Learner Centric Advanced Manufacturing Platform

MORPHOLOGY OF THE LCAMP COLLABORATIVE LEARNING FACTORY

WP6 Industry 4.0 technology absorption through the Collaborative Learning Factory

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GLOSSARY AND/OR ACRONYMS

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.

CONTENT TABLE

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 from the sectors.

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".

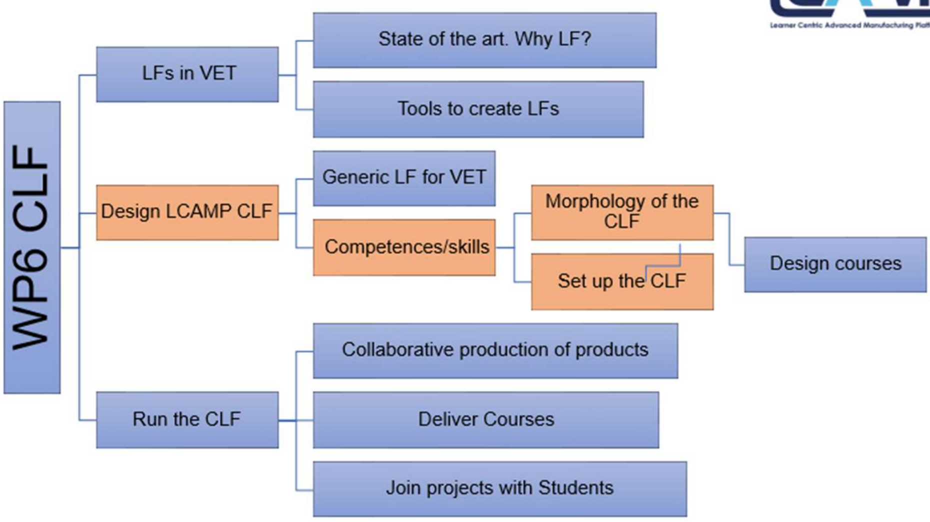


Figure 1. Basic scheme of the WP6.

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 E. et al., 2015).

The presence and development of LFs at the university level is covered extensively in the literature (Belinski et al., 2020) (Enke et al., 2018) (Pittich et al., 2020) but attention to LFs in VET is limited (Roll & Ifenthaler, 2021) (Scheid, 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 2 (IALF, 2021).

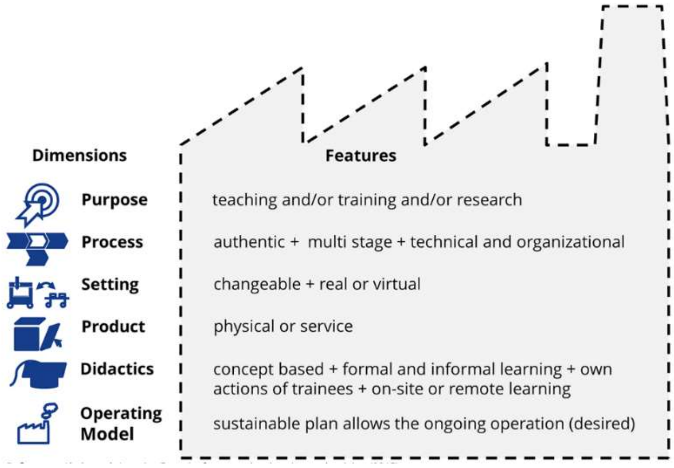


Figure 2. Dimension given by IALF to describe LFs. Source (Abele E. et al., 2015).

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 1.

Table 1. 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 2 which includes an additional 8th dimension to describe the collaborative aspects of the CLF.

Table 2. 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).

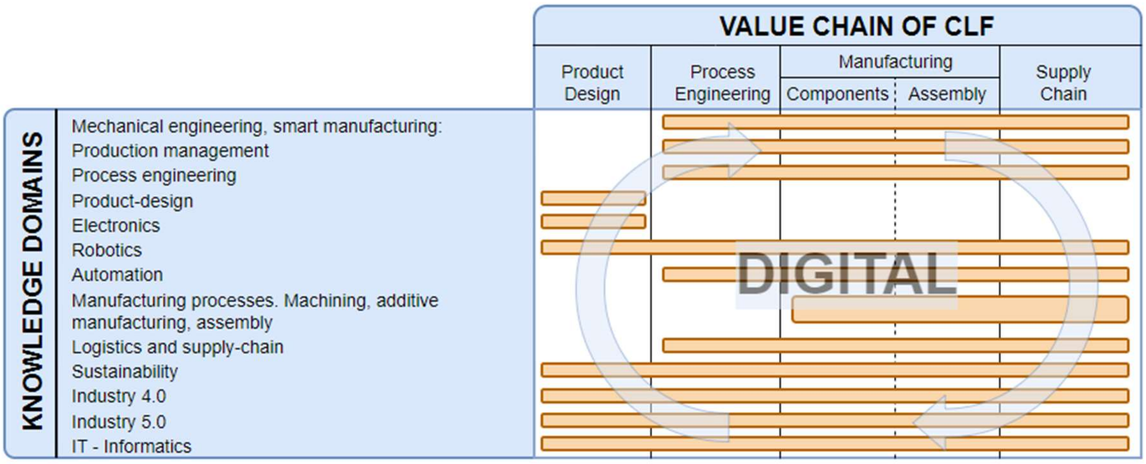


Figure 3. Cross-referencing knowledge domains with Value Chain of CLF processes.

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 4, 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 et al., 2022) which promotes learning on environmental sustainability in the European Union to describe green skills.

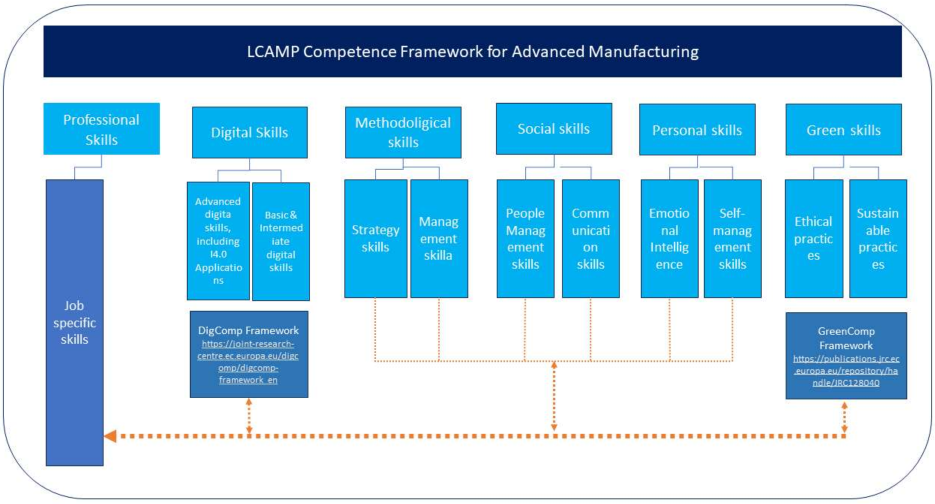


Figure 4. LCAMP's competence Framework for Advanced Manufacturing.

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, 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, 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 5 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.

