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The AAU Smart Production Laboratory for teaching and research in emerging digital manufacturing technologies.

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Abstract

The AAU Smart Production project is a research initiative at Aalborg University, Denmark running 2015-2019. The objective of this program is to research and demonstrate emergent digital technologies and to adapt these to the needs and characteristics of Danish industries.

A Smart Production Laboratory (Smart Lab) has been developed as part of the project. The Smart Lab is a small Industry 4.0 factory containing a number of digital technologies which are integrated into a physical Industry 4.0 demonstrator.

Since its establishment in August 2016, a number of projects have been initiated involving more than 50 students and researchers from various departments at Aalborg University. Most of these projects have been made in collaboration with large end-user companies and a number system integrators and technology providers (most of which are SMEs). There has been a great industrial interest in the Smart Lab. Over the last six months, more than 150 companies have visited the lab, and the interest in engaging in projects by far exceeds our capacity. In the future, we are going to focus on setting up collaboration with SME end-users. Furthermore, we will investigate more systematic approaches for improving the knowledge sharing between the on-going projects and enabling better knowledge co-creation. The paper will present the Smart Lab, and demonstrate how we are teaching and researching using a collaborative approach engaging with end-user, vendors and system integrators.

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1. Introduction

Globally, we are experiencing a tremendous change. This transformation has been labeled: "The Fourth Industrial Revolution". Industry 4.0 has been triggered by an exponential growth in digital technologies, which provides manufacturing companies with an increasing number of new possibilities for the development of new products, processes and services – many of these with the potential of being disruptive.

The new technologies will enable that the role of manufacturing will evolve towards an active value creation component within new business models. To understand this new role of manufacturing we need to enhance our conceptualization of manufacturing towards an extended enterprise [1], and consider the new manufacturing solutions as part of a wider evolution towards digitalization of the entire value chain [2].

This is challenging task, since the systems are complex and the technological development moves very fast. This means that companies must learn new technologies and develop new products, processes and services with ever-increasing frequency. Furthermore, the nature of many of the solutions involves multi-disciplinary activities involving experts, which may not be present in the companies (in particular true in SMEs). This require fundamentally different approaches to knowledge acquisition and to designing solutions within the manufacturing domain. Here agile approaches (as proposed in [3-5]) based on fast iterations and prototyping seems very promising.

In this paper, we will show how an inter disciplinary research program (Smart Production) at Aalborg University have been established, explain the visions, and illustrate how we are working with an integrated prototype based approach to research and teaching in close collaboration with end-users, vendors and system integrators. The next section will present the Smart Production program; following this, our Smart Production Laboratory will be described. Then we present an example of one of the projects carried out in the laboratory, and finally we will discuss the first results and conclude

2. The Smart Production research program

The work presented in this paper is a part of a research program (Smart Production) at Aalborg University (see www.smartproduction.aau.dk for more information). The objective of this program is to research and demonstrate emergent digital technologies concepts and methodologies and to adapt these technologies and concepts to the needs and characteristics of Danish industries.

The Smart Production program is using an interdisciplinary approach, with participants from a number of different research areas (e.g. mechanical engineering, robotics, computer science, electronics, and management). These partners work together in a number of PhD-projects on various relevant topics (e.g. big data, cyber physical systems, compliant robots, virtual commissioning, proactive supply chains).

The present budget of Smart Production and adjacent projects sum up to approximately 7 mill euro. Currently, 8 PhD's and 10 senior researchers work with topics in and around Smart Production. Furthermore, a number of companies (end-users, technology providers and system integrators) are associated Smart Production. These companies are either active in the projects or are providing Smart Production with their technology for research, tests and demonstration.

We have realized that the nature of the new digital technologies, and the involvement of researchers and students from several different fields of studies, and practitioners from end-user companies, technology vendors and system integrators, require us to take a new approach to research and teaching.

Hence, we have decided to prioritize fast iterations, prototyping and demonstration through interdisciplinary collaborative lab projects. These projects in the lab will not completely replace traditional mono topical research. Likewise, these lab projects are not intended to replace industrial innovation projects. Instead, it is our hypothesis that lab projects will facilitate that researchers, students and companies meet and in that way, facilitate to co-creation of new knowledge (see figure 1).

