Introduction to Part 4

Technologies for Smart Production

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Abstract This part of the book addresses the technology aspect of Smart Production. In particular, we focus on the new digital technologies serving as enablers for transforming ordinary factories into smart factories. The part is composed of 10 chapters. This first chapter serves as a general introduction of smart factories, the role of technology in the smart factory and a set of key technologies for realizing smart factories for SMEs. The remaining nine chapters each introduce a specific technology chosen due to their high relevance to smart production in SMEs in general. These chapters will provide a short and concise overview of the respective technologies, discuss the implications specifically for SMEs and provide exemplification of the deployment.

Keywords Industry 4.0 · Smart production · Smart factory

1 Introduction

Over the past decades, we have seen a steep increase in consumer demand for product innovation. Innovation that pushes companies to shorten product lifecycles, releasing new generations more often, and offering ever greater product variance and customization options. Coping with the increasing product innovation pace is in itself challenging, but manufacturing companies also need to address the strain this puts on their manufacturing operations. Consequently, innovation in manufacturing paradigms, platforms and equipment has seen an increase as well, striving towards more dynamic and changeable structures on all levels of manufacturing as well as extensive digitalization of all assets and processes. As a result, we are now seeing a push of a new range of technologies promising the fulfillment of the visions behind Industry 4.0 (Dalmarco et al., 2019; Kipper et al., 2020).

Although the challenge of addressing the increased demand for product innovation is directly related to the value proposition, companies are today also faced with other challenges; in particular, the challenge of addressing both political and societal

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agendas (Deloitte, 2020). If the challenges are seen as the motivators for industry to move towards smart production, the new digital technology-toolbox contains the enablers needed to succeed in this transformation. Thus, technology innovation and adoption are among the central turning points of smart production.

2 Smart Factory

The heart of any production company's operations is the factory. Here, materials and parts are enriched and processed to form the product offerings to the market. It is also here, the increased product innovation pace and the impact of the challenges outlined above truly manifest themselves as challenging the current best practice. In finding new practices, the factory is also where new technologies and digitalization are anticipated to have the largest impact, effectively transforming factories to *smart factories*.

A smart factory is thus an extension of the traditional factory with extensive digitalization allowing data-driven operation. However, a recent definition of the smart factory (Schou et al., 2022) states, that a truly smart factory must also address requirements and agendas of the society in which it operates. Schou et al. (2022) defines the smart factory as:

> *A factory which by interconnecting its assets into a digital ecosystem, uses information to adapt, run and optimize its operations according to actual business conditions, thereby generating and appropriating business value while reflecting societal requirements.*

2.1 Sustainable and Socially Responsible

Companies are becoming more and more aware and focused on societal values and responsibilities as highlighted in a recent report from Deloitte (2020). However, the societal requirements will differ depending on the country and society in which the factory operates. In some societies, the outmost societal requirement might be to fight poverty and hunger, whereas in other countries it might be environmental sustainability.

Accentuating the context around the smart factory is also highlighted in the recent advent of the Industry 5.0 paradigm (Breque et al., 2021), which puts both sustainability and human wellbeing at its center; both of which are considered societal requirements.

2.2 Interconnected and Data-Driven

In literature, there are several other definitions of a smart factory, e.g. (Chen et al., 2017; Deloitte, 2017; Radziwon et al., 2014; Sjödin et al., 2018; Wang et al., 2016), most of which link the smart factory to specific technologies, frameworks, or manufacturing systems. We do not necessarily disagree with all of these; however, it is apparent that such definitions quickly become obsolete as technologies are replaced by newer ones. Thus, rather than pointing at specific technologies, the definition by Schou et al. (2022) specifies the capabilities the smart factory must obtain from deploying novel, digital technologies. Here, the central capability is the ability to govern its operations based on information created by contextualizing large amount of data from across the factory. This data is acquired by interconnecting the factory assets into a digital ecosystem. Assets can be everything from machines, to humans, to IT processes and systems, and thus it spans both horizontally and vertically in the factory. As such, a smart factory is a data-driven factory composed of many digitally interconnected assets.

