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Digital Manufacturing Challenges Education—SmartLab Concept as a Concrete Example in Tackling These Challenges

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Abstract: Digitalization is boosting the manufacturing industry's shift to smart manufacturing systems, which will efficiently utilize the potential of new technologies for their business outcomes and value. However, the literature shows that manufacturing companies have implemented very little digital technology due to a lack of the required knowledge and competences. Increasingly, interconnected, digitalized, and complex processes lead to new skill requirements in companies and thereafter also of their workforce's training needs to respond to the smart manufacturing's new great expectations. The article provides concrete examples of tackling challenges in education arising from digital manufacturing. The case study introduced in this article concerns the additive manufacturing (AM) method, which is expected to give rise to significant changes in various industrial fields, including digital manufacturing. Advances in digital manufacturing requires skilled professionals who are aware of the possibilities and potential of the latest technology. Education therefore needs to be developed. This article points out that the built learning and development environment, SmartLab, supports multidisciplinary approaches and close collaboration between several stakeholders like companies, engineering education courses, students, and RDI actors. The SmartLab concept is thus also expected to provide a remarkable competitive advantage for business in the region.

Keywords: digitalization; digital transformation; industrial internet of things; smart manufacturing; additive manufacturing; 3D printing

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1. Introduction

Digitalization plays a major role in changing society and business due to the adoption of digital technologies in the organization or operating environment [1,2]. In this article, digitalization is understood in its broad perspective as Brennen and Kreiss [3] described: "the adoption or increase in use of digital or computer technology by an organization, industry, country, etc.". Whereas digitization means, for example, the conversion of an existing work process or product to digital form by digitization. Furthermore, Parviainen et al. [1] (p. 64) defined digital transformation as follows: "Digital transformation changes in ways of working, roles, and business offering caused by adoption of digital technologies in an organization, or in the operation environment of the organization.". Digital transformation represents a top strategic priority for manufacturers around the world [4]. Governments in several countries have therefore established research and technology transfer programs to support and facilitate the manufacturing industry in this transformation process [2,5,6] in enhancing their global competitiveness [1,7]. For example, the Industrie 4.0 (I4.0) [5,8] program, launched by Germany, is well known in Europe, while the United States is focusing on smart manufacturing initiatives such as the Smart Manufacturing Leadership Coalition (SMLC) [2,5,9]. Regardless of the background of each initiative or program, the underlying concern is common: how can the manufacturing industry be supported in embracing digital transformation?

The digital transformation is challenging the development and business of the manufacturing industry [2,4]. Smart manufacturing is defined as a production system integrated by multiple subsystems for data exchange, through an interconnected network including the combination of advanced technologies such as the internet of things (IoT), big data, additive manufacturing (AM), artificial intelligence (AI), cyber physical systems (CPSs), and robotic technologies [10]. However, a literature study shows that small and medium-sized enterprises (SMEs) in the manufacturing sector in particular have been alarmingly slow to adopt new digital technologies [11,12]. Accordingly, a constantly evolving and digitizing manufacturing industry challenges education. New kinds of learning and development environments are required in education and training for implementation [13–15]. To understand the new potential and the challenges of the manufacturing industry in more detail, an intelligent production technology, a learning and development environment called SmartLab, has been innovated and built at Lapland University of Applied Sciences (UAS). In this article, we will introduce the development path of our SmartLab environment, explain our vision, and illustrate with a case study how we implement work–life and industry needs, combining them with education and research. In addition, we will focus on clarifying through a case study how it is possible to meet the industry needs of digital manufacturing expertise and how educational challenges can be supported with the SmartLab concept.

This article aims to increase awareness of the manufacturing industry in the changing operating environment caused by digital transformation and how these changes challenge education in the digital era. The purpose of the research is to provide concrete examples of tackling challenges in education arising from digital manufacturing and how new kinds of learning and training environment can support engineering education. The case study illustrated in this article concerns the additive manufacturing (AM) method, more commonly known as 3D printing. AM is a manufacturing method that is the antithesis of the traditional subtractive processes. In AM a part is manufactured based on a 3D CAD model with a layer-by-layer principle directly from the digital file. According to Gibson et al. [16], AM is also referred to as direct digital manufacturing (DDM), because the design phase does not need to be implemented according to the manufacturing method—hence the freedom in design. The article points out that the learning and development environment, SmartLab, supports multidisciplinary approaches, and close collaboration between several stakeholders such as RDI actors, engineering education, students and trainees, companies, and business. The developed SmartLab concept is a unique solution providing the latest digital environment and equipment for exploitation in the manufacturing industry and education in the sparsely populated expanses of Northern Finland.

This article is constructed as follows: First, Section 2 presents a brief description of literature studies and also introduces the selected research method using the developed SmartLab concept. Section 3 illustrates the concrete case study environment from education perspectives and introduces the content of the case study. Section 4 presents the main results of the development activities and the benefits of the SmartLab concept in detail, based on the case study results. Finally, Section 5 discusses the research limitations and further research, with the conclusion explaining the main research results.

2. Literature Study and Research Design

In this section, literature studies will be introduced to offer a general understanding of the importance of the development actions and research done from the regional development perspective and for higher education and the manufacturing industry. The developed SmartLab concept will also be described in more detail to provide the big picture of the involved stakeholders and the investments made during the development projects. Finally, the research design will be clarified with the selected research method and a brief description of the case study research field will be offered.

