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Design and Establishment of a Learning Factory at the FMENA Zagreb

Miro Hegedić*, Petar Gregurić, Mihael Gudlin, Matija Golec, Anja Đenadija, Nataša Tošanović, Nedeljko Štefanić

Abstract: Accelerated technology developments caused by Industry 4.0 create problems in its implementation. One of the most important factors that hinder the transition of companies is ignorance and, therefore, the fear of new technologies present among employees. Learning factories have proven to be one of the best solutions for introducing employees to the technologies of Industry 4.0. Croatia is significantly behind in implementing the features of Industry 4.0, especially compared to more developed countries. To facilitate the transition of the Croatian industry to Industry 4.0, it is necessary to acquaint existing and future employees with its technologies through learning factories. There is currently only one learning factory in Croatia, which is too few. This paper presents the process of design and establishment of a learning factory at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb, which facilitates research work and education of students and employees with Industry 4.0.

Keywords: Industry 4.0; learning factory

1 INTRODUCTION

Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), and Smart Factory are the main components of Industry 4.0, which has been developed and implemented for more than ten years [1]. The most significant features that this latest industrial revolution brings to manufacturing companies are interoperability, virtualization, decentralization, modularity, customization, and real-time capability [2]. Implementation of Industry 4.0 in manufacturing companies is carried out by creating Smart Factories that contain all the components of Industry 4.0 along with the technologies and services that enable the operation of these components [1]. Rapid technological advances present in Industry 4.0, together with high initial costs and the need for highly educated workers, create difficulties with its implementation in manufacturing companies, especially in less developed countries [2].

There is a lot of research conducted to determine the readiness or current performance of countries in relation to Industry 4.0. Readiness or performance index are most often based on several criteria which consider the use of Industry 4.0 components within a company's business processes. Looking at the results of such research, it can be noticed that more developed countries such as Germany and Denmark are in the upper half of the order, while less developed countries are located at the bottom [3], [4]. A study conducted in 2015 by Veža et al. [5] showed that Croatian industry is between the second and third industrial revolution with a score of 2.15. Atik and Ünlü [3] ranked Croatia 18th in the European Union, while according to Hejdukova et al. [4] Croatia was in 22nd place in 2011, which has not changed until 2019. The dire situation in Croatia was confirmed by a recent survey conducted by the Croatian National Bank, which showed that only 1.97% of Croatian companies have the potential to introduce Industry 4.0 [6]. One of the main factors hindering the implementation of Industry 4.0 in manufacturing companies is the fear of new technologies present among employees due to insufficient familiarity with them [7]. The best solution for this problem are learning factories which facilitate the education and familiarization of employees with Industry 4.0 technologies [8].

Learning factories are high complex educational environments whose primary goal is to connect learning processes with actual industrial processes by representing the genuine factory as realistically as possible. The first forms of learning factories appeared in Germany in the 1980s [8]. Still, the most important moment in their history was the development of a learning factory at Penn State University in America, when the term "Learning Factory (LF)" was formed [8]. The number of studies in the field is growing with the advancement of Industry 4.0, resulting in an increase from 25 to 120 established learning factories in the last decade [9]. To gather, organize and improve existing and new knowledge in the field, there was a need to network interested researchers, existing learning factories and their founders. For this purpose, associations and conferences such as International Association on Learning Factories (IALF), Collège International pour la Recherche en Productique (CIRP) working group, and a Conference on Learning Factories (CLF) were launched [8].

In order to establish a learning factory, it is necessary to interconnect learning processes with industrial production processes [10], which can be done with the implementation of three pillars of transformation. Three pillars of transformation are the didactic pillar, the integration pillar, and the engineering pillar which represent a set of characteristics that need to be defined in order for a facility to be considered a learning factory [11]. The didactic pillar is focused on the selection of learning factory target users and learning objectives. The integration pillar requires that in addition to the usual activities of learning factories related to production, design, and logistics, activities related to administration, marketing, and economics are introduced. Finally, the engineering pillar covers the technical and technological contents of LF through the choice of engineering goals, strategies, and technologies [11]. There is a large number of characteristics to choose from when establishing a learning factory using the three pillars of transformation, and it mostly depends on the part of an industry that needs to be covered. In addition to adapting to the part of the industry that needs to be covered, the design of learning factories is also influenced by the available financial resources, which will mainly affect the amount and breadth of technologies that will be used within the learning factory.

