Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0
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Transfer of Industry 4.0 to Small and Medium Sized Enterprises

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Abstract. Industry 4.0 refers to the fourth industrial revolution and technological evolution from embedded systems to cyber-physical production systems. A great challenge for the future lies in the transfer of Industry 4.0 concepts and technologies to small and medium sized enterprises. Despite the expected strong potential of Industry 4.0 in small and medium sized firms, fundamental models for its introduction and application are missing. The research project titled 'SME 4.0 - Industry 4.0 for SMEs' aims to close and overcome this gap through the creation of an international and interdisciplinary research network working on this topic.

Keywords. Industry 4.0, smart manufacturing, small and medium sized enterprises, cyber-physical systems, axiomatic design

Introduction

In recent years, the industrial environment has begun changing radically due to the introduction of concepts and technologies based on the fourth industrial revolution (also known as Industry 4.0) [1]. The characterization and definition of Industry 4.0 still vary greatly and a fundamental, generally accepted representation of Industry 4.0 does not exist at the time of the research [2]. The focus of Industry 4.0 is to combine production, information technology, and the internet. Thus, the newest information and communication technologies are combined with classical industrial processes in Industry 4.0 [3]. Industry needs to introduce such new types of production strategies to maintain the current competitive advantage in the long term [4]. To remain competitive, lead times, flexibility, and the ability to produce many versions of products in low batch sizes, must improve [5]. More functionality and customization options are provided to the client and more flexibility, transparency and globalization for the supply chain [6]. In addition, the return to uniqueness should be achieved by the fourth industrial revolution [7].The development of industry 4.0 should contribute to tackling

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global challenges, like achieving better resource and energy efficiency and strengthing competitiveness of high-wage countries [8].

Based on the principle of Industry 4.0, production creates the conditions to replace traditional structures, which are based on centralized decision-making mechanisms and rigid limits on individual value-added steps. These structures are replaced by flexible, reconfigurable manufacturing systems, offering interactive, collaborative decision-making mechanisms [5]. The biggest opportunity is expected in capabilities of Cyber-Physical Systems (CPS) for self-organization and self-control. CPS are computers with networks of small sensors and actuators that are installed as embedded systems in materials, equipment and machine parts and connected via the Internet [8, 9, 10]. Here the physical and digital worlds are combined and are called 'Internet of things' (IoT) [3]. Production data is provided in a completely new quality and with real time information on production processes, through sensors and the continuous integration of intelligent objects [5, 11]. With networked production technologies, individualized production at low costs will become possible [12]. Summarizing, the potential benefits from the successful implementation of Industry 4.0 are immense and research is still important.

1. Transfer of Industry 4.0 to SMEs

Small- and medium-sized enterprises (SMEs) are the backbone of the European and many other economies [3]. European micro, small and medium sized enterprises provide around 45% of the value added by manufacturing while they provide around 59% of manufacturing employment [13]. SMEs in the United States account for nearly two-thirds of net new private sector jobs in recent decades [14]. In recent years SMEs, moved into the focus of many authors in their scientific work. In addition, many programs like the European Horizon 2020 research and innovation program actively support SMEs by providing direct financial support and indirect support to increase their innovation capacity.

Due to their flexibility, the entrepreneurial spirit and the innovation capabilities, SMEs proved to be more robust than large and multi-national enterprises, as the previous financial and economic crisis showed [15]. Typically, SMEs are not only adaptive and innovative in terms of their products, but also of their manufacturing practices. Recognizing the continuing competitive pressures, small organizations are becoming increasingly proactive in improving their business operations [16], which is a good starting point for introducing new concepts of Industry 4.0.

This leads to the conclusion that the successful implementation of an industrial revolution Industry 4.0 has to take place not only in large enterprises but in particular in SMEs [17]. Various studies point out relevant changes and potential for SMEs in the context of Industry 4.0 [18]. Industry 4.0 technologies offer great opportunities for the SME sector to enhance its competitiveness. The integration of ICT and CPS with production, logistics and services in the current industrial practices, would transform today's SME-factories into Industry 4.0 factories with significant economic potential [19].

Industry 4.0 represents a special challenge for businesses in general and for SMEs in particular. The readiness of SMEs to adapt to Industry 4.0 concepts and the organizational capability of SMEs to meet this challenge exist only in part. The smaller the SMEs are, the greater is the risk that they will not be able to benefit from this

revolution. Actually, most of SMEs are not prepared to implement Industry 4.0 concepts. This opens the need for further research and action plans to support SMEs in introducing Industry 4.0 [17].

