A reference model for SMEs understanding of industry 4.0

A Reference Model for SMEs understanding of Industry 4.0

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Abstract: Industry 4.0 is the largely debated fourth industrial revolution. However, a gap still existing in disseminating its principles in SMEs environment. Reference systems, namely Reference Architecture and Reference Model, seem to foster the actual implementation of system compliant with principles of Industry 4.0. Hence, a Reference Model is presented to cope with the need for a reference system that can be easily understood by SME managers, and can vouch for realization of Smart Factories of Industry 4.0.

Keywords: Industry 4.0; Smart Factories; Reference Architecture; Reference Model; Small and Medium Enterprises; SMEs.

1. INTRODUCTION

The term Industry 4.0 (I4.0) has been adopted worldwide for identifying the expected fourth industrial revolution (Lasi *et al.*, 2014). Manufacturing in I4.0 consists of (i) exchanged information, and (ii) controlled machines and production units acting autonomously and intelligently based on information networked, that lead a transformation of work organization and production technologies (Oesterreich and Teuteberg, 2016). This transformation entails the deployments and optimization of very innovative technologies as well as detailed control of processes and business performances (Arnold, Kiel and Voigt, 2016). For practically developing I4.0 applications, reference architectures (RAs) must be designed (Kagermann *et al.*, 2013). A RA is a model for an architecture description: it has reference character since it provides a template solution for the architecture for a particular domain (Sittón-Candanedo *et al.*, 2019). A RA is designed from a Reference Model (RM) that consists of a minimal set of unifying concepts, axioms and relationships within a particular problem domain, and is independent of concrete details (MacKenzie *et al.*, 2006). Differences between RA and RM relate to the granularity level of details of the architecture designs. The possibility of conceptualizing various system aspects into coherent layers of abstraction allows reference systems (i.e. RA and RM) to suitably tune various elements that I4.0 has brought into industrial environment (Ma *et al.*, 2017), with the aim of providing a guiding blueprint which declare all components needed for structuring systems in a suitable manner (Kagermann *et al.*, 2013). Both practitioners and academia are very involved in architecting I4.0 systems, and one of the most robust and considered reference system is the 'Reference Architecture Model Industrie 4.0' RAMI 4.0, modelled by Adolphs *et al.* (2015) for within the German working group of ZVEI and VDI, and bringing in its name the dual concept of reference (i) architecture and (ii) model (Hankel and Rexroth, 2015). Despite this interest spread over years, especially in manufacturing systems it still exists a misunderstanding of how to implement I4.0 principles through reference architectures (Grassi *et al.*, 2020b). And a gap still exists concerning SMEs (Masood and Sonntag, 2020). SMEs are generally unprepared to understand I4.0 novelties and technical requirements (Schwab, 2017). After all, the inability of SMEs to evolve in the new technology and business scenario lies in their unawareness of new technologies and in the difficulty to implement them (McFarlane, 2018). The research question, this paper faces, is: *"how can a reference system support the development of I4.0 systems in SMEs environment, coping with the need of let SMEs understand I4.0 technologies and technical requirements?"*. A RM of I4.0 is proposed, which aims at identifying a basic technology stack for developing I4.0 systems, and at coping with interoperability with suitable RAs and architectures of I4.0. The reminder of the paper is detailed as follows. Section 2 provides the reader with a literature review of I4.0. Firstly, the components for a technology stack of the I4.0 are reviewed. Secondly, a review of the noteworthy 'Reference Architecture Model for Industry 4.0' RAMI 4.0 is carried out. Section 3 provides the 'Reference Model for Industry 4.0' RMI4.0. Section 4 tests interoperability of the RM with RAMI 4.0. Finally, conclusions are addressed in section 5.

