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A novel approach for teaching IT tools within Learning Factories

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Abstract

Universities around the world are developing strategies to include into their curricula trend topics from Industry 4.0, such as Cyber Physical Systems, robotics, process virtualization and advanced IT tools. However, at the state of the art in literature there is few evidence for educational environments in which all these components are fully integrated. SMALL Factory, an ongoing project in Politecnico di Torino, aims to develop an integrated learning factory based on the technologies triggering the fourth industrial revolution. Beside the transfer of technological skills, the laboratory allows the on field training of students in the use of open source IT tools such as PLM and ERP systems. The present paper aims to present the teaching methodology proposed within the SMALL Factory framework. The ultimate aim of this project is to replace the traditional software teaching, based on tutorials and simple case studies, with a learning by doing, integrated approach, in order to provide students with a comprehensive perspective of a modern manufacturing environment and to train their mindset to be responsive.

Keywords: Industry 4.0; CPS; IT tools; PLM; ERP

1. Introduction

The development of the Smart Factory (SF) is a critical concept in the reindustrialisation of Europe. The most industrialized countries are funding national and international programs to promote the integration of the Industry 4.0 enabling technologies within the manufacturing environments. In Fig. 1, a map highlighting the most active countries, around the world (a) and in Europe (b), and the relative programs is shown.

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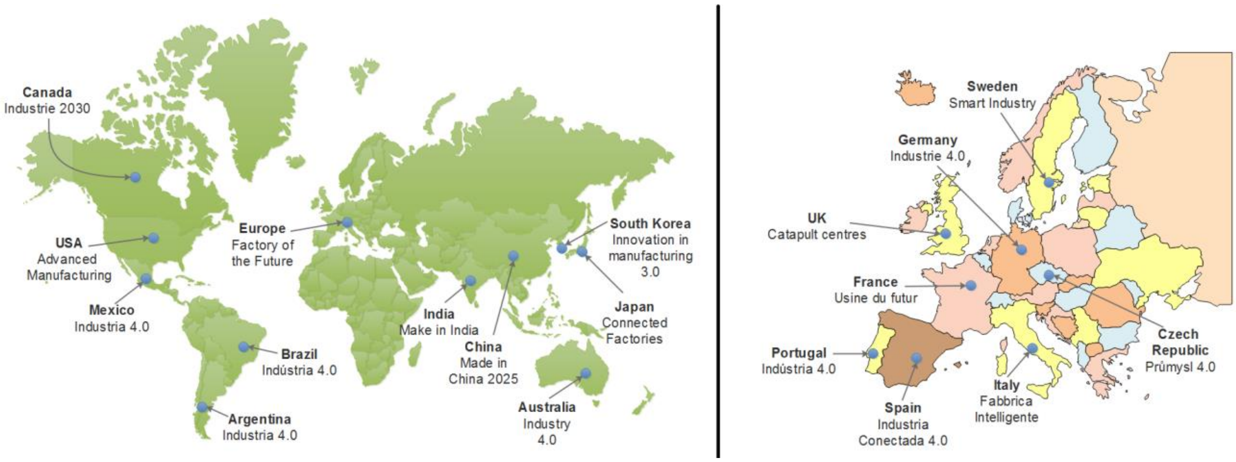

Fig. 1. a) SF around the world b) In Europe.

The SF spread will significantly affect job definition in industry. Today, the staff of a company can be classified in two categories: "white" and "blue" collars. Usually, engineers are asked to be proficient in one domain, and to have some basic knowledge in the other areas, due to the traditional organization culture with clear labor division. However, a new figure, commonly named "grey" collar, is arising: it consists in workers that combine practical skills with technical and intellectual capabilities [1]. Therefore, new engineers will be required to master several technologies to develop their job, including IT tools, manufacturing and automation.

To satisfy this industrial need, education programs must be updated. This need has also been highlighted in a European research [2], which states that the lack of skilled engineers is already restraining companies from generating more business. Recently, universities started to made huge investments to develop and deploy smart factory laboratories. Besides the technological aspects, IT tools play a critical role in the execution of processes and they are vital for any company. Among these tools, some of the most popular are: Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and Discrete Event Simulation (DES). However, at the state of the art in literature there is few evidence for educational environments in which these tools are fully integrated.

The present paper aims to extend the state of the art by describing the activities of the *SMALL Factory* laboratory, developed in Politecnico di Torino. Namely, the focus of this paper is the integrated approach used to teach IT tools, with particular concern for PLM and ERP systems.