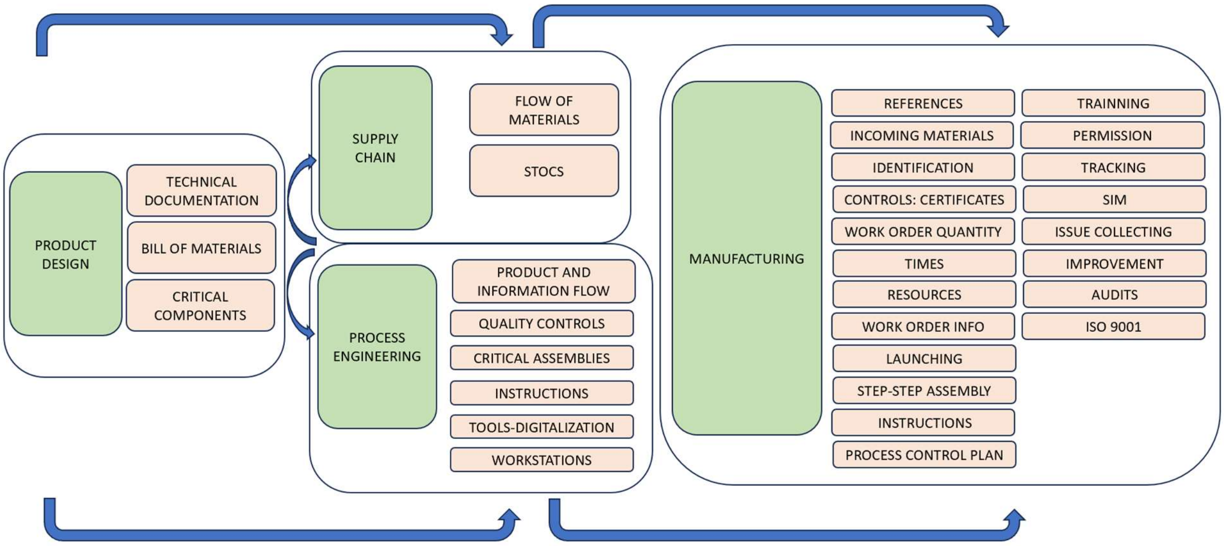


Figure 5. Conception of the LF. Own source.

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 5), 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 5):

- 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 6).

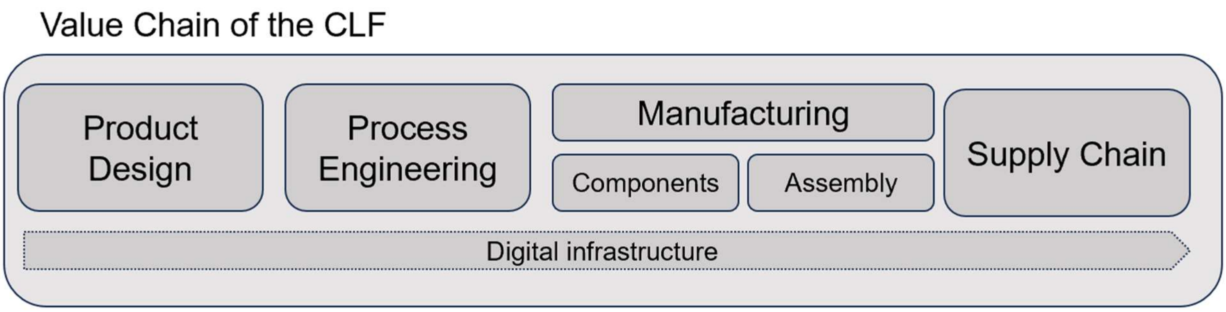


Figure 6. Value Chain of the CLF.

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 et al., 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:

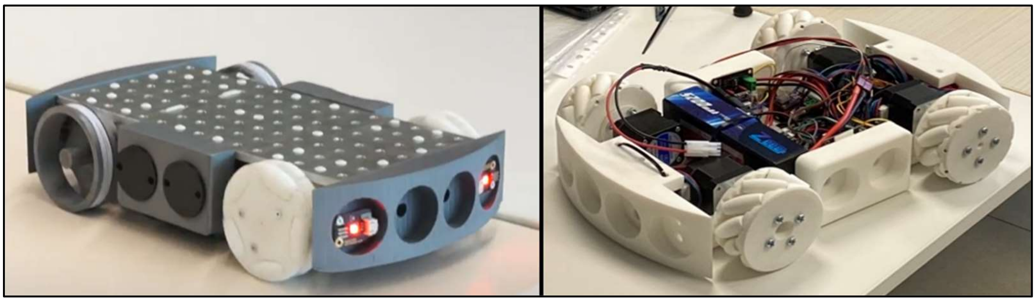


Figure 7. First and second prototypes.

- 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

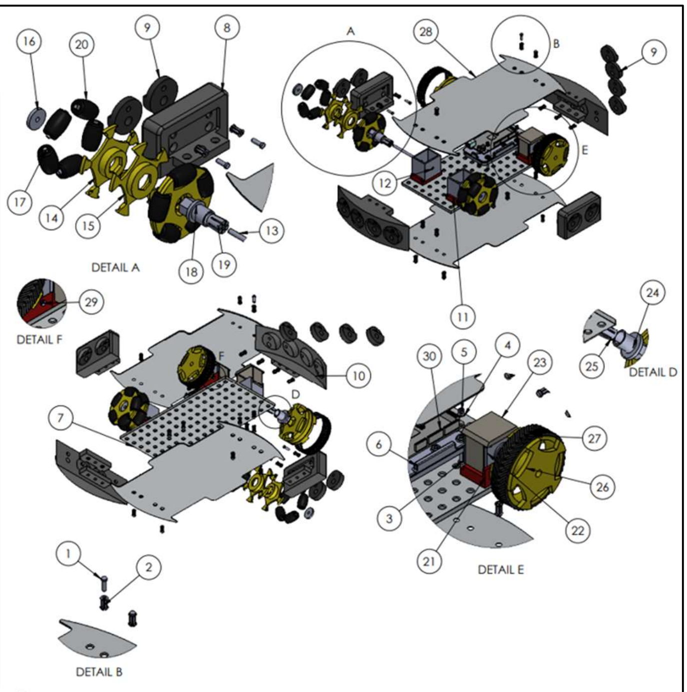


Figure 8. Explosion drawing of the first robot version.

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, 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 et al., 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, 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 et al., 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.

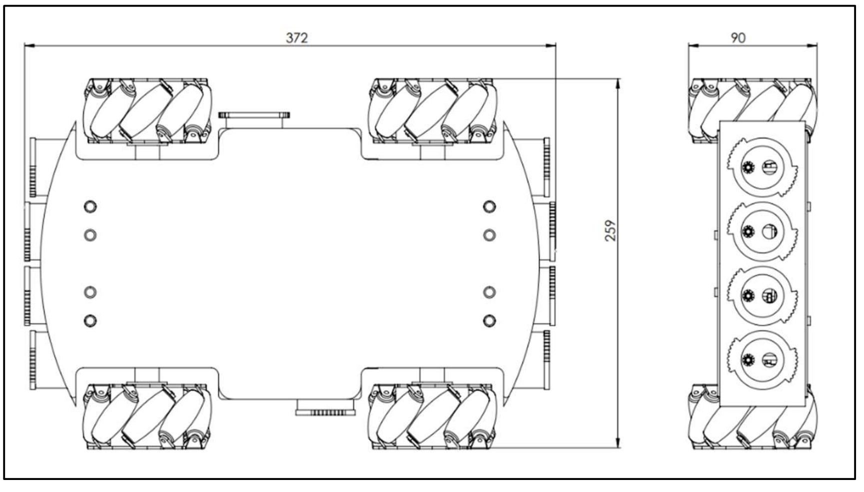


Figure 9. General measurements of one version of the robot.

