Smart Learning Factory – Network Approach for Learning and Transfer in a Digital & Physical Set up

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Abstract. The smart factory promises significant cost savings particularly for high cost labor markets. The challenge in teaching smart factory courses or digitalization of manufacturing is the complexity of the topic. The smart factory is understood as a future state of a fully connected and flexible manufacturing system, operating autonomously or with optimized interaction between humans and machines by generating, transferring, receiving and processing necessary data to conduct all required tasks for producing different types of goods.

Due to this complexity the standard classroom teaching is not achieving satisfactory results. A key element is the understanding of the physical goods process linked to data and IT infrastructure. This digital representation of the physical world is then the base for learning from data for a specific use case for the factory of tomorrow.

This paper describes how the Smart Learning Factory as a sample case at the university of applied sciences OST will be set up as an unique approach with three interconnected locations with a real, daily manufactured product mainly for educational purposes. Over the last years, successful initiatives towards the Smart Learning Factory have been established. This base is the fundament for a significant larger step. We are now approaching this next horizon with strong support by the Canton of St. Gallen and the strategic focus of the entire school. Our goal is to give all students of all technical and economic studies the opportunity to experience the smart factory in the real world. A fully digital twin of the physical world will play a key role in understanding the future of manufacturing. This makes it possible to discuss the conceptual approaches, challenges and success factors to implement a smart factory.

Keywords: Smart factory, Industrie 4.0, Learning Factory, PLM, ERP, Machine Learning, OST, HSR, Digital Transformation

1 Challenges and Target for a Smart Learning Factory

1.1 Understanding the Smart Factory

In recent years, the concept of a smart factory has often been seen as an answer to cope with the strong cost pressure in the high cost labor market. There is no general definition of the smart factory. Elements of a characteristics such as “agility”, “modularity”, “automation”, " cyber-physical-systems ", “combination of software, hardware and manufacturing technology”, “robotics”, “digital twin”, “IT systems” “collaboration between partners” and “learning from data” are often used [7, 9, 13, 14]. In addition, there is often a focus on the sharing between sensors, machines and production systems [9], partially also with a link to a data cloud. The combination and modeling of sensor data, machine data and production systems data will generate new insights, such as quality prediction of produced parts or preventive maintenance information for a production machine.

Based on all elements, we define the smart factory [12] as a future state of a fully connected and flexible manufacturing system, operating autonomously or with optimized interaction between humans and machines by generating, transferring, receiving and processing necessary data to conduct all required tasks for producing different kinds of goods.

1.2 Learning and Transferring

In our daily work as teachers for our engineering students, we are very challenged explaining the smart manufacturing concept on this theoretical basis. Standard class-room teaching does not meet our goals in developing the appropriate student competences. New ways are needed to digest the breadth of the smart factory topic. We are certain that a learning factory, with its ability of real world teaching and creating personal experience for the students, is our way for future teaching.

It is fundamental for students to understand the complexity of the implementation of a smart factory. These implementation barriers are the outcome of two research projects funded by Innosuisse[1] with 6 industrial companies, the University of St. Gallen and the Hochschule für Technik (HSR) [5, 6, 9, 13]. A total of 8 different levers were identified that have to be overcome for a successful implementation of the smart factory (see Figure 1). A key topic is selecting the right use case, followed by understanding the existing processes and data management. When the smart factory path is started, the concept of lean and standard production management techniques hopefully is realized in advance. This will plot the base for the digital journey. Before a new IT system with the appropriate security concept is implemented, it must be ensured that the mathematical model for analyzing the data will generate the required insights for continuous improvement for your use case. The people topic is a massive challenge. Job fear as well

[1] Innosuisse is a governmental organization that funds applied research projects in Switzerland. It is mandatory in every project that industrial companies join forces with academia. A defined business plan by the industrial companies makes the result tangible.

as technology and competence gaps need to be addressed early in any smart factory journey.