2. A REVIEW OF PREVIOUS WORKS

2.1 Review of I4.0 components

The fourth industrial revolution is the result of continuously pushing on digitalization and networking of industrial systems, towards a new intelligent stage of informatization (Zhou *et al.*, 2018). Focusing on a technology stack of I4.0, the view of the fourth industrial revolution of digitalizing and networking systems is realized through three main components, i.e. (i) Cyber-Physical Systems (CPSs), (ii) Internet of Things (IoT) and Internet of Services (IoS), and (iii) Smart Factory (SF) (Kagermann *et al.*, 2013). CPS is defined as new generation of systems exploiting Information and Operation Technologies letting physical objects communicating with others and acting accordingly (Grassi *et* *al.*, 2020b). IoT is the technical infrastructure for the realization of Cyber-Physical Systems (Oks and Fritzsche, 2015), while IoS is the use of this infrastructure for developing and delivering platform and software applications (Moreno-Vozmediano, Montero and Llorente, 2012). CPSs and IoT realize the SF, by means of the Big Data (BD) and the BD Analytics (BDA), that identify the even increasing capability of accessing data from many different sources and processing them to support real-time decision making (Rüßmann *et al.*, 2015). Although other several technologies are considered in literature as enabling I4.0 and addressing the modelling of consistent reference systems (Grassi *et al.*, 2020b), these considered here are enough to characterize I4.0 since the suitability to group all possible enabling technologies of I4.0 by resuming two main characteristics needed, namely the capability of producing data and adding value for company by data exploitation (Brettel *et al.*, 2014).

2.2 Review of relevant RA: the RAMI 4.0

As previously said, both academia and practitioners are interesting in system architecting. On 2020.11.04 a query on Scopus, the largest peer-reviewed literature database, about 'Industry 4.0' and 'Reference Architecture' resulted in 688 documents, whose 391 date back to two-year period 2019-2020. Although the large amount of RAs and RMs designed, RAs and RMs are often stylishly but difficult to put into practice because they either entail too much components, or are too specific of an application (Oesterreich and Teuteberg, 2016). Beyond testing RAs and RMs for specific applications, the need for interoperability with other noteworthy RAs and RMs of I4.0 arouse to widen possible applications of the models (Buenabad-Chavez *et al.*, 2018), and RAMI 4.0 represents a real 'reference' RA in manufacturing industry for testing interoperability (Pisching *et al.*, 2018). Developed in Germany by the working group for I4.0 of VDI/VDE Gesellschaft Mess und Automatisierungstechnik, RAMI 4.0 is a model based on the Smart Grid Architecture Model (Hankel and Rexroth, 2015). The description of the architecture sticks to analysis of Grangel-González et al. (2016) and Zezulka et al. (2016). RAMI 4.0 is a layered architecture in a coordinate three-axis system. Fig. 1 provide the graphic of RAMI 4.0

The vertical axis represents IT perspectives of the business, where complex systems are decomposed into smaller manageable parts, in the look of (i) market aspects, (ii) functions, information, and communication, and (iii) integration ability of the components. Thus, it comprises six layers. Asset layer relates to physical components, parts, documents, representations, ideas and so on. Integration layer realizes the connection between physical reality and virtual reality worlds, and it is composed of both hardware and software, namely it functions as both (i) digitalization system via ICT and as (ii) systems control unit. Communication layer provides standards for communications (e.g. data format, communication protocols), and services for controlling the integration layer. Information layer establishes rules for preprocessing events and coherently describe them for the higher level. Functional layer enables formal description of functions and creates platform for horizontal integration of various functions. It contains modeling environment for servicing business processes and executing environment for applications and technical functionality, and it generates rules and decision-making logics. Business layer secures functions in the value stream by means of regulatory framework conditions, enables mapping processes and business models, addressing rules with which the system must comply, and finally establishes inter-dependences of different business processes.

The horizontal axis on the left-hand side indicates the product life cycle distinguishing between 'Type' and 'Instance', which respectively refers to two phases of (i) devising assets (i.e., design, development, testing products), which is preparatory to its serial production that leads to the second phase of (ii) installation in a particular system. Production phases is incorporated within the Instance. The RAMI 4.0 model enables the representation of data gathered during the entire life cycle, and its value stream in the totally digitalized production according to IEC 62890 Value Stream standardization. Thus, life cycle is linked to value-adding processes.

