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RECONSTRUCTING A MANUFACTURING LABORATORY TO A LEARNING FACTORY: A TTK UAS CASE STUDY

The rapidly developing manufacturing industry constantly needs top specialists to ensure sustainability (resource optimisation, production efficiency, sustainable products) and to implement the latest know-how (digitalisation, big data analytics, artificial intelligence). Those requirements, in turn, place higher demands on universities, curricula, teaching staff and, above all, laboratories to teach the concept of a smart factory. TTK University of Applied Sciences (TTK UAS) has come to an understanding that renovation of existing production laboratories is unavoidable. Keeping this in mind, a study needs to be conducted to investigate best practices and strategies to develop a new concept that best suits TTK UAS. In this article, the authors examine how to renovate and update the existing university laboratories (production, measurement, CAD/CAM) using simulation software with a Learning Factory concept in mind while still ensuring research development capability. Using the case-study methodology, factory automation simulation software, and a new pedagogical approach, the TTK UAS industrial engineering laboratories are functioning as a cluster, achieving higher learning and R&D efficiency.

1. INTRODUCTION

Labour market trends have recently changed significantly. One of the main reasons is the COVID-19 crisis and the broader adoption of various AI technologies. Previous trends, such as robotization and automation, can also not be ignored.

The WEF study of future jobs in the industry shows a decrease in simple manual labour jobs, especially in assembly, and an equivalent increase in process-based jobs, such as welding, mold-making, etc. [1]. A general conclusion can be drawn that the industry is reorganizing, replacing lower and simpler skillset jobs with automated processes, and creating more jobs requiring specialized skills and knowledge. Such a tendency is also confirmed by a different study [2], which for the near future predicts a 27% decrease in physical and manual labour, a 17% decrease in the need for basic literacy and numeracy skills, a 58% increase in special technological skills, a 33% increase in social skills (taking the initiative and

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leadership) and 24% increase in higher cognitive skills compared to the 2016 skillset. The decrease in physical and manual labour can be explained by more comprehensive automation in the industry and the growth of technological skills needed by linking different technologies (machine learning and automation). Analytical thinking, creative thinking, and technological literacy have become essential skills in 2023 in the view of employers [1].

Very rapid changes in organisational culture were triggered by the COVID-19 crisis. It is possible to divide organisational development models into pre-crisis and post-crisis models. The post-crisis changes in the institution's work organization were nothing new. The main developments were related to agile and flexible work, i.e. Smart Working (SW). Previously, such models were mainly applicable to white-collar workers and some service economy sectors. After the crisis, the manufacturing industry had to adapt and rethink its work organisation to prevent production stoppages and ensure sustainability. Still, it is important to understand that the SW concept, based largely on remote work, doesn't completely apply in manufacturing. Production processes can only be carried out with the assistance of equipment, and therefore, it is usually impossible to separate the person from the process. Various sociotechnical models have emerged, summarised as Industrial Smart Working (ISW) [3, 4]. ISW focuses on greater integration of humans, organisation and technology, which does not remove humans from the production process but facilitates and supports the interaction between humans and machines.

Due to previous, entrepreneurs must constantly strive to acquire qualified labour in a rapidly changing environment. Undoubtedly, universities and higher education institutions also must go along with these changes and, in some cases, anticipate them to ensure that students are given the fundamental knowledge and skills to develop top specialists in the industry.

2. LEARNING FACTORY

Learning Factory (*LF*) is a partly artificial environment that combines academic teaching, learning, scientific research and industrial production capacity into one test platform for simulating interdisciplinary scenarios [5–7]. Students of various curricula, lecturers, and industrial specialists are involved in the scenarios. In the design and development of the laboratory base, it is essential to follow the sectoral development trends. The European Factories of the Future Research Association (*EFFRA*) has proposed the following key development areas [8]:

- Advanced manufacturing processes;
- Adaptive and smart manufacturing systems;
- Digital, virtual and resource-efficient factories;
- Collaborative and mobile enterprises;
- Human-centred manufacturing;
- Customer-focused manufacturing.

