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Piloting Industry 4.0 in SMEs with RAMI 4.0: an enterprise architecture approach

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Abstract

Reference Architectural Model Industrie 4.0 (RAMI 4.0) is an influential guide to the ongoing digital transformation in industry. However, the adoption of RAMI 4.0 in small and medium-sized enterprises (SMEs) is still emerging. This paper describes how to deploy pilot projects in the era of Industry 4.0 following an enterprise architecture (EA) approach. The field intervention presents the design of an app for manufacturing that adheres to RAMI 4.0 in the context of SMEs. ArchiMate language is used to model the Industry 4.0 vision in the case company and identify specific requirements for technology developments. Our work presents (1) EA models for the six main RAMI 4.0 layers: business, functional, information, communication, integration, and asset, and (2) the instantiation of a pilot project adopting mobile technologies in manufacturing and quick response (QR) code identification for product traceability. For theory, our study confirms recent research suggesting the suitability of ArchiMate to help in Industry 4.0 initiatives, providing examples of layered models for RAMI 4.0. For practice, the study can be helpful to increase the adoption of RAMI 4.0 in SMEs and exemplify how to deploy specific industry developments starting with a high-level description of the Industry 4.0 architecture. Enterprise architecture approaches to Industry 4.0 can assist companies in their long-term investment plans and ensure technology integration and strategic alignment of Industry 4.0 projects.

Keywords: Industry 4.0, RAMI 4.0, SME, Reference Architectural Models, Archimate.

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1. Introduction

Sustainable digital transformation aims to conciliate social, economic, and environmental outcomes [6][12]. The phenomenon is transversal to different sectors of the economy that are creating new production networks with the integration of information technologies (IT) and redesigned business processes [22]. The term Industry 4.0 was introduced by the German government to create an agenda of industrial transformations (technological, societal, and organizational), "*and it is envisaged that it will only become fully implemented from about 2025 onwards*" [25]. Therefore, new approaches are necessary to support industry managers in shaping their vision of digital transformation.

As an extension of the first three industrial revolutions, Industry 4.0 is based on vertical and horizontal integration of manufacturing systems, continuous digital engineering throughout the product life cycle, and the decentralization of computing resources [29]. The technological portfolio of Industry 4.0 is vast and includes robotics, augmented reality, internet-of-things (IoT), big data, artificial intelligence, or mobile systems [25]. The adoption of Industry 4.0 offers a variety of opportunities for enterprises to maximize efficiency and increase production flexibility so that the current products will increase their value [29]. Small and medium-sized enterprises (SMEs) already recognized the enormous potential of digital transformation to integrate global supply chains. However, these companies often suffer from a lack of innovation capabilities [18][29], requiring particular attention from researchers.

Platform Industry 4.0 was created to promote research in Industry 4.0 for the German industry. They offered an influential Reference Architectural Model Industrie 4.0 (RAMI 4.0) [1], helping organizations to identify and classify areas of Industry 4.0, building foundations for further technological development. However, according to [8], "[t]*he implementation of RAMI 4.0 has been challenging, since it relies on various factors which may affect or hinder the final output, such as the current industrial landscape, as well as the multiplicity of equipment within the factory, which have different sources, diverse construction and various communication capabilities*". Furthermore, the application of RAMI 4.0 is yet too complicated for SMEs since the model is rather abstract [29].

Our project started in cooperation with an industrial SME interested in creating a strategy for Industry 4.0. Their aim was to (1) identify opportunities for digital transformation in technical coatings, (2) deploy a pilot project in their manufacturing process, and (3) create a comprehensive map to guide their incremental Industry 4.0 adoption. More recently, some authors suggested applying enterprise architecture approaches and languages like ArchiMate to produce more detailed models for Industry 4.0, compliant to RAMI 4.0 (e.g., [19]). Inspired by their work, the following research objective was formulated: *deploy a pilot project for Industry 4.0 using RAMI 4.0 guidance in SME context*. Thus, our contribution adds to the body of knowledge on Industry 4.0 pilot projects compliant to RAMI 4.0 and the architectural development of digital transformation in industrial SMEs.