Finally, the horizontal axis on the right-hand side organizes the locations of the functionalities and responsibilities in a hierarchy. The model extends the hierarchy levels defined in the standard IEC 62264 for Enterprise-control system integration, and 61512 for Batch Control, towards specification of components in a single unit. Extension consists of adding the concepts 'Product' on the lowest level and 'Connected World' at the top level, for going beyond the boundaries of an individual factory and describing describes business stakeholders.

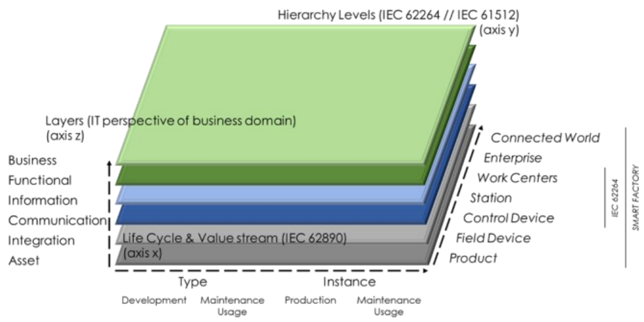

Fig. 1. RAMI 4.0

3. THE REFERENCE MODEL FOR I4.0 RMI4.0

In this work a RM is preferred to RA because of its higher level of abstraction of the system to represent. Moreover, since the focus on technology implementation, the RM is provided in the form of technical architecture model, although a functional viewpoint is provided apart. Technical and functional representation are both needed for giving a comprehensive description of the system design (Buede and Miller, 2016). The architecture exploits the I4.0 components for realizing the SF in manufacturing industry, namely BD and BDA, CPS, and IoT. If this stack is generally accepted as enabler for SFs of I4.0, it must be defined the relations among the technologies for providing a suitable representation. The research carried out has a literature approach and results are provided in the form of a narrative review of literature. Functional viewpoint representing how elements of the stack works is also built by means of notable architectures widely accepted in literature. The RMI4.0 (Fig. 2) and its functional view (Fig. 3) are here introduced for a better comprehension of design descriptions, which follow in the rest of the section with comments to the graphics.

3.1 The technology stack of RMI4.0

Initially aimed to provide fine-grained information enabling company management to measure, plan and act accordingly (Uckelmann et al., 2011), the IoT can be considered the seed of I4.0 in its view of allowing the connection of machines and eventually their interaction in an heavily automated manufacturing environment (Weyrich and Ebert, 2015).

