EXAM 4.0

THE EXCELLENT ADVANCED MANUFACTURING 4.0

Labs for Advanced Manufacturing. Collaborative Learning Factory approach for VET provision

Piloting the Advanced Manufacturing workshop 4.0

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EXAM 4.0 partners:

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

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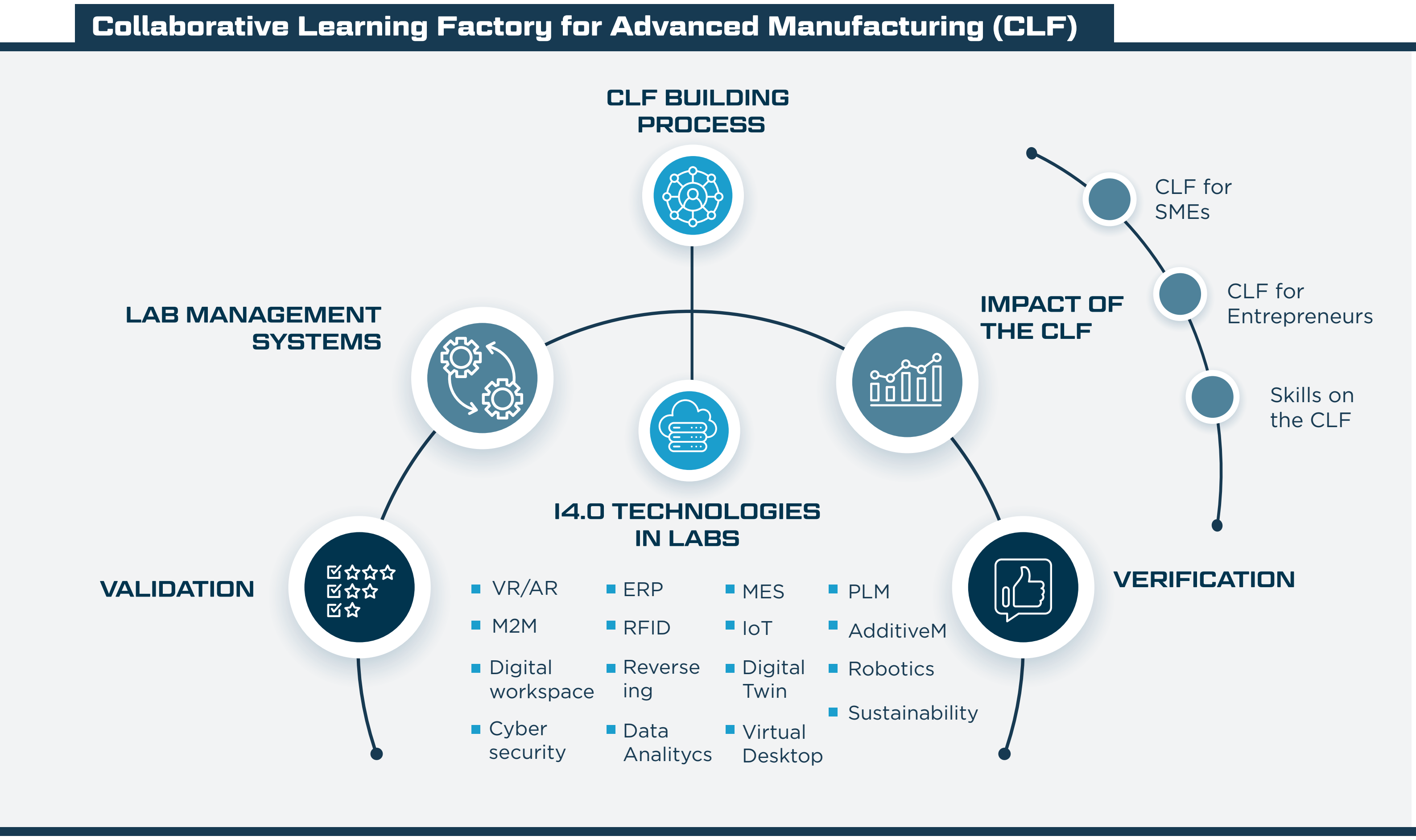
0 Abstract

EXAM 4.0, defines and describes the main features a lab for Advanced Manufacturing education should have (EXAM4.0 , 2020). It also proposes the technological and competence frameworks for Advanced Manufacturing education in VET (EXAM4.0 Framework, 2020). Based on those descriptions, the so called **EXAM4.0 Collaborative Learning Factory** has been defined to pilot the mentioned frameworks and concepts.

EXAM4.0 wp5 has focused on piloting the advanced manufacturing workshops defined in previous WPs. We have generated a number of reports documenting the work we have carried out. The structure of the piloting process is as follows, where each "ball" refers to a specific report:



The document serves as a guide document. It describes the EXAM4.0 Collaborative Learning Factory approach, its current participants in the piloting phase, its operational mode, benefits and main challenges related to its implementation. There is also a final reflection about the potentials of a wider CLF for AM within the European VET sector.

1.1 Learning Factories

Learning Factories (hereafter "LF") appear as highly complex learning environments that enable the development of independent and high-quality competences, which are linked to training, education and research, including Industry 4.0 (Mora & Guarin, 2017)**. This goes hand in hand with the need for new approaches to learning that Abele et al.** (Abele, 2015) **mention**:

- That allow training in realistic manufacturing environments
- That modernise the learning process and bring it closer to the industrial practice
- That leverage industrial practice through the adoption of new manufacturing knowledge and technology
- That boost innovation in manufacturing by improving capabilities of young engineers, e.g. problem-solving capability, creativity or systems thinking capability"

As noted by the authors (Abele, 2015) the learning factory concept is implementable in a lot of different ways. In order to achieve effective competency development, the core of the learning factory concept is a high degree of contextualisation (close to real factory environments) and a hands-on experience of the trainees.

