Chapter 3
Technology Landscape 4.0

Yübo Wang, Thilo Towara and Reiner Anderl

Abstract Companies are facing manifold challenges while trying to implement Industrie 4.0, which are in great parts rooted in the complexity of Industrie 4.0 and its associated fields of research. Initiatives have developed abstract reference architectural models to mitigate these challenges and structure Industrie 4.0. The research on hand uses the reference architectural model Industrie 4.0 (RAMI 4.0), which is developed by the German Platform Industrie 4.0. This work aims to create a concrete, yet universal, application-oriented model that fosters the widespread of RAMI 4.0 in practice. It supports further research and amendments, and hence, facilitates the implementation of Industrie 4.0 in small and medium-sized enterprises. An information and technological navigation tool is developed for mapping technologies in RAMI 4.0. Finally, the foundation for a subsequent inclusion of IT security in RAMI 4.0 is laid.

Keywords Application-oriented RAMI 4.0 · Cyber-physical system · Industrie 4.0 · Internet of things · IT security · Technology landscape 4.0

Y. Wang (✉) · R. Anderl
Department of Computer Integrated Design, Technische Universität Darmstadt, Otto-Berdt-Str. 2, 64287 Darmstadt, Germany
e-mail: y.wang@dik.tu-darmstadt.de

R. Anderl
e-mail: anderl@dik.tu-darmstadt.de

T. Towara
Campana & Schott GmbH, Graefstrasse 99, 60487 Frankfurt am Main, Germany
e-mail: Thilo.Towara@campana-schott.com

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3.1 Introduction

Industrie 4.0 is increasingly gaining importance in the global manufacturing industry. While it is usually regarded as a prospective for large global enterprises, small and medium-sized enterprises (SMEs) are also recognizing the impact of Industrie 4.0 on the industrial future.

Platform Industrie 4.0, which is the leading institution of German Industrie 4.0, is dedicated to promote research in Industrie 4.0 for the German industry and facilitating the realization of this vision in manufacturing enterprises. In 2013 Platform Industrie 4.0 announced 17 technology development areas covering all the Industrie 4.0-related aspects in “Recommendations for implementing the strategic initiative INDUSTRIE 4.0”. An implementation roadmap for Industrie 4.0 is described in this recommendation [1].

As the extension of the first three industrial revolutions, the technical innovation for Industrie 4.0 is based on the vertical and horizontal integration of manufacturing systems, a continuous digital engineering throughout the product lifecycle, and finally the decentralization of computing resources. Enabling such an intelligent network, new technologies like modern internet technologies and flexible hardware and software interfaces are needed [2].

Equipping products and manufacturing environments with these new technologies, Industrie 4.0 offers manifold opportunities for enterprises to enhance efficiency and flexibilize production processes. Therefore, current products will increase in value and the development of new business models is facilitated [1].

According to the existing experiences of the Department of Computer Integrated Design (DiK), the Industrie 4.0 competences regarding communication technologies, digitalization, and IT infrastructure in enterprises, which are considered as key technologies, have to be promoted to bolster Industrie 4.0 implementation and finally, to fully realize the potential benefits [3].

In order to support research, norming processes, as well as practitioners, Platform Industrie 4.0 developed the Reference Architectural Model Industrie 4.0 (RAMI 4.0) . The model helps to classify and identify areas of Industrie 4.0 and creates a solid foundation for the further development of technologies. However, the model itself is rather abstract and its application is complicated for the practical implementation, especially for SMEs. Consequently, the use of RAMI 4.0 is limited to research institutions and first individual use-cases. Due to the abstract design of the model its generic applicability is provided, however, enterprises have to commit substantial resources to populate the model with specific technologies in order to use it as a knowledge foundation [4]. Developing their individual technological roadmaps for the next years, enterprises are facing questions like, which technical solutions would facilitate the development of their enterprise best, how these technologies interact, and how to implement Industrie 4.0 most efficiently.

This work takes these questions into account and proposes an interactive approach to support enterprises in realizing Industrie 4.0 based on RAMI 4.0. The aim is to provide a comprehensive overview of technologies, as well as their topological relationships, and therefore, a knowledge foundation for the implementation of Industrie 4.0 [5].

