Development and deployment of services based on D-BEST methodology for robotics and production automation related pilot lines

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Abstract. The aim of the paper is to summarise the industrial needs relating to the research and development, test-before-invest and life-long learning. The main focus of the research is to increase the utilisation rates of the research and education environments by developing methods to allow access to these for the industry and other stakeholders.The paper starts with the summary of the needs collected from the field. The development of the needed services follows the D-BEST methodology. The paper presents the services catalogue planning and implementation process, and shortly introduces the laboratories where the new investments relating to the services are being deployed. The aim of these services is to bring the research facilities, equipment and expertise to more approachable modules for the SMEs.

INTRODUCTION

The manufacturing industry contributes significantly to the European economy. In particular, the manufacturing sector provides 36 million jobs to Europe. In order to keep the European manufacturing sector vibrant and competitive the companies have started to adopt the emerging technologies outlined in the Industry 4.0 (I4.0) strategy such as robotics, Industrial Internet of Things (IIoT), artificial intelligence (AI) and digital twins. For the large companies the adoption of new technologies does not cause serious challenges. Simultaneously, many of the small and medium sized enterprises (SMEs) are struggling to adopt the new technologies [1]. The reasons behind relate to the skills gap [2] and investment scale. SMEs also lack the understanding of the practical benefits of the emerging technologies in their business. The future of the industry needs a new level of education of the workforce for adapting and using emerging technologies, innovations to boost flexible and efficient production, technological solutions to mitigate climate change, higher level of automation, and work safety [3]. In the international and national context, universities and other research institutions as well as large enterprises are involved as project partners for common research projects. However, for SMEs there are not that many opportunities to systematically collaborate with the universities and research organisations. The SMEs do not have visibility or direct access to the research infrastructures or educational material as the suitable collaboration interface is not yet formulated clearly. This means that the research may not be scaled up among the SMEs fast enough.

Over the past year, all EU countries improved their digital performance. Finland, Sweden, Denmark and the Netherlands scored the highest ratings in DESI 2022 and are among the global leaders in digitalisation [4]. Enterprises were becoming more and more digitised, with large companies taking the lead. Some 82% of Finnish SMEs have at least a basic level of digital intensity, considerably above the EU average of 55%. Advanced technologies continued to be at the heart of Finnish business functions, with 66% using cloud solutions and 16 % integrating AI technology in their operations: twice the EU average for both indicators. The Finnish companies rely strongly on the digital tools in both research and development activities, but also on the products they realise. The typical products are high-value low volume machinery. At the same time there is a large gap in the skilled workforce. Finland's position in higher educated people is below the EU average in OECD 2022 listing. Finally, a large challenge in the manufacturing sector is that the industrial products are the third biggest contributors to greenhouse gas emissions and have a negative footprint on depletion of resources, pollution or biodiversity loss. In order to reduce the carbon footprint of the manufacturing sector, there is a need to identify and support SME's uptake of the digital technologies (e.g., analytics) that are identified important in achieving higher levels of sustainability [5]

LITERATURE REVIEW

Robotization, Artificial intelligence (AI) and cyber-physical systems (CPS) are currently seen by the manufacturing industry as a potential business opportunity that could drastically change the way products are designed, manufactured, used and updated. I4.0 paradigm encompasses a trend in industrial automation that integrates various (also AI-enabled) production and digital technologies to increase the productivity and production quality of industrial plants. Industry 4.0 is mainly focused on the improvement of process efficiency with means of data, connectivity and communication [6]. A new paradigm of Industry 5.0 [7] is extending the I4.0 autonomous manufacturing with human intelligence in the loop. For example, in robotics Augmented Reality (AR) or projected instructions has been used as a human friendly interface [8], [9] and emphasis on user experience [10], [3] and [11] suggest that new digital innovations (e.g., digital twins, analytics, AI and other disruptive and emerging technologies) are essential for sustainable and inclusive industry. However, utilisation of emerging technologies needs to consider the role of the workforce and skills of the people involved [12]. On the recent years there has been emergence of pilot lines and test-before-invest facilities to demonstrate the emerging technologies and create different use cases. A pilot line is a pre-commercial production line that produces small volumes of new technology-based products, or employs new production technology, as a step towards the commercialisation of the new technology [13]. Re-configurable Pilot Lines (RPLs) are one practical concept for implementing the test-before-invest strategy to improve skills and capabilities of European small and medium enterprises (SMEs). SMEs typically have limited resources for systematically exploring the potential benefits of available technologies [11].