In the mechanical and industrial engineering curriculum, we have defined that our students need to reach the Bloom taxonomy competence level 6 [2, 3] for the smart factory lectures. The implementation of the smart factory considering the breadth, complexity and barriers require this substantial learning goal for these two studies.

We have decided to convey the topic of smart manufacturing in existing modules in all technical and economic studies at both the bachelor and master level. In addition, we aim to offer further specific courses around the smart factory. Every module defines the Bloom taxonomy competence levels for itself. The Smart Learning Factory will also support these studies to reach the appropriate taxonomy levels depending on their specific course curriculum. Specific lectures, exercises and practical work will be created.

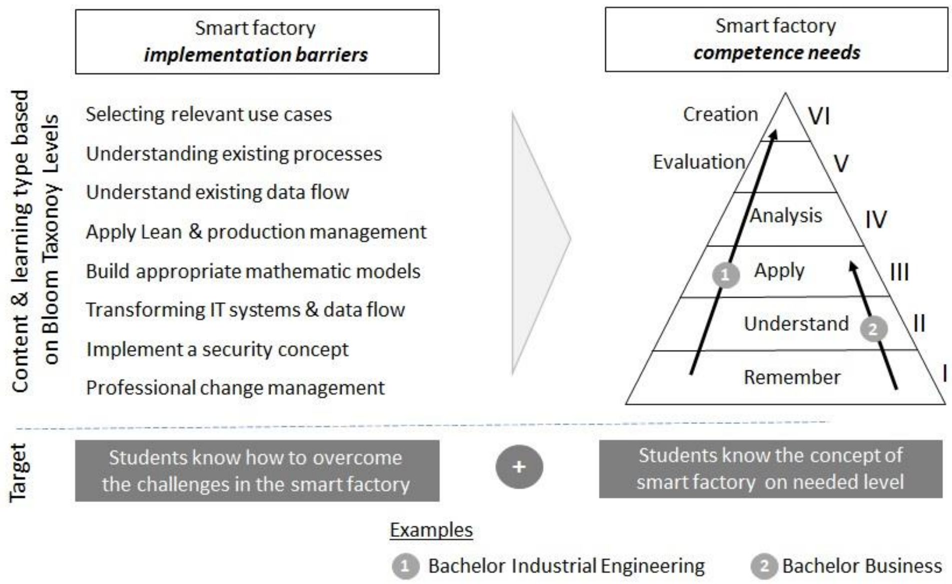


Fig. 1. Smart factory learning targets for the students in regards to competences and implementation barriers for the smart factory

Specifically, the Smart Learning Factory will support the following learning and organizational goals for our school. These goals have been guiding us in defining and building our Smart Learning Factory since 2016.

Learning Goals

1. Students can experience, model and develop the flow of data and materials flow for a smart factory
2. Students can use, configure, implement and further develop the relevant IT systems with their interfaces (IT and Internet of Things) and the required master data

3. Students can understand, model and program data analytics up to machine learning algorithm based on all available data from the Smart Learning Factory
4. Students know how to transform an existing production facility into a smart factory
5. Students will experience failure and can progress successfully in an agile approach
6. The learning goals are relevant for all technical and economic study programs and should allow to tailor different taxonomy levels and smart factory content for the respective course

Organizational Goals

7. Students will be involved in creating the lecture and the future development of the Smart Learning Factory through project work, bachelor and master thesis.
8. The creation of the elaboration examples and the content of lectures are a journey and needs a wide involvement of expertise of many professors

2 First Step Towards the Smart Learning Factory

A learning factory stipulates two directions. Schuh et al. distinguish, based on the definition by the CIRP Collaborative Working Group on learning factories, a learning factory in a narrow and a broader sense. A factory in the narrow sense signifies a real production system and implies the manufacturing of a physical product. The aspect of learning highlights the gain of knowledge as a purpose. Then we talk of a factory in broader sense. Then a physical product is not necessary [15].