3.2 Global Digital Transformation

3.2.1 Global Leading Initiatives

The global digitalization of industries and values chains, along with the corresponding demand for structured research and norming, has brought forward four major initiatives in China, Japan, USA, and Germany. These initiatives address potentials and challenges of digitalization.

The “Made in China 2025” strategy is part of a larger modernization campaign of China. The core elements of the Chinese strategy are enhanced creative ability, improved quality and efficiency, as well as green development. Until 2025 industry and information technology are supposed to be integrated and China’s capacity to innovate and manufacturing productivity are planned to have been improved.

The Japanese Industrial Value Chain Initiative (IVI) is a platform to combine manufacturing and information technologies and facilitate collaboration between companies. It was founded in 2015 and aims to discuss potentials of human-centric manufacturing processes and to build a mutually connected system architecture.

The Industrial Internet Consortium (IIC), founded in 2014 by major telecommunications and technology companies in the US, aims to accelerate the development and deployment of interconnected machines and devices, as well as intelligent analytic tools, not just in manufacturing environments but also in areas like energy, transportation and smart cities. Its focus is the identification and promotion of best practices, while bringing together practitioners, researchers and government institutions.

Plattform Industrie 4.0 is dedicated to research in Industrie 4.0 for German industry and supporting the realization of this vision in manufacturing enterprises. The platform aims to identify all relevant technologies and developments in the manufacturing industry and to foster a common understanding of Industrie 4.0.

3.2.2 Global Leading Reference Architectures

Pivotal for all these initiatives is the development and adoption of common standards and norms to enable technology independent connectivity and interoperability across systems and industries. The IVI, the IIC, as well as the Plattform Industrie 4.0 have developed reference architectures to provide fundamental definitions.

3.2.3 Industrial Value Chain Reference Architecture (IVRA)

The Japanese IVI published the Industrial Value Chain Reference Architecture (IVRA) in 2016 to foster the widespread of so called Smart Manufacturing Units (SMUs), which are defined as individual units within industrial systems that interact with each other autonomously through mutual communication and thereby improve productivity and efficiency. The model analyzes SMUs from three different perspectives: asset view, activity view, and management view. While the asset view shows assets valuable to the enterprise (Personnel, Process, Product, and Plant), the activity view addresses the question how smart manufacturing creates values as the outcome of activities. The latter therefore deploys the common Deming cycle (Plan, Do, Check, Act). The management view shows purposes and indices relevant for management like quality, cost, delivery, and environment, which are used for steering assets and activities [6].

3.2.4 Industrial Internet Reference Architecture (IIRA)

The IIRA was first published in 2015 by the IIC and seeks to allow practitioners and researchers to develop and analyze systems based on common frameworks and concepts put together in a standards-based architectural template. It uses a multi-dimensional approach based on four different viewpoints of stakeholders at individual levels ranging from business topics over usage and functional considerations, to the final implementation. Each viewpoint is detailed in further levels and domains, while being intersected by topics like interoperability, security, and machine-learning [7].

3.2.5 Reference Architectural Model Industrie 4.0 (RAMI4.0)

The Reference Architectural Model Industrie 4.0 (RAMI 4.0) was developed by the Platform 4.0 in 2015. It consists of several layers, hierarchical levels, and the product lifecycle representing the value stream [1].

The fundamental structure is shown in Fig. 3.1. The **hierarchical levels** represent the functional characteristics of the components and are oriented on IEC 62264 and IEC 61512. These levels consist of seven individual levels: *product*, *field device*, *control device*, *station*, *work centers*, *enterprise* and *connected world*, from bottom to top. The lowest level, called p*roduct*, includes products that, due to their ability to communicate, are active elements within the production system. They provide information on their individual properties and necessary production steps. The f*ield device* level includes intelligent field devices such as sensors and actuators, the level c*ontrol device* in turn control devices, controllers and embedded controllers. Production machines, robots, or intelligent logistics vehicles are situated on the *station*