2.1. Literature Study

Several authors have compared the impact of the ongoing digital transformation with the Industrial Revolution [2,4–7,17,18]. Affected by digital transformation, the manufacturing industry is going towards smart manufacturing systems with the industrial internet of things (IIoT). Indeed, there is no single universally accepted definition of smart manufacturing [6]. Instead, definitions vary, e.g., in terms of technology characteristics, design principles, or enabling technologies [19]. The National Institute of Standards and Technology [20] describes smart manufacturing systems as "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs.". The ongoing industrial revolution is based on the introduction of the IIoT and servitization concepts in manufacturing companies, which leads to vertically and horizontally integrated complex production systems [2]. The changes are continuously providing new opportunities and creating added value for the entire manufacturing value chain [4]. Accordingly, smart manufacturing is defined as a collection and paradigm of various technologies that can promote strategic innovation in the existing manufacturing industry through the convergence of humans, technology, and information [9,21]. The added value for such complex content entails enormous potential and advances in manufacturing technology and new business models boosted by digitalization.

Digital transformation in the manufacturing industry is transforming companies' organizational structure, ways of working, practices, and the tools used. Increasingly interconnected, digitalized, and complex processes lead to new skill requirements in companies and thereafter the needs of workforce training to respond to great new expectations [22]. For example, among SMEs, it is even necessary to increase awareness of future skills, e.g., artificial intelligence (AI), big data, machine learning, digital twins, blockchain, cloud computing, 3D, additive manufacturing, and cybersecurity. At the same time, it is required to create new training and professional development solutions that meet companies' specific needs [22,23]. These new skills requirements must also be considered in education.

Moldovan [24] introduced a survey focusing on the knowledge and skills needs of topics related to I4.0 conducted in six European countries within two target groups: SMEs with 117 participants and vocational education and training organizations with 77 participants. The results showed that SMEs typically had a low level of awareness of the I4.0 potential and the requirements at their own company levels. Accordingly, the survey pointed out that only one or two skills were insufficient. Instead, as many skills as possible were needed and they were addressed with a focus on complex problem-solving, technical, and systems skills. In addition, education should be practice-focused. For example, workplace training offered opportunities for training in a real working environment [24]. Ruohomaa et al. [25] also pointed out that learning should take place in real-world environments and the content of education and training must be designed to respond to the new ICT-based technologies that are needed in smart manufacturing and a transdisciplinary approach.

Digital transformation in education has been discussed in several recent publications (e.g., [26–30]) and recognition of the importance of ICT skills and digitalization of education institutions is growing. Schmidt and Tang [30] discussed digital transformation in education, especially its challenges, trends, and transformative potential in all educational system levels (micro, meso, and macro) across all types of education (from primary to continuing education) across the lifespan. They stated that empowering students, stakeholders, and other participants in educational settings requires active participation and the creation of a learning and research environment: "Knowing how to actively engage and participate meaningfully with technology is empowering as digitalization is transforming the contexts in which we learn, work and live.". When digital technologies deliver real-time synchronous interactions in a virtual learning environment that is not constrained by space or time, the transformative potential is realized [30] (p. 308). In the meantime, Marks et al. [28] highlighted a significant variance between the respondents' perception of digital transformations maturity levels and the core requirements of digital transformation maturity in their study on higher education in the United Arab Emirates (UEA). The main digital transformation challenges in UAE higher education were, e.g., a lack of holistic vision, digital transformation competency, personnel competency and IT skills, and data structure, data processing, and data reporting. The combination of the reported challenges hampers digital transformation and business success [28]. Furthermore, Bond et al. [27] stated in their research concerning digital transformation in German higher education that both teachers and students still use a limited number of digital technologies from a learning perspective. However, a study relating to student experiences of using online materials [31] pointed out that learners do want to use technology but online resources must be accessible and easy to use and, on the other hand, educators need to promote online resources that will support learner needs.

European and international policies and standards have been set for supporting digital transformation in education, like International Society for Technology Education (ISTE) (e.g., [32,33]) or OECD's Centre for Educational Research and Innovations (e.g., [34–36]). Today students increasingly use technology in their daily life, also with learning environments, and most of them are born to a digital world [26]. Despite various initiatives, there are still a lack of widespread standards and guidance on how to prepare students for digitalization by public administration education [29]. However, digital transformation also in education is inevitable. Thus, it has been recommended [26] that all kinds of pilot studies that are suitable for the digital transformation and technology integration studies should be carried out and training programs should be updated to include digital acquisitions. Furthermore, to assure the high relevance of the work done by students and to provide more value for the partners, the idea of real-world challenges proposed or developed together with practice partners are preferred rather than abstract challenges [29].

The connection between AM and traditional manufacturing methods, along with digital manufacturing, requires a new kind of perspective on the education of professionals. Concerning AM, a key issue is to realize the need for education, because its industrialization requires skilled professionals who are aware of the possibilities and the potential of the technology. This enables innovations in, e.g., product development and product manufacturing, as for the development of production methods [37]. This has been noted especially at the European level by Assunçao, Silva, and Pei [38], who identify the training of the personnel as for need of comprehensive AM education. Modern manufacturing technologies require new kinds of competence in the education of professionals, especially considering the I4.0 aspect. Chong et al. [39] stated that the integration of AM and elements of I4.0 with engineering education enhances students' self-motivation and awareness of cross-disciplinary learning. This leads to the development of a more diverse perception of the possibilities of digitalization and additive manufacturing. This requires pedagogical development in which the learning and teaching methods need to be developed. AM is considered one part of the fourth Industrial Revolution, because it emphasizes and provides on-demand manufacturing, advanced cross-disciplinary materials, and customized products [40]. This poses new kinds of challenges to education, because companies need trained professionals capable of exploiting the possibilities of the AM technology.