2. SME 4.0 – project structure and network

Therefore, special research and investigations are needed for the implementation of Industry 4.0 technologies and concepts in SMEs. SMEs will only achieve Industry 4.0 by following SME-customized implementation strategies and approaches and realising SME-adapted concepts and technological solutions. Otherwise, the current efforts for sensitization and awareness-building of SMEs for Industry 4.0 are at risk of failing to achieve the expected successes and results.

The proposed research is organized into three fields (see Fig. 1): (i) Smart Manufacturing in SMEs, specific solutions for (ii) Smart Logistics in SMEs and (iii) adapted Organization and Management Models for the introduction of Industry 4.0 and the management of smart SMEs. These fields are further decomposed into nine topics that investigate specific concepts.

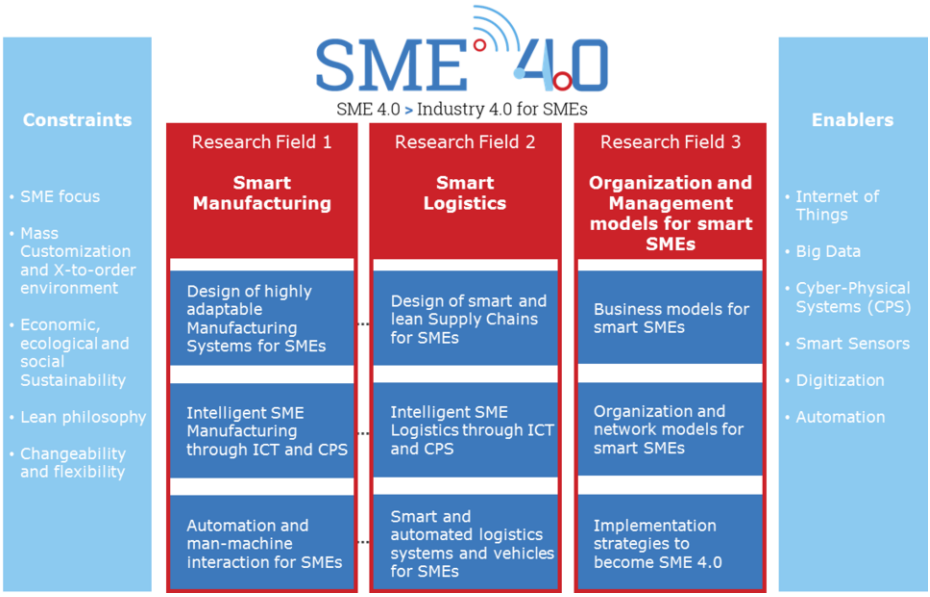

Figure 1. Research fields and topics in the project SME 4.0.

To overcome the gap in research the European Commission financed the research project titled 'SME 4.0 - Industry 4.0 for SMEs' with a grant of 783.000 Euro from Horizon 2020 research and innovation program. The international research network under the leadership of the Free University of Bolzano (Italy) includes academic as well as industrial partners from Europe (Montanuniversität Leoben Austria, Technical University of Kosice Slovakia, Elcom s.r.o. Slovakia), the USA (Massachusetts Institute of Technology and Worcester Polytechnic Institute) and Asia (Chiang Mai University Thailand and SACS Engineering College India).

The main research question to be addressed are:

- What are Industry 4.0 requirements and suitable concepts for SMEs?
- How can promising Industry 4.0 concepts be adapted to the needs of SMEs?
- What are suitable Industry 4.0 implementation strategies and organization models for smart SMEs?

3. Recent advances and results adopting Axiomatic Design

In the current phase, five SME workshops have been held in Europe, USA and Asia to investigate their specific requirements and to deduce ideas for SME specific methods and technologies (see Fig. 2). An average of 10-12 participating companies (owner, general manager, production manager) facitated a productive interaction in the workshops. The workshops had a standardized structure starting with an initial introduction and overview of Industry 4.0 and the presentation of some practical applications and best practice examples. Afterwards the participants were asked to express their requirements to introduce Industry 4.0 concepts in their company. Further they were asked what are the main barriers and limitations for the implementation of Industry 4.0.

Based on the results of the SME workshops the research team applies Axiomatic Design as a research methodology to develop design guidelines for smart SMEs (see Fig. 3). In Axiomatic Design [20] requirements (CAs – customer and stakeholder needs or attributes) are translated into functional requirements (FRs) and constraints (Cs). Hereafter starts a mapping process selecting design parameters (DPs) for individually fulfilling each FR. The following four domains form the base of the Axiomatic Design methodology [20]:

(1) *Customer domain*: the customer domain defines the desires and needs of customer, usually defined as customer attributes (CAs).
(2) *Functional domain*: the functional domain focuses on the functional (FRs) and non-functional requirements (n-FR) of the system, which derive from customer needs. System constraints (Cs) are also considered.
(3) *Physical domain*: the physical domain contains the design parameters (DPs) that help to satisfy the functional requirements.
(4) *Process domain*: the process domain transforms the design parameters into real process variables (PVs).