- **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*.*

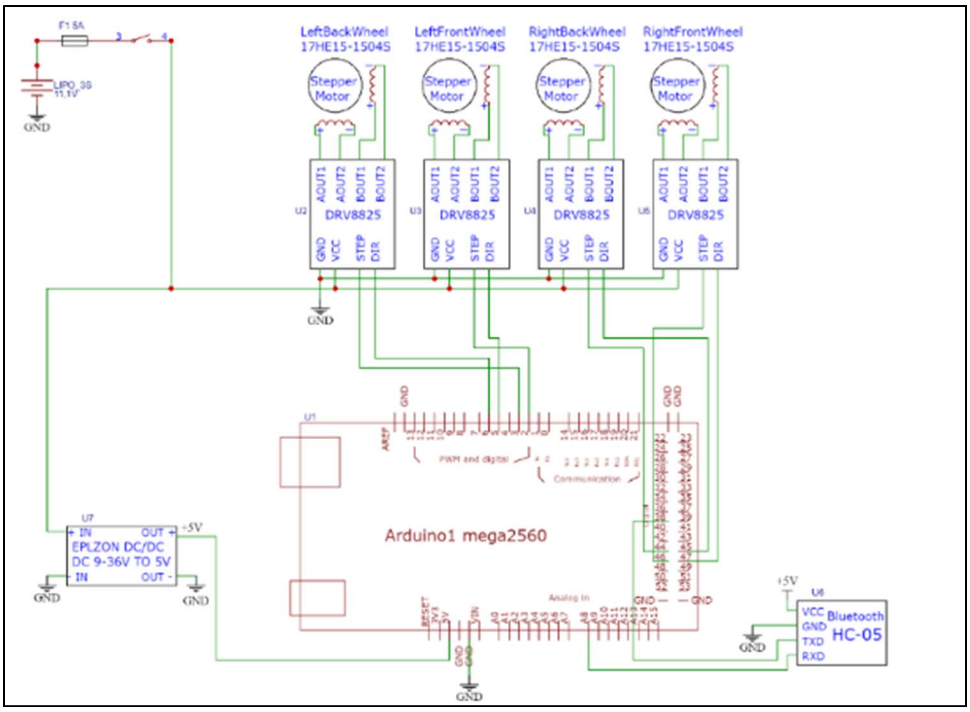


Figure 10.Electrical diagram of the robot

- **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.

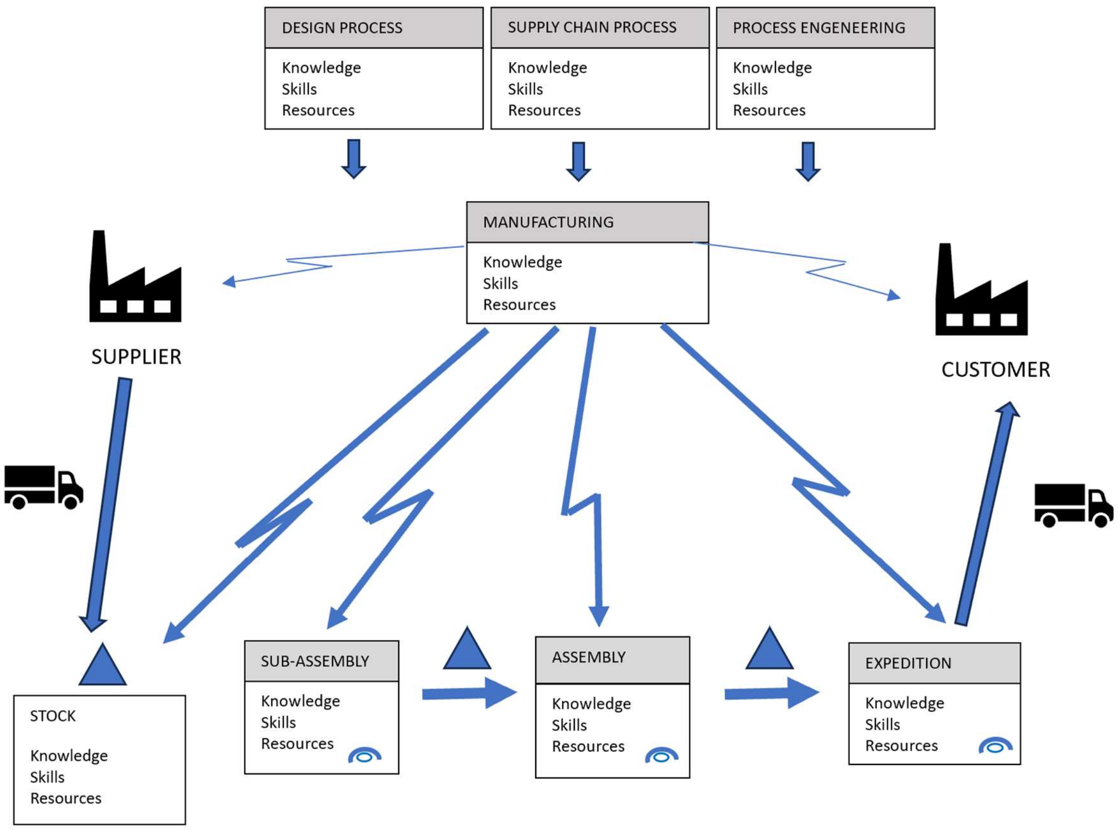


Figure 11. Feasibility analysis

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 12). 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.

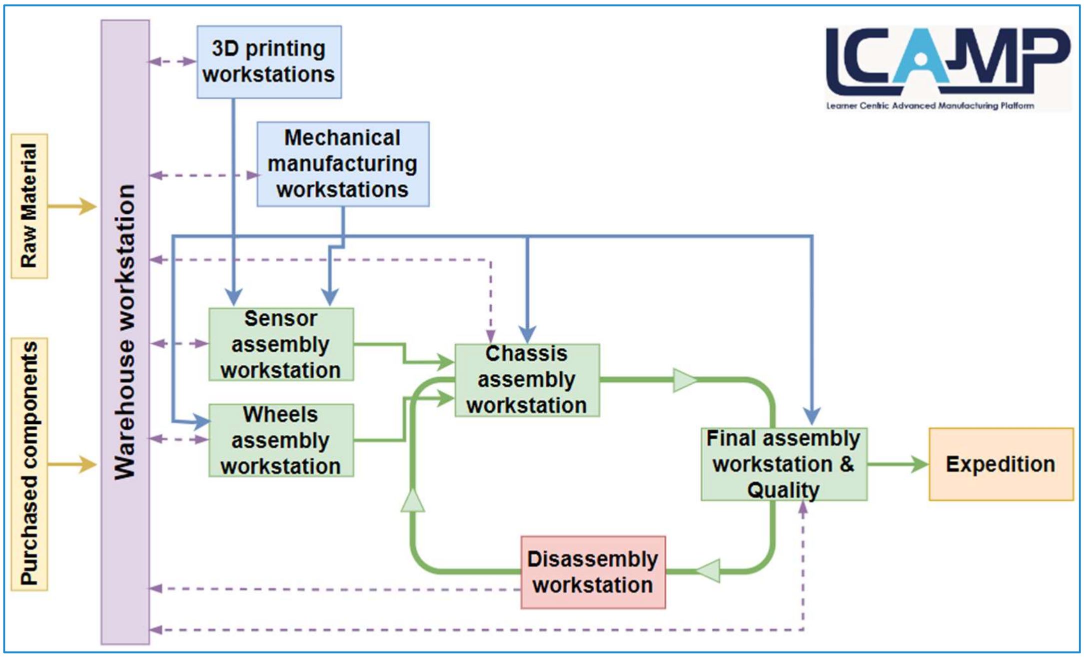


Figure 12. CLF manufacturing process

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

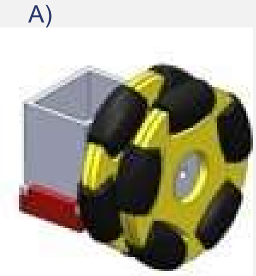
The following table summarizes the main features of the wheel's assembly workstation:

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.