2.2. SmartLab Concept

The starting point and main goal of the SmartLab concept and investment have been to create a new kind of development environment for the Lapland University of Applied Sciences (UAS), where engineering education, RDI and service businesses and companies, and various actors and stakeholders can meet and create synergies to increase the vitality of the Northern Finland region. Such a framework is expected to provide an opportunity for a remarkable competitive advantage for business and education and for the regions [25]. Two separate SmartLab projects have been derived from the needs of the digital age manufacturing industry. Another project focused on enabling all the required investment and the other on increasing awareness, knowledge, and training skills and enhancing educational and research possibilities.

The planning of SmartLab and its framework was based on the needs of several key stakeholders. The primary focus was the development of engineering education in relation to the surrounding industries, companies, and various stakeholders involved. Students and trainees need to develop their skills in relevant and up-to-date learning environments that are valued and needed by different industries in our region and changing new business models [14]. RDI operations can also be perceived as a vessel for knowledge transfer, from research organizations to practice and ultimately to companies. Figure 1 illustrates these main actors of the SmartLab concept.

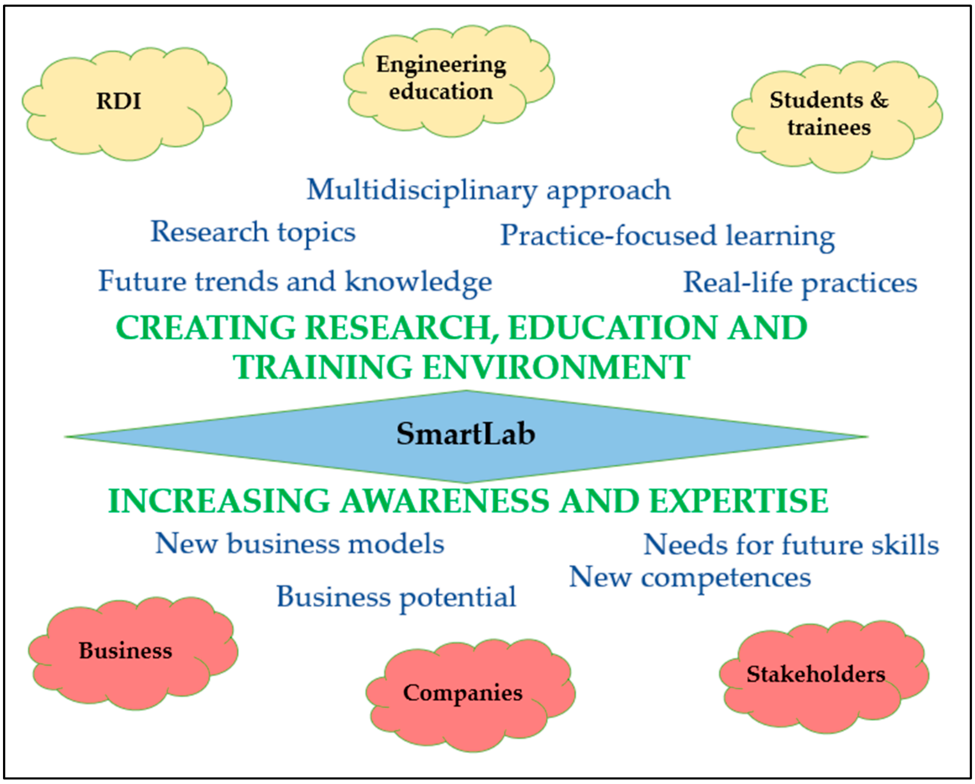

Figure 1. The SmartLab concept, with the main actors.

All investments were planned based on a competence analysis from regional industries and active work with the investment project's steering group members. The competence analysis was undertaken with a directed questionnaire for relevant companies in the region. The importance of an active dialog with the companies about their future needs cannot be understated.

The SmartLab concept consists of two separate projects with related activities and their subgoals: the European Regional Development Fund (ERDF) project [41] and the European Social Fund (ESF) project [42]. Figure 2 presents the SmartLab concept with its main timelines and activities.

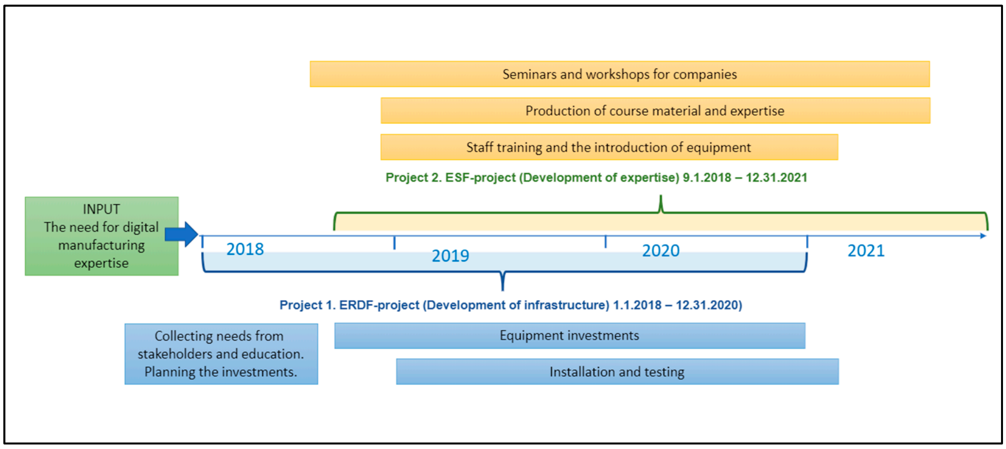

Figure 2. The SmartLab concept with the main timelines and activities.