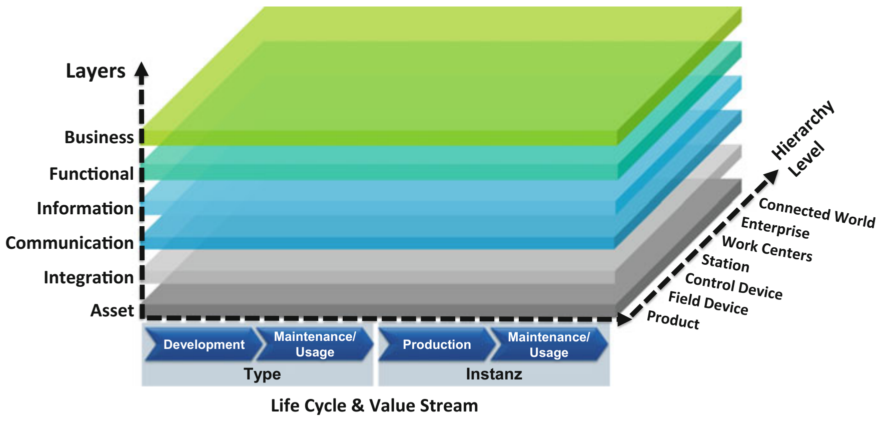

Fig. 3.1 RAMI 4.0

level. Both production plants and departments within a company are assigned to the *work centers* level. The e*nterprise* level considers the company as a whole and the *connected world* level represents its outer networks, e.g. collaboration with business partners and customers [4].

Each component consists of **six layers**. Starting with the lowest layer, the structure consists of *asset*, *integration*, *communication*, *information*, *functional* and *business*. While each layer is distinctively different from the others, elements within one layer are supposed to be homogenous regarding their attributes [8, 9]. The lowest layer is the *asset* layer, i.e. the representation of the physical reality. It contains all real objects such as machines, sensors and documents, as well as humans. In addition, intangible objects such as models, ideas, or patents are also attributed to this layer. Each element or function of the overlying layers must be attributable to an object of the asset layer. The *integration* layer supports the provision of computer-usable information related to the physical assets, such as geometry, hardware, and software, to the overlying layers. It contains all elements associated with the IT, including HMIs, and generates events based on the acquired information. The *integration* layer performs the final control of the technical processes. The purpose of the *communication* layer is to enable communication between the different elements of the network on the basis of uniform communication protocols and data formats. It also provides services to control the *integration* layer. Within the *information* layer the rule-based (pre-) processing of events takes place. For this purpose, data are checked for integrity, summarized into new, higher-quality data, and made available to the superordinate layers via interfaces. Events are received from the communication layer, transformed and forwarded accordingly. The *functional* layer represents the runtime environment for services and applications. It is the platform for the horizontal integration of the various functions and generates rules and application logic. Remote access and the integration of applications and functions take place only here, without interfering with the underlying layers. This ensures the integrity of the information, as well as the technical level. The *business* layer covers the abstract business models and the resulting process logic. It provides legal and regulatory frameworks and ensures the integrity of the functions along the value chain.

The third axis describes the **life cycle and the value chain** of an Industrie 4.0 component. The structure of this axis is based on IEC 62890 and assumes a basic division into product *type* and *instance*. While a type already exists with the basic product idea and covers the phases from order intake over product development to prototype production, an instance stems from the transition to production after the successful completion of all tests. The manufactured product then represents the instantiation of the type. Types, as well as instances, are subdivided into two phases: development and maintenance/usage for types and production and maintenance/usage for instances respectively [1, 4].

3.3 Challenges of German Small and Medium-Sized Enterprises

While implementing Industrie 4.0 companies have to overcome manifold issues. As small and medium-sized enterprises often lack the needed capabilities, for them Industrie 4.0 is especially challenging. The vertical and horizontal integration along the value chain, a continuous digital engineering, as well as decentralized production processes, inhibit great potentials, however, require a profound restructuring of IT and work organization and finally, bring along severe security threats.

3.3.1 Increase of Process Efficiency

Vertical integration of industrial value chains enables a dynamic adaptation to change environments. Accessibility of data is improved which can be used to optimize process efficiency and performance. Decentralized intelligent production systems can be altered in real-time, making even small batches, last-minute changes, or completely customized products economically feasible. Through modern engineering paradigms like collaborative, smart, and digital engineering, development time is further reduced and product supply is ultimately matching product demand [1].

3.3.2 Flexibility of Work Organization

Collaboration of employees and machines is enhanced by the implementation of multimodal Human-Machine Interfaces (HMIs). This symbiosis utilizes human attributes like creativity and flexibility together with the fatigue-free precision of machines.