There is currently only one learning factory in Croatia, established in Split in 2009, which was established for education in the area of lean management without Industry 4.0 technologies present at this time [12]. To facilitate education and familiarization of students and employees with Industry 4.0 technologies and thus improve the state of Croatian industry, the new learning factory, which includes necessary components and technologies of Industry 4.0, is established at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb.

Following the introduction, the paper continues with Section 2, which describes the methods used in the learning factory design and establishment. Section 3 presents and discusses the results obtained during and after the learning factory establishment. Finally, Section 4 presents the conclusion together with plans for future work and research.

2 METHODOLOGY

The learning factory was designed and established at the Faculty of Mechanical Engineering and Naval Architecture (FMENA) in Zagreb. The design process began in 2019, and a learning factory was established in February 2022. The establishment of the learning factory was carried out using the methodology process shown in Fig. 1, which included 4 phases: (1) Literature Research, (2) Developing a Directory of Learning Factories (DoLF), (3) Cross-referencing with the manufacturing market needs, (4) Developing LF at FMENA.

First step in the establishment process of the new learning factory was a review of the available literature on learning factories. A review of the literature was conducted to collect data on existing learning factories and their characteristics from which current trends in research and the presence of certain technologies within learning factories can be observed. The data collected from the literature review will facilitate the selection of the characteristics of the new learning factory that will be designed to enable the use of as many Industry 4.0 technologies as possible, thus increasing the availability of currently underrepresented technologies. A literature review was conducted by searching the keywords: "Learning", "Factories", "LF", "TLF", "Teaching-learning Factory", "Modules", and "Industry 4.0" in Scopus, Web of Science and Google Scholar databases. Necessary data that could not be found within the scientific literature was identified in other public sources.

To facilitate further research and development of new learning factories, it was decided to develop a directory of learning factories that will contain data on existing learning factories found through a literature review. Data on existing learning factories were analyzed and structured to be used within the directory. Structured data is entered manually for each learning factory within the database that will make up the directory. To accelerate directory development, it was decided that it would be developed using no-code tools selected to meet the required criteria. Selection process and technical details of selected no-code tools are explained in detail by Hegedić et al. in [13]. Statistical analysis of the data entered in the directory determined the current state of learning factories in order to identify which technologies and areas of learning are most represented. Additionally, the statistical analysis provided insight into the distribution of learning factories according to institution type and country in which they are established.

For the new learning factory to facilitate the implementation of Industry 4.0 in Croatia, it is necessary that, in addition to educating students, it also enables the education of new and existing employees of Croatian manufacturing companies. The analysis of production processes was conducted in three Croatian companies to determine the steps of the production process and the technologies used in them that needs to be improved. Observed processes and technologies will be implemented in the learning factory so that research can be carried out in order to upgrade them on Industry 4.0 level and later educate employees about them.

In the last step, based on previously defined market needs and the current state of the learning factories, the necessary technologies, equipment, and components that will make up the new learning factory have been defined. The last step of this methodology also includes the procurement of the necessary components and the commissioning of the learning factory.

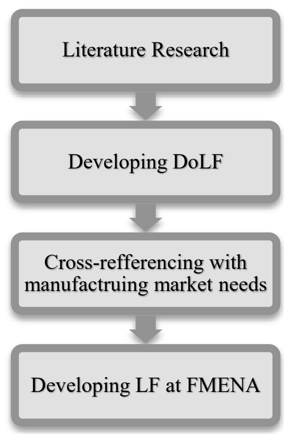

Figure 1 Methodology used for LF design and establishment

3 RESULTS AND DISCUSSION

Through the review of scientific literature and data available from public sources, we found 43 developed and established learning factories. For each learning factory, the data shown in Tab. 1, which describes them, were found, and the learning factories were recorded into the directory database together with their data.