The rest of this paper is structured as follows. Section 2 presents essential literature on Industry 4.0 and related architectures. Next, the research approach is explained. Section 4 details the modeling approach in a metalworking company. Finally, the paper closes in Section 5, stating limitations and future work opportunities.

2. Background

2.1. Industry 4.0

Digital transformation is a top priority in different areas of the globe [22]. Smart factories providing increasingly smart services and products aim to satisfy the needs of each client [28]. The increasing value of information technology [7] boosts innovation and new competitive strategies [5]. Yet, Industry 4.0 is also a social transformation with a significant impact on work practices [17]. This initiative describes how companies can create intelligent networks by connecting machines, systems, and physical assets and how production modules can be autonomously controlled. The ongoing industrial revolution expands the company borders to allow horizontal, vertical, and end-to-end digital integration [3]. Examples include new information systems focusing on production stages and enabling real-time communication with end-customers and advanced product traceability. Through a complex combination of technologies, industries need to rethink process management, value chains, and marketing and distribution phases [23].

SMEs are crucial to most countries and industry sectors [18] but must overcome some obstacles towards Industry 4.0. SMEs need to improve their management processes (e.g., "*planning, using resources, controlling production, and measuring and evaluating operational performance*" [18]). Yet, many SMEs still have a short-term strategy, inhibiting long-term investments. Additionally, there is a lack of expert support functions in SMEs. For example, financial management, IT, and supply chain management. The introduction of new technologies is always risky in SMEs, and some challenges concerning standards, business tools, security, and investment may exist [8].

Designing a "4.0" architecture can be seen as the creation of a system of systems that continuously adapt [20]. The first challenge is "*due to the necessity of defining the required business entities: how these entities participate during the value creation process can be challenging to map and requires the perception of the real implication within the value chain network. The second challenge pertains systems integration and interoperability*" [8]. Therefore, architectures for Industry 4.0 are essential tools to assist industry managers in the development of their strategy.

2.2. Reference architectures for Industry 4.0

Three examples are highlighted in this section. The Industrial Value Chain Initiative (IVI), the Industrial Internet Consortium (IIC), and Platform Industry 4.0 have developed reference architectures to provide fundamental definitions and guidance to industry transformations: Industrial Value Chain Reference Architecture (IVRA), Industrial Internet Reference Architecture (IIRA), and Reference Architectural Model Industrie 4.0 (RAMI 4.0).

IVI published the IVRA in 2016. According to this architecture, Smart Manufacturing Units (SMUs) "*are defined as individual units within industrial systems that interact with each other autonomously through mutual communication and thereby improve productivity and efficiency*" [11]. SMUs can be represented according to three views: asset view, activity view, and management view. The first one shows the assets valuable to the manufacturing organization [11]. These assets are considered properties of the SMUs and, if needed, they can be transferred between distinct SMUs. The second (activity view) covers the activities performed in the SMUs: "*can be seen as a dynamic cycle continuously improving targeted issues proactively*" [11]. Finally, the management view explains the indicators relevant to management. According to [11], "[a]*ssets and activities of SMUs should be appropriately steered in terms of quality, cost, delivery and environment, which represent the management view*". IIRA was published with a similar purpose: to analyze and develop systems based on standard frameworks [16]. Four different viewpoints are included in this reference architecture: business, usage, functional, and implementation. Each of the viewpoints is detailed in other levels and domains, with particular concern in security and interoperability [16].

The reference architecture selected for our work (RAMI 4.0) has differences. RAMI 4.0 is an adaptation of the Smart Grid Architecture Model (SGAM) - a model that provides a structured basis for the design, development, and validation of new solutions and technologies [27] to meet the requirements of Industry 4.0. RAMI 4.0 is a three-dimensional model (Hierarchy Levels, Life Cycle/Value Stream, and Layers) represented in Fig. 1.