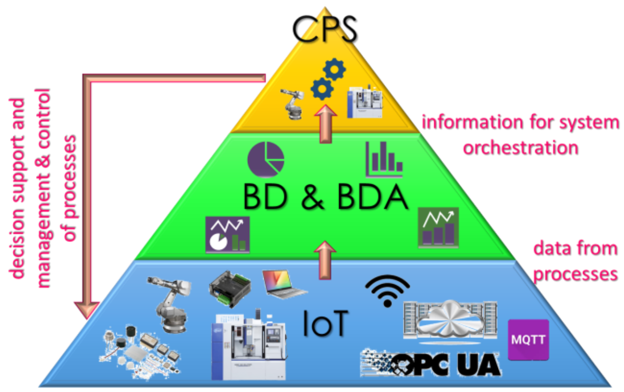

Fig. 2. The Reference Model for I4.0 RMI4.0

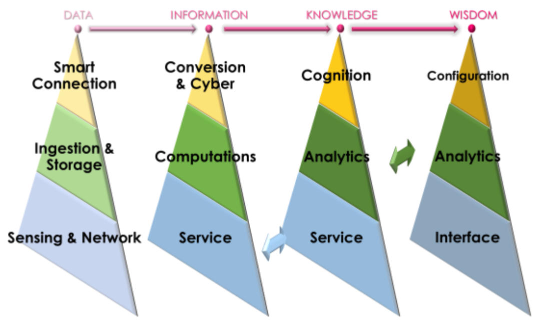

Fig. 3. Functional view of RMI4.0

This even increasing stress on connectivity for anything and communications of assets has eventually developed into the raising of the CPS, systems in a network capable of cooperating with each other via the IoT, indeed (Kagermann *et al.*, 2013; Pisching *et al.*, 2018). CPSs integrate (i) physical assets and processes with computation capacities, as well as (ii) assets and humans capable of be integrated by means of devices acquiring data (Lee, Bagheri and Kao, 2015). Therefore, IoT devices continuously generate data, coming from products, processes, as well as direct inputs (Tu, Lim and Yang, 2018). This concept drives data-driven applications that can generate domain-specific knowledge for decision support, requirements management, and more in general management and control of manufacturing processes (Hedberg *et al.*, 2017). This first result is the paradigm of BD as the exponential increase in volume and accessibility of data, their complexity, heterogeneity, high speed, and lack of structure (Marz and Warren, 2015). Alcácer and Cruz-Machado (2019) even argue that IoT without BD paradigm is more dangerous that advantageous for business. The next result is that BD utilization for decision making allows to integrate CPSs that have emerged as the core technology to blend and coordinate resources producing data and elaborating information towards better orchestration of the system in which resources operate (Chen, Tai and Chen, 2017). As a result, data are in the middle between the data acquisition and the data utilization. Data acquisition is possible via IoT, meant as both (i) complex of objects digitalizing all physical systems (Bortolini *et al.*, 2017), as well as (ii) the infrastructures which collect data and allows to enable CPSs (Oks and Fritzsche, 2015). BDA elaborates into information the large amount of data (i.e. BD) collected and provide them to CPS (Lee *et al.*, 2015), that utilize the information obtaining knowledge of the system towards a kind of system self-regulation (Lee, Bagheri and Kao, 2015). As a result, The RMI4.0 is designed as a hierarchical stack in which IoT is the backbone, BD are produced by IoT and BDA addresses the functionalities of CPS. An approach in which the RM is designed as a pyramid is adopted. Although semi-/heterarchical models can better foster decentralization of intelligences of I4.0 manufacturing systems (Grassi *et al.*, 2020b, 2020a), the approach of the present study relates to traditional information systems hierarchy and automation pyramid reliable and well-understood in SMEs environments, and then clearer to SMEs developers of I4.0 systems. The bottom level is represented by the IoT, the peak is represented by the CPS. In the middle BD are generated by IoT and BDA route information to CPS. Edges of each pyramid sector are permeable to feed forward flows of data and information. Feedbacks from CPS functionality are sent to IoT layer for orchestrating systems via decision support and management and control of processes. Feed forward transfers and feedbacks are represented in Fig. 2 with red-coloured arrows.

3.2 The functional view of RMI4.0

The instrument adopted for depicting the functional view are suitable architectures and frameworks of stack components, namely the ‘IoT architecture’ (Xu, He and Li, 2014), the ‘Big Data framework classification’ (Al-Gumaei *et al.*, 2019), and the ‘5C architecture’ of (Lee, Bagheri and Kao, 2015):

- The ‘IoT architecture’ is composed of four layers: the ‘Sensing Layer’ to acquire the status of objects and systems via actuators, sensors, RFID tags and other devices capable of acquiring data (e.g. PLC); the ‘Network Layer’ that transfers data captured through wired or wireless network to the next ‘Service Layer’, that makes use of technologies (i) supporting services and applications (e.g. data storage, exchanging and management of data) required by the users or applications (e.g. middleware, platforms), and (ii) routing the interoperability among heterogenous devices; the ‘Interface Layer’ that allows to display information in a clear and comprehensible way for managing interaction of machines and humans interconnected.
- The ‘Big Data framework classification’ considers four frameworks: the ‘Data ingestion frameworks’, which deal

with transferring raw data from data sources to the big data system and handle format and integration issues; the 'Data storage frameworks', which include distributed file systems and databases that persistently store varieties of big data formats; the 'Computation frameworks', which refers to capability of (i) processing large datasets and (ii) concurrently routing their elaborations to machines; and the 'Analytics frameworks', which consists of algorithms and computations used (i) to unlock value from big data and (ii) to make predictions about future trends based on past events.
- The '5C architecture' is composed of five hierarchical functions each one corresponding to specific technologies to adopt for realizing CPSs: 'Smart Connection' is the bottom hierarchical level characterized by the data acquisition through sensor network, controllers, as well as enterprise manufacturing systems, and it relates to the system condition monitoring; 'Conversion' is the hierarchical level dealing with transforming data into information, and it consists of suitable algorithms, and relates to system self-awareness; 'Cyber' is the middle layer acting as a central hub, which routes information to every connected system, forming the system network: digital twin and Analytics (e.g. data mining) are needed for elaboration and synthesis of information gathered; 'Cognition' layer deals with providing users with the proper knowledge about the system acquired, for prioritizing and optimizing decisions; 'Configuration' layer realizes the feedback from the cyber to the physical space, making machines self-configure and self-adaptive.