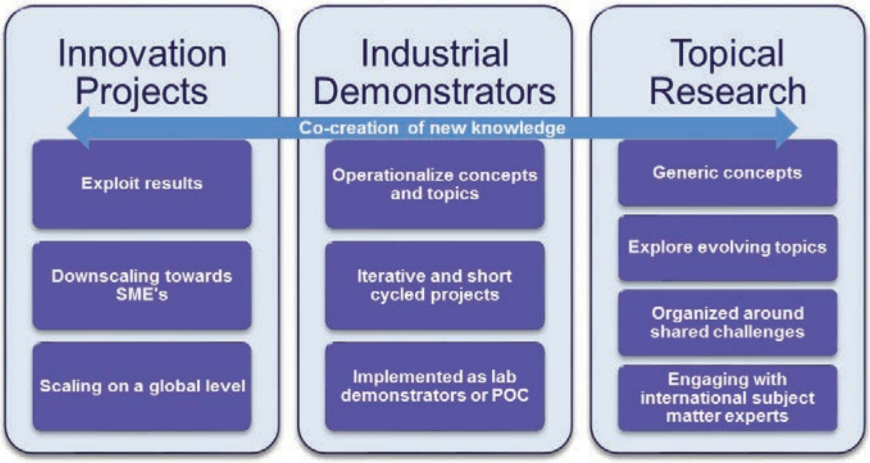

Fig. 1. An Engagement Model for Research and Innovation

3. The Smart production lab setup

Central in the approach we have taken in Smart Production is the Smart Lab, which is a "small Industry 4.0 factory" integrating and demonstrating Industry 4.0 technologies. It acts as a platform, which brings together researchers, companies and students in various integration and demonstrations projects. An overview of the Smart Lab is shown in figure 2.

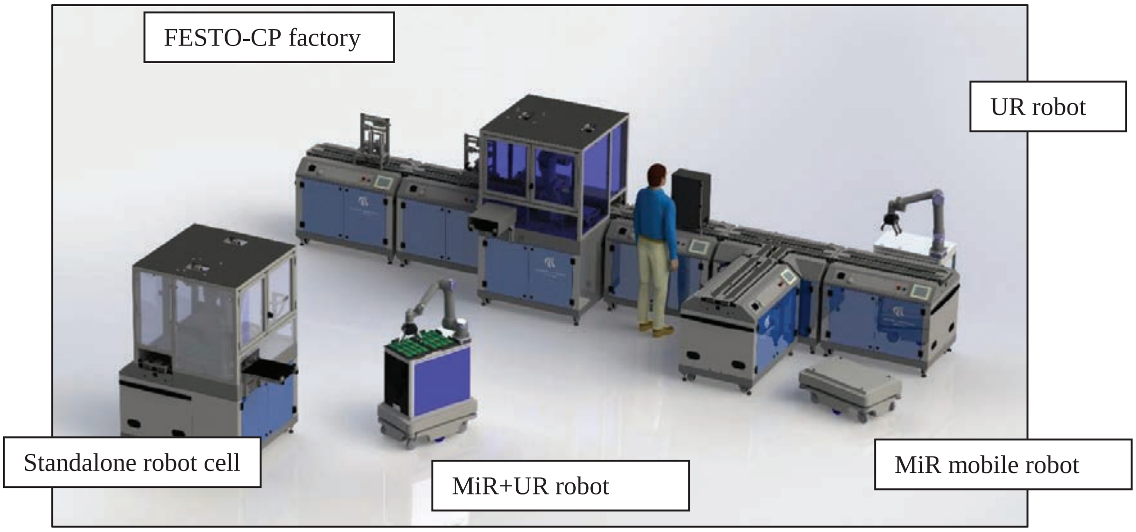

Fig. 2. Overview of the Smart Production Lab.

The Smart Lab is built around FESTOs CP factory, which is a small modular, and expandable factory integrating many relevant Industry 4.0 technologies.

