Using Enterprise Architecture to Model a Reference Architecture for Industry 4.0

Miguel Paiva, André Vasconcelos and Bruno Fragoso
INESC-ID, Instituto Superior Técnico, IST Universidade de Lisboa, Rua Rovisco Pais, Lisboa, Portugal

Keywords: Industry 4.0, Archimate, Enterprise Architecture, RAMI4.0, I4.0 Component Model, Viewpoints, Layers.

Abstract: Enabled by the new technologies brought by the fourth industrial revolution (Industry4.0), organizations have the possibility to address productivity challenges and consequently become more profitable. This research uses the Reference Architecture Model of Industry 4.0 (RAMI4.0) and Industry 4.0 Component Model as ingredients for a reference architecture modelled using Enterprise Architecture (EA). RAMI4.0 EA is modelled using Archimate by producing a mapping between the Archimate and RAMI4.0 concepts. To apply the proposed solution and evaluate it, the EA of an Industry project is modelled including the 4 lower layers of RAMI4.0 (Asset, Integration and Communication, Informational and Functional). The evaluation of the mapping is done using ontological analysis supporting the benefits of using a common language for modelling Enterprise and Industry 4.0 concepts.

1 INTRODUCTION

Industry 4.0 (I4.0) is the term given to the promise of a new industrial revolution, a revolution that promotes even more the junction of the advanced production and operation techniques with smart digital technologies to create a digital enterprise.

Regardless of the technologies, the main purpose of the industrial transformation is to increase the competitive power of the companies (Ustundag, 2017).

According to a survey made by Deloitte (Deloitte Insights, 2018) that measures business and government readiness for the I4.0 revolution, the major areas to focus in technology initiatives are processes and organization operations.

Taking this in account, this paper brings the I4.0 concepts to the broader perspective provided by *Enterprise Architecture(EA).*

In order to get insight in the way businesses works from different perspectives, we use Archimate language to study EA, which allows high-level modellings between different domains. (TOGAF, 2019)

The companies that need to adopt projects under the scope of Industry 4.0 have to be supported by a technological and organizational migration process. RAMI4.0 stands here as a step-by-step migration method from existing systems (i.e., legacy systems) into a digitalized networked industrial environment formally backed by the RAMI4.0 (Reference Architecture Model of Industry 4.0) specification (Schulte and Colombo, 2017).

RAMI4.0 introduces a three-dimensional model, having the special characteristics of combining the life cycle and value stream of the assets with a hierarchically structured definition of I4.0 components through a description of a reference architecture model in the form of a cubic layer model, which provides and architecture for assets in the form of layers, and allows them to be described, tracked and assigned (DIN, 2016). In that context, the model permits a step by step migration from the world of today to an Industry 4.0 compliant one. (Status Report, 2014)

RAMI4.0 was developed by the German industrial normalization and standardization organization *DIN* in order to support all the participants of the industrial businesses and processes. So, it is in the best interest of RAMI4.0 to be aligned with ISO types that specify what an architecture should contain, which is the case of ISO 42010.

The RAMI4.0 isn't aligned with ISO42010, since doesn't provide any kind of viewpoint that ease the visualization and implementation of new I4.0 solutions. This Standard provides several guidelines

Paiva, M., Vasconcelos, A. and Fragoso, B.
Using Enterprise Architecture to Model a Reference Architecture for Industry 4.0.
DOI: 10.5220/0009194307090716
In *Proceedings of the 22nd International Conference on Enterprise Information Systems (ICEIS 2020) - Volume 2*, pages 709-716
ISBN: 978-989-758-423-7

to consider when creating architectures (ISO 42010, 2011), and the focus of this paper is how to tackle this gap in this reference architecture model in order to develop such viewpoints using Archimate.

In order to represent the RAMI4.0's structure in Archimate, this paper provides a mapping from the concepts presented in RAMI4.0 (DIN SPEC 91345) to the Archimate notation.