Work not only becomes more efficient but also more humane. Challenges like the demographic change, the inclusion of employees with special needs, or other barriers can be encountered by intelligent workers' assistance systems. Modern Information and Communication Systems (ICS) allow remote telework, reduce transportation and travel expenses, and flexibilize site selection [1, 10].

3.3.3 Enabling New Business Models

The digitalization of processes along the entire life cycle produces vast amounts of data. The ability to analyze these data employing intelligent algorithms in combination with powerful hardware systems such as in-memory databases is an unprecedented source of information. All potentially relevant information can be recorded and taken into account in operational or strategic planning. Problems with products can be detected at an early stage on the basis of indirect customer feedback via social media. Furthermore, target groups can be analyzed more profoundly and product development adapted accordingly. New data-driven business models are emerging both in B2B (business-to-business) and B2C (business-to-costumer) areas. Services are increasingly important and partly replacing conventional products [10].

Along with these new opportunities, however, companies also face new challenges. Different platforms of various manufacturers must be networked and reliably communicate with each other on a uniform basis. Therefore, cross-platform interfaces and protocols must be defined and used extensively. In order to successfully transition to Industrie 4.0 not only technological solutions have to be implemented within the scope of production, but the entire structure of the company has to be transformed. Individualized product service systems partly displace conventional products. Data-based services and platform solutions require the development of new business models [11].

3.3.4 IT Security in Industrie 4.0

By connecting the formerly separated production and business networks, as well as exchanging data with external partners, new security risks arise. However, due to the requirements of real-time capabilities and limited computing resources, conventional security measures are not fully feasible [10]. To protect sensitive know-how and allow for trust-based collaboration confidentiality and integrity of transferred data must be ensured at all times. In the event of breakdowns, the expected damage is not only limited to monetary aspects, but may also affect the operational safety of machines and systems [12]. In order to implement effective safety concepts, systems must be secured comprehensively and, if possible, already in the development stage (Security by Design) and on several levels (Defense in Depth) [13, 14]. The realization of IT security measures therefore, takes a central position within the framework of

Industries 4.0. It is at the same time the cornerstone for successful networking and one of the key challenges for companies on the road to Industrie 4.0 [2]. To unfold the full potential of Industrie 4.0 applications, resilient and trusted components have to be developed on the asset level (Security by Design) and topics of secure networks, secure processes, secure services, and secure data addressed on the system level following a Defense in Depth approach [14–16]. The approach on hand does not incorporate security aspects yet, but can be extended by further dimensions to regard vulnerabilities and corresponding security technologies.

3.4 Topological Approach

Our topological approach populates RAMI 4.0 with relevant technologies and thereby, describes absolute topologies within the Industrie 4.0 landscape and interrelations between technologies. *Relevant* refers to technologies that are particularly important in the context of Industrie 4.0. Major technologies have hereby been identified based on core Industrie 4.0 paradigms such as *Engineering 4.0*, *Smart Factory 4.0*, and the development towards *Smart Products and Services*.

3.4.1 Requirements to the Topological Approach

Aiming at supporting the introduction of Industrie 4.0 solutions in SME, any concept has to fulfill certain criteria to enable a flexible and effective usage in practice. The requirements of the topological approach are shown in Fig. 3.2. Firstly (**R1**), every relevant technology in the context of Industrie 4.0 has to be considered and presented in a structured manner. As manifold industries are involved, generic technological categories rather than specific manifestations are to be preferred [1]. Secondly (**R2**), the overall concept along with the selection of technologies has to be implemented dynamically. Adjustments and adaptations of the concept to the individual, company-specific, circumstances have to be possible [2]. Thirdly (**R3**), due to the substantial importance of IT security, any concept addressing Industrie 4.0 should either already cover security aspects or provide a foundation for subsequent amendments [16].