Based on the above, and talking in a complementary manner, the work of Guarín et al. (Mora & Guarin, 2017), a LF is defined as an idealised replication of sections of the industry value chain where learning takes place experientially. It is not surprising that within the EXAM 4.0 project itself (EXAM4.0 , 2020) it is stated that adapting the Learning factories approach when it comes to creating the EXAM 4.0 Advanced Manufacturing labs for VET definition makes sense.

The main aspects of LF (Abele, 2015) (Mora & Guarin, 2017) (EXAM4.0 , 2020) are:

Training in real manufacturing settings;

- Contextual learning that is close to industrial practice;
- Integration of new knowledge and technologies being developed in industry, specifically in I4.0;
- Innovation and reinforcement of broad competences: problem-solving, creativity, systemic thinking, etc.;
- Working on real industrial "products";
- Emphasis on the concept of added value and value chain;
- Organisation and production processes (time, cost, quality, etc.);
- Tools and technologies (CAD, CAM, additive manufacturing, simulators, etc.);
- Real-time data management and processing;
- Process automation and industrial robotics;
- Etc.

Therefore, learning factories are based on the requirements and demands of Industry 4.0 and by implementing industrial automation processes in a highly flexible and networked manner, they are geared towards the development of both initial and continuing vocational training .

It is therefore advisable to highlight both the positive aspects and strengths of this new educational-training perspective, as well as to anticipate the problems and/or difficulties that it may entail. On the basis of the experience gained in the EXAM 4.0 project, the pros and cons of this proposal can be identified.

1.2 Pros and cons of Learning Factories as an educational method

Pros

- It is a definitive methodology for teaching I4.0 technologies.
- Learning Factories use realistic situations.
- Learning Factories apply the learning-by-doing principle/methodology.
- The creation of a virtual Learning Factory enables mapping larger factory structures.
- Most Learning Factories produce products to simulate a real value chain, resulting in a revenue.
- A Learning Factory replicates a real production environment where classes can merge to work on different tasks but towards the same production goal, enabling multidisciplinar training.
- The demanded quality requirements are the same as in real production.

Cons

- A Learning Factory simulates real industry production. However, industry is developing at such a high pace that keeping learning factories up-to-date is hard work.
- It is difficult and time-consuming to map factories or networks to create a learning factory.
- There is a lack of mobility in learning factories because production depends on certain machines.

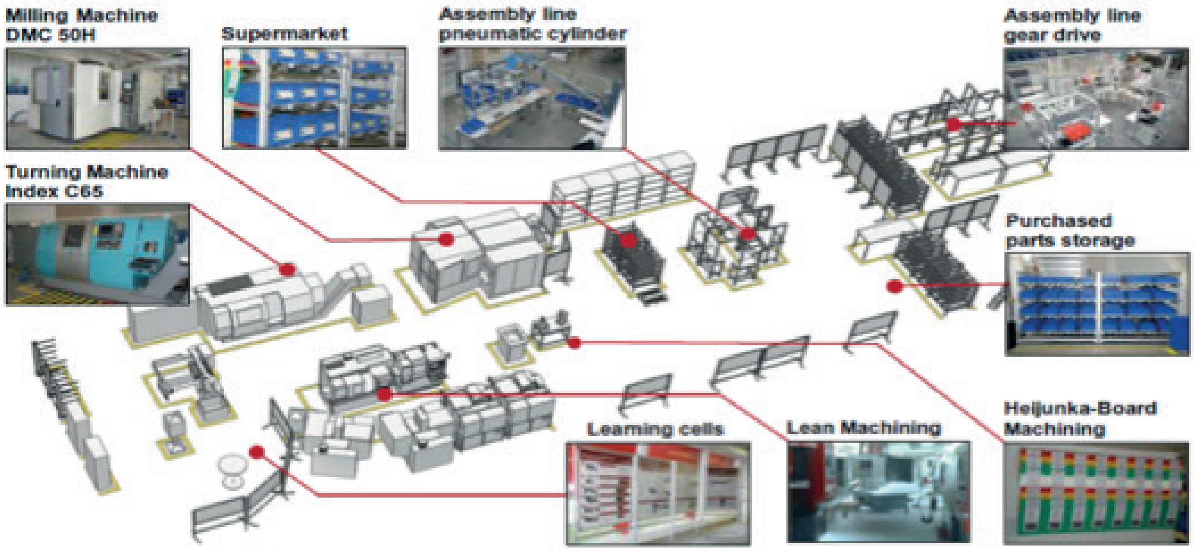


Figure 1 Value chain of the Process Learning Factory CIP in Darmstadt, Germany

2 Varieties of Learning Factories

From the initial definition, a large number of interpretations emerge; this is because different aspects with their corresponding characteristics are taken into consideration. Figure 2 (left) describes these aspects, while Figure 2 right, shows an approach to LF in a broader or narrower sense based on three variables: value chain, manufactured product and communication channel. These in turn are based on three of the characteristics described above: **scenario (real or virtual), product (physical or service), didactics (on-site or remote)**

