Mapping between Reference Architecture Model of Industrie 4.0 and ArchiMate

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Abstract

Nowadays, with the arrival of new technologies brought by the fourth industrial revolution (Industry4.0), the organizations have the possibility to become more profitable.

However, there are still many challenges that need to be addressed by organizations on the road towards I4.0 and all the main changes must start inside of the company, looking for internal processes and how the processes are being made, i.e. the study of Enterprise Architecture.

In this research we will study the Reference Architecture Model of Industry 4.0 (RAMI4.0) and Industry 4.0 Component Model as reference architecture for the development of the EA study, which has acted as beacon in these unknown fields. To model the EA of RAMI4.0 by the viewpoints, we will use ArchiMate, this modelling language is an open and independent Enterprise Architecture standard that supports the description, analysis and visualization of architecture within and across business domains. ArchiMate is one of the open standards hosted by The Open Group and is fully aligned with TOGAF.

So, in order to represent such RAMI4.0’s structure in ArchiMate we will have to produce a mapping between the language ArchiMate and the RAMI4.0, because there is a lack of representation of the several domains of this Reference Architecture.

To apply our proposed solution and evaluate it we propose to model a current EA project being implemented in a DemoCorp, and then see the gaps that DemoCorp’s EA and the one created by us, by modelling the 4 lower layers of RAMI4.0(Asset, Integration and Communication, Informational and Functional). For the evaluation of the mapping we propose an ontological analysis due to the semantic analysis done.

Keywords: Industry4.0; ArchiMate; Enterprise Engineering; Enterprise Architecture; TOGAF; ISO 42010; Viewpoints; RAMI4.0; I4.0 Component Model; Asset Layer; Integration Layer; Communication Layer; Information Layer; Functional Layer; Enterprise Ontology
Resumo

Atualmente, com a chegada das novas tecnologias trazidas pela quarta revolução industrial (Industry4.0), as organizações têm a possibilidade de contornar seus problemas de produtividade e, consequentemente, tornar-se mais lucrativas.

No entanto, ainda existem muitos desafios que precisam ser enfrentados pelas organizações no caminho para a I4.0 e todas as principais mudanças devem começar no interior da empresa, procurando processos internos e como os processos estão sendo feitos, ou seja, o estudo da arquitetura corporativa.

Nesta pesquisa, estudaremos o Modelo de Arquitetura de Referência da Industrie 4.0 (RAMI4.0) e o Modelo de Componente Industrie 4.0 como arquitetura de referência para o desenvolvimento do estudo da EA, que atuou como farol nesses campos desconhecidos. Para modelar o EA da RAMI4.0 pelos pontos de vista, usaremos o ArchiMate, essa linguagem de modelagem é um padrão de arquitetura corporativa aberto e independente que suporta a descrição, análise e visualização da arquitetura dentro e entre domínios de negócios. O ArchiMate é um dos padrões abertos hospedados pelo The Open Group e está totalmente alinhado com o TOGAF.

Portanto, para representar a estrutura dessa RAMI4.0 no ArchiMate, teremos que produzir um mapeamento entre a linguagem ArchiMate e a RAMI4.0, porque há uma falta de representação dos vários domínios dessa arquitetura de referência.

Para aplicar nossa solução proposta e avaliá-la, propomos modelar um projeto de EA atual sendo implementado em um DemoCorp e, em seguida, ver as lacunas que o EA e o criado por nós, modelando as 4 camadas inferiores do RAMI4.0. Para a avaliação do mapeamento, propomos uma análise ontológica, devido à análise semântica feita para o mapeamento.
Acknowledgements

I would like to thanks to my family, Miguel Paiva and Raquel Paiva, to my friends, Postas do Banana.

This work wouldn´t be possible with the special efforts of Bruno Fragoso, André Vasconcelos, Tiago Catarino and Gonçalo Cordeiro
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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I4.0</td>
<td>Industry 4.0</td>
</tr>
<tr>
<td>CPS</td>
<td>Cyber-physical system</td>
</tr>
<tr>
<td>EE</td>
<td>Enterprise engineering</td>
</tr>
<tr>
<td>EA</td>
<td>Enterprise Architecture</td>
</tr>
<tr>
<td>EO</td>
<td>Enterprise Ontology</td>
</tr>
<tr>
<td>RAMI4.0</td>
<td>Reference Architecture Model of Industrie 4.0</td>
</tr>
<tr>
<td>IIRA</td>
<td>Industrial Internet Reference Architecture</td>
</tr>
<tr>
<td>I4.0 CP</td>
<td>Industrie 4.0 Component Model</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology(ies)</td>
</tr>
<tr>
<td>TOGAF</td>
<td>The Open Group Architecture Framework</td>
</tr>
<tr>
<td>DSRM</td>
<td>Design Science Research Methodology</td>
</tr>
<tr>
<td>ADM</td>
<td>Architecture Development Method</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IoS</td>
<td>Internet of Services</td>
</tr>
<tr>
<td>SOA</td>
<td>Service Oriented Architecture</td>
</tr>
<tr>
<td>OASIS</td>
<td>Terminology of the Organization for the Advancement of Structured Information Standards</td>
</tr>
<tr>
<td>GTAI</td>
<td>Germany Trade &amp; Invest</td>
</tr>
<tr>
<td>ZVEI</td>
<td>German Electrical and Electronic Manufacturers' Association</td>
</tr>
<tr>
<td>VDMA</td>
<td>Association of German Machinery and Plant Engineering</td>
</tr>
<tr>
<td>BITKOM</td>
<td>German Association for Information Technology, Telecommunications and New Media</td>
</tr>
<tr>
<td>IMSA</td>
<td>China Intelligent Manufacturing System Architecture</td>
</tr>
<tr>
<td>SC4I.0</td>
<td>Standardization Council Industrie 4.0</td>
</tr>
<tr>
<td>LNI4.0</td>
<td>Labs Network Industrie 4.0</td>
</tr>
<tr>
<td>IIC</td>
<td>Industrial Internet Consortium</td>
</tr>
<tr>
<td>RM-SA</td>
<td>Reference Model – Service Architecture</td>
</tr>
<tr>
<td>ICT</td>
<td>Information Communication-Control Technology</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Source(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>The structure of components, their inter-relationships, and the principles and guidelines governing their design and evolution over time.</td>
<td>[1]</td>
</tr>
<tr>
<td>Artifact</td>
<td>Any designed object with an embedded solution to an understood research problem</td>
<td>[2]</td>
</tr>
<tr>
<td>ArchiMate</td>
<td>An open and independent modelling language for enterprise architecture that is support by different tools vendors and consulting firms, providing instruments to enable enterprise architects to describe, analyse and visualize the relationships among business domains in an unambiguous way.</td>
<td>[3]</td>
</tr>
<tr>
<td>Asset</td>
<td>Object that represents value for the organization</td>
<td>[6]</td>
</tr>
<tr>
<td>Constructs</td>
<td>Constructs provide the vocabulary and symbols used to define problems and solutions</td>
<td>[2][4]</td>
</tr>
<tr>
<td>Design Science Research Methodology</td>
<td>A methodological guideline for effective DS research.</td>
<td>[2][4]</td>
</tr>
<tr>
<td>Design Science</td>
<td>Creates and evaluates IT artifacts intended to solve identified organizational problems</td>
<td>[2][4]</td>
</tr>
<tr>
<td>Enterprise</td>
<td>The highest level (typically) of description of an organization and typically covers all missions and functions. An enterprise will often span multiple organizations.</td>
<td>[1]</td>
</tr>
<tr>
<td>Enterprise Architecture</td>
<td>Discipline or process area that aims to establish and maintain a common architecture consisting of business process, information, data, application and technology layers for effectively and efficiently realizing enterprise and IT strategies</td>
<td>[52]</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
<td>Page</td>
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<tr>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Service-Oriented Architecture</td>
<td>software architecture that follows a service-oriented architectural style</td>
<td>[5]</td>
</tr>
<tr>
<td>service</td>
<td>mechanism to enable access to one or more capabilities where the access is provided by a prescribed interface and is exercised consistent with constraints and policies as specified by the service description.</td>
<td>[5]</td>
</tr>
<tr>
<td>service-oriented architectural style</td>
<td>architectural style that restricts the roles, characteristics and allowed relationships of services and service consumers</td>
<td>[5]</td>
</tr>
<tr>
<td>Methods</td>
<td>A set of steps used to perform a task – how-to knowledge.</td>
<td>[6]</td>
</tr>
<tr>
<td>Models</td>
<td>A set of propositions or statements expressing relationships between constructs.</td>
<td>[6]</td>
</tr>
<tr>
<td>VDI/VDE</td>
<td>Association of German Engineers/ Association for Electrical, Electronic &amp; Information Technologies</td>
<td>[33]</td>
</tr>
<tr>
<td>VDMA</td>
<td>Association of German Machinery and Plant Engineering</td>
<td>[33]</td>
</tr>
<tr>
<td>ZVEI</td>
<td>German Electrical and Electronic Manufacturers’ Association</td>
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</tr>
<tr>
<td>BITKOM</td>
<td>German Association for Information Technology, Telecommunications and New Media</td>
<td>[33]</td>
</tr>
<tr>
<td>Reference Model</td>
<td>abstract framework for understanding significant relationships among the entities of some environment. It enables the development of specific reference or concrete architectures using consistent standards or specifications supporting that environment</td>
<td>[7]</td>
</tr>
<tr>
<td>Stakeholder</td>
<td>An individual, team, or organization (or classes thereof) with interests in, or concerns relative to, the outcomes of the architecture. Different stakeholders with different roles will have different concerns.</td>
<td>[1]</td>
</tr>
<tr>
<td>View</td>
<td>The representation of a related set of concerns. A view is what is seen from a viewpoint. An architecture view may be represented by a model to demonstrate to stakeholders their areas of interest in the architecture.</td>
<td>[1]</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Viewpoint</td>
<td>A definition of the perspective from which a view is taken. It is a specification of the conventions for constructing and using a view (often by means of an appropriate schema or template). A view is what you see; a viewpoint is where you are looking from — the vantage point or perspective that determines what you see.</td>
<td>[1]</td>
</tr>
</tbody>
</table>
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. In these days, with the arrival of new technologies brought by the fourth industrial revolution, the organizations have the possibility to get around their productivity problems and consequently to become more profitable. Regardless of the technologies, the main purpose of the industrial transformation is to increase the competitive power of the companies[8].

These changes in business processes are moving towards industrial production characterized by its automation, self-organizing factories with their production systems connected and integrated and respective information available to the whole company. As matter of fact, I4.0 has been pushing global manufacturers to a whole new level since the economic rewards are immense. The strategic initiative I4.0 will give rise to novel *cyber-physical systems* (CPS) platforms geared towards supporting collaborative industrial business processes and the associated business networks for all aspects of smart factories and smart product life cycles. These new systems that make use of Internet of Things (IoT) in manufacturing benefit the company in many ways: enhanced productivity through optimization and automation, provides real-time data for real-time supply in a real-time economy, higher business continuity through advanced maintenance and monitoring possibilities, better quality products through real-time monitoring, better working conditions and sustainability, new ways of customization, improved agility and the development of innovative capabilities and new revenue models[9]. This trend is supported by new disruptive advances in the cross-reference of concepts and the fusion of information, communication, control and mechatronics technology-driven approaches in traditional industrial systems. Under this perspective, “The industrial competition is increasingly developing into a competition of business/services processes”.[10]

However, there are still many challenges that need to be addressed by organizations on the road towards I4.0 and all the main changes must start in the interior of the company, looking for internal processes and how the processes are being made. The two main principles of organizations compliant with Industry 4.0 are, horizontal and vertical integration of information and communication flows (i.e., processes) within and across organizations are essential, as well as thorough digitization in engineering[11]. In order to transform organizations to that respect, standards and enabling technologies are developed.

Taking this in account, our work is developed in the field of *Enterprise Engineering (EE)* that comes in the perspective of the design of the enterprise providing a theory and a methodology way in order to companies achieve an effective approach for implementing these new strategic initiatives successfully. There are two concepts that underpin these concept and are used in this research called *Enterprise Ontology*(EO) and *Enterprise Architecture*(EA).[12]
In this research we will study the *Reference Architecture Model of Industrie 4.0 (RAMI4.0)* and *Industrie 4.0 Component Model* as reference architecture for the development of the EA study, which has acted as beacon in these unknown fields, RAMI4.0 has been developed by a committee (composed of technical experts in the area of I4.0 and CPS) of the VDI/VDE Society of Measurement.[13]

The transition to Industry 4.0 has to be supported by a technological and organizational migration process. A step-by-step migration from existing systems (i.e., legacy systems) into a digitalized networked industrial environment formally backed by the RAMI4.0 specification. [14] Introduced by the German industrial normalization and standardization organization DIN (DIN's job is to ensure that a DIN SPEC does not conflict with any existing standards) in order to support all the participants of the industrial businesses and processes, those participants as members of the industrial business value chain, control vendors, machine builders, system integrators, product and service providers, product and service users, etc., are confronted with the following major issues:

- Migrate from legacy systems into the new Industrie4.0 compliant network of building blocks (ICPS)
- Migrate from traditional tangible product-oriented business into new tangible product- and service-oriented business (IoT and IoS)
- Migrate from traditional offline product's and system's engineering approaches and tools into virtualization of ICPS and real time integration of virtualized and real systems along their life cycle

Following an approach like smart grids, 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 an architecture for assets in the form of layers, and allows them to be described, tracked and assigned[13]. In that context, the model permits step by step migration from the world of today to an Industry 4.0 compliant.[15]

In order to organizations embrace the new technologies and ways of processing with the advent of Industry 4.0, they must reorganize their processes. To help model such processes, *ArchiMate* is chosen to act as a modelling tool (or notation) to develop enterprise architectures, according to TOGAF methodology, based on the principles of RAMI 4.0 architecture. From the specification DIN SPEC 91345[13], that stands as a “document that describes two fundamental references models for the Industrie 4.0 concept: the RAMI4.0 and the I4.0 component reference model”, is retrieved a description, concepts and structure of this reference architecture.

Taking ISO 42010[16] that addresses the creation, analysis and sustainment of architectures of systems through the use of semantically rigorous architecture descriptions, as reference to help the extraction of information from [13] we came to conclusion that RAMI4.0 isn’t aligned with this ISO, since doesn’t provide any kind of viewpoints that ease the visualization and implementation of new I4.0 solutions.

The focus of our work is how to tackle this gap in this reference architecture model in order to develop such viewpoints using ArchiMate. To address this problem, we will need to make use of Enterprise
Ontology to study the foundations and meanings of ArchiMate and RAMI4.0 concepts, with the view to structure a concept mapping able to modulate the various layers of RAMI4.0 with ArchiMate concepts. A mapping and analysis technique are used in this field in order to evaluate the mapping based on Wand and Weber ontology.

1.1. Context

This section describes the “Identify Problem & Motivate” step of the DSRM Process Model (presented at section 1.4) and has the objective to describe the research problem. In addition to that, in sections 1.2 and 1.3, we will define the specific research problem that is addressed in the dissertation work.

The digital transformation that industry 4.0 brings, means that organizations will increasingly be able to adopt more digital and physical technologies to improve their operations, which represents the continuous paradigm of change in the industry. According to a survey made by Deloitte[17], that sought to measure business and government readiness for the I4.0 revolution, show as the major area to focus in technology initiatives, was the processes and how to the organization operates that introduces the study of EA.

The discipline of EA looks for understanding the organization, optimize the operations and provide alignment between all the layers of an organization and its primary goal is to define the desirable future state of the organisation’s business processes and IT systems and to provide a roadmap for achieving this target from the current state[18].