3.4.2 Global Structure of the Topological Approach

Technologies are assigned to the corresponding levels based on their area of usage. While sensors and actuators can be clearly assigned to the *field device level*, computer and terminals may be used as discrete stations to control production facilities or on a higher level within departments for engineering or administrative purposes. Servers can equally be used on the *enterprise level* or, if provided by external partners, on

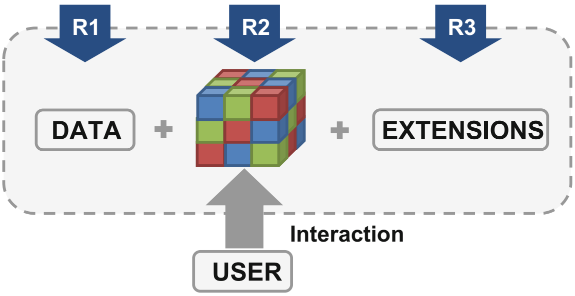

Fig. 3.2 Requirements for topological approach

the *connected world level*. The assignment of technologies to the hierarchy levels of RAMI 4.0 is therefore not definite but depends, within boundaries, on the concrete use case.

The positioning of technologies on the second axis of RAMI 4.0 (layers) depends on their core functionalities. Technologies that are providing means for communication like transmission technologies or communication protocols are assigned to the *communication layer*. Technologies providing specific functions like software products for engineering purposes or control software are assigned to the *functional layer*.

Technologies can be used throughout different product lifecycle phases. While there are certain technologies that are used regardless of the currently viewed lifecycle phase like computers and servers, technologies, such as x-in-the-loop, will be primarily used throughout the *type* lifecycle phase. The global view of the topological approach is shown in Fig. 3.3.

The three-dimensional design along with its dynamic usability concept allow users to view the model from six different perspectives, change the currently displayed level, layer, and lifecycle phase and actively interact with its content using intuitive multi-touch gestures. By selecting any technology, additional information regarding specific manifestations and related use cases are provided. This concept allows for adding further informational layers to the model, e.g. addressing vulnerabilities and corresponding security mechanisms. The detailed view of Instance, Production is shown in Fig. 3.4.

3.4.3 Mapping Technologies in RAMI 4.0

Cloud services represent a model for providing scalable, ubiquitous and on-demand retrievable network resources that can be flexibly adapted to current demand. Platforms in the context of industry 4.0 describe open application platforms for service orchestration [11].

Web services are services provided by applications or machines that can be used by other entities within a network. Offering independent, frequently standardized and modularized services, they play a central role within M2M communication within a service-oriented software architectures (SOA) [16].

Business Intelligence (BI) describes all concepts, models and information systems that are designed to support, carry out and control operational activities. Information systems (IS) can, in turn, be described as socio-technical systems, which aim to provide information and communication skills including applications and systems to support collaboration [17].

The integration of cyber-physical systems within industrial applications offers numerous possibilities for process monitoring, as well as remote services. **Smart** sensors, as well as smart material systems provide information about material stresses and loads. The data obtained is used for developing new business models, products or **services** [18].

Before physical production, manufacturing, assembly and testing processes can be simulated, the components' behavior and material stresses must be analyzed. Various product configurations and interactions third-party components can be simulated via powerful and interoperable software systems like x-in-the-loop methods in an **application or control software** [10].

To exchange model and simulation data, **software interfaces** are required, that enable cross-platform data exchange. When it comes to cross-company collaboration, integrated data security functionalities and protection of intellectual property gains importance [19].

Virtual and Augmented Reality (VR/AR) technologies are increasingly being used for industrial purposes. VR describes a computer-generated virtual environment that