Our version of CP factory consists of number of standard FESTO-CP-factory transportation modules (linear conveyor belts) and one branch module. These have well defined electrical, pneumatic and mechanical interfaces and they are on wheels so that the typology of the system can easily can be changed

Different process modules (e.g. a part dispenser, a drilling module, an inspection module, an assembly module) can be mounted on the transportation modules. These modules carry out the actual material transformation processes, and the functionality of the system can be changed by substituting the modules. In Smart Lab we have modules from FESTO as well as modules developed in various projects.

A number of robots are available in Smart Lab. A dedicated robot (KUKA) assembly cell, developed by FESTO as part of CP Factory, is integrated in to the production line. A standalone robot cell (SCARA robot from Adept) is available for performing various tasks (e.g. production of subcomponents for the main FESTO production line). Furthermore, two mobile robots (MiR) and two collaborative robots (UR-robots) are integrated into the operation of the system. Presently one of the UR robots is mounted onto a MiR robot for fetching parts from the standalone robot cell and feeding them into the system. The second UR robot is used for packaging the finished parts for further processing (see figure 2).

An example of the type of products that are being produced is shown in figure 3. It consists of a house, a circuit board, 0-2 fuses and a cover. In the current configuration, a total 12 variants can be produced (by varying the number of fuses and holes in the house).

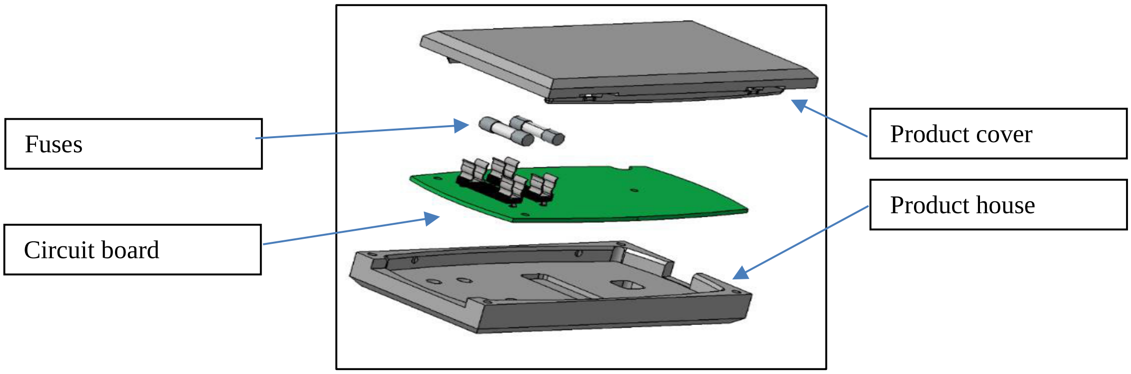

Fig. 3. Product produced in the Smart Production Lab.

One of the distinguishing features of Industry 4.0 is Single Piece Flow. Single piece flow production is enabled through the use of RFID reader on the modules and RFID tags on pallets carrying the products. This enable us to uniquely identify every single product, and produce to a specific customer order.

The production can be controlled by FESTOs MES system: MES4, which is working with an access database and communicating with the CP Factory through dedicated TCP/IP connections. Furthermore, our system is integrated with an SAP ERP instance and can be controlled by SAP ME though OPC UA connections. In our configuration, the SAP instance is hosted by an SAP UCC in Germany and is accessed through the cloud.

4. Examples of use of the Smart Production Lab

To illustrate how the Smart Lab is used, this section contains a short description one of the ongoing projects. This project was carried out as a collaboration between Aalborg University, a large end-user and a local system integrator. The main resource was a team of 5 students (Manufacturing Technology 7 semester) working on the project Sep 16-Jan 17.

The focus of the project was on the production of a product family from the end-user company. Today, these products are produced on dedicated production lines (one for each family member). This imposes two painful drawbacks: (1) a comparably low utilization due to fluctuations in demand, and (2) an inability to react to market changes quickly, because the time to realize a new production line can be quite long.