As Figure 2 shows, the goal of the SmartLab concept was to increase the expertise of digital manufacturing in the Lapland UAS mechanical engineering degree. The ERDF project targeted equipment investments in the area of modern machines, equipment, and technologies. The ERDF project started on 1 January 2018 with collecting the needs of the stakeholders and education and lasted until 31 December 2020. This was done by forming an executive team consisting of representatives of different companies. In addition, this stage included communication with work–life representatives from the area and mapping the needs of the mechanical engineering degree. As a result, a plan was made to initiate the acquisition of the necessary equipment. The ERDF project included the investments, installation, and testing of the equipment. The ESF project targeted the development of expertise from the area of modern technologies and digital manufacturing. The ESF project started on 1 September 2018 and will continue until 31 December 2021. This project included staff training in the use of the acquired equipment and the development of expertise in companies and different cooperation partners. This is performed through seminars, courses, and workshops, where the representatives from companies can participate in the training in the use of the equipment. In addition, the ESF project was used to develop different courses for the mechanical engineering degree (including course content, learning processes, and material) [41,42].

2.3. Research Design

Digital manufacturing with digital transformation is a complex phenomenon that today challenges both the manufacturing industry and educational organizations. A case study research approach [43] was selected to create a better understanding of AM in the digital manufacturing and education environments, because case studies often examine complex and unrepeatable circumstances like the previously described phenomena of digital manufacturing and thus gather information for the creation of new knowledge [44]. Our research question was to clarify if training of AM technologies can be supported by the developed SmartLab concept. In addition, the case study was utilized in evaluating if and how the developed SmartLab environment fulfills the goals set in the ERDF and EFS projects. Since the ESF project, focused on developing expertise from the area of modern technologies and digital manufacturing, will continue until 31 December 2020, the case study provided a descriptive model of project status and results and potential even if it did not cover all potential activities of the SmartLab concept.

In Section 3, we focus on clarifying through the AM case study how it is possible to meet industry needs for the digital manufacturing expertise and how educational challenges are supported by the SmartLab concept.

3. Case Study: SmartLab Concept and 3D Printing Environment

The 3D printing environment of the Lapland UAS was connected with the SmartLab concept via integrated product development functions, in which the first part of the SmartLab path (from idea to product) was handled. The environment consists of three polymer printing technologies: (1) FDM = material extrusion, (2) SLA = stereolithography, and (3) SLS = selective laser sintering of polymers. These represent the three most used AM technologies worldwide [45]. The 3D printing environment focuses on education in AM technologies, where various AM-related phenomena can be learnt and researched. The main outputs are functional prototypes, end-use products, and various tooling products for manufacturing.

3.1. Main Functions of SmartLab Concept

The goal of the SmartLab concept was to create an environment where an idea or need could be manufactured into a product. Figure 3 presents the SmartLab concept in more detail, with its main functions.

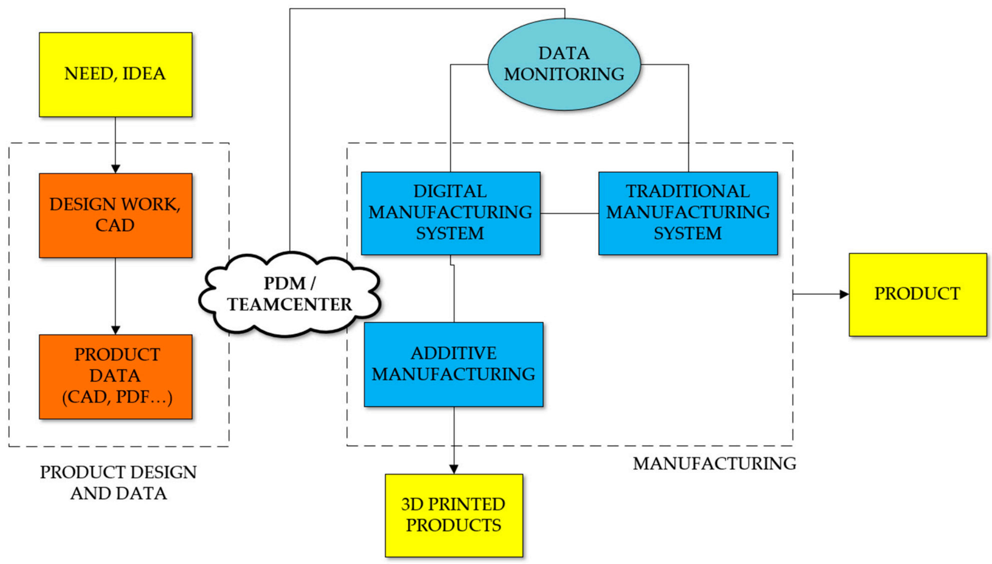

Figure 3. The SmartLab concept functions.

As Figure 3 illustrates, the SmartLab concept consists of two parts, the design and the manufacturing phase; hence, the principle, from idea to product. The need or product idea is developed in the design phase, in which the Lapland UAS mechanical engineering students perform engineering design work to produce the necessary product data (e.g., CAD files and documents such as instructions, etc.). These assignments can either be learning projects or even assignments from the partners of outside customers. The output is the product data that is uploaded to the product data management system (PDM), enabling the control of the data (e.g., distribution and version control). The PDM system is part of a larger digital product lifecycle management system (PLM) called Teamcenter software [46]. Teamcenter connects the product lifecycle with the SmartLab processes by providing an interface for controlling product development, manufacturing, and quality, to mention only a few [46]. The manufacturing part consists of digital and traditional manufacturing systems and AM. Digital manufacturing consists of a Festo Cyber-Physical (CP) Lab environment [47] with automated modules such as turning, milling, robotics, camera inspection, pick-by-light assembly, the pressing station, and storage. The system is a compact learning system where the I4.0 principles can be practiced with different learning scenarios. The product or part is transferred between the modules on top of a pallet via conveyor belts. The system uses radio frequency identification (RFID) to recognize the pallet in the different stages of the process. The system enables the assembly of a product via a manual pick-by-light assembly station. The system can be expanded with different application modules [48]. Conventional manufacturing consists of welding with multiple methods, an NC plasma cutter, an NC controlled sheet metal bending machine, and other tools and equipment for manual manufacturing and finishing. The AM department consists of polymer printing technologies, enabling the direct manufacturing of products and prototypes. In addition, AM provides parts for the products manufactured and assembled in the digital/traditional manufacturing departments. This enables hybrid products in which all these three manufacturing alternatives meet. Digital and traditional manufacturing are monitored through data (e.g., production data such as lead time, efficiency, and energy consumption). The whole is controlled and monitored through the Teamcenter interface, enabling enterprise resource planning (ERP) activities. From the education perspective, the whole provides novel scenarios for learning modern manufacturing.