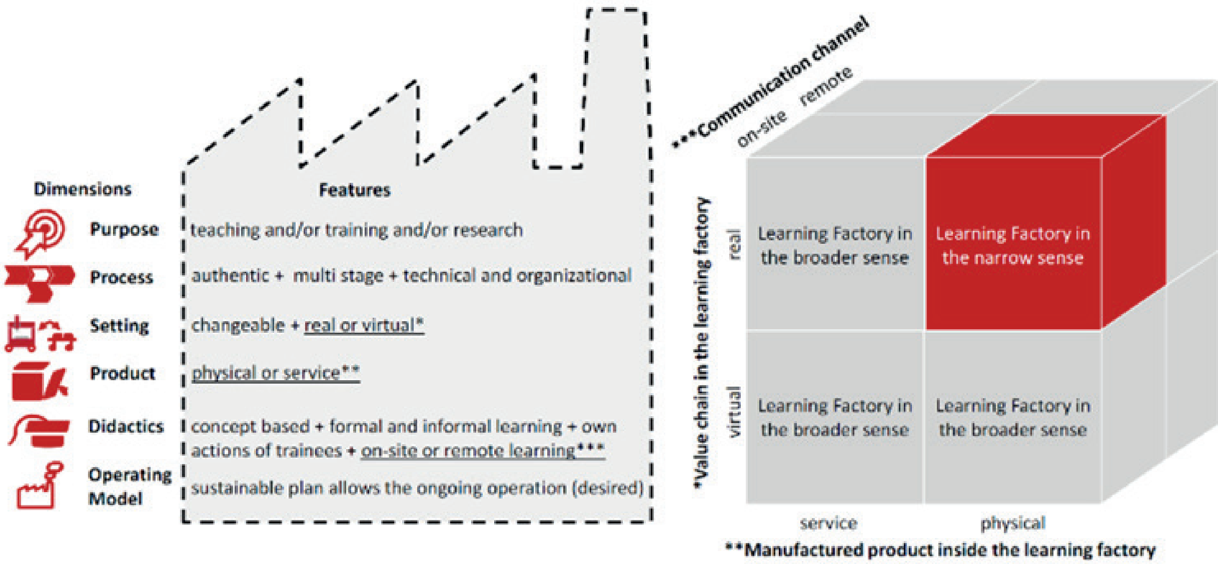


Figure 2 Key features and variants of Learning Factories Source: Abele et al. (2015: 2).

The strict interpretation of the concept of learning factories, places us in a practical environment related to the production of a physical product, which generates a value chain and where interactions between people take place in situ.

The 4.0 concept associated with production systems, provides other development settings that broaden the interpretation of the concept to include **the generation of services that can produce virtual value chains and where interactions can be conducted remotely**.

3 Does a LF make sense in VET education?

Learning factories are based on a didactical concept emphasizing experimental and problem-based learning. The continuous improvement philosophy is facilitated by own actions and interactive involvement of the participants. (Laperrière R. , 2015))

On the other hand, one of the main characteristics of the VET educational systems is its practical and hands-on approach.

The prominently practical character of European VET systems make LFs more than suitable scenarios to materialize training programs in Industry 4.0 and specifically in Advanced Manufacturing.

Following the morphology of LFs proposed by the IALF (IALF, 2021) it is possible to design and implement LFs that respond to specific needs. The proposed structure is adaptable to a wide range of contents, target audience and qualification levels.

In addition to highlighting the practical nature of VET, the LFs offer several advantages:

a) They provide the opportunity to reproduce the **entire value chain** of a production process. (From raw material to final product), thus giving students a holistic view of the processes.

b) They allow the implementation of a wide range of Industry 4.0 technologies in the value chain; giving the possibility of integrating them or using them in isolation throughout the process. This matter offers great versatility in the use of LFs.

c) It is **scalable**, i.e., starting from a more or less simple base, it is possible to add layers of complexity to the system, depending on the needs and the resources.

d) It offers **an ideal scenario for virtualization**, which also facilitates dissemination and accessibility of the proposal.

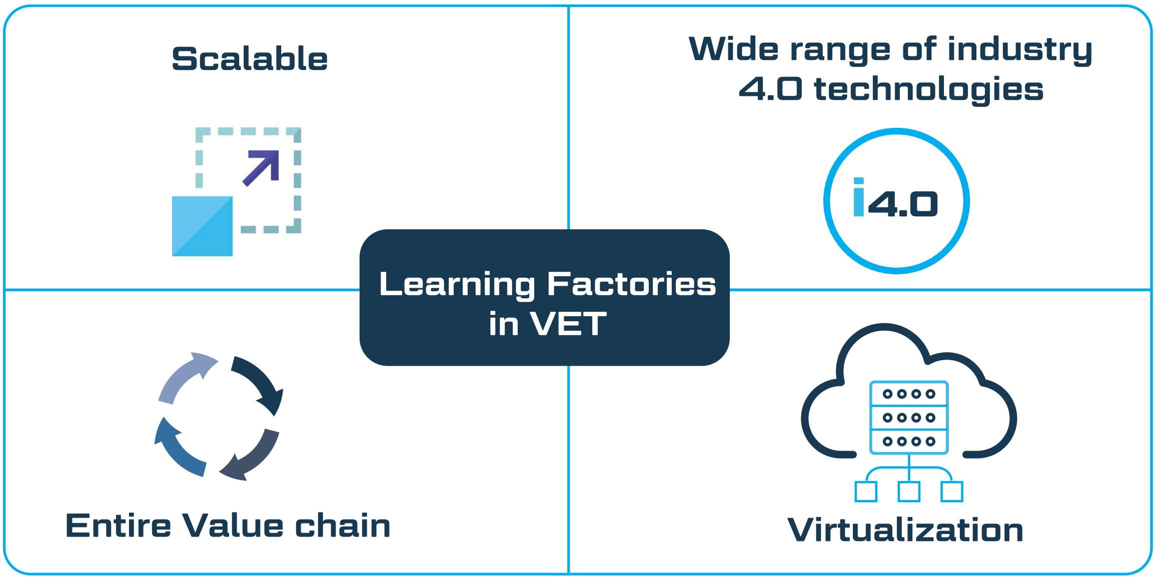


Figure 3 Advantages of LFs. Source: Exam4.0

All this points to the fact that, the potential of LFs in VET environments is very interesting.