The rest of the paper is organized as follows. The state of the art in training laboratories on Industry 4.0 is presented in section 2. In sections 3 and 4, the SMALL Factory project is introduced and one of the manufactured products is presented. In section 5, the approach to teach PLM is presented; the methodology used to train students to ERP systems is described in section 6. Finally, in section 7 conclusive remarks and future development plans are discussed.

2. State of the art

In the last years, several universities around the world implemented Learning Factories (LF). In Germany, a consortium led by the University of Kaiserslautern created the SmartFactory^{KL}: it is a hybrid production facility that has been built as a demonstration and development platform for the production of colored liquid soap [3]. Bochum University created a learning factory that comprises a holistic model of a producing company, from the ERP level – Top Floor – to the Field Level – Shop Floor [4]. Their main objective is the on-field training of students that are already working with SMEs. However, the kind of product is not specified. The Process Learning Factory CiP (Center for industrial Productivity) from Darmstadt University fabricates a pneumatic cylinder and a gear motor [5]; lean manufacturing techniques are also introduced. In Canada, the University of Windsor created a LF, a truly reconfigurable and changeable manufacturing assembly system [6]. The Escola Politécnica of USP, Brazil, is developing a learning factory [7].

These LF realizations mainly focus on the manufacturing process. However, the highly skilled workers necessary in the next future will be employed both in the development of the "smart" applications and in the implementation of those applications at manufacturing sites. For this reason, besides the technological tasks, students also have to learn how to use the same systems that are employed in industry. In TU Vienna, students learn how to deal with a complete product development: customer order, design, planning and manufacturing. The teaching approach consists in an exercise to develop a slotcar and its production process [8]. The objective of this research is to present another methodology aimed at introducing the use of IT tools within the SMALL Factory project. Here, special attention is given to product design and its management. Therefore, the use of a PLM system is strategic. Moreover, an ERP system is deployed to manage and design the production.

3. SMALL Factory project

The Smart Lean Learning (SMALL) Factory is a project funded by Politecnico di Torino to enhance the skills of future engineers. The aim of this project is to reproduce a smart factory for educational purposes in a laboratory environment, in terms of both hardware and software. This environment will allow students to become familiar with production applications commonly found in the modern facilities and to experience realistic situations, as required by the "Gemba walk". Gemba refers "the real place" where the actual action is executed. Its effective use encourages the "go-see" principle: it is a mechanism for "catching" people doing the right things and getting recognized for it [9].

Fig. 2 shows the didactic approach of the SMALL factory. From the hardware perspective, heterogeneous facilities will be integrated with each other: the goal is to train students in updating old facilities – according to the Industry 4.0 paradigm – and integrating them with new resources and with automation systems. The final aim is to integrate traditional manufacturing processes and new technologies.

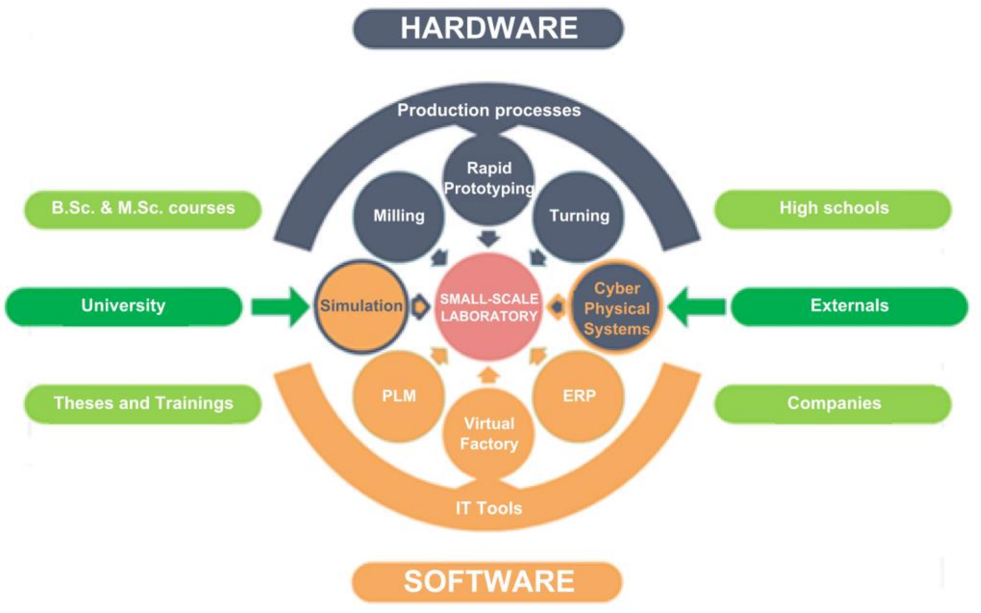

Fig. 2. Didactic approach of the SMALL laboratory.

