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# Development of Virtual Learning Factory Toolkit for Production Engineering Education

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**Abstract.** The advent of industry 4.0 and the continuous digitalization of production ask for the enhancement of human skills and competences in the field of information and communication technology (ICT). Therefore, higher education has to keep pace with the global market needs for the necessary ICT skills and the overall understanding of the complexity of industries in 21st century. This paper focuses on the development and integration of Virtual Learning Factory (VLF) tools that can be used in production management and engineering education. The digital tools integrated in VLF toolkit can help students to exploit enabling technologies like simulation and virtual reality in their manufacturing studies and practical projects with industrial companies.

## 1. Introduction

There is no doubt, the main wealth generating activity for many nations is the manufacturing. Manufacturing has a significance contribution in the Gross Domestic Product (GDP) of Europe. Although there is recent development and growth in service sector, international markets are still persuading the importance of manufacturing in Europe and manufacturing remains a dominating factor in the total global trade with the contribution of 70% [1]. The current and prospect importance of manufacturing can be observed in many fora, a comprehensive report on “the future of manufacturing in Europe” is one of the great example of future-oriented study about manufacturing [2], where the technological development, its exploration and adaptation perceived as a key-game changer across the Europe.

Since manufacturing faces the rapid advancement in production related technologies, tools and techniques. Therefore, in this new era of manufacturing, industrial workers and engineers need to rely on the new learning schemes to keep up with those advancements. Higher education plays a vital role and a major driver to build a skill and knowledge-based workforce of new generation in manufacturing [3]. Furthermore, the latest advances and incorporation of Information and Communication Technology (ICT) in manufacturing leads the digitalization of manufacturing, and similar trend like ‘industry 4.0’ demand the training and professional development of workforce in this field, which is a challenge for the educational institutions. The concept of learning factories can be an effective enabler and contribute to establish the relevant theoretical and practical knowledge about the new advancements [3, 4]. There



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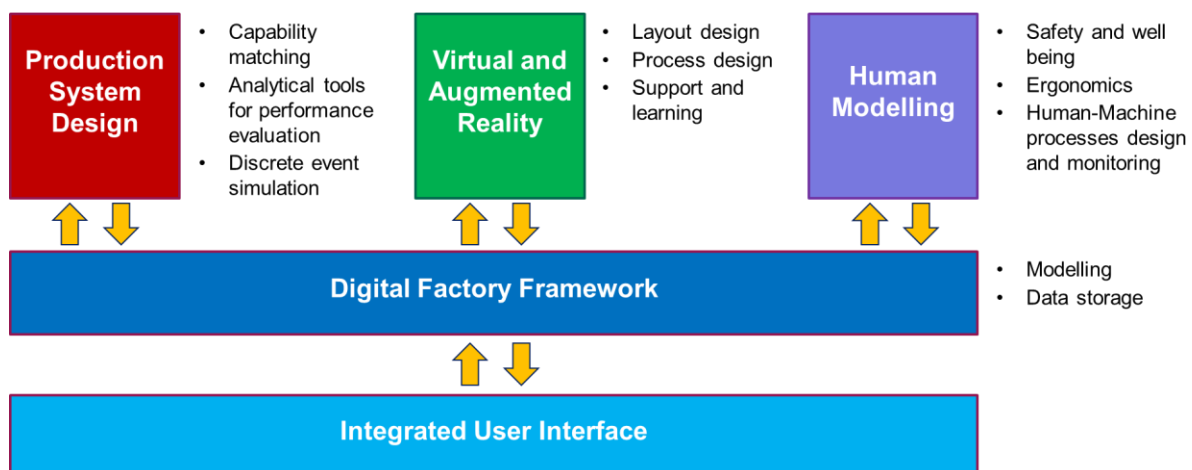
are advanced learning labs, FESTO didactics and competence centres, adopted by many educational institutions to cope up with the challenges of digitalization in manufacturing and to learn new technological skills, knowledge and expertise in manufacturing [5, 6].

On the other hand, the learning can be organized virtually by using digital tools to design, analyse, and visualize the manufacturing processes and systems. In many production engineering and management related curricula, learning via creating the virtual environment of a real production system or even a whole production factory has been practiced due to its prevalent benefits. Moreover, this kind of learning is quite appealing and justified in the current pandemic of COVID-19 and its impact on educational institutions. There are developments in the virtual learning approaches with the help of simulation based digital tools and many studies are currently carried out in the domain of virtual and digital factory [7, 8]. Nowadays, several technical institutions and research centres are developing their own virtual factory tools or they are using and enhancing existing software platforms and systems to develop optimization and control algorithms for factory simulation and visualizations. Nevertheless, the developed digital tools are actually employed by scientists and practitioners involved in research activities and these software tools developed during the research are not yet widely available for teachers and students.