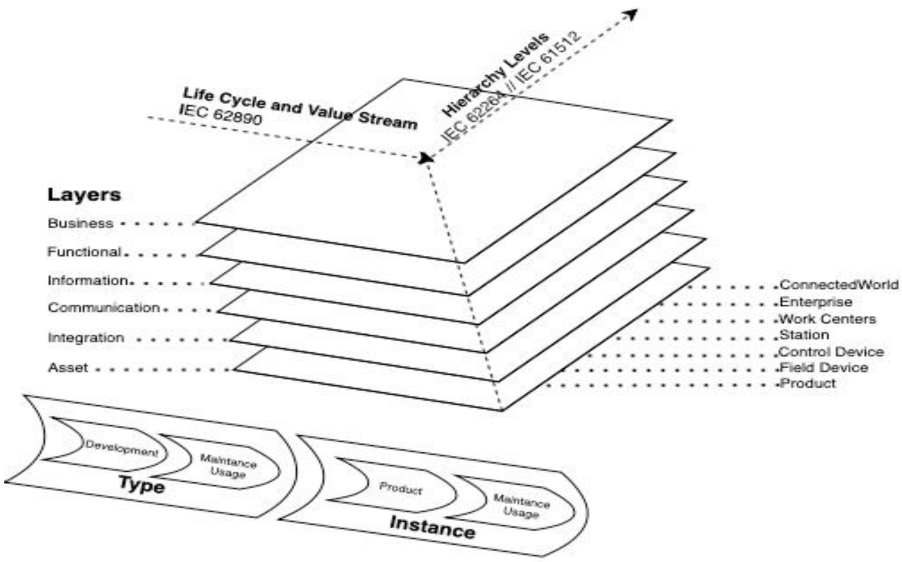

Fig. 1. RAMI 4.0 (adapted from [1]).

The hierarchy levels axis (on the right) has seven levels: connected world, enterprise, work centers, station, control device, field device, and product. These levels are oriented according to the IEC 62264 / IEC 61512 standard for enterprise control system integration [1][21]. The lowest level includes products that can become active elements in the production system due to their ability to communicate. These products can provide digital information about their properties and production steps. The field device covers sensors and actuators, requiring the control device layer to be successful. Next, the "station" may include robots, production machines, or intelligent logistics vehicles. The work centers encompass departments and production plants within a company (enterprise level). Finally, the connected world represents outer networks as collaborations with business partners and customers and internet-based services.

The life cycle & value stream axis (e.g., facilities and products) is based on IEC 62890 [21]. This axis assumes a primary division into product type and instance: "[w]*hile 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*" [29].

Finally, RAMI 4.0 integrates six individual layers (from top to bottom) [1]: business, functional, information, communication, integration, and asset. They describe the structure of machines and physical entities to enable virtual mapping [29]. Layers represent data maps, communication behaviors, and functional descriptions.

2.3. Modeling RAMI 4.0 with ArchiMate

ArchiMate is an enterprise architecture language created by the Open Group [26]. It is a general-purpose modeling language addressing different organizational layers, namely, strategy, business, applications, technology and physical, and implementation and migration [26]. Adopting ArchiMate, designers can represent the elements existing in each layer and their interactions (e.g., software and its users, organizational goals, or services).

Some authors have tried to adopt ArchiMate for RAMI 4.0 modeling, finding good results [10]. A search using the keyword combination "RAMI 4.0" + ArchiMate returns 24 results in Google Scholar (the majority in the last five years), revealing its emergent nature. The potential alignment is confirmed [13]'s preliminary discussion, but the author also suggests additional work to model socio cyber-physical systems in Industry 4.0. More recently, [19] provides a detailed mapping of ArchiMate and RAMI 4.0 concepts, facilitating architectural paradigms' integration. The business layer is proposed for future research by these authors. Another work recently published in KES reveals the deep integration between enterprise models and Industry 4.0 adoption and the need for more real EA projects to advance the field [14]. These significant contributions on synergies between RAMI 4.0 and ArchiMate have inspired our contacts with a small manufacturing industry. Our work aims to address the gap of (1) modeling the business layer of RAMI 4.0 with ArchiMate and (2) present a real example of architecting Industry 4.0 in an SME.