It is also true that the implementation of LFs in VET institutions is a great challenge. There are three key aspects to consider:

- The technical complexity of implementing a number of industry 4.0 enabling technologies in VET labs: Technological partners, advanced knowledge, retrofitting of existing equipment, upskilling of internal staff, etc. are required.
- The investment required, depending on the size and complexity of the LFs, can be significant. Setting up LFs involves medium-long-term projects, scaled over time.
- It requires a highly involved and motivated team of teachers and trainers, with a clear and well-defined strategy and a strong culture of digital transformation. The methodological and curricular changes that the implementation of LFs can bring about can be highly disruptive.

4.1. The idea

One of the objectives of the EXAM4.0 as Platform of CoVEs in Advanced Manufacturing, is the definition of the main characteristics of the AM labs in VET institutions to respond to the emerging needs in terms of qualifications/skills that have arisen due to the digital transformation and Industry 4.0.

The EXAM4.0 consortium, aware of the contributions that the adoption of the LFs described in the previous paragraphs, has formulated a LF model to converge solutions to gain skills 4.0 and co working opportunities offered by a CoVE's network. The model defined and piloted in EXAM4.0 is called Collaborative Learning Factory (CLF).

It is a LF of LFs composed of 4 organisations from 4 European countries whose the aim is:

- To co-create in LF environments among the members of the platform
- To enrich the regional LF proposals
- To accelerate the implementation of I4.0 enabling technologies at the participating centres
- Formulate a collaboration model where more VET schools can join in.
- Improve skill provision systems for AM

Figure 4 Collaborative Learning Factory's goals Source: Exam4.0

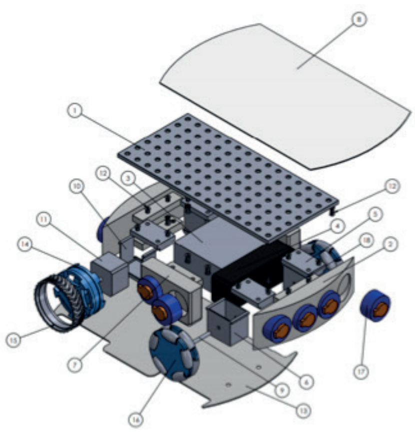
4.2. The approach

EXAM4.0 CLF adopted the morphology of LFs proposed by IALF, composed of a Scenario (process and technological framework), a **product** and a **pedagogical (didactic) framework**.

The differential component is the character of distributed LF (geographically) that requires indispensable **coordination/cooperation/collaboration**, as well as an adoption of I4.0 technologies for this remote/collaborative work to be carried out.

A) PRODUCT

An autonomous mobile robot for education.



ITEM NO.	PART NUMBER	CENTER IN CHARGE	QTY.
1	Main plate	Miguel Altuna	1
2	Curved sensor box	DHBW	2
3	Controller	DHBW	1
4	Akku battery	DHBW	1
5	Top	Curt Nicolin Gymnasiet	4
6	Wheel shaft	Curt Nicolin Gymnasiet	2
7	Small sensor box	DHBW	2
8	Coverplate - top	Miguel Altuna	1
9	Axis	Curt Nicolin Gymnasiet	2
10	Stepmotor holder	Curt Nicolin Gymnasiet	2
11	Stepmotor nema 17	Curt Nicolin Gymnasiet	2
12	Clipper	Curt Nicolin Gymnasiet	36
13	Coverplate - bot	Miguel Altuna	1
14	EXAM wheel	Da Vinci College	2
15	Tire	Da Vinci College	2
16	EXAM omni wheel	Da Vinci College	2
17	Sensor	DHBW	12
18	Pin for clipper	Curt Nicolin Gymnasiet	36

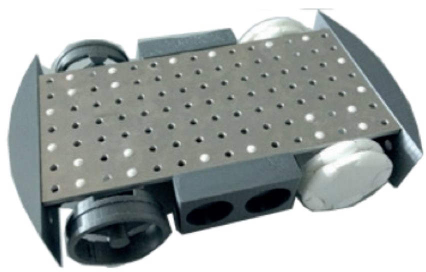
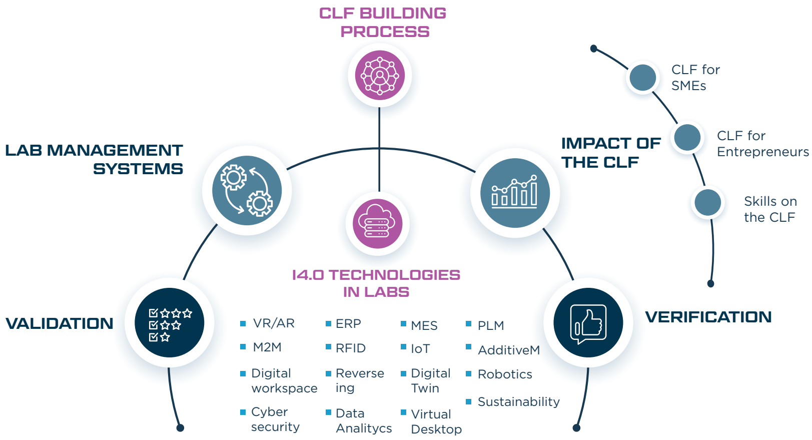


Figure 5 Autonomous mobile robot for education Source: Exam4.0

Detailed description of the product and design process in the
Reference documents:

3 Advanced Manufacturing Workshop 4.0 running

4 Evidences on performance: Recorded data



B) SCENARIO. The Process

The CLF has divided its value chain into 4 stages (product design, process engineering, parts production and product assembly) as can be seen in the following image.