The purpose of this paper is to present a Virtual Learning Factory Toolkit (VLFT) framework that contains digital tools and their integration. The study provides a systematic approach about the activities and digital tools used to design, evaluate and visualize manufacturing processes and systems. Moreover, it gives an overview – how the learning process should be conducted, which is validated through a case scenario of manufacturing system configuration. The case was tested in the form of joint learning lab among different students, where the digital tools are used and improvements suggested. The paper is connected to the ERASMUS+ VLFT project that aims to integrate the existing digital tools into a usable toolkit for students.

## 2. VLFT Framework and Workflow

The VLFT is a set of existing digital tools to support advanced engineering education in manufacturing. Modelling, analysis, virtual and augmented reality, as well as the role of the human workers in the factories have been among the main building blocks of VLFT framework. The functionalities of VLFT framework are production system design, exploiting virtual and augmented reality in manufacturing, and human modelling in manufacturing with the help of digital tools. An integrated user interface and a guideline to support the adoption of the tools in an engineering curricula are included in the framework. The framework is shown in Figure 1.



**Figure 1:** VLFT Framework

### 2.1. Digital tools and related activities

For production systems design, evaluation and visualization, the following tools are included in VLFT and are being used for the case study with their corresponding activities.

- Graphical User Interface (GUI) Tool i.e., *OntoGUI* [9] – for the definition of production systems configuration. It includes part types, process plans, operations, capabilities of the production resources like machine tools, transporters, storage systems.
- *Java Modelling Tools (JMT)* [10] and *ARENA* – Rockwell Automation [11] – for performance evaluation via discrete event simulation of production systems and respective Key Performance Indicators (KPIs) analysis i.e., throughput, utilization, lead time, etc.
- Unity3D [12], libraries of *Babylon.js* [13] and *ApertusVR* [14] – for the 3D visualization, animation and interaction with production systems and resources via virtual and augmented reality.

The use of these digital tools at different levels of manufacturing helps not only the industrial users to execute a series of analysis for system design and performance evaluation of resources. It also helps in a teaching context, the adoption of digital tools supports the application of complex engineering approaches such as simulation and analytical performance evaluation, which can assist to reach a set of learning objectives and to improve the students' learning effectiveness. More information about the VLFT tools can be found in [15].

### 2.2. Workflow for practicing digital tools

The set of digital tools for the Virtual Learning Factory Toolkit are aiming at improving the learning effectiveness of engineering students. To examine the digital tools, we identified a series of case studies covering different manufacturing topics representing both real engineering application and learning use cases. Four different case studies are taken into consideration addressing manufacturing at different levels of detail and from different points of view. They are as follows and consider the manufacturing process to be executed, the *equipment*, the *human workers* and the *monitoring*:

1. Manufacturing system (re-)configuration
2. Process-System design and analysis
3. Humans in manufacturing
4. Manufacturing system monitoring