3. Research approach

This research follows the Soft Design Science Methodology (SDSM) [2]. Having its roots in the work of [24], design science research (DSR) is one of the research approaches that can be used to create innovative artifacts in natural settings [9]. Moreover, knowledge can be accumulated over time, improving reference models with enhanced industry-research collaborations [15]. Among the different variations of research processes available to conduct DSR, we selected the SDSM, merging "*the common design science research process (design, build-artifact, evaluation) together with the iterative soft systems methodology*" [2]. The reasons are threefold. First, SDSM focuses on the continuous iteration of the traditional steps of designing, creating, and evaluating artifacts. Second, SDSM combines DSR steps with the soft systems methodology [4], which is particularly interesting for systems development and continuous improvement in organizational settings. Third, it is closely associated with prototyping, which may start with vague requirements that are progressively improved in cooperation with the practitioners. The SDSM proposed by [2] evolves in seven steps:

1. *Identify the problem to be addressed*. RAMI 4.0 is one of the most prominent reference architectures for Industry 4.0. However, its adoption in SMEs requires particular attention, and there is a shortcoming of cases reporting field studies of systems development using RAMI 4.0.
2. *Clarify the requirements for the solution*. New approaches are necessary to translate RAMI 4.0 layers into more specific instantiations of IT in organizations.

3. Tra*nslate the problem in the social and technical dimensions within the systems world*. For example, manufacturing processes in Industry 4.0 can be supported by advanced identification techniques and apps to help the company and the customers.
4. *Derive a solution for the class of problems identified through systems thinking*. Modeling RAMI 4.0 using enterprise architecture languages like ArchiMate may contribute to identifying Industry 4.0 requirements.
5. *Compare the general design requirements with the requirements identified in step 2*. ArchiMate language provides a comprehensive view of the enterprise, including both social and technological layers. However, its utility in pilot project development for Industry 4.0 is still unspecified.
6. *Search for a specific instance of a possible solution*. The case company participating in this research is interested in creating a comprehensive strategy for Industry 4.0 and build a pilot project. Pilot projects are popular approaches to start Industry 4.0 investments, requiring the definition of a strategy.
7. *Build and deploy the solution in a social system, hopefully improving the problematic situation and learning*. The case reported in this paper explains how modeling RAMI 4.0 with ArchiMate can be helpful for an instantiation of a mobile app.

This work is conducted in a small technical coating company founded in 2017. Coatings are essential to increase the durability and reliability of different components used in the industry. The techniques include thermal spraying, composite, laser coatings, or electrodeposition and creates an extra layer of material that will increase the useful life of components. The company exports to Europe and South America, and their customers include automotive, aeronautic, energy, naval, petrochemical, paper, among other relevant process industries with demanding process requirements. Our case company is growing almost 150% each year and aims to create a comprehensive guide for Industry 4.0 investments. Moreover, they want to deploy digital solutions since it is considered an important differentiation in the market. Particularly, they are engraving QR codes in their products (product traceability is critical for them because products may return over time for maintenance, and the customer needs to identify all the information in case of an accident – e.g., aeronautics, or to request new coating interventions), digitalizing manufacturing data (e.g., adopting augmented reality to visualize the product coating history), and creating an app suitable for their customers' interaction (e.g., identify the component information, material used, coating history).

4. Results

Our modeling approach started with the business layer analysis and the specificity of their production process. Fig. 2 illustrates our case company setting and primary process (RAMI 4.0 business layer modeled with ArchiMate).

