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UNIVERSIDADE Ð COIMBRA

Ana Carolina Ribeiro Bandeira

Towards a Sectoral Enterprise Architecture Framework

SEAF

Dissertation in the context of the Master in Informatics Engineering, specialization in Information Systems, advised by Professor João Barata and presented to the Department of Informatics Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

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Introdução da Framework de Arquitectura Empresarial Sectorial
SEAF

Dissertação no âmbito do Mestrado em Engenharia Informática, especialização em Sistemas de Informação, orientada pelo Professor João Barata e apresentada ao Departamento de Engenharia Informática da Faculdade de Ciências e Tecnologia da Universidade de Coimbra.

Julho 2023

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This master's thesis is dedicated to my dear grandparents, Maria and João. Your resilience, hard work, and perseverance inspire me beyond words. You brighten me up every day.

Abstract

Digital Transformation (DT) combines digital technologies with solid business strategies to generate value for organizations. Due to the quick and market-driven industrial development under Industry 4.0 (I4.0), DT studies are multiplying and covering several aspects, such as product design, engineering, production, and life-cycle management. Enterprise Architecture (EA) can assist companies in their DT efforts by outlining a strategic plan with business opportunities associated with emerging technologies. Since each sector of the industry requires a tailored EA approach, a solid knowledge of the sector and its segments is essential. Therefore, it is necessary to study the sector, mostly to identify the right technology and assess the impact of changes.

The present work follows the Design Science Research (DSR) methodology and addresses the initial proposal of a framework to create a sectoral EA for industry contexts. The Sectoral Enterprise Architecture Framework (SEAF) may be helpful to provide a high-level analysis of the potential of data and digital technologies across segments of sector-specific supply chains. The SEAF development process was carried out in collaboration with Air Conditioning and Refrigeration Sector (ACRS) association, interested in exploring the potential of I4.0 for their sector and modeling the opportunities of DT. In the course of the current work, several known Enterprise Architecture Framework (EAF) were analyzed and some tools have been studied to implement this concept.

Therefore, EA models were created using ArchiMate modeling language to illustrate SEAF viewpoints. As a result, the present work includes (1) the details of SEAF models, (2) the roadmap to guide the practitioners, and (3) the applicability of the models created in the industry sector, selected for this work.

In conclusion, by identifying essential features of EAF (e.g., multiple layers, a sequence of steps to guide the enterprise architects in their work) and due to the lack of sector-specific frameworks, which are more suitable for industry associations, SEAF may offer a complementary assessment of the digital opportunities emerging from cross-company interactions in particular industry sectors.

Keywords

Enterprise Architecture; Industry 4.0; Supply Chain; Digital Transformation; Sustainability; Data Integration

Resumo

A Transformação Digital combina tecnologias digitais com estratégias de negócio sólidas para gerar valor para as organizações. Devido ao desenvolvimento industrial rápido e orientado para o mercado no âmbito da Indústria 4.0, os estudos sobre Transformação Digital estão a multiplicar-se e a abranger vários aspectos, como por exemplo a concepção de produtos, a engenharia, a produção e a gestão do ciclo de vida. A Arquitetura Empresarial pode ajudar os negócios nos caminho da Transformação Digital, delineando um plano estratégico com oportunidades de negócio associadas às tecnologias emergentes. Uma vez que cada sector da indústria requer uma abordagem de Arquitetura Empresarial adaptada, é essencial um conhecimento sólido do sector e dos seus segmentos. Assim, é necessário estudar o mesmo, sobretudo para identificar a tecnologia certa e avaliar o impacto das mudanças inerentes.

O trabalho desenvolvido segue a metodologia DSR e aborda a proposta inicial de uma framework para criar a Arquitetura Empresarial sectorial para contextos industriais. O SEAF pode ser útil para fornecer uma análise de alto nível sobre o potencial dos dados e das tecnologias digitais nos segmentos das cadeias de abastecimento industriais. O processo de desenvolvimento do SEAF foi realizado em colaboração com a associação ACRS, interessada em explorar o potencial da Indústria 4.0 para o seu sector e modelar as oportunidades de Arquitetura Empresarial. No decorrer trabalho, foram analisados várias frameworks de Arquitetura Empresarial, assim como algumas ferramentas para implementar este conceito.

Neste sentido, foram criados modelos de Arquitetura Empresarial utilizando a linguagem de modelação ArchiMate para ilustrar os viewpoints do SEAF. Como resultado, o trabalho inclui (1) o detalhe dos modelos SEAF, (2) o guia para orientar os praticantes, e (3) a aplicabilidade dos modelos criados no sector industrial, selecionado para este trabalho.

Em suma, ao identificar as características essenciais de uma frameworks de Arquitetura Empresarial (por exemplo, as várias camadas e uma sequência de etapas para orientar os arquitectos empresariais no seu trabalho) e devido à lacuna de frameworks sectoriais específicas, que são mais indicadas para associações industriais, o SEAF pode oferecer uma orientação complementar das oportunidades digitais que emergem das interacções entre os negócios em determinados sectores industriais.

Palavras-Chave

Arquitectura Empresarial; Indústria 4.0; Cadeia de Abastecimento; Transformação Digital; Sustentabilidade; Integração de Dados

Contents

Acronyms

ACRS Air Conditioning and Refrigeration Sector.

ADM Architecture Development Method.

AI Artificial Intelligence.

APIRAC Associação Portuguesa da Indústria da Refrigeração e Ar Condicionado.

DODAF Department of Defense Architecture Framework.

DSR Design Science Research.

DT Digital Transformation.

EA Enterprise Architecture.

EAF Enterprise Architecture Framework.

EFRIARC Associação Portuguesa dos Engenheiros de Frio Industrial e Ar Condicionado.

EIRA European Interoperability Reference Architecture.

FEAF Federal Enterprise Architecture Framework.

GEA General Enterprise Architecting.

HVAC Heating, Ventilation, and Air Conditioning.

I4.0 Industry 4.0.

IoT Internet of Things.

IT Information Technology.

PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

RAMI 4.0 Reference Architectural Model Industrie 4.0.

SEAF Sectoral Enterprise Architecture Framework.

TOGAF The Open Group Architecture Framework.

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Chapter 1

Introduction

This document presents the work associated with the Master's Degree in Informatics Engineering, with specialization in Information Systems, of the Faculty of Sciences and Technology from the University of Coimbra, during the academic year of 2022/2023. This dissertation takes place in the Centre for Informatics and Systems of the University of Coimbra (CISUC), Department of Informatics Engineering (DEI) of the University of Coimbra.

The chapter structure is as follows. Section 1.1 explains the context of this study. Next, Section 1.2 introduces the motivation. Section 1.3 summarizes the objectives and the threshold of success of this dissertation, and Section 1.4 outlines the document structure.

1.1 Context

Digital Transformation (DT) in the I4.0 requires a robust and interconnected infrastructure that integrates different technologies and approaches, like the Internet of Things, Robotics, Artificial Intelligence, or Advanced Data Analytics, to serve and operate the increasingly complex supply chain [1]. Remarkably, the I4.0 movement is not restricted to the boundaries of each organization, requiring a comprehensive view of the product lifecycle since the early stages of raw material processing [2]. Moreover, sustainability within the manufacturing supply chain is now a priority for management worldwide [3].

Simultaneously, Enterprise Architecture (EA) is essential to understand multiple interrelated layers of modern organizations, including both business and Information Technology (IT) elements. There are prominent Enterprise Architecture Framework (EAF) available for companies to align their businesses with IT. Examples include the well-known TOGAF® Standard [4] created by the Open Group for corporate EA projects, the Zachman framework [5], the governmental proposal like the FEAF [6], and more boundary-spanning approaches, like the DODAF [7]. Although the existence of several EAF's, the existing approaches do not fulfill the current needs of industry sectors.

Therefore, the present work aims in developing the SEAF to address the common EA interests in product offerings throughout the supply chain of company segments [2]. Thus, it is being developed in collaboration with the APIRAC, which represents over 500 companies operating in the ACRS. APIRAC's main responsibility is to defend and safeguard its associates' interests, including the entire supply chain of ACRS products in Portugal. They were preparing a study about the I4.0 potential for their sector and needed a guide on how to identify digital opportunities. The task was challenging because their associates include manufacturers, distributors, installers, certification entities, and technical management in buildings, each with their own agenda but needing to cooperate in different product phases (e.g., development, use, or recycling).

1.2 Motivation

Each sector has its business scope, competencies, processes, services, and infrastructure and all need to target the mission with the right IT operations for their business strategy. Aligning the IT strategy with the business potentiates the technology transformation of the organizations, achieves a better business management, and serves the needs of the stakeholders [8]. In this sphere of action, EA is a discipline that attempts to capture the business and technology logic using models, accessible to different organizational experts [9]. Through EA models, enterprises can understand the "as-is" situation and establish a vision for the "to-be" architecture that will develop the business, increasingly supported by information technologies [10]. The benefits are becoming more visible, e.g., in Smart Manufacturing Systems, by updating the business models, and assisting companies in keeping up with innovative technology [11].

Although multiple EAFs have been proposed to guide the alignment of business and IT, the existing approaches do not yet support how to represent (as-is) and guide (to-be) the DT of an entire industry sector. Regarding the conducted literature review, the findings confirmed the problem identification and motivation, by showing a lack of modeled EAFs to represent the role of digital technologies in a sector-wide supply chain.

1.3 Objectives

The present study concluded that the reviewed EAF were not created to focus on the industrial context and address the entire supply chain. Although there are some EAFs for the industrial context, none serve the purpose that SEAF comes to fill. Therefore, the following research objective was formulated: *propose an EAF to integrate the supply chain segments of an industrial sector, adopting I4.0*.

Thus, the proposed solution is aiming at the ongoing DT in industry, for the ACRS. Due to its popularity and openness, ArchiMate notation mapped with TOGAF ADM [4], provided the initial inspirations for methodology and language, respectively. Moreover, the collaboration with business associations, such as APIRAC, provided insights for the initial proposal of SEAF, which focuses on the supply chain segments, processes, products, drivers, and goals that ACRS represents. Therefore, SEAF will model the different segments of the ACRS supply chain (e.g., distribution, installation, maintenance), its products (e.g., air conditioning), and its drivers and goals (e.g., sustainability). This dissertation has the following goals:

- Design and develop the SEAF structure and the definition of relevant viewpoints modeled in ArchiMate, necessary to represent and guide an industrial sector-specific supply chain.
- Demonstrate and evaluate the SEAF metamodels, for ACRS, with the collaboration of APIRAC.

Therefore, SEAF's purpose is to guide industrial sectors in DT by adopting I4.0 and aligning them with the needs of the supply chain segments and the priorities of the entire sector. Some conditions must be achieved to reach the Threshold of Success. The following steps must be accomplished:

- SEAF should be developed and evaluated by APIRAC.
- Develop a technical report that may be published by APIRAC on their website, explaining the potential of new technologies in different segments of ACRS, guided by SEAF models.

1.4 Document Structure

The remainder of this document is presented as follows. Chapter 2 includes the semesters' planning, the Design Science Research [12] approach selected for developing SEAF, and Risk Analysis. Chapter 3 explains the State-of-the-Art foundations of EA frameworks, languages, and tools that guided the theoretical lenses for the design of SEAF. Chapter 3 ends with the Systematic Literature Review. Chapter 4 presents the design and development of the proposed framework. Chapter 5 demonstrates SEAF with the selected sectoral association and presents the corresponding evaluation. The dissertation closes in Chapter 6, including the work communication, limitations, and future work opportunities.

- **Chapter 2 – Planning:** This chapter describes the dissertation's temporal planning. It also discusses the methodology selected to propose an enterprise architecture framework to guide digital transformation in industrial sectors. This work's risk management plan follows in this chapter's final section.

- **Chapter 3 – State of the Art:** This chapter reviews key aspects of Industry 4.0, Enterprise Architecture, ArchiMate, and Digital Transformation. The systematic literature review undertaken is also presented at the end of this chapter.

- **Chapter 4 – Proposal:** This chapter describes the problem that the present work intends to address and describes the design and development process undertaken.

- **Chapter 5 – Demonstration and Evaluation:** This chapter's purpose is to instantiate SEAF in a real scenario by providing proof of its efficiency and suitability in addressing the research questions. Furthermore, evaluates the contributions made by the research, discusses how the study addresses the research gap noted in the State of the Art, analyzes the significance and distinctiveness of the findings, and suggests how the study might impact the field.

- **Chapter 6 – Conclusion, Limitations, and Future work:** This chapter underlines the work contributions, and limitations, and makes some pointers for future work.

Chapter 2

Planning

This chapter presents the strategy selected to conduct the proposed work. First, describes the tasks' schedule in the First Period in Section 2.1 and Second Period in Section 2.2. Then, it clarifies the Methodology selected for the study in Section 2.3. Ends with the Risk Analysis of what may compromise the study in Section 2.4.

2.1 First Period

The present work is organized in two periods. The First Period consists, essentially, of the State of the Art, which involved the research and analysis of Enterprise Architecture (EA), the in-depth study of the concept of Enterprise Architecture Framework (EAF) and its foundations, to integrate the needs of today's society and to respond to the Digital Transformation (DT), for the industrial sector. Thus, during this period, were conducted the Design Science Research (DSR) steps (1) *"Identify Problem & Motivate"*, (2) *"Define Objectives of a Solution"* and the beginning of (3) *"Design & Development"* [12]. Figure 2.1 presents the Gantt chart for the First Period.

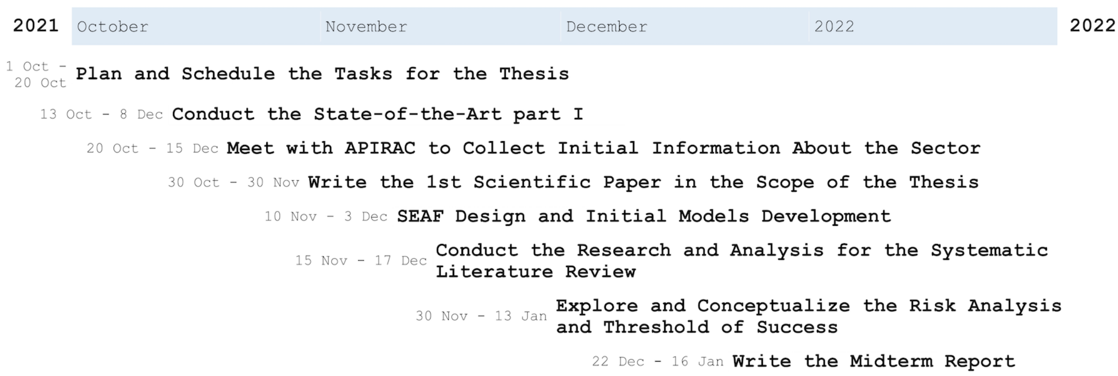


Figure 2.1: Original Schedule of the First Period

For the present work, weekly meetings were held to receive guidance and to consolidate the work done. In every meeting, it would be discussed the last task done, any doubts that might have happened, and the next task that needed to be accomplished was planned. The last task of the First Period, *"Write the Midterm Report"*, concluded in the presentation of it.

2.2 Second Period

The Second Period consists of the development, demonstration, and evaluation stages of SEAF. During this phase, it was possible to complete the DSR steps of (3) *"Design & Development"* of the artifact, to perform the steps (4) *"Demonstration"* and (5) *"Evaluation"*, [12] by applying the case study with Air Conditioning and Refrigeration Sector (ACRS), and the collaboration of Associação Portuguesa da Indústria da Refrigeração e Ar Condicionado (APIRAC). The final DSR step (6) *"Communication"* included the dissertation and two scientific papers reporting the early studies conducted with APIRAC and the first version of the Sectoral Enterprise Architecture Framework (SEAF), respectively. The following Figure 2.2 represents the Gantt schedule for the Second Period.

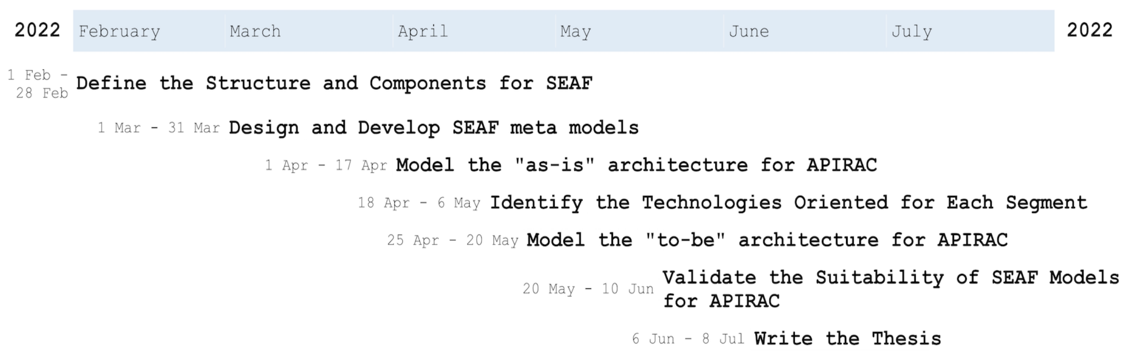


Figure 2.2: Original Schedule of the Second Period

In the Second Period, the plan was to start defining the structure, the components, and to design and develop meta-models for SEAF. After this initial step, the modeling of the "as-is" architecture for APIRAC would start, followed by the "to-be" architecture. These tasks were planned to occupy three months. Succeeding the end of the demonstration, the evaluation was completed. Finally, the rest of the time would be dedicated to the elaboration of the final report. In addition, there are risks that could prevent the plan from being carried out. To prevent this, a Risk Assessment was carried out, which is detailed in Section 2.4.

2.3 Methodology

DSR was the methodology chosen for the present study. It is a rigorous problem-solving method to develop and design innovative artifacts, contribute to research, evaluate, and communicate. These artifacts may include models, methods, and instantiations according to the identified problem and the situation's context [12]. The artifact is at the core of DSR since the research aims to structure the work methodology and lead to the artifact's production. The solution that the artifact will promote should be relevant to the business problem, and its utility, quality, and efficiency must be evaluated [12] [13]. An iterative DSR process is suggested by Peffers, Tuunanen, Rothenberger, and Chatterjee [12]. This methodology involves six essential activities and is executed in the following order: (1) *"Problem Identification and Motivation"*, (2) *"Define the objectives for a solution"*, (3) *"Design and Development"*, (4) *"Demonstration"*, (5) *"Evaluation"*, and (6) *"Communication"* [12]. Moreover, as Figure 2.3 shows, the research process considers multiple cycles to sharpen the artifact, repeating some steps if necessary.

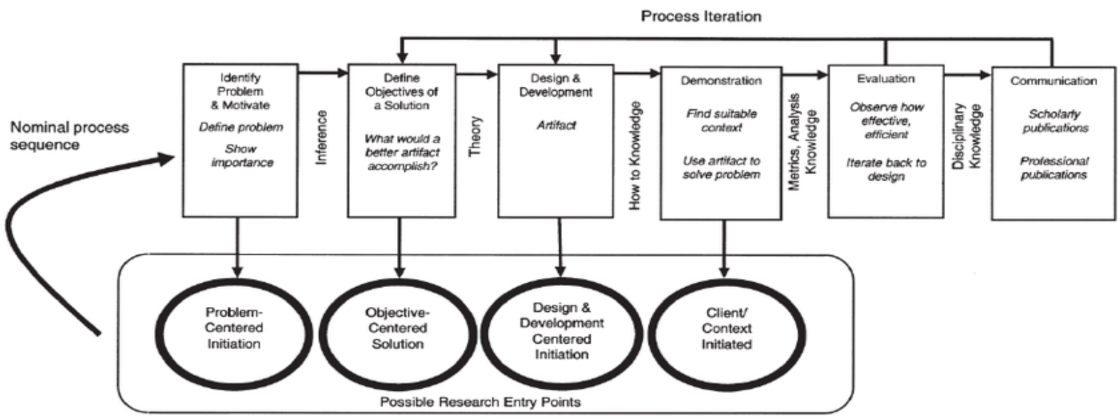


Figure 2.3: Design Science Research Methodology Process Model [12]

Contacts with APIRAC experts and the literature review findings confirmed the problem identification and motivation (first step on the left of Figure 2.3). The *"Problem - Centered Initiation"* [12], started with a systematic literature review with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [14] to answer the following question: *"What has been done regarding the digital transition in the domain of Enterprise Architecture, within the supply chain?"*. The research showed a lack of modeled EAF frameworks to represent the role of digital technologies in a sector-wide supply chain. The methodology process and outcome analysis of PRISMA is explained in Section 3.6. In parallel, some meetings were conducted with the experts of APIRAC to understand the characteristics of their sector and the particularities of each segment to understand opportunities for DT.

Afterward, the objectives for the solution (step 2), with the proposal of SEAF, were defined. The design and development outputs were (1) SEAF structure and (2) the definition of relevant viewpoints modeled in ArchiMate, necessary to completely represent and guide a sector-specific supply chain of industrial products. The demonstration used real data from APIRAC, subsequently evaluated with the case setting.

2.4 Risk analysis

This section evaluates the internal and external factors that could threaten the work's success. Towards a qualitative risk assessment, the following Table 2.1 follows a Probability/Impact method analysis [15], used to rate Probability (P) and impact (I) of risks. For the present work, the analysis uses a 1 to 3 scale, where the Risk Score (RS) equals the probability multiplied by the impact.

In terms of Probability	In terms of Impact
i. Hight - three points ii. Medium - two points iii. Low - one point	i. Critical - three points ii. Moderate - two points iii. Low - one point

Table 2.1: Probability/Impact Risk Assessment

Table 2.2 presents the Risk Scenarios, as part of the risk management process of the present work [16]. This scenario helps in identifying how, where, and why adverse events can occur. So, associated with each risk exists a Mitigation Strategy and the Risk Score analysis, from the Probability/Impact Risk Assessment.

Risk Identification	Risk Mitigation Strategy	P	I	RS
Delays from entities' collaboration	Establish efficient communication channels and assure that a delay takes no more than four days.	3	2	6
Losing focus of the Methodology	Periodic reviews of the state of the SEAF and research must be followed, to assure equivalence with domains of I4.0, Enterprise Architecture, and Digital Transformation.	1	3	3
Doubts on technology identification	Define the requirements for each segment of the ACRS to do a most assertive identification of technology.	2	3	6
Balancing the thesis with professional work	Define sprints and periodic goals to comply with the expected timetable.	2	3	6
Project complexity	Deepen the knowledge of existing architectures and frameworks and contact APIRAC to understand fundamental concepts.	2	2	4

Table 2.2: Risk Scenarios & Mitigation Strategy

Although the work was completed, the planning suffered some adjustments since the initially identified risk, ***"Balancing the thesis with professional work"*** became real. Therefore, Figure 2.4 shows the real schedule of the First Period.