To overcome these drawbacks, the end-user company has been investigating into Modular Manufacturing Systems (MMS) where components, controllers and machine tools are decomposed into modules, and manufacturing lines are developed as one particular combination of modules selected based on a specific set of manufacturing requirements. In literature MMS has been described as Reconfigurable Manufacturing Systems [6], Holonic Manufacturing Systems [7], Evolvable Production Systems [8] and Changeable and Reconfigurable Manufacturing systems [9] to which we view MMS as a super category [10].

The ability to reconfigure (i.e. to change, add, and/or remove) modules entails the capacity and functionality to be adjustable, which imply responsiveness according to changes in the marked. Hence, the drawbacks listed above can be overcome if modules efficiently can be established and exchanged

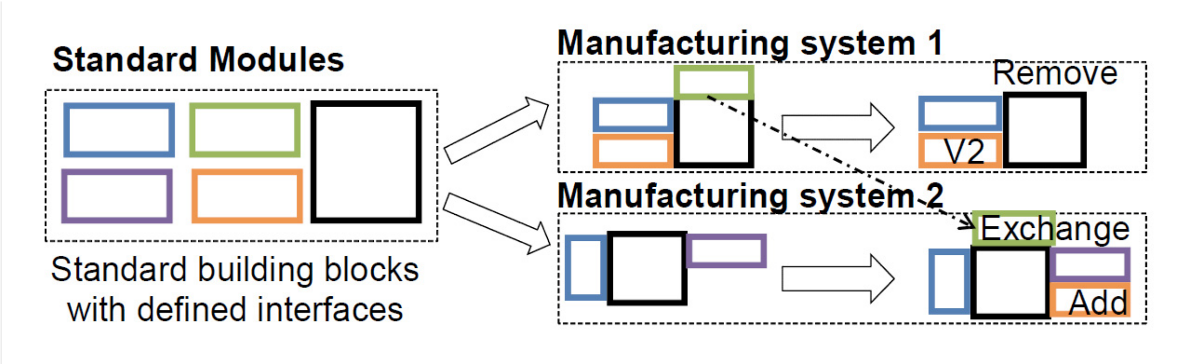

Fig. 4. The main principles of modular manufacturing systems [10].

Prior to the start of the student project, the end-user company has made thorough investigations into the potential of MMS and has made a classification of the production tasks to identify potential production modules. However, they had only little experience on the actual design of modules and no experience concerning the actual reconfiguration task.

Hence, the objective of the student project was; 1) based on an analysis of the production at the end-user company to come up with an overall concept for realizing MMS; 2) establish a physical demonstrator showing how the modular production can be reconfigured; 3) get some empirical data related to the reconfiguration of a task (e.g how long time does it take to reconfigure the system tasks?)

As part of the project, a number of process modules was specified and developed. These were integrated with the Smart Lab and a number of experiments was carried out demonstrating various reconfiguration tasks (see figure 5).

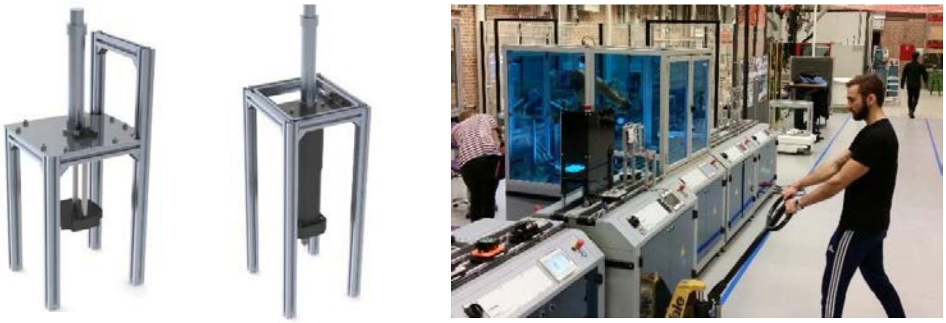

Fig. 5. Left hand side: Examples of process modules developed as part of the project. Right hand side: Picture from the of the reconfiguration experiments.