In order to organizations implement projects under Industry 4.0 scope in order to be compliant with smart manufacturing’s practices, organizations feel the need to adopt reference architectures with the aim of obtaining guidance and a starting point for its development. For assisting in the production of organization architectures to be in accordance with the arrival of this industrial revolution, where its fundamental purpose is link all the objects that represent value to an organization in the industrial manufacturing field, was chose a service oriented architecture called Reference Architecture Model of Industrie 4.0 (RAMI 4.0) for this purpose along with I4.0 Component Model that describes the properties of cyber-physical systems, developed by Federal German Associations.[13]

RAMI4.0 propose using state-of-the art Information Communication-Control Technology (ICT) to support structural reconfigurability and evolvability of industrial systems, whilst aiming to make the industrial processes more controllable and manageable in real-time operational condition when emergent behaviours arise. RAMI4.0 provides a structured description of the key elements of an asset using a model level consisting of the 3 axes of the model. In essence, these three axes work as views, that provide the architect with a means of explaining the architecture to stakeholders according to[19], which are nothing more than levels of abstraction of a system from the domain’s perspective of their functions and function-specific data as represented in vertical axe in the form of layers: business, functional, information, communication, integration and asset.
To model the EA of RAMI4.0 by the viewpoints, we will use ArchiMate, this modelling language is an open and independent Enterprise Architecture standard that supports the description, analysis and visualization of architecture within and across business domains. ArchiMate is one of the open standards hosted by The Open Group and is fully aligned with TOGAF[20] [20] “an architecture framework that provides the methods and tools for assisting in the acceptance, production, use and maintenance of an EA”[1] Many companies recognize the value of these architectural models in understanding the dependencies between their people, processes, applications, data and hardware. Using ArchiMate allows them to integrate their business and IT strategies.

By using an architecture framework, aligned with ISO 42010, a standard that provides a core ontology for the description of architectures that serve to enforce desired properties of architecture descriptions[21], as the core of TOGAF, the Architecture Development Method (ADM), we is able to develop an enterprise architecture based on its principles following RAMI4.0 procedures.

Despite RAMI4.0 stands as the model that ease the implementation of architecture or systems to Industry 4.0 by non-property solutions of current systems, enabling Industries to comply with the transition of legacy systems to I4.0 systems[15], it does not provide a specific approach to bridge the gap between the desired architecture and the current one. Moreover, this reference architecture is not aligned with the approach of ISO 42010 that designates that various view are applied to describe an architecture, that will generate a set of models that represent viewpoints relate to stakeholders’ interests. However, the creation of these viewpoints poses a new challenge as it is necessary to ensure the traceability of concepts between the various views as well as to ensure their consistency, i.e. the uniform use of the same concept in different views.

1.2. Problem definition

In order to represent such RAMI4.0’s structure and do a correct representation of the terminology in ArchiMate, that stands as a specification of the conventions for a particular kind of architecture view and is composed of one or more model kind that establishes convention for a type of modelling[1], we will have to produce a mapping between the language ArchiMate and the RAMI4.0.

To model RAMI4.0 with ArchiMate language is necessary to develop a mapping between the concepts inherent in RAMI4.0 and ArchiMate language. For this purpose, we will have to penetrate in the Enterprise Ontology world, where is studied the basis for the common understanding of some area of interest among a community with different cultural backgrounds, here ontology act as the body of theory from which to extract a set of generic constructs in representing reality [22]. The absence of such careful definition of the concepts used to construct the EA’s models could lead to several problems of interpretation, communication and modulation[23].

So, 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, we have to validate the theoretical mapping between RAMI4.0 and ArchiMate concepts.

If the necessary conditions are met, and the correct mapping completed, the current organizations that have their enterprise architectures modelled in ArchiMate are able to adopt this reference architecture through several viewpoints to be developed, in order to support the process of implementing I4.0 solutions with specific system concerns relevant to its stakeholders. The success of this work will provide several viewpoints that illustrates the several domains in the I4.0 solution, and with this RAMI4.0 is provided with a visual representation, through viewpoints with a correct notation using ArchiMate language.
1.2.1. Research resume, Objectives and Assumptions

RAMI4.0 doesn’t possess any direct means of linking its structure and processes to EA principles and concepts such as applications, technology or business processes, therefore becoming isolated and, eventually, turning obsolete.

EA has several benefits for the success of an organization[24], therefore by not possessing any integration mechanisms with EA, RAMI4.0 cannot take advantage of those benefits. Furthermore, most organizations can’t obtain know-how regarding the changing impact in their processes in order to minimize cost, planning and implementation efforts.

All in all, RAMI4.0 only provides a vocabulary and a description for the several domains within and lack the means of visualizing and understanding its architecture and structure. In short, the research problem can be defined as the lack of a graphical notation, aligned with TOGAF and ISO420100, for the RAMI4.0. And the respective I4.0 Component Model

The next questions will lead the development of our work:

Question 0. How to model Reference Architecture Model of Industrie 4.0?

Question 1. How to model RAMI4.0 and the respective i4.0Component Model with ArchiMate?

Question 2. In order to realize this modelling, how can we validate the theoretical mapping between ArchiMate and RAMI4.0 concepts?

Challenges that, by itself, raises other relevant questions, such as:

- What is a viewpoint?
- Which are the best fitting viewpoints to graphical represent RAMI4.0?
- How to develop viewpoints of RAMI4.0?
- How to evaluate/analyse this mapping?
- Is WBB Ontology applicable for this analysis?
- How to classify the mismatches in the mapping?
- Can we identify inconsistencies between RAMI4.0 and ArchiMate language in terms of definitions, processes or structuring?

For the continued development of this research, we will consider the following allowances that we will consider to be true in the realization of this work:

A1. RAMI4.0 and I4.0 Component Model compose the reference architecture model

A2. RAMI4.0 isn’t aligned with ISO 42010, because at least don’t provide viewpoints

1.3. Solution objectives

We aim to propose a mapping between a modulation language and a Reference Architecture, using ArchiMate (language modulation) to integrate RAMI4.0 (Reference Architecture) with EA principles and
models in order to properly implement projects under Industry4.0. To maximize the effectiveness of the solution, we propose to embed the RAMI4.0’s and I4.0 Component Model’s processes, architecture and organization structure enablers’ rationale directly in the models of EA.

When achieving the mapping, our solution will try to provide:

- A mapping between RAMI4.0 concepts (Asset, Integration, Communication, Information and Functional Layers) and ArchiMate language
- Several viewpoints, based on ArchiMate, to visualize a project under i4.0’ scope following RAMI4.0’s principles and structure (Asset, Integration and Communication, Information and Functional layers)
- A representation of RAMI4.0 and I4.0 Component Model, in ArchiMate.
- Identify which RAMI4.0’s concepts are being misrepresented by ArchiMate
- Identify the mismatches in the structure and terminology used between RAMI4.0’s models and other current EA models, in ArchiMate

To achieve this, we propose to demonstrate the solution, by applying it to one government owned company, in the industrial production sector, named DemoCorp in this work. After the demonstration in section 4, we will be able to do:

- The differences (Gap Analysis) between current EA models of a DemoCorp and RAMI4.0, through a description of the current state of a project implemented in a Shop floor of a DemoCorp(modelled in ArchiMate with 4 viewpoints: Asset, Integration and Communication, Information and Functional)
- Ontological evaluation of the concept mapping

As an additional help of our endeavour, if we have time for its analyse, the metamodeling of RAMI4.0 toolbox [25] will help to guide the construction of the viewpoints.

1.4. Research methodology

The research methodology of this thesis proposal is based on the Design Science Research Methodology, which is a research development tool to solve the stated problem[4]. According to Simon [26][27][2] the term Design Science describes the aspects of what and how things should be and in the realization of objects, i.e. artifacts, built for a particular purpose with a view to achieve certain objectives. 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, as illustrated in next figure:
The DSRM process allows the use of interdisciplinary material for the analysis of this project. Besides the analysis of the proposed entrepreneurial architectures is used several concepts of different domains nature, such as Industrial management, industrial manufacturing, economics and information systems is used.[27]

With a view to achieve a rigorous procedure to deliver a right solution, we choose DSRM which creates solutions that serve human purposes to reach the intended goals. Thus, this research can produce different kinds of results or artifacts, such as, according to March and Smith[27] [28]:

- Constructs: concepts that forms a domains’ vocabulary
- Models: set of prepositions which express the reactions among the different concepts of a domain
- Methods: set of used steps to complete a specific task
- Instantiations: realization of an artifact in its environment, demonstrating the feasibility and effectiveness of models and methods

Enterprise Architecture is an applied research discipline, where researchers frequently apply theory from other disciplines in order to solve problems in the integration of design as a major component of research, in order to solve relevant organizational problems. Researchers frequently apply theory from other disciplines, such as economics, computer science, and the social sciences, among others, in order to solve problems at the intersection of information technology (IT) and organizations[2].

To solve these organizational problems, DSRM proposes the design and development, followed by a demonstration and evaluation of artifacts, which may include models (abstractions and representations), methods (algorithms and practices), constructs (vocabulary and symbols) and instantiations (implemented and prototype systems).

In this thesis, the artifacts are designed and evaluated by their own intrinsic value, effectiveness in a specific context, in order to achieve the master thesis goal: validate the theoretical mapping to be developed between ArchiMate language and RAMI4.0 concepts in order to create RAMI4.0’s viewpoints.
To define such RAMI4.0’s viewpoints, we will divide the several domains presented in RAMI4.0 by views, and we will try to address all the requirements presented in TOGAF for the development of viewpoints.

This methodology can prove to be useful throughout this research, because it forces to do research in an iterative way, in order to obtain frequent and valuable feedback for the design process and incremental improvement of it. With this methodology, we hope from this research to achieve more valuable outcomes.

Regarding the next sections, they follow the methodology's steps: this section of “Introduction” and “Related Work” cover aims and objectives as the awareness and recognition from a state of art review, giving us the main issues that must be addressed. The Section “Proposal” presents a proposal as an attempt to solve the previously described problem. Afterwards, “Demonstration” and “Evaluation” compare the results with the research questions. At the end, the “Conclusion” describes the proposal applicability, in order to justify the value of the proposed solution.

### 1.5. Document structure

To be coherent with our research work, this dissertation follows the same structure as DSRM which phases are easily mapped to the structure of this document.

The development of this work follows the DSRM’s steps, where the “Identify Problem & Motivate” is approached in sections 1.1 (Context), 1.2 (Problem) and 2 (Related Work).

The “Define Objectives of a Solution” is present in section 1.2.1 (Research Resume, Objectives and Assumptions) and section 1.3 (Solution objectives).

The “Design & Development” is presented in section 3 (Proposal).

The “Demonstration” step is in section 4 (Demonstration), then the “Evaluation” one in section 5 (Evaluation).

The “Communication” step is approached in section 6 (Conclusion).
2. Related work

2.1. Industry\textsuperscript{1}4.0

\textsuperscript{1} In the development of this thesis, we assume that the term related to the fourth revolution as Industry4.0. The only moments that we write this term as Industrie 4.0 is when we reference the Reference Architecture Model of Industrie 4.0.
2.1.1. History behind Industry 4.0

Since early stages the human being came to develop his skills of manufacturing. In the beginning all our goods were produced by hand or with the help of work animals. In the 19th century manufacturing began to change with the first industry revolution. Machines powered by water and steam were developed to aid works in production what led to business growth making the small businesses to evolve his organizations with owners, managers and employees serving customers creating the first factories[29]. The Industry 2.0 came when the electricity became the primary source of power. Much easier to use than water and steam and enabled businesses to concentrate power sources to individual machines. It has become common for larger companies to use mass production using assembly lines, concept introduced by Henry Ford, where all the work is divided into small steps where each worker does a part of the total job to increase the efficiency and effectiveness of manufacturing facilities. One of the first management consultants was Frederick Taylor, American mechanical engineer who sought to improve industrial efficiency introducing approaches to optimize worker and workplace methods in order to improve the quality and output of manufacturing. In the end of 20th century, Industry 3.0 appeared as the Digital revolution marking the application of digital computers and computing power. The invention and manufacture of electronic devices, integrated circuit chips made it possible to more fully automate individual machines to supplement or replace operators. In order to capitalize this new electronic hardware, a lot of development of software systems had been made to follow this big revolution. Integrated systems were replaced by tools that enabled humans to plan, schedule and track product flows through the factory. This revolution really empowers people, started to replace people from just doing repetitive tasks, to have robots doing that, and upskilling some workers in programming.
2.1.2. Defining the term Industry 4.0

Now we are looking to the Industry 4.0 as a confluence of a number of technologies. This term originates from a high-tech strategy of the German government. Industry 4.0 introduces what has been called the Smart factory[30][31] in terms of industrial production, which cyber-physical systems, 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-sustain through Internet of things, communicating and cooperating both with each other and with humans in real time.

Modern information like Big Data and Cloud Computing will help predict the possibility to increase productivity, quality and flexibility within the manufacturing industry and thus to understand advantages within the competition.[32]

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 and ZVEI’s report[33](developed the reference architecture that we will study), 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.

The term, Industry 4.0 completely encounters to a wide range of concepts including increments in mechanization and automation, digitalization, networking and miniaturization [34]. Moreover, Industry 4.0 relies on the integration of dynamic value-creation networks about the integration of the physical basic system and the software system with other branches and economic sectors, and also, with other industries and industry types. In this respect, transformation to Industry 4.0 is based on none 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, see image X.

These technologies should be supported with both basic technologies such as cyber security, sensors and actuators, RFID and RTLS technologies and mobile technologies, and seven design principles named as real time data management, interoperability, virtualization, decentralization, agility, service orientation and integrated business processes [31].
2.1.3. Principles of Industry4.0

In this thesis there are some principles that have to be very well represented across the final work. In Germany the so-called Industry4.0 have the name of “Industrie 4.0”, because it introduces the fourth industrial age and is ready to revolutionize manufacturing and production. INDUSTRIE 4.0 represents a paradigm shift from "centralized" to "decentralized" smart manufacturing and production made possible by technological advances which constitute a reversal of conventional production process logic. INDUSTRIE 4.0 connects innovative embedded system production technologies and smart production processes to pave the way to a new industrial age which will radically transform industry and production value chains and business models in tomorrow’s smart factories[35]. This smart manufacturing is centred in a key technology called Cyber-Physical Systems (CPS) together with other technologies as cloud, IoT and big data[36]

In order to better understand this news concepts, next we will present the basic principles of this term, Industry4.0 and Smart Manufacturing, according to Herman[37]:

- Modularity or agility can be defined as the capability of system components being separated and combined quickly and easily. A high modularity allows a high level of integration and enables the real time capability what makes the system respond to changes in the customer requirements and to work around internal system flaws.
- Interoperability is the ability to share information within system components and products and business information between companies and their customers. CPS enables connection over the IoT. In order to facilitate the flexibility among the systems there is controllers such as OPC UA sharing meaningful information.
- Decentralization is the ability of deciding autonomously in real time with-out violating organizations goals. Embedded computers enable autonomous CPS to interact with their environment by sensors and actuators.
- Virtualization is used to monitor and control its physical aspect, which send data to update its virtual model in real time. It’s used to create an artificial factory environment with CPS similar to the actual environment. This artificial environment will allow creating digital prototypes by checking, modifying and testing before its order in the physical system, implementation of designs, train the workforces, by guiding them while performing manual processes, diagnosing and predicting faults and the corresponding maintenance.
- Service orientation as the manufacturers companies are evolving, their products are reaching equality of competitiveness, so manufacturing industries are becoming ser vice providers. Instead of only focusing in profits and margins, products and services are sold together. Basically, in a smart factory tend to outsource secondary processes and concentrating in their core processes. This encourage innovation and make a manufacturing industry will sell its core process as a service to other industries.
- Real time capability: capability of a system to respond automatically to system changes like customers’ requirements, failures and malfunctions. Disturbances have to be detected on real time and the system should have the ability to recover fast. To make this possible the
system as to be able to investigate the possibility of meeting those changes by access and analyze data in real time, using its resources through reconfigurations and cooperation via CPS or Cloud manufacturing requesting services that are not available in the factory.
2.1.4. Pillars of Industry 4.0

We can divide Industry 4.0 in nine main categories, as illustrated in figure 2:

![Figure 2: Pillars of Industry 4.0](image)

**Autonomous Robots** to be used in manufacturing in order to solve difficult tasks which cannot be easily solved by human beings, autonomously. The basic idea is to program the robot to respond a certain way after an external stimulation without explicit human control. It has a broad range of implementations and applications, including locomotion, localization, navigation, and mapping. Therefore, the needed information would be provided by the operator and control system, giving orders to the autonomous robots.[38] As the Managing Director of VDMA, the robotics+ automation Association, defines: “Robots are the most flexible automated tool—why they are the heart of Industrie 4.0. They are becoming more autonomous, can sense their environment and their ambiguity in digital networks is leading to ‘cloud robotics’. More and more we are seeing that people will work hand-in-hand with robots”. [39]

**Simulation tools** help achieving the design of the production system, playing a supportive role in activities related to manufacturing, and have the ability of self-configuration. The simulation being capable of planning the operations with the knowledge of information and accurate estimations about the systems, offers the necessary adjustments for the implementation of production systems.[40]

System Integration or **Cyber-Physical Systems** (CPS) is one of the main components of this Industry which promotes the computerization of manufacturing by making decentralized decisions. Monitoring
physical process, it is possible to create virtual copies of the physical world, simulating parts of processes and implementing new control policies to take the best decision possible. CPS can be explained as supportive technology for the organization and coordination of networking systems between its physical infrastructure and computational capabilities. In this respect, physical and digital tools should be integrated and connected with other devices in order to achieve decentralized actions. In other words, embedded systems generally integrate physical reality with respect to innovative functionalities including computing and communication infrastructure.[41]

Cloud is the enabler of the Industry 4.0. Cloud is the underlying storage and compute foundation. This allows any workload to be transferred and access at any time and any location. Data can be easily moved between environments, depending on the business needs and provides countless services and products.[42]

Additive manufacturing can also be defined as 3D printing is used in niche items. It is defined as the process of make object from 3D model data. The process starts in the designing, then fit and function prototyping to production. Is the new changing in the design because can save huge amounts of time and money while avoid costly errors and enhancing the quality of the products.

