Learning through action: on the use of Logistics4.0 Lab as learning developer

Mirco Peron, Erlend Alfnes and Fabio Sgarbossa

Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Richard Birkelands vei 2B, Trondheim, 7034, Norway

Abstract. The concept of learning factory is taking more and more hold as teaching method, especially after the advent of Industry 4.0 (I4.0). Learning factories have in fact proved to be effective in developing knowledge and skills necessary for students to master the potentialities of adopting new I4.0 technologies in several aspects of production and logistics systems. Driven by these potentialities and aiming to create and spread new knowledge on the use of I4.0 technologies in production and logistics systems, the Production Management group at NTNU, with the support of the Department of Mechanical and Industrial Engineering, has established in 2018 the Logistics 4.0 (Log4.0) Lab. Since then, the Log4.0 Lab has been used to develop state-of-the-art research investigating the impact of I4.0 technologies on production and logistics systems and to transfer the developed knowledge to the students to render them ready for and attractive to the job market. In this paper, we provide some examples of the use of the Log4.0 Lab for teaching purposes, and specifically we focus on its use with respect to the Lean 4.0 concept, i.e., the integration of I4.0 technologies with Lean practices and concepts.

Keywords: Logistics 4.0 Lab, action learning, learning factory, teaching

1 Introduction

Traditional teaching methods show limited effects in the development of skill sets for industrial applications. Applied sciences such as manufacturing and logistics cannot, in fact, be learned effectively only inside a classroom, and new teaching approaches enabling training in realistic manufacturing environments are hence needed [1]. Modernizing the learning processes and bringing it closer to industrial practice allow to better educate students and to provide them the skills required by the job market [2]. In this perspective, learning factories have emerged as a very effective solution.

Learning factories are facilities with an authentic factory environment that is used for research, training, and/or learning purposes, and often have a multiple of machines and equipment that can be used to enable a changeable setting for problem- and action-oriented learning [3]: they hence offer the possibility of realistic representation of a factory (sub) system with the necessary products, processes, and resources in an experience-orientated, participative, digital as well as realistic learning environment [4].

The learning factory concept was developed in 1990s, when Penn State University established a large facility equipped with machines and equipment to do industry-sponsored projects. This center is still ongoing and is doing projects that involve students and employees. Recently, the use of learning factories has increased, focusing on many different topics, among which also the Lean concept. However, it is after the advent of Industry 4.0 (I4.0) that the use of learning factories has reached the peak, taking many forms, from the traditional factories to smaller lab environments [3]. There are in fact now more than 120 learning factories worldwide, with more than 50 in Germany, the homeland of I4.0 [4].

Learning factories have in fact proved to contribute to strengthen the transfer of new skills and ways of working needed for adoption of new I4.0 technologies through the use of student projects and research projects with industry [5,6]. Driven by the benefits associated with learning factories, the Production Management group at NTNU, with the support of the Department of Mechanical and Industrial Engineering, decided to establish the Logistics 4.0 (Log4.0) Lab with a twofold goal. First, to identify new benefits associated with the use of emerging technologies in production and logistics systems, and second, to transfer the developed knowledge to students.

In this paper, we will provide some main examples of the use of the Log4.0 Lab as learning factory for bachelor and master students as NTNU. Specifically, we will describe its use as learning factory only within the concept of Lean 4.0, where students are taught how I4.0 technologies can be integrated with Lean practices and concepts.

2 Logistics4.0 Lab

In 2018, the Production Management group at NTNU, with the support of the Department of Mechanical and Industrial Engineering, established the Logistics 4.0 Lab with the main purpose to create new knowledge on the use of emerging technologies in production and logistics systems. Specifically, through the test and study of the impact of emerging technologies on logistics systems, done in collaboration with companies, either as suppliers of such technologies or as case applications, new methods and models for designing and management of future logistics systems are being developed. Moreover, the Logistics 4.0 Lab is an important platform and arena where the knowledge developed through learning games, hackathons, project-works and master projects is transferred to bachelor and master students.

To do this, a replication of real-life operations and material handling activities in production systems has been made, including assembly workstations, a storage area and material handling systems, and a material management support system. These elements of a conventional production and logistics system have been integrated with a wide range of emerging technologies, such as indoor positioning system, motion capture system, augmented, virtual and immersive reality, visual interactive board, real time control and advanced simulation tools, 3D mapping, mobile robots, smart material handling systems, assistive devices and tools for smart operators & managers.