Functional view proposed relates to the smartification of the systems towards the realization of the SF, which in SMEs environment relates to the use of data for gaining benefits in manufacturing and business practices. An approach towards the smartification of the system is closing the gap between the knowledge of the system and its wisdom (Ardito *et al.*, 2019). Knowledge and wisdom are set according to the Data-Information-Knowledge-Wisdom (DIKW) model of Ackoff (1989). In this work, this approach is developed by means of the Rowley' 'Wisdom hierarchy' (2007) that maps the DIKW hierarchy onto the information system hierarchy built by the author according to the ISA 95 automation pyramid, which is is made of four systems: the 'Transaction Processing System', the 'Management Information System', the 'Decision Support System', and the 'Expert System'. The 'Wisdom hierarchy' is here used to link the information system hierarchy, largely accepted and adopted in industry, and the architectures and frameworks of I4.0 previously introduced. The full combination of structures is provided in the bullet list below. DIKW meanings are provided by Ackoff' definitions (1989) (in italic font), and then are mapped to types of information systems as made by Rowley (2007). Meanings of each element towards I4.0 technology stack is found out from the original architectures considered:

- *Data are defined as symbols that represent properties of objects, events and their environment in a useable form.* Data in the Rowley' information system hierarchy are contained in the 'Transaction Processing System'. They are acquired at the 'Sensing layer' of IoT by means of sensor belonging to the bottom function 'Smart Connection' of CPS, and then are transferred to the IoT 'Network layer' for 'Data ingestion' and 'Data storage' of the BD frameworks.
- *Information is inferred from data, and it differs from data because of its function. It is contained in descriptions and answers to questions.* It lies is the middle architecture functions 'Conversion' and 'Cyber', since the relationship with the 'Management Information Systems' level of Rowley. 'Conversion and Cyber functionalities' are realized by means of 'Service layer' and 'Computation frameworks' of IoT and BD, respectively.
- *Knowledge is know-how and is what makes possible the transformation of information into instructions.* In the derived information system hierarchy of Rowley, it matches to the 'Decision Support System', which in the 5C architecture of CPS is related to the high function 'Cognition' realized through 'Analytics framework' of BD still within the 'Service layer' of IoT architecture.
- Finally, Intelligence and Wisdom belonging to the 'Expert System' of information system in Rowley, are reached, and they refer to the ability of increasing efficiency and effectiveness: *wisdom adds value by means of judgement.* It matches the higher CPS function 'Configuration' realized through 'Interface layer' of IoT by means of 'Analytics frameworks' of BD.

Table 1 recaps how DIKW hierarchy and architecture of I4.0 are interconnected achieving wisdom within SFs of I4.0. The functional view of RMI4.0 has been provided in Fig. 3. Four views describing functionalities of each components consider hierarchical levels of the RMI4.0 technology stack (Fig. 2), and each layer belong to suitable classification of relative architectures. The lower level of the pyramid relates to data acquisition from objects, and data transfer to systems capable of processing them. The next level relates to processing for transforming data into information useful for acquiring knowledge of the system in the upper level. Finally, at the top reside the functionalities related to the information routing to suitable machines and devices that accordingly interact and behave.