Augmented reality enhances human-machine interaction. This technology provides a view of a physical things, giving the motion control of its users by using sensor technology to make certain tasks. User is able to interact with a virtual environment without miss out on observing the real world.

Cyber Security refers to preventive methods used to protect information from being stolen, comprised or attacked. It requires an understanding of potential information threats, such as virus and others malicious codes. Cybersecurity strives to assure the attainment and maintenance of the security properties of the organization and user’s asset against relevant security risks in the cyber environment.[43]

Internet of things (IoT) is according to Kranenburg [44]:“a dynamic global net-work infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual ‘Things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network”. IoT can be described by its key utility factors [45]. A system/device to be in accordance with this new technology have to gather the following characteristics: should have the capacity to dynamically adapt to new changes and may have the ability to take actions based in their operating requirements. A self-configuring capability, allowing a huge number of devices, supported by interoperable communication protocol that must be integrated into the information net-work, to work together, by communicating with each other, exchanging data to provide some functionality. Each device has a unique identifier, such as an IP address, in order to users query the devices, monitor their status and control them remotely using an interface.
2.2. Enterprise Engineering

Enterprise engineering is an emergent discipline, comparable to electrical engineering or civil engineering. It is our conviction however that this discipline is needed. Dietz, in [46], defines enterprise engineering as “the whole body of knowledge and know-how regarding the development, implementation and operational use of enterprises, as well as their practical application in engineering projects”. Over the years academic insights have been developed about how to: enhance the effectiveness and efficiency of enterprises, effectively ensure quality, service and customer orientation, avoid core reasons for strategic failure.[47]
2.2.1. Enterprise Ontology

The first concept that underpin from the concept Enterprise Engineering is called *Enterprise Ontology (EO)*. According to Uschold “The central purpose of the Enterprise Ontology is to achieve effective sharing of meaning”, the main reason for formalising the EO is to provide a more precise specification of the meaning of the terms that is possible in natural language[48].

**Ontology**

Ontology as a branch of philosophy is the science of what is, that is the kinds and structures of objects, properties, events, processes and relations in every area of reality. Philosophical ontology seeks a classification that is exhaustive in the sense that all types of entities are included in the classification[49]. The original Greek word from which the English word “ontology” stems, means study or knowledge of what is or exists, and the philosophical branch with the same name has taken up the term as referring to the reality around us, regardless our own view on it. In other words, ontology requires us to make a strict distinction between the observing subject and the observed object.

Ontology serves to provide a basis for the common understanding of some area of interest among a community of people who may not know each other at all, and who may have very different cultural backgrounds. Normally we hear this concept in the context of the World-Wide Web, particularly in the context of the Semantic Web that is an extension of the current web in which information is given well-defined meaning, enabling a better cooperation between computers and humans.

**Semantic Web**

We will adopt the definition of ontology [50] that is: an ontology is a formal, explicit specification of a shared conceptualization. Explicit means that the type of concepts used and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine understandable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not restricted to one individual but accepted by a group.[51]

[52] It states the core properties that our notion of ontology also will contain. First, it regards the conceptualization of (a part of) the world, so it is something in our mind. Because of our constructivist stance, we consider these mental pictures be checked and adapted in communication. Second, this conceptualization is supposed to be shared, which is the practical goal of ontologies. This takes also place in communication. Third, it is explicit; an ontology must be explicit and clear, there should be no room for misunderstandings. Fourth, it is specified in a formal way. Natural language is inappropriate for this task, because of its inherent ambiguity and impreciseness.

These notions are discussed by understanding what the factual knowledge about a world is, that will led us to a definition of world ontology. By factual knowledge we mean knowledge about the state and the state changes of a World.
**Factual Knowledge**

The basis for understanding factual knowledge is the meaning triangle [52], which shows the core notions in semiotics and their relationships, by explaining how people use signs as representations of objects in order to be able to communicate about these objects in their absence, represented in the next figure:

![Figure 3 Meaning triangle](image)

The notion of subjective means that it concerns things that can only exist inside the human mind, on the other hand objective concerns things outside the human mind.

Concept is the outcome of an agreement between the subjects that use the sign for their communication, this sign is an object that is used as representation of something else, and object is a concrete object, an observable and identifiable individual thing.[53]

![Figure 4 Meaning triangle cont.](image)

The concept being a subjective individual thing, as a thought or mental picture of an object, is by definition typed: it is always and inevitably a concept of a type. It is how human mind works, by applying types in the outside world. A class is a collection of objects, that by definition a class contains all objects that conform to the associated type. Ontology is about the essence of things, not about how we name them. The resulting figure is called the ontological parallelogram.

Other definition that fit in the scope of our research is[54]: “Ontology means a specification or a formal representation of a subject domain and logical expressions which describe what the terms means, how the terms correlate with each other and how the terms may or may not be interrelated”.

32
Summing up, to communicate, plan, think we need a conceptualization of the world:

» What kinds of things are there? What are their properties? What are their relationships? »

These things define our ontology the ontology provides us a single coherent reference model for the whole enterprise, by supporting the enterprise architect, the applications and data. An ontology is used to make assumptions about the meaning of a term available[55].
2.2.2. Enterprise Architecture

Semantically, according to ISO 42010:2011 standard [56], the definition of Architecture is the fundamental concepts or properties of a system in its environment, embodied in its elements, relationships, and in the principles of its design and evolution, and according to The Open Group 2011 an Enterprise is any collection of organizations that has a common set of goals and/or a single bottom line.

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 [57]. 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 goes to the meeting of the needs of the different stakeholders involved.

The role of the architect is to identify the motivation and strategy expressed by stakeholders, developing an architecture with different views that show how it addresses and balances stakeholders’ concerns [3] by developing systems according to business goals, optimizing and providing alignment between business, data, application and technology layers.

Next we will present some developments that play a important role in the continuous maturation of the field of the enterprise architecture: The Open Group Architecture Framework (TOGAF) and ArchiMate.[58]

ArchiMate

ArchiMate is a modelling language that offers a uniform representation for diagrams that describe EA. The 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.[3]

The major design restriction on the language was to be as small as possible in terms of concepts which can be an element or a relationship. The core of the Framework ArchiMate defines a structure of elements and relationships, which can be separated in different layers, and different aspects:

- Business layer that demonstrates all business services which are realized by business processes and performed by business actors
Figure 5-Business layer

- Application layer that demonstrates the application services that support the business, and the applications that realize them

Figure 6-Application layer

- Technology layer that demonstrates the technology services needed to run the applications
The aspects of the core are defined by the three different types of elements:

- **Active Structure aspect** that depicts the structural elements, i.e. the elements that display actual behavior
- **Behavior aspect** that depicts the behavior performed by the actors
- **Passive Structure Aspect** that depicts the objects on which behavior is performed

As illustrated in next figure, to the core of the ArchiMate is added some new concepts. The physical elements are added to the Technology layer for modelling physical equipment’s, facilities and materials. The Implementation & migration demonstrates the models and concepts that can be used for specifying a transformation of the organization’s architecture to a new and higher level. The Motivation extension depicts the motivation behind the core elements.

The ArchiMate language 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.
Here we introduce a classification framework that helps architects and others to find the right viewpoint(s) given their task at hand, i.e., the purpose that a view must serve and the content it should display.

**Figure 8-ArchiMate Framework**

**Development of Viewpoints**

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Passive structure</th>
<th>Behavior</th>
<th>Active structure</th>
<th>Motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business</td>
<td></td>
<td></td>
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<tr>
<td>Application</td>
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<td></td>
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</tr>
<tr>
<td>Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation &amp; Migration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Layers**

<table>
<thead>
<tr>
<th>TYPICAL STAKEHOLDER(S)</th>
<th>PURPOSE</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGNING</td>
<td>navigate, design, support design decisions, compare alternatives</td>
<td>UML diagram, BPMN diagram, Testbed diagram</td>
</tr>
<tr>
<td>manager, CIO, CEO</td>
<td>decision-making</td>
<td>cross-reference table, landscape map, list, report</td>
</tr>
<tr>
<td>employee, customer, others</td>
<td>explain, convince, obtain commitment</td>
<td>animation, cartoon, process illustration, chart</td>
</tr>
</tbody>
</table>

**Figure 9-Viewpoint decisions**
With the help of this framework, it is easier to find typical viewpoints that might be useful in a given situation. This implies that we do not provide an orthogonal categorisation of each viewpoint into one of three classes; these categories are not exclusive in the sense that a viewpoint in one category cannot be applied to achieve another type of support. For instance, some decision support viewpoints may be used to communicate to any other stakeholders as well.

For characterising the content of a view we define the following abstraction levels:

- Details – Views on the detailed level are typically focussed on one layer and one aspect from the ArchiMate framework (Figure 15). Typical stakeholders are a software engineer responsible for design and implementation of a software component or a process owner responsible for effective and efficient process execution. Examples of views are a Testbed process diagram and a UML class diagram.

- Coherence – At the coherence abstraction level, either multiple layers are spanned or multiple aspects. Extending the view to more than one layer or aspect enables the stakeholder to focus on architecture relations like process-uses-system (multiple layer) or application-uses-object (multiple aspect). Typical stakeholders are operational managers responsible for a collection of IT services or business processes.

- Overview – The overview abstraction level addresses both multiple layers and multiple aspects. Typically, such overviews are addressed to enterprise architects, and decision makers such as CEOs and CIOs.

<table>
<thead>
<tr>
<th>TYPICAL STAKEHOLDER(S)</th>
<th>PURPOSE</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Details</td>
<td>software engineer, process owner</td>
<td>design, manage</td>
</tr>
<tr>
<td>Coherence</td>
<td>operational managers</td>
<td>Analyse dependencies, impact-of-change</td>
</tr>
<tr>
<td>Overview</td>
<td>enterprise architect, CIO, CEO</td>
<td>change management</td>
</tr>
</tbody>
</table>

*Figure - Viewpoint Characteristics*

In Figure 11, the dimensions of purpose and abstraction level are visualised in a single picture, together with examples of stakeholders.
TOGAF

The TOGAF standard is an architecture framework, developed and maintained by the members of The Open Group, that provides the methods and tools for assisting in the acceptance, production, use, and maintenance of an Enterprise Architecture and it can be used by any organization that wishes to develop an Enterprise Architecture. [59]

An architecture framework describes a method for designing a target state of the enterprise in terms of building blocks, and how they fit together by providing a foundational structure which can be used for developing a broad range of different architectures.

Using TOGAF standard results in an Enterprise Architecture that is consistent, reflecting the needs of the stakeholders, employing best practices for adding value and addressing the current requirements and the perceived future needs of the business.

TOGAF standard is designed to support: Business Architecture which defines the business strategy, governance, organization, and key business processes. The Application Architecture which provides a blueprint for the applications to be deployed, their interactions, and their relationships to the core business processes of the organization. The Data Architecture that describes the structure of an organization’s logical and physical and physical data assets and data management resources. The technology Architecture describes the logical software and hardware capabilities that are required to
support the deployment of business, data, and application services, including IT infrastructure, middleware, networks, communications, processing, and standards.

This standard provides a tested, iterative, and repeatable process for developing architectures, called Architecture Development Method (ADM). The ADM includes establishing an architecture framework, developing architecture content, transitioning, and governing the realization of architectures. In order to transform organizations in response to business goals and opportunities, all these activities are carried out within an iterative cycle of architecture definition and realization.

Developing Views

“Architects therefore need ways to express these architectures as clearly as possible, both for their own understanding and for communication with other stakeholders. To date, there is no standard language for describing architectures, and they are often described in informal pictures that lack a well-defined meaning. This leads to misunderstandings, and makes it very difficult to provide tools for visualisation and analysis of these architectures".[60]

One of the main decisions that an architect has to make is what architectures views is developed. The architect has to ensure completeness, integrity of the architecture by addressing all the concerns of its stakeholders and connecting all the several views to each other. The choice has to be constrained by considerations of practically and by the principle of fitness-to-purpose.

As explained in Architecture Development Method in TOGAF, the development of architecture views is an iterative process. There are two types of progressions: the first is using business scenarios to properly identify all pertinent concerns, the second one is start from high-level overview to lower-level detail, always referring back to the concerns and requirements of the stakeholders throughout the process.
Figure 11-Taxonomy of Viewpoints

In the domain of enterprise architecture, The Open Group’s TOGAF framework describes a taxonomy of views for different categories of stakeholders, see figure 12. Next to this description of views, TOGAF also provides guidelines for the development and use of viewpoints and views in enterprise architecture models.

**Service-Oriented Architecture (SOA)**

Applying the reality of the Industry 4.0 to the context of Enterprise Architecture, in order

**2.3. ISO 42010**

With the development of man-made systems, new opportunities arrive along with increased challenges for the organizations that create and utilize systems. Concepts, principles and procedures of architecting are increasingly applied to help the managing of such systems. When we are before an architecture description, the conceptualization of a system’s assists the understanding of the system’s essence and key properties regarding its behaviour, compositions and evolutions that will affect concerns of the system.[21]

Architecture descriptions are used by the parties that create, utilize and manage modern systems to improve its concerns, enabling them to work in an integrated manner. Architecture frameworks and architecture description languages are being created as assets that codify the conventions and common practices of architecting and the description of architectures within different communities and domains of application.
ISO 42010 addresses the creation, analysis and sustainment of architectures of systems through the use of semantically rigorous architecture descriptions. This Standard provides a core ontology for the description of architectures that serve to enforce desired properties of architecture descriptions. Also serve as a basis on which to compare and integrate architecture frameworks and architecture description languages (ADLs) by providing a common ontology for specifying their contents.

We should use ISO 42010 because there is a broad consensus that having a good architecture is critical to the success of systems in an enterprise, reflecting the current consensus of the systems engineering community’s best practices for describing architectures. This International Standard can further be used to assess conformance of an architecture description, of an architecture framework, of an architecture description language, or of an architecture viewpoint to its provisions.
2.3.1. Context of Architecture Description

ISO/IEC/IEEE 42010[61] is based upon a conceptual model or meta model of the terms and concepts belonging to Architecture Description. The conceptual model is presented using UML class diagrams to represent classes of entities and their relationships. This diagram captures terms and concepts of systems and their architectures, as a context for understanding Architecture Description.