3.2. Main Functions of the 3D Printing Environment

The AM part of the SmartLab concept concentrates on the early stages of the product development process, where CAD data is processed into prototypes and products. In addition, the laboratory includes 3D scanning, enabling reverse engineering applications. The students can learn and practice technologies and phenomena related to additive manufacturing.

Related to the SmartLab concept, the 3D printing environment can function in two different ways. First, the environment can be used for the manufacturing of polymer parts based on student or customer projects. The student projects can be related to, e.g., a course or BSc thesis topic related to AM. The customer projects can be, e.g., from cooperation partners where companies can implement their product development project in collaboration with the Lapland UAS mechanical engineering degree course. Second, the 3D printing environment can function as part of the SmartLab manufacturing chain. Figure 4 presents examples from the placement of AM functions in the SmartLab product manufacturing.

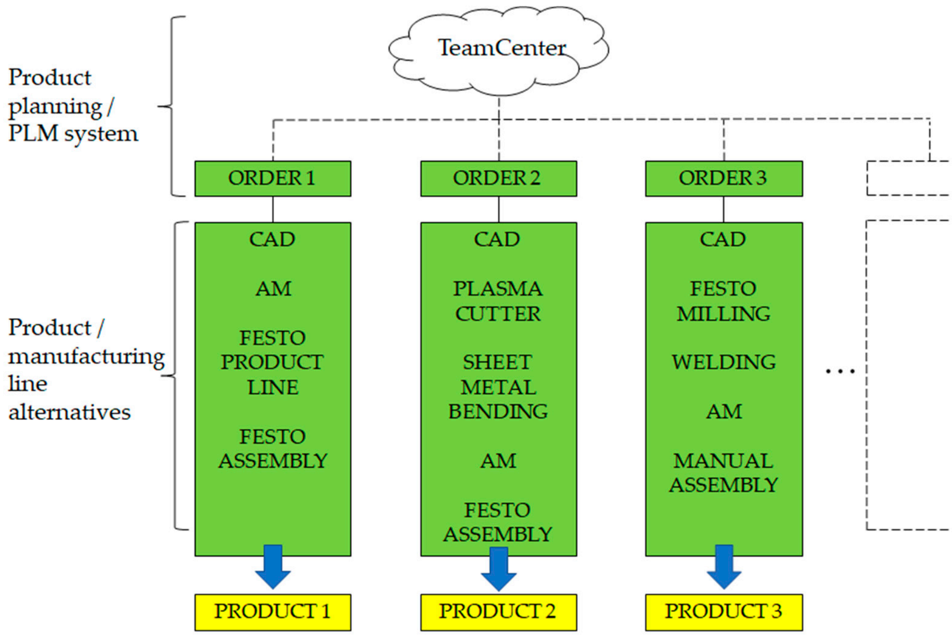

Figure 4. Connecting 3D printing to the SmartLab products.

As Figure 4 shows, the SmartLab concept operates within the Teamcenter software, which connects the functions of product development and handles the planning of the product line. The product line can consist of several different alternatives, according to the product requirements. In the first alternative, CAD data is taken to the 3D printing environment, where the necessary parts are manufactured. The parts are then taken to the

Festo product line, where they can be integrated with, e.g., standard machine parts such as bearings and nuts and then assembled into a product. In the second alternative, CAD data produces information for cutting thin sheet metal with plasma. The sheet metal is then processed in the NC bending machine with material-specific parameters. The part can be taken to the Festo assembly line and combined with 3D printed parts. In the third alternative, the CAD data enables the milling of parts, which can then be joined together with a digitally managed and controlled welding process. This intermediate product can be integrated with 3D printed parts and assembled manually, even without the Festo equipment. These are just some examples of the many ways the SmartLab concept can be used. At the center of it all is the PLM system and the principle of digital manufacturing, where engineering education meets the possibilities of modern manufacturing.

4. Results

The SmartLab concept relied on two supporting projects. The first ERDF investment project focused on the construction of the SmartLab physical environment. The second and still ongoing ESF project focuses on the increase of knowledge and competences required by the invested equipment and systems. These actions are processed in deep cooperation with industry.

4.1. Increasing Awareness and Knowledge

The set of key indicators of each ERDF project evaluates the success of the project and impact of the results. In this ERDF investment project these were the number of participants involved the project and the amount of new co-operation partners during or after the project. The latter indicator is somewhat hard to implicate as a direct result of the project as co-operation can also evolve naturally between individuals from different enterprises and organizations. The visibility in relevant medias that covers the region is a traditional way of communication. The increase of social media presence in our UAS shows more accurately the reachability of our communication and increases the awareness of the region's industries and people about our teaching and RDI environments. The social media platforms seem to reach more active participation and discussion on the recent developments at our UAS. Additionally, various platforms offer tools to analyze reads, visits, and time spent on our media releases. The information can then be used to further enhance our communication to the public.