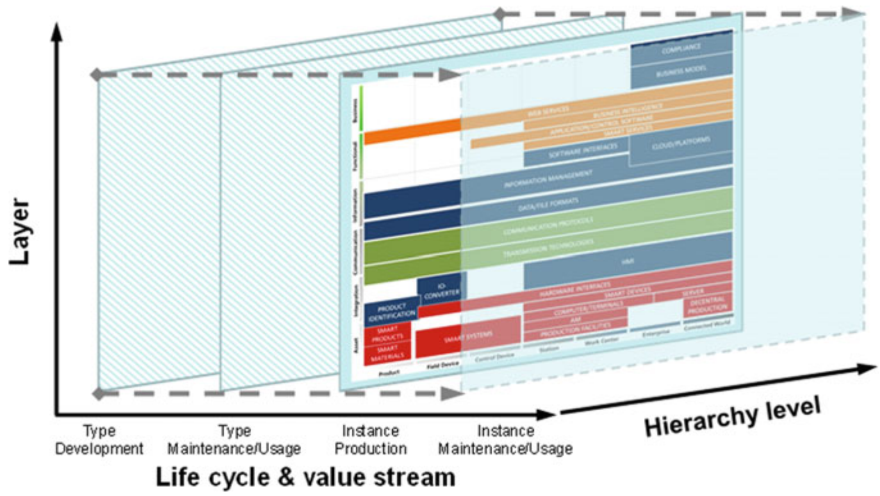

Fig. 3.3 Global view of topological approach to map technologies in RAMI 4.0

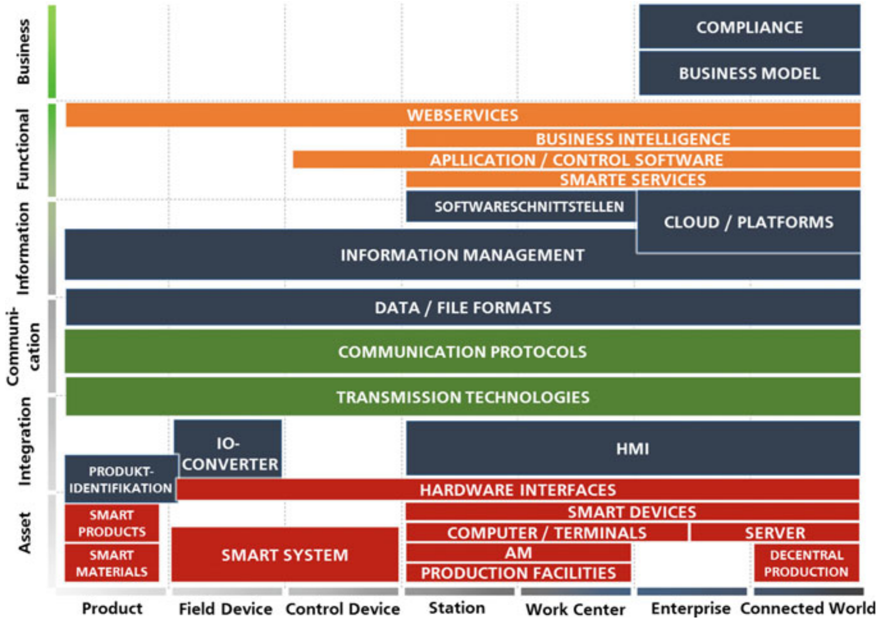

Fig. 3.4 Technology Landscape 4.0

serves as a HMI. The **human-machine interaction** can hereby take place in a multimodal way—addressing tactile or kinesthetic senses in addition to an audiovisual stimulation. AR refers to an expanded reality, in which the physically perceived reality is enriched by computer-generated information. Apart from VR/AR applications, **smart devices** providing context sensitive information can be used for alerts or tracking purposes and displace static, often paper based, information tools [10, 20].

Through digitization of value-added processes, large quantities of data are created. The efficient management and utilization of this data is a core task in Industrie 4.0. Only by deploying structured recording, storage, analyses and data provision processes in an **information and data management** system inefficient media breaches can be avoided and insights generated [21].

A prerequisite for cross-platform data exchange is the definition and use of uniform standards for **data formats**. In order to avoid redundant data generation and data losses, data formats must be fully transferable [22].

In order to ensure the collaboration of elements involved in the value-added process, their ability to communicate via platforms, interfaces and various transmission technologies must be ensured. The core technology cross-company **communication protocols**, and therefore for vertical and horizontal integration, is the Internet technology.

For wireless **data transmission** in industrial applications various open and proprietary technologies are available. In addition to WLAN, Infrared, NFC and Bluetooth, or further technologies based thereupon (e.g. ZigBee) are used. Mobile network technologies such as HSPA (High Speed Packet Access) or LTE (Long Term Evolution) can also be used for mobile networking of employees and systems. The individual technologies differ in frequencies used, transmission rates, range, as well as power consumption [23].

Manufacturing needs to be dynamically adaptable to changing demands and requirements. Therefore, modular production systems with interchangeable components need to be deployed. The usage of such components requires standardized, platform independent **hardware interfaces** to assure a sound communication among the different components. These hardware interfaces can either be wireless or tethered [10].

The **identification of products** and objects along the value chain is a core element of Industrie 4.0. Besides active technologies based on embedded systems, in practice, passive identification technologies via RFID, barcodes or data matrix codes are used. In contrast to active technologies, passive technologies allow only a temporary intelligence of the products, associated with the demand for additional reading devices. Alternatively, objects can also be identified and addressed directly through their assigned IP addresses [24].