4. INTEROPERABILITY OF RMI4.0 WITH RAMI 4.0

For validating RMI4.0, RAMI 4.0 is mapped onto it. This practice follows an approach largely adopted in literature to our best knowledge, namely the comparison of design of reference systems for assessing their interoperability. The RAMI 4.0 realizes different viewpoints through the IT representation layers (i.e. the vertical axis) (Kannengiesser and Müller, 2018), namely the 'Production Control', 'Business Processes', and 'Integration' viewpoints. These viewpoints are expressed by meeting or not specific layers of (i) product life cycle and (ii) hierarchy levels of system functionalities axes. Integration and Communication layers express the 'Integration' viewpoint; Information, Functional, and Business layers realizes the 'Production Control' and 'Business Processes' depending on what system hierarchy and product life cycle levels they meet.

Table 1. Mapping I4.0 architectures onto DIKW hierarchy, towards system smartification

DIKW hierarchy	Information system hierarchy level (Rowley, 2007)	IoT layers (Li, Da Xu and Zhao, 2015)	BD frameworks (Al-Gumaei *et al.*, 2019)	CPS functionality (Lee, Bagheri and Kao, 2015)
Data	Transaction Processing System	Sensing Network	Data ingestion Data storage	Smart Connection
Information	Management Information System	Service	Computation	Conversion Cyber
Knowledge	Decision Support System		Analytics	Cognition
Wisdom	Expert System	Interface		Configuration

As a result, it is useful mapping RMI4.0 onto IT representations layers to surely meets its all layers and levels. A characterization of IT representations layers comes from (Ye and Hong, 2018). Authors relate the 'Asset' layer to the real world of field devices and objects (e.g., machines, robots, sensors, actuators, controllers, RFID). 'Communication' and 'Information' layers deal with elaborating the digitalized real world, providing communication and information services, respectively. It is realized by data transport (e.g., fieldbus protocols, AutomationML, MQTT, OPC UA, Edge network) and data management (e.g., Systems Modelling Language, Cloud, Machine Learning, process modelling, Edge/Fog computing, accordingly). 'Integration' layer is in the middle between 'Asset' layer, and 'Communication' and 'Information' layers, digitalizing the real world and providing the digitalization to the cyber world. 'Function' and 'Business' layers realize domain specific applications for the enterprise process-control system (e.g., knowledge management, platform applications, service applications, control strategy, APIs, HMIs, SOA-based resources). Moreover, according to Pisching et al. (2018), CPS realizes the functionalities of 'Function' and 'Business' layers, whereas IoT realizes the 'Asset', 'Integration', 'Communication', and partially 'Information' layers functionalities. Therefore, RAMI 4.0 can be successfully mapped onto RMI4.0 as in Table 2.

Table 2. Mapping RAMI 4.0 onto RMI4.0

RAMI 4.0	RMI4.0
Asset layer	IoT LEVEL
Integration layer	IoT LEVEL
Communication layer	IoT LEVEL
Information layer	IoT and BD & BDA LEVEL
Function layer	CPS LAYER
Business layer	CPS LAYER

5. CONCLUSION

The RMI4.0 in this work is aimed at fostering design of I4.0 architectures, especially for SMEs. This is supposed to better explain the technology stack to implement, and foster data-centered business principles to push in new industrial scenario, usually missed or misunderstood by SMEs. A simple design is preferred to design entailing too many components and hence difficult to understand. A RM is preferred to RA, and the design observes a specific literature approach for deriving relation of identified components, i.e., IoT, BD & BDA, and CPS. RMI4.0 pursues some fundamental purposes for dissemination of I4.0 architectures within SME environments. First, it realizes a technical viewpoint of I4.0, for providing SME managers with the technology stack to implement. Second, it is simple and clear for letting SME management understand how to realize systems and structures of I4.0. Furthermore, for helping SMEs in understanding I4.0 systems, an approach in which it relates to traditional information systems hierarchy and automation pyramid has been followed, since these frameworks are well-understood and adopted in SMEs for a long time. Although it is generally accepted that hierarchies and vertical structures develop into networks in I4.0 systems, this aspect has been judged useful for fostering I4.0 dissemination among SMEs, well-conscious that a high-level description of the I4.0 system does not bias its actual implementation. Finally, although interoperability with other noteworthy reference systems has been positively discussed, a practical verification in real industrial environment of alignment between RAMI 4.0 or other reference systems and RMI4.0 is missing, and future works can move from this consideration.

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