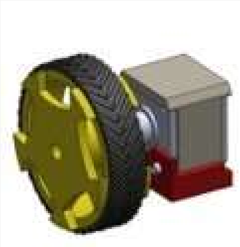
- **Regular wheel (B):** standard cylindrical shaped wheels with rubber on the outer edge for traction
- **Mecanum wheel (C):** The main difference between Omni and Mecanum is the direction the wheels on the outer edge are facing. Instead of being perpendicular to the main wheel, Mecanum wheels are made of conical-shaped wheels that face at a 45* angle from the main.

Sub product's picture:

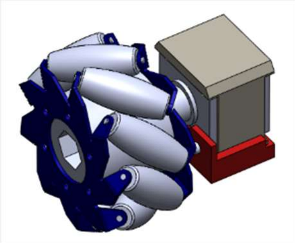
A)



B)



C)



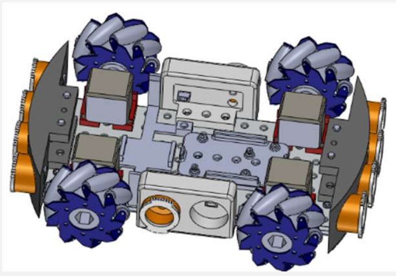
Works station's set up description	
Ergonomics	Standard mechanical assembly table
Assembly area	Workbench with a board with tray holders, necessary tools and a support for the instructions
Tools	Pliers
Measurements (approx.)	1 square metre. An ergonomic evaluation will be carried out to establish the 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

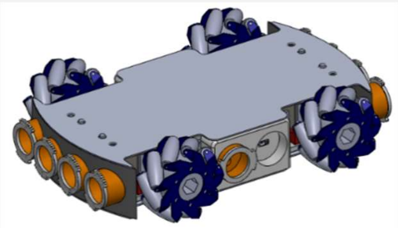
The following table summarizes the main features of the Chassis assembly workstation:

<table>
<tr><th colspan="2">Name: Chassis Assembly Workstation</th></tr>
<tr><td colspan="2">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>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="2">Works station's set up description</td></tr>
<tr><td>Ergonomics</td><td>Standard mechanical assembly table</td></tr>
<tr><td>Assembly area</td><td>The assembly table which workstation with necessary tools and a support for the instructions</td></tr>
<tr><td>Measurements (approx.)</td><td>Two metres wide, one metre high, one metre wide</td></tr>
<tr><td>Number of boxes (approx.)</td><td>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>Paper instructions or using augmented reality (headset)</td></tr>
<tr><td colspan="2">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
8. Prepare the workstation for the next assembly
9. Make continuous improvements to increase workstation efficiency</td></tr>
<tr><td colspan="2">Associated documents:
1. Manufacturing Order(s)
2. Assembly instructions
3. Technical drawing documents of the parts to be assembled
4. Instruction on assembly sequence</td></tr>
</table>

5. Quality instructions 6. Maintenance standard 7. Support material (training videos, maintenance videos, support videos)

5.2.5. DESCRIPTION OF FINAL ASSEMBLY WORKSTATION

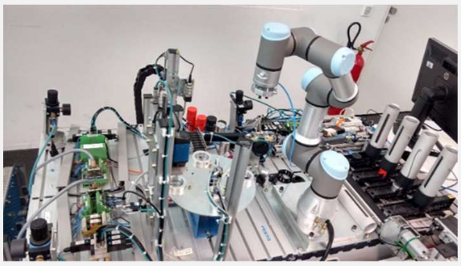
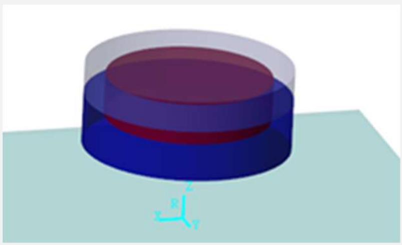
The following table summarizes the main features of the Final assembly workstation:

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:

<table>
<tr><td></td><td>• 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</td></tr>
<tr><td>Associated technologies / New trends</td><td>1. Digital work instructions
2. AR
3. RFID/Barcode/QR
More options: pick-to-light technology, robots, automated guided vehicles, and manipulators, motion monitoring</td></tr>
<tr><td colspan="2">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</td></tr>
<tr><td colspan="2">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</td></tr>
</table>

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

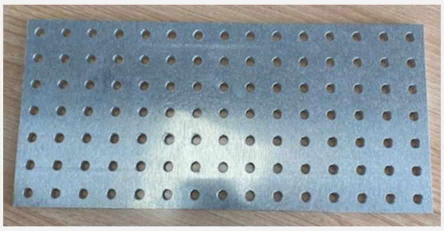
The following table summarizes the main features of the Warehouse workstation:

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
• 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>
</table>

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	
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	**Sub product's picture (example of a part):**

<table>
<tr><td></td><td></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.

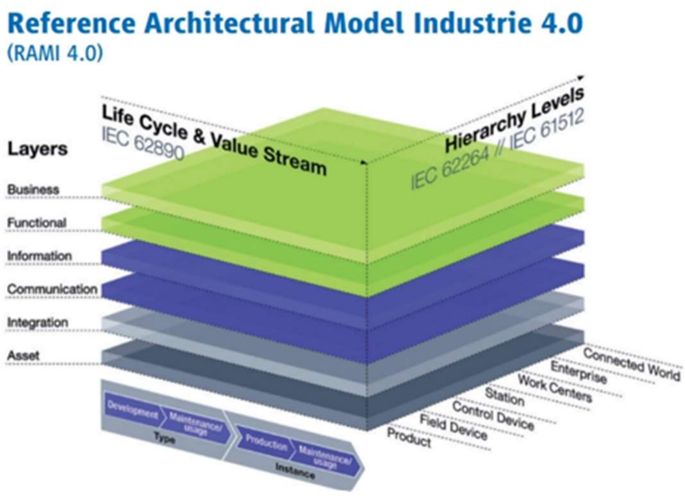


Figure 13. Architectural Model Industry 4.0. Source: Platform Industry 4.0.

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.

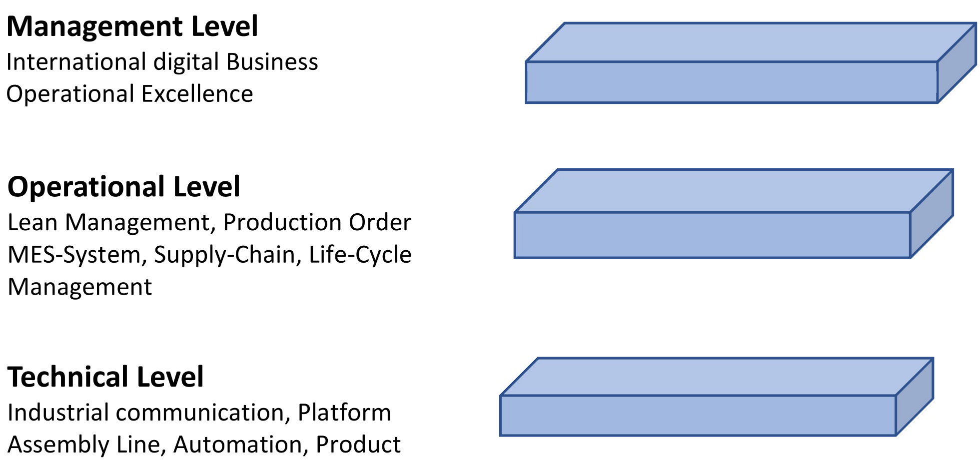


Figure 14. Levels according to RAM Industry 4.0 Model.