Thus, the problem that originates the development of this research is the feasibility of being able to verify the existing conditions to carry out the representation and modelling of such viewpoints to be developed in RAMI4.0 domains using Archimate language. For that purpose, this research validates the theoretical mapping between RAMI4.0 and Archimate concepts.

The major goal of this paper is to propose a mapping between an EA language and a Reference Architecture, using Archimate (notation), integrating RAMI4.0 (Reference Architecture) with EA principles and models in order to properly implement Industry4.0 projects. This is then applied in the analysis to the representation of a project currently being implemented in an organization, following the structure, principles and vocabulary of RAMI4.0, through the modelling of 4 viewpoints.

The following questions lead the development of this research:

Q1. How to model Reference Architecture Model of Industry 4.0?

Q2. How to model RAMI4.0 and the respective i4.0Component Model using Archimate?

The research methodology used in this paper is based on the Design Science Research Methodology (DSRM) (Vaishnavi and Kuechler, 2013).

The DSRM is developed in an iterative process of six stages composed by: identify problem & motivate, define objectives of a solution, design & development, demonstration, evaluation and communication.

The "Identify Problem and Motivate" step is presented in section 1 The "Define Objectives of Solution" step is presented in section 1.1 (Solution Objectives). The "Design and Development" step is presented in section 3 (Mapping Industry 4.0 in Archimate). The "Demonstration" and evaluation steps are presented in section 4. Finally, the "Communication" step is presented in section 5.

2 RELATED WORK

2.1 Industry 4.0

Industry4.0 is a confluence of a number of technologies. This term originated from the high-tech strategy of the German government. Industry 4.0 introduces what has been called "Smart factory" (Bitkom, ZVEI and VDMA, 2015) and includes concepts as Cyber Physical Systems (CPS), the Internet of Things, the Internet of Services, monitor the physical processes of the factory and make decentralized decisions. The physical systems are becoming self-sustained through Internet of things, Internet of Services, the Cloud, communicating and cooperating with other things and with humans in real time. In this respect, transformation to Industry 4.0 is based on nine foundational technology advances: IoT, Autonomous Robots, data analytics and artificial intelligence (Big Data and Analytics), Simulation and System Integration (CPS), Cloud systems, Additive Manufacturing, Cybersecurity and Augmented Reality.

Industry 4.0 was first declared by German government during Hannover Fair in 2011 as the beginning of the 4th industrial revolution. As explained in Bitkom, VDMA, ZVEI's report (2015), an increasing number of physical elements obtain receivers such as sensors and tags as a form of constructive technology and these elements have been connected after then the improvements seen in Internet of Things field. Additionally, electronic devices connection is conducted as a part of distributed systems to provide the accessibility of all related information in real time processing. On top of it, ability to derive the patterns from data at any time triggers more precise prediction of system behavior and provides autonomous control. All these circumstances influence the current business and manufacturing processes while new business models are being emerged. Hence, challengers for modern industrial enterprises are appeared as more complex value chains that require standardization of manufacturing and business processes and a closer relation between stakeholders.

2.2 Enterprise Architecture

Enterprise Architecture (EA) is a coherent whole of principles, methods and models that are used in the design and realization of an enterprise's organizational structure, business process, information systems and infrastructure (Lankhorst 2005). Providing a holistic view of the enterprise, bringing together information from related or non-related individuals domains, EA provides the translation from the strategy of an organization to daily operations. To achieve this quality in EA an approach is needed that makes understandable all the processes to all the employees from different domains. To create this integrated perspective, where different stakeholders have different viewpoints on the architecture, is required an integrated set of methods for the specification, analysis, and communication of enterprise architectures (that addresses the expectations of different stakeholders). Archimate is a modelling language that offers a uniform representation for concepts that describe the EA. Archimate is an open and independent EA standard that supports the description, analysis and visualization of architecture within and across business domains provided by the Open Group. (Archimate, 2013) The core of the Archimate Framework defines a structure of elements and relationships, which can be separated in different layers, and different aspects.