ISO 42010 distinguishes an architecture from architecture description. An architecture is abstract and represent “fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution”. An Architecture description is a “work product used to express an architecture” and is intended to be usable from many approaches including document-centric, model-based, and repository-based techniques and the requirements on architectures descriptions are specified in ISO 42010.

An architecture description can include one or more architectures views. An architecture view addresses one or more of the concerns held by the system’s stakeholders and is defined by: “work product expressing the architecture of a system from the perspective of specific system concerns” and this expression is made in accordance with an architecture viewpoint. A viewpoint frames one or more concerns and is responsible to govern the architecture view. Is defined by: “work product establishing the conventions for the construction, interpretation and use of architecture views to frame specific system concerns”, these conventions can include languages, notations, model kinds, design rules, modelling methods, analysis techniques and other operations on views.

Views and Viewpoints

The task of establish a coherent enterprise architecture is complex task because it involves different people from different backgrounds using different notations. To go through this complexity, researchers focused on architectural frameworks for classifying and positioning the several architectural descriptions with respect to each other, as the Zachman framework, the main problem of this approach is that it categorizes architectural descriptions rather than providing insight into their coherence[3].

In the ArchiMate approach, architects can define their own views on the enterprise architecture, and those views are specified by viewpoints. This notion of architectures oriented to viewpoints was early recognised in requirements and software engineering. In the 1990s several researchers worked on: “the multiple perspectives problem”[62]. They referred to the problem of how to organize and guide development about a subject with many actors, diverse representation schemes, diverse domain knowledge and different strategies. To address those issues, a general framework[62] was developed where a viewpoint combines the notion of “actor” or “role” in the development process with the idea of a “view” or “perspective” which an actor maintains. Viewpoints are defined as locally managed, distributable objects and containing identity, state and behaviour. These ideas paved the way into ISO/IEC 42010 on which we have based our definitions. The TOGAF framework describes a taxonomy of views for different categories of stakeholders, also provides guidelines for the development and use of viewpoints and views in enterprise architecture models.
To reflect the architecture in a holistic manner, each view only needs to represent the whole system from the perspective of the system concerns framed by its governing viewpoint. One important point of ISO 42010 is the use of multiple views to express architecture, but because of the wide range of opinions, ISO 42010 not define a set of viewpoints, only encourages the practice of defining or selecting viewpoints appropriate to the system of interest.

The metaphor:" a view is to a viewpoint as a program is to a programming language" highlights the difference between those terms, where a viewpoint specifies the conventions (notations, languages and types of models), for constructing a kind of view, and can be applied to several systems. Each view is one application, similar to a program that is an instance of applying a programming language to a specific situation.

Architecture view is a representation of a system from the perspective of a set of concerns and is composed of one or more architecture model that represents a subject of interest, these models will provide a simplified and/or abstract representation of the subject matter and can be part of more than one view.

Architecture viewpoint is a specification of the conventions for a particular kind of architecture view and is composed of one or more model kind that establishes convention for a type of modelling[1].

Benefits of using Views and Viewpoints

To describe the architecture of a system, the use of views and viewpoints benefits the architecture definition process. Firstly, the description of many aspects of the system by a single representation result in independent aspects linked in a model. The separation of different models of a system into distinct descriptions will help the design, analysis and communication processes, through a separation of concerns allows to focus on each aspect separately. This a viewpoint-oriented approach helps the effective communication with the different groups of stakeholders in order to address their different concerns, thus different stakeholders can be quickly guided to different parts of the architecture based on their particular concerns. Dealing simultaneously with all of the aspects of a system becomes a complex task for one person to handle. So this approach provides a management of complexity by treating each aspect of a system separately and an improved developer focus to ensure that the right system gets built.[63]
2.3.2. Another ISOS

More importantly, under the rationale section of the Space Systems Reference Architecture, the Reference Architecture cites numerous international standards, to include the ISO Reference Model for Open Distributed Processing [ISO/IEC 10746-1, 2004], the Recommended Practice for Architectural Descriptions of Software-Intensive Systems [IEEE 1471, 2000] and Standard for Application and Management of the System Engineering Process [IEEE 1220, 2005].[64]


Another important ISO addressed in this thesis is the ISO/IEC 18384-2:2016 that “describes a Reference Architecture for SOA Solutions which applies to functional design, performance, development, deployment and management of SOA Solutions. It includes a domain-independent framework, addressing functional requirements and non-functional requirements, as well as capabilities and best practices to support those requirements.”[66] From this ISO we retrieve our definition of Reference Architecture.

ISA-95

The current view of industrial and automation IT architecture is the “automation pyramid”. [67] ISA-95 developed by the Instrumentation Systems and Automation Society (ISA) defines a complete functional model for enterprise-control use as a reflection of an organizational structure of functions which can be replaced addressing different demands of the enterprise. ISA-95 is originally a US standard which has been adopted as an international one under IEC/ISO 62246. As currently envisioned, the ANSI/ISA-95 series will consist of the 5 parts under the general title, Enterprise-Control System Integration, as we can see in the next image retrieved in [thesis]:
The ANSI/ISA 95 standard is an architecture that defines the level of a manufacturer company. The system is represented by 5 levels in which each layer represents hierarchy organizational elements. Starting by level 0, is where the physical processes are comprising the products and their product machines. The level 1 is represented by the automation system where the sensors actuators are monitoring and manipulating the production process, in other words the field devices. Next at level 2 is responsible for supervisory control and automated control of the production process and data acquisition. This first 3 levels composed the manufacturing control, the level 3 is responsible for the management of this operations and last level is concerned with the business planning and logistics.

In this study we will focus on the lowest levels where the data is generated, provided and analyzed. So, in this “automation” model the scope will range from the Level 0 til something between the Level 2 and 3. We will center the investigation on first four levels where the products are produced, the information extracted, analyzed and monitored.

2.4. Referencing the German view of Industry4.0

As we saw at section of Industry4.0, the fourth industrial revolution, has been widely adopted across the world and obviously each country has adopted this term to their own culture and current needs. In this thesis, we will take the perspective of this term from the Europe leader and pioneers in this field of industrial manufacturing, Germany. The Germans give the name INDUSTRIE 4.0 to the German strategic initiative to establish Germany as a lead market and provider of advanced manufacturing solutions[35]. One of the ten “Future Projects” identified by the German government as part of its High-Tech Strategy 2020, this project represents the major opportunity for Germany to establish itself as an integrated lead market and provider. “Smart production” becomes the norm in a world where intelligent ICT-based machines, systems and networks are capable of independently exchanging and responding to information to manage industrial production processes.
Germany Trade & Invest (GTAI) is the economic development agency of the Federal Republic of Germany. With more than 50 offices in Germany and abroad, and its network of partners throughout the world, GTAI supports German companies setting up in foreign markets, promotes Germany as a business location and assists foreign companies setting up in Germany. The Supervisory Board is chaired by the State Secretary at the Federal Ministry of Economic Affairs and Energy, and is composed of seven public and seven private sector representatives. Two of the main partners of GTAI, are the Association of German Machinery and Plant Engineering (VDMA) and the German Electrical and Electronic Manufacturers’ Association (ZVEI). Those two associations together with German Association for Information Technology, Telecommunications and New Media (BITKOM), are part of another platform steered and led by the federal minister for economic affairs and energy, and the federal minister of education and research and high-ranking representatives from industry, science and the trade unions. Experts from many areas develop operational solutions together with representatives from various deferral ministers in thematic working groups[68]. The launch of the platform was officially announced at Hannover Fair 2013.

In May 2015, China and Germany jointly set up the Sub-Working Group Intelligent Manufacturing/Industrie 4.0 of the Sino-German Standardisation Cooperation Commission (Working Group). Later in December 2015, the first Working Group conference was held in Shanghai and a constructive suggestion of mutually recognizing the Reference Architecture Model for Industry 4.0 (RAMI4.0) and China Intelligent Manufacturing System Architecture (IMSA) was proposed and confirmed. In November 2016, the third conference was held in Berlin, a consensus on Sino-German Intelligent Manufacturing/Industrie 4.0 System Architecture was achieved and an alignment result was initially shaped[69].

The Federal Ministry for Economic Affairs plans to invest 40 billion euros annually in Industry4.0 applications by 2020, in a country where 20% share of automotive companies that use self-controlled systems today. This investment will lead to 153 billion euros additional growth by 2020, thus 82% share of companies that believe that their value chains will be marked by a high level of digitalisation by 2020.[70]

Through a close partnership with the Standardization Council Industrie 4.0 (SCI4.0), the results of Platform Industrie 4.0 are quickly placed in international standardization bodies. The cooperation with the Labs Network Industrie 4.0 (LNI4.0) ensures that the practical experience gained from numerous initial use cases in the standardization processes is adequately taken into account.
Figure 13- Platform Industrie 4.0
2.4.1. Reference Architectures of Industry4.0 across the world

Through the international cooperation of the Platform Industrie 4.0, RAMI 4.0 has been compared with reference architecture models from the USA, France and China and is considered by the partners to be an important reference point for a uniform understanding.

The main area of focus of the Reference Architecture (2.5) have to be about industrial manufacturing, to provide production systems with seamless integration and easy operation throughout their lifecycle, from planning, configuration, commissioning and operation. And this is why we chose RAMI4.0 as reference architecture for the development of this thesis.

Why not other Reference Architecture?

The Industrial Internet Consortium (IIC) is an American open membership organization, with 258 members as of 22 November of 2016. [71] The main purpose of this organization is to accelerate the development, adoption and widespread use of interconnected machines and devices and intelligent analytics. Founded by AT&T, Cisco, General Electric, IBM and Intel, the IIC catalyzes and coordinates the priorities and enables technologies of the industrial internet. “It accomplishes this by enabling trustworthy industrial internet systems, where systems and devices are securely connected and controlled to deliver transformational outcomes across multiple industries. These industries include healthcare, transportation, energy, public domain infrastructures as well as manufacturing.” [72]

In 2015, representatives of IIC and Platform Industrie4.0 met to explore the potential alignment of their two architecture efforts (RAMI4.0 and IIRA), understand the technical issues from both perspectives and reduce market confusion.

An initial key finding of the collaboration is that the effort of IIC and Platform Industrie 4.0 is highly complementary as depicted in next figure: IIC addresses concerns about IoT across industries broadly stressing cross-industry commonality and interoperability; Platform Industrie 4.0 focuses mainly on manufacturing in depth.
China Intelligent Manufacturing System Architecture (IMSA) is a reference architecture in a form of cubic layer model, as RAMI4.0. Due to the similar structure can be found big similarities between both models.

With respect to the Layers dimension on RAMI 4.0 and Intelligent Function dimension on IMSA, both reference models consider the influences and improvements of manufacturing from the IT point of view. Specifically, the Asset phase on RAMI 4.0 is corresponding to the resource elements on IMSA; the Integration phase on RAMI 4.0 is corresponding to the System Integration on IMSA; the Communication phase on RAMI 4.0 is corresponding to the Interconnection on IMSA; the Information phase on RAMI 4.0 is corresponding to the Information Fusion phase on IMSA; while both the Functional phase and Business phase on RAMI 4.0 are corresponding to the New Business phase on IMSA. The other two axes or dimensions, Life Cycle and Value Stream (RAMI4.0) and Lifecycle dimension (IMSA) match because both reference models consider the process from product prototype development to recycling. The marketing phase on IMSA is not considered in RAMI 4.0; Hierarchy Levels dimension (RAMI4.0) and Hierarchy dimension (IMSA), both reference models consider organization structure of production related activities according to IEC 62264 and also the extension of the smart factory to the outer space, i.e., the collaboration with external engineering firms, component suppliers and customers.[69]
Table 1 - RAMI 4.0, IIRA, IMSA layers

<table>
<thead>
<tr>
<th>RAMI 4.0 layers</th>
<th>IIRA Functional Domains and Crosscutting Functions[72]</th>
<th>IMSA layers[69]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical aspect of the Assets Layer refers to Physical components, documents, software and human actors</td>
<td>Physical Systems (not formally defined)</td>
<td>Resources elements refer to a hierarchy used to achieve the digital process with resources or tools by the enterprise during the manufacturing process;</td>
</tr>
<tr>
<td>Integration Layer Digitally represents the physical assets and their digital capability; Provides computer-aided control of the technical process; generates events from the assets</td>
<td>Control Domains Functions performed by the industrial assets or control systems executing closed-loop control that may involve sensing, control and actuation.</td>
<td>System integration refers to a hierarchy used to achieve integration of intelligent equipment in the intelligent production unit, intelligent production line, digital workshop, intelligent factory, and even intelligent</td>
</tr>
<tr>
<td>Functional Layer</td>
<td>Communication Layer</td>
<td>Information Layer</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>If the functions are Industry 4.0 compliant then they refer to the functional layer</td>
<td>Provides standard communication for services and event/data to the information layer Provides control commands to the integration layer</td>
<td>Describes (logical) services and events/data of an asset (technical functionality) with regard to its role in the Industrie 4.0 system (as a “semantic self-description”)</td>
</tr>
<tr>
<td><strong>Connectivity and Distributed Data Management and Integration Crosscutting Function</strong></td>
<td><strong>Interconnection and interworking refers to a hierarchy used to connect equipment, equipment and control system, between enterprises through wired, wireless and other communication technology;</strong></td>
<td><strong>Information Domain Functions for collecting, transforming and analysing data to acquire high-level intelligence of the entire system</strong></td>
</tr>
<tr>
<td><strong>Information Domain Functions</strong></td>
<td><strong>Information fusion refers to a hierarchy used to achieve collaborative information sharing with cloud computing, big data and other new generation of information. This further includes communication technology based on the interconnection and interworking to ensure the information safety;</strong></td>
<td><strong>Functionality to form business</strong></td>
</tr>
<tr>
<td><strong>Operations and Application Domains Functions for assets and control systems management and maintenance to ensure their continuing operations Functions for applying use-case-specific logic, rules and models based on the information obtained from the information domain to achieve system-wide optimization of operations</strong></td>
<td><strong>Manufacturing system by the enterprise;</strong></td>
<td><strong>Business Domain Functions for integrating information across</strong></td>
</tr>
</tbody>
</table>
processing and linking between different business processes in supporting of the business models under the legal and regulatory constraints

business systems and applications to achieve business objectives, such as work planning, customer relation management (CRM), enterprise resource planning (ERP), manufacturing execution system (MES), etc.

perform value chain integration between enterprises to form new industry conformations by the enterprise.

In this thesis we will choose the RAMI4.0, in a ranking of selected IoT reference frameworks ranked by Google Scholar (research relevance) and Google Trends (public interest) appearance, this German reference architecture was placed at top 3 of frameworks in 2018. [73]

2.5. Reference Architectural Model of Industrie 4.0 (RAMI4.0)

The Working Group “Reference Architectures, Standards and Norms” of Platform Industrie 4.0 is working on a lingua franca for the industrial internet. Develops concepts that form the foundation of future standards. Their considerations set an important framework for standardization processes nationally and internationally. The main and only output from this working group was RAMI4.0 as a framework for orientation and the I4.0 Component Model, known as The Administration Shell. The first step was set up the RAMI4.0 that includes technical standards, business processes, organizational issues, and other business-related issues. To ensure the dissemination, it has been integrated into international standardization committees and cooperation’s: is recognized as a DIN standard (DIN 91345) and an international pre-standard (IEC PAS 63088) [68].

The “Reference Architectural Model Industry4.0” (RAMI4.0) was “draw” as reference model for Industrial production and automation to differentiate different architectural views that are related to each other [15]. RAMI is a three-dimensional model, as illustrated in next figure, 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. In the left horizontal axis, the product life-cycle 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 inter-action of single assets. Every asset has its own life cycle, depending in which state it actually is.

There are four main aspects in Industry 4.0 that are covered by RAMI4.0: First, vertical integration in the factory that describes the networking of means of production, as new aspect, the product or workpiece is also involved. End to end engineering through-out value stream means that all data created in production are kept consistent within the enterprise and can be accessed via network, always. The third aspect is horizontal integration, extending the factory walls, beyond individual locations and facilitating the creation of such added value networks. Finally, the human beings orchestrating the value stream.