Since 2016 we have focused on a model and not a real product. The complexity and investment on the aspect of learning with a Smart Learning Factory were the driver for this decision. We used a pick-and-place LEGO robot as a product. Fradl, Sohrweide and Nyffenegger described the example extensively [4]. The robot sorts LEGO bricks. This LEGO robots exists as a full digital twin. In addition, we have installed different sensors to collect data of the robot in production. A RFID chip identifies all LEGO bricks that we sort. Serialization of the robot with its key components is implemented using a 2D-Matrix code and the link to the ERP system. Specific Kanban processes were set up using ERP-controlled Kanban transparency dashboards. We have designed the full LEGO robot in CAD, then send the data to a PLM system, where we are managing the bill of material and the document change process. This BOM is then transferred into the ERP system, where we have set up a factory to produce the LEGO robot. In addition, we implemented a configurator in the ERP system to sell the different versions based on product management guidelines. Currently, we are extending the IT system landscape into the MES system. This system will then be the central data collector and allows data to be displayed on a dashboard.

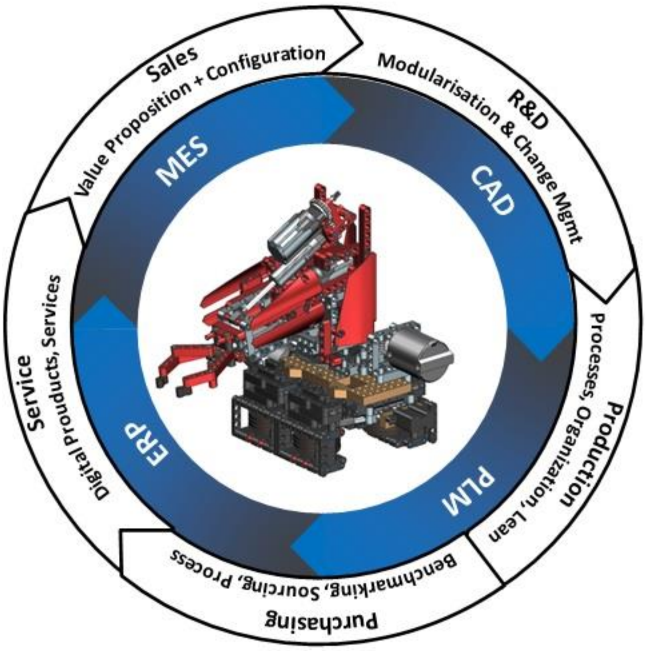


Fig. 2. Elaboration example LEGO pick & place robot

A key topic are the different lectures and practical work with semi – guided exercises along the way. In one course the students work in groups of 5 and have to design and build a production plant to manufacture the pick & place robot. They also have to configure and partially implement the required IT systems. The goal of the course is to configure and issue a real purchase order for their built production plant for one customer order for one pick & place robot. Organizationally the course starts with the R&D process, where the focus lies on modularization and document change management. Then followed by the manufacturing, sourcing and service module. For this course, the LEGO bricks offer a big advantage. You can assemble and disassemble the product. By doing so, you will experience the bill of material, a possible manufacturing and assembly strategy including stock concept. Additionally, two critical parts have to be sourced and a service portfolio including digital services has to be defined. At the end of the course, a sales approach including a digital configuration of the robot completes the lecture.

This elaborations example have been developed and continuously improved by many bachelor and master thesis. Additional funds by the school were highly important. The school sees this elaboration example as a corner stone for the education for the mechanical and industrial engineers.

With this model, we have built a first and comprehensive step of our Smart Learning Factory, primarily focusing on the data flow. The basis for any smart factory is an integrated data flow and processes [10]. In addition, the processes need to follow waste free lean processes as much as possible. Through assembly and disassembly of a LEGO based product it is very easy to understand certain topics (Bill of material, Kanban flow), but limitations are reached when physical material flow is needed (size, complexity, technology, organizational aspects). The digital twin of the LEGO robot is on the other hand very tangible, and the students can switch easily between the physical and the digital world. The different interfaces between CAD – PLM – ERP – MES can be experienced, discussed and further developed.