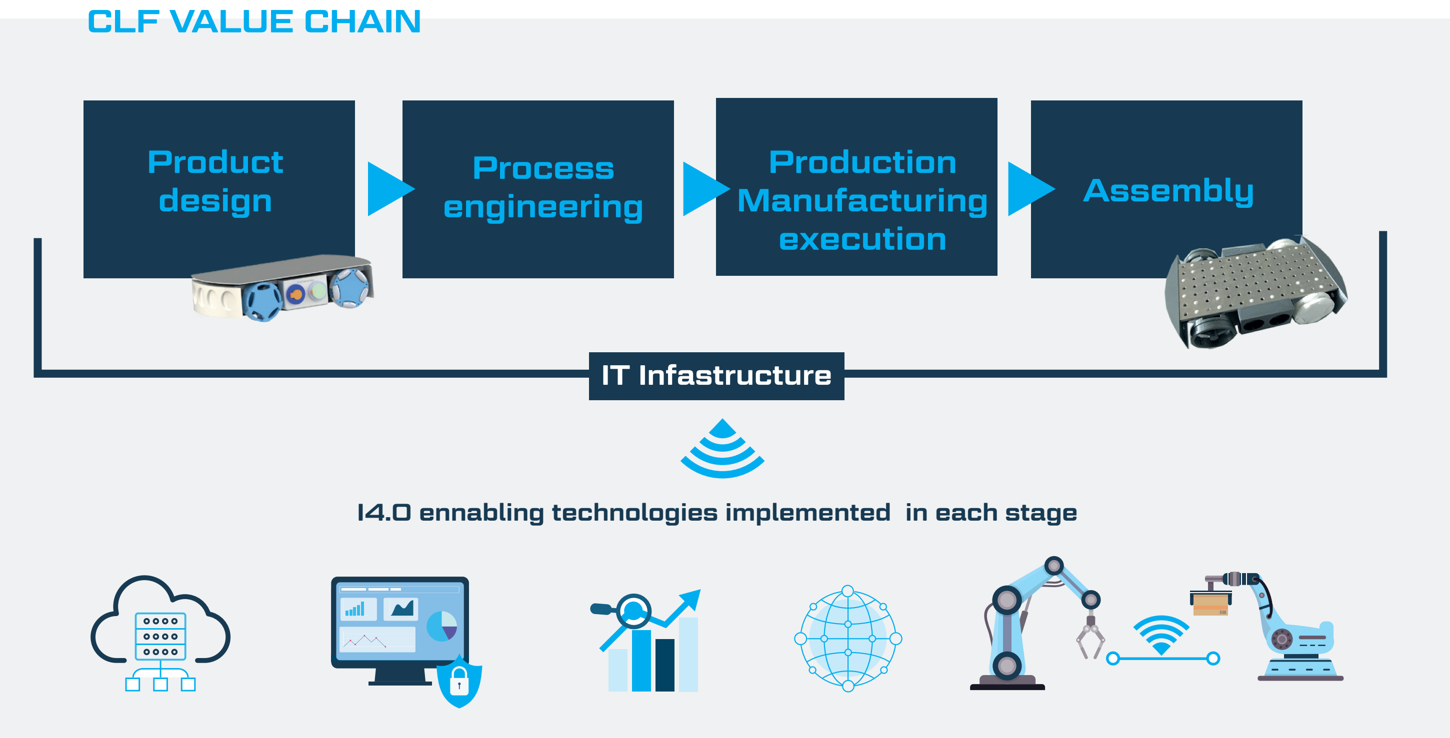


Figure 6 CLF value chain Source: Exam4.0

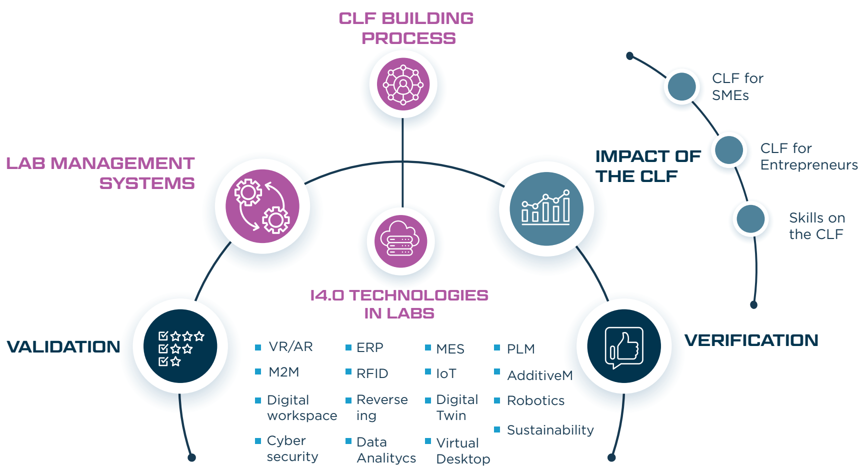
Reference documents:

2 The ERP, Enterprise Resource Planning, adapted to the project needs.

3 Advanced Manufacturing Workshop 4.0 running

4 Evidences on performance: Recorded data

5 Report on registered updates of the equipment and processes management



Technology framework (EXAM4.0, 2020)

C) PEDAGOGICAL FRAMEWORK.