The knowledge and experience transfers are mainly done through dedicated training and seminars throughout the ESF project. The seminars are divided by various technologies based on the investments done for the SmartLab and have attracted wide interest from actors and stakeholders from various industry fields in the region. The topic of the first seminar was PDM-related systems, technologies, and user experiences. The second seminar addressed topics focusing on metal additive manufacturing technologies. The third seminar opened aspects of future manufacturing technologies and digital solutions for industrial automation and robotics. The fourth and last physical seminar introduced the key elements of ERP systems and user experiences in an SME. The fourth seminar also featured advances in the internet of things framework at Lapland UAS. The technology-oriented seminars play a central and significant role in increasing awareness of the latest technology around the digital manufacturing industry. Thus far, around 25 companies and more than a hundred individuals of various expertise have attended these seminars.

The COVID-19 pandemic greatly affected the physical events held after March 2020 in the middle of the three-year ESF project. As a result, the planning of the events shifted to virtual event arrangements, and all future seminars and events in the ESF project will be held virtually. Such an arrangement presents new challenges, because the SmartLab environment itself is very physical, although many functions are digital. At the time of writing, the next planned events feature topics ranging from project management and enterprise resource planning to lean principles. Various technological demonstrations are also planned during the ESF project to further elaborate the required competences and skills required to fully utilize the new equipment and systems. The technical demonstrations will focus on other digital applications for smarter manufacturing and the management of production processes.

4.2. Renewing of Education

The Lapland UAS 3D printing environment for the SmartLab concept was launched in early 2020. The launch consisted of the introduction of the equipment and the inception of 3D printing courses for mechanical engineering students. Due to the COVID-19 outbreak, the introduction of the environment was put on hold until the fall semester of 2020. The final development of the environment, which consisted of final equipment installations and the installation of air extraction casings for the 3D printers, continued until the end of 2020. The purpose of the casings was to control the particle and odor emissions from the printers (FDM and SLA). The SLS printing was enclosed in a separate space with glass walls and a ceiling within the 3D printing laboratory, which controlled the spread of the powder and odors from the printing process. The environment commenced full operation in early 2021. At the same time, the installation of the SmartLab and the equipment was completed in late 2020, when the digital and traditional manufacturing equipment commenced operation.

For the connection between AM and the SmartLab manufacturing, a team of Lapland UAS mechanical engineering students developed a preliminary concept for one product in the fall of 2020 to spring of 2021, combining AM, sheet metal work, and the Festo digital manufacturing and assembly line. The goal was to implement this in the fall semester of 2021, because this project lays the ground for the actual implementation. A concept for a credit card casing was developed, which can be seen in Figure 5.

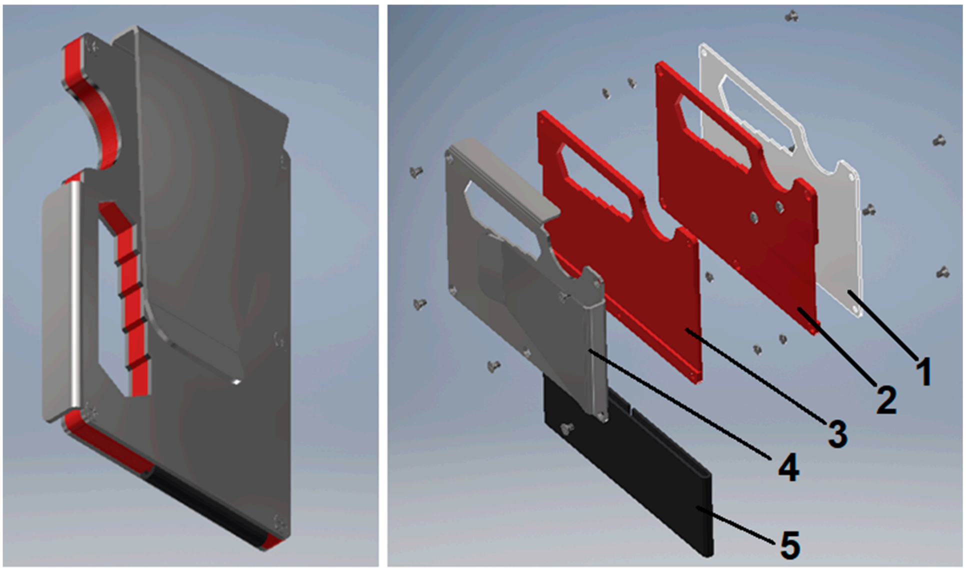

Figure 5. Credit card casing assembly.

As Figure 5 shows, the credit card casing assembly consists of five separate parts. The basic idea is that the assembly works with a rubber band, allowing the insertion of cards inside the casing. A form for different standard sizes of hexagonal holes was implemented, allowing the use of the product as a "wrench". This was also a design aspect that emphasized the mechanical engineering trade at the same time. The product includes a bent holder for bills. The bent holder/flap can also be used to attach the casing to a belt. In Figure 5, part one (1) is manufactured from a stainless steel sheet with an NC controlled plasma cutter (traditional manufacturing). Parts two (2) and three (3) are 3D printed from PLA. Part four (4) is manufactured from the stainless steel sheet, cut with an NC controlled plasma cutter, and bent with an NC controlled sheet metal bending machine. Part five (5) is made from a rubber presenting material, which is the standard material bought outside the project. The assembly is done on the digital Festo manufacturing line, where the parts are processed, buffer stored, and finally manually put together in the manual assembly station of the Festo line with small screws. The processing of the assembly requires the programming of the Festo line through the manufacturing execution system (MES4) system. MES4 is a database-founded system that enables process planning, the programming of workflows and work orders, and the presentation of information from costs, lead time, and, e.g., power consumption [37]. In the manufacturing of the credit card casing, the Festo system allows the order, identification, mid-storage, and handling of the parts in assembly.