The Archimate notation also provides a flexible approach in which architects and stakeholders can use their own views on the Enterprise Architecture, thus views are specified by viewpoints that define abstractions on the set models, each aimed to address particular set of concerns.

2.3 RAMI4.0

The "Reference Architectural Model of Industry 4.0" (RAMI4.0) was "drawn" as a reference model for the Industrial production and automation (Status Report, 2014).

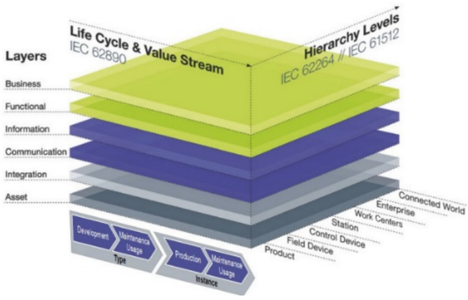

Figure 1: Reference- Architecture Model of Industry 4.0 (RAMI4.0).

RAMI4.0 is a three-dimensional model, as illustrated in Figure 1, showing how to approach the issue of I4.0 in a structured manner, with three axes: Hierarchy Levels, Layers and Life Cycle Value Stream. On the vertical axis, based in the standard, layers are used to represent the complex IT perspectives, such as data maps, functional descriptions, hardware, assets, and communications protocol:

- The Asset Layer represents the reality, the assets that exists in the physical world, which will be represented in the layers above it.
- The Integration Layer represents the transition from the physical world to the information world.
- The Communication Layer describes which data is used, where it is used and when it is distributed.
- The Information Layer describes the data that is used, generated or modified by the technical functionality of the asset.
- The Functional Layer describes functions of an asset with regard to its role in the Industry4.0 system.
- And, the Business Layer, that will not be address in this paper, describes the commercial view.

In the left horizontal axis, the product lifecycle is represented based in the IEC 62890 standard. In the right-hand horizontal axis, Hierarchy levels represents the roles and the responsibilities/ functionalities within the factories/plants, based on the IEC 62264(adding the elements "Connected world", "Field Device" and "Product") and IEC 61512. Hierarchy Levels and Life-Cycle Value Stream form the Industry 4.0 plane. This allows the representation on which area as well as the classification from a management point of view between the interaction of single assets. Every asset has its own life cycle, depending in which state it actually is.

The main objective of RAMI4.0 and the respective I4.0 Component Model is to roll out the administration shell and enable long-term interoperability in digital ecosystems.

RAMI4.0 "permits step by step migration from the world of today to that of I4.0, and the definition of application domains with special stipulations and requirements". (DIN, 2016)

The reference architecture model RAMI4.0 has been put forward for standardization as DIN SPEC 91345. (DIN, 2016)

2.3.1 Asset

An asset is an object that represents value to the organization, exists in itself and has a lifetime. The most important question when designing a system is whether and to what extent this information (its existence, identity, state and lifetime) is known to the information system, and how much of the information is used/presented in the system. (DIN, 2016)

An asset can be classified, depending on the quantity data available and on its communication capability. (VDI/VDE, 2016).

2.3.2 I4.0 Component Model

I4.0 components are globally and uniquely identifiable capable of communication and comprises the administration shell and the asset with digital connection within an I4.0 system and offer services. (BMWi, 2015)

An asset is not necessarily an I4.0 component, only if it is an entity, has at least passive communication and has been equipped with an administration shell. (Schreiber, 2017)

The administration shell is the logical representation of any equipment in the production system. Its structure is based in automation, ICT technologies and equipped for futures developments regarding the aspects of Smart Manufacturing.

3 MODELING INDUSTRY 4.0 IN ARCHIMATE

3.1 Solution Approach

Architectural descriptions are made for different 'layers' of the organization. The lower layers provide functionality to support the higher layers. The layers that are usually recognized in this context are the business layer, the application layer and the technology layer (Petasis, 2011). The research is more focus on the last two layers. Thus, Data, Application and Technical Infrastructure domains of Archimate are focus in this paper.