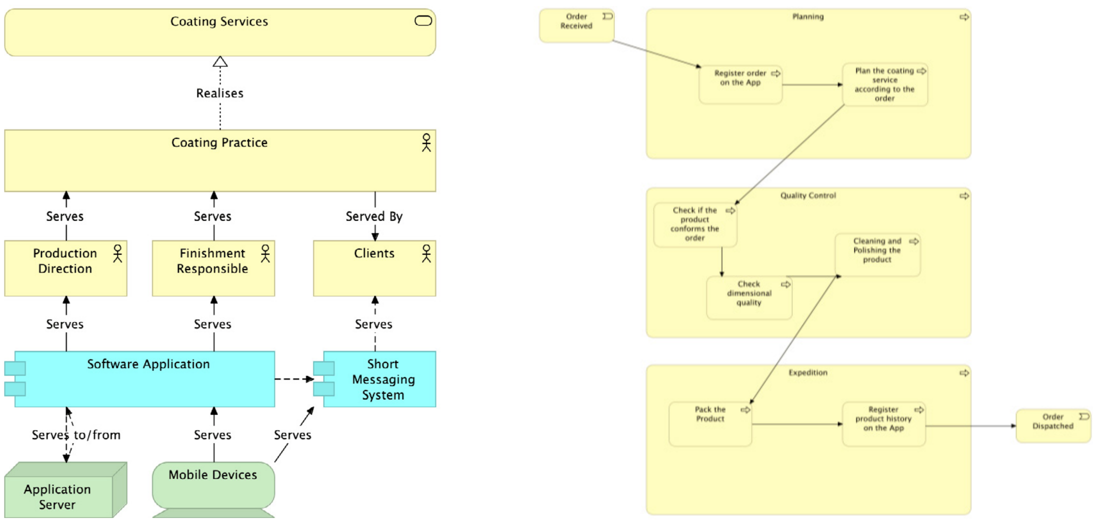

Fig. 2. Case company setting.

The rightmost image represents the primary service provided by this company (yellow elements on the business layer in ArchiMate). The application layer (blue) and infrastructure (green) present a simplified representation of the new IT system planned for the pilot project. The production process (on the right) is divided into planning, quality control, and expedition. First, a work order starts the process. Then, the product coating is planned according to the requirements. Quality control checks if the product is compliant (e.g., size) before preparation for the expedition. The product is packed and begins operation in the customer (usually heavy industries working 24/7). Fig. 3 presents the company strategy, integrated with RAMI 4.0 business layer.

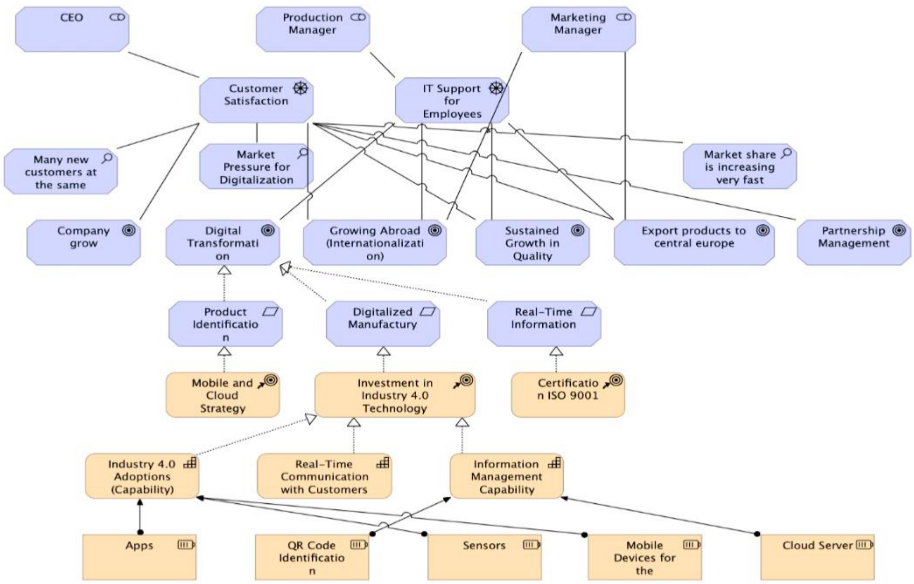

Fig. 3. Case company strategy for Industry 4.0.

The model presented in Fig. 3 summarizes the Industry 4.0 strategy of the case company. Strategic development is one of the most critical steps to create pilot projects that adhere to a comprehensive vision. For example, the model reveals their main motivations (e.g., internationalization, quality) and the strategy: courses of action (e.g., mobile and cloud strategy, ISO 9001 certification), capabilities that need to be developed (e.g., real-time communication), and resources that need to be created. The mobile app and the QR code integration in their product using laser engraving machines are visible at this stage. Having modeled the company vision and priorities, the team continued to the other RAMI 4.0 layers more specific to the pilot project deployment.

