provide Ongoing Support and Resources by TKNIKA: - Help Desk: Establish a dedicated help desk or support team to assist teachers with technical issues and questions. - Online Resources: Use 3DEXPERIENCE online resource library with tutorials, FAQs, and troubleshooting tips. - Regular Training Updates: Offer refresher courses and workshops to keep teachers up-to-date with the latest PLM developments and best practices. 5. Evaluate the Training Program: - Feedback Mechanisms: Gather feedback from teachers through surveys, interviews, and focus groups. - Assessment of Learning Outcomes: Evaluate the effectiveness of the training by assessing teachers' knowledge and skills. - Continuous Improvement: Use feedback and assessment results to refine the training program and address any shortcomings.
#5. Integrate Technology into Curriculum and Learning Activities	
	The students who are working with PLM at TSCMB (Slovenia) are students at level: - EQF 4/ Mechanical engineering technician – use of PLM for project management and collaboration: learn how to manage projects efficiently, from initial design to final product disposal in collaborative environment. - EQF 5/ Mechanical engineer - use of PLM for project management, collaboration, data management and digital transformation: learn how to manage projects efficiently, from initial design to final product disposal in collaborative environment, use of teamwork, learn about industry standards for data exchange and interoperability and learn how to create digital twins of products to simulate and optimize performance.
#6. Evaluation and Continuous Improvement	
	In process

15.12. USE CASE 12. PRODUCT CONFIGURATOR

USE CASE	**Product Configurator**
Author	Baden-Württemberg Cooperative State University Heidenheim site, Germany
Description	A CLF serves to train students and professionals in realistic production environments. In this setting, it is important to be flexible, adaptable and dynamic in responding to learning needs and technical requirements. **Flexibility**: Different teaching and learning modules can be dynamically configured and adapted to the needs of the learners. **Efficiency**: Production resources and learning objectives are optimized and synchronized with each other. **Collaboration**: Different users (teachers, students, administrators) can easily access and work with the necessary configuration in distributed educational institutions. The Configuration Manager ensures the coordination and management of all relevant variants, systems, assembly equipment and associated learning content. A configuration manager for a collaborative learning factory serves as a central hub for managing processes, learning content,

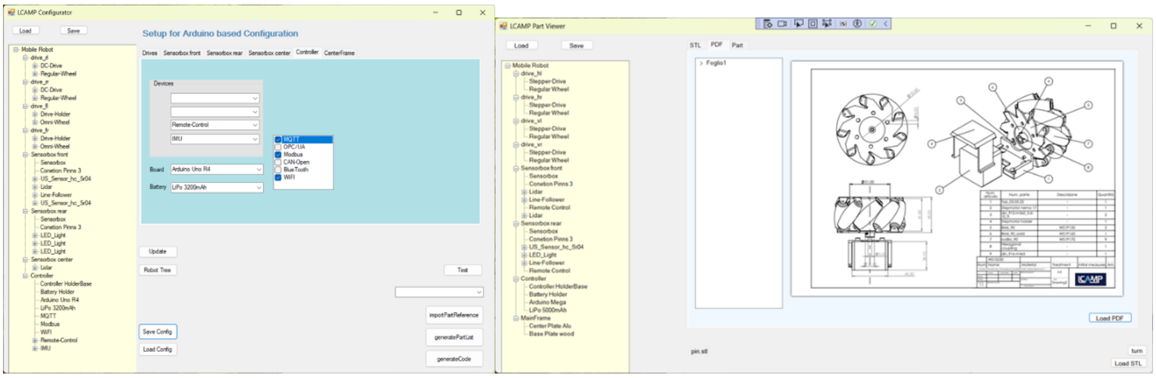
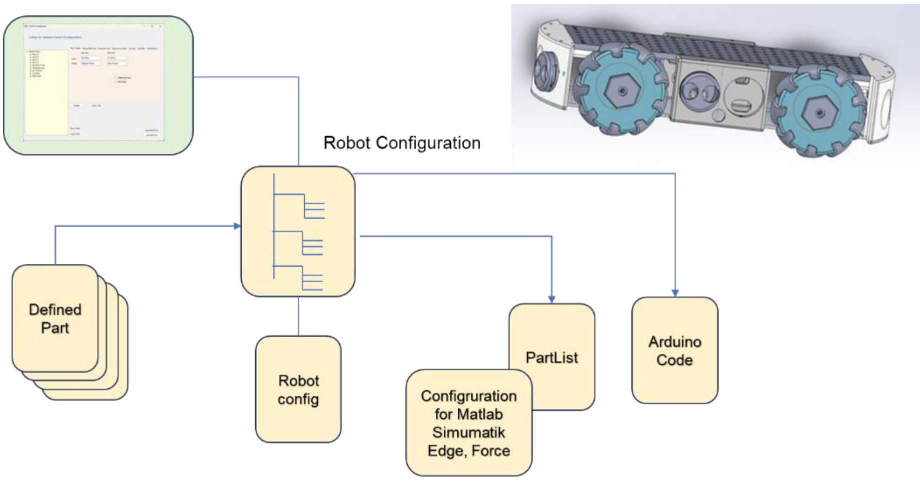
<table>
<tr><td></td><td>users, and data. It enables creating a flexible, efficient and safe learning environment to meet the needs of modern I4.0 production environments. The integration of process planning into the CLF ensures that learners can gain practical experience.</td></tr>
<tr><td>Location</td><td>DHBW – Heidenheim Germany</td></tr>
<tr><td colspan="2">
Figure 53 Product Configurator with Knowledge Tree</td></tr>
<tr><td colspan="2">#1. Identification of a need or a problem to solve,</td></tr>
<tr><td>Purpose (technical)</td><td>