The reference architecture model RAMI4.0 has been put forward for standardization as DIN SPEC 91345. [13]

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.
2.5.1. Layers

This vertical axis describes the properties and system structures with their functions and respectively information in the form of layers. They represent a certain part of the asset behaviour. Interaction is only possible by adjacent layers and some of them not always have to have content, so they can be ignored if not relevant. At the bottom layer represents the asset and the layers above represent the various types of functions of an asset [74].

**Asset Layer**

Represents the reality.

This layer is concerned with describing all the physical objects and methodologies used. It turns out to be a representation of the real factory, both the physical apparatuses, work pieces, as much as the workers. These are connected to the virtual world via the Integration Layer.

**Integration Layer**

This layer covers all technological methodologies for digitally integrating assets, by providing the infrastructures that exists in order to implement a function and store the properties and process-related functions that make the asset valuable. This asset’s information is needed to other layers create events in the form of so-called administration shells. To show the context of each asset, also provides the usage and integration of network components like routers, switches, terminals or passive ones like QR-codes and includes a human-machine interface. Examples of direct connectors: Arduino; Raspberry; Intel galileo; Zigbee

**Communication Layer**

The emphasis of this layer is to describe mechanisms and protocols for the interoperable exchange of information between components, using a uniform data format, in the context of the underlying case, function or service and related objects or data models. In other words, describes which data is used, where it is used and when it distributed. Provides the services for control the integration layer. Approach for implementation: OPC UA: Basis IEC 62541 was designed to support Examples of protocols: HTTP/HTTPS; MQTT3.1; Constrained application protocol.

**Information Layer**

Describes the rules of how data is represented and transformed into information. It contains the information that is being used and exchanged between functions, services and components, information objects and canonical data models. This last two represent the common semantic for functions and services that allows an interoperable information exchange. Ensuring data integrity in all system with a consistent integration of different types of data and higher quality. Receive events and transforming them into a suitable form for the data available to the functional layer. The administrative asset shell is implemented on this layer, making available data and functionality of the adjacent layers [74]. These data are divided into non real time data and real time data [75]. Approach for implementation: IEC
**Common Data Dictionary; Characteristics, classification and tools to eCl@ss; Electronic Device Description; Field Device Tolls**

**Functional Layer**

Represents functions, services, and their relationships from an architectural viewpoint. Independently of the actors and physical implementations in applications, systems and components. Rules and decision-making logic are generated by extracting the use case functionality. To ensure the integrity of the information and conditions in the process, remote access and horizontal integration are performed in this layer. This layer is responsible for describing the logical and technical functions of an asset by providing a digital description of its functions Approach for implementation: Field Device Integration

**Business Layer**

Represents the commercial view on the information exchange related to industrial processes. Maps out the business models and the resulting overall processes as monetary conditions. Business capabilities and business process for given production or process segments ensuring the integrity of functions in the value-added chain.

To the purpose of this investigation, we will focus on the first 5 levels, don’t paying much attention to this last layer called business.

Furthermore, the different layers differentiate the component of a production system in terms of their physical and IT aspects. These layers are used to represent the production modules as follows[76][77] in the next table:

*Table 2- RAMI4.0 layers*

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description for a production module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td>Plg’n’Produce or “production module as a service” as business model</td>
</tr>
<tr>
<td>Functional</td>
<td>Providing a service for executing manufacturing, assembly, test, and handling processes</td>
</tr>
<tr>
<td>Information</td>
<td>Properties: data, functions</td>
</tr>
<tr>
<td>Communication</td>
<td>Standard for service representation: Ethernet with OPC UA</td>
</tr>
<tr>
<td>Integration</td>
<td>Information Model</td>
</tr>
<tr>
<td>Asset</td>
<td>Production Model</td>
</tr>
</tbody>
</table>
2.5.2. Hierarchy Levels

This represents a functional hierarchy that structures the different responsibilities and aggregations from field devices over control hardware to higher level applications. The focus here is not the implementation but functional assignment, by separation in management of cyber physical system. This model was based in the Purdue Reference Model for computer-integrated manufacturing which was adopted by IEC 62264-1(enterprise-control system integration) plus IEC 61512(standard of batch control) in order to cover a broader area. The separation by levels follows the concept of functional separation, different functions are separated to specific zones, as illustrated in next figure.

At the bottom of the hierarchy, Product linked to the exploring smart factory products, reflect the necessities of the produced products within a section, and enables the produced products to be treated as assets what brings a standard description for information elements.

Next, Field Device, basically are electronic devices used for detecting and identifying components and sensor technologies.

Working above that are the Control devices, like programmable logic controllers are the center of manufacturing, used to manage input/output commands.

The control system architecture that uses networked data communications and graphical user interfaces for high level process supervisory management based on real-time information it's called Stations.

Then, Work Center, keeps the manufacturing information, defines the state of production helping decision makers improve the quality of production (MES).

Next, usually defined in terms of ERP called business management software comes Enterprise. These are core business processes as production planning, service delivery, retail, marketing, etc.

The top category is linked with stakeholders, suppliers, customers and service providers. It shares all the information within the enterprise which is important to maintain relationships along the supply chain, called Connected World.
On right horizontal-axis, Hierarchy Levels based in IEC 62264 and IEC 61512, comparing with ISA 95 make a direct linkage to structure our work. In this study we will focus on the lowest levels where the data is generated, provided and analyzed. So, in the hierarchy levels the scope will range from the Product to Station. We will center the investigation on first four levels where the products are produced, the information extracted, analyzed and monitored.
2.5.3. Life Cycle & Value Stream

This last dimension is divided into two stages. The first one, called type phase, addresses the product development and maintenance of a new product, and the second one addresses the usage process, to produce and maintain single instances of the product itself once it has been fully designed and developed called instance phase. Includes the basic definitions and building blocks that allow to model the smart value chain.

This last axis is used to visualize and standardize relationships and links, and the central importance is the distinction between type and instance. A type is created with the initial idea (product and machine), this covers the development phase, design orders and testing to first sample and prototype, only after that is released for series production. Then, when each manufactured product passes through the assembly process, identified for example by an id number, becomes an instance. To customers, initially the products are again types until being installed in a particular system. Like each instance, the type is also subject to use and updating to lead to an enhancement of the new type documents, which creates new instances, as illustrated in figure 6. For example: the output of in-stance phase of a vendor machine’ components could be a good input of the type phase in the developing and designing of a new component. On product type the design is produced and refined, on the other hand, product instance is manufactured, maintained and used [78]. This allows a better understanding of the various phases of life cycle (Product, Component, Order, Factory, Machine) improving its management. Further-more, it underlines dependencies on external enterprises.

The life cycle of a product has to be viewed with the value-adding processes it comprises provides huge potential for improvement.

Logistics data can be used in assembly, purchasing sees inventories in real time, the customer sees the completion status. This linking is very important, and the Life Cycle cannot be seen in an isolated way but rather in the collective with all the parties involved. We will focus at the instance production and the respective type usage.

<table>
<thead>
<tr>
<th>Life Cycle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type Development</td>
<td>This represents the first idea of a product. At this stage the every aspect</td>
</tr>
<tr>
<td></td>
<td>around the product is displayed, from commissioning to development, testing</td>
</tr>
<tr>
<td></td>
<td>and the generation of the first prototypes.</td>
</tr>
<tr>
<td>Type Maintenance</td>
<td>Representing the result from the development stage, this shows the first</td>
</tr>
<tr>
<td></td>
<td>model or prototype of the machine or product.</td>
</tr>
<tr>
<td>Instance Production</td>
<td>After specifying the requirements and generating a type, all products are</td>
</tr>
<tr>
<td></td>
<td>developed after this template. This stage represents the development of a</td>
</tr>
<tr>
<td></td>
<td>single part before being unique.</td>
</tr>
<tr>
<td>Instance</td>
<td>The final product or machine is represented here. To meet the needs of this</td>
</tr>
<tr>
<td>Maintenance</td>
<td>stage, a part has to be unique and in usage.</td>
</tr>
</tbody>
</table>

*Figure 18 - Life Cycle & Value Stream*
2.5.4. I4.0 Component Model

According to [79] 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 in accordance with QoS properties. It could be anything from a production system to an individual machine module [80]. An asset is not necessarily an I4.0 component (image X), only if it is an entity, has at least passive communication and has been equipped with an administration shell. An I4.0 component has the following properties: identifiability, the state in the lifetime based in the section before, it must be possible, always, for other users to query the state of each I4.0 component in an I4.0-compliant communication, an appropriate profile that describes which services are implemented, and what technology is used for this, the real time range for productive communication, maximum fail safe security, granular clock synchronization, interoperability. For security the confidentiality, integrity of data, functions and availability of the technical functionality must be ensured. Must have I4.0 compliant semantics, classified using the following data elements: general business conditions (Business), mechanics (Construction), functionality (Function), place (Location), capability (Performance). This information is generated according to RAMI4.0 as a virtual, structured representation of the real asset in an I4.0-compliant data format.

![Figure 19 - I4.0 Component](image)
2.5.5. I4.0 Component

Defining an Asset in the Information World

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.

An asset can be classified, depending on the quantity data available:

- Unknown assets are not known to the information world;
- Anonymously Known, only can be recognized in the information world as an asset of a particular type at a particular place;
- Individually Known, it has a unique name that is known in the information world;
- Administered as an entity, due to its importance is administered in the information world, entities are like assets that possess objects of their own and are represented by information, this means that the data is kept(either on or in the relevant I4.0 component) and can be made available to the outside world(I4.0-compliant communication)

An asset can be classified, depending its communication capability:

- Assets without communication, has no functionality as an information carrier or if it has information carrier functionality but no digital interface;
- Assets with passive communication, has an information carrier which can read by interfaces (RFID or barcode).
- Assets with active communication, can take part in network communication by actively identifies itself with the network and logs in to participate in communication.
- Assets with I4.0-compliant communication, have all the capabilities of an I4.0 service system user as an I4.0 component (at least have a connection to the asset via an information system).

The passive communication capability is a minimum prerequisite, once you can integrate an asset that has passive or active communication capability, but not I4.0 compliant, by using a proxy for I4.0-compliant communication based on service-oriented architecture (SOA).

An asset can be classified in terms of presentation (publicity in the information system), which is completely independent of its communication capability, and can be freely chosen and is a design decision. An asset can be classified, depending its technical functionality that encompasses all data and properties which characterize an associated asset or represent important information for other assets.

The following applies to every asset:

- The asset is designed, created, used and disposed of;
The asset can be an idea, a software program, an archive, a service or any physical item (in other words it does not have to exist in a physical form);

• The asset has a lifetime;
• The asset is clearly identifiable;
• The asset is represented in the virtual world by its administration shell;
• The asset can have multiple virtual representations specified according to the rules of Industrie 4.0 for different purposes;
• Assets can be combined to create new assets with different properties;
• The asset is characterized in a process by means of time, location and state;
• Each piece of information has a carrier;
• The asset's characteristics are described using Industrie 4.0 vocabulary that includes a collection of terms which describe properties.

**Administration Shell**

The asset Administration Shell provides a flexible framework that promote the Smart Manufacturing. It's the standardized digital representations of the pillar of the interoperability between the manufacturing systems and the applications managing. It includes all the relevant information for representing the asset and its technical functionality.

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.[81]

The structure of the I4.0 administration shell is composed by a Header that provides identification, designation of the asset and of the Administrative Shell, and a Body that administers submodules with hierarchical properties which refer individual information and functions.

The administration shell can contain any number of I4.0-compliant partial models. These partial models are created using RAMI and in terms of properties, using data elements (based in IEC/TR 62794).

The respective property structures are arranged in a standardized format (based in IEC 61360), while for the different information and functions is possible to access to complementary formats. The administration shell contains the administration shell management in the form of the component manager and the manifest. This component administers and organizes the information in the administration shell with its partial models and forms an expanded service that executes the maintenance of all stored data and enables innumerous options of querying access based on service-oriented architecture. On the other hand, manifest includes the properties of the asset, the information about interrelated properties, relationships between I4.0 components and formal descriptions of the functions as well as relevant procedures. The main difference is that Manifest contains information that is publicly known in order to implement I4.0 systems.
Each partial model specifies its properties, data and functions according to uniform rules for the header and body and must provide the basic views: Business, Design, Performance, Functional, Local, Security, Network view, Life cycle and Human.
3. Proposal

In the section 2, we have analyzed the related work in order to identify and define some key concepts, which are relevant for the correct implementation and maintenance of a model based in the RAMI4.0. Furthermore, we define the solution’ steps to achieve the thesis objectives.

3.1. Solutions Steps

As we have identified in section 2, RAMI4.0 helps to implement industry4.0 projects, by providing the semantics of their architecture by layers, but does not provide an approach in order to facilitate the implementation and representation as we know the viewpoints.

Being the fundamental objective of this thesis to create a mapping between the RAMI4.0 and ArchiMate language, in order to develop a EA baseline capable to implement Industry4.0 project using ArchiMate for the representation, this discipline (EA) is defined as a framework to use in architecting the operating or systems in order to meet vision, mission and business goals and to deliver the enterprise strategy.[57]

ArchiMate is a modelling language for EA and enterprises have their business processes modelled in this language.[82]. Unfortunately, RAMI4.0 does not have any kind of viewpoints of its processes represented in ArchiMate (or other modelling language or notation) in order to facilitate the implementation of the Industry4.0 projects. What makes hard the connection of RAMI4.0 and organizations’ processes.

As stated in the next figure, we present our initial solution’ steps that represents what our research intends to demonstrate in order to clarify the research problem in the adoption of i4.0 projects. First, we will make a mapping between concepts of RAMI4.0 and ArchiMate, then we will model RAMI4.0 and the respective I4.0 Component Model with the selected elements. After the modelling of the several domains we will compare them to a current project undergoing in a DemoCorp in order to make an assessment and identify the inconsistencies (principles, structure, and terms) between the project and the RAMI4.0 model by a Gap Analysis.

Figure 20 - Solution Steps

The proposed solution make clear of how an organization that have its processes modelled in ArchiMate can start to develop or transform projects under the scope of Industry4.0 and potentiate new possible
scenarios through this language. ArchiMate notation will provide tools that can help us to get the job done.

For the first step of the proposed solution, Mapping Concepts, we will only focus on the best way to realize a correct mapping between these two frameworks. We will start by the identification of the several domains presented in ArchiMate framework, then we will try to map it with the domains and layers presented in the RAMI4.0, for then we make a correspondence between elements that represent the same concepts.

As we can see in image, our proposal is a concept mapping and the respective modulation of RAMI4.0, and we will try to demonstrate our proposal by analysing current processes modelled in ArchiMate of a DemoCorp, and comparing it to the our modulation of RAMI4.0 in several layers. Furthermore, such solution steps will follow the architecture viewpoints defined in ArchiMate (next table).

Table 3- Viewpoints of ArchiMate used in each step

<table>
<thead>
<tr>
<th>Solution’s Step</th>
<th>ArchiMate Architecture Viewpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrastructure</td>
</tr>
<tr>
<td>1. Mapping Concepts with ArchiMate</td>
<td></td>
</tr>
<tr>
<td>2. Model RAMI4.0 &amp; I4.0 Component</td>
<td>x</td>
</tr>
<tr>
<td>4. Model Organization’s EA</td>
<td>x</td>
</tr>
<tr>
<td>6. Gap analysis</td>
<td></td>
</tr>
</tbody>
</table>
3.1.1. Step1- Mapping concepts of RAMI4.0 with ArchiMate

In this first step we will try to match the concepts from ArchiMate that fit in the description of the various layers presented in RAMI4.0. For that we will first analyze the domains addressed by ArchiMate’s layers (Technology, Application, Business layers). Then we will redefine and analyze the domains addressed in RAMI4.0. With both analyze we can then try to find the best ArchiMate elements for the descriptions presented at DIN SPEC 91345 of RAMI4.0.