From the software point of view, which is the core of this contribution, the ultimate aim of the authors is to build a set of course plug-ins that can be integrated with each-other and adapted to the audience of students, (i.e. their field of specialization, their level, their background,…). Such courses must concern the IT tools most common in modern facilities, regarding both product design and management and the related manufacturing process. The goal is to formulate a course in Smart Factories, deploying a kind of plug-in approach. This approach is intentionally opposed to the traditional one, consisting in huge, standard courses to be taught to every kind of student, which usually do not take into account the specificities of the attendants.

In addition, the infrastructure can be used to both university courses (at B.Sc. and M.Sc. levels) and external entities such as high schools or companies interested in the topics.

4. The product

The products to be manufactured are a family of trolleys for sliding doors. The sliding door trolley (Fig. 3) is a key component of commercial garage doors and gates since it links the gate framework to the surrounding structure. The trolley runs on a monorail that is fixed to the wall. It should be designed and constructed to prevent the door from falling down, collapsing or de-railment during normal operation or in case of contact with stationary obstacles.

Each group of students has to develop its own specific product with different requirements. Fig. 3 presents two different product configuration. The main product variant is the load that the trolley can support (from 50 kg to 500 kg). The load directly affects the diameter and, consequently, the screw thread of the main pin. Other variables that can be modified are the number and diameter of the wheels, the distance wheel to wheel and the length of the thread.

Fig. 3. Two trolley variants.

5. PLM teaching approach

The PLM teaching approach is based on team collaboration during product development. The PLM strategy is presented in Fig. 4. It is composed by three stages of the product lifecycle: product design, process design and virtual factory simulation. In the next paragraphs further details of each step are given.

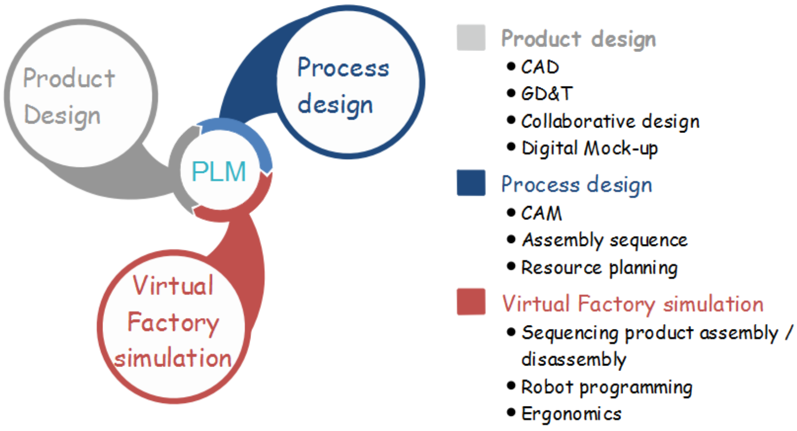

Fig. 4. PLM strategy.

5.1 Product Design

The design strategy follows the steps defined by Pahl et al. [10]: requirements, concept, preliminary lay-out, definitive lay-out and product documentation. These steps are integrated in a PDM system by means of a series of workflows. Each stage of the design process reaches a release stage.

In the laboratory two PDM systems are available: a market leader, Teamcenter, and an open source system, Aras Innovator. Besides the PDM system, a CAD system, Nx, is available.

In the first phase, the requirements of the product are given to each team. A team leader and several team members compose the design team. The former is responsible of the requirements study, labour division and assembly management. The latter are responsible of part design.

The wheels components are well defined and only slight changes can be made to the design. Conversely, designers have completely free choices in the design of the main threaded pin.

In order to validate the concept design a digital mock-up and a physical prototype are mandatory. A 3D printer is employed in order to obtain a first prototype. Once the concept is validated or corrected, the definitive lay-out is produced. Finally, the product must be completed with the tolerance according to the GD&T (ASME).

5.2 Process design

This phase is composed by two main steps: part production and assembly sequence.

In the former phase, each component that has to be manufactured has to be studied (the nuts and the spheres are bought). The production plan must contain the complete operation sequence, starting from a stock, to obtain the required part. In the PDM system, the operations are linked to the necessary resources (tool, machine and fixtures). Moreover, every operation has to be validated with a CAM simulation. Most of the parts require turning operations and, in some cases, drilling and milling. The CAM simulation produces the necessary G-Code program to operate the machine.