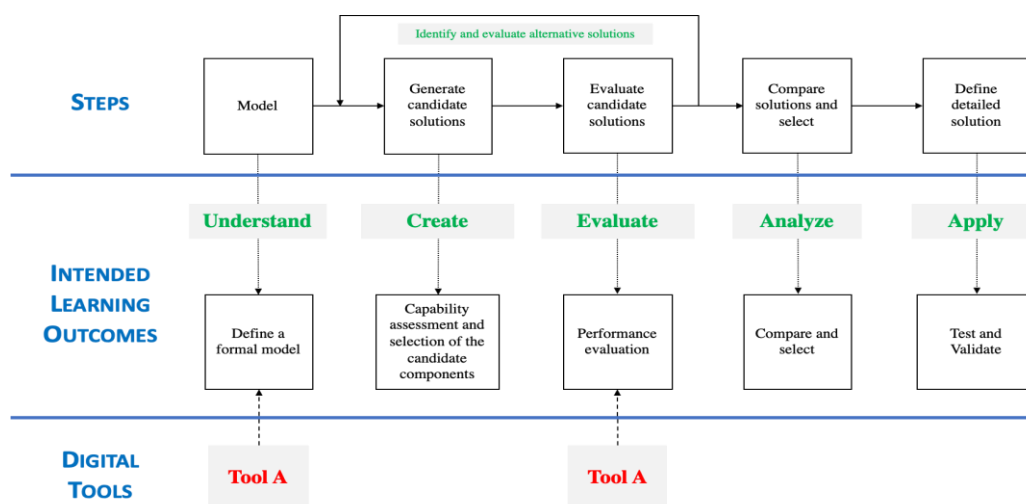


Figure 2: Structure of a workflow

For each case study, a workflow can be defined to represent the logical steps to solve it and identifying the best solution. The standard three-layer workflow structure is illustrated in Figure 2, acting as the definition of a common skeleton to be adapted and tailored for the different application cases. The first layer describes a sequence of steps, starting from the formalization and modelling of the problem under study, to the definition of the final solution, passing through design and analysis steps. For each step, the Intended Learning Outcomes (ILOs) are declared and linked to proper digital tools whose utilization aims at improving the quality of the ILOs and the pace to reach them. Moreover, ILOs describing what students should know and be able to do at the end of the learning activity that they do not know before.

### 3. Case Study of Manufacturing System Configuration

The configuration of a manufacturing system is a key activity since the decisions to be taken have a long-term impact on the lifecycle of the system under study. Starting from a set of requirements in terms of capability and capacity, the set of pieces of equipment and their arrangement must be analysed to find the best configuration solution, for example – minimizing the equipment cost (under performance constraints). In order to do this and specifically for reconfigurable manufacturing systems, a very large number of alternative configurations should be evaluated and analysed. Thus, digital tools can support the management of real industrial cases even in teaching engineering approaches in Bachelor or in Master courses.

#### 3.1. Workflow for the case study

The configuration and re-configuration process can be described in terms of a sequence of steps, starting from the modelling of a hypothetical system or the existing one (in case of re-configuration) and ending in the virtual commissioning where the selected best solution is validated and tested.

The first step entails the modelling of the system under study. In case of green-field design, these modelling entails some basic decisions, for example, the adopted architecture (job shop, flow shop, etc.), the class of transportation schemes and routes, etc. In case of a re-configuration, this modelling phase is devoted to provide a formal representation of the existing system and the associated constraints.

Once the modelling phase has been completed, the configuration workflow proceed to the selection of the pieces of equipment to be in the system (Select equipment) and, then, a set of candidate solutions are generated by composing the pieces of equipment in different alternative combinations. These two tasks have to take as input the characteristics of the products to be produced, the associated production process, the derived capability associated to the process steps and the requirements in terms of volumes, flexibility, etc. The final output is the formal representation of the candidate system configurations to be further analysed. During the execution of these steps, backtracking actions can be operated to modify/improve the selected candidate configuration grounding on the assessment of the associated capability.

These candidate configurations are evaluated in terms of production performance. First, analytical approaches are used to quickly evaluate and possibly slim down the set of candidate configurations (Analytical evaluation of the candidate configurations). Then, Discrete Event Simulation (DES) approaches are used to provide a more detailed evaluation (DES evaluation of the candidate configurations).

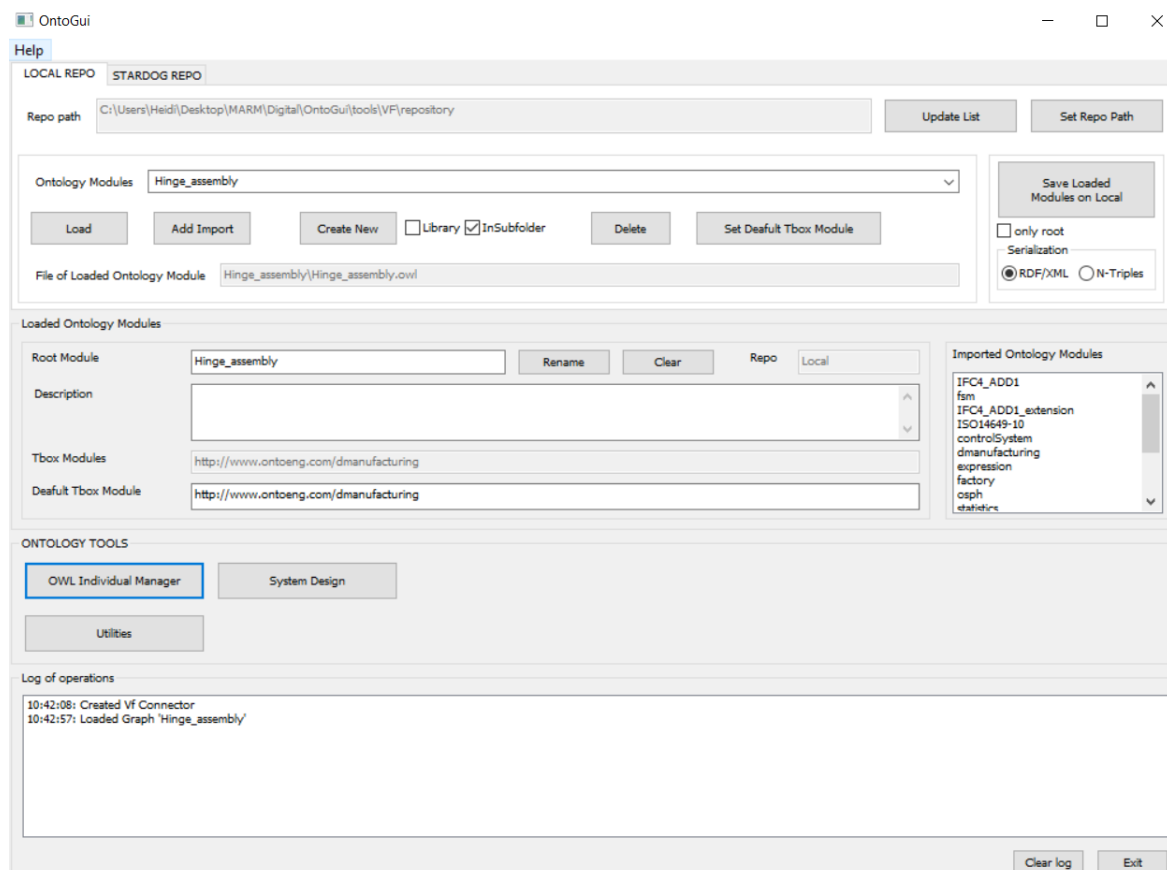
After these two performance evaluation steps. The candidate solutions are transformed in more detailed layouts to assess them in a more realistic way and, in the end, the best solution(s) is (are) selected. The realistic environment of a manufacturing/production system can be created through 3D modelling and visualization tool.