Among them, it is worth mentioning those which will be further discussed in the following sections. The first one is the motion capture (mocap) system. The researchers in the Logistics 4.0 Lab have developed, in collaboration with the supplier, the integration of such system with a virtual reality (VR) platform in order to replicate the operations in a virtual 3D environment. The motion capture system is a suit composed by 29 inertial sensors which are used to create a digital twin of the operator who is wearing the suit. In the VR platform, the virtual environment can be recreated using 3D models and, through the integration with the suit, the operator can see her/himself in such virtual environment using a VR set. The combination of the mocap system with the VR has been studied in the Log4.0 Lab to virtual design the assembly workplace, showing the students how this solution can highly reduce the time and resources required by traditional workplace design procedures.

The second example of technology studied in the Log4.0 Lab is the integration of photogrammetry with several camera devices and supporting systems. In this way, the pictures taken through different cameras (action camera, 360 camera, smartphone camera) can be merged thanks to some photogrammetry software in order to create a virtual environments (3D scanning). These solutions have been developed for multiple purposes. They have been integrated with CAD systems to support re-layout design and they can be also interconnected to digital twin in order to replicate the real environment into the virtual environment. Moreover, the researcher at Log 4.0 Lab have developed the use of such solution for virtual factory tours, Gemba walks and 5S analysis.

Then, another example of technology studied in the Log4.0 Lab is the Augmented Reality (AR). In this case, the researchers have implemented Microsoft Hololens for assisting workers in various operations, from assembly to order picking. These AR glasses have a specific software development kit which can be used to develop functionalities based on the requirements of the users. In this way, the information and instructions can be given to the user through the glasses, and they are dynamically adapted to the user's point of view. In the Log4.0 Lab, the students have been taught how AR can act as Poka-Yoke in order picking operations in a warehouse and how it can support operators' cognitive tasks.

Another technology implemented in the lab to convey and give information to operator is conventional projector integrated with motion sensing input device (in specific, Microsoft Kinect). The projector is used to send the information to the desk where the operator is working, and the motion sensing input device performs gesture control as input for deciding which information to be sent to the operator. As before, this application has been shown to be an effective Poka-Yoke solution for assembly operations, and students have had the possibility to study it in first person.

3 Action learning at the Log4.0 Lab: some examples

Since the establishment of the Log4.0 Lab in 2018, the Production Management group has pushed its vocation to action learning even further by using the Log4.0 Lab for teaching and research purposes. Many activities have in fact been carried out, involving more than 20 students between summer jobs and master theses, resulting in the development of new teaching materials and/or in the publication of the results in both conference papers and international journals. In the following we will focus on the results of these activities in terms of new teaching materials. The topics covered by the new teaching materials have been many, but in this work we will focus only on the teaching materials relevant for the Lean4.0 concept (i.e., the integration of Lean practices and concepts and I4.0 technologies), and specifically on those showing how the design and the operational level can be affected by the integration of Lean and I4.0 technologies. More in details, the new teaching materials show that the design level is positively affected by the possibility provided by I4.0 technologies to reduce wastes (waste of resources, time, …) and by the increased efficiency, and that, similarly, the operational level is positively affected by I4.0 technologies since, when serving as support for the operators, they limit the probability of the operators to do mistakes and they facilitate cognitive tasks. In the following we will describe separately the main content of each of these teaching materials, starting from those related to the design level and finishing with those related to the operational level. It is worth mentioning that the teaching materials herein considered are the results of four master theses.

3.1 Teaching materials on Lean4.0 in the design level

Immersive Virtual Mock-Up Approach for Workstation Design

The following teaching material shows how the use of mocap system and VR can assist and improve the design of assembly workstations. The combined use of mocap system and VR allows to design assembly workstations in a virtual environment, without the need to build a physical mock-up [7,8]. Thanks to the developed teaching materials, students at both bachelor and master level have the possibility to learn how to design an assembly workstation in such a way. Moreover, they learn the theoretical foundations necessary to evaluate the design considering either productivity, operators' wellbeing, or both. Students are shown how to create different workstation layouts for assembling a jet pump, as well as to test the different layouts virtually for then choosing the best solution considering both the productivity and the operators' wellbeing aspect. An example of the virtual assembly operation is reported in Figure 1.