In the latter phase, the assembly sequence has to be studied. The PDM system is capable of managing the assembly plan and to link it to the necessary resources.

5.3 Virtual Factory simulation

Once the assembly process has been defined, the following step is the assembly process verification simulation. The nominal assembly sequence of operations defined in the previous step are simulated in a virtual environment. The aim of this task is to verify the feasibility of the assembly process by validating reachability and collision clearance. This check is performed by simulating the full assembly sequence of the product and the required tools. The PDM system is needed since it contains all the digital representations of the resources employed in the simulation. The expected outputs of the verification are the sequencing of product assembly, the cycle time and human ergonomics. Moreover, robot programming can also be obtained from this stage.

6. ERP teaching approach

The ERP course is designed to show students how to manage a manufacturing process from the business perspective. An open source software, Odoo, is available in the laboratory.

The course is structured in two parts. In the first one, the software and its functionalities are introduced to the students through frontal lectures performed in the laboratory. The main themes dealt during these lectures are: the description of a company and the definition of business roles; the implementation of a Bill of Materials (BoM); the description of workcenters and routings; the management of warehouses; the management of sales and purchases. Procedures are shown by the teacher; then, students are required to perform basic exercises on-the-fly. To encourage students in practicing the software also beyond the lectures, video tutorials have been uploaded on the Youtube channel PGP@PoliTo. This part of the course approximately takes 12 hours.

In the second part of the course, team collaboration is promoted. Students are divided in groups of 6-8 people: each of these teams is asked to simulate the business of a company. Each group is provided with a description of the virtual company, its suppliers and its customers, the available machines and the production times, and with a set of BoM and BoP concerning the finite product sold by the virtual company. The latter two input are provided by the work performed in PLM teaching.

Therefore, the first step to be performed is the implementation of the database to describe the activities of the company. Each student in the team has different responsibilities; namely:

1. A warehouse manager, who is in charge of monitoring the stocks for both the finite products, the intermediate components and the raw materials;
2. A planning manager, who is in charge of planning the manufacturing activities to satisfy the demand of the customers
3. A manufacturing manager, who is in charge of running the production according to the output of the planning manager: he has to interact with the warehouse responsible to collect all the resources necessary to run the process.
4. A purchase manager, who interacts with the warehouse and virtual suppliers and has to order the necessary raw materials
5. A sales manager, who interacts with the warehouse and the virtual customers, to analyze and dispatch the orders
6. A marketing manager, who has to manage the accounting tasks, including invoices, and check that the virtual company is producing in a profitable way
7. A coordinator, who has to ensure that the company activities are carried out.

After these preparatory tasks, each student of the team is enabled to enter the database of his company and perform his work. Further, to enhance the cooperation within the team, the software installation is performed in a client-server architecture: in this way, different people within the same group can access the same database at the same time, like it is usual in a company.

In the successive laboratory sessions, the teacher provides each team with a set of orders containing: (i) the items to be delivered and their quantity; (ii) the target customer; (iii) the due date. Each team has to identify and plan all the activities necessary to satisfy the customers orders within the due date (or with the lowest possible delay): raw materials and semi-finite components must be available, and the manufacturing activities must be managed, as well as the delivery orders.

7. Conclusions and further developments

This paper describes a part of the work done within the framework of the SMALL Factory project, at Politecnico di Torino. Here, the attention was focused on the methodology used to train students in deploying two common classes of IT tools to support product management within companies, namely PLM and ERP. At the end of the courses, students are provided with questionnaires to assess the course. The overall satisfaction is high; in particular, the possibilities to work in teams and to deal with a real-life industrial problem are appreciated. Furthermore, students appreciate the learning-by-doing approach, since they can put in practice their theoretical knowledge and deal with issues that would have not be faced in frontal lectures.

The most important effect of the proposed didactic framework is the students' mindset growth. On one hand, students can discover their areas of interest, the activities to which they are talented and topics that may fascinate them. On the other hand, they can easily find flaws in their education, tasks that they are not enthusiastic to do in the future and job positions that may not motivate them. This self-discovering can be achieved only if they are put into almost-real work situations. In addition, positive implications for companies could follow. Newly graduates will be familiar with the IT tools and manufacturing processes to work effectively. Thus, the adaptation period from university to industry will be reduced.

In the next developments, laboratory sessions to manufacture the product will be developed: this step will enable to better exploit the information management performed by the PLM and to remove a simulation step from the ERP exercise. Further, MES can be introduced to students, with the aim of managing the production process and to monitor the involved resources. Finally, the manufacturing session would enable students to put in practice their technological competences learnt in previous courses.

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