The purpose of creating an LF has to be similar to industry – developing and producing a product or service, starting from the development and ending with disposal while simulating or performing all the processes in between. This approach has shown better results compared to classical learning for the acquisition of knowledge and skills [9].

2.1. TTK UAS LEARNING FACTORY

At TTK University of Applied Sciences (TTK UAS), like in many other universities, various technology laboratories have been created to study industrial engineering. The study process is carried out by focusing only on one technological process at a time and performing the practical work necessary to connect theoretical knowledge. Laboratories work separately, and the connections between them can often go unnoticed by students. Based on the advantages of the LF concept, changes must be introduced to the existing laboratory base of accordance with the needs of Industry 4.0 (I4.0) [10].

Figure 1 shows the simplified process after reconfiguration. It begins with the customer (placing an order) and ends with the customer (receiving the order from the warehouse and preparing an invoice).

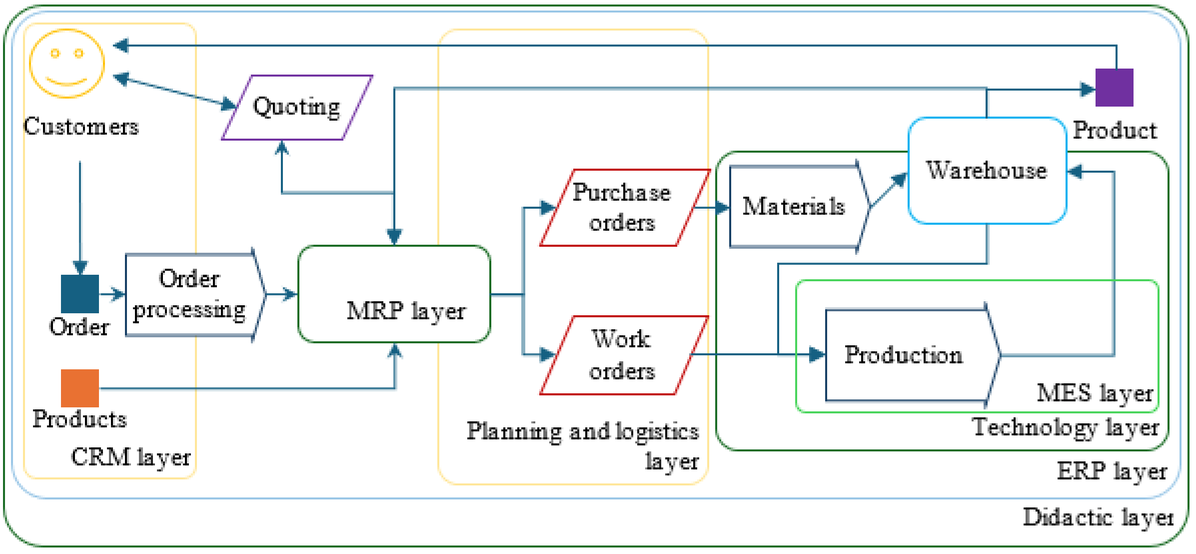

Fig. 1. Conceptual model of TTK UAS LF work process

The process is covered by different layers that ensure the necessary competencies. The layers and their competencies are listed below:

- Technology – All physical equipment (CNC turning and milling centres, machine tending and transport robots, Tools) and software (CAD/CAM/CAE). The selection of equipment is based on the suitability analysis [11];
- Material Requirement Planning – product, service information (BOM, BOO, deadlines) is analysed, planned and evaluated;
- Customer Relationship Management – collection, processing and planning of activities for customers and people valuable to the company;

- Planning and Logistics – internal and external logistics management;
- Enterprise Resource Planning – planning and management of the factory as a whole;
- Didactic layer – covers all previous layers, responsible for using optimal teaching methods and techniques.

3. PEDAGOGICAL APPROACH

To carry out the teaching process effectively, it is not enough to change only the learning environment. To get the best results, we must introduce changes to the teaching methodology and the teaching process. Based on the literature review, the teaching methodology that ensures effective assimilation of engineering education comprises the psycho-didactical model of engineering Fig. 2 and the competency model of engineering educators Fig. 3.