One activity of pilot lines relate to the life-long learning and educational activities known to have a central role in supporting uptake of I4.0 in SMEs [14]. In general, European industrial growth will require emphasis of training in science, technology, and mathematics (STEM) as there is a clear correlation between productivity and basic STEM skills [15], technology oriented vocational education [16] and continuous efforts on up-skilling the workforce [17]. Countries such as Italy and Germany with strong vocational education system collaboration with local industry excel in teaching specific technical skills required for the growth of SMEs [18]. This has also positive impact on employment rate [19]. In the context of a smaller nation a central challenge in SMEs' digitalization journey is the need for heterogeneous skills [20]. Learning emerging manufacturing technologies at the workplace requires understanding about the introduction of the new technologies, I4.0 competences and related training needs [21], [22]. Educational institutes should support companies in their transformation towards I4.0 by re-skilling existing staff throughout the process of taking up a novel technology such as robotics [23] and present new digital learning models and platforms [24]. Also, different assistance systems at the workplace can support training new processes, e.g., related to assembly tasks [25].

METHODOLOGY AND RESEARCH SETTINGS

The research method in this research was done in three phases illustrated in the Figure 1. The first phase focused on the needs and requirements analysis based on the interviews and surveys conducted in several national projects during 2020-2022. The second phase consisted of analysing the interview results and digital capabilities we have at the moment in the selected pilot lines. The third phase focused on the modeling of the services based on the D-BEST methodology and service categorisation developed in the AI REGIO project. The final phase, which is currently in progress, will be the piloting of the first batch of the defined services for the industry.

In this research three re-configurable pilot lines were taken into service development. These are Tampere Didactic Factory, which consist of two separate robotics education environments (Robolab Tampere [26] and Human-Robot-Collaboration (HRC) pilot line [27]) and TAMK FieldLab [11], all illustrated in the Figure 2. The Robolab Tampere consist of educational (e.g. Fanuc educell) and collaborative robot cells (several UR5, Kuka Iiwa, PRob, Doosan, two Francka Pandas, and Fanuc collaborative educell), mobile robots, other robotics equipment and end-effectors, and several sensor sets that can be used for different platforms.The HRC Pilot line consists of two larger ABB 4600 robots, linear axis, laser scanners and light curtains, and in-house-build projector based augmented reality (AR) and safety monitoring system. TAMK FieldLab has versatile machines similar to industrial operating environment, all in use for students, staff, and companies. The technologies include e.g. 5-axis machining center, track mounted 6-axis industrial robot, large scale enabled 3D printing platform, collaborative robots, industrial automated welding operations, and mobile robot fleet.