The application of the Independence Axiom from Axiomatic Design favors DPs do not influence FRs other than the one they were selected to fulfill. Furthermore, the Information Axiom assures, that in case of alternative DPs, the best DP has the lowest information, i.e., least complexity, or greatest probability of success. Through a top-down decomposition approach FR-DP pairs are decomposed from an abstract level to detailed. In the following both Axioms are described more in detail [20]:

- Axiom 1 – Independence Axiom: the design of a system is considered ideal if all functional requirements are independent of the others in order to avoid any kind of interaction among them. Each defined design parameter is only related to one functional requirement and has no influence on other functional requirements.
- Axiom 2 – Information Axiom: the Information Axiom helps the designer to choose among multiple possible solutions. The design parameter should be part of the physical domain with the smallest information content, to ensure a higher probability to satisfy a requirement. The aim is to minimise the information content of the design.

Figure 2. Identification of specific requirements through international SME Workshops.

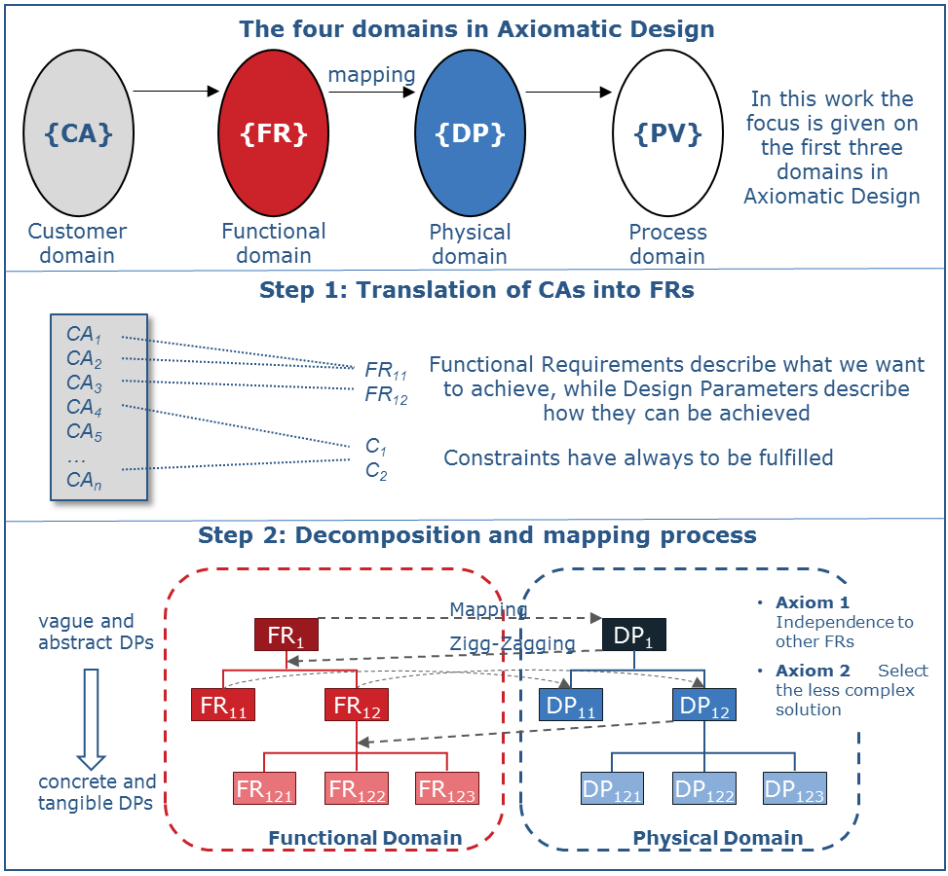

Figure 3. Axiomatic Design approach to develop design guidelines for smart SME factories.

In addition, the research team conducted an elaborate literature review based overview of existing Industry 4.0 methods as well as an assessment model for the identification of the individual company status in the introduction of Industry 4.0 (see Fig. 4). Currently, this pilot assessment model is applied and tested in SMEs participating in the initial workshops. So far 5 pilot assessments in 3 SMEs in the United States and 2 SMEs in Italy have been conducted. The pilot assessments are used to review and evaluate the methodology and to subsequently fine-tune the assessment tool.

Within the framework of the pilot assessments it was found that the Industry 4.0 concepts for a self-assessment are still too little known and companies may not be in a position to respond. Therefore, a guided interview approach is being considered for the future, in which an expert first explains the individual concepts and then the companies complete the assessment. On the other hand, a self-assessment via an own website with textual and graphic explanations and visualisations of the Industry 4.0 concepts is being considered.