a) b)

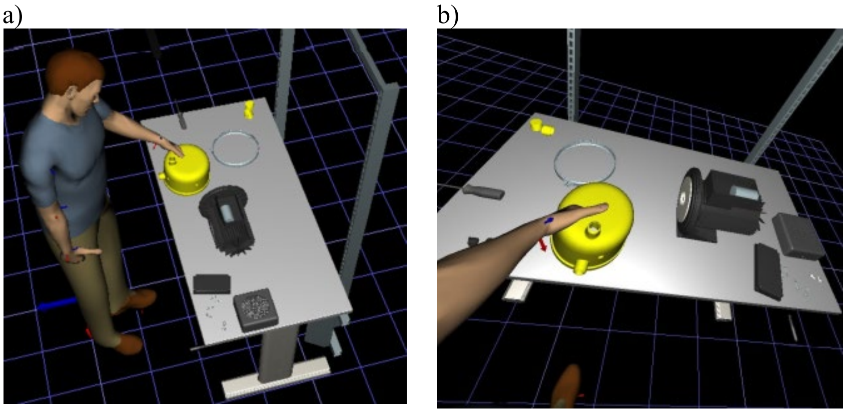

Figure 1. Birdseye (a) and operator's (b) view of the assembly operation

Use of 3D Scanning for Manufacturing Layout Redesigns

The following teaching material shows how Industry 4.0 technologies can improve the redesign of the facility layout, and this can greatly contribute to the success of a company by acting on the reduction of the Lean waste of unnecessary transportation and handling activities (a well-designed manufacturing facility layout is reported to potentially reduce operating expenses by 50% [9]). Thanks to this teaching material, students at both bachelor and master level learn how the most suitable approach for solving facility layout designs, i.e. systematic layout planning (SLP) [10], can be supported by an innovative technology like the 3D scanning [11]. Specifically, students learn to operate the two most common 3D scanning types (i.e., photogrammetry and structured light) to determine the detailed and accurate information of the layout required by SLP. Students are shown how to redesign the shopfloor of a workshops (Figure 2) using the two different 3D scanning, highlighting the pros and cons of both technologies.

a) b)

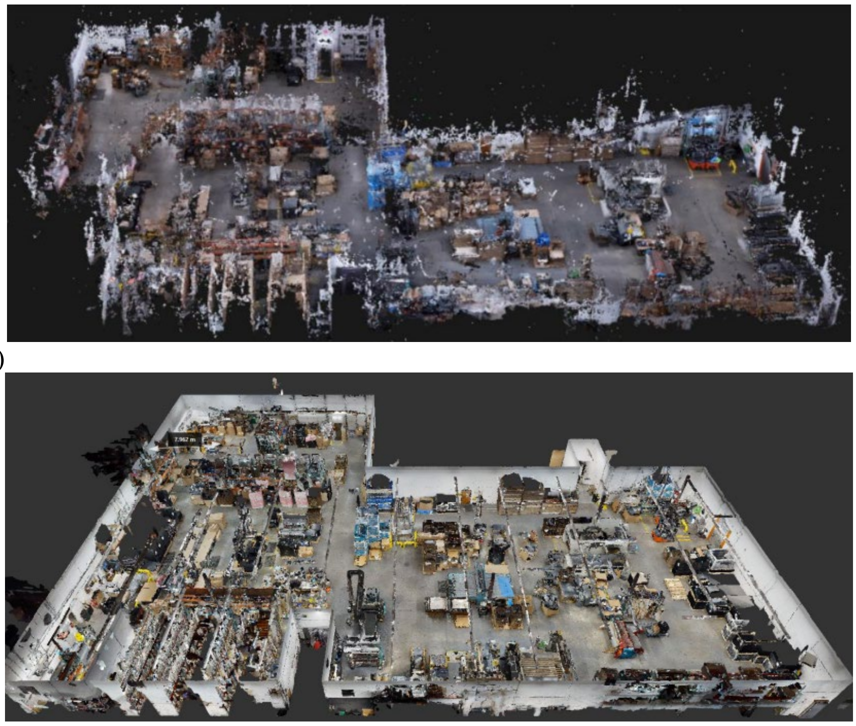

Figure 2. Areal view of the shopfloor with 3D scanning photogrammetry (a) and structure light (b) type

Moreover, it is worth mentioning that 3D scanning has been used in a master level course to allow the students to have a digital Gemba of a warehouse during pandemic times and to provide digital safety tours for new lab users, but this won't be discussed in this work.