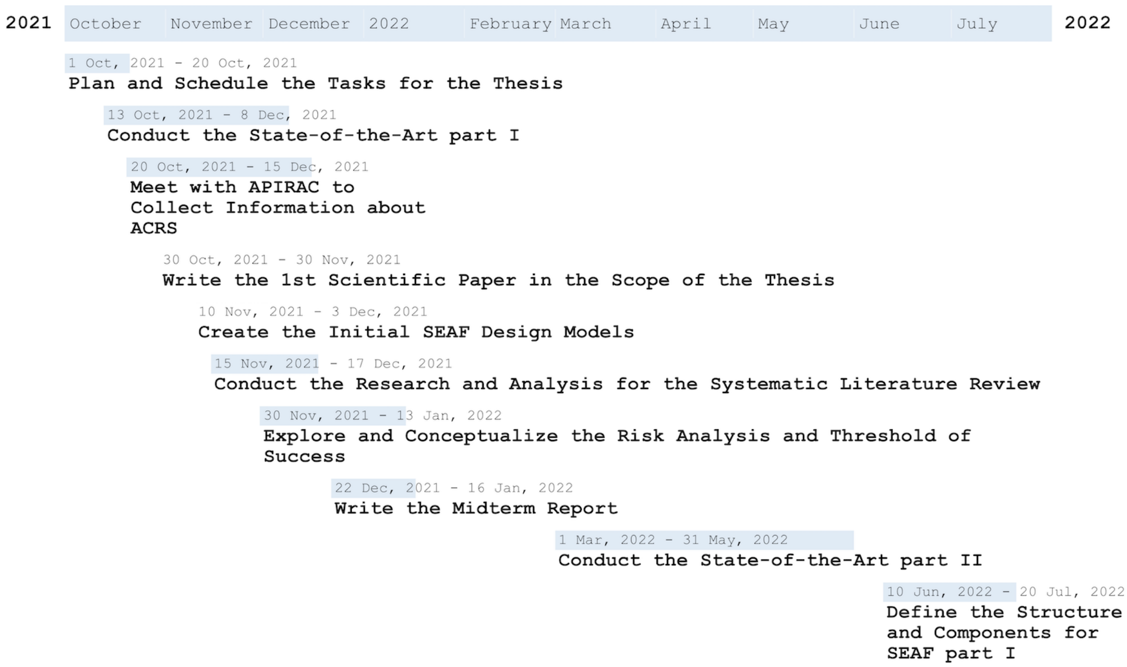


Figure 2.4: Real Schedule of the First Period

The risk mentioned earlier started at the beginning of January 2022. Thus, the two following tasks *"Conduct the State-of-the-Art part II"* and *"Define the Structure and Components for SEAF part I"* were conducted in part-time, i.e. at the end of the days and at the weekends of that period. Although the efforts, the impact of the risk affected the whole planning for the Second Period. The following Figure 2.5 shows the real schedule.

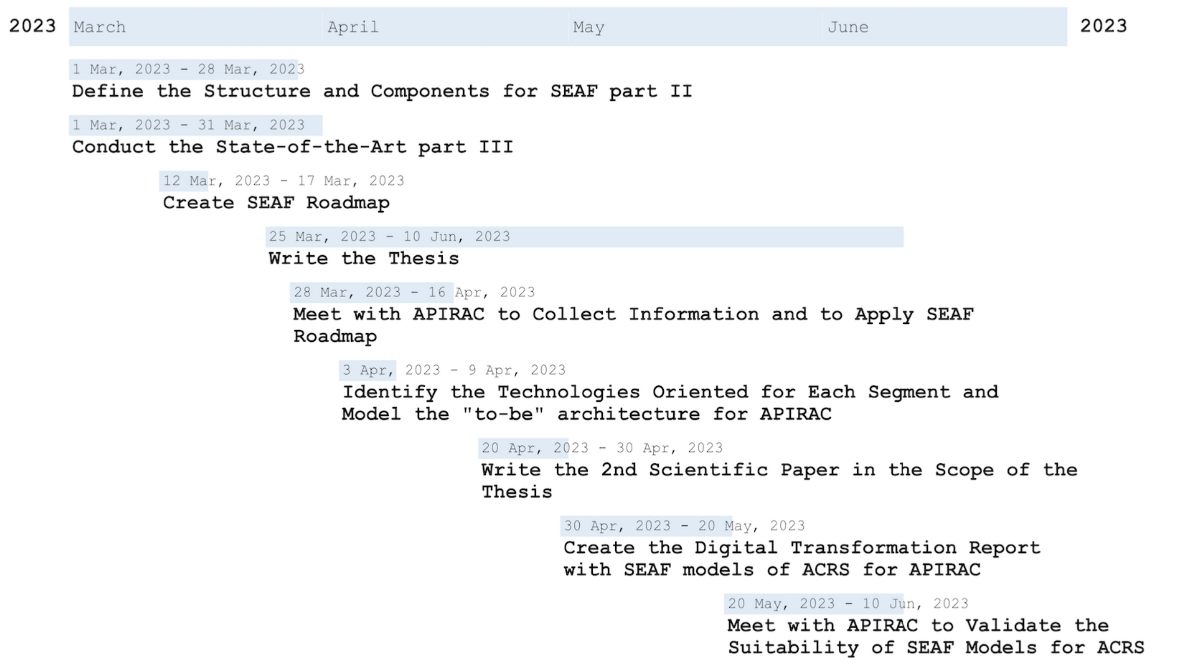


Figure 2.5: Real Schedule of the Second Period

Once the risk *"**Balancing the thesis with professional work**"* became real, it changed the entire planning for the Second Period and compromised the delivery of the work on time. To minimize the severity of the impact, the aforementioned risk was annulled for two months, enabling the thesis work to be developed full-time, during those months. The previous Figure 2.5 represents the rescheduled work, where all the tasks were conducted full-time, except the last one that was done part-time. In conclusion, despite the collateral damage of delaying the delivery of the work, the tasks were accomplished in a similar sequence to the one initially planned. Moreover, the delay allowed to consolidate the analysis for the development of SEAF and to write a second scientific paper. The next chapter covers the State-of-the-Art.

Chapter 3

State of the Art and Background Review

This chapter presents some fundamental concepts about Enterprise Architecture (EA) in Section 3.1 and a review of relevant EA frameworks in Section 3.2. Follows the Section 3.3 about Modelling Language, namely ArchiMate, Section 3.4 about Industry 4.0 (I4.0) and Section 3.5 about Digital Transformation (DT). This chapter ends with Section 3.6 which describes the Systematic Literature Review conducted with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [14] and the outcome analysis.

3.1 Enterprise Architecture

This section approaches EA and is divided into three subsections. It initiates with subsection 3.1.1 by defining EA, followed by subsection 3.1.2 addressing Enterprise Architecture Framework (EAF) and ends with subsection 3.1.3 covering the notion of View and Viewpoint in EA.

3.1.1 Defining Enterprise Architecture

EA can be defined as "a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure" [17]. EA aims at the activity of aligning strategy with technology and governing transformation. Therefore, a key outcome of architecture is to model an enterprise's artifacts and their relationships, such as creating models of architectural designs. The architecture modeling activity improves the system specification and enables a better understanding of the organizational setting [18]. Therefore, EA can be important in addressing the complexity of modern businesses since it describes and models the organizations' elements and shows how they are organized, connected, and operate as a whole [19].

The business mission serves as the key driver in the construction of an EA and gives the first direction, with the business principles, goals, and drivers. Follows the applications to store and provide the data to support the mission, and lastly comes the tools used to implement the applications [20]. Overall, an EA follows a hierarchical structure of layers, as follows: business layer, data layer, information systems/application layer, and technology layer. Each layer delegates work to the layer below, and each one is constituted by elements, such as processes and services [20]. The following Table 3.1 describes the role of the layers.

Layer	Description
Business Layer	Business functions offering services to each other and external entities.
Data Layer	Business information and other valuable stored data.
Application Layer	Business applications offering information services to each other and to business functions.
Technology and Physical Layers	Generic hardware, network, and platform applications offering platform services to each other and to business applications.

Table 3.1: EA Layers

3.1.2 Enterprise Architecture Framework

An EAF can be seen as a system of rules, ideas, and principles used to plan or decide something [13] within a specific domain. The standard ISO/IEC/IEEE 42010:2011 [21] proposes that an EAF is specified by methods, tools, definitions, and practices such as:

1. the relevant stakeholders in the domain.
2. the types of concerns arising in that domain.
3. the architecture viewpoints framing those concerns.
4. the correspondent rules integrating those viewpoints.

Therefore, by providing tools and methods, an EAF defines how to organize the structure and views of the architecture, enabling the production of the artifacts. EAF uses viewpoints to create views that represent the different perspectives of an architecture model. Common viewpoints are business architecture, data architecture, application architecture, and technological architecture [18]. The authors in [18] put forward a set of common goals for an EAF, presented in the following Table.

Element	Description
Architecture Definition and Understanding	Make use of standard terms, principles, and guidelines for consistent application of the framework for the communication of architecture information to stakeholders.
Architecture Process	Employ a well-defined process to guide the construction of architecture.
Architecture Evolution Support	Employ processes and mechanisms that support systems' evolution.
Architecture Analysis	Provide a set of viewpoints to guide the collection and analysis of information for making architecture choices.
Architecture Models	Provide consistent standards to document architecture specifications for the planning, management, communication, and execution of activities related to system development.
Design Tradeoffs	Select a design from more than one choice by resolving multi-dimensional conflicting requirements.
Design Rationale	Document reasons behind design decisions for verification, i.e., "architect for a reason".
Standardization	Ensure development and architectural standards are maintained.
Architecture Knowledge Base	Provide consistent representation and repository of design and architecture design rationale.
Architecture Verifiability	Provide sufficient information or explanation in the architecture design for review and verification.

Table 3.2: EAF Elements

3.1.3 Viewpoint & View

Viewpoints provide the standards, guidelines, and languages for constructing, presenting, and analyzing views. A model can be created from any viewpoint that captures all the objects, relationships, and constraints of the system. Thus, a viewpoint is focused on a perspective and represents the elements associated with that perspective. ISO/IEC 42010:2007 [22] defines a viewpoint as a specification for an individual view. Comparatively, a view is a representation of a whole system from the perspective of a viewpoint and may consist of one or more architectural models. For example, in the Zachman Framework [5], the views embrace a group of work products whose development requires a particular analytical and technical expertise because they focus on the "What", "How", "Where", "Who", "When", and "Why" of the enterprise.

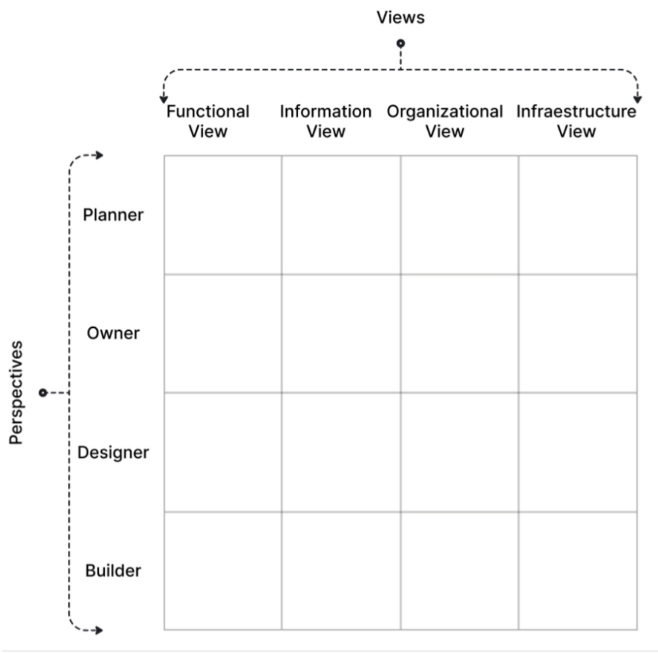


Figure 3.1: Views & Viewpoints in EA (adapted from [5])

Figure 3.1 represents the matrix that correlates the various perspectives of those involved with the existing architectural views, giving the possible viewpoints.

3.2 Enterprise Architecture Frameworks Review

This section reviews four EA frameworks and aims to evaluate them regarding their capabilities and qualities. Moreover, this analysis provides inspiration and support for the development of the Sectoral Enterprise Architecture Framework (SEAF). Therefore, this subsection is divided into five. It begins with subsection 3.2.1 by defining Federal Enterprise Architecture Framework (FEAF) [6], followed by subsection 3.2.2 addressing Department of Defense Architecture Framework (DODAF) [7], then subsection 3.2.3 approaches The Zachman Framework [5] and subsection 3.2.4 reviews The Open Group Architecture Framework (TOGAF) [4]. In addition, a brief review was made of the General Enterprise Architecting (GEA) [23] framework and European Interoperability Reference Architecture (EIRA) [24], which is mentioned in the last subsection 3.2.5, which presents an outcome analysis of the reviewed frameworks.

3.2.1 FEAF

Using a set of reference models and practices that apply to all federal agencies in the executive branch, the FEAF supports shared development for common federal processes, interoperability, and information sharing among federal agencies and other government institutions of the United States of America. The FEAF practice guidance adopts a segment architecture approach, which allows critical parts of the overall federal enterprise, referred to as architectural segments, to be built separately while being integrated into the more comprehensive EA [6]. FEAF allows the government to find opportunities to leverage technology by providing a consistent vocabulary to define the relationship between federal business processes, technology, and information. Those opportunities allow to [6]:

1. Reduce unnecessary redundancy.
2. Facilitate intergovernmental information sharing.
3. Establish a direct relationship between IT and agency performance.
4. Maximize Information Technology (IT) investments to achieve better mission outcomes.

The Consolidated Reference Model (CRM) is at the core of the FEAF, which is a set of tools designed to assist government planners in implementing. The CRM comprises a group of interconnected "reference models" to identify duplicative investments, gaps, and collaboration opportunities inside and between organizations. CRM has six sub-architecture domains: strategy, business, data, applications, infrastructure, and security. Based on EA best practices, each sub-architecture domain represents a specific section of the overall framework and has its own artifacts.

The Collaborative Planning Methodology (CPM) lays out steps for planners to follow throughout the planning process to flesh out a transition strategy to make the future state a reality. It is a straightforward, repeatable approach that incorporates sponsors, stakeholders, planners, and implementers in an integrated, multidisciplinary analysis. There are two phases to the CPM [6], namely (1) organize and plan and (2) implement and measure.

Planners play a critical role in the first phase, facilitating communication between sponsors and various stakeholders to identify and prioritize needs, research other organizations with comparable needs, and develop strategies to satisfy the stated needs. In the second phase, planners take on a more active role, assisting other individuals in the implementation and monitoring of change activities. Planners specifically help with investment, procurement, implementation, and performance evaluation actions and decisions as part of the methodology's second phase [6].

The CMP focuses on understanding and validating needs from the viewpoints of sponsors and stakeholders, planning for those needs, and ensuring that what is planned eventually results in the expected outcomes - step one. Furthermore, this methodology is designed to embrace the principles of leverage and reuse by assisting planners in determining whether other organizations have previously addressed similar needs and whether their business model, experiences, and work products can be leveraged to speed up improvement – step two. Ultimately, the CPM assists planners in articulating a roadmap that defines needs, what will be done to address those needs, when actions will be taken, how much it will cost, what benefits will be realized, when those benefits will be realized, and how those benefits will be measured in collaboration with sponsors and stakeholders – step three. The methodology also helps planners in assisting sponsors and stakeholders in determining which courses of action are best for the mission, such as specific investment and implementation decisions - step four. Finally, and perhaps most crucially, the technique guides planners in measuring the actual performance changes that have come from the recommendations and, in turn, incorporating these findings into future planning activities – step five [6]. The following Figure 3.2 illustrates FEAF.

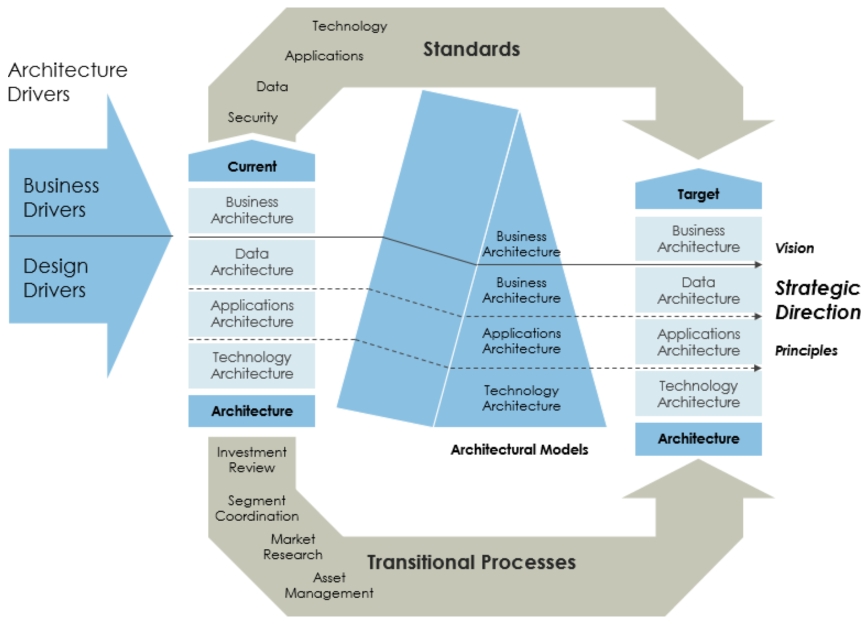


Figure 3.2: FEAF [6]

The six reference models are the following [6]:

Performance Reference Model (PRM)

Target metrics that measure business, data management, application, infrastructure, and security performance are at the core of the process. Its purpose is to connect investments or activities to the strategic vision by aligning three areas: goal, measurement, and measurement category. The Performance Reporting is integrated with the PRM, contributing to the definition of the relationship between investment and agency strategic goals, providing investment-specific performance metrics, and reporting on investment results.

Business Reference Model (BRM)

When applied in business analysis, design, and decision support to improve performance, the BRM represents "what we do" with actual utility and value. For business and IT leaders, it aids in discovering cost-cutting and innovative business capabilities and the achievement of strategic goals. The link between strategy, performance, and business functions is used to evaluate if the organization's function supports the strategic objective. In terms of projects and investments, it allows for the identification of a similar business aim and the discovery of chances for collaboration and reuse of shared services.

Data Reference Model (DRM)

Its main goal is to promote standard data management practices by enabling information sharing and reuse and discovering common data. As a standard way to ease the discovery and exchange of information across organizational boundaries, data is described, categorized, shared, and classified by purpose or business. This method's advantages include identifying possibilities for strategic coordination and improving corporate processes and decision-making performance.

Application Reference Model (ARM)

Different components, interfaces, and software that support or may be adapted to support are categorized. The focus is on opportunities to minimize IT costs and improve strategic performance and the potential to improve business processes and develop new business capabilities. It is also important to look for opportunities to share, reuse or consolidate information systems and identify data storage, interchange, and technical infrastructure requirements.

Infrastructure Reference Model (IRM)

Infrastructure sharing and reuse cut costs, improve interoperability among partners, facilitate purchase and deployment, and provide broader access to information across companies. The IRM is used to categorize IT infrastructure asset inventories and their management, being essential as an IT decision-making tool, delivering cost efficiencies, reducing duplication and redundancy, and promoting information sharing. The ever-changing demands and needs of diverse business customers are solved by providing and managing IT services. In the scope of best practices, principles, practices, analytical tools, and models of COBIT [25] and ITIL [26] are essential for business guidance, IT, and governance experts.

Security Reference Model (SRM)

Security must be integrated throughout all the sub-architectures of the overarching EA across all the other reference models since it is an intrinsic aspect of all architectural domains and at all levels of an organization. Security standards, rules, and norms are defined and followed in the scope of enterprise architecture governance. It is used to convert department-specific regulations into security controls and measures, such as the type of information processed, required controls, and resulting business process limitations or risks. Understanding the purpose and impact of security measures on business processes or IT systems helps risk-based decision-making to meet security objectives. Security integration across layers of the architecture is critical to ensure the security of information and IT assets.

3.2.2 DODAF

DODAF was designed to address the United States Department of Defense's of the United States of America unique business and operational requirements and is represented in Figure 3.3. It specifies a method of displaying an enterprise architecture that allows stakeholders to concentrate on individual areas of interest inside the company while keeping the larger picture in mind. DODAF provides a means of abstracting key information from the underlying complexity and presenting it to maintain coherence and consistency to assist decision-makers. One of the main goals is to display the data in a way that the numerous stakeholder groups involved in developing, delivering, and sustaining capabilities in support of the stakeholder's mission can understand [7].

DODAF 2.0 serves as the overarching, comprehensive framework and conceptual model enabling the development of architectures to facilitate Department of Defense (DoD) managers at all levels to use architectures developed under the DODAF in support of more effective decision-making through organized information sharing across the Department, Joint Capability Areas, Components, and Program boundaries. DODAF 2.0 focuses on architectural data and information required by key DoD decision-makers, rather than on developing individual products [7].

Therefore, this organized data is part of an analysis-based architecture that ensures decision-making is based on the most recent, appropriate, and valid data available. This data is taken automatically from structured datasets, and its analysis is divided into static (value judgment) and dynamic (running and observing the behavior). Furthermore, five key principles are defined to maintain the quality of the architectural description and foster further innovation to spawn new analytical activities in the future: consistency, completeness, transformation, iteration, and lack of ambiguity [7].

A methodology-based approach to the development of architectural descriptions in the DOD represents best practices and specifies how to derive relevant information about an enterprise's processes and business or operational requirements and how to organize and model that information. Approaches for collecting, arranging in a specific grouping or structure, and storing acquired data for later presentation in decision-making processes are referred to as architecture methods. The following are the steps used by DODAF to generate an architectural description for a specific purpose [7]:

1. Determine the architecture's purpose.
2. Determine the architecture's scope.
3. Identify the data that will be needed to support architecture development.

4. Collect, organize, correlate, and store architectural data.
5. Analyze the situation in support of the architecture goals.
6. Document the findings in accordance with the needs of the decision-makers.

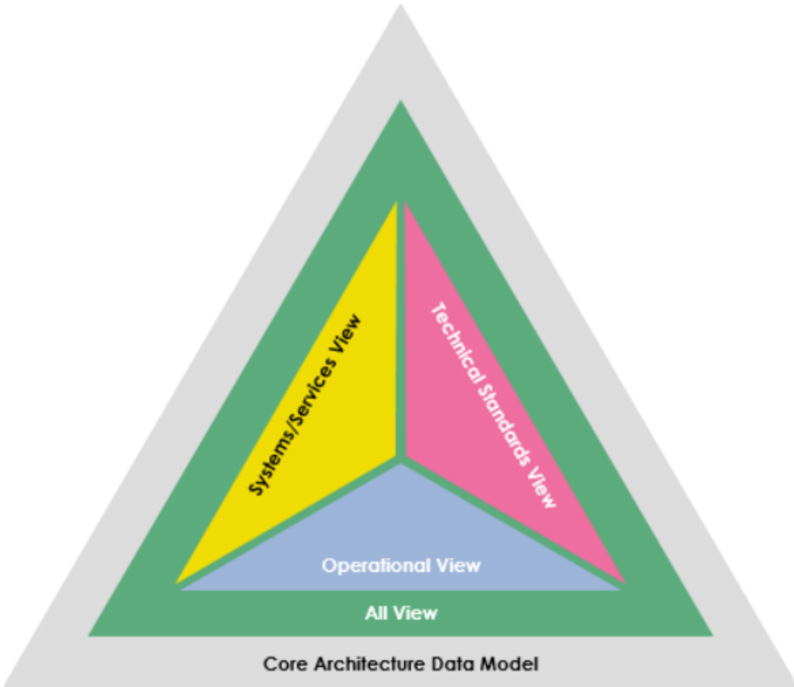


Figure 3.3: DODAF [7]

To implement these steps, the meta-model data groups and their guidelines must be used. It was feasible to identify the architecture's meta-model data groups, which are divided into twelve data groups, and comprehend how they define the model's language and procedures. Each data group must have its own definition, as well as the information it collects and how it should be used [7]:

1. Define it in terms of what it is, its applicability, and its purpose, considering the context in which it is used.
2. Capture the data for the data group's architectural description and define the techniques for identifying, capturing, and defining it.
3. Describe the data group's purpose and usefulness, as well as measurement measures.

3.2.3 The Zachman Framework

The Zachman Framework is a rigorous and well-structured method of defining a business [5], represented in Figure 3.4. It is based on a two-dimensional classification model (displayed as a matrix) that uses six basic communication interrogatives ("What", "How", "Where", "Who", "When", and "Why") and intersects six distinct model types (Strategists, Executive Leaders, Architects, Engineers, Technicians, and Workers) to provide a holistic view of the enterprise. The matrix decomposition allows for the development of numerous diagrams of the same data sets for the same architecture, each with a higher level of detail [27].