Figure 54 Product Configurator as a connecting hub in the CLF
The complex technical product for the CLF could not be handled by a single student group. The Robot has mechanical aspects, Electronic- and Software aspects and the interaction between Product CLF and the users. These domains could be linked together without special knowledge of an Enterprise Resource Planning (ERP) or Product Livecycle Management (PLM) System. A student group could focus on a special topic with access to all the other domains.</td></tr>
<tr><td>Purpose (didactic)</td><td>The configurator serves the different variants of a mechatronic product. It is located below the Product Lifecycle Management (PLM) at a low threshold. The configurator provides a connection between PLM and the operational levels. Real configurations can be created and the prototypes manufactured. The low-threshold approach allows processes to be implemented directly in the laboratory. The configurator is run directly on the LCAMP platform or students can use the complete source code to drive specific developments.</td></tr>
<tr><td colspan="2">#2. Technology Selection and Feasibility Study</td></tr>
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	The robot consists of subsystems that must perform the required function. A basic configuration is the omnidirectional robot, which is remotely controlled. This can be produced with different technologies. Either in different 3D printing technologies, with cutting technologies or classic machining, primary forming or forming technologies. Only certain configurations that are selected by the configuration manager are useful. The data is pulled in the simple form from Json configuration files. These can be specifically adapted for each use case but can also be transferred via the cloud. The hurdle of database administration is overcome, and every student can install the system locally on his notebook. In the Configurator are defined: Mechanical factors: function, connection dimensions, stability ç Bill of materials including positions, 3d geometry and assembly constraint is generated. Electronic factors: connectivity, function, security. ç source code for Controller is generated. Logical factors: Structural structure, traceability, quality data ç Json File is generated with the logic configuration. In addition to the functional requirements, design aspects are also considered. The color combination as well as the material composition and the connection technology (screwing, riveting, gluing, …). The entire robot is the result of the interaction of many individual processes that can be largely asynchronous. Parts are either procured externally (purchased parts), procured internally through the partners or manufactured in-house. The assembly is then carried out completely individually. Each robot is therefore unique. Some of these processes are accompanied by teaching materials embedded in micro-credentials Circular economy in the context of training and to impart the skills of the circular economy, the aim is to ensure that the robot can be completely disassembled and merged into a new configuration. The robot thus represents a special warehouse for the configurator.
#3. Develop a Phased Implementation Plan	
	The Configurator is based on the description of the Robot. Multiple configurations are handled. Integration of a 3D drawings in the Configurator. Integration of new and modified parts for further development. Generate the Code for Arduino or other Controllers Activate the Interface to Matlab/Simscape Activate the Interface to Simumatic Activate the Interface to FORCAM Force/ Edge
#4. Training	
	The training is linked to a Micro credential to get the Skill in Configuration Management. This Course is performed in the CLF for students from technical Faculty and the business department.
#5. Integrate Technology into Curriculum and Learning Activities	
	EQF 6/ Integrated Engineering, Mechanical Engineer, Industrial Engineer – Using the configurator for industrial process management, collaboration, data management and digital transformation as well as working with circular processes to strengthen sustainability. Mechatronics Engineers, Informatics Engineers - develop in student projects new Variants and functional Modules for the configurator.
#6. Evaluation and Continuous Improvement	
	In process

16. CONCLUSION AND OUTLOOKS

The report outlines a method for integrating advanced technologies into Learning Factories and workshops within VET and HVET institutions. It introduces a six-step framework for adopting I4.0 technologies in educational labs:

1. Identify a Need or Problem to Address
2. Select Technologies and Conduct a Feasibility Study
3. Develop a Phased Implementation Plan
4. Provide Training
5. Embed Technology into Curriculum and Learning Activities
6. Evaluate and Continuously Improve

To demonstrate the application of this guideline, the report presents nine use cases. These examples highlight the guideline's adaptability to diverse scenarios and illustrate its practical value. It is worth mentioning that not all the steps are yet reflected in the use cases, for instance the *Evaluation and Continuous Improvement* phase, as the processes are still underway. Completion of the entire guidelines anticipated by the conclusion of the LCAMP project.

From an educational perspective, a relevant step is the *Embed Technology into Curriculum and Learning Activities.* For the use cases shown, the adaptation of curriculums are very context dependant. Regional legislations set up the scope for such integrations.

Future efforts will focus on standardizing courses and learning outcomes within activities derived from technology implementation, ensuring their applicability to international counterparts. Specifically, the LCAMP CLF will incorporate the LCAMP Competence Framework into its courses. This adoption aims to ensure the courses' alignment with international standards, enhancing their usability and relevance across borders.

Finally, during LCAMP lifespan, more I4.0 technologies will be incorporated gradually. In a short term, traceability systems, smart fastening systems, dashboards for data analysis, connected wearables are planned to be incorporated.

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18. INDEX OF FIGURES

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