### 3.2. Testing of tools in joint learning lab of students

The developed workflow for manufacturing system configuration and the identified digital tools in VLFT were tested in the joint learning lab of students. It was the first joint student workshop, held under the climax of ERASMUS VLFT project. The purpose of the joint student workshop was to develop and test the set of identified digital tools, and improve these tools through students' feedback. In the workshop, 11 different students from 3 different institutes were involved in developing and testing the digital tools. Tutors and evaluator from partner institutes were also participated in the workshop.

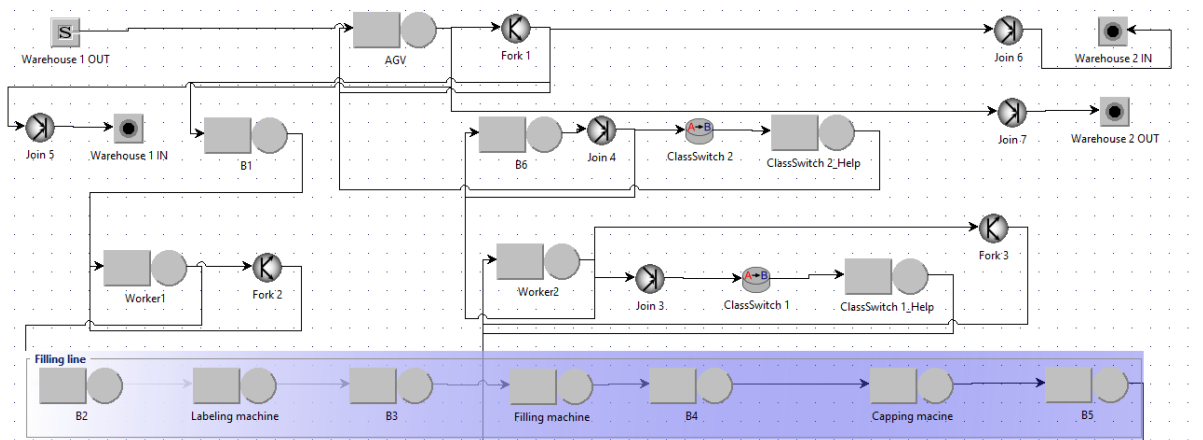
The development, learning and testing of the digital tools were practiced within two phases. During the first phase, students worked independently at their home institutes. During the second phase they were involved in a joint workshop and were asked to work together by exchanging information, improving their skills and learning from each other. The students were divided into two mixed groups considering the technical skills and the activities they already addressed. Each group addressed a different use-case and following three groups of activities: a, b and c specifically tested with the use-cases. Students submitted their work, which included: the formalization of the use-cases using OntoGui, simulation models using both Arena and JMT, a representation in virtual reality of the use-cases using Unity3D.