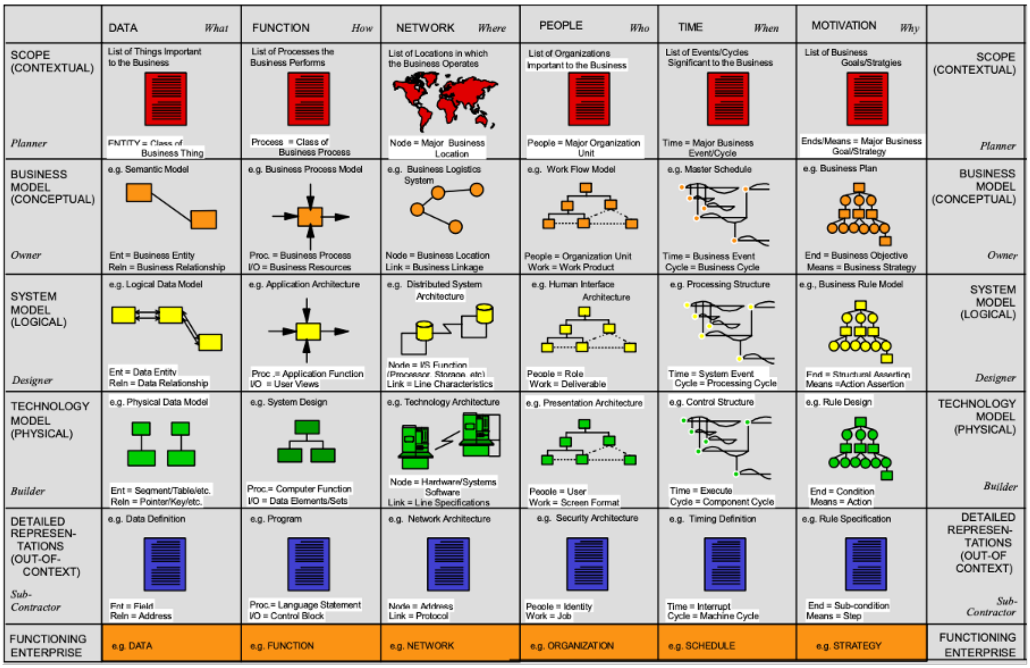


Figure 3.4: The Zachman Framework [5]

"What", "How", "Where", "Who", "When", and "Why" are the six primitive interrogatives, and the answers to these questions constitute the total knowledge base for the subject in the description. Therefore, each column of the framework represents a variable; in other words, it represents each interrogative [27].

The Zachman framework seeks to be generic by not dictating a specific implementation or modeling methodology. However, there is some high-level advice available. Zachman identifies two primary stages in enterprise modeling, similar to previous frameworks [27]:

1. Model the existing enterprise to improve existing operational processes.

2. Alter the enterprise using a generalization of the models established.

Given the wide range of objectives that underlie enterprise integration efforts, enterprise architects must be able to choose modeling languages that allow them to communicate their intent and design as needed for the task. Zachman architectures argue that the given engineering domain already has appropriate tools to define any delivery, and the architecture's role is just to create a checklist of deliverables and explicit connections [28].

3.2.4 TOGAF

TOGAF is a comprehensive architecture framework and methodology which enables practitioners to design, evaluate, and build an appropriate architecture for the organization [4]. The TOGAF Architecture Development Method (ADM) supports the TOGAF architecture development approach for architectures that meet business needs. TOGAF's ADM, represented in Figure 3.5, prescribes methodology, not products or modeling notation, and should be used with other architecture frameworks, as appropriate [4], [29].

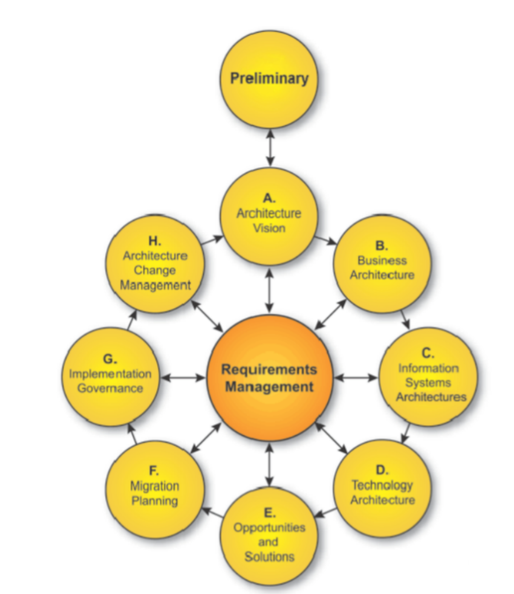


Figure 3.5: TOGAF ADM [4]

The TOGAF ADM Cycle is about understanding existing architectures and working out the best way to improve them. It is divided into ten phases, covering five topics: objectives, approach, inputs, steps, and outputs. Also, it is organized into four stages: Architecture Capability, Architecture Development, Transition Planning, and Architecture Governance [29].

By nature, enterprise architecture deals with uncertainty and is responsible for making changes to address stakeholder concerns and meet evolving requirements [29]. Therefore, knowing the current state and the target state and analyzing the differences between them consists of a Gap Analysis. Furthermore, the Migration Planning Techniques allow the architect to group the gaps identified, assess potential solutions, and look at dependencies, priorities, value, returns on investment, or risk [29]. Because Enterprise Architecture-based change is a massive undertaking for a company, it is critical to know if the company is ready, willing, and capable of making such changes. As a result, Readiness Factors must be determined and TOGAF provides examples and assessment methods to classify and analyze them. The Business Factor Assessment Factory is used to classify for success throw factor rating, and the Business Transformation Readiness Assessment is used to present the factors through their maturity. In addition, the risks associated with each factor are identified, assessed, and mitigation measures are identified before the process begins to be tracked during the transformation [4].

TOGAF approaches business scenarios as they are used to help identify and understand company requirements. Hence, it extracts the business requirements that must be addressed by architecture development and, eventually, IT. As a result, it assists with one of the most prevalent challenges IT executives face: aligning IT with the business. TOGAF provides a set of goals for business objectives as guidance in this area. Gathering, analyzing, and reviewing the information in the business scenario are all iterative processes in architecture development [4], [29].

The Capability Framework in Figure 3.6 gives principles for aligning the business vision and drivers with the business capabilities at six levels of maturity: none, initial, under development, defined, managed, and measured. Also, this framework is meant to describe the overall conceptual structure and major components of an organizational structure, as well as the need to link Governance with other enterprise-wide disciplines' governance. The focus begins with alignment to business governance, IT governance, and EA governance [4].

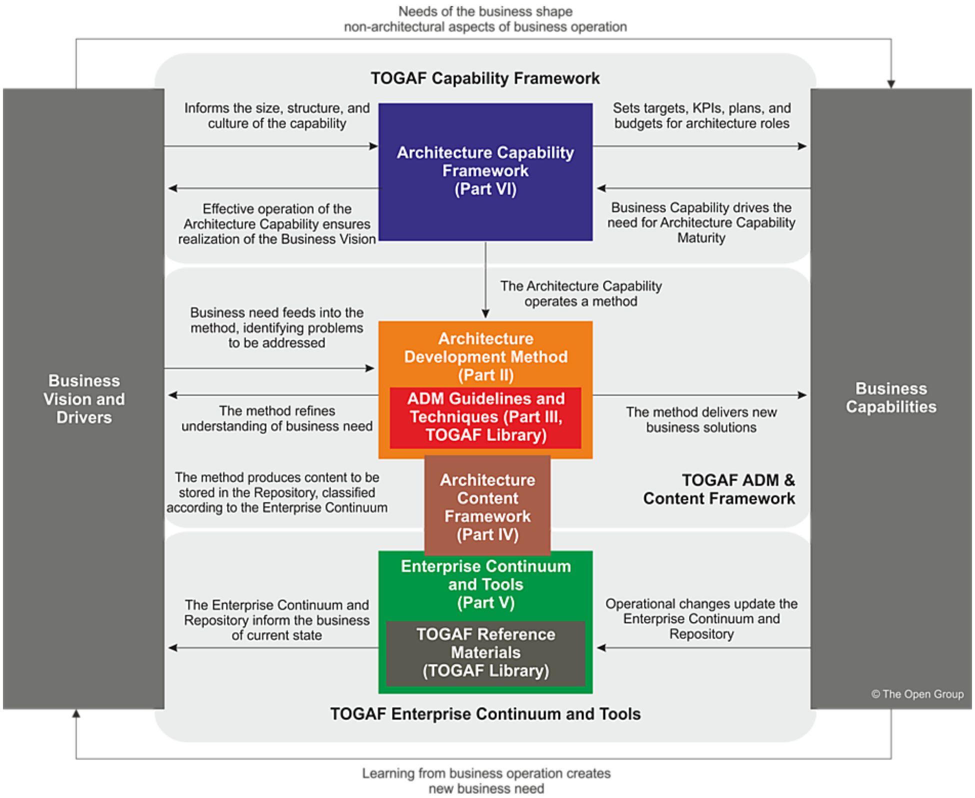


Figure 3.6: TOGAF Capability Framework [4]

In this line of thought, stakeholder management is a critical discipline that architects employ by identifying, understanding, and distinguishing key stakeholders based on power, influence, and interest [4]. It is critical to analyze each stakeholder's readiness, in terms of their level of commitment to the enterprise architecture initiative, and to judge the required level of commitment. This step allows us to quickly identify which stakeholders are likely to be opponents or critics of the initiative and which are likely to be advocates and supporters [4].

Another topic that TOGAF emphasizes is security architecture. Each relevant ADM phase in that scope explains how to adapt the ADM to handle security architectural challenges and security artifacts and EA processes. Identifying mitigating security measures through security services of identification, authentication, authorization, data confidentiality, data integrity, non-repudiation, assurance, and audit, is vital to refer to during the technology architecture phase. Their applicability must be assessed, and the cost/value of protection, as well as a means for measuring and communicating the efficacy of security measures on an ongoing basis. Identifying non-renewable resources, recognizing resource depletion, and taking efforts to respond by minimizing the causative variables or restricting the effects of resource depletion to non-critical functionality, can all help to improve the system's overall reliability and availability [4]. Regarding the enterprise continuum and tools, to simplify the development and management of the EA, the concept of architecture partitioning is applied, in which the subject matter, the time, the maturity, the volatility, and the depth are the support partitioning criteria [4], [29].

In conclusion, TOGAF describes each phase of the ADM and provides a set of principles and strategies on the different themes that contribute to the transformation of successful architecture.

3.2.5 Enterprise Architecture Frameworks Review Outcome Analysis

This section presents some conclusions drawn from the analysis of the studied frameworks: FEAF [6], DODAF [7], The Zachman Framework [5] and TOGAF [4]. Additionally, it gives a brief insight into the analysis made to the GEA [23] framework and EIRA [24]. The study revealed that these frameworks were not specifically created for industry sectors and their supply chains. Nonetheless, these EAF can provide a broad scope of inspiration and are essential to guide SEAF.

The FEAF structure presents (1) the actual and the desired state; (2) models the layers, e.g., business data and technology, and (3) presents a transformation process. FEAF's intent is to identify duplicative investments, gaps, and collaboration opportunities inside and between federal organizations. Therefore, the DT priorities for the sector and the layers that need to be modeled for a specific sector can be inspired in FEAF. This could be adapted to segments that cooperate in a supply chain.

DODAF is an analysis-based architecture that ensures decision-making by focusing on data analysis, validity, and availability. This framework's mission is to ensure that data coherence and consistency are maintained to assist decision-makers. Each data group has its own definition, as well as the information it collects, and how it should be used. The DODAF's data analysis may be adapted for the data integration between segments.

The Zachman Framework reveals essential questions that an EAF should answer, namely, "What", "How", "Where", "Who", "When", and "Why".

Lastly, TOGAF provides insights into the main steps and the process of developing an EA. For example, the Migration Planning Techniques, The Business Factor Assessment Factory, the Business Transformation Readiness Assessment, The Capability Framework, the Architectural Governance Framework, the Security Architecture Framework, and the Enterprise Continuum and Tools. Therefore, TOGAF may provide valuable guidance for the steps of SEAF deployment in specific industry sectors.

In brief, the authors in [30] highlight the importance of the Zachman Framework, FEAF, DODAF, and TOGAF. Contrasting with TOGAF, designed to support architecture development, providing insight into the main steps and the process of developing an EA [4], FEAF and DODAF are domain-specific frameworks. While FEAF supports shared development for common federal processes, interoperability, and information sharing among federal agencies and other government institutions, DODAF was designed to address the United States Department of Defense's unique business and operational requirements. The influential Zachman framework provides a holistic view of the enterprise by using communication interrogatives ("What", "How", "Where", "Who", "When", and "Why") intersected with model types (Strategists, Executive Leaders, Architects, Engineers, Technicians, and Workers) [5]. Other important examples include GEA [23], with relevant domain-specific viewpoints, and EIRA [24], which aligns very closely with a sectoral perspective, although not specific to industry supply chains.

The following Table 3.3 presents a comparison of the four most mentioned enterprise architecture frameworks in the surveys found during this work. The authors in [31], and [19] analyze the structural elements that an EAF must encompass, and the authors in [32] and [34] assess the capabilities that an EAF should meet to respond to today's expectations. The last elements come from the capabilities, that this work finds relevant, for an EAF to comply with.

	EAF Elements	Zachman	FEAF	DODAF	TOGAF
[31]	Non-functional Requirements	N	N	N	Y
[19]	Specification Document	Y	Y	Y	N
	Meta Model	P	N	P	N
	Role	N	Y	P	N
	Technique	N	N	Y	P
	Procedure Model	P	Y	Y	Y
[32]	Domain-specific	N	Y	Y	N
	Meet Customers' Needs	N	N	N	N
	Socio-economic Engagement	N	N	N	N
[34]	Manage Dynamic Environments	N	N	N	N
	Manage Products and Services	N	N	Y	Y
*	Manage Digital Strategy	N	N	N	Y
*	Innovation Assessment	N	N	N	N
*	Manage Information and Data	N	Y	Y	Y
*	Manage Digitalization	N	N	N	N
*	Manage Collaboration	N	Y	Y	Y
*	Manage Customer Experience	N	N	N	N
*	Manage Business Agility	N	N	N	Y

Table 3.3: Comparision of EAF elements

* Analysis and conclusions from the study conducted in the present work.
Y is Yes **N** is No **P** is Partial

Based on the analysis conducted, it can be deduced that the well-known frameworks currently available exhibit limitations in effectively addressing some fundamental aspects of enterprise architecture. It is noteworthy that these frameworks, such as the Zachman Framework, originated in the 1970s [5], while the FEAF [6] and DODAF [7] frameworks emerged in the 1980s. Since their introduction, these frameworks have not undergone significant adaptations to accommodate the demands of the digital era, thus leaving them incapable of effectively supporting the DT process. Consequently, it has been established that businesses must promptly respond to customers' needs, a capacity that these frameworks are ill-equipped to facilitate. In the present day, organizations heavily rely on technology to enhance their operations and maintain competitiveness. Furthermore, the integration of data assumes paramount importance in the success of a framework in the 21st century, as it serves as the foundation for all information and holds the potential for optimizing business processes. Consequently, it is evident that these frameworks fail to capitalize on the possibilities offered by technology and neglect to address the alignment between business objectives and digital strategies.

In conclusion, this section identifies the critical guidance available in the existing frameworks to guide sector-specific EA approaches to DT in the industry. A new sectoral EAF may be useful to guide companies across the planification, implementation, and migration of new technologies suitable to their supply chain. The next section discusses the concept of a modeling language and its role in modeling an EA. In particular, it talks about the language chosen to use in the present work.

3.3 ArchiMate Modelling Language

Regarding EA models, it is imperative that a modeling language is employed to ensure the rigor, consistency, interoperability, and replicability of the message. For example, Unified Modeling Language (UML), Business Process Model and Notation (BPMN), Service Oriented Architecture Modeling Language (SOAML), or System Modeling Language (SysML). Therefore, for the present work, ArchiMate [33] modeling language was the chosen modelling language.

ArchiMate is a free and open EA standard for describing, analyzing, and visualizing architecture within and across business domains. It includes elements representing behavioral, structural, motivational, and composite architecture presentation [17]. Further, not only it offers support for modeling four (related) aspects [33]: the Enterprise itself, the Strategy of the Enterprise, the Change of the Enterprise, and the Intentions of an Enterprise, but it also enables the modeling of organizations from different viewpoints [33]. For example, the **Business Layer** is used to describe the business strategy, while the **Application Layer** represents the structure and interaction of the applications. More physical layers include the **Technology Layer**, describing the structure and interaction of the platform services, and logical and physical technology components. Nevertheless, it is also possible to model Motivation, for example, relating stakeholders and their primary goals. Lastly, the **Strategy Layer** is used to express how the enterprise wants to create value for its stakeholders, capabilities, and resources. The most current specification of ArchiMate is 3.1 [33], represented in Figure 3.7.

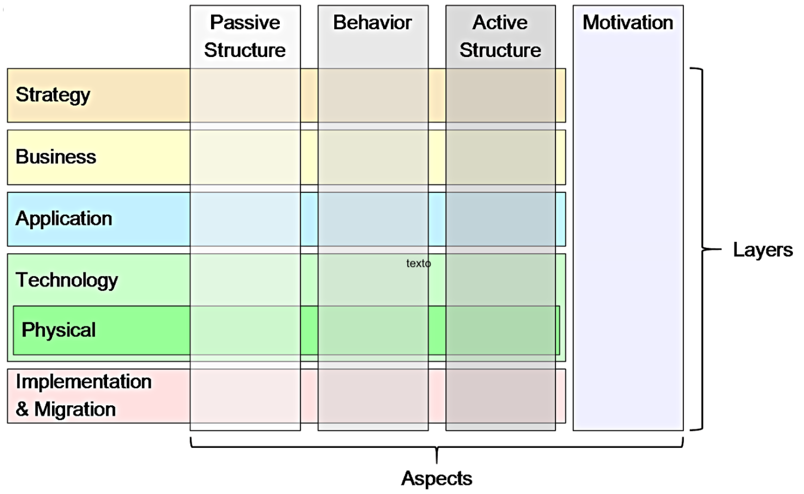


Figure 3.7: ArchiMate Layers [4]

Therefore, ArchiMate models the global structure of an EA through its layers, representing their relationships and elements [34]. The following Figure 3.8 represents a fundamental example of ArchiMate layers and their relationships.

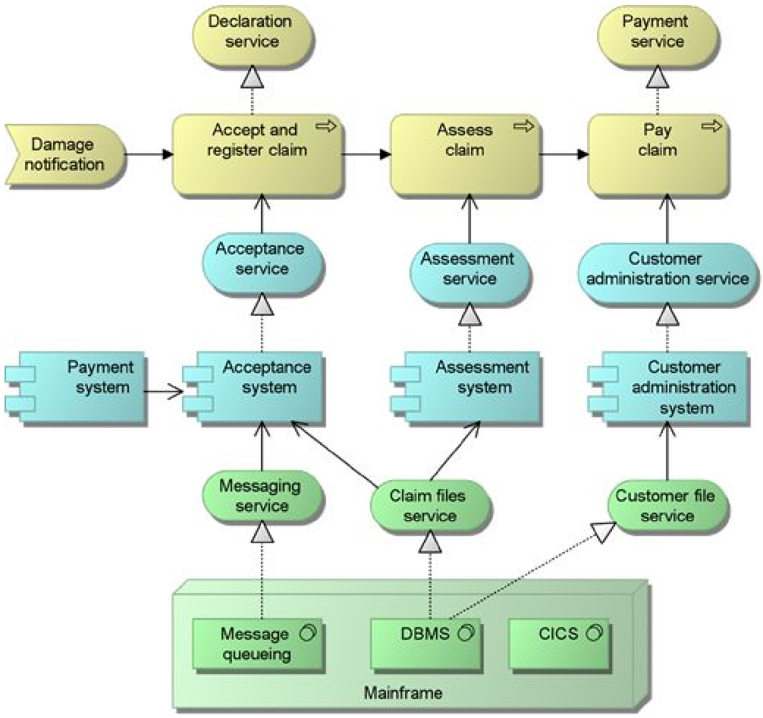


Figure 3.8: ArchiMate Layers - Elements and Relationships [4]

As the previous Figure illustrates, ArchiMate organizes the elements of the architecture into different layers. Each layer has its own specific elements and relationships, however, there are also relationships between elements of the different layers, enabling an integrated and comprehensive view of the enterprise architecture. Thus, the layers are connected through the realization, aggregation, dependency, association, assignment, and flow elements [33]. The following section introduces I4.0.

3.4 Industry 4.0

This section approaches I4.0 and is divided into three subsections. It initiates with subsection 3.4.1 by defining I4.0, followed by subsection 3.4.2 addressing I4.0 on product industrial development and ends with subsection 3.4.3 covering the adoption of I4.0 on the supply chain.

3.4.1 Defining Industry 4.0

The fourth industrial revolution, also called I4.0, is a new industrial age that has been gaining ground and new followers all over the world. The term I4.0 appeared in Germany to define a political strategy to improve manufacturing with digital technologies. Other similar terms emerged in different areas of the globe, for example, Advanced Manufacturing (AM) in the United States of America also addresses the energy and sustainability priorities [2].

This revolution is the result of the widespread adoption of advanced resources of information and communication technologies (ICT) combined with the Internet of Things (IoT) and Cyber-Physical Systems (CPS) in systems, which has given rise to smart factories that provide smart products and services designed to meet the requirements of customer segments. As a result, the CPS connected to the Internet is frequently referred to as the IoT [35], meaning that the CPS offers digital representation, intelligent services, and interoperable interfaces to support flexible and networked production environments [36]. I4.0 is categorized into multiple clusters [36] [2]: Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data & Analytics (BDA), Cloud Computing, Artificial Intelligence (AI), Blockchain, Automation and Industrial Robots, Additive Manufacturing (AM), and Simulation & Modelling, (Figure 3.9).

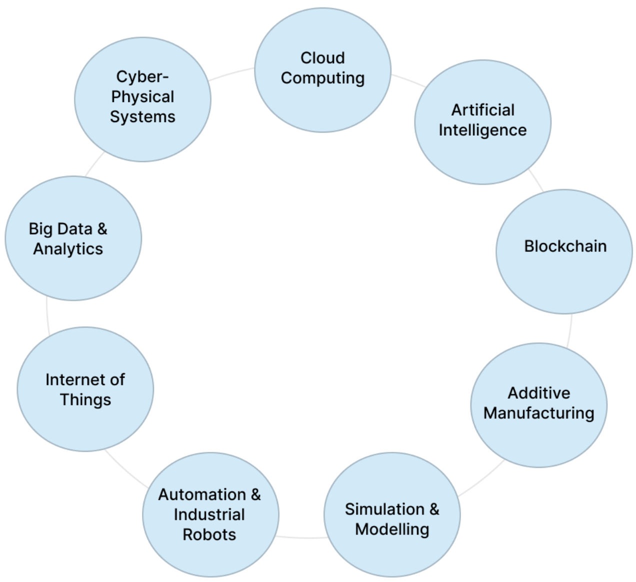


Figure 3.9: Industry 4.0 Technologies (adapted from [2])

System Integration or Cyber-Physical Systems: by making decentralized decisions, CPS supports the computerization of manufacturing. CPS is characterized as supporting technology for networking systems and coordination between the physical infrastructure and computational capabilities. To accomplish decentralized tasks, physical and digital tools should be integrated and connected with other devices.

Internet of Things: is the global, dynamic, self-managed network architecture composed of interconnected devices based on sensors, communication, networking, and information processing technologies that allows the tracking and tracing of both physical and virtual "things." The IoT enables connection between smart products, sensors, and actuators to facilitate information exchange between "things," such as machines and products.

Big Data & Analytics: the field that focuses on collecting and analyzing large amounts of data that are available, utilizing a variety of techniques to filter, capture, and report insights. Here the data is processed in higher volumes, at greater speeds, and with a broader variety.