Table 1 Collected information on learning factories

Column name	Description
Operator's name	Name of the company/institution that manages the LF
Location	Name of the country where the LF is located
Initiation Year	The year the LF was initiated
Images	Self - explanatory
Institution type	Academic Institution or Private Company
Functional Modules	Available operations
Areas of Study	Available teaching disciplines
Final product	A product that it produces

The information found about the learning factories was analyzed so that similar data explained in different terms could be clustered to reduce the amount of data for easier statistical analysis and presentation of results. Directory development was done using no-code tools that allow people without coding knowledge to develop software solutions quickly and easily. Different no code tools were used for backend and frontend development which were selected according to the criteria listed in the Tab. 2. The development of DoLF provided easier access to the required data and their statistical analysis, which facilitated the further development of the learning factory. It can be assumed that the developed directory will also facilitate future research on learning factories and enable their comparison and networking.

Table 2 Criteria for no-code tool selection

	Backend	Frontend
Criteria	Most adequate for the needed number of records	Compatible with backend tool
	Functionality for adding attachments	Possibility of adding new entries without login
	Free of charge	
	Good support and maintenance ability	
		Option for custom domains

For the further design of the learning factory, the most interesting data are those about the functional modules included in the existing learning factories and those about the areas of study that they cover. Analysis and clustering defined 13 different function modules that make up individual facilities. All defined function modules are shown in the Fig. 2, from which it can be seen that the learning factories included in DoLF consist mainly of machine tools, robots, and assembly lines.

As in the case of functional modules, after analyzing areas of study included in the learning factories database, 12 different areas of study were identified, the representation of which is shown in Fig. 3. From Fig. 3, it can be seen that in more than 80% of the included learning factories, lean philosophy can be taught, while only 2,3% of learning factories can be used to teach machine learning.

In addition to statistics on functional modules and areas of learning, the developed directory illustrated that 36% of the learning factories included in DoLF are located in Germany and that in 86% of cases, they are based in academic institutions. Although these numbers are not directly relevant to the design of the learning factory, as Germany is in the upper half of most Industry 4.0 implementation ranks, they may indicate the positive effect of learning factories on facilitating the implementation of Industry 4.0 and justify the development of such systems within academic institutions.

A review of the literature and the result of statistical analysis shows that machine learning is poorly represented within existing learning factories, while trends show that it will be an integral part of most industries in the future [14]. In addition to the low representation of machine learning within learning factories, there is a need to create new frameworks and systematize guidelines for the development of machine learning models to facilitate and enable their application in production [15, 16]. To increase the representation of machine learning within learning factories and to enable research aimed at creating frameworks and guidelines for the development and application of machine learning models, it is necessary to implement it within the new learning factory.