3.2 Teaching materials on Lean4.0 in the operational level

Use of smart glasses in order picking operations

Thanks to this teaching material, students at bachelor level have the possibility to learn how smart glasses can serve as Poka-Yoke for error proof order picking operations, which represent the most time-consuming, labor-intensive and expensive activities for most warehouses [12]. Specifically, they have the possibility to reflect on the advantages of a pick-by-vision solution compared to the traditional paper-based order picking system. Moreover, thanks to this learning material, students learn also how to carry out cost-benefit analyses. Students are in fact shown through a case study where different customer demands are simulated how to compare the pick-by-vision solution to other innovative order picking systems (i.e., are barcode handheld, RFID tags handheld, pick-by-voice, pick-by-light and RFID pick-by-light systems) from both productivity and economic perspectives in order to determine when it is convenient to adopt the pick-by-vision solution. An example of a student using the pick-by-vision solution for order picking operations is reported in Figure 3.

Figure 3. Details of the pick-by-vision

Kinect-Projector-based Assistance Technology for Manual Assembly

Thanks to this learning material, students at bachelor and master level are taught how digital assistance technologies can support an error proof manual assembly. Students, in fact, are able to experience firsthand that digital technologies can provide clear and easy-to-read assembly instructions, as reported in literature [13,14], and they are shown quantitatively the benefits of adopting such technologies. Specifically, students can experience firsthand how the digital technology developed in the Log4.0 Lab (consisting of a projector coupled with a Microsoft Kinect motion sensing device, Figure 4) decreases the number of assembly errors and the cycle time for the assembling of a LEGO model compared to paper-based instructions.

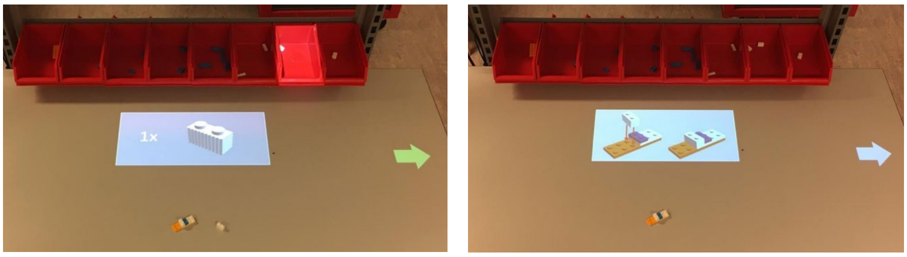

Figure 4. Examples of assembling operations projected onto the workplace

4 Conclusions

In this paper we reported some examples of the use of the Logistics 4.0 Lab as learning factory by the Production Management group at the MTP Department at NTNU. Specifically, due to space limitations, we focused only on the developed teaching materials relevant for the Lean4.0 concept (i.e., the integration of Lean practices and concepts and I4.0 technologies). In particular, we show how the design and the operational levels can be affected by the integration of Lean and I4.0 technologies, allowing students to understand thanks to tangible examples how I4.0 technologies can assist Lean practices and concepts.

Students revealed to be enthusiastic for the new teaching materials. Some of their comments collected by the responsible of the courses during the periodic students-teacher meeting are here reported:

"It was an amazing experience to cherish and I learnt a lot of useful information on how Industry 4.0 technology could be used to make our lives easier and automate the manual tasks."

"Working with these technologies was really interesting at a personal and academical level. I was able to apply the 3D scanning on a real case and it was fascinating to see its practical implementation and benefits."

"I did like it! I feel like I gained a lot of useful knowledge and it helped me expand view within the field."

However, although these benefits achievable by using the Log4.0 Lab as learning factory, there were also some drawbacks associated with it. The main drawback is the necessity for the researchers in the Log4.0 Lab to master the new technologies. This requires highly skilled and highly motivated researchers, that are willing to keep pace with the continuous technological advancements. However, these are characteristics that are intrinsic in persons who have decided to follow the academic career, where producing state-of-the-art research and teaching is the order of the day, and the Production Management group at the MTP Department has proved over the year to be extremely successful in this.

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