Additive Manufacturing (AM) is a primary forming process in which the object geometry is produced by laminating volume elements of the same thickness. This allows a flexible production of any geometry based on three-dimensional CAD models. The potential for this lays above all in the freedom regarding component design, the elimination of special tools and machines, the possibility for a flexible individual parts production and the further reduction of development times [25].

Modern sensor-actuator systems are distinguished into passive, adaptive and active systems. While the characteristics of passive systems are firmly defined due to their construction and the materials used, adaptive systems can be adapted to altered environments in discrete stages. Semi-active systems even allow for continuous adaptation. Both adaptive and semi-active systems are often based on passive components such as springs and dampers and therefore limited in their solution space. This limitation is overcome by the combination of sensor and actuator elements together with controls to active, respectively smart, systems. Hereby, sensors and actuators are not additionally attached to the structure but directly integrated into it. Core components of **smart systems** are **smart materials**. These are often integrated with auxiliary materials into a multifunctional material system and fulfill requirements to actuators and sensors, as well as load-bearing tasks [26].

3.5 Benefits of the Topological Approach

Figure 3.4 presents a two-dimensional projection of the topological approach. In order to improve clarity within this paper, a projection of the hierarchy levels, as well as the layers, for the product lifecycle phase *instance—production* is performed. Its elements represent relevant technologies for the respective product lifecycle phase.

Through the population of RAMI 4.0 with generic technologies, the approach enables users to get a profound, yet swift, overview of the Industrie 4.0 landscape. Core elements are displayed and their topological relationships exposed. The dynamic interaction with the three-dimensional model further reveals the spread of technologies throughout the different product lifecycles. Users can navigate through the dimensions using intuitive controls that are based on current smartphone applications and support the future deployment of VR technologies.

The model is used in many projects as a knowledge foundation along the different stages of Industrie 4.0 implementation as described by the Generic Procedure Model to introduce Industrie 4.0 in SME (GPMI 4.0) [15]. It supports the preparation, analyzation, idea generation and valuation of solutions and concepts for the implementation of Industrie 4.0 in small and medium enterprises. The approach thereby fosters the implementation of Industrie 4.0 and enables practitioners to develop and validate their technological roadmap.

Regarding the future development and widespread of RAMI 4.0 the topological approach helps to reify the abstract RAMI 4.0 without omitting its generic applicability to the diverse industries and company specific backgrounds. It is the first model to actively promote the usage of RAMI 4.0 in practice and therefore, will create valuable feedback from practice and support the future development of RAMI 4.0. Especially regarding IT security, the topological approach sets the foundation for adding another dimension to RAMI 4.0 that specifically addresses security issues in Industrie 4.0.

The approach addresses the prior set requirements as every currently relevant technology is covered and due to the generic and dynamic design of the model newly emerging technologies can be assigned to an already existing category or simply added to the model in the future (R1). The three-dimensional and VR-ready design allows for manifold user interaction to display information in a profound, yet understandable and clear manner (R2). Due to its design, further informational layers can be added and thereby, the original model amended. Based on the technologies described associated vulnerabilities and corresponding security mechanism could be added in the future. The approach, therefore, already lays the foundation for a later integration of IT security aspects with the security-by-design concept (R3).

3.6 Conclusion

Industrie 4.0 requires a horizontal and vertical integration of the industrial landscape towards a fully digitalized enterprise. This integration brings along manifold security issues, which to address is one of the key prerequisites for Industrie 4.0. The diversity of technologies employed in industrial IT, the complexity of networks and new business models, as well as the challenges of securing those, are hurdles companies need to overcome.

The aim of RAMI 4.0 is, among others, to support the implementation of Industrie 4.0 and to help companies to overcome these hurdles. The approach on hand improves its direct applicability as the abstract model design is populated with more concrete technologies and their relationships among one another are exposed. Therefore, the transmission of RAMI 4.0 from research to practice is facilitated. Despite its importance for Industrie 4.0, IT security is so far not covered in RAMI 4.0. The topological approach described lays the foundation for an expansion of RAMI 4.0 to add another dimension addressing security aspects. Further research is needed to develop such an expansion and analyze vulnerabilities of the relevant technologies described, as well as corresponding security mechanisms.

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