2.3 Resilient

Given the increasing dynamic nature of the product market and the surrounding society as explained in Sect. 1, a smart factory needs to be resilient to the changing business conditions under which it operates (Schou et al., 2022). In can become so, by (1) responding in due time to changes in the demand, supply, legislation, and other operating conditions; (2) utilizing data to predict equipment health and process quality; and (3) using adaptable equipment to seamlessly changeover to new variants and quickly scale up and down in capacity.

2.4 Beyond Profit Value-Creation

The traditional factory creates value by processing materials and parts into products, and thus enabling the company to generate a profit. However, a truly smart factory can also extend this purely profit-focused value creation, by either purely or simultaneously generating other types of value for the company. It could be in the form of a *learning factory*, which serves to generate learnings, experience, and knowledge (Grøn et al., 2020); or as a *pilot factory* which serves as a sandbox for testing new technology, products, and methods (Hennig et al., 2019).

3 Technology

Although the *definition* of a smart factory (Schou et al., 2022) is independent of specific technologies, the implementation of a smart factory cannot be. For its embodiment, a smart factory needs technology, and new, digital technologies are the necessary enablers to achieve the capabilities and values outlined in Sect. 2.

3.1 Industry 4.0 Technology Stack

Since the dawn of the fourth industrial revolution (Kagermann et al., 2013), both industrial consultants and academic scholars have offered their take on which specific technologies are the essential enablers for Industry 4.0 (Bortolini et al., 2017; Craveiro et al., 2019; Ghobakhloo & Iranmanesh, 2021; Kipper et al., 2020; Sikandar et al., 2021). Boston Consulting Group (BCG) proposed in 2015 one of the best-known illustrations on industry 4.0 technologies (Russmann et al., 2015). The illustration points out nine technologies as being central to Industry 4.0, see Fig. 1.

Over the years, many others have proposed similar pictures of the key technologies in Industry 4.0 (Bortolini et al., 2017; Kipper et al., 2020; Sikandar et al., 2021).

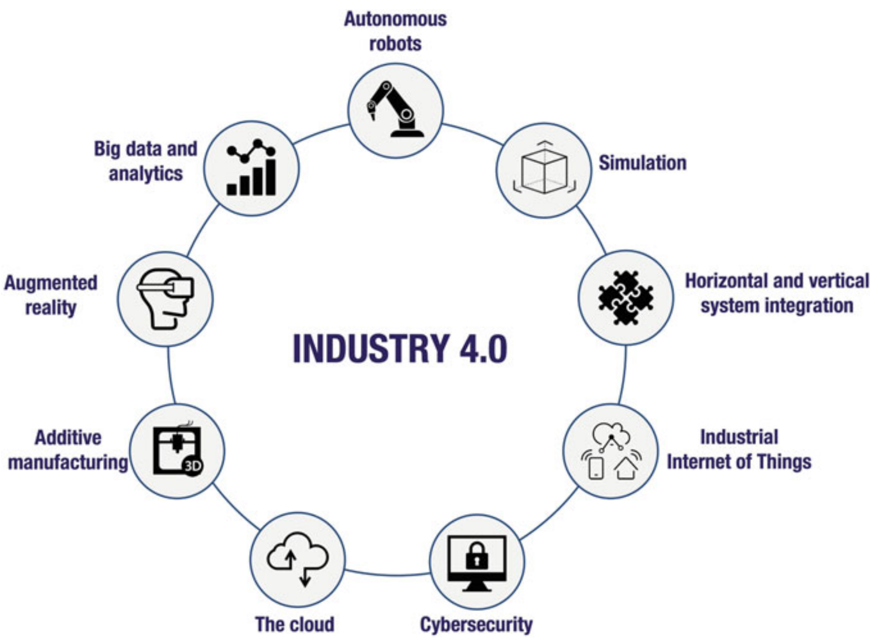

Fig. 1 Nine key technologies proposed by Boston Consulting Group as the main technological pillars of industry 4.0. Reproduced from (Russmann et al., 2015)

However, most are still closely aligned with the proposal from BCG shown in Fig. 1, emphasizing these as still being the key technologies of Industry 4.0.