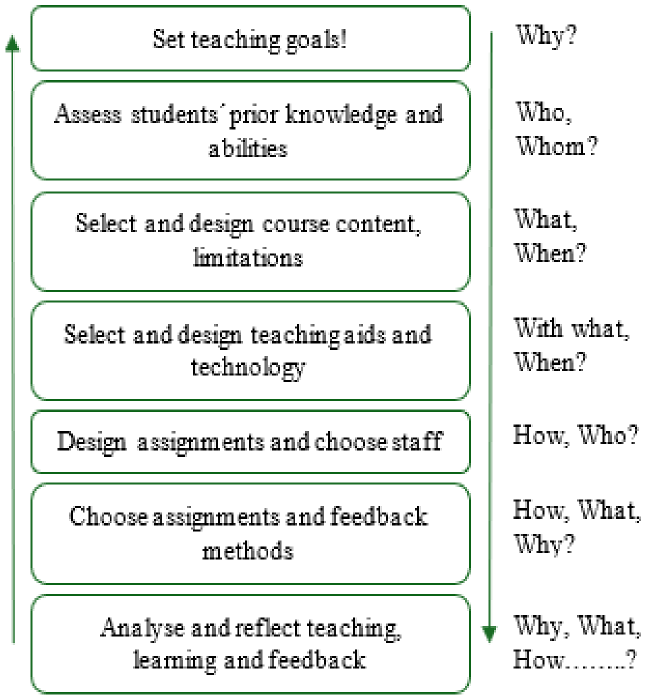

Fig. 2. Psycho-Didactical Model of Engineering Pedagogy [12]

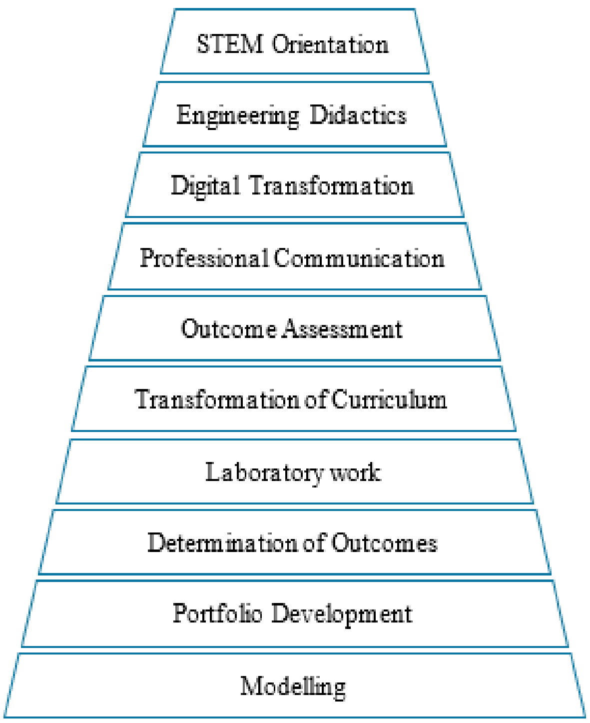

Fig. **3.** Competency model of Engineering Educators [13]

The teaching process must be a well-thought-out whole, divided into lecture-based sprints and independent and extra work. Since LF teaching is integrated between different fields, it is extremely important that the cooperation between the lecturers and specialists is sufficient, and information moves quickly for corrections in the lecture plans.

Conducting effective and inclusive lectures and sprints requires various methods and skills Fig. 3. The common denominator of the methods is STEM, which stands for Science, Technology, Engineering, and Math.

4. CASE STUDY

This case study is an analysis of the layout of the TTK UAS laboratories and the implementation of LF principles in the new Gene Haas Advanced Machining Lab (*GHAML*). The developed LF must provide the necessary knowledge and skills to the engineers in the I4.0 production system and point out the connections between various modules, configurations, and their impact on the final product. GHML consists of technology, process monitoring sensors, software and connecting links. The production process is described in Fig. 4. The input is product data (drawings, 3D models, BOO), required materials (BOM) and work orders (MRP/MES). The product will be manufactured according to the BOO, and each technological step or operation is reported to the manufacturing execution system (MES). A corresponding CNC program is created for each operation. When all the steps are completed and the quality control is passed, the product is declared ready.