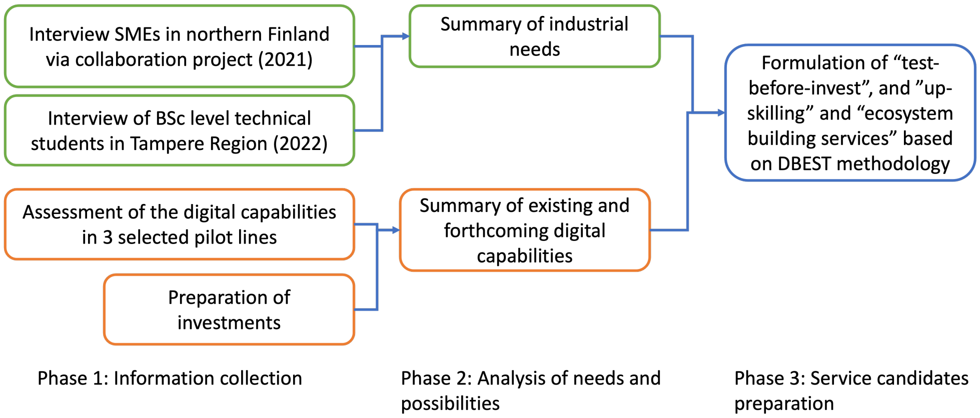

FIGURE 1. The research phases of the service development

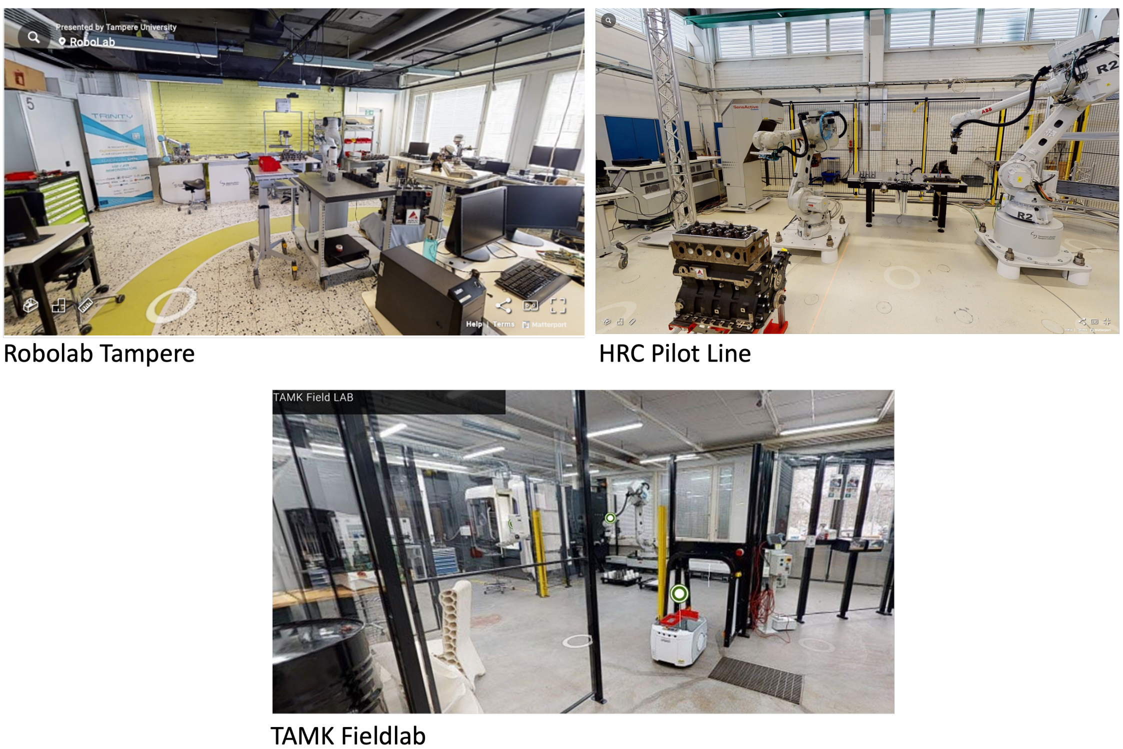

FIGURE 2. Three Pilot lines considered in the research

Data analysis from the qualitative interview

For the first interview conducted in 2021 the total 11 manufacturing SMEs were interviewed. The interview followed a qualitative semi-constructed thematic interview for the upper management personnel in each company. The interviews were done in face-to-face manner. The thematic areas of the interview were 1) General data, 2) Digitalisation, ICT and data, 3) Sustainable development and operations, 4) Robotization and production automation, 5) Education, competences and skills development. The form in each section was to inquire about the current state, needs, and future vision. The answers were quantified in the simple manner and clustered into a needs matrix to form clear thematic groups. Based on the analysis the greatest needs were on the robotics, collaborative robotics, and digitalization. The table 1 illustrates the needs collected from the companies (first 12 results out of 24). Based on these needs we selected the robotics and digitalisation as the focus area, as the available developer resources were most suitable for these categories.