3.2 Technology Innovation

Technologies tend to have a lifecycle; they are invented, matured, exploited, and later succeeded by newer technologies (Kim, 2003). Therefore, a static picture like Fig. 1 does not adequately capture the true technology potential of Industry 4.0. With the dawn of Industry 4.0, we have seen a large increase in innovation of manufacturing technology, resulting in a stream of new technologies labelled as *smart* or *industry 4.0 ready*. A stream that continuous today, and thus constantly brings new technological innovations and opportunities. An overview of upcoming, current, and mature technologies is presented by Gartner in their annually updated *Gartner Hype Cycle on emerging technologies* (Gartner, 2021). The Hype Cycle offers some insight into the maturity and readiness level of individual technologies, and thus constitutes a great tool for companies to both stay updated on emerging technologies and navigate the hype around new technologies.

3.3 Smart Factory Technologies for SMEs

By aligning the smart factory vision presented in Sect. 2, with the key Industry 4.0 technologies presented in Sect. 3.1 and the continuous flow of new technology discussed in Sect. 3.2, we have chosen nine key technologies that we deem central to the transformation of factories into smart factories in SMEs. The nine technologies and their relations are visualized in Fig. 2.

Given that SMEs tend to lack behind large companies in the digital transformation (Zeitschel et al., 2022), it is no surprise that the technologies suggested for the smart factory transformation for SMEs in Fig. 2 correspond well with the technologies proposed for Industry 4.0 by BCG in 2015. Although newer technologies have been introduced since, and more are on the horizon, the nine technologies in Fig. 2 are still today central and well-proven in the smart factory transformation.

Following the smart factory definition by (Schou et al., 2022), these nine technologies constitute a toolbox of *current* technologies that can embody the envisioned digital ecosystem and interconnect assets of the factory. For this purpose, Fig. 2 also visualizes how the nine technologies can form a new IT/OT architecture compared to the traditional automation pyramid. As shown in Fig. 2, some technologies provide the infrastructure necessary for the interconnection of assets, some enable the data flow, analysis, and management, and others exploit the available data, information and knowledge from the ecosystem. In brief, the nine technologies are:

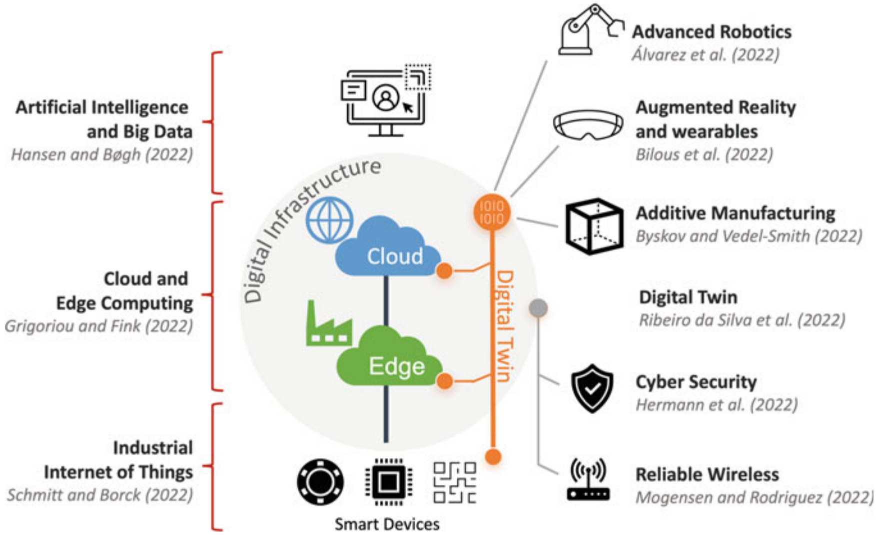

Fig. 2 Nine key technologies for the smart factory transformation in SMEs. The figure visualizes how the nine technologies fit into a smart factory IT/OT architecture. The references on the figure link the technologies to the following chapters in this part of the book

Industrial Internet of Things: Schmitt and Borck (2022) present industrial internet of things as the fundament of the asset interconnection in a smart factory and the data exchange of individual assets. This is achieved through Industrial Internet of Things promoting extensive connectivity of devices using smart devices (sensors, actuators, and controllers), new data exchange protocols and new cloud-based data-collection platforms.