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.

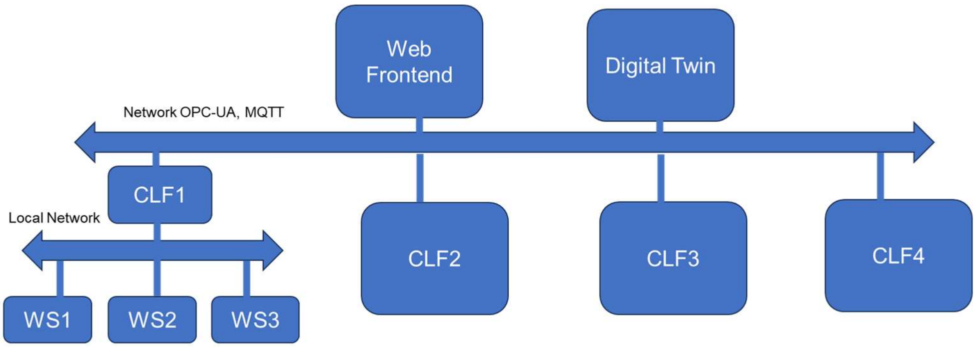


Figure 15. MES system of the CLF.

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 16). 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.

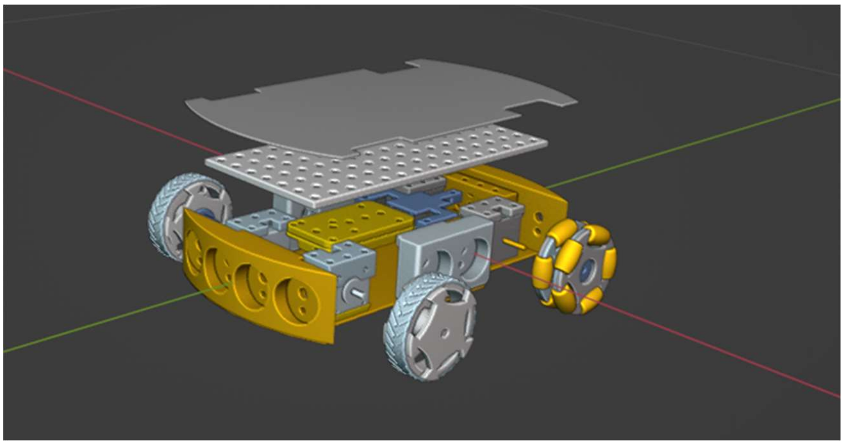


Figure 16. Parts of the virtual robot.

Furthermore, the robot will incorporate up to 10 sensors, as illustrated in Figure 16. 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.

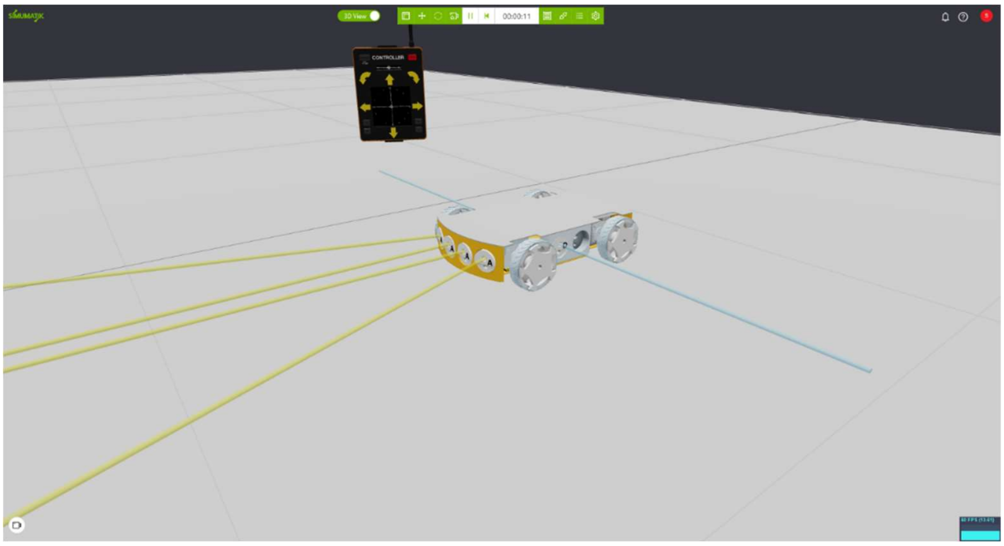


Figure 17. a virtual robot equipped with sensors and a hand controller

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.

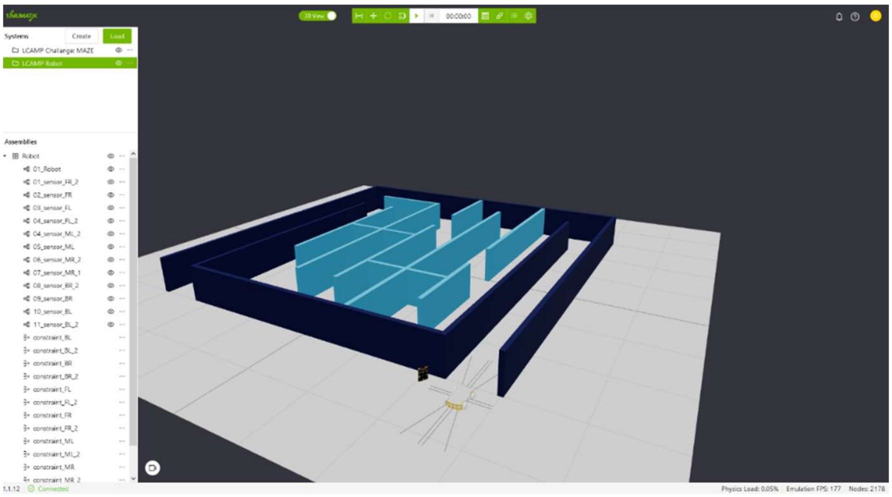


Figure 18. Example of the area for the robot

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.

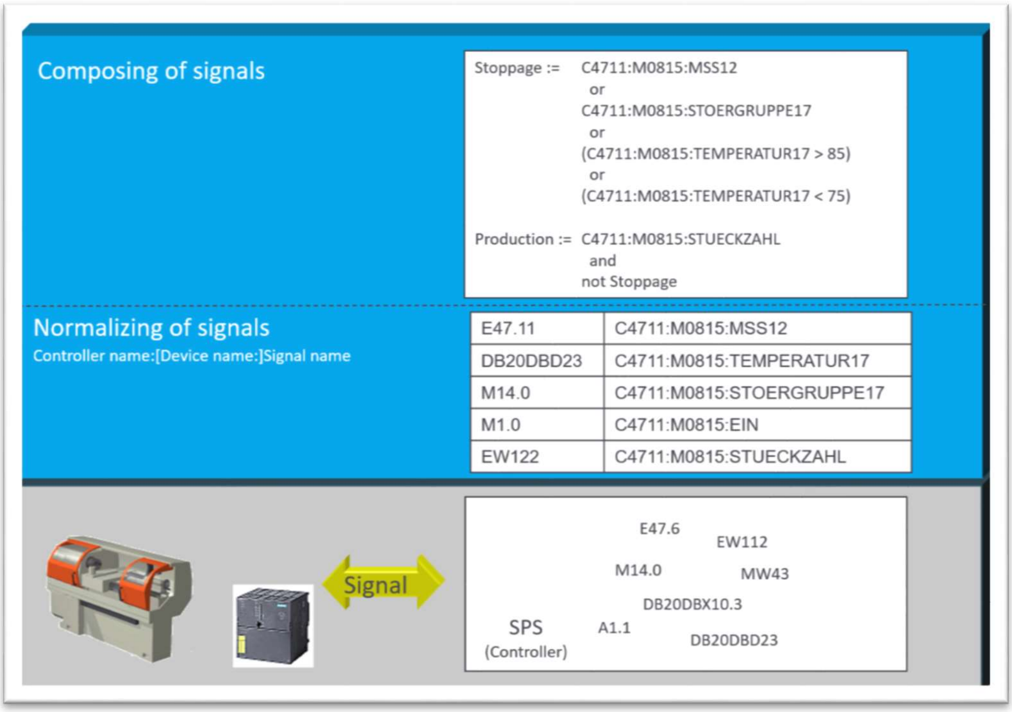


Figure 19. The transformation way from machine signal to manufacturing relevant information.