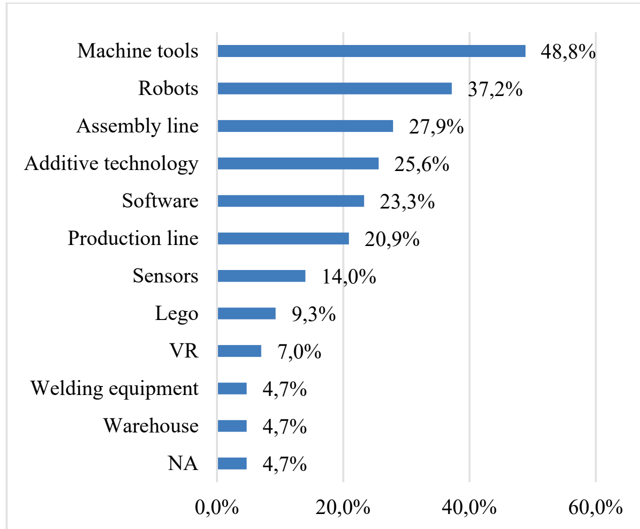

Figure 2 Frequency of functional modules

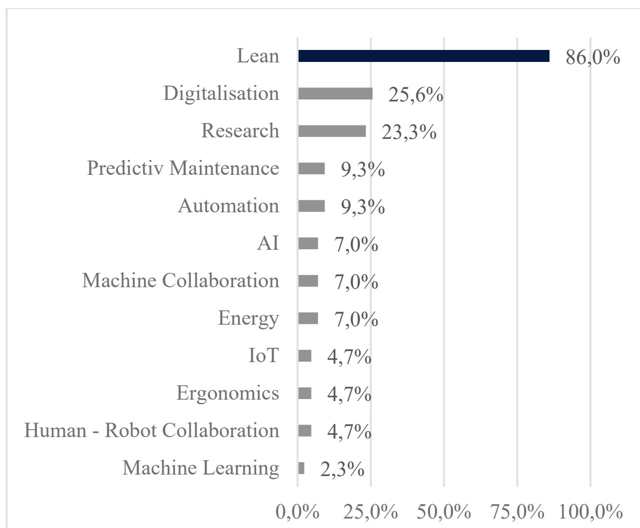

Figure 3 Area of study frequency

The analysis of production processes was conducted within three Croatian companies, one of which is a large company engaged in the production of power transformers, and the other two are SMEs. One of the SMEs is the producer of windows and doors, while the other manufactures fireplaces. The analysis showed that their discrete productions begin with the material processing where particle separation processing such as drilling, turning, and milling and the process of changing properties such as pressing, casting, and tiling are the most used. The second most important process within the analyzed companies is the assembly that is carried out on manual workstations. In addition to the above processes, the need to improve the connection of manual workstations and the need to conduct inter-phase quality control was noted.

By analyzing the discrete production of the mentioned companies and data on existing learning factories obtained through literature review and directory development, the modules that will make up the new learning factory shown in Tab. 3 were selected.

Table 3 Selected modules for new LF

Module	Description
Properties changing	Simulation of a specific operation from a production process where the workpiece changes its properties (e.g., pressing, casting, tiling).
Particle separation	Simulation of a specific operation from the production process against particle separation procedures (e.g., drilling, turning, or milling).
Warehouse	A module that simulates buffers or final warehouse in the process.
Magazine	A module that stores materials or parts and automatically places them on a production line.
Production line input/output	A module that will simulate the input system of materials into the production line (automatic acceptance and transmission).
Manual workstation	Simulation of manual work in production. This module must also have a system for human-workstation interaction (e.g., industrial tables).
Mobile robot	An autonomous device that simulates the transfer of products (and information) between different operations.
Machine Learning	Machine learning algorithms combined with computer vision for quality control of products and production.
Collaborative Robots	Robotic arms designed especially for collaboration with humans mounted on manual workstations.
Additive technology	System for manufacturing 3D products by depositing materials in multiple layers. (e.g., 3D printer)
Augmented Reality	A system that adds interactive information's to a real word perception via wearable devices such as a smartphone or smart glasses.
Smart Maintenance	A system that includes spare parts warehouse and software for learning factory maintenance control.
Energy Monitoring	System for electrical energy and air consumption monitoring.

Four modules that together form one production line were procured to simulate the above-mentioned material processing in the learning factory. The drilling module allows simulation of particle separation processing, pressing simulates properties changing and assembly of parts using force, the magazine is used to place materials or parts on the production line, and the branch module to enter and exit products from the production line. Each module can be used separately or interconnected into different formations, thus achieving modularity and flexibility of production. Four manual workstations have been designed to integrate the assembly process into the learning factory. One workstation has fixed dimensions, while the other three allow height adjustment to the user, which therefore allows learning and research on ergonomics at work. All workstations are equipped with the necessary tools, equipment, and parts for assembly, as well as with interactive screens that enable more accessible training of employees and education about the lean philosophy in production. Manual workstations are separated from the rest of the production line, and a mobile robot is used as a connection. Mobile robot, together with collaborative robots located on two manual workstations, enables education and research in the fields of advanced robotics and human-robot collaboration. Two manual workstations are additionally connected with a belt conveyor on which interphase quality control is performed. In addition to interphase quality control, quality control of the final product and management of the work process will be carried out to optimize the operation and ergonomics of work. These controls will be performed using RGB cameras and cameras with depth sensors, and the data obtained will be analyzed using machine learning algorithms. The involvement of machine learning within the learning factory is important for the reasons already mentioned, and in addition to them, it will enable awareness raising and education of students and employees about this technology. In addition to interactive screens, augmented reality will be used for easier acquaintance with the available modules and for obtaining instructions in the assembly process. Implementation of augmented reality into the learning factory will enable education and research on this technology. To enable education and research in additive manufacturing and facilitate the adaptability of production in the learning factory, a device for additive production will be implemented.