TABLE 1. Requirement matrix

Theme area	Technology	Description	Index
Robotics	Collaborative Robotics	Using cobots to move parts of a production cell and for other production operations. Possibilities and limitations. Related: Machine service robots	10
Digitalisation	Digital work order	Changing the management of work phasing in the operations control system to digital so that a paper work order is no longer needed and all the necessary information and reporting takes place digitally.	8
Digitalisation	Automation of data collection and reporting (e.g. Power BI).	A digital information system that transforms information from multiple sources into coherent, visual and interactive insights and reports.	8
Digitalisation	Simulation of production/material flow	Simulation of material flow and/or production based on virtual (3D) models. Identification of bottlenecks; optimization of flow, buffers and warehouses. Can be used to make "what if" scenarios and production/investment plans.	7,75
Digitalisation	Digitization of the order-delivery process	A digital information system that allows purchase order information and product specifications to be distributed electronically to suppliers and through which suppliers can provide information related to deliveries.	7
Robotics	Machine tending robots	The use of industrial robots for machine service and other production operations.	7
Digitalisation	Cell/production fine loading (APS), production queue optimization	The task of the Advanced Planning and Scheduling (APS) system is to produce a detailed production schedule and capacity-limited fine loading before the actual operational activity. With APS, phase chains of orders are scheduled and different options can be simulated. Minimizing setup and waiting times.	6,75
Other	Best practices in production	Practices found to be good in production, with the help of which a production advantage is achieved - e.g. efficiency, quality, waste minimization. Development of working methods, production and its organization.	6,5
Other	Business cooperation	A way of working between two or more companies, where the parties to the companies benefit from the other parties.	6,25
Digitalisation	Automation, digitization of quality management & measurement data	Automation and archiving of measurement data collection related to quality management.	5,75
Robotics	Machine Vision	Utilization of machine vision/computer vision (AI) in production and/or quality assurance. e.g. identifying and positioning pieces; reading barcodes and QR codes.	5
Robotics	Robotic sanding/de-burring	Automation of the manual work phase by utilizing a robot. Used after machining, casting or welding to improve product quality.	4

Survey on SMEs' pilot line needs

A total of 178 responds were collected in an online survey where the aim was to build understanding about the industry's needs regarding Research, Development, Innovation and Education (RDIE) environments and services universities can provide. For the current paper, responses by respondents working in manufacturing SMEs (n = 13) and microenterprises (n = 3) were selected in order to analyse SME needs for manufacturing Digital Tools, Application Areas, and Technologies. The respondents answered three questions: Q1: "What kind of technological capabilities and competences will the company need in the next 5 years from the year 2023 onwards?"; Q2: "What equipment, environments and services related to the RDIE environments and services does your company need and/or is it willing to cooperate with in the future?"; and Q3: "What are the biggest obstacles to the digital transformation?". The answers for the Q1 were collected on a Likert Scale (1 to 5 i.e,. not at all relevant to very much relevant) (see Table 2). Table 2 illustrates that more than half of the respondents found digital design and optimization, model-based design, robotics, human-machine collaboration, cybersecurity, cloud services, and Machine Learning / AI relevant in their businesses in the near future. Further, digital twins, simulation technologies, cobotics, flexible manufacturing, and I4.0 were identified as relevant topics for the future.

TABLE 2. The Digital Tools, Application Areas, and Technologies and the percentage of the respondents rating them relevant or very relevant (i.e, 4 or 5) on Likert scale.

Digital Tools	Application Areas	Technologies
Digital Twin (31%)	3D Printing (20%)	5G-Connectivity (36%)
Simulation (47%)	Robotics (53%)	Cybersecurity (67%)
VR / AR / XR technologies (27%)	Cobotics (43%)	Industry 4.0 (40%)
Digital Design and Optimization (50%)	Flexible Manufacturing (47%)	Industrial Internet of Things (29%)
Model Based Design (56%)	Human-machine Collaboration (64%)	Edge Computing (14%)
		High Performance Computing (13%)
		Cloud Service (53%)
		Big Data (27%)
		Machine Learning or AI (57%)

The breakdown for answers for the Q2 is shown in the Table 3. The seven technologies most useful for the basis of RDIE services and collaboration were simulation, digital design and optimization, model-based design, robotics, flexible manufacturing, human-machine collaboration, and machine learning / AI.

TABLE 3. The percentage of respondents from of SMEs and microenterprises needing RDIE services or collaboration for the technology.

Digital Tools	Application Areas	Technologies
Digital Twin (12.5%)	3D Printing (19%)	5G-Connectivity (6%)
Simulation (37.5%)	Robotics (37.5%)	Cybersecurity (25%)
VR / AR / XR technologies (12.5%)	Cobotics (19%)	Industry 4.0 (19%)
Digital Design and Optimization (44%)	Flexible Manufacturing (44%)	Industrial Internet of Things (19%)
Model Based Design (37.5%)	Human-machine Collaboration (31%)	Edge Computing (0%)
		High Performance Computing (0%)
		Cloud Service (25%)
		Big Data (6%)
		Machine Learning or AI (37.5%)