On the RAMI4.0 side, the focus is on the lowest domains, which are represented in following layers: asset, integration, communication, information, and functional.

In the development of this research a refined RAMI4.0 is used. The following RAMI4.0 layers are addressed considering Archimate's domains: Asset, Integration, Communication, Information and Functional.

For the correct mapping, after the correspondence between domains in Archimate and the RAMI4.0's layers, this paper proposes a match among the concepts from Archimate and from RAMI4.0 (DIN SPEC 91345). Therefore, this section starts by analyzing the domains addressed by Archimate layers (Technology, Application, Business layers). Then the domains addressed from RAMI4.0 are analyzed. Finally, the solution proposed identifies the mapping between Archimate elements and DIN SPEC 91345 of RAMI4.0.

3.2 Modelling I4.0 Component Model

"Asset" and "Administration Shell" are two main concepts addressed in RAMI4.0 and I4.0. From RAMI4.0 its architecture represents the concept "Asset" across all the layers. From the I4.0 Component Model, although it also goes around this concept, the "Asset", is always together with a "Administration Shell" that is responsible for the representation (Status Report, 2014) of the asset. This representation is the virtual, digital and active representation of the asset in some system.

Before modelling it is important to understand how these two concepts are related.

The asset represents technical objects that are intentionally manufactured in order to fulfil a specific purpose(Status Report, 2014). It only become an i4.0 component if assets are equipped with an administration shell that provides a structured information asset description that will act as a virtual representation of an asset.

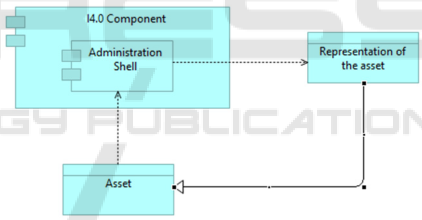

Figure 2: I4.0 Component Model in Archimate.

Furthermore, in Figure 2 is modelled in Archimate the I4.0 component.

To represent the "asset" a data object was chosen since "A data object is defined as a passive element suitable for automated processing".

To represent the "Administration Shell", that records all asset related information and make it available to everything, the authors propose Archimate "Application component" element, since it represents "an encapsulation of application functionality aligned to implementation structure, which is modular and replaceable. It encapsulates its behaviour and data, expose services, and makes them available through interfaces" (Archimate, 2013). To represent the I4.0 component, it is proposed the "application component" as well.

The result of the composition of a I4.0 component is the link between the asset and its administration shell, where at a certain point of the process, the Administration shell will create a digital description of the asset itself that will realize the asset, independently if it is a digital or physical asset.

The mapping between RAMI4.0 and Archimate, is performed considering the semantics of the concepts presented in both specifications, RAMI4.0 and Archimate.

3.3 Modelling RAMI4.0

Considering the solution approach presented, in this section the steps proposed to model the Asset, Integration and Communication, Information, Functional layers of RAMI4.0, using Archimate elements are developed.

The solution is used for modelling the RAMI4.0' Asset, Integration and Communication, Information and Functional layers in Archimate.

To model RAMI4.0 layers and I4.0 Component Model the approach proposed uses some of the architecture viewpoints defined in Archimate – see Table 2.

The match was made by the process that is presented in the Table 1 for each concept.

Table 1: Matching process.

Definition of RAMI4.0 concept: (from din spec 91345, here retrieve definitions and descriptions) Key words: (Choose keywords) Concept: (Name of the RAMI4.0 concept)
ArchiMate Concept: (ArchiMate Specifications) Definition: (ArchiMate Specifications) Image
RAMI 4.0 definition proposal: (here we propose a definition of the RAMI4.0 concept taking in account the mapped element in ArchiMate)
Rami4.0 concept map in ArchiMate: (RAMI4.0 concept represented in ArchiMate)

Table 2: Viewpoints addressed by layers.