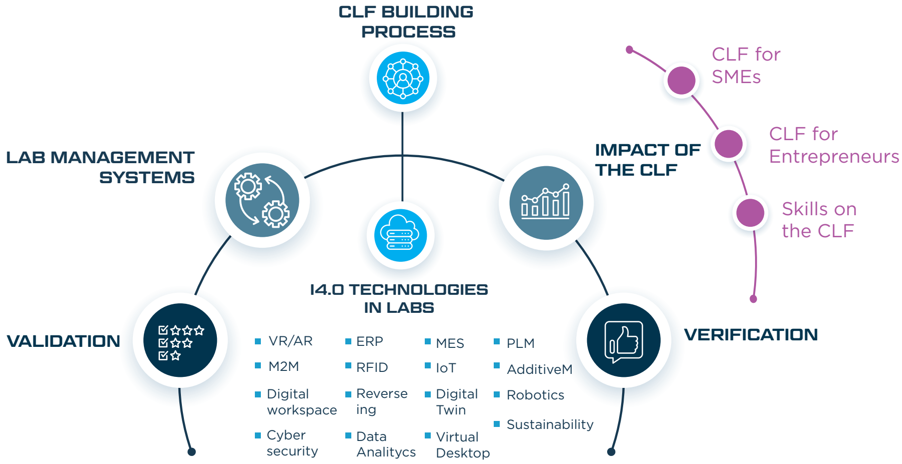
A competence framework to describe the way the institution addresses I4.0 competences and skills through the CLF has been elaborated. Section 4.5 in this document gives further information on the didactics of CLF.

Reference documents:

6 Protocol of exploitation of CLF by SMEs

7 Protocol of exploitation of CLF by Entrepreneurs

8 Report on skills acquired by the students taking part in the piloting



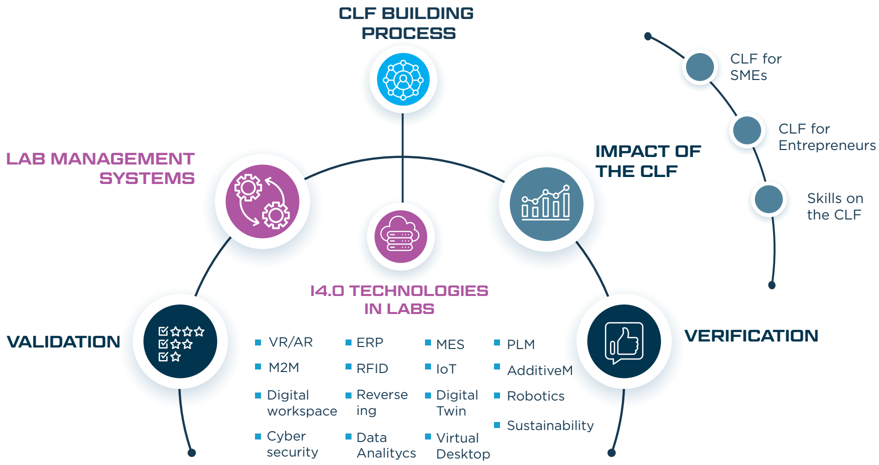
E) COLLABORATION and CO CREATION

Following the principles of CoVE platforms, EXAM4.0 is an international network of regional skills ecosystems. Collaboration between platform members is a key feature. In particular, the aim was to promote the culture of collaboration by making the most of the opportunities offered by Industry 4.0. In addition to co-creation in all phases of the manufacturing process, an IT infrastructure has been defined for the exchange of information and data (PLM-MES-ERP systems and IIoT platform). More advanced features to enhance collaboration as digital twins are foreseen for the near future.

Reference document:s

2 The ERP, Enterprise Resource Planning, adapted to the project needs.

3 Advanced Manufacturing Workshop 4.0 running



4.3. The team

5 full partners and 3 affiliate partners from **4 countries** have contributed to the CLF

Miguel Altuna LHII (Spain) Coordination, process engineering, part's manufacturing, implementation of Industry 4.0 technologies	
Tknika, (Spain) Implementation of Industry 4.0 technologies	
DHBW (Germany) Product design, part's manufacturing, assembly, implementation of Industry 4.0 technologies, automation of the assembly	
Curt Nicolin Gymnasiet (Sweden) Product design, part's manufacturing, implementation of Industry 4.0 technologies	
Da Vinci College (Netherlands) Part's manufacturing, implementation of Industry 4.0 technologies	
Affiliate partners: **Bidasoa LHII, IMH, Usurbil LHII (Spain)** Implementation of Industry 4.0 technologies	

Figure 7 Contributors to the CLF

4.4. Pilot activities and piloted I4.0 enabling technologies

The holistic approach of LFs gives room to the application of a large number of I4.0 technologies. In addition, the remote location of the facilities requires appropriate (industrial) communications infrastructure and collaboration tools.

It is interesting to note that these implementations present opportunities in three pedagogical areas:

1) Competences in the implementation of I4.0 elements
2) Competences in the use of these technologies once implemented in the CLF
3) Improvement of transversal skills

Before deciding upon I4.0 technologies, VET institutions need to answer the following questions:

What do I want to reach? and, even more relevant, Why do I need this improvement?