According to the survey, six technologies respondents found most relevant during the next five years were cybersecurity, human-machine collaboration, machine learning / AI, cloud services, model based design, and robotics. On the other hand, six most important technologies respondents find worth collaboration with universities were simulation, robotics, digital design a optimization, flexible manufacturing, model based design, and machine learning / AI, while the cloud services and cybersecurity are considered to be bought as a service from known vendors. The answers for the Q3 focused on finding out central obstacles in skills, resources, business cases challenging the uptake of emerging technologies (Table 4). The obstacles most commonly causing trouble in uptaking emerging manufacturing technologies relate to skills, costs of investments, and technological challenges. Roughly half of the respondents identified skills, costs, and technological challenges hindering the uptake of emerging manufacturing technologies. In short, the results encourage focusing on skills development together with industry in a manner ensuring continuous access to skilled labor (i.e., life-long or continuous learning), support in finding investments for hardware, and support in challenges related to implementation. The latter can be done by providing practical test-before-invest services where technological challenges are solved together with the company. Based on the results it seems that there should be an option to target services on a practical level if the company requires help in basic development of skills.

As the result the of this analysis, the most suitable candidates for the service planning were the Model Based design, Digital design and optimization, Robotics and Human-machine collaboration, Machine Learning and AI and Cybersecurity (illustrated in Table 2). During the analysis phase, it was concluded that the Robotics and Digitalization are indeed the most common and suitable categories to start with the both service and investment planning. Nevertheless, in order to cover the needs from the industrial sector the participating organisations decided to include the the human machine collaboration and use of AI in manufacturing for the robotics category, and for the digitalisation category the technologies that could be demonstrated in the laboratory would include Digital and Model based design, digital twins, connectivity (e.g. protocols and 5G). This focus helped us to proceed with the investment plan finalisation. As

TABLE 4. A list of obstacles and the number of respondents finding the obstacle relevant.

Obstacle	Percentage of respondents finding relevant
Lack of skills	37,5%
Availability of skilled labour	31%
The cost of hardware investments and software	62%
Technological challenges of implementation	37.5%
Digitalization does not bring a competitive advantage in the industry	12.5%
Difficulty choosing which technologies to focus on	12.5%
Conflicts between goals and practical need	12.5%
Missing networks and partners	6%

there were constraints on equipment availability and delivery times, the final investment focused on the robot cells intended for manufacturing processes (with the capabilities for human-robot collaboration), computer and machine vision systems, robotized grasping, and connectivity of the systems.

D-BEST methodology

Sassanelli et al [28] introduced a data-driven Business-Ecosystem-Skills-Technology (D-BEST) model that was developed to classify the extant service portfolios of the Digital Innovation Hubs (DIHs) belonging to the network, to detect which new services should be provided in the future by the network of DIHs, and to identify opportunities for collaboration among DIHs fostering the creation of a pan-European DIH. The methodology includes a Customer Journey (CJ) analysis method. These methods have been found suitable for developing higher level service descriptions. The levels in D-BEST model includes the aspects for the Ecosystem (E), Technology (T), Business (B), Skills (S) and Data (D). For the research cases introduced in this paper, the methods were used to define more specific services relating to the re-configurable pilot lines. The customer journeys for the technology user include the phases for Observation, Awareness, Experiment, Experience, and Adoption. In the technology user's case the observation level indicates the light level of interest. The awareness level indicates a bit more active participation towards specific technologies or technology fields. The experiment, experience, and adoption refers to the levels where the company is actively participating and utilising specific services. For the Technology Provider's case the levels are Ideation, Design&Engineering, Minimum Viable Product (MVP), Verification & validation, and Go-to-Market. The conceptual design and brainstorming takes place in the ideation phase, and more detailed design of a system in the follow-up phase. The MVP is dedicated for the small demonstrations. The two later phases are for the actual productization.

RESULTS

The service development focused on the customer journeys in technology provider and technology user perspective. The customer journeys for students have already been discussed up to degree in previous work [26]. In this paper the technology user refers mainly to a manufacturing company, who utilises the emerging technology, but does not develop technology by them selves. The Figure 3 illustrates the user journey from the technology user perspective. The majority of the services offered for technology user customer segment are mainly placed in the Observation, Awareness, Experiment, and Experience levels according to the general operating principles of the Tampere University (TAU) and Tampere University of Applied Sciences (TAMK). At the TAU services & customer journey the Adoption of the technologies is considered to be too close to product and production development, and thus something that should mainly happen at the companies. The pilot lines selected to this case study were focused on the robotics and production automation solutions. The services relating to the DeepDive workshops and demonstrations have been the most used so far. The up-skilling and training services have also been rather straight forward to deploy. The main development needs for the services in this model related to "the access to the infrastructure" and "data access". The data sets produced in this environment are very specific e.g. they relate mainly to image data sets or augmented data sets from industrial metal products.