RAMI4.0's domains	Archimate architecture viewpoint
Functional (Enterprise) layer	Application Usage
Information layer	Information structure
Integration and Communication layer	Infrastructure
Asset (Field) layer	-
I4.0 Component Model	Application Usage

3.3.1 Asset Layer

Figure 3 presents the asset layer modelled in Archimate. This viewpoint presents information asset as a physical asset, and what is needed to consider an asset as an i4.0 component.

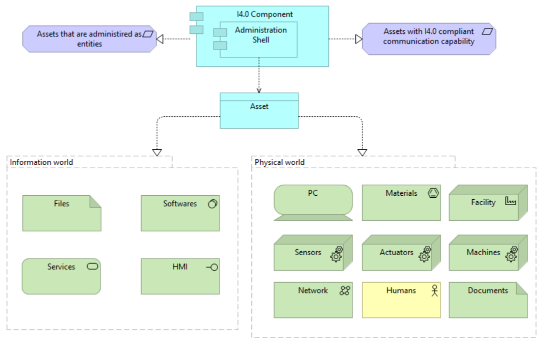

Figure 3: Asset layer in Archimate.

An asset that comprises these requirements turns into an I4.0 component. Table 3 presents the mapping of concepts between Archimate and RAMI asset layer.

Table 3: Asset Layer RAMI-Archimate mapping.

	RAMI4.0 concept	Archimate concept
Asset Layer	Asset	Data Object
	PC	Device
	Materials	Material
	Sensors	Equipment
	Facility	Facility
	Network	Communication Network
	Information	Artifact
	Software	System software
	Services	Technology service
	Humans	Business actor

3.3.2 Integration and Communication Layer

Archimate Infrastructure viewpoint is used for modelling the Communication layer (that describes how the access to assets' information and functions work) and the Integration layer (that represents the transition from the physical world to the information world describing the infrastructure that exists in order to implement a function or to store the properties and process related functions that make the asset usable) – Figure 4.

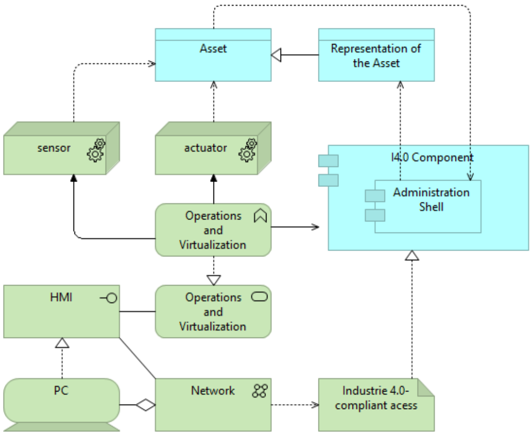

Figure 4: Integration and Communication layer in Archimate.

Table 4 presents the concepts correspondence between Archimate and RAMI Integration and Communication Layer.

Table 4: Integration and Communication Layer RAMI-Archimate mapping.

	RAMI4.0 concept	Archimate concept
Integration and Communication Layer	Virtualization	Technology function
	Network	Communication Network
	HMI	Technology interface
	Cables	Path
	Sensor/Actuator	Equipment
	Virtualization Service	Technology service
	Industriy 4.0 compliant acess	Artifact
	Representation of the asset	Data Object

3.3.3 Information Layer

For modelling the Information layer that describes the data that is used, generated or modified by the technical functionality of the asset (Archimate, 2013), the Information Structure Viewpoint is used. This viewpoint is used because is comparable to the information models created in the development of an information system – Figure 5.

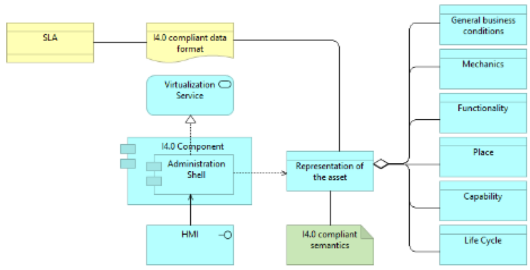

Figure 5: Information layer in Archimate.

Additionally this viewpoint presents the structure of the information used in the enterprise or application in terms of data types (Archimate, 2013). Table5 presents the concept mapping between Archimate and RAMI information layer.