Cloud Computing: the foundation of computing and storage. The Cloud enables any workload to be transferred and accessed at any time and from any location. Depending on the demands of the business, data can be simply transferred between environments that offer a wide range of services and products.

Artificial Intelligence: the field in which the system relies on six key disciplines — natural language processing, knowledge representation, automated reasoning, machine learning, computer vision, and robotics — to think rationally as humans do.

Blockchain: is a database that creates a distributed and tamperproof digital record of transactions, including timestamps of blocks maintained by every participating node.

Automation & Industrial Robots: is used in manufacturing to handle complex problems that humans find difficult to resolve on their own. The fundamental concept is to program the robot to perform a certain way in response to an external stimulus without direct human intervention. Locomotion, localization, navigation, and mapping are just a few of the various implementations and uses it has. Thus, the operator and control system gives the necessary information to autonomous robots.

Additive Manufacturing: the process of creating items from 3D model data by combining materials in consecutive layers in order to "unlock" design options and maximize the potential for mass customization.

Simulation & Modelling: support manufacturing-related tasks, assisting in the development of the production system, and having the capacity for self-configuration. The simulation, which can plan operations using information and precise system forecasts, provides the necessary adjustments for the operation of production systems.

The following subsection addresses I4.0 in the context of product development and establishes a correlation between I4.0, its applicability on the product, and the external factors impacted.

3.4.2 Industry 4.0 for Product Development

Regarding the products (raw materials or produced goods), these are referred to as smart products or processes in the I4.0 [11]. Smart products have the ability to carry their own data, including features, destinations, and actions to be performed during the manufacturing process. From a development standpoint, the Internet of Things (IoT) serves as a conduit for connecting all relevant users, enabling direct data collection from the product. Concurrently, the integration of Big Data and Analytics facilitates intelligent decision-making processes and product adaptation [2].

Through autonomous decisions and communication between manufacturing machines and products, the production system can manage each product uniquely, according to its characteristics and needs [37]. The investigation made by the authors in [2], contributed to identifying some applicability of the I4.0 enabling technologies for smart manufacturing. Within the scope of this study, the involvement of external factors assumes significant importance, thereby a noteworthy correlation was established, based on [37], and [2], that is presented in Table 3.4.

<table>
<tr><th>I4.0 Technology</th><th>Applicability</th><th>Impacted Factors</th></tr>
<tr><td>CPS</td><td>Smart product development.</td><td rowspan="8">Circular Economy

Trends

Customer Needs

Product Lifecycle

Innovation

Sustainability Development

Quality Assurance

ESG Values</td></tr>
<tr><td>IoT</td><td>Data collection for product design and features improvements.</td></tr>
<tr><td>Cloud Computing</td><td>Distributed and collaborative design.</td></tr>
<tr><td>Artificial Intelligence</td><td>Data processing and analysis for product design improvements.</td></tr>
<tr><td>Blockchain</td><td>Track the entire product lifecycle.</td></tr>
<tr><td>Simulation & Modelling</td><td>Support and accelerate virtual prototyping.</td></tr>
<tr><td>Additive Manufacturing</td><td>Digital complex design and rapid prototyping.</td></tr>
<tr><td>Automation & Industrial Robots (Digital Twins)</td><td>Replicates the digital representation of physical products for iterative optimization, maintenance, and reparation.</td></tr>
</table>

Table 3.4: I4.0 Technologies, Applicability and External Factors Impacted

This subsection provides insights into the suitability of technology in the realm of product development. In the following subsection, an examination is conducted on the suitability of I4.0 technologies in facilitating the integration of the supply chain.

3.4.3 Industry 4.0 for Supply Chain Integration

The integrated supply chain entails the comprehensive management of various elements shared among stakeholders within the sector, encompassing raw materials, suppliers, inventory, and demand forecasting. The implementation of digital technologies to oversee and control these aspects holds the potential to enhance the integration and coordination of the supply chain [34]. Thereby a noteworthy correlation was established, based on [37], and [2], in the following Table 3.5.

I40 Technology	Applicability	Impact on the Supply Chain
IoT	Virtual control of supply chain.	Advanced quality control and planning during the sourcing process. Track and trace goods along the supply chain.
	Network of stakeholders along the supply chain.	
Cloud Computing	Advanced data repository for planning and forecasting.	Facilitating supply decision-making process for complying (or not) with customer-desired product varieties, volumes, and times.
	Communication among consumers, design activities, manufacturing, and logistics in the supply chain.	
	Storage of structured information for sharing and exchange.	
Big Data & Analytics	Collect and process data along the supply chain.	Facilitating optimal material and product transportation routing. Improve the matching of supply and demand processes. Trade-off between cost-effective performance and sustainability in distribution planning.
	Cooperation with partners.	
	Support distribution planning.	
	Marketing and supply chain management functions.	
Blockchain	Collaboration among stakeholders.	Enable trusted and autonomous relationship among different actors in the supply chain, both suppliers and customers. Product information can be traced transparently and authenticated.
	Real-time materials identification and tracking.	

Table 3.5: I4.0 Technologies, Applicability and Impact on the Supply Chain

The combined implementation of IoT, BDA, and Cloud Computing technologies augments the integration and automation of the supply chain, thereby facilitating the prediction and proactive shaping of future customer demands [18]. Consequently, this integration leads to greater efficiency in product delivery. Furthermore, it is crucial to recognize the influence of societal trends, such as sustainability, on the product and its developmental processes. Thus, through accurate monitoring of customer requirements and pertinent societal trends, enterprises can enhance their operational efficiency and align their production planning, culminating in enhanced market success [32].

This section provided insights into the suitability of technology in the realm of supply chain integration. In the following section, is made an approach to DT on the connection with I4.0 and its role in today's organizations.

3.5 Digital Transformation

This section approaches DT and is divided into two subsections. It begins with subsection 3.5.1 by defining DT and ends with subsection 3.5.2 addressing the role of DT in the industrial and business context of the supply chain.

3.5.1 Defining Digital Transformation

DT refers to the integration of digital technologies and processes across various aspects of an organization, leading to fundamental changes in how businesses operate, deliver value, and interact with customers. DT and I4.0 are closely intertwined concepts. Their correlation lies in their shared focus on leveraging digital technologies to drive innovation, efficiency, and competitiveness in industries. DT initiatives provide a strategic framework for organizations to adapt to the rapidly changing technological environment and embrace the core principles of I4.0. Although this approach has been discussed for some time, there is still no straightforward methodology for digitally transforming business models, specifically, which phases and instruments should be considered [25]. Nevertheless, the authors in [1, 28] identified relevant practices that a DT Framework must cover, such as managing customer experience, innovation, products and services, partnership, and resources, making EA approaches well-positioned to address the problem.

3.5.2 Digital Transformation on Industry

DT, closely intertwined with I4.0, has begun to strongly impact organizational operations by recognizing the inherent duality between physical assets, such as machines and sensors, and the large data they generate, exchange, and consume [8]. In the context of DT, the increasing flow of information and the essential system integration across the supply chain brings significant challenges for organizations. A promising way to address these challenges involves exploring the convergence of data with IT-driven methodologies, exemplified by the adoption of EA [2]. The I4.0 revolution, aided by DT initiatives, empowers businesses to unveil improved flexibility in their manufacturing processes and enables real-time analysis of substantial data volumes, thus enhancing strategic planning and operational decision-making capabilities [12]. Furthermore, within the notion of digital transformation, the establishment of collaborative networks among enterprises operating within the same supply chain assumes critical significance in facilitating efficient information exchanges [6]. Additionally, each sector of the economy necessitates a sustainable and tailored strategy to embrace I4.0, recognizing the significant variations that can arise depending on the specific product focus.

Thus, Section 3.6 describes the Systematic Literature Review (SLR) conducted about the incorporation of the concepts analyzed in this chapter, within the supply chain of a specific industrial sector.

3.6 Sectoral Framework Proposal Systematic Literature Review

A Systematic Literature Review (SLR) was conducted by following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) methodology [14] to answer the following question:

"Which accomplishments have been achieved regarding the digital transition in the domain of Enterprise Architecture, within the supply chain?"

3.6.1 Literature Search Methodology

The research was conducted through October 26th of 2021 and all the results had to be published between 2017 and 2021 and written in English. The documents collected were about Computer Science, Engineering, Business and Economics, and Automation Control Systems. For this review, only journal or conference papers, articles, and reviews were considered. Grey literature, workshops, books, and editorials were excluded, as well as works not related to the domain.

The search strategy was based on one query made with different focuses of research. The research was made by searching the existent literature, regarding the concept, the population, and the context in Scopus and Web of Science Core Collection, detailed in Table 3.6. It is important to note that the values corresponding to the queries still have duplicate articles. The literature considered for this study included (1) digital transformation relevance, (2) industry 4.0 technologies (3) business and IT governance on the supply chain, and (4) information sharing and data integration.

Concept	Population	Context	Limitations
"Enterprise Architecture" "IT Governance"	"Supply Chain"	"Digital Transformation" "Sustainability" "Industry 4.0" "Data Integration"	2017-2021 Only journal, conference papers, articles, and reviews. Refined by Computer Science, Engineering, Business Economics, and Automation Control.
3217			
49			
27			

Table 3.6: PRISMA Keywords definition

In Table 3.6 is possible to see that when the query is made using the keywords from each column (Concept AND Population AND Context AND Limitations) the literature review yields 27 publications.

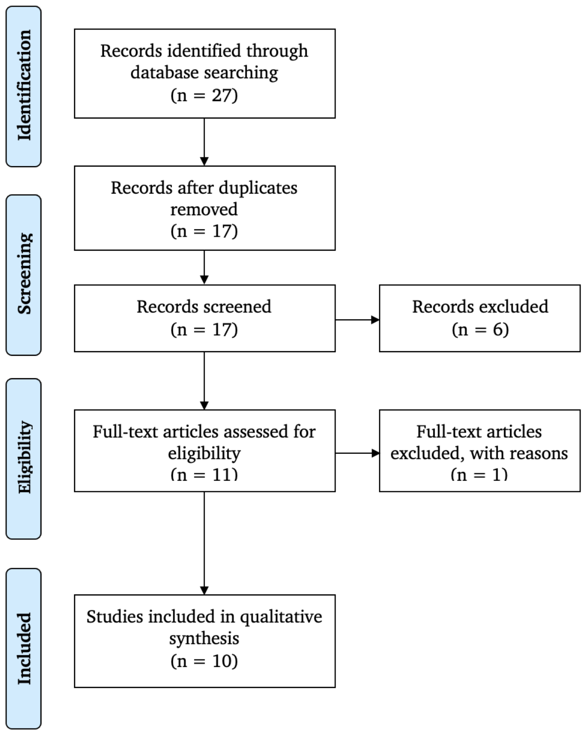


Figure 3.10: PRISMA Workflow Diagram

Therefore, after performing a manual process, towards the identification of significant subjects on their research questions, identifying the outcomes, and removing the duplicates, 10 documents were obtained, described in more detail in Appendix C. The research systematization considered the year, area, research question topic, and a small description. The above Figure 3.10 shows the PRISMA workflow diagram from the total of articles studied.

After assessing all the included studies, it was possible to acknowledge the growing importance of EA to manage the sharing of information across the supply chain and the consequent data integration for companies. Figure 3.11 shows the main objectives found for EA to address the aforementioned.

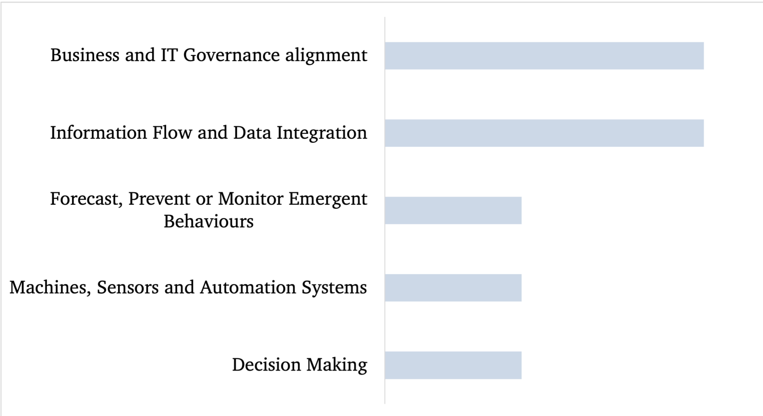


Figure 3.11: Main Objectives from the Systematic Literature Review

The majority of studies focus on Data Integration (62%) as a key component for DT (46%), highlighting Forecast, Prevention, or Monitorization (15%) and Artificial Intelligence (15%) as the main technologies. Regarding the objective of improving supply chain interoperability, there is a lack of modeled EA frameworks to represent the role of digital technologies in a specific-sector supply chain addressing sustainability practices. The following Figure 3.12 represents the statistics obtained from this PRISMA literature search.

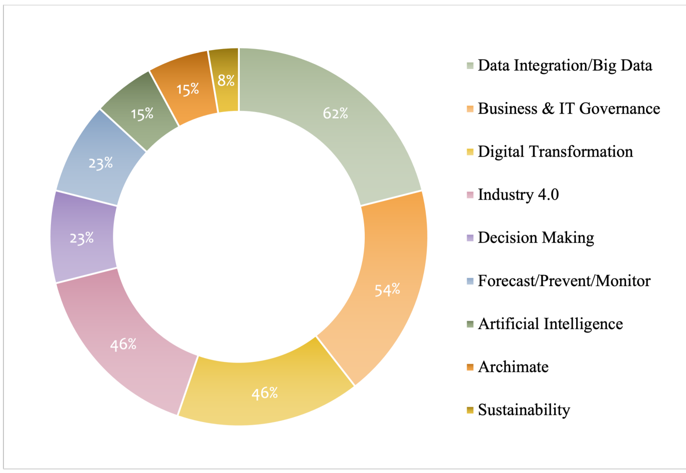


Figure 3.12: Main Topics from the Literature Review

3.6.2 Literature Review Outcome Analysis

Nowadays, IT is so dynamic in terms of innovation, and clients' expectations are so demanding that an EA framework is a must to obtain a competitive advantage. It allows the company to be more agile, undertake digital transformation, and stay ahead of the competition. Moreover, the quality of a product's components, which were procured from different suppliers at different times, has a substantial impact on customer satisfaction. Consequently, to boost the customer's confidence in using the product, more effective supply chain coordination is critical to success [38]. Business and IT alignment is not a new research topic, but it is becoming increasingly important as DT allows multinational firms to change the rules of the game on a global scale [39]. Therefore, traditional businesses must adapt their strategy and business model in order to meet the difficulties posed by the environment, and these changes must be monitored and evaluated [39].

As a result, real-time demands could prompt quick responses in all supply chain parts [40], but also organizations must prepare for emergent behaviors. This reality is game-changing, and the complex part is the increasing information flows and system integration within organizations and along the supply chain [41]. Having said this, the industries require a robust, interconnected infrastructure that integrates sensors, industrial, and office devices in order to serve and operate the immensely complex supply chain. Continuous technological breakthroughs, such as those brought by I4.0, can help integrate data across the supply chain companies [1].

Therefore, understanding how this wealth of (big) operational data can be used in alignment with IT-driven frameworks like EA [41] is important. EA is an appropriate framework to manage the increasing supply chain information flows and data integration [42], as far as helps organizations adapt to change [57]. Aided by a modeling language, such as ArchiMate, EA can improve interchain coordination and point out specific key mechanisms, such as chain management, interchain sustainability, coordination, and interchain activity coherence [44]. Strategic management is thus responsible for aligning and integrating business and IT. Due to numerous relationships across EA models, while evolving towards diverse alternatives, enterprise architects face a major task in managing EA transition [45]. Considering the goal of this study to adopt I4.0 and identify strategies on EA, a list of the main topics discussed in each of the reviewed articles is described in Figure 3.12.

Chapter 4

Proposal

This Chapter is constituted by Section 4.1, addressing the Design and Development of the proposed Sectoral Enterprise Architecture Framework (SEAF) and its Roadmap.

4.1 Design and Development of SEAF

This section starts by introducing SEAF. Then follows subsection 4.1.2 where it is explained the structure of SEAF. Next, subsection 4.1.3 addresses the ontological mapping of ArchiMate for SEAF. Afterward, is SEAF Roadmap, its structure, and steps and ends with subsection 4.1.5 describing the Roadmap outputs.

4.1.1 Introducing SEAF

One of the first design decisions for SEAF was to innovate on the supply chain level while keeping it aligned with the most influential Enterprise Architecture (EA) frameworks and languages. The development of SEAF followed an incremental approach as the starting point, adapting influential EA frameworks to ensure better consistency and interpretation of the models by practitioners. Considering that SEAF aims to be an integrative framework, the first step was to follow The Open Group Architecture Framework (TOGAF) Architecture Development Method (ADM) and the (well-mapped with TOGAF) ArchiMate notation, due to their prominence and openness, which provided the initial inspirations for methodology and language, respectively. The next step was to develop the Vision Layer, which is aligned with the GEA's [23] coherence elements definition. Then, for the Digital Business Strategy Layer, the major inspiration came from the work done by the authors in [49]. The following step was to understand how Department of Defense Architecture Framework (DODAF) views and viewpoints could be used to extend the "strict company focus" and increase interoperability between supply chain segments of an entire sector. Lastly, for the development of Application and Technology Layers, Reference Architectural Model Industrie 4.0 (RAMI 4.0) [37] architecture explicitly created for Industry 4.0 (I4.0), provided a great source of knowledge and inspiration, also suggesting alignment with standards like IEC 62890, IEC 62264, and IEC 61512.

The next subsection explains and justifies the layers, along with SEAF's representation. Then describes the scope of each view and layer, followed by an explanatory description of the aforementioned.

4.1.2 SEAF Structure

SEAF fills a gap in traditional Enterprise Architecture Framework (EAF) by being domain-specific and ensuring supply chain coordination, not only by focusing on more internal aspects of the business but also by considering external ones. It is fundamental for an EAF structure to integrate the business, application, and technology layers [4]. However, the content of the layers and how the elements interact must respond to the needs imposed by the policies that influence each economic sector. For example, a company operating in the solar energy production sector (e.g., a glass producer, a solar panel producer, a virtual power plant operator) should create an EA that not only incorporates their "own" policies (as happens with TOGAF-based approaches) but also the policies, technologies, drivers, and applications that make the entire sector competitive. SEAF is depicted in Figure 4.1.

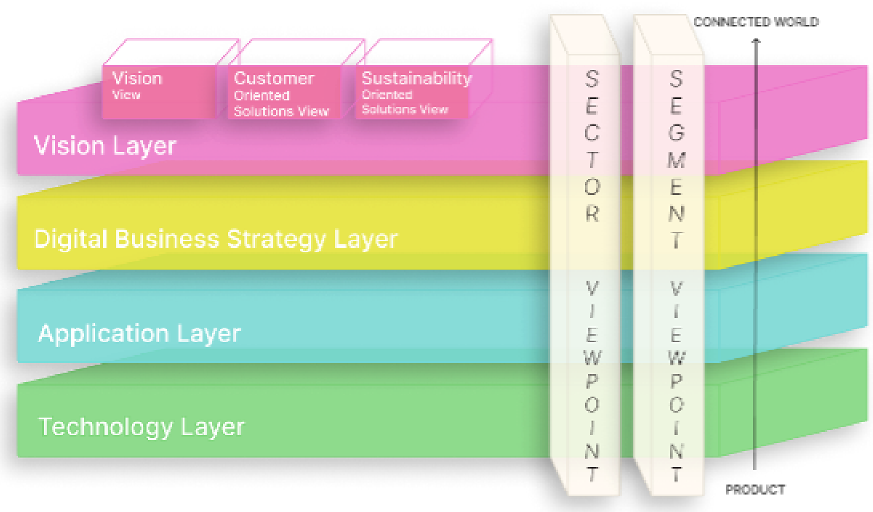


Figure 4.1: SEAF representation

The SEAF layers presented in Figure 4.1 are detailed in Table 4.1

Ref	Layer and Description
[3] [46] [32] [47]	**Vision Architecture Layer** Vision View • Identifying the sector stakeholders, external drivers, strategic vision goals, and the course of action to achieve them. Customer Oriented Solutions View • Representing customers' needs and demands by refining the customer experience. • Innovating the quality, origin, environmental and social impacts of the product. • Responding to dynamic market trends with specific timings. • Engaging with servitization, i.e., the relationship between the product and the service. Sustainability Oriented Solutions View • Engaging with the Sustainability Development concept to meet the needs of the current generations without compromising the environment and the ability of future generations to meet their own needs. • Innovating the products to product-service systems, extending the products' life cycle, changing the consumer patterns, and reducing the total use of products and materials.
[3] [48] [49]	**Digital Business Strategy Architecture Layer** • Evaluating the value propositions of products and services and to identify ways of interaction between supply chain segments and with the customer, promoting innovation, performance, optimization, and sustainable development.
[50] [49]	**Application Architecture Layer** • Representing the Smart Manufacturing applications and the I4.0 enabling technologies, e.g., Big Data and Analytics, Cloud Computing, Industrial Robots, or Additive Manufacturing, which enables service--oriented and event-driven information.
[50] [49]	**Technology Architecture Layer** • Identifying the devices responsible for collecting data, what data is relevant to collect, and where the devices are connected, considering the entire product lifecycle, since the early stages of production.

Table 4.1: Layers and Views of SEAF

Industrial sectors adopting I4.0 are pressured to respond to consumer needs, like mass personalization [2] and the development of sustainable practices [50]. These are examples of sectoral topics incorporated in the "Vision Architecture Layer", represented in the "Customer Oriented Solution View" and "Sustainability Oriented Solutions View", respectively. This first layer is followed by the "Digital Business Strategy Layer", which represents the business elements, such as roles, services, functions, and processes. The "Application Layer" follows, and finally, the "Technology Layer" will address SEAF infrastructure.

The contacts with industry experts highlighted the differences between each segment and specific links that can be established. For example, the association participating in our study is responsible for supplying specific information to the Ministry of Economics about the products sold (for energy planning procedures), requiring close contact with distributors. However, there are strategic links between segments, for example, refrigerator manufacturers and technical management, to understand the performance of the products in the market. These examples are difficult to capture in traditional EA projects focusing on a specific company. I4.0 applications' processes and applicability in the segment context must include the data sources, i.e., how and where the data is collected. This way, the critical data flows of the entire sector can be identified in the models. The "Sector Viewpoint" (Figure 4.6) and "Segment Viewpoint" (Figure 4.5) allows integrated and segmented analysis, respectively. The first, models the whole sector, representing products, consumers (or areas of interest), and (with less detail) the connections between each segment. The latter represents each segment in detail.

The following subsection presents the elements used to model SEAF views and viewpoints, ontologically mapped from ArchiMate.

4.1.3 Ontologically Mapping ArchiMate for SEAF

The ontological mapping aims to define a presentation that is meaningful to stakeholders, valuable to management, and compatible with the organization's culture. Therefore, to develop the views and viewpoints for SEAF using ArchiMate, the first step was to map the SEAF elements with the ArchiMate concepts, presented in the above Table 4.2 and Table 4.3). Each ArchiMate concept and description are extracted from the ArchiMate 3.0.1 Specification document [33].