- a) Formal modelling and defining production (assembly) processes of use-cases by using OntoGui (see Figure 3)



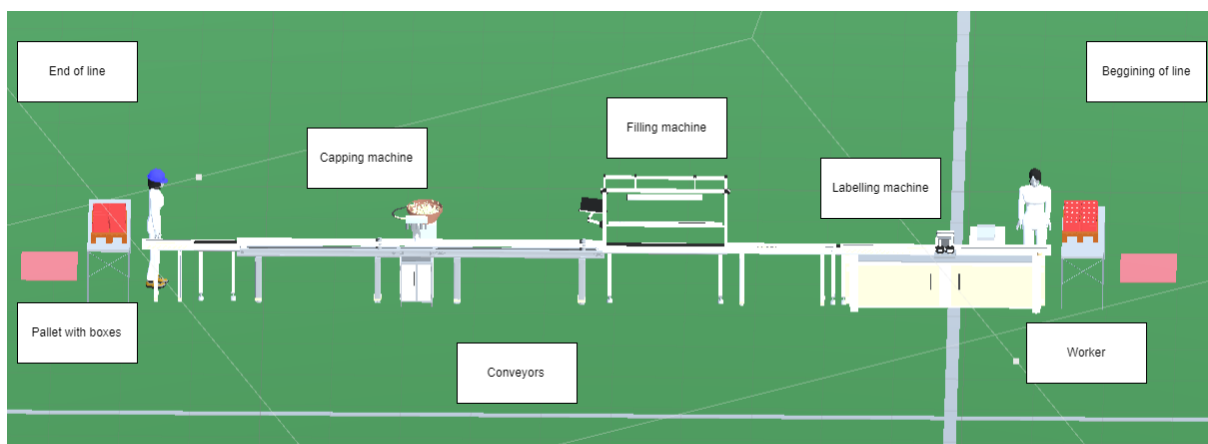
**Figure 3:** Use-case example of OntoGui

- b) DES for performance evaluation by using JMT and ARENA. Prepared a procedure for the automatic generation of a DES model using JMT starting from the OntoGui repository for both use-case (see Figure 4).



**Figure 4:** Use-case example of JMT

c) 3D modelling, visualization and animation for products and systems associated to the use-cases. 3D scenes were generated via Unity3D (see Figure 5) and CAD models were created through solid modelling software and open source libraries. The animated output was visualized by means of VR.



**Figure 5:** Use-case example of Unity3D

Some concluding observations of tutors about the students’ work: (*pros*) – the virtual representation of both the use-cases was in line with the expectation accordingly to the available time. (*cons*) – the formal representation of the assembly use-case was not in line with the expectations, the quality of the simulation models was low, the integration between digital tools was not addressed sufficiently.

### 3.3. Student feedback

After the workshop, students’ feedback was collected through a survey. The survey consists of the questions related to the following aspects (few points are included in this study), the corresponding graph of responses for each aspect is portrayed in the Figure 6.

- a. General appreciation for the workshop
- b. Learning ability
- c. Learning level reached
- d. Self-evaluation

The satisfaction of the students is expressed in a 1-5 scale: 1 = *Very dissatisfied*, 2 = *Dissatisfied*, 3 = *OK*, 4 = *Satisfied*, 5 = *Very satisfied*



**Figure 6:** Graphical representation of students' feedback about the workshop

From the survey outcomes, it concludes that the student workshop was satisfactory, students have learned, contributed and tested the digital tools and methods. However, there were few shortcomings like in the learning outcomes of the digital tools used with respect to workflow definition, performance evaluation and virtual modelling. It was also observed, there were some missing competences related to programming and the integration of digital tools. Moreover, communication and cooperation skills were found out as very necessary aspects in the team work.

#### 4. Conclusion

The development of virtual learning factory toolkit is a contribution to the modern learning in manufacturing engineering education. This work presents the framework for the VLFT, the suitable digital tools were identified and included into the toolkit, learning activities were defined, and workflows were designed and tested that help in the study of production systems and enhanced the ICT skills in manufacturing curricula. The selected and tested digital tools facilitates to define, evaluate the



performance, visualize the production systems and related processes in the virtual environment based on the 3D simulations, virtual and augmented reality concepts. Testing and using the new VLF toolkit, improve the ICT skills of teachers and students, promote better understanding of the actual processes and production management, including developing of virtual factories. The tools and related learning activities were experimented in the form of joint students' workshop, which resulted in a positive experience and a way to improve the VLFT. The integration of digital tools was not sufficiently addressed in this study. Within the last segment of VLFT project, it will be enhanced and disseminated in the future workshops.

## 5. Acknowledgements

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