Figure 4 Current LF setup

All these modules and systems are interconnected using the Manufacturing Execution System (MES), which allows remote production management, as well as education and research on the system itself. To increase awareness of the need for sustainable and greener production systems, smart maintenance and energy monitoring systems are also included in the learning factory. The learning factory at FMENA was established and commissioned in February 2022 and currently consists of the drilling, pressing, magazine, and branch modules that make up the production line, one manual workstation, a mobile robot, smart maintenance, an energy monitoring system, all connected to the MES and showed in Fig. 4. The characteristics for the rest of the equipment which will make up the complete learning factory shown in Fig. 5 are defined and currently going through the procurement process. The established learning factory has already made it easier to get acquainted with some of the technologies of Industry 4.0, and once established in its final form will provide education on most Industry 4.0 technologies, from the basics of electrical, mechanical, and computer engineering to complex systems such as MES.

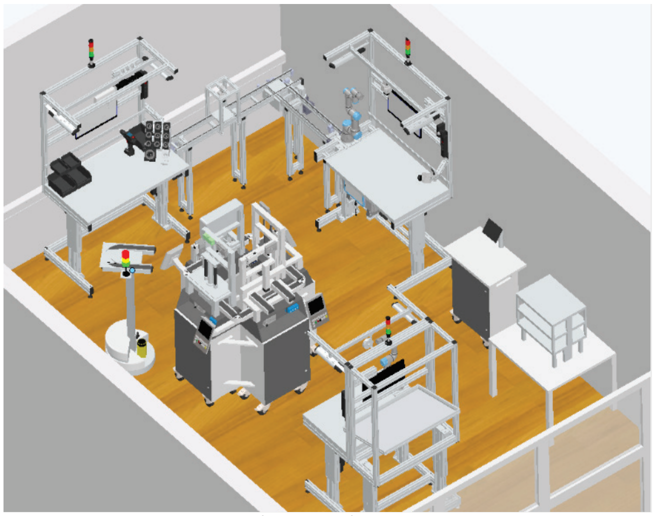

Figure 5 3D model of a complete LF

4 CONCLUSION

The fact that Croatia is significantly lagging with the implementation of Industry 4.0 and that there is only one existing learning factory established more than ten years ago results in need for new learning factories. A new learning factory was designed and installed at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. The process of design and establishment is described in this paper. The Learning Factory was commissioned in February 2022 in a partial form that will be supplemented with the rest of the equipment upon completion of the procurement process. The new learning factory has already provided knowledge and education about certain technologies of Industry 4.0, so it can be concluded that after establishing in its complete form, this learning factory will significantly facilitate further research and education of students and employees with Industry 4.0 and thus facilitate the implementation of Industry 4.0 in Croatia. A directory of learning factories was developed through a learning factory design process to enable insight into the current state of learning factories and thus the design process itself. Statistical analysis of the data obtained by directory development has facilitated and justified the establishment of this learning factory. Still, care should be exercised when explaining results due to the relatively small sample size.

Further work and research will focus on the establishment of the entire learning factory and development of materials needed for its use in education. Furthermore, efforts will be made to add new features and entries to the DoLF and to keep it up to date.

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Notice

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Authors' contacts:

Miro Hegedić, Asst. Prof. PhD
(Corresponding author)
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
mhegedic@fsb.hr

Petar Gregurić, mag. ing. mech.
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
pgreguric@fsb.hr

Mihael Gudlin, PhD
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
mgudlin@fsb.hr

Matija Golec, mag. ing. mech.
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
mgolec@fsb.hr

Anja Đenadija, univ. bacc. ing. mech
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
ad199650@fsbhr.onmicrosoft.com

Nataša Tošanović, PhD
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
ntosanovic@fsb.hr

Nedeljko Štefanić, Prof. PhD
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb,
Ivana Lučića 1, 10 000 Zagreb, Croatia
nstefanic@fsb.hr