Table 5: Information Layer RAMI-Archimate mapping.

	RAMI4.0 concept	Archimate concept
Information Layer	SLA	Contract
	Data format	Representation
	Interface	Application interface
	I4.0 compliant semantics	Artifact

3.3.4 Functional Layer

The Application Usage Viewpoint is used for modelling the Functional Layer that describes the logical functions of an asset. This viewpoint is used because it describes how applications are used to support business processes or other applications – see Figure 6.

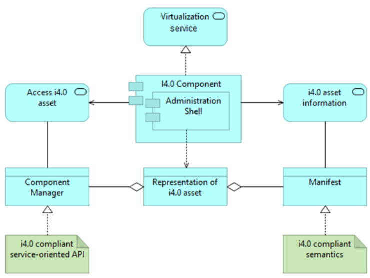

Figure 6: Functional layer in Archimate.

Regarding RAMI4.0 and the respective I4.0 component model, from this model one can understand the structure of an administration shell and the services of the administration shell's components (component manager and manifest).

Table 6 presents the mapping between Archimate and RAMI functional layer concepts.

Table 6: Functional Layer RAMI-Archimate mapping.

RAMI4.0 concept		Archimate concept
Functional Layer	Virtualization Service	Application service
	Access i4.0 asset	Application service
	I4.0 asset information	Application service
	I4.0 compliant service-oriented API	Artifact
	I4.0 compliant semantics	Artifact
	Component Manager	Data Object
	Manifest	Data Object

4 EVALUATION

In order to assess the proposed solution some viewpoints of an organisation's EA are developed (4 layers, 4 viewpoints). The viewpoints represent the AS-IS of a Government owned company – DemoCorp. These viewpoints are used to compare with the 4 layers of RAMI4.0 presented in the previous section.

4.1 Model Organization EA in Archimate

This step represents the organization's EA in Archimate, considering projects under the scope of Industry4.0 - see in Figure 7 and Figure 8

This models focus on the organization AS-IS, namely a project under development at DemoCorp. This project major goal is to digitalize all the information generated from industrial production's machines, in a shop-floor plant environment.

For the execution of this step the main structure and terms used in a project are analysed and identify. This project provides a solution to obtain plant visibility and improve the efficiency of the line of

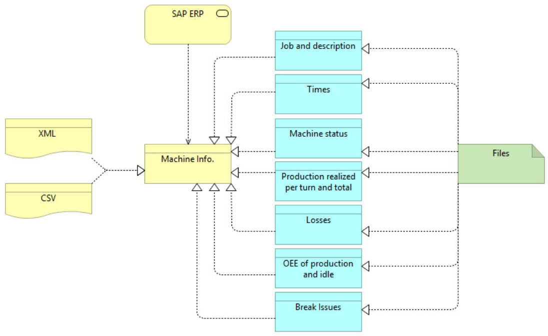

Figure 7: Organization EA's Information viewpoint.

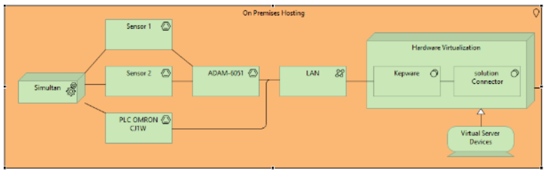

Figure 8: Asset (Machine name) viewpoint.

production. Figure 7 and Figure 8 presents 2 of the 4 viewpoints used to compare with RAMI4.0 4 layers. Through a software accessed by cloud, this service provides connection from any mobile device or pc from anywhere in the world. The information generated is used to deliver information to support the continuous improvement efforts of the organization.

Once the deployment of the system is done and the connectivity established, the information generated is composed by: Uptime/downtime of the machines, Automated Break Creep, Late Start tracking, Changeover exceeded times, Production counts and Scrap reporting, Production summary and Speeds, Filtering by crew/shift/product type, OEE Reporting, Centralized report creation and sharing, Email report distribution and proactive alerts, Plant floor visualisation for operators and supervisors via their electronic boards

The main Business value of the project is to provide tools and information for productivity improvement.