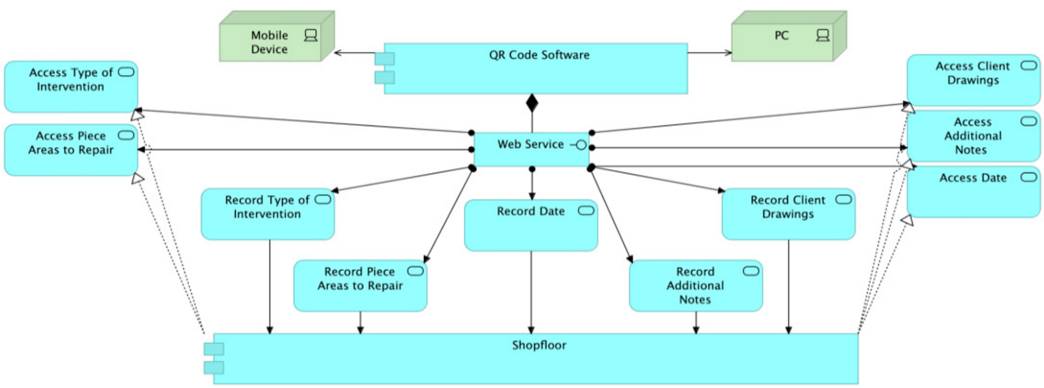

Fig. 4. Functional layer for Industry 4.0 (pilot project focus).

The functional layer shows which services are offered by the new system and how they are connected. Elements on ArchiMate application (blue) and technology (green) are used for this purpose. Although far from exhaustive, Fig. 4 highlights some of the key features to incorporate in the app (e.g., record notes, drawings).

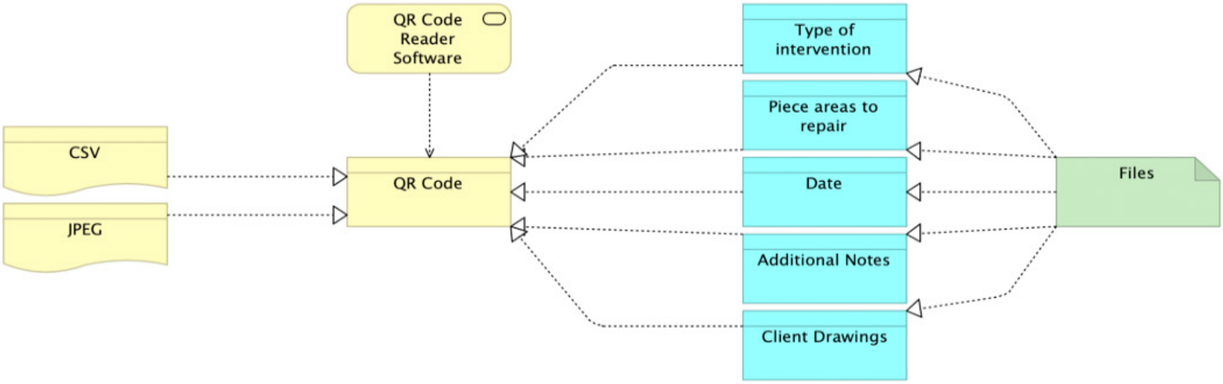

Fig. 5. Case company information requirements for Industry 4.0 (pilot project).

Fig. 5 presents the main entities that need to be included in the database and accessible via QR code engraved in the product. The company wanted to provide details to their customers about the coating process, allowing traceability. The lower levels of RAMI 4.0 (more related to physical elements) can be modeled using technical features available in ArchiMate (Fig. 6).

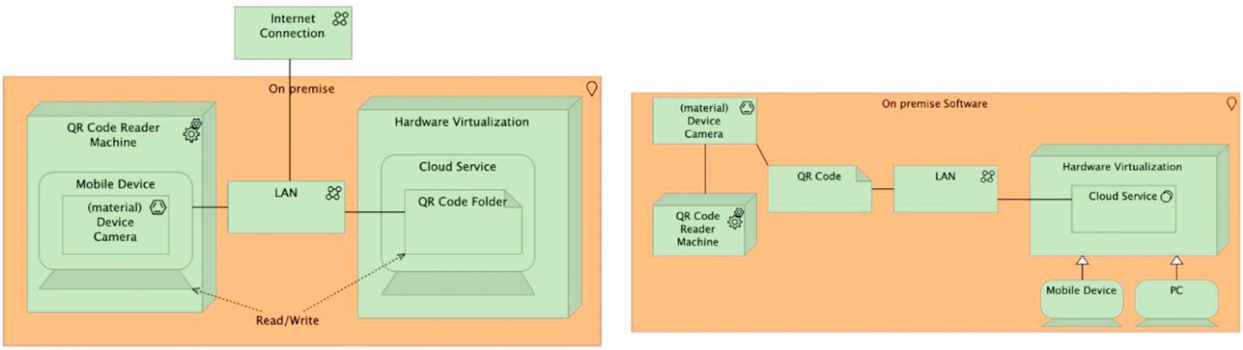

Fig. 6. Integration and communication layer (on the left) and the asset layer (on the right) - pilot project.