	Achievement with LEGO Robot
Learning Goals	
• Students can experience, model and develop the flow of data and materials flow for a smart factory	• data: yes / material: no
• Students can use, configure and develop the relevant IT systems with its interfaces (IT and Internet of Things) and needed master data	• IT systems: Yes / IoT: partially
• Students can understand, model and program data analytics up to machine learning algorithm based on all available data of the Smart Learning Factory	• no
• Students know how to transform an existing production facility into a smart factory	• partially, primarily on the data side
• Students will experience failure and can progress successfully in an agile approach	• yes
• The learning goals are relevant for all technical and economics studies and should allow tailor different taxonomy level and smart factory content for the respective course	• partially, real factory will help
Organizational Goals	
• Students will be involved in creating the lecture and in the future development of the Smart Learning Factory through project work, Bachelor and Master thesis.	• yes
• The creation of the elaboration examples and the content of lectures are a journey and needs a wide involvement of expertise of many professors	• partially, can be expanded

Fig. 3. Meeting the goals of the Smart Learning Factory with the LEGO robot model

The Lego robot offers a good learning platform for digitalization. The weakness is identified in in the area of experiencing the smart factory on a real product, instead of a LEGO example. This is also the biggest criticism by the students. Although the feedback on the quality on learnings is very positive, the students prefer a real product, e.g. it is difficult to source a LEGO motor or the scaled up real motor based on digital LEGO data. Due to the model and its technical capabilities, we cannot run sufficient production quantities. This limits us from modeling a use case for data analytics or machine learning in a real world environment.

3 Approach of a Physical Smart Learning Factory with Digital Representation

Many initiatives at the same time brought a strong force behind a new approach for a Smart Leaning Factory with a real physical product with further expanded digital representation.

Political and organizational driver: The Canton of St. Gallen is focusing heavily with its "IT Bildungsinitiative" [8] on the IT competencies which should be taught to all students on all level. In addition, three universities of applied sciences (Rapperswil, St. Gallen, Buchs) merge to one new university of applied science "OST" [11] with in total around 4’000 Students, 400 researchers and around 45 Mio Fr. research and project turnover. The new Smart Learning Factory is one cornerstone in this merger, because the different competences of the original universities complete each other very well and make the concept solid and strong. To do so, a large project is set up and supports the integration into one school through the buildup of the Smart Learning Factory. The fund of these two strategic directions is the financial base for the new Smart Learning Factory.

Clear and holistic vision: The school developed jointly a clear and holistic picture to start with. The scope of Smart Learning Factory is not restricted to the manufacturing processes. It will also include the development, purchasing, service and sales processes. In the future, an extension towards integrating partners on the supply chain as well as customers is foreseen in a 2nd step.

Strong research departments: The new University of applied science OST has a very strong technical department with around 200 people and 30 professors that focus on their research mainly in industrial companies. The digital transformation is a key topic in their research. In addition, the research departments own many different production machines from different vendors with relevant production technologies from plastic molding, 3D printing, sintering, grinding, milling, robots, adaptive robots, plastic extrusion, assembly, quality control and testing.

LEGO robot as a successful first step: The success by the LEGO robot motivated the involved people to look for the next step. The feedback of the students shows the direction. We need to have a real smart factory.

Three locations in one school is an advantage: All three schools have focused in the past four years already on the topic of Learning Factory, e.g. the location Buchs built up a fully integrated electronics manufacturing and assembly line. Some significant investments into hard- und software were made. Due to the different focuses of all three schools, all the past investment is 100% complementary. This brought us to the decision to combine all efforts into one Smart Learning Factory over three locations and produce one physical product.

New laboratory building: Due to the significant growth of the University of Applied Sciences HSR in Rapperswil over the past years, the board has decided to build a new 5000m^2 laboratory building, called TechPark. The focus of this new laboratory building will be on the topic of Smart Learning Factory.

Above six driving forces make the significant path forward realistic. Financial and people resources are available. Figure 4 shows the dimensions according to Abele et al.

[1] of the Smart Learning Factory at the newly merged university [11] as a natural progression of existing investments and initiatives.