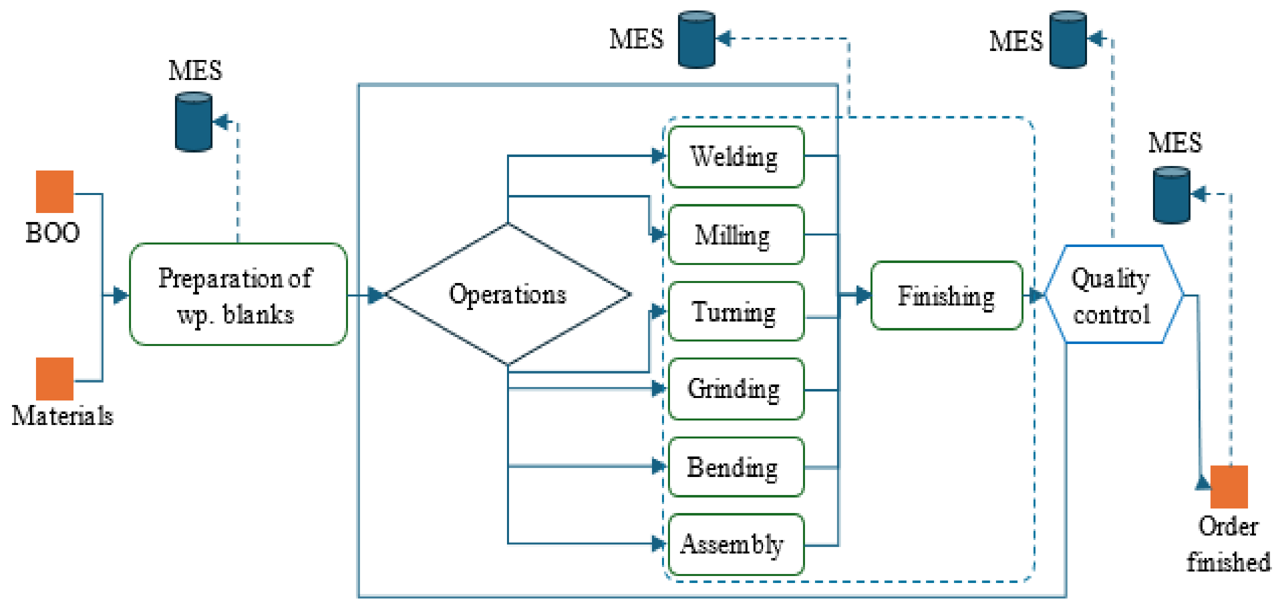

Fig. 4 Production process flow

To implement the production process, it is necessary to perform a manufacturing simulation analysis to determine a reasonable workflow in the production unit. At the beginning of the analysis, it was clear that to fulfil the set goals, the laboratories located in different buildings at the university (measurement laboratory, CAD/CAM classroom, welding and assembly laboratory) must be brought together on one level and location. All the while ensuring that the travel path between laboratories is reasonable. The following were chosen as the objectives of the relocation:

- Aggregation of similar processes and logical sequential arrangement;
- Material flow as linear as possible;
- Common warehousing for materials;
- Quality control in the LF premises;

- Optimisation of travel path lengths and queues;
- Sensors necessary for process monitoring and control;
- Addition of reporting terminals.

A virtual model was created with the help of 3D manufacturing simulation (Fig. 5) software according to the conditions of the university. CNC-machines, industrial robots, other equipment and furniture were inserted in the virtual environment. During the simulation different layouts, as well as machine tending and transport robots were observed [14]. As the last step, using virtual reality technology, all rooms were virtually walked through and adjusted to be comfortable for the person (Fig. 6).