The provided the end-user company with the first practical experiences with systematic manufacturing reconfiguration. It also provided the company with quantitative data, which will be the basis for decisions on the design of a larger scale manufacturing system.

The project was carried out in very close collaboration with the end-user and the system integrator partners. This involved frequent meetings at both Aalborg University and the End-user company sites. The project was multi-disciplinary in nature, involving mechanical design, process control, MES systems updates, and business understanding.

Discussions and future work

The above example is one example out of a number of different projects that have been running since the inaguration of the Smart Lab in August 2016. Other examples of projects involving industry 4.0 enablers are:

- IoT-based remote monitoring (together with a larger Danish robot integrator)
- Design of a mobile robot manipulator (based on MiR and UR robots)
- Virtual Recommissioning (together with Xcelgo A/S (modelling the modular components of the Smart Production Lab for virtual commissioning)).
- A Smart Manufacturing - Reference Architecture Model Industry 4.0 (RAMI4.0) demonstrator (together with Qualiware)
- Cyber Security (hacking the system)
- Design of assembly module for Smart Production
- Open Source ERP module for the Smart Lab (Odoo)

Based on these activities we have gained the first experiences concerning the use of the Smart Lab. The preliminary findings are listed below:

- The lab appears to enable multi-disciplinary projects:

  We have been successful in initiating a number of projects (>10) involving more than 50 students and researchers from various departments at Aalborg University (e.g. from mechanical engineering, robotics, computer science, electronics, business). They have used the Smart Lab to provide them with requirement specifications and as a test site where they can integrate their result in a larger context. As a result, we had many students/researchers working on different parts of the Smart lab at once. This opened op for some unformal knowledge exchange (e.g: How can we program this PLC ?; How do we change the MES system ?)

  However, in general, the overall interaction between the projects was limited; they focused much on their own projects. In the future, we will attempt to formulate larger projects requiring a larger degree of coordination. Furthermore, we will make regular meetings between the project participants, and organize a workshop at the end of the semester.

- The lab attracts attention from industry:

  There has been a great industrial interest in the Smart Lab. Over the last six months, more than 150 companies have visited the lab, and the interest in engaging in projects by far exceeds our capacity. This also implies that we need to enhance our capability to organize demonstrations for practitioners.

  Our goal is to continue the open lab strategy and to maintain the interest by constantly introducing new technologies into Smart Lab. It is also our goal to formulate more formal strategic collaborations with selected companies. The first of such collaboration agreements has been established.

- Engaging SME:

We have been successful in engaging a number of SME system integrators and technology providers. However, involving SME end-users has been difficult. This could be due to the time frames of the projects we run (which can be long for SMEs). Furthermore, it can be difficult for SMEs to abstract from the fact that the Smart Lab is not identical to their production. Finally, we hear from SMEs that they don't feel they are Industry 4.0 ready. They would rather hear something closer to industry 3.0. We will make the SME challenge a priority in the future.

- Co-creation of new knowledge:
  We have working closely with fellow researchers, students and practitioners from various sectors, and have broken in new grounds. But we have also realized, that we need systematic approaches to working with demonstrator projects and learning factories. This will be important insight to explore deeper in an upcoming research program on digitalization that recently have been awarded to us through the MADE organization (www.made.dk).

5. Conclusions

In this paper, we have presented Smart Lab, and we have demonstrated how teaching and researching is enabled using a collaborative approach engaging with end-user, vendors and system integrators. This work contributes to the design science tradition, where the artifact created, in casu solutions, are used as driver of innovation [2].

We have identified four principles that we take on as guidelines for activities in the Smart Lab:

- Inter-disciplinary, cross functional teams
- Solution design using design thinking [4]
- Fast prototyping and demoing in the lab [5]
- Iterative and short cycled projects using the lean startup approach [6]

Following these principles, we have initiated the first wave of projects in the Smart Lab, and have by now had more than 50 students working on different project. These projects have demonstrated that our Smart Lab have the potential to function as a vehicle for collaboration and integration of different disciplines, academics and practitioners, technology providers and end-users, and thus contribute to making Danish industry smarter!

Acknowledgements

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