The starting point for the development of this mapping is trying to connect the similar domains presented in RAMI4.0 and ArchiMate.

Domains addressed and concepts covered by ArchiMate

On the side of ArchiMate, if we look to ArchiMate’s meta-model, we can see a collection of so-called conceptual domains, each covering specific areas. We base our choice of conceptual domains on the domains commonly distinguished in architectural frameworks or methods such as the TOGAF framework, the Zachman framework and the architectural practice within organizations participating in ArchiMate projects[83]. In the next image we can see how the different domains are presented in the Architectural Framework of ArchiMate.

![ArchiMate Domains](image)

**Figure 21 - ArchiMate Domains**

The core framework is divided by aspects, where the information aspect represents the structural elements, the behavior aspect represents the behavior elements, and the structure aspect represents the objects on which behavior is performed. Based on the common aspects of these domains and layers, we make a first generalization of the core concepts. In our view, a system or organization primarily consists of a set of entities, which have an internal structure, perform behavior, and use and exchange information.

In the current practice of organizations, architectural descriptions are made for different ‘layers’ of the organization. These are layers in the sense that 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[3]. The research is more focus on the last two layers in the Data, Application and Technical Infrastructure domains.
Domains addressed and concepts covered in RAMI4.0

The Industry4.0 technical committee (ZVEI, BitKom, VDMA), RAMI4.0 being the reference model defined as one that can be widely applied and use to derive specific models, in fact the user can reconstruct the model based on different user-specific application scenarios. The main area of focus on RAMI4.0 is industrial production, to provide production systems with seamless integration and easy operation throughout their lifecycle, from planning, configuration, commissioning and operation.

To cope with this in order to accommodate the industrial production of a manufacturing system, we adopted a refined architecture referencing the RAMI4.0 model[84]. As seen in the left figure. (cubic model), there are 6 layers covered by Industry4.0. The lowest two levels (asset and integration) are strongly connected to field devices, and the highest two layers (business and function) are strongly application domain-independent[85].

![Diagram showing RAMI4.0 model and its relation to a four-layer architecture for process-control system.]

**Figure 22 - RAMI 4.0 Refined**

Generally, the field layer contains resources from the real world, while the other three layers are situated in the digital world and provide virtual descriptions of physical system assets. So, we finish with a refined RAMI4.0 with a four (big) layers architecture for process-control system.

When we started this work, we wanted to focus on the domains that are needed until we reach the functional level, so the: asset, integration, communication, information, and functional. Translating this choice to the refined architecture we will address the lowest three ones (Field, Communication and Information), and part of the highest one (on enterprise layer we will only address the function part).

Note: In order to adapt the RAMI4.0 model for the best mapping possible with ArchiMate for the purpose of this thesis, the layer of integration, instead of being modeled with the asset layer, as is showed in next table, in this thesis is represented with the communication layer because of the great similarities between the terms of these layers when representing those two layers in ArchiMate, and due the
importance of the asset layer in this model, this asset layer is represented alone as is represented in the next table, in blue the refined architecture and in orange the actual layers addressed in RAMI4.0.
Another main feature of this model is the I4.0 component model that makes part of the RAMI4.0 model, this component is transversal to the whole architecture, and we will have to address and represent it in the refined RAMI4.0. In the next chapter of this section (Mapping I4.0 Component Model concepts with ArchiMate), we will demonstrate how we approach the development of the process to represent I4.0 component model in ArchiMate, that is used across all the viewpoints to be develop.

After the covered domain’s addressed by ArchiMate (Physical, Technology, Application, Business, Motivation) and RAMI4.0 we can map both domains, to centre our work.

Table 5- RAMI4.0&ArchiMate’s layers and domains addressed

<table>
<thead>
<tr>
<th>ArchiMate layer</th>
<th>Archimate domains</th>
<th>RAMI4.0 domains</th>
<th>RAMI4.0 domains refined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>technical infrastructure</td>
<td>Asset</td>
<td>Field</td>
</tr>
<tr>
<td>Technology</td>
<td></td>
<td>integration</td>
<td>Communication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication</td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>Data</td>
<td>Information</td>
<td>Information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Functional</td>
<td>Enterprise(Functional)</td>
</tr>
<tr>
<td>Business</td>
<td>Information</td>
<td>Business</td>
<td>Enterprise(Business and Functional)</td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>organization</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this table we can see which RAMI4.0 layers will have to be addressed after selecting the ArchiMate’s domains in the section before: Asset, Integration, Communication, Information and Functional. We finish with refined domains within RAMI4.0: Field, Communication, Information, and Enterprise (functional).
**Mapping concepts - I4.0 Component Model**

From the concepts retrieved in section Related work in section 2, the second model (section 2.5.4), developed by BITCOM, VDMA, and ZVEI, the I4.0 Components Model it's the first and only specific model which goes out from the RAMI4.0 model[86] presented in section 2.5. It enables a description in more detail of the properties of cyber-physical systems, by describing its features and the communication among virtual and cyber-physical systems. As stated in section I4.0 Component Model, an asset only is considered an I4.0 component when is administered as an entity, has at least passive communication capability and is “surrounded” by an administration shell.[15]

These are the two main concepts that are addressed all over these two models. From RAMI4.0 its architecture tries to represent the concept “Asset” across all the layers and from the I4.0 component model, although it also goes around this concept and its virtual, digital, active representation, this term is always together with a “Administration Shell” that is responsible for that representation[13]. Before we even try to model anything, we need to understand how these two concepts remain together and how we going to modulate them.

From the related work retrieved, in section 2.5.4, as we can see in the next figure 23, the structure of an i4.0 component

![I4.0 Component](image)

**Figure 23: I4.0 Component**

The asset: technical objects that are intentionally manufactured in order to fulfil a specific purpose, [13] only become an i4.0 component if are equipped with an administration shell that provides a structured information asset description that will act as a virtual representation of an asset.

Furthermore, in the next figure is modelled in ArchiMate the I4.0 component.

To represent the “asset” we chose a data object, a deeper analysis is done next, that represent “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, we chose Application component that represents “an encapsulation of application
functionality aligned to implementation structure, which is modular and replaceable (priorities to be discussed). It encapsulates its behaviour and data, expose services, and makes them available through interfaces". To represent the I4.0 component, we chose an application component too as the name states [3].

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.

![I4.0 Component modelled in ArchiMate](image)

**Figure 24**: I4.0 Component modelled in ArchiMate

Thanks to the great similarities and unquestionable link between Reference Architecture Model of Industrie 4.0 (RAMI4.0) and I4.0 Component model, in the next solution’s sections this two models will be used as one, referring it as just RAMI4.0. The concept of I4.0 component and administration shell play a vital role in communication and information layers [87] although in the meta-model the concept of administration shell being represented at Integration layer, which also makes sense because administration shell can be centralized or decentralized, that is, you can save the information in a database-oriented system or you can incorporate the decentralized shells, for example directly into the managed technical object, hence the administration shell is the sum of all pieces of data of all objects related to that administration shell.[87] In the designing the several layers of RAMI4.0 we will use both models together, to understand why the administration plays a central role in the RAMI4.0 model.

In order to make a complete mapping between RAMI4.0 and ArchiMate, we elaborate a table that is presented at the end of this thesis. Note that, this mapping was based only in the semantics and acknowledge of concepts present in both specifications, RAMI4.0 and ArchiMate.

In the Annex B we elaborate a table with the all mapping between the description presented in DIN-SPEC13945 with the elements of ArchiMate Specification.

The semantic match between the concepts and explanations of these columns contributes for the proposed RAMI4.0 and I4.0 component model to ArchiMate ontological mapping.
### For the I4.0 Component Model

#### Table 6-Mapping the I4.0 Component Model with ArchiMate

<table>
<thead>
<tr>
<th>ASSET</th>
<th>Definition of RAMI4.0 concept:</th>
<th>Asset definition - Object which has value for an organization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Key words:</td>
<td>Object</td>
</tr>
<tr>
<td></td>
<td>Concept:</td>
<td>Asset</td>
</tr>
<tr>
<td></td>
<td>ArchiMate Concept:</td>
<td>Data Object</td>
</tr>
<tr>
<td></td>
<td>Definition:</td>
<td>Data structured for automated processing</td>
</tr>
<tr>
<td></td>
<td>RAMI 4.0 definition proposal:</td>
<td>Object that represents value translated to information structured for automated processing</td>
</tr>
<tr>
<td></td>
<td>Rami4.0 concept map in ArchiMate:</td>
<td>Asset</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADMIN. SHELL</th>
<th>Definition of RAMI4.0 concept:</th>
<th>Virtual digital and active representation of an I4.0 component; The administration shell is what converts an asset into an I4.0 component. It is the virtual digital and active representation of an asset in an I4.0 system.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Key words:</td>
<td>I4.0 component</td>
</tr>
<tr>
<td></td>
<td>Concept:</td>
<td>Administration Shell</td>
</tr>
<tr>
<td></td>
<td>ArchiMate Concept:</td>
<td>Application Component</td>
</tr>
<tr>
<td></td>
<td>Definition:</td>
<td>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</td>
</tr>
<tr>
<td></td>
<td>RAMI 4.0 definition proposal:</td>
<td>It encapsulates its behaviour and data, expose services, and makes them available through interfaces, is what converts an asset into I4.0 Component</td>
</tr>
<tr>
<td></td>
<td>Rami4.0 concept map in ArchiMate:</td>
<td>Administration Shell</td>
</tr>
</tbody>
</table>
### Representation of i4.0 Asset

**Description of RAMI4.0 concept:** The administration shell includes the relevant information for representing the asset and its technical functionality. It provides the information world with information on the asset, structured according to RAMI4.0; It is the virtual digital and active representation of an asset in an I4.0 system.

**Key words:** Representing; Asset; Information; Structured; Representation of an asset

**Concept:** Representation of the Asset

**ArchiMate Concept:** Data Object

**Definition:** Data structured for automated processing

**RAMI 4.0 definition proposal:** the relevant information for representing the asset and its technical functionality. It provides the information world with information on the asset, structured according to RAMI4.0 for automated process generated by Administration Shell.

**Ram4.0 concept map in ArchiMate:** Representation of the i4.0 asset

---

### I4.0 Component

**Definition of RAMI4.0 concept:** An asset that has all the capabilities of an I4.0 service system user is known as an I4.0 component due to its special role in the I4.0 system. I4.0 components whose software and hardware form a unit are called autonomous I4.0 components; The administration shell is what converts an asset into an I4.0 component. It is the virtual digital and active representation of an asset in an I4.0 system.

**Key words:** I4.0 component; Representation of an Asset; Software; Hardware; Unit

**Concept:** I4.0 Component

**ArchiMate Concept:** Application Component

**Definition:** 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

**RAMI 4.0 definition proposal:** Asset and an Administration Shell forms an I4.0 Component (2.5.4)

**Rami4.0 concept map in ArchiMate:** I4.0 Component
Specification of the rest of the mapping

Next we present the mapping for each element of ArchiMate:

For elements of ArchiMate that are in more than one layer

<table>
<thead>
<tr>
<th>Description of RAMI4.0 concept:</th>
<th>asset that actually exists in the physical world</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key words:</strong></td>
<td>Asset; Physical world</td>
</tr>
<tr>
<td><strong>Concept:</strong></td>
<td>Sensors, Actuators, Machines</td>
</tr>
</tbody>
</table>

| ArchiMate Concept:             | Equipment                                        |
| **RAMI 4.0 definition proposal:** | is one or more physical machines, tools, or instruments that can create, use, store, move, or transform materials |

| **RAMI 4.0 definition proposal:** | Asset that exists in the physical world and is one or more physical machines, tools, or instruments that can create, use, store, move, or transform materials |

| Rami4.0 concept map in ArchiMate: | ![Sensors](image), ![Actuators](image), ![Machines](image) |

<table>
<thead>
<tr>
<th>Description of RAMI4.0 concept:</th>
<th>asset that actually exists in the physical world; describing methodologies used at the factory level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key words:</strong></td>
<td>Asset; Physical world; Factory Level</td>
</tr>
<tr>
<td><strong>Concept:</strong></td>
<td>PC</td>
</tr>
</tbody>
</table>

| ArchiMate Concept:             | Device                                                                                           |
| **Definition**                 | is a physical IT resource upon which system software and artifacts may be stored or deployed for execution |

<p>| <strong>RAMI 4.0 definition proposal:</strong> | asset that exists at the factory level, is a physical IT resource upon which system software and artifacts may be stored or deployed for execution |</p>
<table>
<thead>
<tr>
<th><strong>Rami4.0 concept map in ArchiMate:</strong></th>
</tr>
</thead>
</table>

| **Description of RAMI4.0 concept:** asset that actually exists in the physical world; describing methodologies used at the factory level |
|**Key words:** Asset; Physical world; Factory level |
|**Concept:** Network |

<table>
<thead>
<tr>
<th><strong>ArchiMate Concept:</strong> Communication Network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong> represents a set of structures that connects computer systems or other electronic devices for transmission, routing, and reception of data or data-based communications such as voice and video.</td>
</tr>
</tbody>
</table>

| **RAMI 4.0 definition proposal:** Asset that exists in the physical world and represents a set of structures that connects computer systems or other electronic devices for transmission, routing, and reception of data or data-based communications |

| **Rami4.0 concept map in ArchiMate:** |

| **Description of RAMI4.0 concept:** A human-machine interface (HMI) |
|**Key words:** HMI |
|**Concept:** HMI |

<table>
<thead>
<tr>
<th><strong>ArchiMate Concept:</strong> Technology Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong> represents a point of access where technology services offered can be accessed.</td>
</tr>
</tbody>
</table>

| **RAMI 4.0 definition proposal:** represents a point of access where technology services offered can be accessed. |

| **Rami4.0 concept map in ArchiMate:** |

| **Description of RAMI4.0 concept:** An I4.0 component provides its representation, including its dynamic behaviour, using standardized, I4.0-compliant semantics. |
|**Key words:** I4.0 compliant semantics |
Concept: 14.0 component; 14.0 compliant semantics

**ArchiMate Concept**: Artifact

**Definition**: A piece of data that is used or produced in a software development process, or by deployment and operation of a system

**RAMI 4.0 definition proposal**: 14.0 compliant semantics, piece of data that is used or produced in a software development process, or by deployment and operation of a system

**Rami4.0 concept map in ArchiMate**:

---

**Description of RAMI4.0 concept**: asset that actually exists in the physical elements such as linear axes and sheet metal parts, services, documents, circuit diagrams, ideas and archives,

**Key words**: Asset; Physical world; Services

**Concept**: Services, Virtualization and Operations;

**ArchiMate Concept**: Technology Service

**Definition**: represents an explicitly defined exposed technology

**RAMI 4.0 definition proposal**: Asset that exists in the physical elements such as services that represents an explicitly defined exposed technology

**Rami4.0 concept map in ArchiMate**:

---

**Description of RAMI4.0 concept**: runtime and modelling environment for services and business processes; runtime environment for applications and technical functionality.

**Key words**: Services; Applications; Technical functionalities

**Concept**: Virtualization Services

**ArchiMate Concept**: Application Service

**Definition**: an explicitly defined exposed application behavior.
For the Asset (Field) Layer

**Description of RAMI4.0 concept:** an asset is not necessarily an I4.0 component. Only if it is an entity, has at least passive communication capability and has been equipped with an “administration shell” does an asset become an I4.0 component.