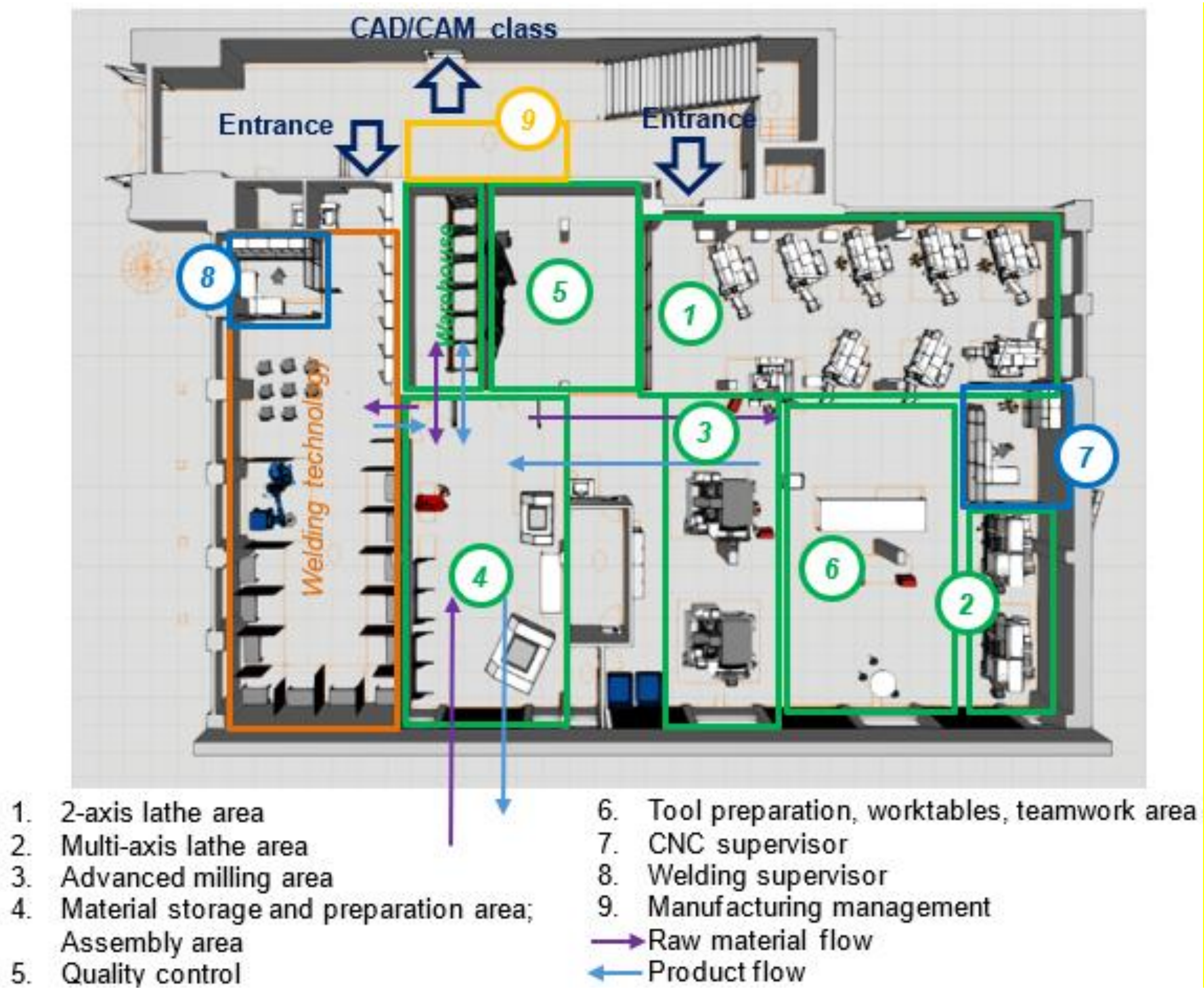

Fig. 5 Gene Haas Advance Machining Lab layout

CNC centres are connected to the MES system using three solutions: Evocon (EC), Global Reader (GR) and Haas WiFi connect (HC). In the case of the first two, spindle on and off times are logged. Logged data is used to calculated the Equipment Overall Effectiveness (OEE) together with parts count reporting. In the case of HC, data logging is broader, including program name, processing speeds and states, among other parameters.