4.2 Gap Analysis

This Step aims to analyse the gaps and major differences between the AS-IS and the desired TO-BE (RAMI4.0): structure of the solution, and terminology used in the architectures.

Through the analysis presented one compare those the structures and terms with the ones presented by RAMI4.0.

In the analysis of the gaps found across all layers the main difference between these two architectures has to do with terminology, whether or not each model considers what is an asset and an i4.0 Component that present in its specifications (Asset Layer).

Due to the absence of the concept of the I4,0 component (absence of an administration shell for the major assets) in the organization, another main gap was discovered at the Information layer where the types of information retrieved was very low in the DemoCorp, comparatively with the ones mentioned in the RAMI4.0 specifications.

5 CONCLUSIONS

The first contribution of this paper is the systematization of an analysis for the representation of RAMI4.0 in Archimate.

The second contribution, after mapping and modelling RAMI4.0, is the representation of a I4.0 reference architecture through the study of DIN SPEC 91345 (which is expect to support the development of I4.0 projects in the broader context of the Enterprise).

The third contribution is the proposal of the mapping of concepts between RAMI4.0 and Archimate.

The realization of this mapping was applied in a case study of an organization developing a modernization of its processes (projects under the scope of Industry4.0).

Regarding RAMI4.0, this paper only focus on the Asset, Integration, Communication, Information and Functional layers. For future work an analysis of the Business layer should be performed.

In the construction of the RAMI4.0's viewpoints, the approach proposed assumes that the relationships presented in the Archimate viewpoints are the same as between RAMI4.0 elements and their I4.0 Component Model. Future work should be done by diving the properties adjacent to the administration shell: encapsulation and aggregation of administration shells. It would be expected that Archimate elements like Node, Path and Technology Collaboration would be used in future mappings.

The toolbox of RAMI4.0 is also been planned as future work for further assessment of the solution proposed.

Regarding Archimate, this research focus its lowest layers, namely: Physical, Technology and Application layers. For future work the concepts in Archimate and RAMI4.0 highest layers should be performed.

ACKNOWLEDGMENTS

This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UIDB/50021/2020 and by the European Commission program H2020 under the grant agreement 822404 (project QualiChain)

REFERENCES

A, ÜSTÜNDAĞ. (2017) Industry 4.0: Managing The Digital Transformation. Retrieved from: https://www.linkedin.com/pulse/industry-40-managing-digital-transformation-alp-üstündağ/

Deloitte Insights. (2018) The Fourth Industrial Revolution is here—are you ready?, Deloitte Insights, p. 28,

The TOGAF® Standard, Version 9.2. (2019) Retrieved from: https://pubs.opengroup.org/architecture/togaf9-doc/arch/chap31.html.

Schulte, D. and Colombo, A. W. (2017) RAMI4.0 based digitalization of an industrial plate extruder system: Technical and infrastructural challenges.

DIN (2016) Reference Architecture Model of Industrie 4.0- DIN SPEC 91345

ISO/IEC/IEEE 42010. (2011) Systems and Software Engineering – Architecture Description

(2014) Status Report - RAMI4.0. Ecowas Centre for Renewable Energy & Energy Efficiency

Vaishnavi, V. and Kuechler, B. (2013) Design Science Research in Information Systems, ISWorld

Bitkom, VDMA, and ZVEI, (2015) Implementation Strategy Industry 4.0, Report on the results of the Industry 4.0 Platform

Lankhorst, M. (2005) Enterprise Architecture at Work

Archimate Specification. (2013) Open Group Standard

VDI/VDE. (2016) Status Report – Technical Assets

BMWi. (2015) Structure of the Administration Shell, Federal Ministry for Economic Affairs and Energy

Schreiber, A. (2017) Industry 4.0 component

Petasis, G. (2011) Knowledge-driven multimedia information extraction and ontology evolution