**Key words:** Asset; Entity; communication

**Concept:** Assets with I4.0 compliant communication capability; Assets that are administered as entities

**ArchiMate Concept:** Requirements

**Definition** A statement of need that must be met by the architecture.

**RAMI 4.0 definition proposal:** Requirements needed to an asset become an I4.0 Component

**Description of RAMI4.0 concept:** asset that actually exists in the physical world

**Key words:** Asset; Physical world

**Concept:** Material
**ArchiMate Concept:** Material  
**Definition:** is defined as Tangible physical matter or physical elements

**RAMI 4.0 definition proposal:** asset in the physical world, tangible physical matter or physical elements

**Rami4.0 concept map in ArchiMate:**

---

**Description of RAMI4.0 concept:** asset that actually exists in the physical world  
**Key words:** Asset; Physical world  
**Concept:** Facility

**ArchiMate Concept:** Facility  
**Definition:** Facility is a physical structure or environment.

**RAMI 4.0 definition proposal:** Asset that exists in the physical world and is a physical structure or environment.

**Rami4.0 concept map in ArchiMate:**

---

**Description of RAMI4.0 concept:** asset that actually exists in the physical world such as linear axes and sheet metal parts, services, documents, circuit diagrams, ideas and archives  
**Key words:** Asset; Physical world; documents; ideas; archives  
**Concept:** Documents; Files

**ArchiMate Concept:** Material  
**Definition:** is defined as Tangible physical matter or physical elements

**RAMI 4.0 definition proposal:** Asset that exists in the physical elements such as documents, ideas and archives (files in information world).

**Rami4.0 concept map in ArchiMate:**

---

**Description of RAMI4.0 concept:** asset that actually exists in the physical world; The physical world includes all physical products, installations, resources, IT systems, loaded programs, etc. When classifying software, it
should be noted that the algorithm itself belongs to the information world, but the executable program loaded to a system is part of the physical world.

**Key words:** Asset; Physical world; Programs

**Concept:** Software

**ArchiMate Concept:** System Software

**Definition:** represents software that provides or contributes to an environment for storing, executing, and using software or data deployed within it.

**RAMI 4.0 definition proposal:** asset that actually exists in the physical world and it represents software that provides or contributes to an environment for storing, executing, and using software or data deployed within it

**Rami4.0 concept map in ArchiMate:**

**Description of RAMI4.0 concept:** asset that actually exists in the physical world and humans

**Key words:** Asset; Physical world; Humans

**Concept:** Humans

**ArchiMate Concept:** Business Actor

**Definition:** is a business entity that is capable of performing behaviour

**RAMI 4.0 definition proposal:** Human entity that is capable of performing behaviour

**Rami4.0 concept map in ArchiMate:**

**For the Integration and Communication (Communication) Layers**

**Description of RAMI4.0 concept:** where the properties and process-related functions that make the asset usable for its intended purpose are stored; The Industrie 4.0 component provides a digital description of the object, making it possible to represent that object virtually.

**Key words:** Properties; process-relates functions; virtually

**Concept:** Operations and Virtualization

**ArchiMate Concept:** Technology Function

**Definition:** is a collection of technology behaviour
**RAMI 4.0 definition proposal:** is a collection of technology behaviour where the properties and process-related functions that make the asset usable for its intended purpose are stored.

**Rami4.0 concept map in ArchiMate:**

---

**Description of RAMI4.0 concept:** Object which has value for an organization; describes Industrie 4.0-compliant access to information and functions of a connected asset by other assets.

**Key words:** Industrie 4.0-compliant access

**Concept:** Industrie 4.0-compliant access

**ArchiMate Concept:** Artifact

**Definition:** A piece of data that is used or produced in a software development process, or by deployment and operation of a system.

**RAMI 4.0 definition proposal:** describes Industrie 4.0-compliant access to information and functions of a connected asset represented as a piece of data that is used or produced in a software development process, or by deployment and operation of a system.

**Rami4.0 concept map in ArchiMate:**

---

**For the Information (Information) Layer**

**Description of RAMI4.0 concept:** execution of rules; persisting of data represented by the models

**Key words:** Rules; persisting of data

**Concept:** SLA

**ArchiMate Concept:** Contract

**Definition:** Contract represents a formal or informal specification of an agreement between a provider and a consumer that specifies the rights and obligations associated with a product and establishes functional and non-functional parameters for interaction.

**RAMI 4.0 definition proposal:** Service level agreement

**Rami4.0 concept map in ArchiMate:**
**Description of RAMI4.0 concept:** formal description of models and rules; information is generated according to RAMI4.0 as a virtual, structured representation of the real asset in an I4.0-compliant data format.

**Key words:** Description; structured; I4.0 compliant data format

**Concept:** I4.0 compliant data format

**ArchiMate Concept:** Representation

**Definition:** represents a perceptible form of information carried

**RAMI 4.0 definition proposal:** represents the rules of a structured representation of the asset by a perceptible form

**Rami4.0 concept map in ArchiMate:**

---

**Description of RAMI4.0 concept:** The properties and functions of the asset are classified using the following data elements: general business conditions (Business), mechanics (Construction), functionality (Function), place (Location), capability (Performance) and Lifecycle

**Key words:** general business conditions; mechanics; functionality; place; capability; lifecycle

**Concept:** (Category of Information that can be retrieved)

**ArchiMate Concept:** Data Object

**Definition:** Data structured for automated processing

**RAMI 4.0 definition proposal:** Category of information as collections of many data structured for automated processing

**Rami4.0 concept map in ArchiMate:** see 4.1.3

---

For the Functional (Functional) Layer

**Description of RAMI4.0 concept:** The services of the component manager are provided by the I4.0-compliant service-oriented API (Application Programming Interface).

**Key words:** I4.0 compliant service-oriented API

**Concept:** I4.0 compliant service-oriented API
**Archimate Concept:** Artifact

**Definition:** A piece of data that is used or produced in a software development process, or by deployment and operation of a system

**Rami4.0 concept map in ArchiMate:**

---

**Description of Rami4.0 concept:** The information in the administration shell with its partial models must be administered and organized. This is done by the component manager and the manifest.

The Manifest contains mandatory information on the I4.0 component, including on connection to the asset or assets by means of appropriate identification.

This information is generated according to Rami4.0 as a virtual, structured representation of the real asset in an I4.0-compliant data format. One part of this representation is the manifest, which must have I4.0-compliant semantics.

The component manager directly or indirectly forms an expanded service that carries out both the lifelong maintenance of the information contained, as well as enabling powerful querying options based on service-oriented architecture (SOA). It is the link between the IT technical services of the I4.0 component which provide external access to the information of the representation and to the technical functionality of the asset. It organizes the autonomous administration and access to the resources of the I4.0 component and ensures protection appropriate to the asset's use.

**Key words:** structured; representation; information; asset; manifest; component manager

**Concept:** Manifest; Component Manager

---

**Archimate Concept:** Data Object

**Definition:** Data structured for automated processing

**Rami4.0 concept map in ArchiMate:** see 4.1.3

---
4. Demonstration

This section corresponds to the demonstration step of DSRM process model.

Taking into account the description of the solution proposal in the section 3, in this section we will demonstrate the usage of the proposed solution. We will follow up the steps above presented and we will modulate the Asset, Integration and Communication, Information, Functional layers of RAMI4.0, with the concepts mapped in appendix B.

4.1. Step 2 – Modelling RAMI4.0 and I4.0 Component Model (article 38 technical requirements)

The next step is to model RAMI4.0 and I4.0 component model using ArchiMate language. In RAMI4.0 the work is based in all layers, except the business one: Functional, Information, Communication, Integration and Asset layer. Note that the Integration and Communication will work together. To model RAMI4.0 layers we will follow the architecture viewpoints defined in ArchiMate. Note that, each architecture viewpoint will only represent some concepts that are related with RAMI4.0.

<table>
<thead>
<tr>
<th>RAMI4.0’s domains</th>
<th>ArchiMate architecture viewpoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional (Enterprise) layer</td>
<td>Application Usage</td>
</tr>
<tr>
<td>Information layer</td>
<td>Information structure</td>
</tr>
<tr>
<td>Integration and Communication layer</td>
<td>Infrastructure</td>
</tr>
<tr>
<td>Asset (Field) layer</td>
<td>-</td>
</tr>
<tr>
<td>I4.0 Component Model</td>
<td>Application Usage</td>
</tr>
</tbody>
</table>

To model RAMI4.0 we propose an approach by dividing their reference architecture by the layers presented in the model, that, in essence, are nothing more than levels of abstraction of a system from different perspectives: Functional, Informational, Communication and Integration, and Asset, which will result in the construction of 4 artifacts based on the selected viewpoints in ArchiMate.
4.1.1. Asset Layer

*Concepts of ArchiMate to represent RAMI4.0’s Asset (Field) Layer*

From the description of this layer, we retrieved a general description: “describing all the physical objects and methodologies used at the factory level”. This description will match elements from the physical and technology layer of ArchiMate. To represent the asset layer, we select from the ArchiMate’s physical layer the next concepts: Equipment, Facility and Material. From the technology layer, we select: Device, System Software, Communication Network, Artifact, and Technology Service. The humans have to be represented too so we chose from ArchiMate’s Business Layer the Business Actor element.

To represent the element Asset, after a full study of ArchiMate specifications, we conclude that the best fitting option is a Data Object from the application layer (due to the general description of an asset we chose this element because it can be described as products, materials, methodologies or services translated to information processed). Other options were the element Resource (“A resource represents an asset owned or controlled by an individual or organization.”[82]) from the strategy layer of ArchiMate. Other option was the Node from the Technology layer: “A node represents a computational or physical resource that hosts, manipulates, or interacts with other computational or physical resources.” But due to the definition of physical assets (as for example linear axes, files and ideas) we chose not to use. The other best option was Business Object but the business layer will not be addressed so we stayed by the Data Object.

Once that an Asset has such a general definition, even if the asset is physical, and if it the conditions are met to be considered as an I4.0 component (i.e. have an administration shell, uniquely identifiable and I4.0 compliant communication), at some point of the process, its administration shell will create a virtual representation of the physical asset in terms of information and functionalities to use in the digital world. Because of that, independently of the nature of the asset we will consider that an asset is a Data Object, since will not be the asset accessed itself but its Digital Representation, produced by the Administration shell, for the above layers in RAMI4.0.

In this thesis we chose not to use the Strategy, Motivation or Business layer, due to what is said in section 3.1.1 (Step1. Domains addressed and concepts covered in RAMI4.0), only if there is no best option to represent a concept from RAMI4.0.

Note that in the modulation of this layer we do not use any kind of viewpoint because of the general description presented at DIN-SPEC of RAMI4.0. This layer is used to represent all the things (physical and non-physical i.e.digital) that represents value for the company, specifies the kind of assets that can exist and what is needed to an asset be presented as an I4.0 component (Requirements concepts in ArchiMate).

*Modelling RAMI4.0 Asset Layer with ArchiMate*

We start to model the Asset layer that represents reality, the asset that actually exists in the physical world and is represented virtually in the layers above it. From this model we can understand what an
organization consider as an information asset and as a physical asset, and what is needed to consider an asset as an I4.0 component.

Figure 25- Asset layer of RAMI4.0 in ArchiMate

An asset that comprises these requirements turns into an I4.0 component.
4.1.2. Integration and Communication Layer

**Concepts of ArchiMate to represent RAMI4.0’s Integration and Communication Layer**

From the description of Integration layer, we retrieved a general description: “all technological methodologies for digitally integrating assets, by providing the infrastructures that exists in order to implement a function and store the properties and process-related functions that make the asset valuable”. This description will match elements from the technology layer of ArchiMate. To represent the Integration layer of RAMI4.0, we select from the ArchiMate’s technology layer: Equipment, Technology Function, Artifact, Technology Interface, and Path.

For the Communication layer: “to describe mechanisms and protocols for the interoperable exchange of information between components, using a uniform data format, in the context of the underlying case, function or service and related objects or data models”. This description will match elements from the technology layer of ArchiMate. To represent the Communication layer of RAMI4.0, we select from the ArchiMate’s technology layer: Artifact, Communication Network, Technology Service, Technology Function, and SS.

The modulation of the Integration and Communication layer of RAMI4.0 follow the structure of Technology viewpoint of ArchiMate as we can see in Figure 26. This viewpoint “contains the software and hardware infrastructure elements supporting the application layer, such as physical devices, networks, or system software”.

![Figure 26- Technology Viewpoint](image)

Elements that have not been select from the Physical and Technology layer of ArchiMate: node, technology collaboration.
Modelling RAMI4.0 Integration and Communication Layer

For modelling the Communication layer, that describes how the access to assets’ information and functions work, and for modelling 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[13], we used the Technology viewpoint that contains the software and hardware infrastructure elements supporting the application layer[3].

Figure 27 - Integration and Communication layer of RAMI4.0 in ArchiMate
4.1.3. Information Layer

Concepts of ArchiMate to represent RAMI4.0’s Information Layer

From the description of this layer in 5.5, we retrieved a general description: “Describes the rules of how data is represented and transformed into information”. This description will match elements from the business, application and technology layer of ArchiMate. To represent the Information layer of RAMI4.0, we select from the ArchiMate’s layers: Representation, Business Object, Business Event, Application Interface, Application Service and Artifact.

The modulation of the Information layer of RAMI4.0 follow the structure of Information Structure viewpoint of ArchiMate as we can see in Figure 28. This viewpoint “shows the structure of the information used in the enterprise or in a specific business process or application, in terms of data types or (object-oriented) class structures. Furthermore, it may show how the information at the business level is represented at the application level in the form of the data structures used there, and how these are then mapped onto the underlying infrastructure;”

Figure 28- Information Structure Viewpoint

Modelling RAMI4.0 Information Layer with ArchiMate

For modelling the Information layer that describes the data that is used, generated or modified by the technical functionality of the asset[13], we used the Information Structure Viewpoint because is comparable to the information models created in the development of any information system. Apart from that show the structure of the information used in the enterprise or application in terms of data types or object-oriented class structure[3].
Regarding RAMI4.0, in this layer we are able to understand how are done the semantics of an i4.0 asset, its representation and what agreements there is in this asset. The information of an asset is provided by interface to access the respective administration shell.

The Administration Shell, provides a digital representation of the asset, structuring in categories its information: Business, Mechanics, Functionality, Location, Performance and life cycle.
4.1.4. Functional Layer

Concepts of ArchiMate to represent RAMI4.0’ Functional Layer

From the description of this layer, we retrieved a general description: “Represents functions, services, and their relationships from an architectural viewpoint”. This description will match elements from the business, application and technology layer of ArchiMate. To represent the Functional layer of RAMI4.0, we select from the ArchiMate’s layers: Business Function, Application Service, Application Component, Data Object and Artifact.

The modulation of the Functional layer of RAMI4.0 follow the structure of Application Usage viewpoint of ArchiMate as we can see in Figure 22. This viewpoint “describes how applications are used to support one or more business processes, and how they are used by other applications”.

![Application Usage Viewpoint](image_url)

**Figure 30- Application Usage Viewpoint**

With the presentation of these viewpoints, now we have the conditions to move forward to the modelling of RAMI4.0 and the respective I4.0 Component Model in ArchiMate by the several layers.

**Modelling RAMI4.0 Functional Layer**

For modelling the Functional Layer that describes the logical functions of an asset, we used the Application Usage Viewpoint because it describes how applications are used to support business processes or other applications.
Figure 31 - Functional layer of RAMI4.0 in ArchiMate

Regarding RAMI4.0 and the respective I4.0 component model, from this model we understand the structure of an administration shell and the functions of the administration shell’s components.
5. Evaluation

This section is the “Evaluation” step of the DSRM process, where we will evaluate our proposal. First we will complete the modulation of organisation’s EA, (4 layers, 4 viewpoints) that will represent the AS-IS of a DemoCorp, and then we will be able to compare them with the 4 layers of RAMI4.0 (TO-BE) presented in section 4.

In order to evaluate the mapping, in section 5.3 we will use the Wand and Weber (1993) ontological analysis method to evaluate our concept mapping.

5.1. Step 3 – Model Organization’s EA with ArchiMate

In this step it’s essential to represent the organization’s EA in ArchiMate, regarding projects under the scope of Industry4.0. This modelling tries to figure out the organization AS-IS. We chose a project that is under development and is being implemented in a DemoCorp in an area of industrial production based in Portugal.