The integration and communication layer (on the left) presents a high-level view of the physical structure. In contrast, the asset layer outlines the low-level representation of the assets in the production module. Fig. 7 illustrates examples of mock-ups made for the case company pilot project identified with our modeling approach.

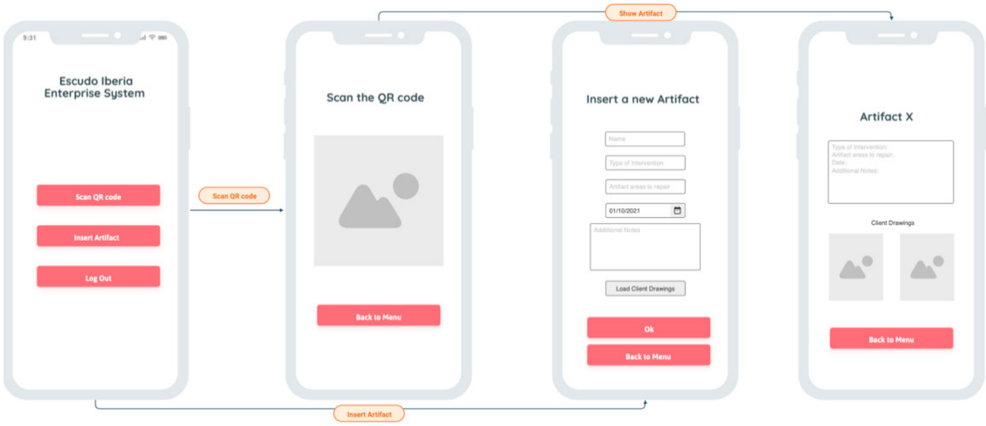

Fig. 7. Mobile app for manufacturing – mock-ups extract.

Fig. 7. illustrates the basic functionalities of the new app for manufacturing. The main menu allows scanning the QR Code and inserting products. When QR code scan is selected, the device opens the camera. After checking the desired QR code, information about the product is shown (e.g., specification, access to drawings, coating intervention). Appendix A connects the ArchiMate models created for the case company with RAMI 4.0. Our modeling approach allows continuously deploying digital technologies that adhere to RAMI 4.0 representation and are integrated into a coherent overall strategy modeled in ArchiMate. Nevertheless, we also found problems during the design. First, the association between ArchiMate and RAMI 4.0 is not simple, and many elements do not have a direct translation (e.g., artifact in ArchiMate mapped with document/ file in RAMI 4.0). Second, the case company found these models accessible, but if the number of elements increases substantially, the representations may become indecipherable by company users. These problems also open new opportunities for research, included in the next section.

5. Conclusion and outlook

This paper presented an approach to model Industry 4.0 adoption and pilot project deployment in SMEs. RAMI 4.0 and EA modeling techniques are used to assist our case company in their (1) strategy definition and (2) pilot project identification. The study confirms the viability of ArchiMate to create more specific models for RAMI 4.0, extends previous studies with the business layer modeling, and presents an example of a mobile manufacturing management system with product traceability that can be deployed according to the reference architecture.

Some limitations must be stated. First, this study is conducted in a small technical coating company starting their Industry 4.0 strategy. The approach was helpful in assist their vision for Industry 4.0, identify their priorities for pilot projects, and provide a guide for future developments. However, the approach may not suit companies with more mature Industry 4.0 strategies and more complex technological developments. Second, the app is not yet deployed in the case company, so we do not have customer feedback.