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 3. 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! No se encuentra el origen de la referencia.**, 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! No se encuentra el origen de la referencia.** 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.

8. REFERENCES

Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H., . . . Ranz, F. (2015). Learning Factories for Research, Education, and Training. *Procedia CIRP, 32*, 1-6.

Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H., . . . Ranz, F. (2015). Learning factories for research, education, and training. Procedia CIRP. *32*, 1-6. https://doi.org/ org/ 10. 1016/j. procir. 2015. 02. 187

Aegilmez, S. (2021). *Forcam Force Edge Manual*. (F. gmbh, Producer) https://forcam.com/app/uploads/2021/11/Manual-FORCAM-FORCE-EDGE.pdf

Belinski, R., Peixe, A., Frederico, G., & Garza-Reyes, J. (2020). Organizational learning and industry 4.0: findings from a systematic literature review and research agenda. *Benchmarking, 27*, 2435–2457. https://doi.org/ org/ 10. 1108/BIJ- 04- 2020- 0158

Bianchi, G., Pisiotis, U., & Cabrera Giraldez, M. (2022). *GreenComp The European sustainability competence framework.* Luxembourg: Punie, Y. and Bacigalupo, M. editor(s), EUR 30955 EN, Publications Office of the European Union. https://doi.org/10.2760/821058, JRC128040, ISBN 978-92-76-53201-9

Cervera, S. L. (2018, September). *Openaccess.* https://openaccess.uoc.edu/bitstream/10609/144051/5/Diseno%20y%20fabricacion%20inteligente_Modulo2.3_Definicion%20de%20especificaciones%20del%20producto%20o%20servicio.pdf

Clara R. Behrend, A. G. (2022). *Understanding future skills and enriching the skills debate (BEYOND4.0 deliverable D6.1).* Dortmund: BEYOND4.0. https://beyond4-0.eu/storage/publications/D6.1%20Understanding%20future%20skills%20and%20enriching%20the%20skills%20debate/BEY4.0_WP06_Task_6.1-%203rd%20Update%2008.2022.pdf).

Enke, J., Glass, R., Kreß, A., Hambach, J., Tisch, M., & Metternich, J. (2018). Industrie 4.0: competencies for a modern production system: a curriculum for learning factories. *Procedia Manuf 23(2017)*, 267–272. https://doi.org/// doi. org/ 10. 1016/j. promfg.2018. 04. 028

ETHAZI. (2016). ETHAZI: https://tknika.eus/eu/cont/proyectos/ethazi-2/

European commission. (n.d.). *Advanced Technologies for Industry*. Augmented Virtual Reality: https://ati.ec.europa.eu/technologies/augmented-virtual-reality

European Commission. (n.d.). *Advanced Technologies for Industry*. Advanced Manufacturing Technology: https://ati.ec.europa.eu/technologies/advanced-manufacturing-technology

European Commission. (n.d.). *Advanced Technologies for Industry*. Advanced Materials: https://ati.ec.europa.eu/technologies/advanced-materials

European Commission. (n.d.). *Advanced Technologies for Industry*. Artificial Intelligence: https://ati.ec.europa.eu/technologies/artificial-intelligence

European Commission. (n.d.). *Advanced Technologies for Industry*. Connectivity: https://ati.ec.europa.eu/technologies/connectivity

European Commission. (n.d.). *Advanced Technologies for Industry*. Robotics: https://ati.ec.europa.eu/technologies/robotics

European Commission. (n.d.). *Advanced Technologies for Industry*. Internet of Things: https://ati.ec.europa.eu/technologies/internet-things

European Commission. (n.d.). *ESCOpedia*. Competence: https://esco.ec.europa.eu/en/about-esco/escopedia/escopedia/competence

European Commission. (n.d.). *ESCOpedia*. Skill: https://esco.ec.europa.eu/en/about-esco/escopedia/escopedia/skill

European Commission. (n.d.). *Internal Market, Industry, Entrepreneurship and SMEs*. SME: https://single-market-economy.ec.europa.eu/smes/sme-definition_en

European Commission. (n.d.). *Research and innovation*. Industry 5.0: https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en

European Union. (n.d.). Security: https://ati.ec.europa.eu/technologies/security

EXAM 4.0. (2020). https://examhub.eu/

EXAM 4.0. (2020). *Methodologies for analysing and anticipating skills need in the Advanced Manufacturing sector.* examhub.eu: https://examhub.eu/wp-content/uploads/2021/04/WP_2_3.pdf

Harvard Business Review. (2020). *A Brief History of the Modern Office.* https://hbr.org/2020/07/a-brief-history-of-the-modern-office

IALF. (2021). *International Association of Learning Factories*. https://ialf-online.net/index.php/home.html

Kumar Agarwal, A., & Kumar, R. (2020, 9, 30). *Directions of Production Planning & Production Control System: Mathematical Evolution from the Flexibility Point of View.* Ecuatorian Science Journal: https://journals.gdeon.org/index.php/esj/article/view/68

LCAMP. (2023). *LCAMP Alliance. Strategic plan.* lcamp.eu: https://lcamp.eu/wp-content/uploads/sites/53/2023/03/D2.2_Strategic-Plan-of-the-LCAMP-Alliance_Final-Version.pdf)

LCAMP. (2023). *Open Innocation Comunity.* lcamp.eu: https://lcamp.eu/wp-content/uploads/sites/53/2023/07/D4.1_Open-Innovation-Community-Model.-Applied-Research-and-Innovation-in-the-OIC_Final-version-1.pdf

LCAMP. (2023). *Role of the Learning Factories in VET education.* https://lcamp.eu/wp-content/uploads/sites/53/2023/07/D6.1-PartI-Role-of-LFs-in-VET-1.pdf

LCAMP. (2023). *Stakeholder Engagament Plan.* https://lcamp.eu/wp-content/uploads/sites/53/2023/07/9.6_Stakeholder-Engagament-Plan_Final-version.pdf

Lundvall, B.-Å. (2016). The Learning Economy and the Economics of Hope. In *The Learning Economy and the Economics of Hope* (pp. 112-115). Anthem Press. https://doi.org/10.26530/OAPEN_626406

Pittich, D., Tenberg, R., & Lensing, K. (2020). Learning factories for complex competence acquisition. *European Journal of Engineering Education, 45:2*, 196-213. https://doi.org/\\10.1080/03043797.2019.1567691

Plattform Industrie 4.0. (2018, 08, 09). *RAMI4.0 –Reference Architectural Model for Industrie 4.0.* PLATFORM INDUSTRIE4.0: https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/rami40-an-introduction.pdf?__blob=publicationFile&v=7

Priffi, L., Knigge, M., Kienegger, H., & Kremar, H. (2017). A Competency Model for "Industry 4.0" Employees. *Wirtschaftsinformatik (WI) 2017*, (pp. 46-60). St. Gallen, Switzerland.