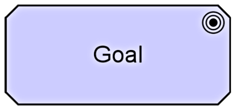
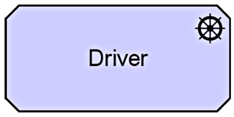
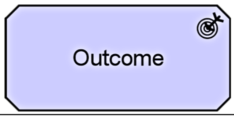
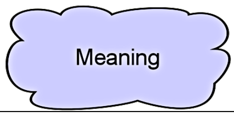
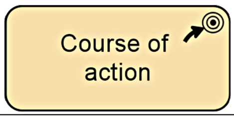
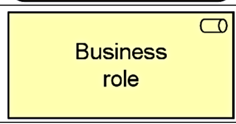
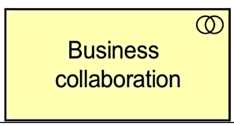
SEAF Notation & Concept Description	**ArchiMate Elements**
Stakeholder - represents sector associations, potential entities interested in the sector, and external entities that encourage the existence of drivers or entities with whom the sector has obligations.	
Vision (Goal) - describes what the sector is, what it stands for, and its purpose. It explains the sector's existence and its wanted path. **Strategy** (Goal) - defines the long-term goals and the plan each segment must follow to achieve them toward the mission.	
Customer Oriented Priorities (Driver) - external factors that stimulate innovation in the sector to respond to consumer demands in terms of the product and service delivered. **Sustainability Oriented Priorities** (Driver) - external factors that encourage the adoption of sustainable economic, environmental, social, and technological practices, which will be reflected in the sector's processes, products, and services.	
Outcome - describes the tangible results from the implemented courses of action and how they impact the Customers.	
Touchpoint Meaning - represents the intention/meaning of a stakeholder in interacting with the sector.	
Course of Action - represents actions that the segment can adopt regarding internal processes, the product itself, and its services to achieve the established goal.	
Business Role - the role of a person or group of people whose functions are within the sector and include realizing the tasks to achieve the goal.	
Business Process - an activity that, when consistently performed, contributes to achieving a segment's specific process purpose.	
Business Function - specific set of activities from one segment of the sector supply chain which transforms inputs into outputs.	
Business Service - associated with the product that changes according to the functions that the segment can provide.	
Business Collaboration - can be established with another segment (e.g., exploring joint investments with I4.0 technologies to improve horizontal integration) or partnership.	

Table 4.2: ArchiMate and SEAF Ontological Mapping

SEAF Notation & Concept Description	**ArchiMate Elements**
Product - the final output(s) of the sector. It aggregates the services that each segment can provide.	Product
Smart Manufacturing Application Component - represents the I4.0 smart manufacturing applications and their purpose.	Business service
Application Function - identifies the function of the application (e.g., IoT-based applications) in the data collection.	Application function
Application Process - describes the behavior of smart manufacturing applications.	Application process
Application Service - describes the applicability and the tangible impact of smart manufacturing applications.	Application service
Data Object - identifies the information that can be obtained by the service performed by a smart manufacturing application, e.g., IoT.	Data object
Application Collaboration - the application collaboration that can be established with another segment or partnership.	Application collaboration
Application Interaction - interactions between applications pertaining to a larger system.	Application interaction
Application Interface - the interface where the user can manage the I4.0 application services.	Application interface
Equipment - identifies relevant physical machines for the tasks carried out in the segment or the physical product.	Equipment
Material - identifies essential raw materials for the segment to develop the product.	Material
Operation Place - represents where the segment processes actuate.	Facility

Table 4.3: ArchiMate and SEAF Ontological Mapping - Continuation

The previous Tables 4.2 and 4.3 represent the 21 essential elements found in Archimate for SEAF. The first elements, in purple, are used to model the Motivation relationships. The second element, in orange, is used to model Strategy actions. Third, the elements in yellow, are used to describe the Digital Business Strategy Layer, while the fourth elements, in blue, represent the applications interaction of the Application Layer, and the last ones, in green, describe the physical technologies of the Technology Layer. The next subsection introduces the

SEAF Roadmap.

4.1.4 Introducing SEAF Roadmap - Structure and Phases

The methodological guidance for applying SEAF in practice follows the TOGAF ADM [4]. TOGAF ADM found out to be suitable to the sectoral EA steps with minor adaptations subsequently presented. Therefore, the SEAF Roadmap starts with the **Preliminary Phase** and **Phase A: Architecture**. The next three phases are **Phase B: Business Architecture**, **Phase C: Information System Architecture**, and **Phase D: Technology Architecture**. The last phase adopted from ADM is **Phase E: Opportunities and Solutions** [29]. The following Figure 4.2 represents the mapping from TOGAF ADM Phases to SEAF Roadmap Phases.

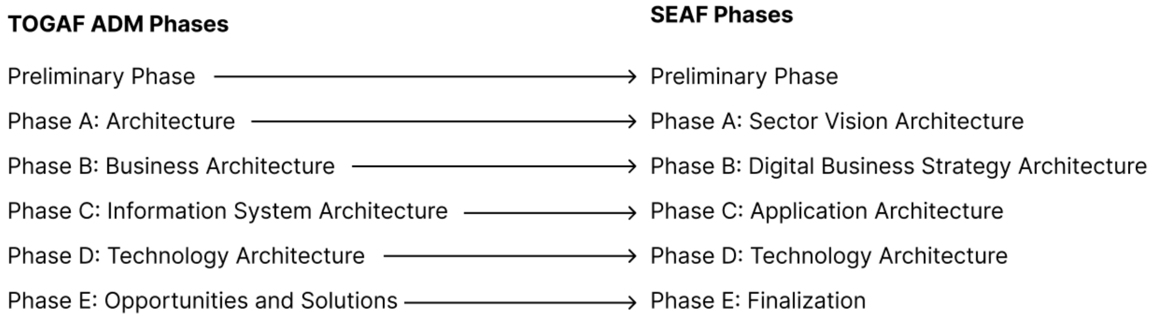


Figure 4.2: TOGAF ADM Phases to SEAF Phases

Following the TOGAF ADM inspired sequence, the objective is to (1) represent the industrial sector and its segments ("as – is" architecture) and (2) propose the digital transformation opportunities supported on I4.0 technologies ("to – be" architecture). Therefore, the proposal for the SEAF Roadmap follows the phases previously presented and has several outputs. From the Preliminary Phase and from Phase A it is obtained the Sector Scope and the Sector Vision. These two models contribute to developing, in Phase E: Finalization, the final viewpoints: the Segment and the Sector Viewpoints. Thus, SEAF Roadmap is presented as follows:

Preliminary Phase

This phase determines the architecture capability and for SEAF this reflects on defining the Sector Scope, by identifying the sector, the segments, the products, and the customers or fields of interest.

1. Identify the Sector Scope.
   (a) Identify the association.
   (b) Identify the sector.
   (c) Identify the sector segments.

   (d) Identify the Portfolio of Products in the sector.
   (e) Identify the key Customers/Areas of Activity/Type of Applicability.

2. Represent the Sector Scope.

Phase A: Sector Vision Architecture

This phase identifies the main stakeholders and their concerns, the external drivers, and the strategic goals that the sector can embrace.

1. Develop the Sector Vision View
   (a) Identify the Vision of the sector.
   (b) Identify the sector Stakeholders, e.g., partners, and interested entities.
   (c) Identify the Touchpoint Meaning with the identified Stakeholders, i.e., what is the reason for the relationship with the sector in terms of what information or documents they share with each other.
2. Develop the sector Customer Oriented Solutions View
   (a) Identify the Customer-Oriented Drivers.
   (b) Identify the Stakeholders associated with the Customer-Oriented Drivers.
   (c) Associate the Stakeholders with the Customer-Oriented Drivers.
   (d) Identify the Strategic Goals that the sector must define to put into action the Customer-Oriented Drivers' intentions.
3. Develop the sector Sustainability Oriented-Solutions View
   (a) Identify the Sustainability-Oriented Drivers.
   (b) Identify the Stakeholders associated with the Sustainability-Oriented Drivers.
   (c) Associate the Stakeholders with the Sustainability-Oriented Drivers.
   (d) Identify the Strategic Goals that the sector must define to put into action the Sustainability-Oriented Drivers' intentions.
4. Represent the Sector Vision Viewpoint.

Phase B: Digital Business Strategy Architecture

This phase describes the course of action to achieve the strategic goals defined in the Sector Vision Architecture. This relies on identifying, for each segment the business functions, processes, services, roles, and collaborations.

1. Develop the Digital Strategy Business Architecture Layer, for each segment
   (a) Identify for this segment the main Drivers, Stakeholders, and Goals.

(b) Outline the Course of Action, i.e., the strategic steps to achieve each Goal.
(c) Identify the principal Business Function performed in this segment.
(d) Identify the key Business Processes, performed within the Business Function, such as responsibilities or main processes of the segment.
(e) Identify the key Business Role that represents a set of tasks and responsibilities of the person who performs the Business Processes in this segment.
(f) Identify the key Business Services of this segment, realized by the Business Function, with impact on the final product.

Phase C: Application Architecture

This phase describes how data and applications enable the Business Architecture and the Sector Vision Architecture, identifying the application processes and services.

1. Develop the Application Architecture Layer, for each segment
   (a) Identify the key Application Functions regarding the type of data they collect.
   (b) Identify the Application Interaction that performs the collection of this data.
   (c) Describe the ETL Application Process and identify the Application Interaction technology responsible.
   (d) Identify the Smart Manufacturing Application Component and its applicability.
   (e) Identify the Application Process with an effective impact on the product or service.
   (f) Identify if there is a User Application Interface and through what.

Phase D: Technology Architecture

This phase identifies the physical applications and logical data components that enable the applications identified in the Application Architecture Phase.

1. Develop the Technology Architecture Layer, for each segment
   (a) Identify the Node as a representation of the devices, e.g., Sensors.
   (b) Identify the Facility as a representation of where the devices can be assigned.
   (c) Identify the Equipment, e.g., machines, transports, or tools where the devices can be assigned.

(d) Identify relevant Raw Materials for this segment to work for/on the product.

2. Collaboration

   (a) Identify the significant Collaborations this segment could establish, at business and application levels. This collaboration can be with another segment of the supply chain or with external entities.

Phase E: Finalization

This phase generates the complete version of the SEAF views and viewpoints, throughout the adoption of previous steps of the SEAF Roadmap.

1. Represent the Sector Viewpoint.
2. Represent the Segments Viewpoints.

The SEAF Roadmap ends in **Phase E: Finalization** where the Sector and the Segments Viewpoints are modeled and represented. Therefore, the next subsection represents all the SEAF Roadmap outputs, including the Sector Scope and the Sector Vision Viewpoint.

4.1.5 SEAF Roadmap Outputs

SEAF embodies the four layers previously explained in subsection 4.1.2 with the ontologically mapped elements from ArchiMate in subsection 4.1.3. The layers of SEAF are directly correlated with the layers that ArchiMate models. Regarding the views and viewpoints conceived for SEAF, these are also not considered in ArchiMate documentation. Therefore, the views and viewpoints of SEAF come to fill in the gap. In this way, the first presented view is Sector Scope (Figure 4.3), followed by the Sector Vision Viewpoint (Figure 4.4), then the Segment Viewpoint (Figure 4.5), and lastly the Sector Viewpoint (Figure 4.6).

Sector Scope

The Sector Scope represents the sector Product Portfolio, associated with the sector Customer(s) and the relationship to the various segments, which are sequentially represented, accordingly with the supply chain workflow. Figure 4.3 depicts the Sector Scope.

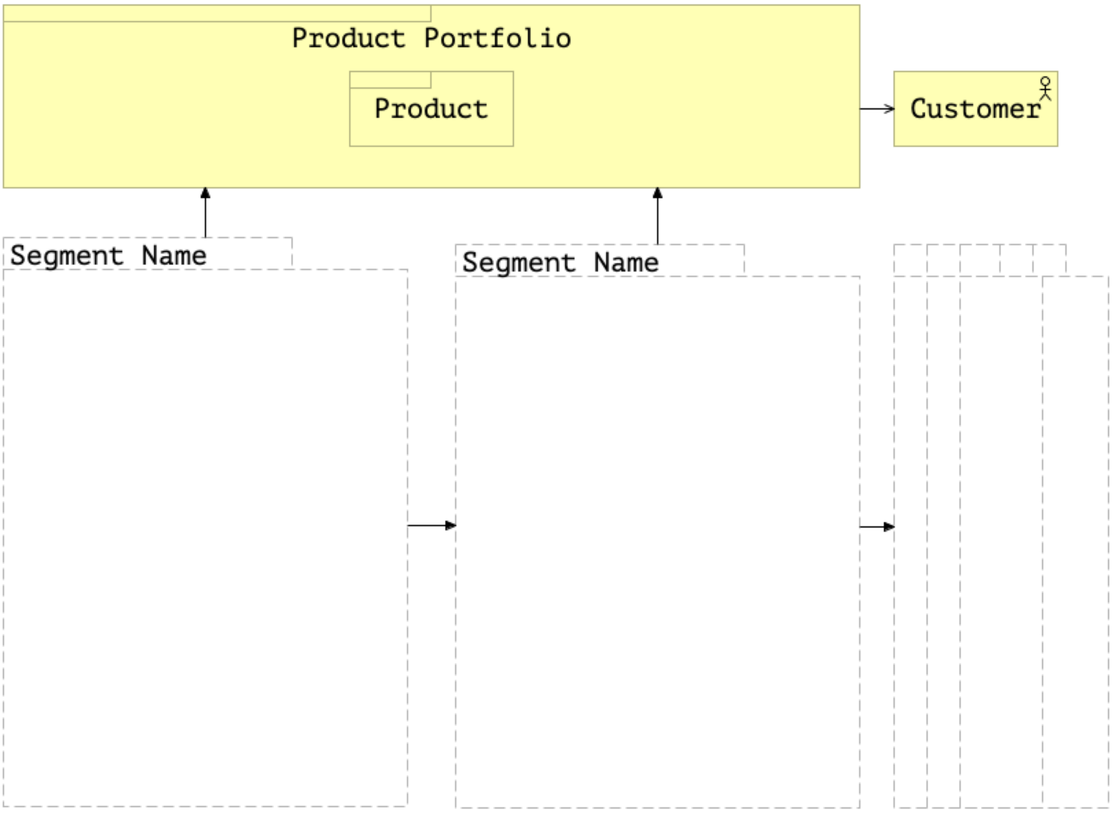


Figure 4.3: Sector Scope

The Sector Scope is then incorporated into the Segment Viewpoint (as it is explained in Segment Viewpoint, presented ahead). The Sector Scope is also adapted to the Sector Viewpoint (which is clarified in Sector Viewpoint, further down). The following explains the Sector Vision Viewpoint.

Sector Vision Viewpoint

The Sector Vision Viewpoint is an aggregation of the three views stated earlier in subsection 4.1.2: Vision View, Customer Oriented Solutions View, and Sustainability Oriented Solutions View. Thus, in Figure 4.4 the Customer Oriented Drivers, the Sustainability Oriented Drivers, and the associated Strategic Goal(s) are identifiable. The aforementioned drivers are associated with the Stakeholders, which ultimately define the Sector Vision Viewpoint. Their relationship with the sector is described by the Touchpoint Meaning element.

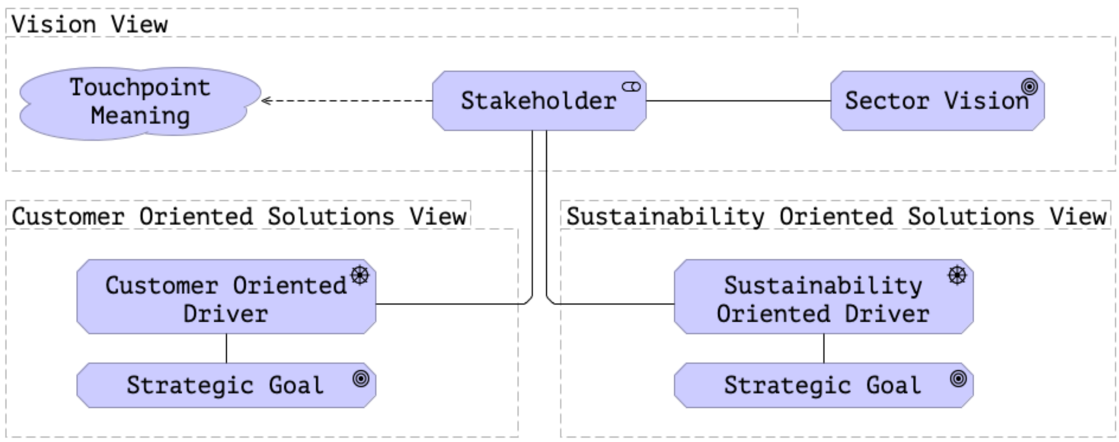


Figure 4.4: Sector Vision Viewpoint

This viewpoint is then incorporated into the Sector Viewpoint, as explained ahead in Figure 4.6. Additionally, apart from being associated with the drivers and goals of the sector, each segment also has external factors and specific goals of its own context. Therefore, the Sector Vision Viewpoint is also incorporated into the Segment Viewpoint, by linking the motivation elements with the remaining ones, establishing a cause-effect relationship, that can be seen with the following description regarding the Segment Viewpoint.

Segment Viewpoint

The Segment Viewpoint integrates all five ArchiMate layers. As stated before, at the top of Figure 4.5 is the incorporation of the Sector Scope and the adaptation of the Sector Vision Viewpoint, linked with the other elements.

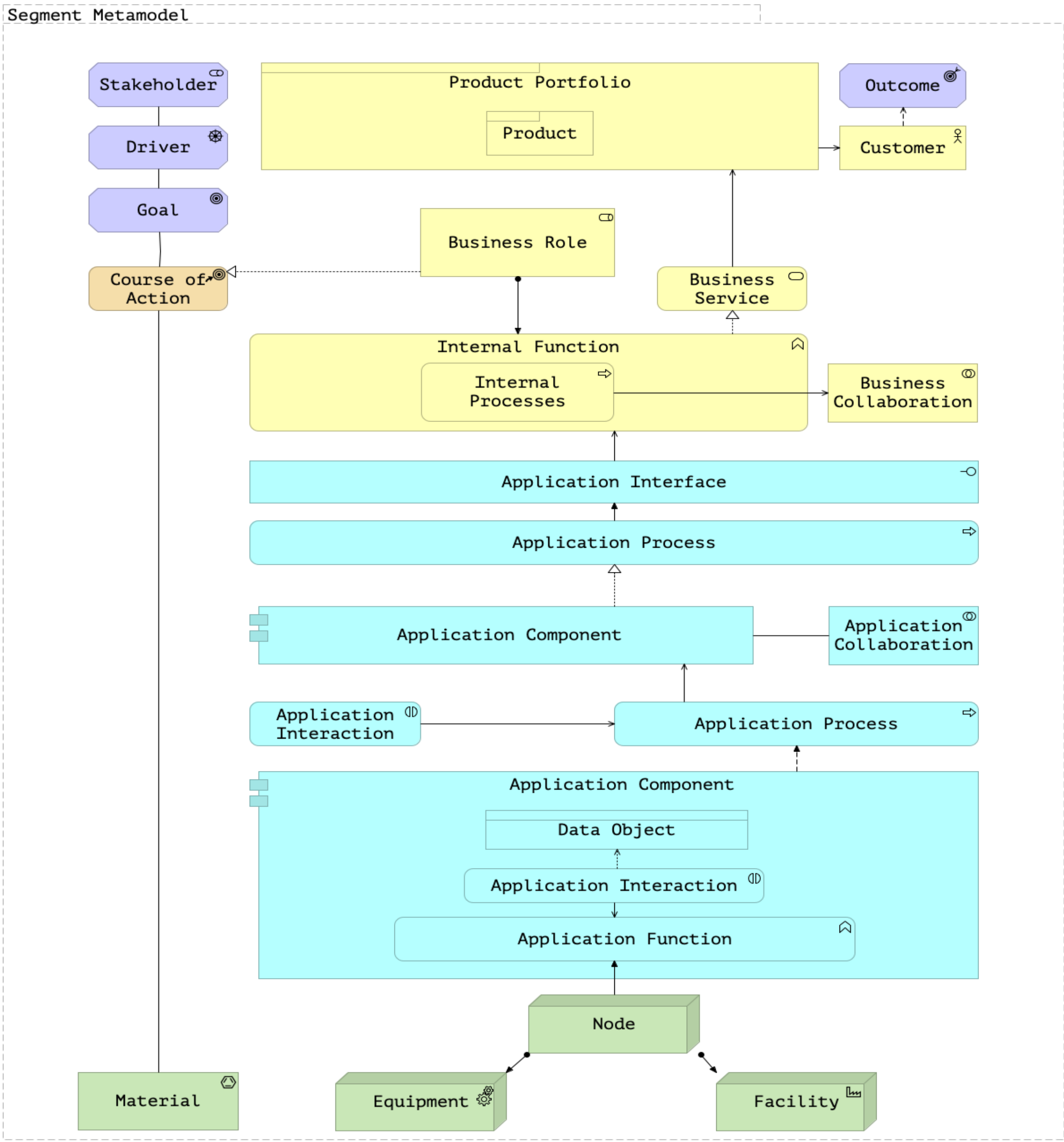


Figure 4.5: Segment Viewpoint

Regarding the motivation elements, the Stakeholder fosters the Drivers (i.e., external factors) which in turn leads the segment to define the Goals for addressing it. The Course of Action is defined and is directly linked with the business capabilities/responsibility of the segment. Here the role of Digital Transformation (DT) takes place, by leveraging business internal processes, functions, services, and collaborations (with other segments) modeled in the Digital Business Strategy Layer through I4.0 technologies. The Application Layer models the I4.0 components, processes, functions, and interactions within the technologies' role.

Regarding the data collection, the Application Component at the bottom of this layer is intended to describe that process, being directly linked with the elements from the last layer, the Technology Layer. The former addresses the diverse types of Nodes (i.e., devices) that collect the different types of data from Equipment and/or Facility. Additionally, certain Materials (i.e., raw materials) can be associated with the Course of Action, as a means to achieve a Goal. Lastly, at the top, the Outcome element, associated with the Customer element, is the ultimate achievement of this viewpoint, reflecting the impact of the segment's work.

The Segment Viewpoint is modeled for each segment identified within the sector in scope. Thus, generates as many versions as there are segments. Moreover, regarding the Segment Viewpoint, the "as - is" and the "to - be" architectures are modeled for each segment. To clarify, the "as - is" architecture intends to model the existing architecture of the segment, whereas the "to - be" architecture aims at proposing a possible DT architecture, focusing on the Application and Digital Business Strategy Layers. The following addresses the Viewpoint Sector, which is a synthesized coupling of the Viewpoint Segment of the "as - is" architectures from all segments.

Sector Viewpoint

Similar to the Segment Viewpoint, the Sector Viewpoint also integrates all five ArchiMate layers. Furthermore, this being a synthesized coupling of the Viewpoint Segment of the "as - is" architectures from all segments, both viewpoints follow a similar structure. Thus, at the top of the following Figure 4.6 is the incorporation of the Sector Scope and, at the left, the adaptation of the Sector Vision Viewpoint.

This viewpoint represents the segments sequentially, following the sector's supply chain workflow. The modeled relationship between the business's Internal Function element, of the various segments, highlights this connection visually. Regarding the content of this viewpoint, each business and application element points to the key service, role, function, and component carried out in that segment, since the purpose is to give a general overview without going into too much detail.