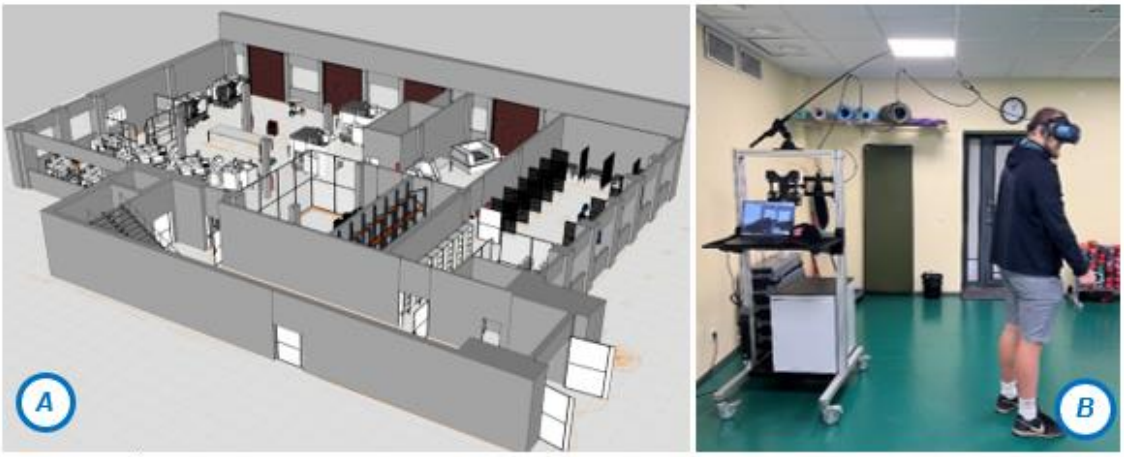

Fig. 6. Validation in virtual reality. A – VR model of the GHML, B – VR walkthrough

5. CONCLUSIONS AND FUTURE WORK

TTK University of Applied Sciences, receiving input from the labour market, professional associations, and entrepreneurs, understood the need to update production technology laboratories. In order to effectively carry out the laboratory development process, a sectoral study had to be conducted, and the characteristic features of a modern teaching laboratory had to be found. A literature review of the LF concept and the pedagogical approach to use in that framework was carried out. Suitable methods and tools were selected, and the Gene Haas Advance Machining Lab learning factory concept was designed and completed during the case study. A list of goals and parameters was drawn up, emphasising sectoral development trends such as adaptive and smart manufacturing systems, VR/AR technologies, human-centred and customer-focused manufacturing, and new directions and developments in pedagogy.

The Psycho-Didactical Model of Engineering Pedagogy was decisive when setting the goals. The application of the model starts with the student, whose prior knowledge is evaluated, and the objectives are set. Hereby, smart production is divided into small operations or workshops, through which the student will gain the necessary prior knowledge to understand the entire production process faster and more effectively. The biggest risks are the integration of different parts and subjects into a single whole and the communication between teaching staff.

Based on the above, a new process was developed, similar to the production process in a manufacturing company but also carrying all the necessary characteristics of the higher education teaching/learning process. The manufacturing process was planned so that similar operations were arranged in a logical sequence and quality control in the middle. Common warehousing for materials used in different operations and material flow as linear as possible, achieving both time and space savings. The proposed solution is unique among Estonian higher education institutions. The developed process was the basis for further analysis. 3D manufacturing simulation and virtual reality software tools were used to perform the analysis. With the new concept, the lengths of the travel path were decreased more than five times. The production flow was optimised for workplaces where queues might occur (sawmills, measuring devices, computer workplaces), and parallel production capacity was added where necessary. Between areas 4,1 and 6, the mobile industrial robot MIR100 was the best material transport solution. In area 3, the preparation of tools was organised using tool pre-setters and QR codes for information transfer. The following steps will be the renovation and reconstruction of the laboratory premises and the implementation of the above-mentioned results.

For future research, it is necessary to monitor and document how the proposed solution fulfils the originally set goals in real teaching and development. The biggest danger here is the fact that smart manufacturing is a constantly developing concept, and the currently implemented solutions may not be the most effective and sustainable in the long term. Also, we must consider that if there is a major turnaround in SM, it will be quite difficult for the university to meet the investment and research needs. According to this, it is vital to integrate the existing systems, narrow the research field, and offer usable solutions to the local industry.

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