The future steps in the case company include deploying the system and modeling the following pilot projects identified during this research. The most exciting candidate for the second pilot project is an augmented reality app that their customers can use to see the changes in the coated components (e.g., evaluate wear over time), strengthening their ties with the company. However, the most promising opportunities for research emerge in the domain of Industry 4.0 architecture. First, it will be interesting to test ArchiMate modeling in other industry sectors and technologies (e.g., pilot projects using artificial intelligence, blockchain, or augmented reality) – only cloud and mobile systems are addressed in our work. Second, it will be interesting to compare different modeling approaches for Industry 4.0 adoption. Third, RAMI 4.0 and ArchiMate revealed their utility for the design-time of an Industry 4.0 vision and pilot project requirements elicitation. However, it would be interesting to evaluate the utility and evolution of Industry 4.0 architecture at the “run-time” phase. For example, (1) representing the technological maturity of the organization in each model/element of the Industry 4.0 architecture, (2) evaluating the challenges of model maintenance over time, when multiple development projects may coexist, (3) adopting a risk-based approach to digital transformation supported by architectural models (e.g., return on investment, reliability/immutability of information, or security issues in the integration and communication layer). Finally, it would be interesting to understand the potential of architectural models for quality audits (e.g., ISO 9001) in more digitalized industry settings. For example, the architecture can provide evidence of continuous improvement initiatives and help the assessors in their tasks.

Acknowledgments

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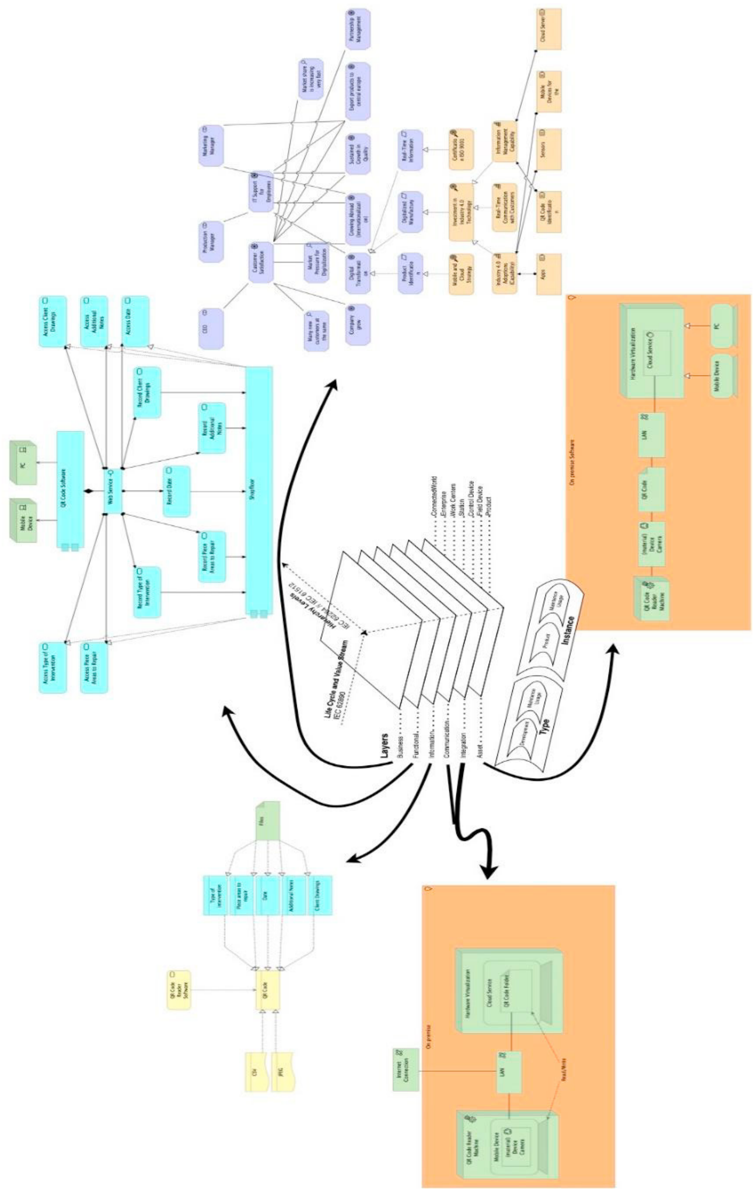
Appendix A: Creating an Industry 4.0 vision with multilayered models of RAMI 4.0



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