Roll, M., & Ifenthaler, D. (2021). Learning Factories 4.0 in technical vocational schools: can they foster competence development?. *Empirical Res Voc Ed Train 13*, 20. https://doi.org/10.1186/s40461-021-00124-0

Schäfer, M., & Löwer, M. (2020, 12, 31). *Ecodesign—A Review of Reviews.* MDPI: https://www.mdpi.com/2071-1050/13/1/315

Scheid, R. (2018). Learning Factories in Vocational Schools. In R. Scheid, *Digital Worplace Learning* (pp. 271-289). Geelong, Australia: Springer Cham.

Schumann, J. (2022, 12, 2). *The Importance Of Protecting Collaboration Tools From Cyberattacks.* Forbes: https://www.forbes.com/sites/forbestechcouncil/2022/12/02/the-importance-of-protecting-collaboration-tools-from-cyberattacks/?sh=289946d61ae7

Sierra-Pérez, J., Domínguez, M., & Espinosa, M. d. (2014, 11 18). El ecodiseño en el ámbito de la ingeniería del diseño (Ecodesign in design engineering). ResearchGate: https://www.tecnicaindustrial.es/el-ecodiseno-en-el-ambito-de-la-ingenieria-de/

Simumatik. (2020). *Simumatik*. https://simumatik.com

The Council of the European Union. (2020, December 2). Council Recommendation on vocational education and training (VET) for sustainable competitiveness, social fairness and resilience. *Official Journal of the European Union*, p. 4. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cedefop.europa.eu/files/celex_32020h120201_en_txt.pdf

Tisch, M., Ranz, F., Abele, E., Metternich, J., & Hummel, V. (2015, 08 27). Learning factory morphology: Study on form and structure of an innovative learning approach in the manufacturing domain. *Turkish Online Journal of Educational Technology, Special Issue*, 356-363.

Vuorikari, R. K., & Punie, Y. (2022). *DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes.* Luxembourg: EUR 31006 EN, Publications Office of the European Union. https://doi.org/\\10.2760/115376, JRC128415 ISBN 978-92-76-48882-8,

Vuorikari, R., Kluzer, S., & Punie, Y. (2022). *DigComp 2.2: The Digital Competence Framework for Citizens - With new examples of knowledge, skills and attitudes.* Luxembourg: EUR 31006 EN, Publications Office of the European Union. https://doi.org/10.2760/115376, JRC128415 ISBN 978-92-76-48882-8,

Ziarsolo, U., Araiztegui, I., Irazabal, J., Errrasti, L., & Rupp, K.-D. R. (2023). Collaborative Learning Factory as An Integration Tool for the Learner Centric Advanced Manufacturing Platform. *Proceedings of the 13th Conference on Learning Factories (CLF 2023)*. https://ssrn.com/abstract=4469793

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

Country	Related National Qualifications	Knowledge Domains: 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	EQF level
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
Franc	**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.

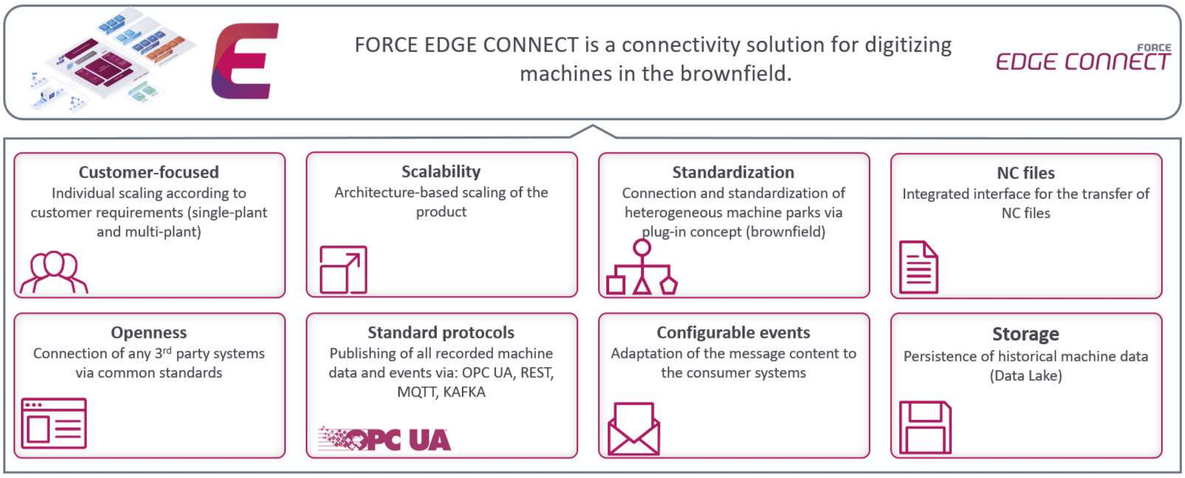


Figure 20. Summary of the FORCE EDGE features

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.

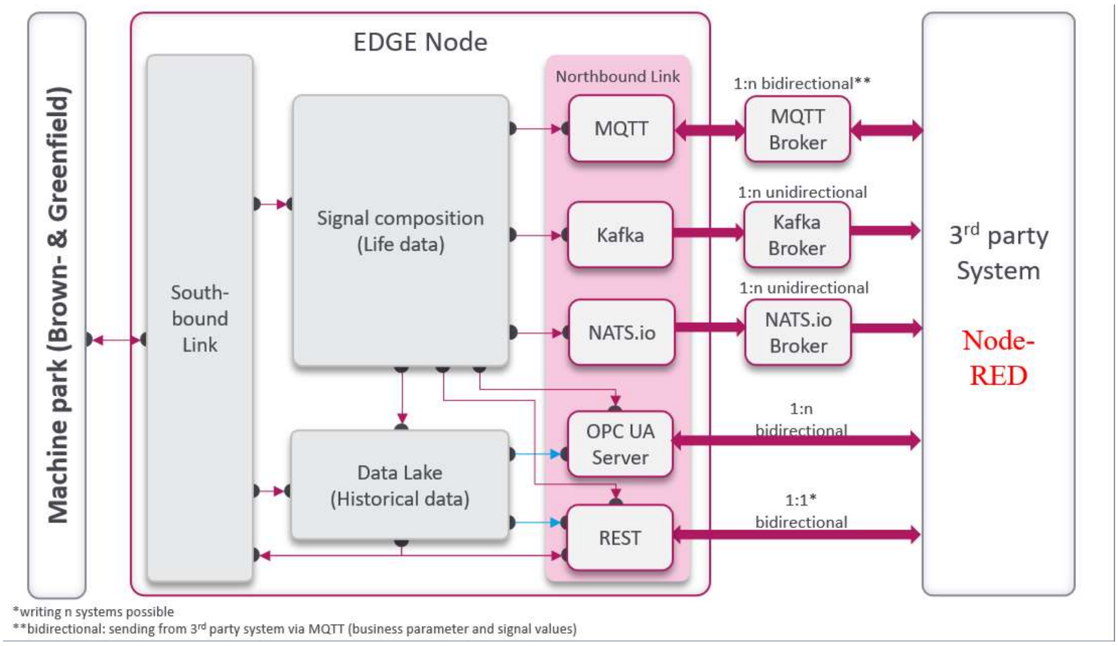


Figure 21. Architecture overview of FORCE EDGE

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.