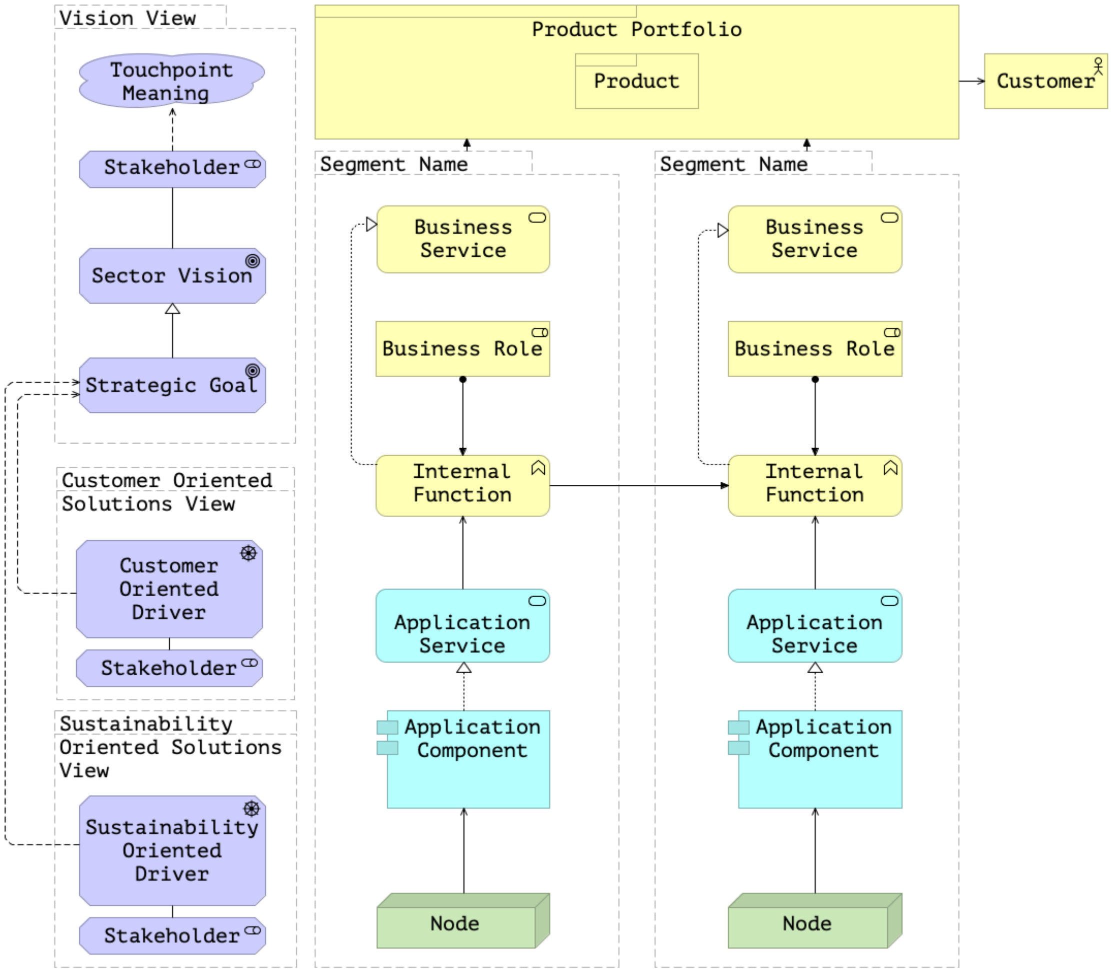


Figure 4.6: Segment Viewpoint

The following Chapter presents the demonstration of all the previously described models, applied to the Air Conditioning and Refrigeration Sector (ACRS), giving a better understanding of their usability.

Chapter 5

Demonstration

This Chapter presents the demonstration of the proposed Sectoral Enterprise Architecture Framework and ends with the evaluation of SEAF, in Section 5.2.

5.1 Applicability and Demonstration of SEAF

This section starts in subsection 5.1.1 by introducing the case study with Air Conditioning and Refrigeration Sector (ACRS) and contextualizing the role of the Sectoral Enterprise Architecture Framework (SEAF) for the Associação Portuguesa da Indústria da Refrigeração e Ar Condicionado (APIRAC). Subsection 5.1.2 demonstrates the applicability of SEAF, regarding the "as - is" architecture, and ends with subsection 5.1.3, presenting the "to - be" architecture proposal.

5.1.1 Introducing the Case Study

Initial meetings were held with the APIRAC experts, providing an understanding of the ACRS characteristics, and the particularities of each segment and recognizing the existing Digital Transformation (DT) opportunities. The complete APIRAC sector has six segments and SEAF's output is divided into the "as - is" architecture and the "to - be" architecture, returning six Segment Viewpoints. Regarding the "as - is", the Sector Scope and the Sector Vision and the Sector Viewpoint are also returned. Therefore, the demonstration of ACRS for APIRAC provides a first template of SEAF's applicability and demonstrates its usefulness. Also, it can contribute to supporting other industry sectors' adoption.

SEAF integrates two prominent societal trends in today's society (e.g., responding to customer needs and engaging with sustainability development goals) and aligns them with I4.0. Thus, SEAF Application Layer provides visibility to Industry 4.0 (I4.0) technologies, their processes, and the services they enable. Furthermore, this layer is intrinsically linked to the Vision Layer, as it represents the Course of Action to respond to the strategic goals, which in turn realizes the drivers' ambitions and stakeholders' interests. The following subsection demonstrates the "as - is" architecture of ACRS for APIRAC.

5.1.2 SEAF "as - is" Architecture

This subsection presents the applicability of SEAF views and viewpoints of ACRS, for APIRAC. First, it presents the Sector Scope for APIRAC with Figure 5.1, followed by the Sector Vision Viewpoint for APIRAC with Figure 5.2. Then comes the Segment Viewpoints with Figures 5.3 and 5.4. Considering that the industry under study has six segments, there have been conceived six Segment Viewpoints for the "as - is" architecture. The present demonstration uses two out of the six Segment Viewpoints as examples, namely the Environmental Hygiene and Indoor Quality Segment Viewpoint and the Installation, Maintenance, and Technical Assistance Segment Viewpoint. These Segment Viewpoints were chosen because they are the most characteristic segments of the sector and have shown great potential in adopting I4.0. The subsection ends the demonstration with the Sector Viewpoint for APIRAC, Figure 5.5.

Sector Scope for APIRAC

The Sector Scope for APIRAC is presented in Figure 5.1.

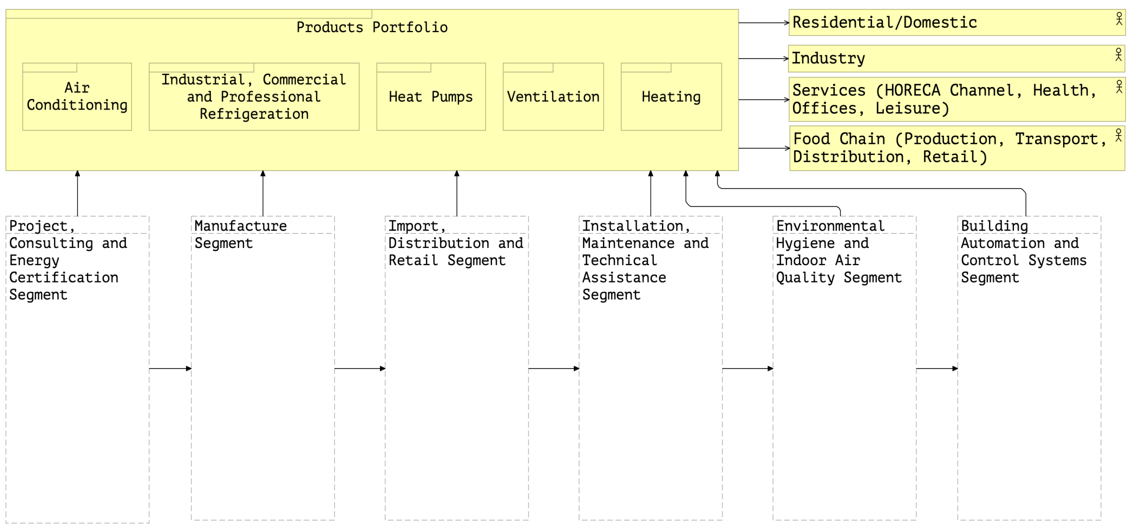


Figure 5.1: ACRS Scope for APIRAC

Figure 5.1 represents the Product Portfolio, namely: Air Conditioning, Industrial, Commercial, and Professional Refrigeration, Heat Pumps, Ventilation, and Heating. On the right are the Customers/Areas of Activity, such as Residential/Domestic, Industry, Services, and the Food Chain. The Sector Scope represents all the segments following the supply chain workflow, being that the Project, Consulting, and Energy Certification Segment; the Manufacture Segment; the Import, Distribution, and Retail Segment; the Installation, Maintenance, and Technical Assistance Segment; the Environmental Hygiene and Indoor Air Quality Segment; and the Building Automation and Control Systems Segment. The following is an explanation of the Sector Vision Viewpoint. Both the Sector Scope and the Sector Vision are integrated into the Segment Viewpoint and the Sector Viewpoint.

Sector Vision Viewpoint for APIRAC

This Figure represents the drivers of both Customer and Sustainability Oriented Solutions Views, associated with the goals outlined by the sector. Additionally, the stakeholders influence the drivers, depicting the link between the two in the Viewpoint. The touchpoint meaning element represents the issue of the connection between the stakeholders and the sector.

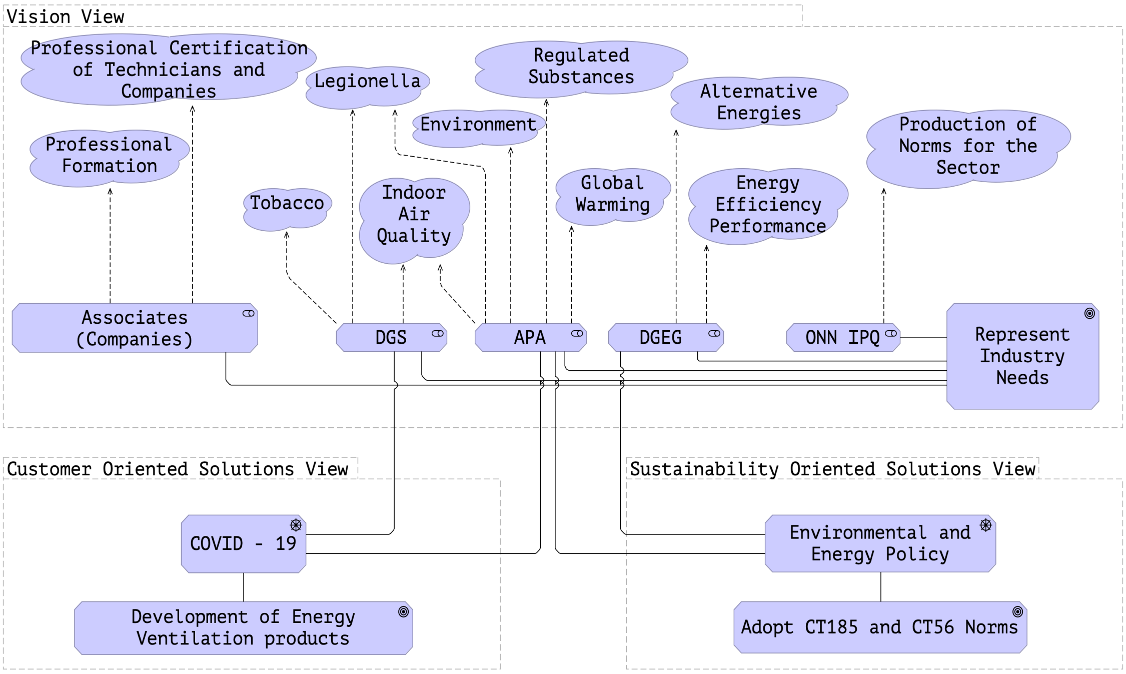


Figure 5.2: ACRS Vision Viewpoint for APIRAC

Figure 5.2 represents the various entities with which APIRAC maintains frequent communication to meet the sector's needs and to comply with imposed requirements by certain stakeholders (i.e., DGS, APA, DGEG, ONN IPQ). The main concerns that APIRAC has to communicate or discuss are related to information about Tobacco Regulation, the Energy Performance of Equipment, and Indoor Air Quality, among others. Finally, the two current focuses of the sector are customer and sustainability-oriented factors, triggered by the mitigation of COVID-19 and the standards placed by the Energy Environmental Policies. Follows the introduction of the Segment Viewpoint with the demonstration of two segments of ACRS.

Segment Viewpoint for the Environmental Hygiene and Indoor Quality Segment

Figure 5.3 represents the modeled "as - is" architecture of the Environmental Hygiene and Indoor Quality Segment.

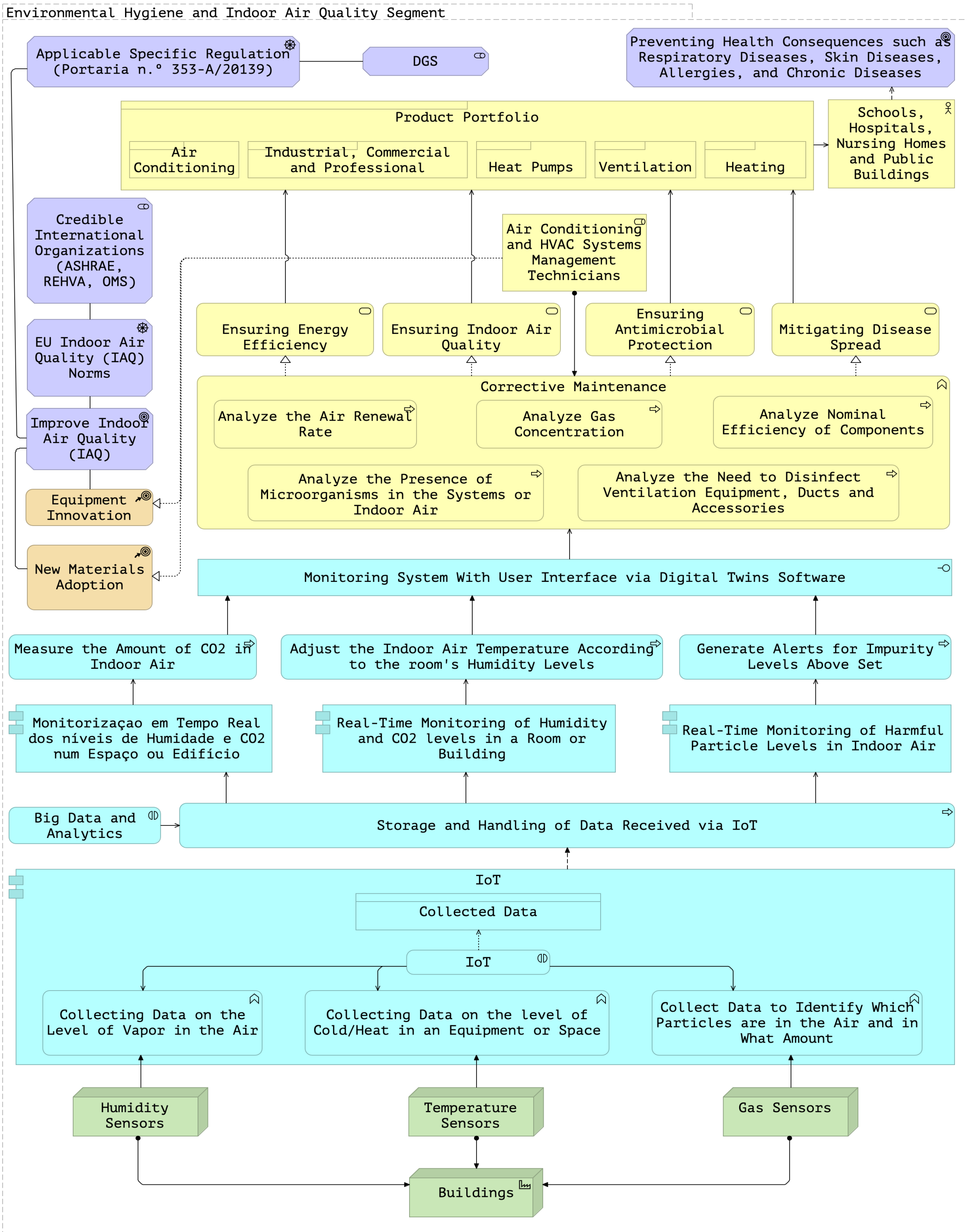


Figure 5.3: Environmental Hygiene and Indoor Quality Segment Viewpoint

To model this segment, the first step was to integrate the Sector Scope, adapting the Customer element to its reality. The second step was to (1) identify the

Drivers that specifically impact the segment in question, such as the "EU Indoor Quality Norms", (2) what/which Stakeholders have an influence on them ("Credible International Organizations"), and (3) the Goals defined to address the situation, such as "Improve the Indoor Air Quality". Associated with the latter are the Courses of Action that the segment undertakes, which in this case are "Equipment Innovation" and "New Materials Adoption". Thus, the motivation and strategy elements allied to the business elements constitute the starting point for defining the direction of the segment.

The information collected about the ACRS at APIRAC, regarding the business processes in this segment, primarily involves analyzing the air renewal rate, examining the presence of microorganisms in systems or indoor air, and evaluating the concentration of gases in spaces, among other factors mentioned in Figure 5.3. These processes support the segment's business services, which are: ensuring energy efficiency, indoor air quality, antimicrobial protection, and mitigating the spread of diseases.

Concerning the technology identified as "in use" in this segment, it is based on the gathering of data through IoT, and later stored and processed. This process is allowing real-time monitoring of the humidity and CO^2 levels in the air, as well as the levels of harmful particles to health. This way, technological processes such as measuring and regulating CO^2 levels in the air, adjusting air temperature, and generating safety alerts about impurity levels are possible.

The above description showcases the potential insights that can be derived from this Segment Viewpoint, illustrating the extensive information that can be obtained from this comprehensive model. The following example exemplifies the practical application of the Viewpoint Segment to the Installation, Maintenance, and Technical Assistance Segment.

Segment Viewpoint for the Installation, Maintenance, and Technical Assistance Segment

Figure 5.4 represents the modeled "as - is" architecture of the Installation, Maintenance, and Technical Assistance Segment.

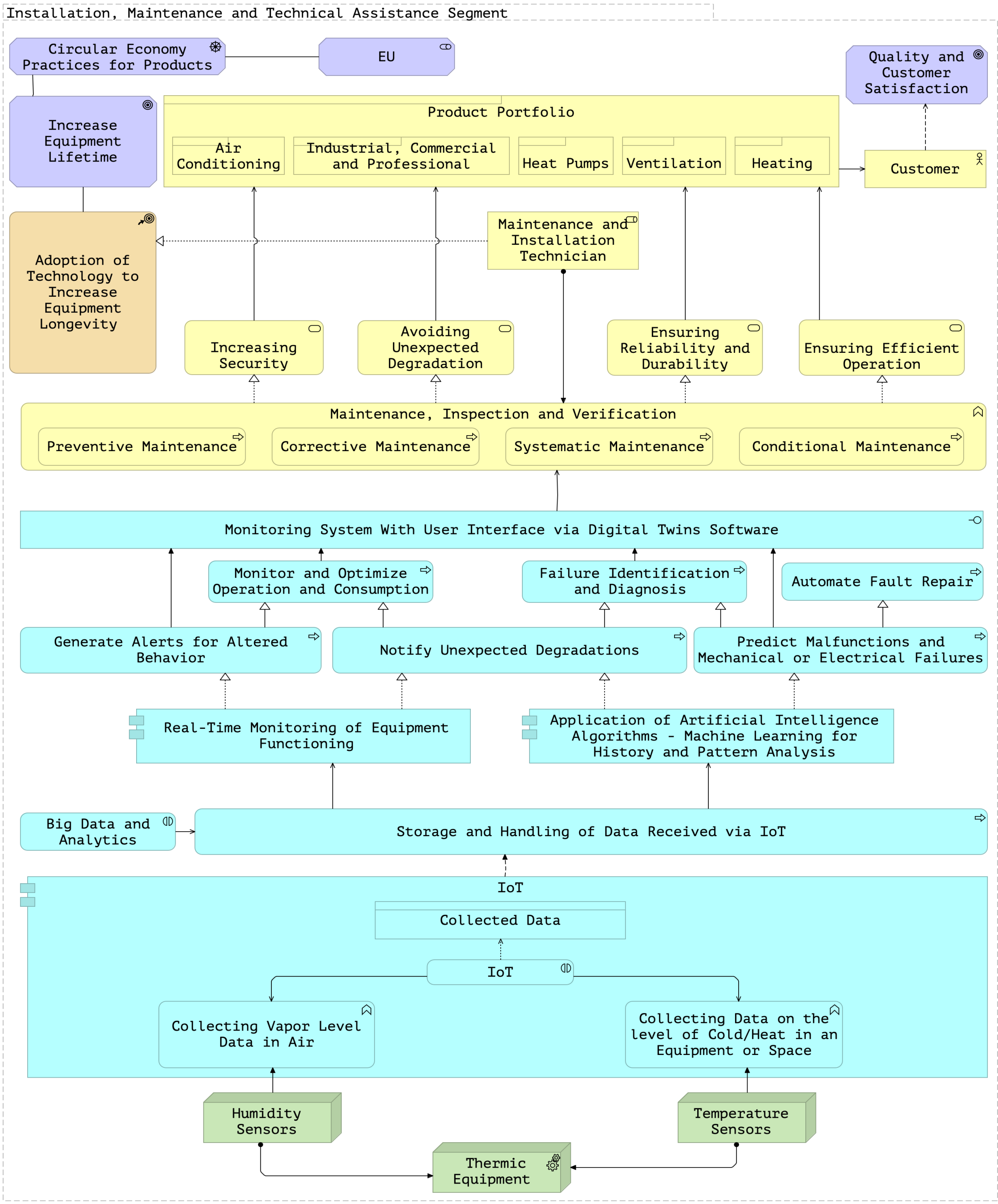


Figure 5.4: Installation, Maintenance, and Technical Assistance Segment

To model this segment, the first step was also to integrate the Sector Scope, adapting the Customer element to its reality. The second step was to (1) identify the Drivers that specifically impact the segment in question, such as the "Circular Economy Practices for Products", (2) what/which Stakeholders have an influence on them ("EU"), and (3) the Goals defined to address the situation, such as "Increase Equipment Lifetime". Associated with the latter are the Courses of Action that the segment undertakes, which in this case is "Adoption of technology to Increase Equipment Longevity". Moreover, the main outcome identified for this segment (which impacts the Customer) is "Quality and Customer Satisfaction". Thus, the motivation and strategy elements allied to the business elements constitute the starting point for defining the direction of the segment.

In terms of business processes, the information collected about the ACRS at APIRAC for this segment highlights several key maintenance types, namely preventive, corrective, systematic, and conditional maintenance. These processes form the foundation of the segment's business services, which include enhancing security, preventing unexpected degradation, ensuring reliability and durability, and promoting efficient operation.

Regarding this segment, the technology identified as "in use" revolves around the collection of data through IoT, which is later stored and processed. This process enables real-time monitoring of equipment functioning and supports Artificial Intelligence (AI) algorithms. As a result, technological processes such as generating alerts for altered behavior, notifying about unexpected degradation, and predicting malfunctions and mechanical or electrical failures become possible.

This Segment Viewpoint provides a comprehensive understanding of the subject matter, showcasing the diverse amount of information that can be obtained. It is not only beneficial for APIRAC but also for external entities interested in gaining insights into the segment. This single model serves as a valuable resource for all stakeholders involved, offering valuable knowledge and insights. The remaining "as - is" Segment Viewpoints, in Appendix A. The following subsection presents the Sector Viewpoint ACRS for APIRAC.

Sector Viewpoint for APIRAC

Figure 5.5 represents the modeled "as - is" architecture of the ACRS Sector Viewpoint for APIRAC.