Edge and Cloud Computing: Given the data exchange of individual assets, a digital ecosystem can be realized by integrating the data in a central platform. As discussed in Grigoriou and Fink (2022), using an edge and cloud-based platform, further promotes the integration between remote sites. Cloud computing also allows companies to draw on software tools and capabilities as a service, introducing new IT business models and architectures.

Artificial Intelligence and Big Data: With comprehensive data available in the digital ecosystem from across the company's assets, Hansen and Bøgh (2022) discuss how big data and artificial intelligence (AI) tools can be used to derive patterns and insight from the data. Thus, extracting information and eventually knowledge from the raw data. Such information and insight allow the company to adapt and optimize its operations and processes.

Reliable Wireless: The increasing need for more flexible and reusable production resources gives rise to more mobile and frequently changing systems; for instance, autonomous mobile robots and ad-hoc deployable production resources. Mogensen and Rodriguez (2022) argues that such systems benefit from a highly robust and fast wireless communication infrastructure beyond the capabilities of current Wi-Fi solutions.

Cyber Security: The extensive connectivity of assets, the switch to cloud computing architectures, and the increased use of wireless communication comes with the prerequisite of an inherent secure digital infrastructure. However, as discussed in Hermann et al. (2022), the ever-increasing cyber thread to companies' digital values means cyber security cannot be an aftermath, but must be an integrated part of smart factory solutions.

Digital Twin: Ribeiro da Silva et al. (2022) explains how the abundance of data available coupled with the analysis tools to extract insight and knowledge enables the creation of an accurate digital twin. Such digital twin allows the company to verify hypothesis and assess planned changes virtually. Thus, a digital twins will become an integrated part of the digital toolbox a smart factory uses to adapt its operations.

Additive Manufacturing: The resilience of a smart factory also comes from the application of flexible assets and processes. One example of such process-technology is additive manufacturing. Byskov and Vedel-Smith (2022) describe how additive manufacturing makes it possible to go directly from digital design to physical product. Apart from the inherent manufacturing flexibility, it also yields new freedom in product design and sourcing.

Augmented Reality and Wearables: The extensive digitalization of the shop floor is not contained to the automated processes. As production tasks grow increasingly more dynamic, the need to support the human workers grows too. Bilous et al. (2022) explain how introducing wearable technology for the operators and augmenting their workspace using augmented reality, digital support can be provided directly in-situ, and valuable data can be collected to represent the manual processes in the digital ecosystem.

Advanced Robotics: Álvarez et al. (2022) discuss how robots are among the key shop floor assets of the smart factory, given their versatile nature. However, as traditional industrial robots are intended for a fixed life in terms of hardware and programming, more advanced robotics solutions are needed. Solutions that are more autonomous and collaborative, allowing robots to operate in the dynamic environment of the human worker, and thus adapt to a greater task diversity over its lifetime.

4 Concluding Remarks

Growing market dynamics push companies to increase their product innovation to remain competitive. Meanwhile, political, and social agendas are also playing an increasing role to companies' operation and value proposition. Seen from an operation perspective, the manufacturing operations must become resilient to the frequently changing boundary conditions. This leads companies to pursue smart factories, which utilize new digital technologies and extensive data collection to continuously adapt and optimize. However, the solution space of new technologies is vast and continuously growing. In this chapter, we have suggested nine well-established technologies that together constitute a toolbox for the successful transformation of a factory to a smart factory for SMEs. The next nine chapters of this book (the rest of this Part) provide a catalogue of these technologies, including: a short introduction, implications for SMEs, and one or more examples of deployment.

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