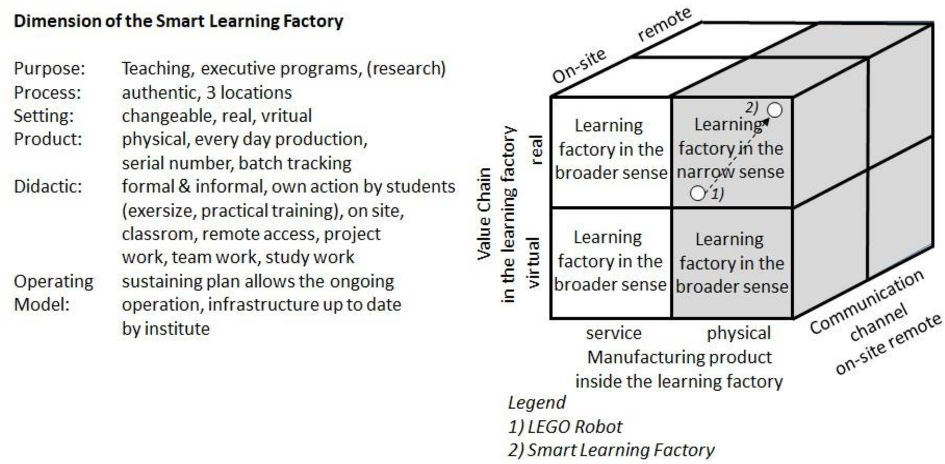
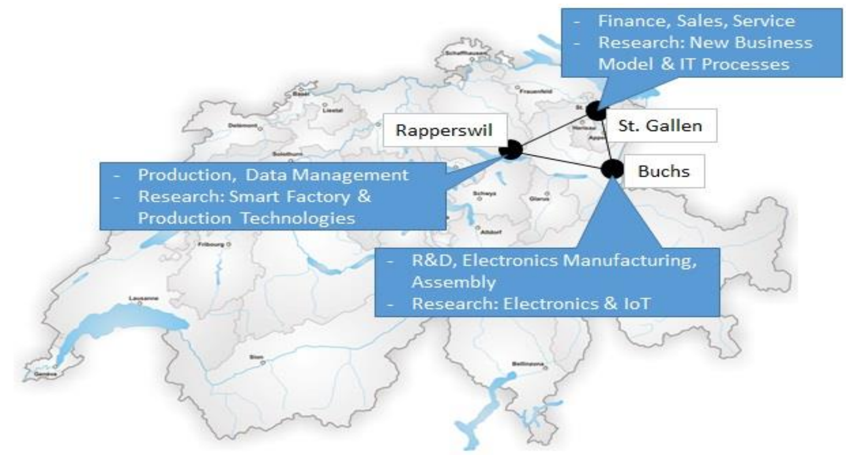


Fig. 4. Dimension of the Smart Learning Factory at OST

The Smart Learning Factory is focusing on producing a physical product daily. The value chain is real and virtual. Teaching is possible on-site and remote. This product will be produced every day. This gives enough production and sensor data. The daily production gives the opportunity for many lectures to involve the Smart Learning Factory in their courses independent from the lecture schedule. In addition, the smart factory will be managed in a production network with three locations in St. Gallen, Buchs and Rapperswil. See Figure 5 below for the role and focus of research for each location.



Source: Wikipedia "Datei:Karte Gemeinden der Schweiz 2017.04.02.png", accessed 22.03.2020

Fig. 5. The three connected sites of the Smart Learning platform with its focus

The nearly 5000m² Rapperswil facility will be connected digitally but also logistically to the different sites in Buchs and in St. Gallen (see Figure 6). In Rapperswil the different parts of the product will be produced or molded, then shipped to Buchs, where the assembly and sourcing takes place. A physical inventory is located in Buchs. In St. Gallen the headquarter with Finance, Sales and Service is organized.