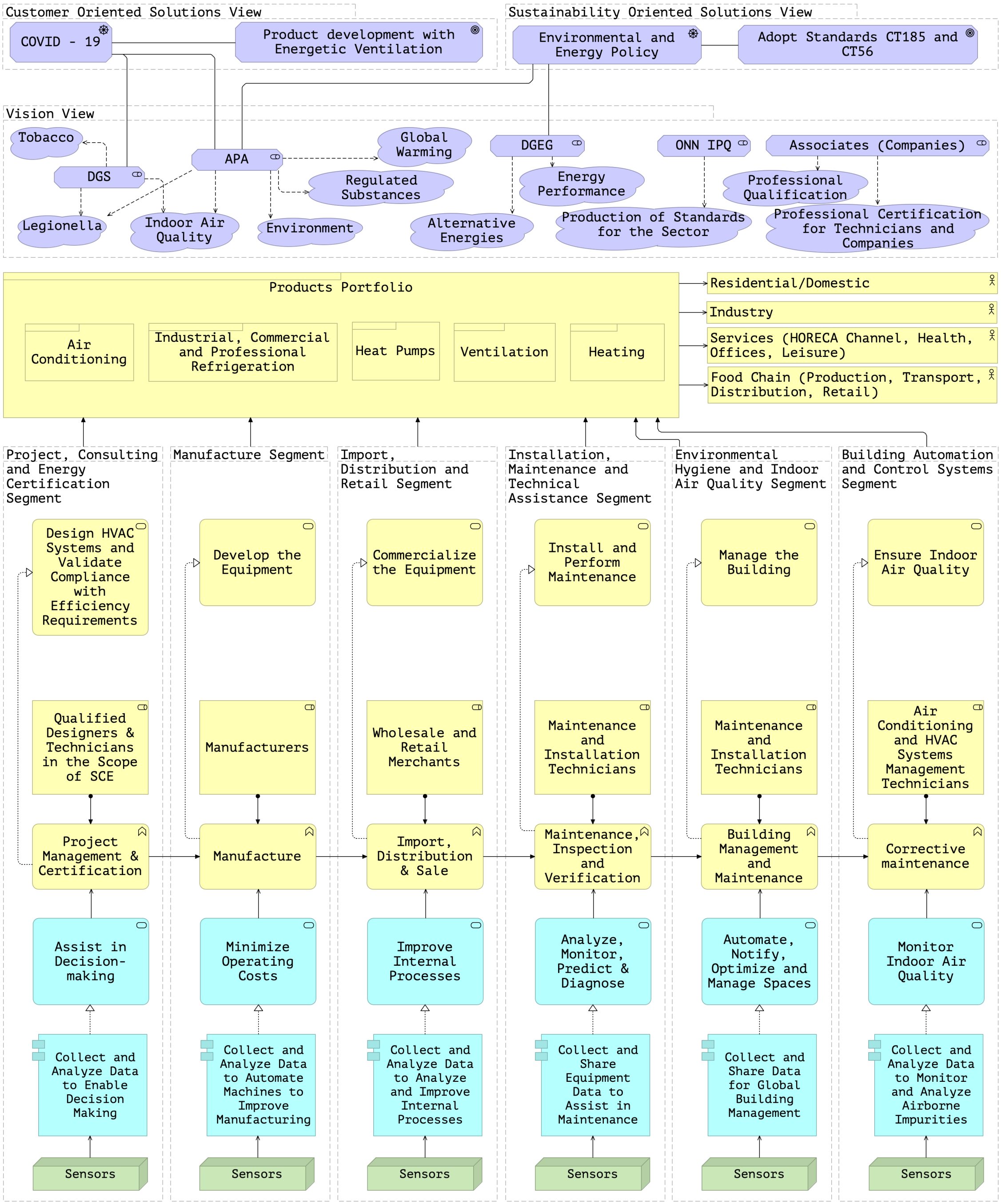


Figure 5.5: ACRS Sector Viewpoint for APIRAC

As in Figure 5.5, the Vision Viewpoint is incorporated at the bottom of the Sector Viewpoint and the Sector Scope, is at the top. This viewpoint represents the segments sequentially, following the sector's supply chain workflow, starting in the Project, Consulting, and Energy Certification Segment and ending in the Building Automation and Control Systems Segment. This viewpoint offers the opportunity to gain insights into the sector by providing a brief overview of each segment. Each segment has its own layered architecture, and through this viewpoint, a comprehensive understanding of the sector can be achieved.

The following subsection introduces the proposed "to - be" architecture Segment Viewpoints, for the Digital Transformation in the ACRS, for APIRAC.

5.1.3 SEAF "to - be" Architecture

This subsection is focused on the "to-be" architecture for APIRAC, by presenting the proposal for the DT of the sector, suggesting the technologies with the most impact and added value for each segment. For clarity, the "to-be" architecture focuses on the Application and Business Layers. The selected business function, processes, services, and segment scope remain the same, relative to the "as-is" architecture of the segment. The "to-be" proposal is based on the I4.0 trends [51] and experts' insights collected during this study. All segments are modeled following the same approach, ultimately reaching completeness. The Segment Viewpoint allows understanding the relationship between the elements, i.e., in the Application Layer, is possible to identify the IoT, Cloud, and Edge Computing opportunities. The following presents the "to - be" architecture for the Segment Viewpoint of the Environmental Hygiene and Indoor Quality Segment.

Segment Viewpoint for the Environmental Hygiene and Indoor Quality Segment

Figure 5.6 represents the proposed "to - be" architecture for the DT of the Environmental Hygiene and Indoor Quality Segment. For this segment, some fundamental processes were considered to outline the integration with I4.0 technology, namely: analyzing the air renewal rate; analyzing the presence of microorganisms in systems or indoor air; and analyzing the concentration of gases in spaces, among others. The proposal for DT in this segment is essentially focused on the use of AI integrated with other technologies, namely connected equipment, real-time monitoring, and voice recognition. Through connected equipment management, technicians can control the various types of equipment, adjusting them to the needs of the spaces. Regarding real-time monitoring, it enables the automated verification of air quality and helps improve air diagnosis. Finally, voice recognition enables "hands-free" control of equipment in spaces.

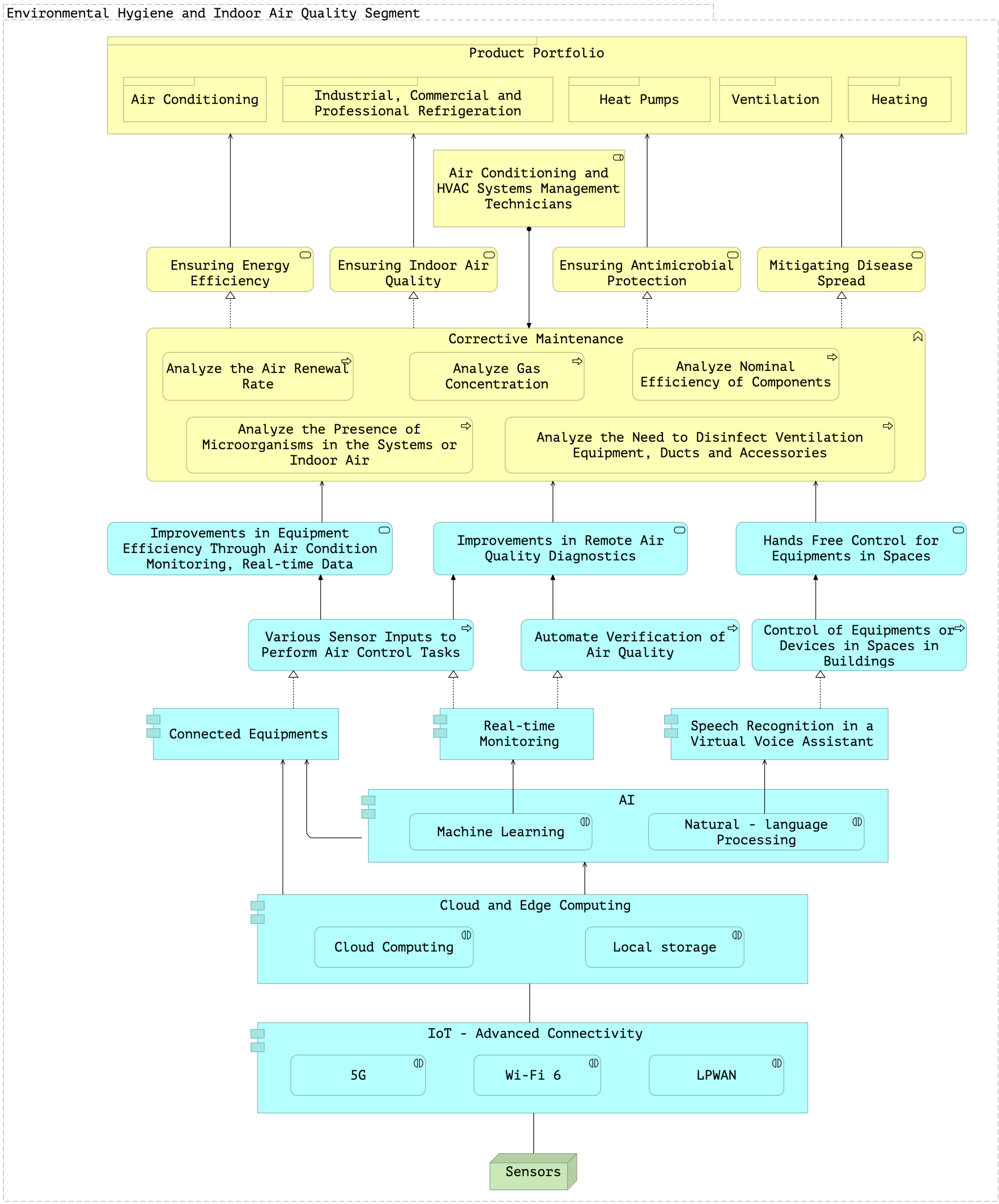


Figure 5.6: Environmental Hygiene and Indoor Quality Segment Viewpoint

The technological processes and inherent services proposed for this segment are aimed at ensuring energy efficiency, indoor air quality, antimicrobial protection, and mitigating the spread of diseases. The operation of these technologies is always based on the existence of databases (Cloud and Edge Computing) and the collection of such data through IoT, which at the industrial level, is mostly done through sensors. The following presents the other segment demonstration of ACRS for APIRAC.

Segment Viewpoint for the Installation, Maintenance, and Technical Assistance Segment

Figure 5.7 represents the proposed "to - be" architecture for the DT of the Installation, Maintenance, and Technical Assistance Segment.

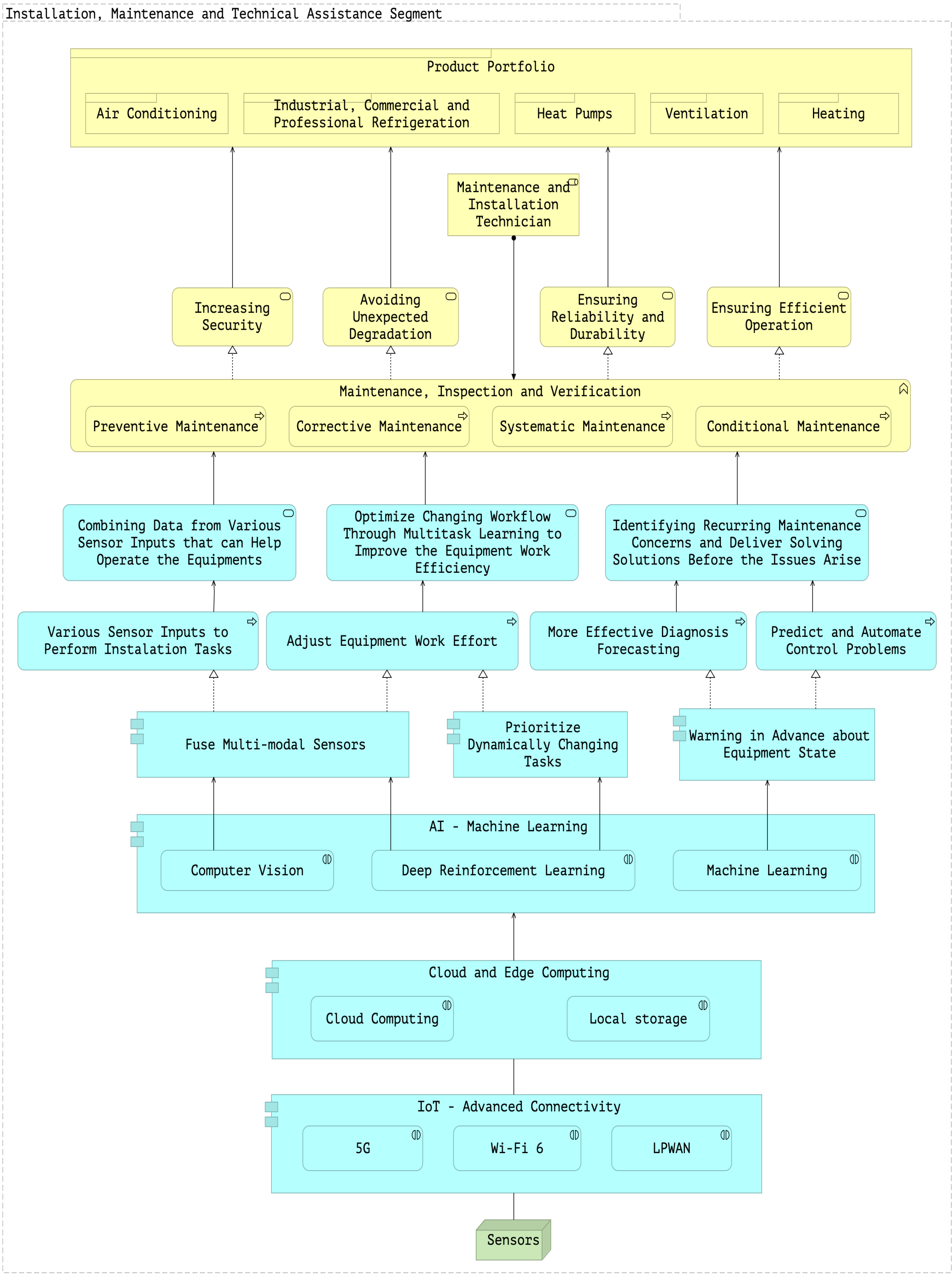


Figure 5.7: Installation, Maintenance, and Technical Assistance Segment

Four main business processes were considered: Preventive Maintenance, Corrective Maintenance, Systematic Maintenance, and Conditioned Maintenance.

The proposal to integrate I4.0 technologies boils down to the adoption of AI, integrating some of its most prominent dimensions. The first hypothesis is to combine data from various sensor inputs to assist in the operation of equipment, such as installation tasks. A second hypothesis is to enable technicians to adjust, based on the evidence that AI provides, the performance effort of equipment. This allows them to optimize their efficiency. The last hypothesis is to enable preventive notifications about equipment status, allowing for more effective predictive diagnosis and automated troubleshooting. The technological processes and inherent services proposed for this segment are aimed at increasing equipment safety, avoiding unexpected degradation, ensuring reliability and durability, and guaranteeing efficient operation. The operation of these technologies is always based on the existence of databases (Cloud and Edge Computing) and the collection of such data through IoT, which at the industrial level, is mostly done through sensors. The remaining "to - be" Segment Viewpoints are in Appendix B.

In summary, this chapter demonstrated the various viewpoints of SEAF applied to the ACRS case study. It provided a perception of SEAF's usability and potential. In this sense, a public folder was created with a permanent DOI [52], intending to be an example for future users of SEAF. The following section makes an evaluation of SEAF.

5.2 Evaluation of SEAF

This section refers to the *"Evaluation"* step of the Design Science Research (DSR) [12] process. In the evaluation process, the effectiveness of the artifacts' support for a solution to the study topic will be observed and measured. It aims to compare the solution's goals to real the outcomes obtained, by utilizing the artifact provided in Chapter 5. Therefore, during the first DSR iteration, was confirmed that the sector stakeholders (business associations, consultants, assessors, and specific companies operating in the supply chain) can use the SEAF models as a communication tool. For example, to support the adoption of innovative technologies, support decision-making for sectorial trends and identify segment's needs. The models also seem promising for internal and external audits, guiding the assessment of data resources, applicable legislation, and the I4.0 tasks of the digital business. Moreover, the models can be used to introduce the sector to outside people. Nevertheless, as a sector-specific analysis, the Enterprise Architecture (EA) models are only a starting point to assist more detailed EA projects in each company, aligned with their sector.

The real application also allowed to identify some limitations in the artifacts. Firstly, to represent the sector, the viewpoints tend to have a lot of information, which can be challenging. Secondly, redundancies may occur in the corresponding models when dealing with the modeling of multiple elements. Lastly, since only the viewpoints of the sector and for each segment were modeled, it is not possible to visualize the integration and flow of the data between the segments.

This could be achieved with a data viewpoint. Thus, the next chapter is about the work's contribution, limitations, and future work.

Chapter 6

Conclusion

This chapter presents the conclusion of the present work and is divided into two sections. Section 6.1 and describes the contributions and limitations of the conducted work. Section 6.2 describes the future work to be addressed.

6.1 Contributions and Limitations

The first phase of this work started with developing a working plan, defining the project guidelines, planning for each of the semesters, and doing the risk analysis for the project context and domain. The work involved a literature review about the core concepts of Enterprise Architecture (EA), Industry 4.0 (I4.0), and Digital Transformation (DT) in the industrial sector. The four selected frameworks were studied and compared to inspire the development of Sectoral Enterprise Architecture Framework (SEAF). The systematic literature review, with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), allowed to know the work done in this field, some limitations encountered, and the results obtained. This phase was critical to set the basis of the work and establishing the requirements and domain analysis of the problem. Moreover, this phase was essential to acknowledge the importance of a new proposal in EA frameworks, since it was not possible to find an enterprise architecture similar to SEAF. The proposal of SEAF can be relevant for entities such as associations that have an interest in various segments of the economy, focusing on specific products.

To lead the demonstration of the work on the Air Conditioning and Refrigeration Sector (ACRS) case study, a series of meetings were conducted with Associação Portuguesa da Indústria da Refrigeração e Ar Condicionado (APIRAC) to gain a comprehensive understanding of the association's role and the associated tasks. These meetings, along with the documentation made available by the association, played a fundamental role in gathering pertinent information about the sector. The data collection process focused on acquiring detailed insights into the products, stakeholders, segments, as well as the responsibilities and needs of APIRAC as the representative association of the ACRS in Portugal. Furthermore, a dedicated meeting was held with Associação Portuguesa dos Engenheiros de

Frio Industrial e Ar Condicionado (EFRIARC) to further delve into sector-specific knowledge and identify any potential topics of relevance to SEAF. Additionally, extensive research on Heating, Ventilation, and Air Conditioning (HVAC) systems was conducted, essentially through industry magazines such as [53], which significantly contributed to expanding the knowledge about the sector.

Therefore, the results obtained with SEAF were shared with APIRAC, the case study association, by applying the proposed approach. The results include (1) a set of domain attributes, (2) a domain ontology, (3) a graphical representation of the SEAF's metamodels, and (4) a demonstration of the applicability of SEAF in ACRS, revealing the interdependencies (and particularities) within each segment of the supply chain.

Moreover, two publications were made during the course of this thesis. The first is a book chapter presenting the initial results of the literature review and technology analysis in APIRAC [54]. The second contribution to sectoral analysis using EA techniques was accepted for presentation as a short paper at the *31st International Conference on Information Systems Development (ISD 2023)* and publication in the conference proceedings [55]. ISD is an AIS-affiliated conference ranked A in the Computing Research and Education Association of Australasia (CORE) 2018.

Despite the interesting results obtained during this master's thesis, several limitations must be acknowledged. First, the artifacts created contribute to improving the current practice of modeling sectoral enterprise architectures. However, the results do not hold evidence of SEAF's performance improvements (e.g., comparing KPIs) in supporting the sector's investment decisions. Second, it used literature research and process documentation analysis from a single association to identify domain concepts, ontology, and critical domain attributes. Conducting industry assessments in the future may contribute to optimizing the roadmap or refining the relationships between the elements of the graphical notation. Third, the Air Conditioning and Refrigeration Sector greatly utilizes DT, returning very positive impacts on societal trends. Nevertheless, the association does not represent all the industrial sectors, and others may reveal different dynamics (e.g., strategic goals, I4.0 applicability, and data integration). Fourth, the results were evaluated without involving enterprises already adopting EA practices. How to integrate SEAF with company-specific EA needs to be studied. Improving the SEAF metamodels with more relationships between the elements will allow to understand how to support data integration.

6.2 Future Work

Future Design Science Research (DSR) cycles need to integrate more industrial sectors using SEAF, improving the study evaluation. For example, additional work in the textile sector or the jewelry sector is promising. There are three important ways to expand the developed work. First, understating the relationship between segments to develop the data exchange process between them. For example, SEAF could be tested in the development of the emerging digital product passports architecture. Second, identify how the data exchanged can contribute to each segment (data value and data market). Third, understanding the best way of promoting data flow and integration within the sector to optimize its communication. Additionally, SEAF could test the integration of HERM's views, improving the study evaluation. Moreover, comparing in the same sector TOGAF and GERAM, with SEAF will be a way of evaluating the work. The evaluation at this stage is merely descriptive, requiring additional iterations. The next steps could include improving the representation of data exchange processes between each supply chain segment and using SEAF models to assist the business association in developing a sectoral report for I4.0 adoption.