This product was developed to exemplify how the traditional and digital manufacturing line could be integrated to produce a useful product. The design process included the following topics from the learning perspective:

- Engineering design;
- Product design principles;
- Material knowledge;
- Combining the principles of traditional and digital manufacturing;
- Programming the digital assembly functions;
- Understanding from automated manufacturing and process planning.

This design process was supported by courses dealing with the principles of I4.0, IoT, and digital manufacturing, which represent new areas for learning mechanical engineering. To perform the work, the students had to implement these subjects in the traditional subjects of mechanical engineering.

Concerning the outcome from a knowledge point of view, the students' learning towards AM was investigated during 2020 by mapping the situation before and after in a separate 3D printing course called "3D printing and applications". This was done with a separate questionnaire where the students' perspectives to learning AM were viewed. The feedback was collected online via the survey and reporting tool, Webropol. Pikkarainen et al. [49] used the quantitative approach where numerical feedback concerning students´ learning and knowledge acquisition were mapped by presenting questions on the scale 0–10 where zero referred to, e.g., "Easy" and ten to "Difficult". This enabled the feedback from different AM related topics. Students felt that their skill and knowledge level increased during the course when using multiple AM technologies (FDM, SLA, and SLS) simultaneously. The usage of multiple AM technologies was seen as a versatile and motivational way to learn AM. The results summarized that the students could adjust even to more complex situations learning-wise and that this enables them to develop into experts more efficiently with the SmartLab opportunities.

5. Discussion

This article has introduced the SmartLab concept, which has been developed in close collaboration between several stakeholders such as regional actors, companies, researchers, engineering educations, students, and trainees. The developed SmartLab concept provides the latest environment and equipment to be exploited both in the digital manufacturing industry and education. In addition, it increases the awareness and potential of digital manufacturing in Northern Finland. Such lab approach initiatives are proposed by Ruohomaa et al. [25] to increase competitiveness and support the adaptation of regional smart manufacturing in Finland and Europe. Furthermore, this article introduces a case study of AM usage with the preliminary concept of credit card casing assembly, which provides a concrete example of the exploitation of the SmartLab concept in education.

5.1. Actors Involved the SmartLab

The connection of AM with the SmartLab digital manufacturing concept enables the students to function in a real-life environment, where a product idea or an order is processed into a real-life product. Students can operate in the different phases of the product development and manufacturing process. Second, the students can become acquainted with modern digital manufacturing, in which the principles of Industry 4.0

are applied to product manufacturing. The SmartLab concept allowed the implementation of AM in digital manufacturing through suitable applications. The students can learn about and apply concepts such as digital data transfer, the internet of things (IoT), automated manufacturing, and intelligent automation. Although the COVID-19 situation meant the case study could not be implemented with the equipment in time for this article, the design process showed that the principles of digital manufacturing could be included in traditional product development functions. Modern manufacturing often leans on digital solutions and this also sets demands for engineering education. This can be referred to as "the digital transformation of engineering education", in which traditional subjects must be updated for a new era. Fumagalli et al. [50] also noted that research institutions and universities should develop the competences of engineering students in the smart manufacturing field and the lab approach especially is a key element for making a physical environment available to carry out cutting-edge research and education activities. The Lapland UAS SmartLab concept enables numerous different applications in which students can learn and function in a real-life automated manufacturing environment. The main research question was to clarify if training of AM technologies can be supported by the developed SmartLab concept. The students' feedback was collected before and after the course in 2020 and responses were very positive and promising. Students felt that their skill and knowledge level increased during the course [49]. The SmartLab environment enables the using of multiple AM technologies (FDM, SLA, and SLS) simultaneously. The usage of multiple AM technologies was seen as a versatile and motivational way to learn AM. In addition, the students responded that their motivation to use AM in manufacturing increased significantly during the course [51]. The results pointed out that the students could adjust even to more complex situations learning-wise and that this enables them to develop into experts more efficiently with the SmartLab opportunities.

The purpose of the article was to clarify with the case study how the needs of digital manufacturing expertise could be met and education challenges supported with the SmartLab concept. The results indicate that the SmartLab environment with the vision to create a new piloting and education environment of digital manufacturing in the Lapland University of Applied Sciences (UAS), where various actors and stakeholders will meet, is appropriate and necessary. The SmartLab concept applies a work-based learning philosophy and enables both students and SMEs and their stakeholders to keep up with the latest innovations and technologies, as Moldovan [24] emphasized. Akyazi et al. [23] also pointed out that only workers with up-to-date skills and knowledge will be able to adapt to the digital transformation, shifts in new production systems, and trends, thus enabling the industry to keep up with evolving digitalization. Engaging SMEs and other region stakeholders and introducing new technologies with open lab strategy enables SMEs to shift from an Industry 3.0 level toward readiness for I4.0 [13]. The widespread interest in the seminars and events held supports the conclusion that this goal has been successfully achieved, despite the fact that the actual ESF project remains ongoing. Figure 6 illustrates how largely and deeply each SmartLab actor has been involved and supported to date.

As Figure 6 shows, the work to fully engage the remaining segments of our planned stakeholders is ongoing. The development of the region's industries relies partly on the capabilities and competences offered in engineering education at Lapland UAS. The SmartLab is clearly establishing its role in the education portfolio where digitalization and novel technologies meet. The students and trainees will gain a unique opportunity to develop their skills for the increasingly rapidly changing manufacturing industries, which are challenging the conventional way of thinking and static industry perceptions.