On the IT side, we run the Smart Learning Factory first on one standard ERP, PLM and MES. Additional further ERP/MES tools will be added over time to be independent. Different CAD System or other data sources provide the necessary input data (eg. design, simulation) for the Smart Learning Factory. This concept will allow to integrate continuously relevant learnings of different research project into the Smart Learning Factory. So new technologies and approaches can be added.

All finished products are tracked by serial numbers and batch tracking for relevant material is intended. An RFID Chip is integrated during the molding process. A data matrix code is additionally placed on the product for the serial number identification.

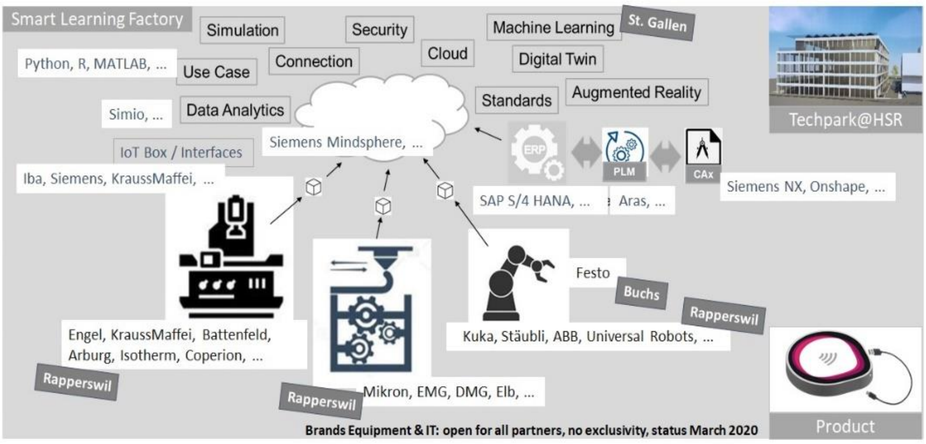


Fig. 6. Technologies used in the Smart Learning Factory @ University of Applied Science OST

The risk and criticism on a Learning Factory in the narrow sense is the complexity, cost and flexibility of needed change [1]. Actual machines and IT tools is a further need. To cope with these challenges, we have set up the following requisites and organizational responsibilities:

- Every institute is responsible for keeping the machines and IT Infrastructure actual and state of the art. It is in their interest to do this as their research also depends on this equipment. Therefore, the infrastructure continues to belong to the institutes.
- Due to the strategic relevance, financial funds are foreseen by the Canton of St. Gallen and OST.
- Since two years, a large project team has been working in implementing the Smart Learning Factory. Specific resources have already be assigned to the project.

- The different competences of the three locations are combined and complement each other. This positive energy is crucial for the success.
- Additional resources for the operation support for the Smart Learning Factory will be assigned.
- Different learning modules will be developed on a central base. This content can then be used by the different lectures in different studies.

4 Project Status, Open Points and Next Steps

The project is in the implementation stage. The new TechPark as a physical building is ready to move in towards June 2020. A key challenge will be setting up the IT infrastructure including all relevant IoT interfaces. We are building up our know how on a frequent basis. Our research activities supporting the connectivity, standardization and integration challenges heavily. Our new Smart Learning Factory is challenging our industrial partners on the machine as well as the IT side. We have included these partners early in the process and therefore support is given. Naturally resource discussions are given. A key point will be to develop the different education modules. We are talking about lectures, exercises and practical work. Our location Buchs has gained over the last two years significant experience on teaching in a Learning Factory environment. The scale of the Learning Factory was different, but the learning can be transferred to our new set up over 3 locations.

We will not underestimate the support needed for this complex set up. We have named two persons for the support on the IT infrastructure side as well as on the machine and connectivity side. We see that this will not be enough and will require further concentration. The project management will be challenging also in the future. Many different ideas on content and strategic direction need to be aligned. It is very critical that a clear agreed and digestible plan is rigorously followed.

With the new Smart Learning Factory, we find a way expanding the knowledge of implementing the digitalization of factories in Switzerland. The industrial companies in high cost countries are very challenged with the high cost structure, therefore, it is fundamental to drive the smart factory content and competences on a next level in education.

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