Once field tests are finished the assessment model will be provided on the project website as online self-assessment tools for interested SMEs.

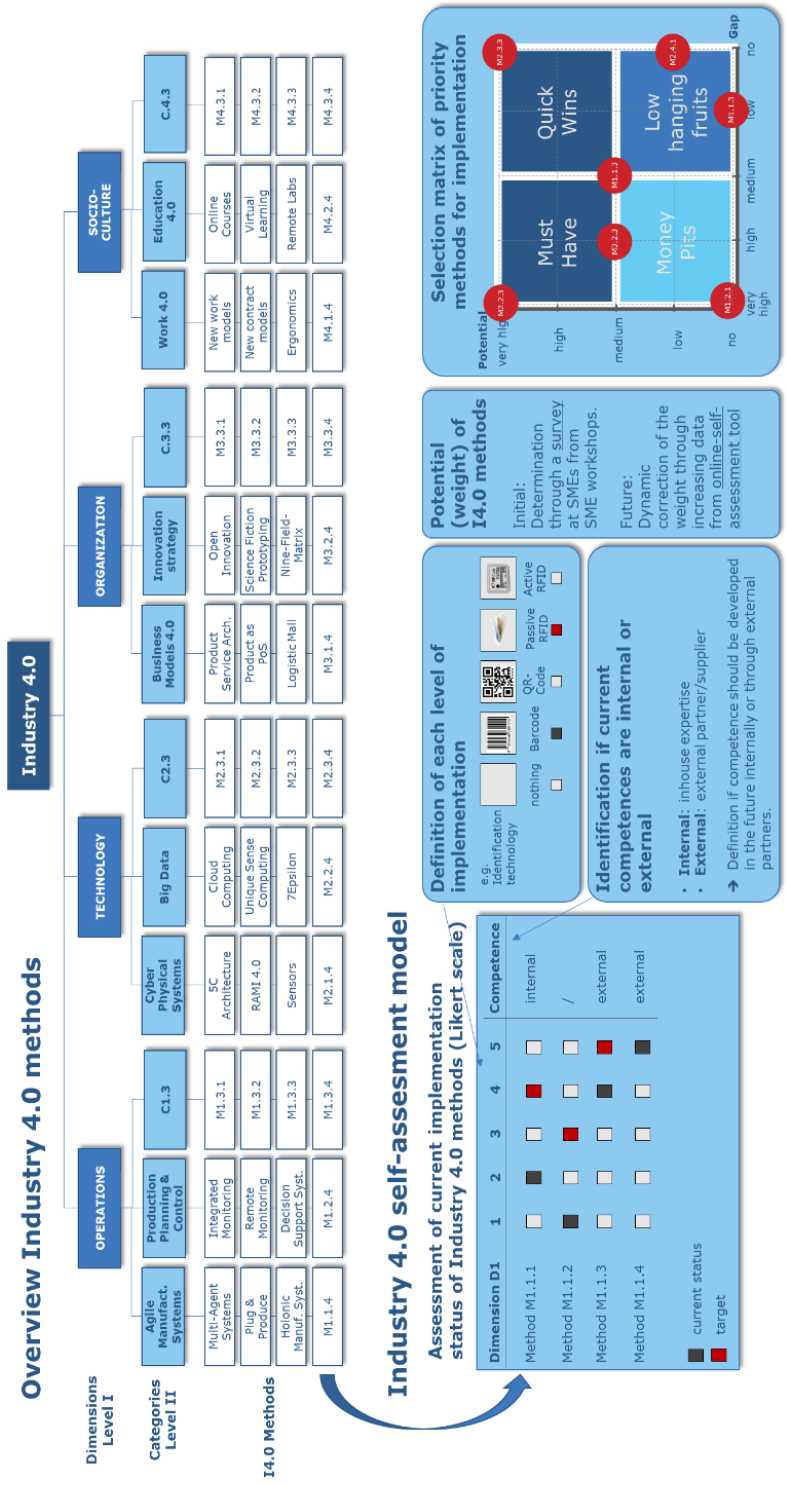

Figure 4. Development of an Industry 4.0 assessment model for self-evaluation.

4. Outlook

Industry 4.0 will shape companies in a similar way as the introduction of Lean Management has done. As in the Lean age, many of the Industry 4.0 methods are developed mainly in larger enterprises and have to be adapted to the specific requirements of SMEs. The research project presented aims to support SMEs in the introduction of Industry 4.0. As described in 3.2 first results have been successfully achieved. Following this first phase, the international research team will work on the assessment of Industry 4.0 concepts for their suitability in (i) small and (ii) medium sized enterprises. Further they will work on the adaptation of the most promising Industry 4.0 concepts according to the needs of SMEs testing them in academic laboratories and industrial case studies.

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