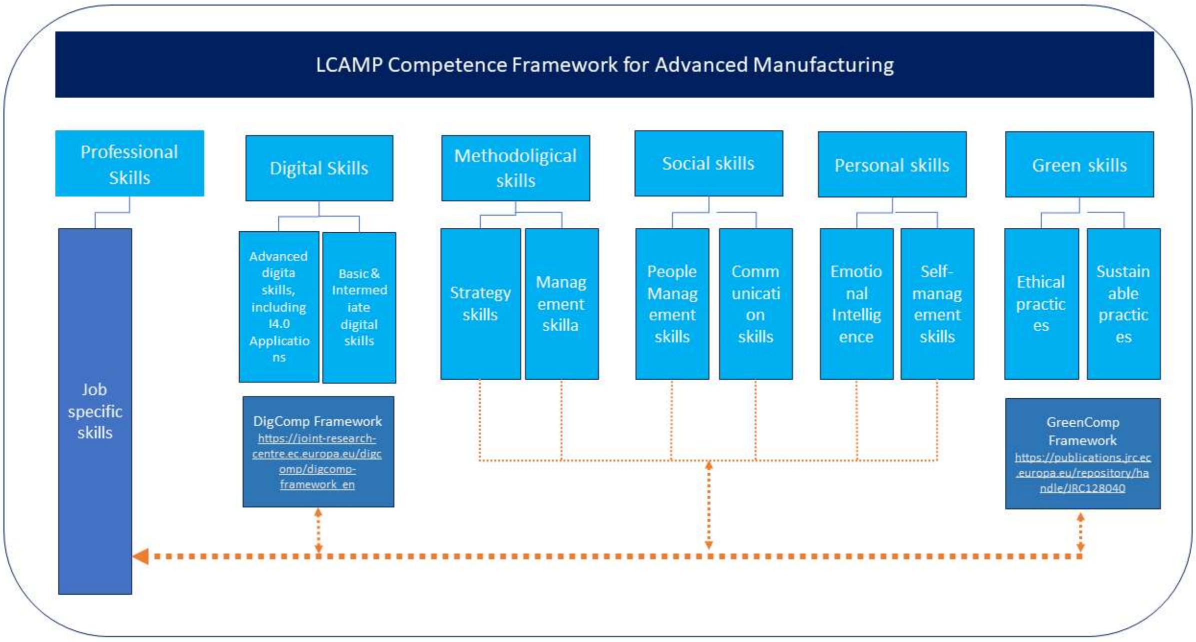


Figure 22. LCAMP's competence Framework for Advanced Manufacturing.

LCAMP's competence framework gathers the classical skills categories according to Heyse/Erpenbeck used in the educational landscape (Priffi et al., 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 et al., 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 et al., 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 5. Courses related to the selected knowledge domains included in the CLF

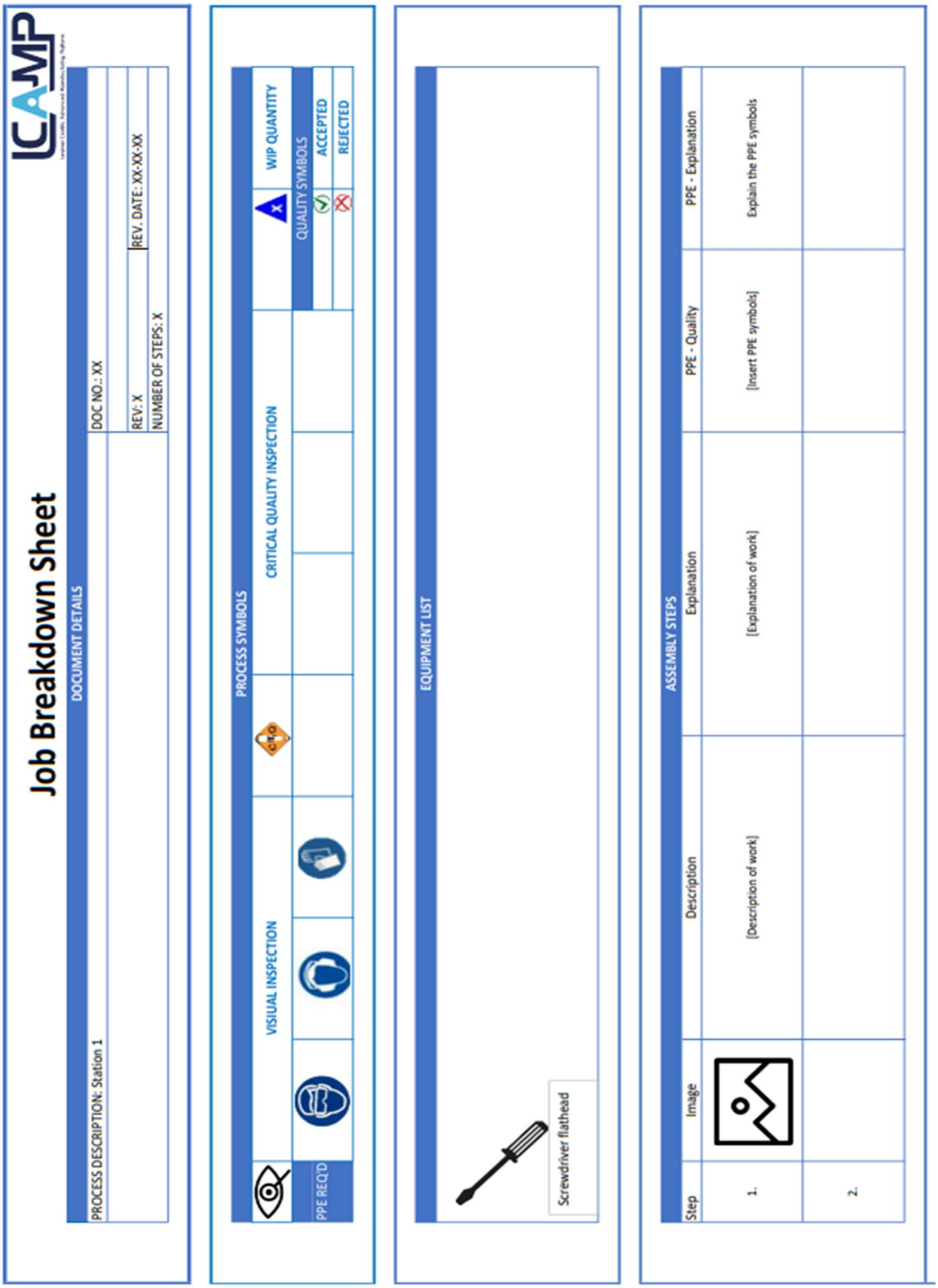
Country	Tittle of the Course	Mechanical engineering, smart manufacturing	Production management	Process engineering	Eco-design	Electronics	Robotics	Automatization	Manufacturing processes. Machining, additive manufacturing, assembly	Logistic and supply chain	Sustainability	Industry 4.0	Industry 5.0	Computer 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
Fr a	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		
Germany	Order management for highly varied distributed production		■												6		
Germany	Sensor Systems with Arduino					■									6		
Germany	ROS –Training –						■								6		
Germany	Robotics Seminar						■								6		
Germany	Autonomous configuration of assembly cells							■							6		
Germany	Distributed Logistics									■					6		
Germany	Resources efficient realization of a robot										■				6		
Germany	Reduction of power loss in the manufacturing process										■				6		
Germany	Production Controlling in distributed environment		■												6		
Germany	Customer Value Management supported by CLFs		■												6		
Germany	Risc- and Change management Seminar		■												6		
Germany	Technical Communication Seminar		■												6		
It al	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

VISUAL INSPECTION	CRITICAL QUALITY INSPECTION	WIP QUANTITY	QUALITY SYMBOLS
PPE REQ'D			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.					

LCAMP

Learner Centric Advanced Manufacturing Platform

Co-funded by
the European Union