There are some limitations relating to the research. The case study was focused on the 3D printing technologies, a certain part of the SmartLab wholeness. This selection was done based on pragmatic reasons. All equipment of the SmartLab environment was installed and tested by the end of 2020, but the COVID-19 pandemic is one reason for the environment not being "officially" opened with a public physical opening happening in the future. On the other hand, the 3D printing equipment was installed earlier and that content had been piloted by students, so our case study focused on the 3D printing. However, students' feedback was collected only from one course with a limited amount of responses. That is why the research results were merely descriptive insights of the SmartLab concept and its potential. However, the literature studies pointed out the same kinds of results, which confirms the reliability of the research results.

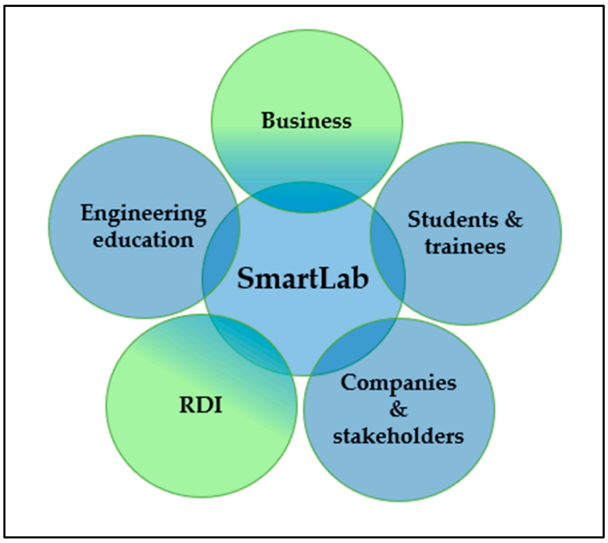

Figure 6. The SmartLab actors involved and supported to date.

5.2. Technical Challenges and Future Studies

When looking at the arrangement of education related to the SmartLab concept at Lapland UAS, the biggest challenge is the student group sizes. The group size can be up to 60–70 students and the study type is part-time where the students are physically present at the university three to four times per semester. The rest of the time the learning happens via distance-learning. Usually, the tasks derived from different SmartLab topics require a decent group size (e.g., a maximum of four students per task/device). This requires detailed planning of physical resources (e.g., space and time usage and group control) in a way that supports the division of groups sizes. The physical on-site learning with the SmartLab equipment requires also the support of digital technology. Concerning the Festo digital manufacturing and assembly line, the first supportive element is the Digital Twin concept where the students can plan and simulate the equipment online in the 3D environment. The students can perform the tasks before the actual physical environment. The group size in not a limiting factor in this case. When entering the physical SmartLab environment, the planning of the timetable and group sizes are an important issue. First, the total group must be divided into subgroups (e.g., 3×20 students) where one group is in the laboratory environment at a time. After, the subgroup must be divided so that each task (e.g., machine vision and robotics) includes only a certain number of students. Therefore, the SmartLab concept must consist of numerous different learning tasks. Considering the AM environment, the most important task is the formation of the subgroups. The Lapland UAS mechanical engineering 3D printing environment allows a maximum of 20 students at a time so that the usage of the 3D printers is still efficient and logistically fluent. The AM equipment requires a physical presence of the students, so timetable planning is a key factor. Due to the nature of the AM process, the students must perform also a lot of independent work with the printers. Therefore, the reserving of printers and printing time require concentrated time reservation (e.g., as an online service) where the students and instructors can view the usage of the equipment. One key issue in this is the simulation of the AM process; the students must plan the actual printing with the AM slicing software, e.g., with SLS printing, the printing times are rather long, and the part removal must happen within a certain amount of time in order to preserve the properties of the polymer powder. This sets its own challenges to the planning of the printing time. During the writing process of this article, this online time reservation system is under development at the Lapland UAS mechanical engineering degree.

One promising network to investigate further is The Network of Scandinavian Universities related to Festo CP factory systems. The focus of the network is to share experiences in training and research with the Festo CP factory system. The possible forms of co-operation include workshops and conference visits to locations with CP factory systems within the network participants. So far, the network consists of 19 participant institutions within the education field ranging from vocational institutes to technical universities.

Other networks to consider are in line with the equipment and systems acquired within the ERDF project. The themed networks could involve machine automation, pneumatics, hydraulics, and condition monitoring of such systems. The additive manufacturing is also a very current theme for network participation as the area of research evolves rapidly. As with all networks around a specific theme, joining such would speed up the learning and utilization process and offer peer support on specific issues—if such might arise.

The companies actively participating in both projects have openly offered their views and visions for the future needs, because they see clear benefits in such cooperation. Future innovations are more easily realized in such an open atmosphere between actors. Mortensen and Madsen [14] have also noted that it is vital to provide an appropriate training platform, an I4.0 learning lab, in which cross-disciplinary skills can be acquired, and all the relevant industrial and academic stakeholders can be trained. This requires continuous curriculum planning, in which the principles of digital manufacturing are spread over semesters, forming a logical path enabling the education of engineers in acquiring knowledge for work–life. The next step in fulfilling the vision of the SmartLab concept will be to strengthen the connection with RDI activities with a selected number of topics. 3D printing technology alone has a wide range of applications related to virtually every field of industry [52]. One such interesting topic could be linking the material research aspects of Lapland UAS more closely to 3D printing technologies and product design. In addition to RDI interests at Lapland UAS, we are closely monitoring the recent developments in other technologies and businesses that could benefit from the SmartLab concept. By fulfilling the vision, the Lapland UAS will remain an important and integral part of the region's future.

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