TAMK services targeted for technology developers in FieldLab are divided in four different categories, namely, Building digital flow (e.g., data for varying assembly scenarios or model-based definition practices in a product life-cycle); Additive manufacturing capability up to large scale products (e.g., multi material printing, sustainable 3D

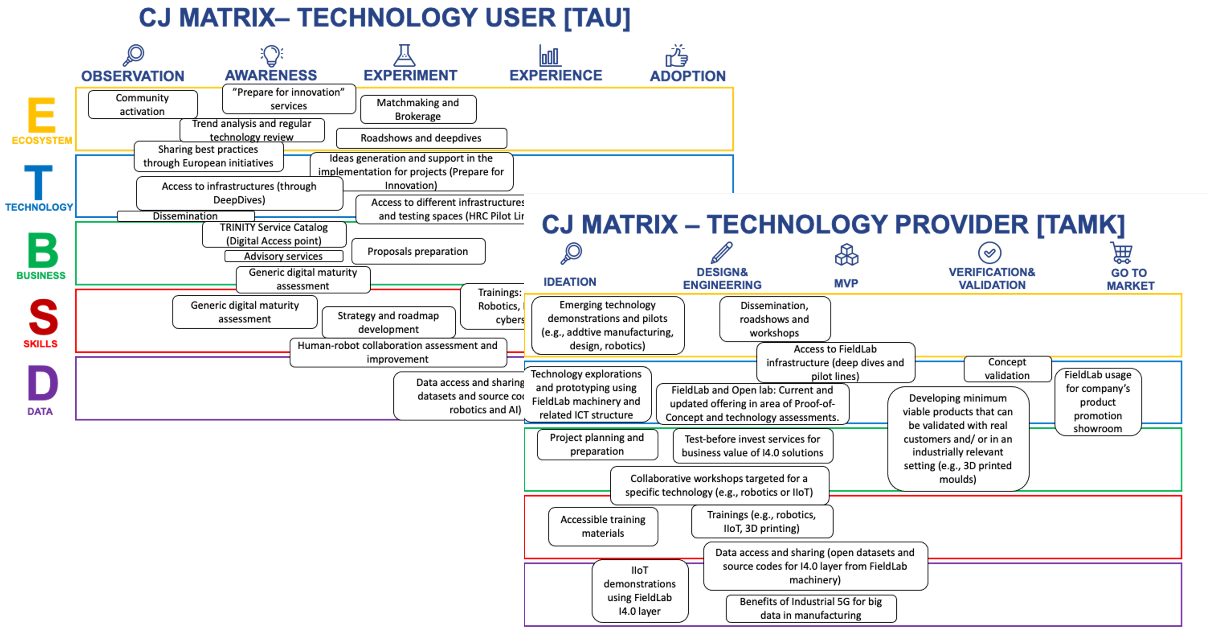

FIGURE 3. The research phases of the service development

printing materials for different designs and applications, and design and optimisation for robot enabled large-scale 3D printing); Connected machines enabling data driven manufacturing environment (e.g., designing industrial IoT and big data analytics to optimise processes); and Robot applications in manufacturing (e.g., programming mobile robot fleets or design of collaborative robotics). At the moment, the services have been realized by using emerging technology introductions in terms of DeepDives as well as workshops and seminars, technology pilots, education and finally, generic or specific demos showcasing how new technologies can be implemented in a variety of use-cases to support companies in their technology development activities.

CONCLUSIONS

In this paper we introduced the results from the interviews done for the Finnish Manufacturing SMEs about their future investment plans, training, and up-skilling needs and barriers they have experienced. The second part of the research was to develop a first batch of services for SMEs based on their needs. While the development of services may seem an easy task, it is quite hard to model the research, facility and education services in such manner that they are easy to understand, have a set price and content. And finally, to ensure that the services have longer lifetime and are not too dependant on a specific skill of one researcher. The first testing of the specific services such as educational modules for the adult learners about collaborative robotics, standardisation and legislation, and design for assembly (DFA) were conducted in 2022. The feasibility study (duration of 1 person month) and DeepDive workshops to our laboratories about the technologies have been conducted. The work is on the first phases, and the future work will consist of six industrial workshops organized in spring 2023 for evaluating and detailing the planned services.

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