In EXAM4.0, in order to identify the key technologies for the CLF, both **pedagogical aspects** (what competencies should be developed in the LF depending on the target audience) and **technological trends** in industry and their current scope have been considered. The reports that reflect these analyses are ***EXAM4.0 5.1 AM labs design validation report*** and ***5.2 The ERP, Enterprise Resource Planning, adapted to the project needs.***

The tested I4.0 enabling technologies for each stage are listed in the following table:

STAGE	Tested I4.0 enabling technologies	Ongoing
Product design	PLM system. Sensor, electronic integration, communications	PLM integration; Digital twins. Eco design, virtual desktops
Process engineering	PLM-MES-ERP integration, IoT platforms, digital workplace	Integration; Digital twins, energy efficiency
Manufacturing	Machining, Additive manufacturing, IIoT, MES, PLM, ERP, Augmented Reality, RFID, digital workplace	Enhanced ERP, PLM integration, IIoT platform, data exploitation tools. Smart maintenance systems
Assembly	Automation, robotics, rfid, artificial vision, AR	Digital twins, Cobots, traceability
IT/OT tools	IIoT platform, cybersecurity	Cloud/edge computing solutions.

The figure 8 shows the interrelation of the technologies in the different stages.

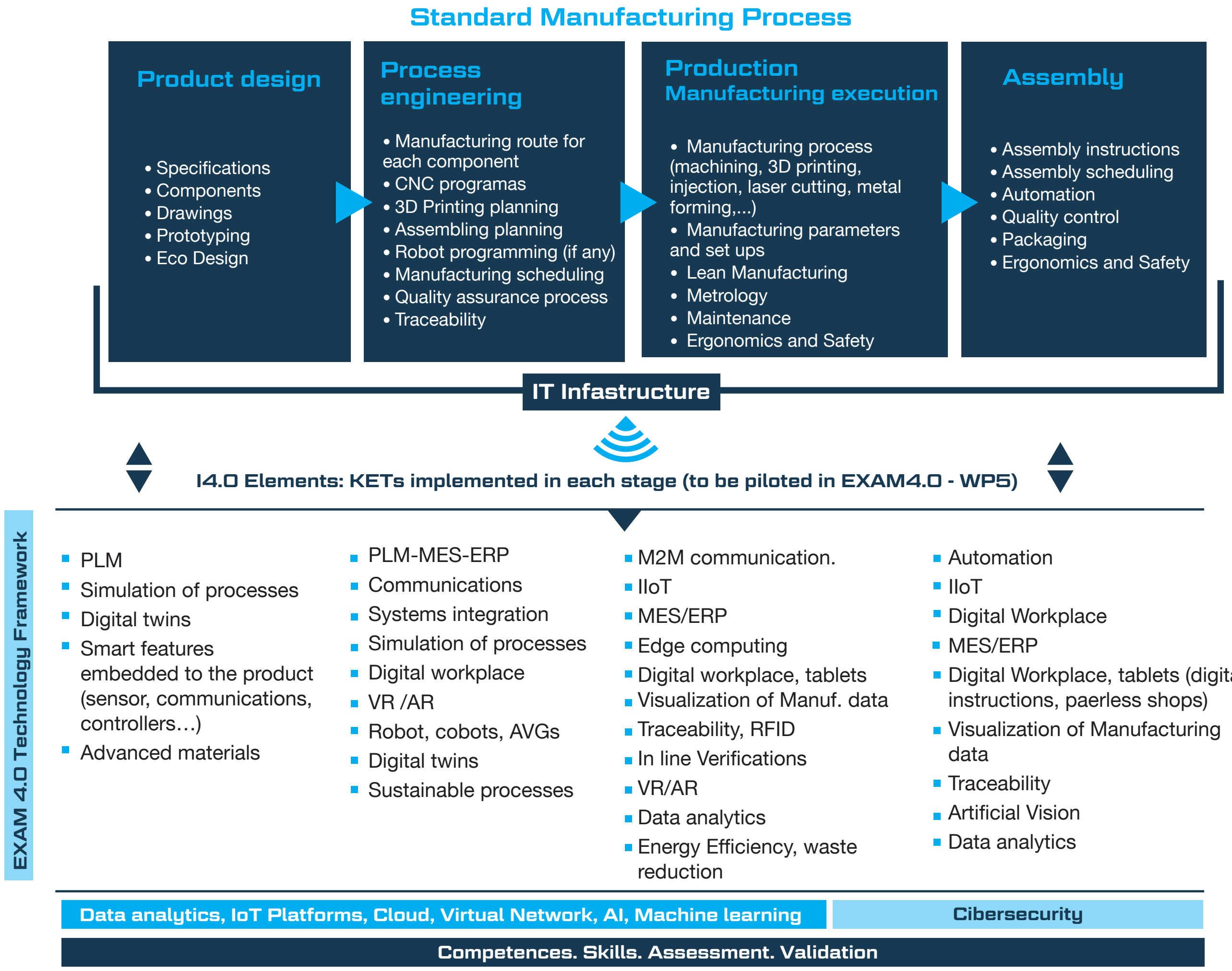


Figure 8 EXAM4.0 Collaborative Learning Factory (CLF) Value Chain Source:Author's creation

The reader will find a detailed description of the whole process in the document ***EXAM4.0 5.4 Evidences on performance: Recorded data*** and ***support media on the website EXAM4.0 hub.***

All the above technologies are necessary for the proper functioning of the CLF. However, it is perhaps worth mentioning some elements because of their integrative nature. For example, PLM-MES-ERP systems have an important role in ensuring the operability of the collaborative system. The current approach is to implement local MES systems connected to a centralised and common PLM-ERP system. On the other hand, the IIoT platform serves as a tool for data acquisition and exploitation, both locally and remotely, allowing users in other places use the data created in one place for different didactic purposes.