For the execution of this step we analyse and identify the main structure and terms used in a project that tries to digitalize all the information generated from industrial production machines, in a shop-floor plant environment. This project provides a solution to obtain plant visibility and improve the efficiency of the production line. A cloud-based software 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. This is a kind of solution that all manufacturers have to adopt to face the challenge of minimizing waste, increasing throughput and reducing operational costs. Those who embrace this challenge are best positioned to improve profitability, manage resources predictably and defer capital outlay for additional equipment only until truly necessary. Fundamentally, there are two components to improving productivity; increase throughput and/or reduce downtime. This methodology supports both of these, which directly map into standard performance metrics such as Overall Equipment Effectiveness.
5.1.1. Overview of a DemoCorp’s project

The implementation methodology tries to deliver three enabling pillars of success to achieve manufacturing excellence. This process has three phases: the first one is to get connection to all production assets, involving physical wiring and mounting of equipment, resulting in the lengthiest part of the implementation. Next, phase 2 leverages the solution analytics, where the providers of the solution have to set the rules with the clients around downtimes, micro stops, slow runnings, late starts, break creep and other hidden losses. The last phase is critical to ensure plants leverage the system to drive Return of Investment (ROI). Annex A shows the overview of the solution infrastructure.
5.1.2. Model Organization’s Asset Layer

Next we present the Organization’s asset layer, where are represented the low-level concepts of the structure of the assets in a production module. The machine (asset) in question is, here, the Simultan machine and all the assets that are connected for the visualization process.

![Figure 32: Organization’s Asset Layer](image-url)
5.1.3. Model Organization’s Integration and Communication Layer

Next we present the Organization's Integration and Communication layer, where are represented the high-level concepts of the structure of the assets in the integration and communication scope in a determined production module.

![Diagram of Organization’s Integration and Communication Layer]

*Figure 33 - Organization’s Integration and Communication Layer*
5.1.4. Model Organization’s Information Layer

Next we present the Organization’s Information layer, where are represented the representation of the I4.0 component at business level with the correspondent information object and the formats of data

![Diagram of Organization’s Information Layer]

*Figure 34—Organization’s Information Layer*
5.1.5. Model Organization’s Functional Layer

Next we present the Organization’s Functional layer, where are represented the concepts that structure the Solution. Which services it offers and how they are connected with the organization.

![Figure 35 - Organization’s Functional Layer](image)

5.2. Step 4 – Gap Analysis

The two first Steps are intended to design EA by layers of a project under scope of Industry4.0, regarding RAMI4.0 and the respective I4.0 component model, which will work as our TO-BE.

In Step three, the organization’s EA should be designed according to how the organization is working with the solution presented at section 5.1, in four layers: Asset, Integration and Communication, Information and Functional, which will work as our AS-IS.

This Step aims to analyse the gaps and major differences between the AS-IS and the desired TO-BE structure of the solution, and terminology used in the architectures.
For this end, we present the Migration Viewpoint that entails models that can be used for specifying the transition from an existing architecture to a desired architecture, as presented in the next figure.

Using this template, we can identify the gaps between RAMI4.0 and EA organization (baseline architecture). In addition, this viewpoint allows the organization to discuss the gaps detected, so they can adopt I4.0 projects correctly. For that, it’s necessary to make strategic decisions, which may be different for each organization. Some gaps may not be fixed, as the organization could decide that only some issues should be treated. Some gaps can be maintained as explained. By applying this template, we get differences between EA DemoCorp and the RAMI4.0 at the asset layer, integration and communication layer, information layer and functional layer.

Through the analysis done in the previous section we can now compare those structures and terms with the ones presented by RAMI4.0.
5.2.1. Analysis of the gaps found

Gaps at Asset Layer

The main difference between these two architectures is that each model considers an asset and an i4.0 component.

In the Asset layer, we will not worry about the structure of the asset layer viewpoint, because we are not based on any viewpoint defined by ArchiMate to model or the RAMI asset layer. In this asset layer view, the main modelling issue lies in the distinction between assets and an I4.0 component (Requirements elements and an Administration Shell). The second issue concerns RAMI4.0 specifications - there is a clear distinction between physical and digital assets. These are the two points that the asset layer viewpoint intends to play.

On the DemoCorp Asset Layer side, we present a lower level structure, a simultaneous machine process. In the specifications of this project there is no reference to an i4.0 asset or component definition, so let's consider the RAMI4.0 definitions to compare these two AEs.

In this case, an asset can be: Equipment, Material, and Communication Network. According to the requirements for an asset to become an i4.0 Component or single asset that comes close to this definition.

PLC, ADAM sensors / materials and hardware virtualization (OPC), are the only assets that, although they are a connection to the digital world via LAN, are identifiable only in the system, but have no mention of the concept of Administration Shell or anything like that, so cannot be considered i4.0 components.

Gaps at Communication and Integration Layer

This layer is the one with the least differences. The RAMI4.0 framework follows a service-oriented architecture, always with the clear idea that the Administration Shell is about providing all the information needed to make an operation and virtualization service.

On DemoCorp’s AE side, apart from the Administration Shell, the structure seems to be very similar, where there is a device and ss for each machine (RAMI4.0 side sensors and actuators), and its internet connection (in RAMI4.0 is made by i4.0 Component). There is a security gap here, in our RAMI4.0 modulation we didn’t cover the security part (adding a section that says i4.0 compliant access already ensures that each asset is only reached by intended user for example).

Gaps at Information Layer

There will be quite a few differences here, as RAMI4.0 is very strict about semantics and information access in the Shell administration. As for the type of information presented, the Administration Shell presents the most varied types of information. We chose to present some of the main categories of domains (general business conditions, mechanics, functionality, place, capability, life-cycle).
On DemoCorp’s EA side, the solution presents its data format, and in relation to the type of information only presents 6 types of information that will be present in 3 (capability, mechanics and functionality) of the categories presented in RAMI4.0.

**Gaps at Functional Layer**

For the Gap analysis at this level, we conclude that the structure of EA’ organization at this layer complies with the architecture and principles of RAMI 4.0.

Even they don’t follow the exact architecture’ approach, the Organization’ EA follow the classic approach of ISA-95 (section 2.3.2), the principles inherent in both architectures are the same, where both follows a Service-Oriented Architecture.

### 5.3. Using Ontological Analysis

According to [82] historically there are three areas mainly responsible for creating a demand for the application of ontologies in computer science, namely, database and information systems, software engineering (in particular, domain engineering), and artificial intelligence.

In Information Systems (IS) for example, ontology is considered as a kind of agreement on a domain representation. Thus, an engineering view of ontology is taken in IS, where is defined: “ontology is an explicit account or representation of a conceptualization” [83]. This conceptualization includes a set of concepts, their definitions and their inter-relationships. Preferably this conceptualization is shared or agreed.

In this research we will consider the IS ontology approach and use the ontological analysis in the field of Enterprise Architecture as some other researchers that used the same methodology in the analysis of their works by studying the ArchiMate ontology as in [18][84][85][86][87][88][16][89].

In [90][91][92], a framework is defined for evaluating expressiveness and clarity of modelling grammars, i.e., with the focus on the system of representations as a whole, in the sense that there is a need for identification of shortcomings of the current ontological analysis process.
5.3.1. Wand and Weber Method

To evaluate concept mappings from RAMI4.0 to ArchiMate [88][24], we will perform an analysis according to two criteria: completeness and clarity. This method is called BWW[89] analysis is based on the Wand and Weber ontological evaluation of grammars method, where we compare two sets of concepts to identify four ontological deficiencies:

- **Incompleteness**: can each element from the first set be mapped on an element from the second?
  - The mapping is incomplete if it is not total.
- **Redundancy**: are the first set elements mapped to more than a second set element?
  - The mapping is redundant if it is ambiguous.
- **Excess**: is every first set element mapped on a second set one?
  - The mapping is excessive if there are first set elements without a relationship.
- **Overload**: is every first set element mapped to exactly one second set element?
  - The mapping is overloaded if any second set element has more than one mapping to a first set one.

**Overload and Redundancy**

The number of concepts in RAMI4.0 that have no representation in ArchiMate defines the lack of completeness, clarity is a combination of redundancy, overload and excess of concepts. Lack of completeness can be a serious issue while lack of clarity can make the mapping unidirectional and hard to reverse.
In the next table we can see that in some cases there is relation of 4:1 (Overload), [90] “construct overload occurs when a single grammatical construct can stand for two or more ontological constructs, the grammatical construct is overloaded because it is being used to do more than one job”, between RAMI4.0 concepts and ArchiMate. With this we can conclude that the ArchiMate is a high-level notation, that is usefull to model any kind of architecture, but for the correct mapping between these two frameworks is needed a new layer or new specifications for elements to model correctly the RAMI4.0: “Construct overload is considered an undesirable property of a modelling language since it causes ambiguity and, hence, undermines clarity. When a construct overload exists, users have to bring additional knowledge not contained in the specification to understand the phenomena which are being represented”

<table>
<thead>
<tr>
<th>RAMI4.0 (I4.0 Component Model or layers)</th>
<th>ArchiMate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset (I4.0CP, asset)</td>
<td>Data Object</td>
</tr>
<tr>
<td>Representation of the Asset (I4.0CP, asset)</td>
<td></td>
</tr>
<tr>
<td>Component Manager (functional)</td>
<td></td>
</tr>
<tr>
<td>Manifest (functional)</td>
<td></td>
</tr>
<tr>
<td>I4.0 Component (I4.0CP, functional)</td>
<td></td>
</tr>
<tr>
<td>Administration Shell (I4.0CP, functional)</td>
<td>Application Component</td>
</tr>
<tr>
<td>Virtualization service (functional)</td>
<td></td>
</tr>
<tr>
<td>Acess I4.0 asset (functional)</td>
<td></td>
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<tr>
<td>I4.0 asset information (functional)</td>
<td></td>
</tr>
<tr>
<td>I4.0 compliant s-o API (functional)</td>
<td></td>
</tr>
<tr>
<td>I4.0 compliant semantics (Information)</td>
<td></td>
</tr>
<tr>
<td>I4.0 compliant acess (Integration)</td>
<td></td>
</tr>
</tbody>
</table>

_**Excess and Incompleteness**_

For the Representation of the rest of the mapping we did not find any problem. The most cases forma a relation 1:1.

The main incompleteness issue that we have found was when trying to modulate the assets from the physical world.
By choosing a data object to represent an asset in the physical and information world, we have come to the conclusion that a data object from ArchiMate is not the best option to modulate assets from the physical world.

In the specifications of ArchiMate the no representation of the Technology object (absence of notation), limited our options in finding the best way to structure the development of the mapping and the viewpoints.

Note that to model the element Asset of RAMI4.0, we generalize and adapt the concept of Data Object of ArchiMate, through a Representation of the Asset (another Data Object), to represent every kind of assets. In the modulation of the Asset layer, this concept is composed by other elements, as seen in section 4.1.1. If we analyse literally both specifications, we will see a link of Asset (RAMI4.0) to many other concepts of ArchiMate. So, the link Asset to Data object isn’t complete, thus there is a redundancy because there is ambiguity in the best elements of ArchiMate to model the element Asset present in RAMI4.0.
6. Conclusion

6.1. Contributions

The major contribution is the mapping of ArchiMate for Organizations that want to adopt projects under the scope of Industry4.0, provides guidance in the decision making of what is the best for the company, through easing the many links between the different areas of the organization.

ArchiMate mapping with a reference architecture is currently implemented by the German government.

From the solution proposed in section 1.3, we address all the points, providing all the viewpoints, representations, terminology and gaps that we set out at the beginning of the work except the objective: “Identify which RAMI4.0’s concepts are being misrepresented by ArchiMate”. We not fully address this point because this objective because is impossible to do it, due to the single (author) observation and analysis of just on point-of-view.

6.2. Limitations
6.2.1. RAMI4.0

From the reference Architecture chosen, we are not dealing with Business Layer;

In the construction of the RAMI4.0’s viewpoints we assume that the relationships presented in the ArchiMate viewpoints are the same as those presented between RAMI4.0 elements and their I4.0 Component Model, due to time restrictions. So we don’t study the relations between relationships in ArchiMate and RAMI4.0.

One of the great gaps in the RAMI4.0 analysis, was that we haven’t deepened the adjacent properties of the Administration Shell: encapsulation and aggregation.
6.2.2. ArchiMate

From the notation chosen for modelling, we just tried to focus on the following layers: Physical, Technology and Application.

The no-representation of the Technology object (absence of notation) in the specifications of ArchiMate 3.0.1, limited our options to model elements like physical asset elements.
6.2.3. Mapping

In the making of the solution proposal, to link the elements of RAMI 4.0 with those of ArchiMate, we use a semantic analysis process (definitions and descriptions presented at both of the specifications) so the result may differ depending on the intuition and experience of the person who is reading the thesis covered fields.

6.3. Future work

Regarding RAMI4.0 we only focus on the Asset, Integration, Communication, Information and Functional layers. For future work we propose an analysis of the Business layer.

In the construction of RAMI4.0 viewpoints, we assume that the relationships presented in the ArchiMate viewpoints are the same as between RAMI4.0 elements and the mapped I4.0 Component Model as, due to time and length reasons, one of the great gaps in the RAMI4.0 analysis was that we have not dived into the properties adjacent to administration: encapsulation and aggregation of administration shells. Properties that translated to ArchiMate, would make us use elements like Node, Path and Technology Collaboration for example.

The toolbox of RAMI4.0, will be a good way to approve or decline our solution, but due to the late finding of the [28] article we were not able to use it on the execution of this thesis. Note that the meta model was useful to make decisions in the construction of the Layers or viewpoints in ArchiMate.

In this modulation language or notation (ArchiMate), we focus on the lowest layers too: Physical, Technology and Application. For future work we can try modulating the highest levels with RAMI4.0 for future validation.
7. References


[34] A. Ustundag and E. Cevikcan, Industry 4.0: Managing The Digital Transformation.


T. R. Gruber, “Towards principles for the design of ontologies used for knowledge sharing?”


“Industrie 4.0 BMWi.” [Online]. Available: https://www.bmw.de/Redaktion/EN/Dossier/industrie-
40.html.


[88] M. Alexandre and D. C. Vilela, “Enterprise Architecture and ITIL Information Systems and

8. Anexos

8.1. A- Solutions’s Overview Viewpoint
### 8.2. Concepts Mapped

<table>
<thead>
<tr>
<th>RAMI4.0 concept</th>
<th>ArchiMate notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field (Asset Layer)</td>
<td>Asset&lt;br&gt;Data object</td>
</tr>
<tr>
<td>PC</td>
<td>Device</td>
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<tr>
<td>Materials</td>
<td>Material</td>
</tr>
<tr>
<td>Sensors</td>
<td>Equipment</td>
</tr>
<tr>
<td>Facility</td>
<td>Facility</td>
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<tr>
<td>Network</td>
<td>Communication Network</td>
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<tr>
<td>Information</td>
<td>Artifact</td>
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<tr>
<td>Software</td>
<td>System software</td>
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<tr>
<td>Service</td>
<td>Technology service</td>
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<tr>
<td>Humans</td>
<td>Business actor</td>
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<tr>
<td>Field (Integration and Communication Layer)</td>
<td>Virtualization&lt;br&gt;Technology function</td>
</tr>
<tr>
<td></td>
<td>Network&lt;br&gt;Communication Network</td>
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<tr>
<td></td>
<td>HMI&lt;br&gt;Technology interface&lt;br&gt;Path</td>
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<tr>
<td>Component</td>
<td>Diagram</td>
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<tr>
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<tr>
<td>Virtualization Service</td>
<td><img src="image" alt="Technology service" /></td>
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<tr>
<td>Industry 4.0 compliant access</td>
<td><img src="image" alt="Artifact" /></td>
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<td>Information (Information Layer) SLA</td>
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<tr>
<td>Information (Information Layer) Data format</td>
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<tr>
<td>Information (Information Layer) I4.0 compliant semantics</td>
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<td>Business/Function layer Virtualization Service</td>
<td><img src="image" alt="Application service" /></td>
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<tr>
<td>I4.0 asset information</td>
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<tr>
<td>I4.0 asset information-oriented API</td>
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<td>I4.0 compliant semantics</td>
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<tr>
<td>Manifest</td>
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