Virtual tools are also worth mentioning. The potential of these technologies is enormous. The acknowledgement of virtualisation solutions, from virtual, augmented, extended, mixed realities, simulations... to different variants of digital twins, leads to not only powerful didactical applications but also to opportunities for remote collaboration and dissemination. Augmented reality solutions in the CLF environment of labs are currently being tested.

4.5. Didactics of the CLF

The final goal of the EXAM 4.0 CLF is to train people in Advanced Manufacturing. So far, it has described and referenced the most technological and operational part of the CLF. All this deployment pursues a didactic objective.

The analysis of the equipment and technologies needed in the CLF in parallel with the target competences has been conducted. The aforementioned technological and competency frameworks included in WP2 define and measure the collection of skills and attributes necessary to carry out specific tasks, in many cases emerging tasks due to digital transformation.

The aim of CLF is to create a scenario where learners acquire these predetermined competences. Therefore, the competences required in the CLF, strongly specify its implementation. CLF didactification, refers to the adaptation of technological contents and ways of learning to ensure that certain students achieve the predefined skills.

The complexity of the CLF model lies on, among other factors, the fact that student competences and different educational systems are being dealt with jointly. Note that the CLF is composed of training centres from 4 different countries. **Therefore, the didactic nature of CLFs has to be worked on at least two levels:**

- At regional level, where each training centre adapts the new characteristics of CLFs to the programmes, curricula and competences included in their educational systems.
- At consortium level, where it is necessary to reach a consensus on the competences to be worked on collaboratively in the CLF so that all the agents involved can then integrate them into their respective national systems.

The didactification of the CLF, for both levels, includes the development of didactic solutions for the predefined competences worked on in Advanced Manufacturing. These didactic solutions will include aspects such as:

- Creation of specific contents
- Modularization of contents in order to achieve flexibility
- Delivery mechanisms/Learning method according to contents, target audience: *e.g. active methodologies, gamification, micro learnings, mobile learnings, digital twins for training, pbl, cbl...*
- Work methodologies for joint tasks among international students
- Learning pathways aimed at specific occupations
- Updating of curricula and training programmes
- Creation of new courses
- Assessment systems
- Accreditation and micro-credentialing systems

In the EXAM4.0 piloting phase, the focus has been established on evaluating the impact of the CLFs at regional level. That is to say, to evaluate the impact of implementing a CLF on the didactic aspects of the training programmes involved.

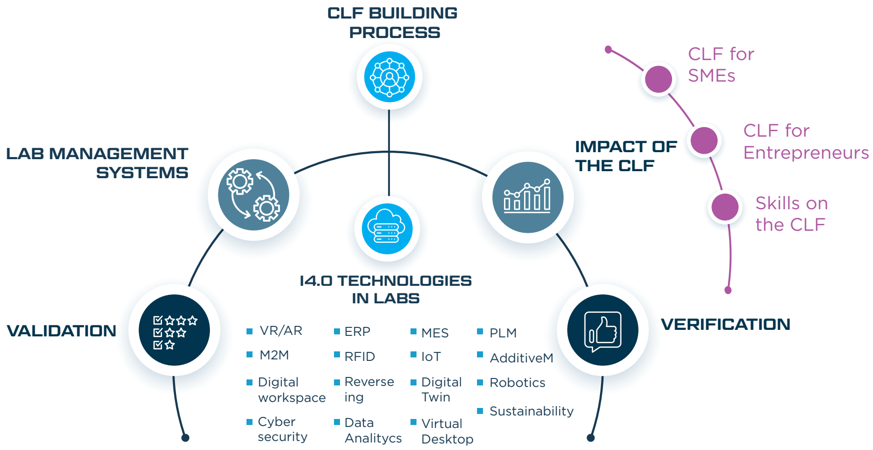
At this stage, the influence of a CLF implementation on other side programs of the involved organizations has been also evaluated.

Reference documents:

8 Report on skills acquired by the students taking part in the piloting

6 Protocol of exploitation of CLF by SMEs

7 Protocol of exploitation of CLF by Entrepreneurs

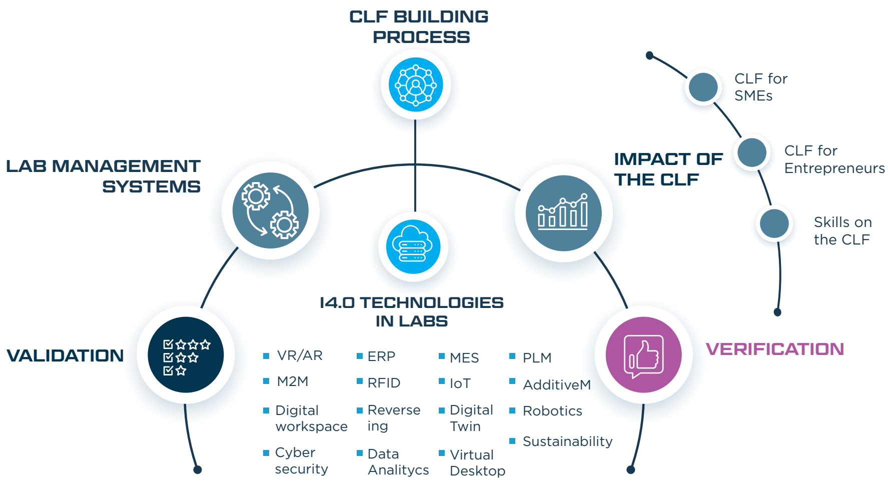


5 Challenges

The consortium, with the collaboration of a group of stakeholders verified the results of the pilot activities. We have gathered all the evaluation results on the Verification report.

Reference document:

9 Verification Report



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