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Appendices

Appendix A

SEAF "as - is" Architecture Segment Viewpoints

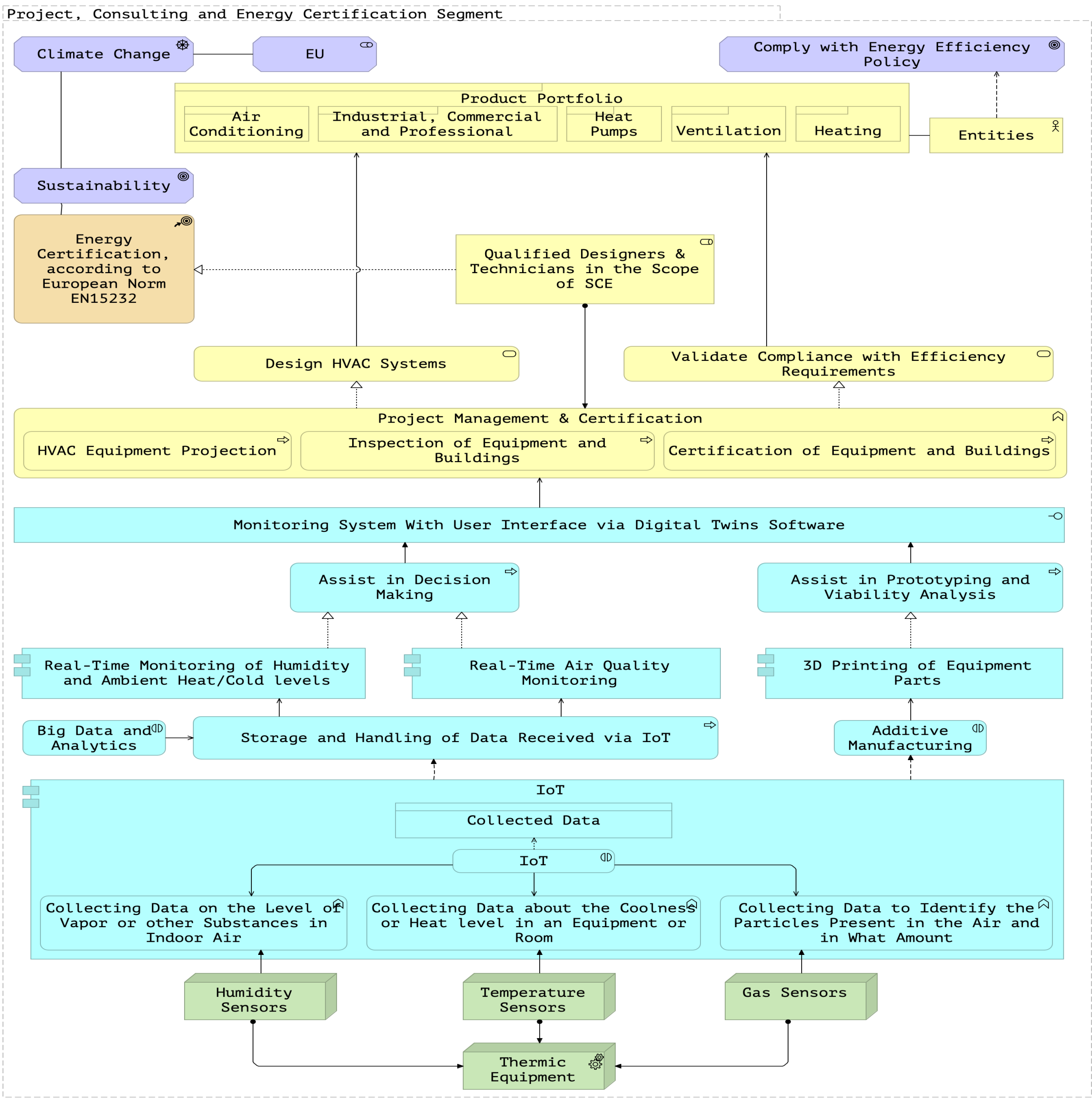

Figure A.1: Project, Consulting, and Energy Certification Segment Viewpoint

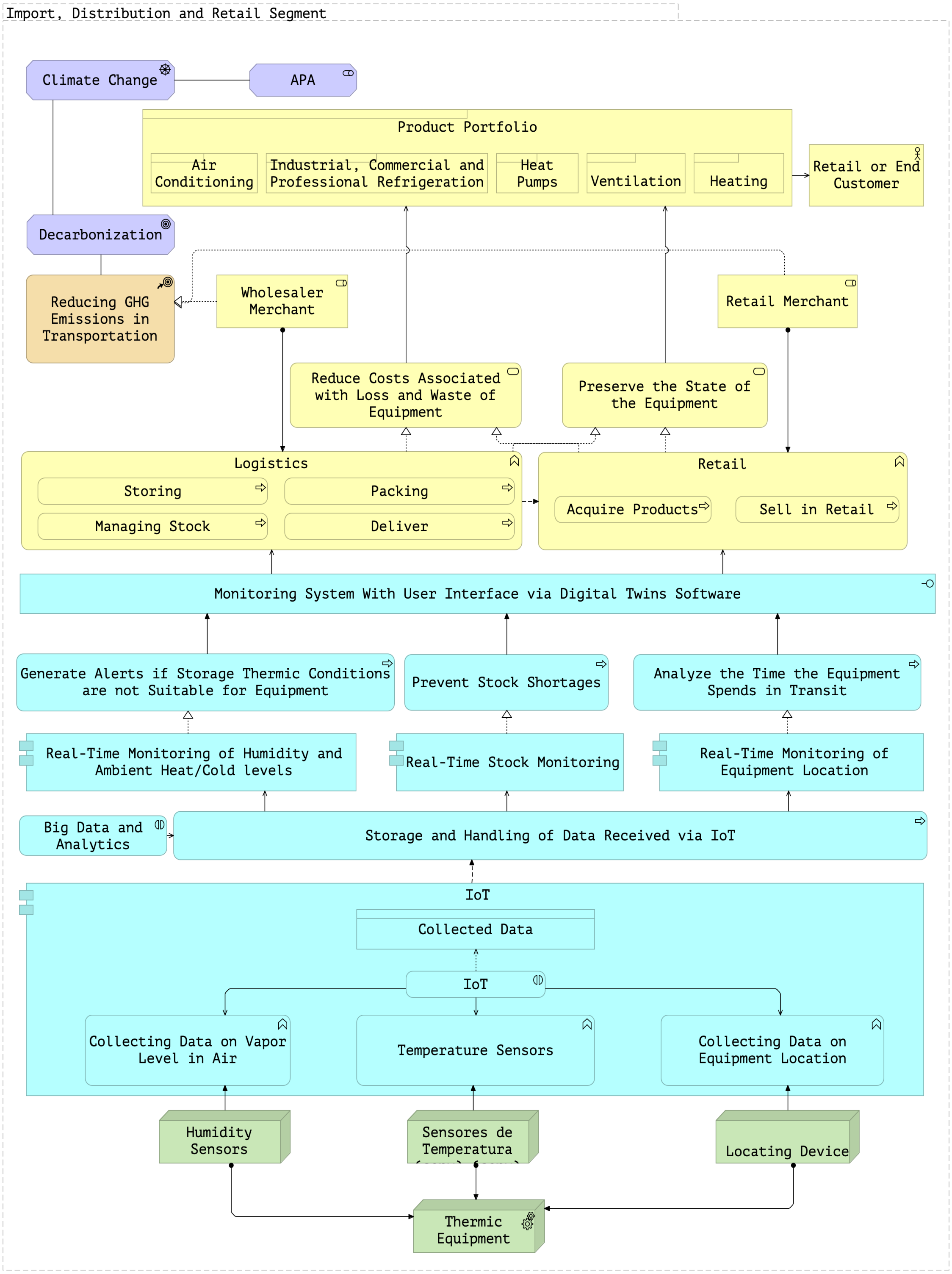

Figure A.2: Import, Distribution and Retail Segment Viewpoint

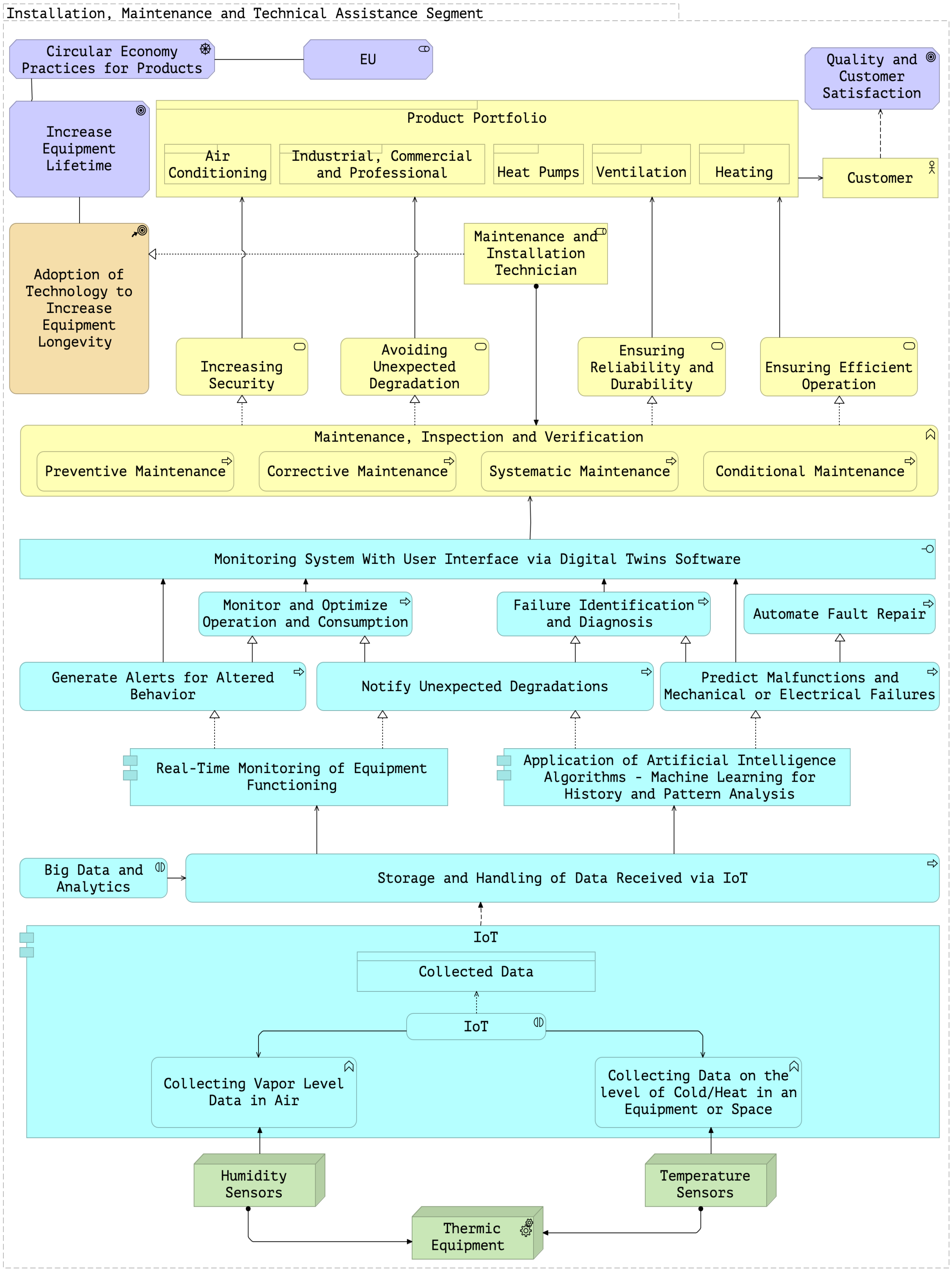

Figure A.3: Installation, Maintenance, and Technical Assistance Segment Viewpoint

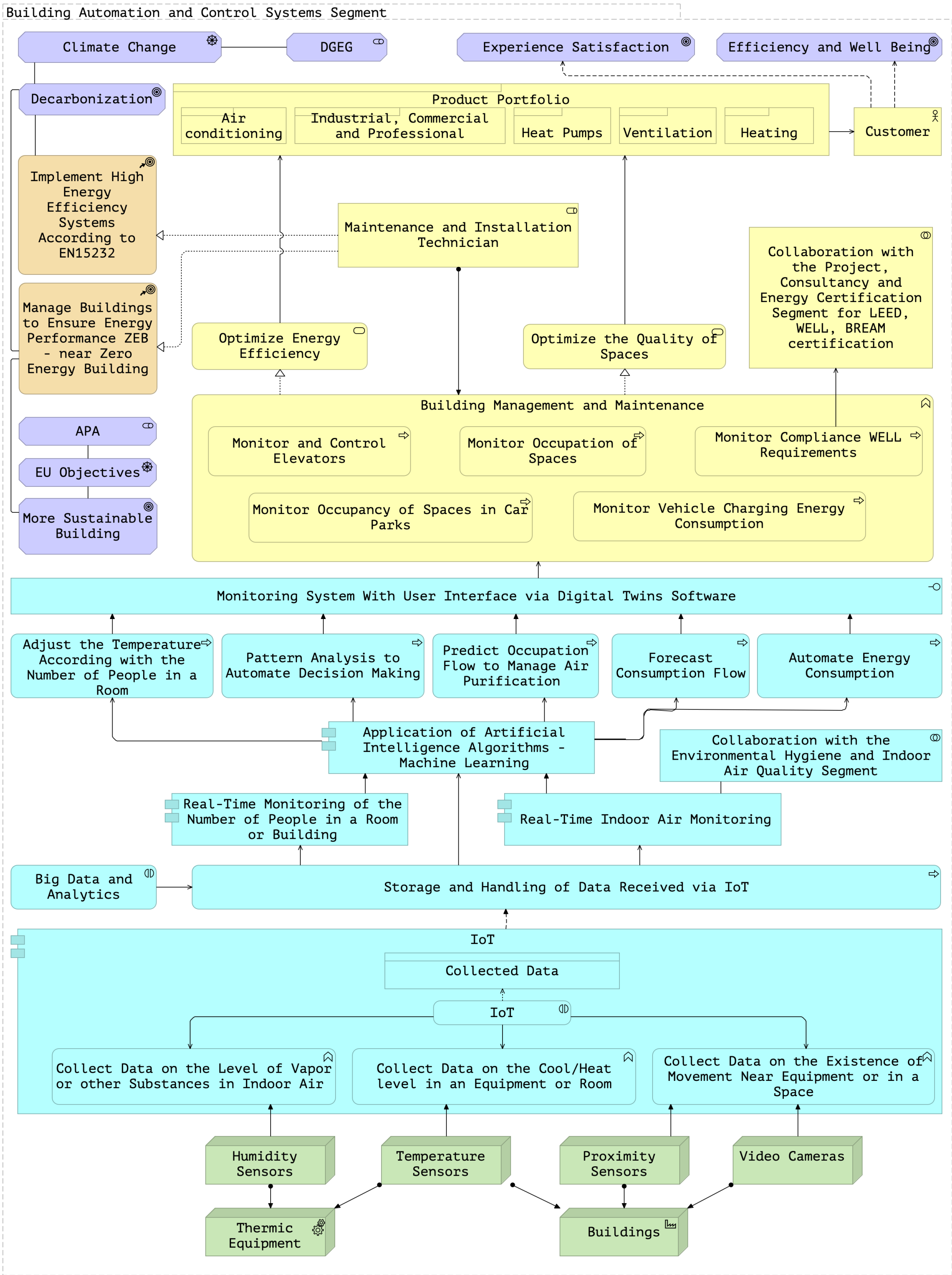

Figure A.4: Building Automation and Control Systems Segment Viewpoint

Appendix B

SEAF "to - be" Architecture Segment Viewpoints

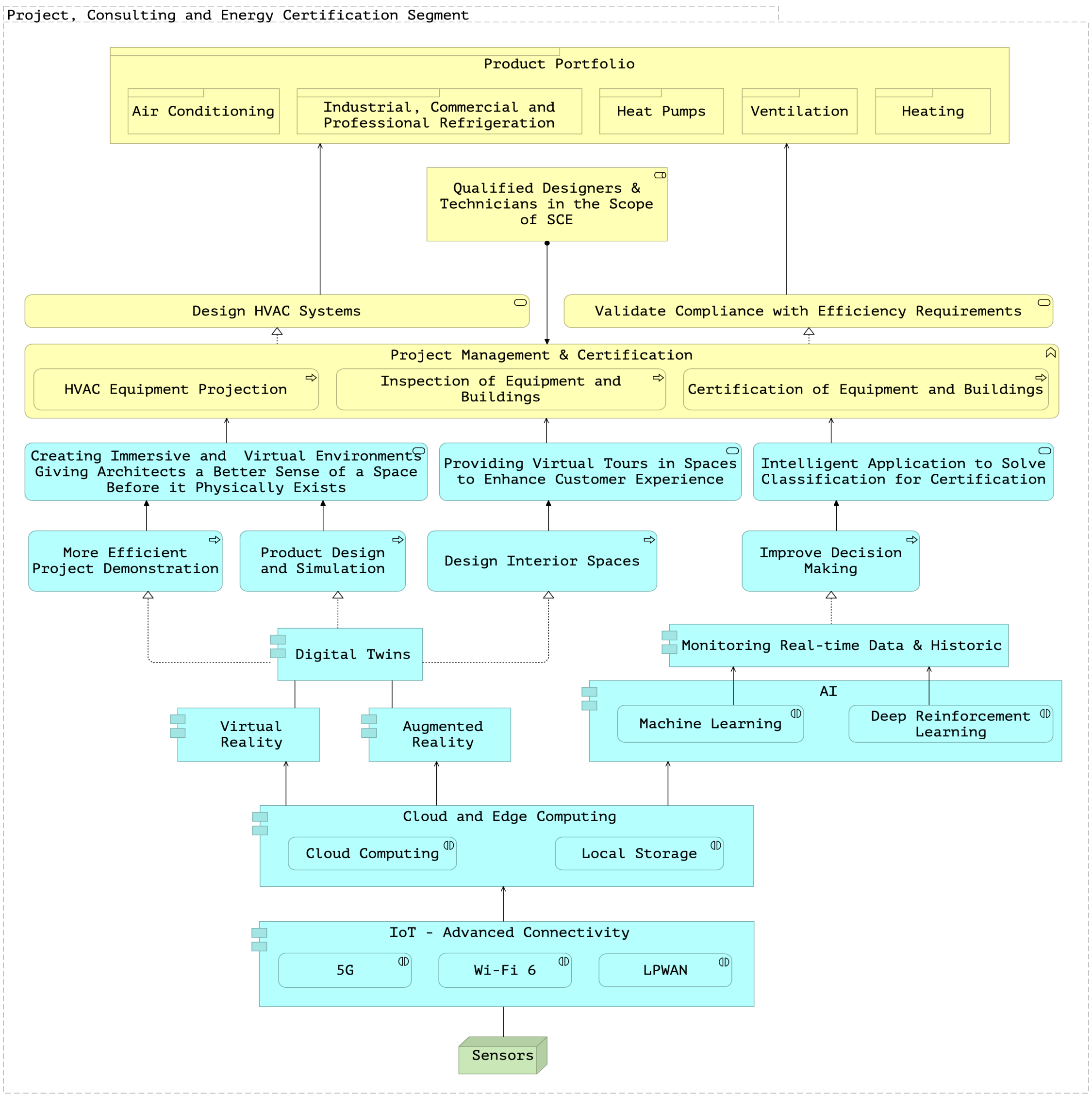

Figure B.1: Project, Consulting, and Energy Certification Segment Viewpoint

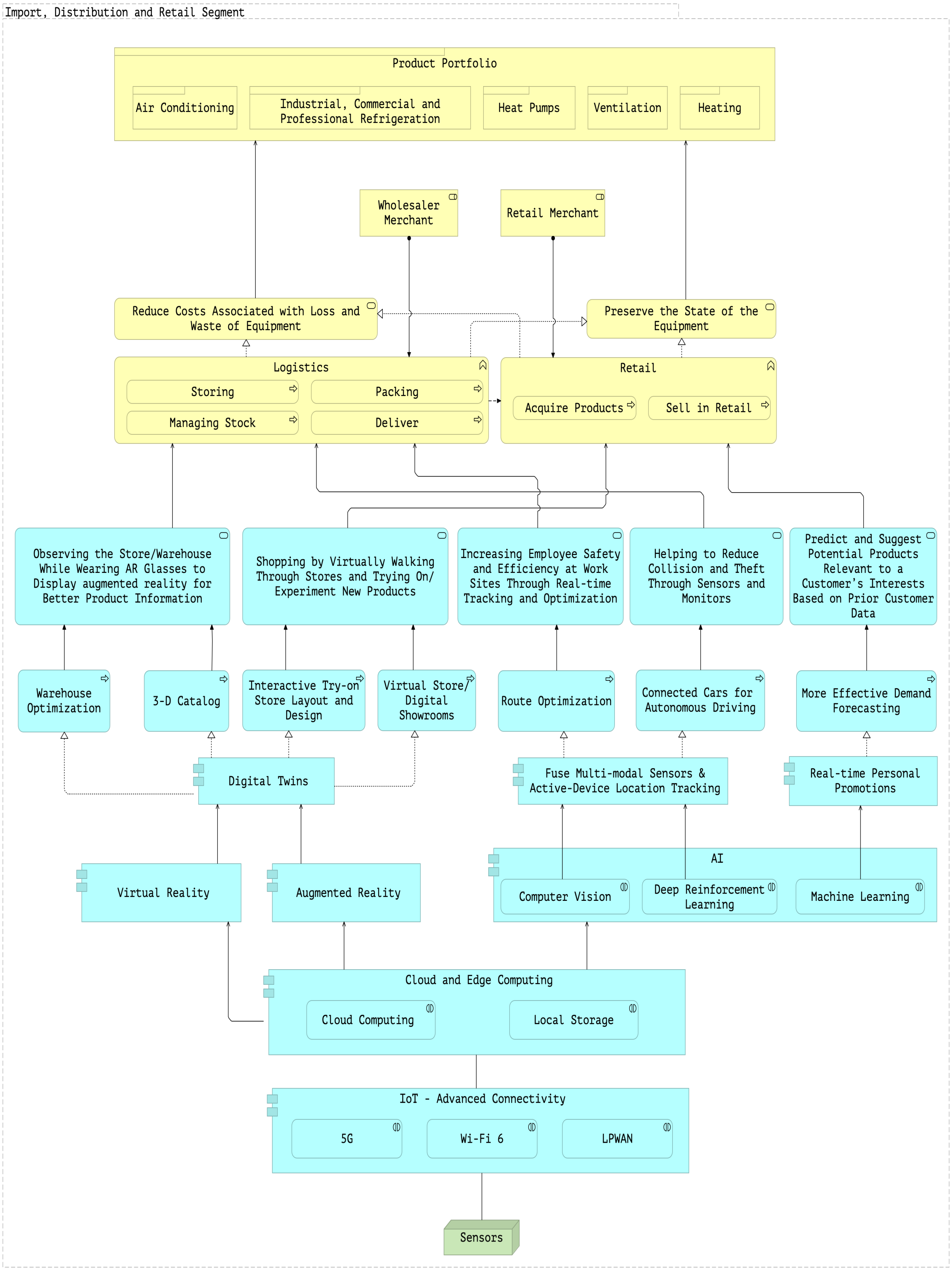

Figure B.2: Import, Distribution and Retail Segment Viewpoint

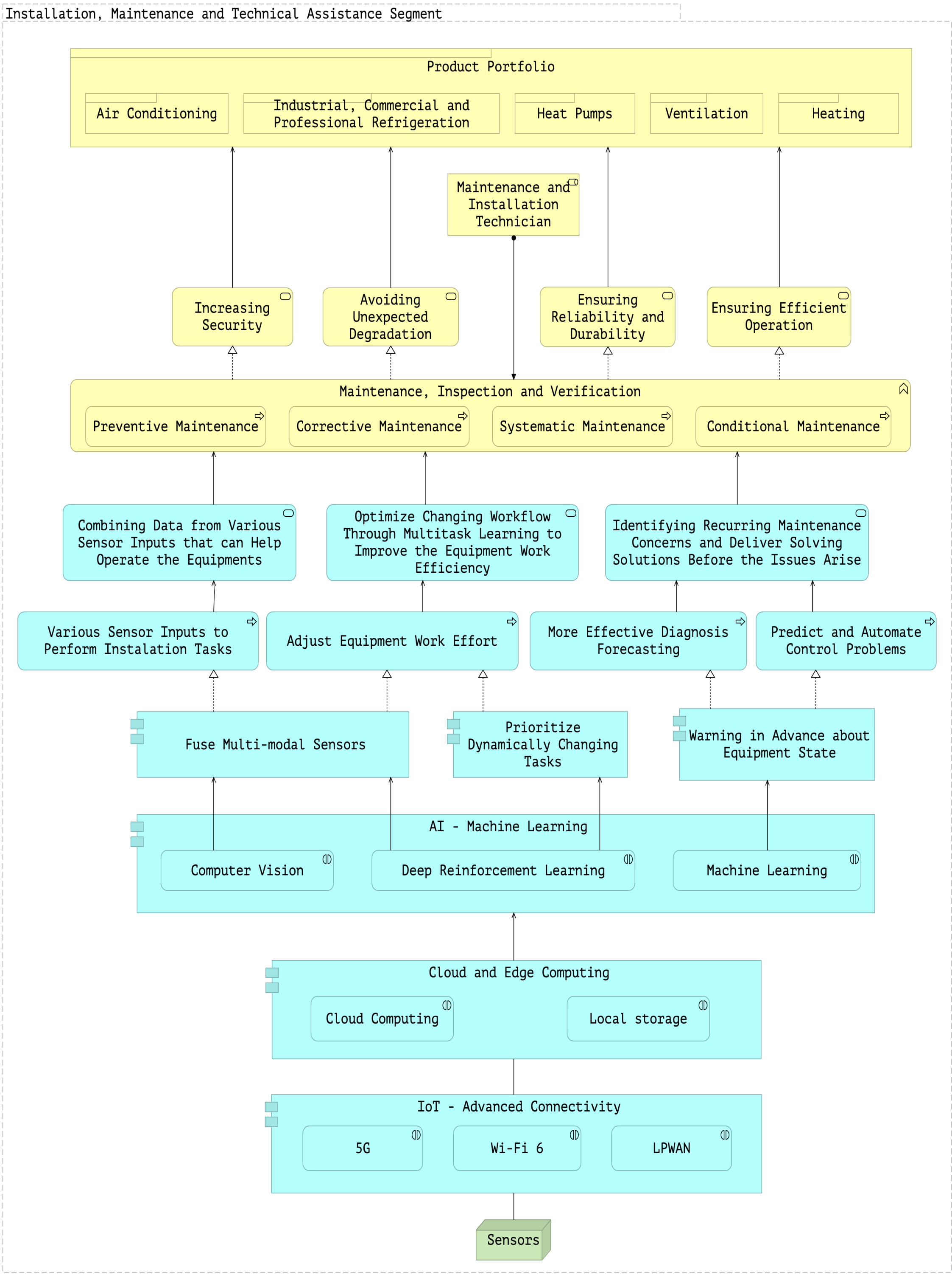

Figure B.3: Installation, Maintenance, and Technical Assistance Segment Viewpoint

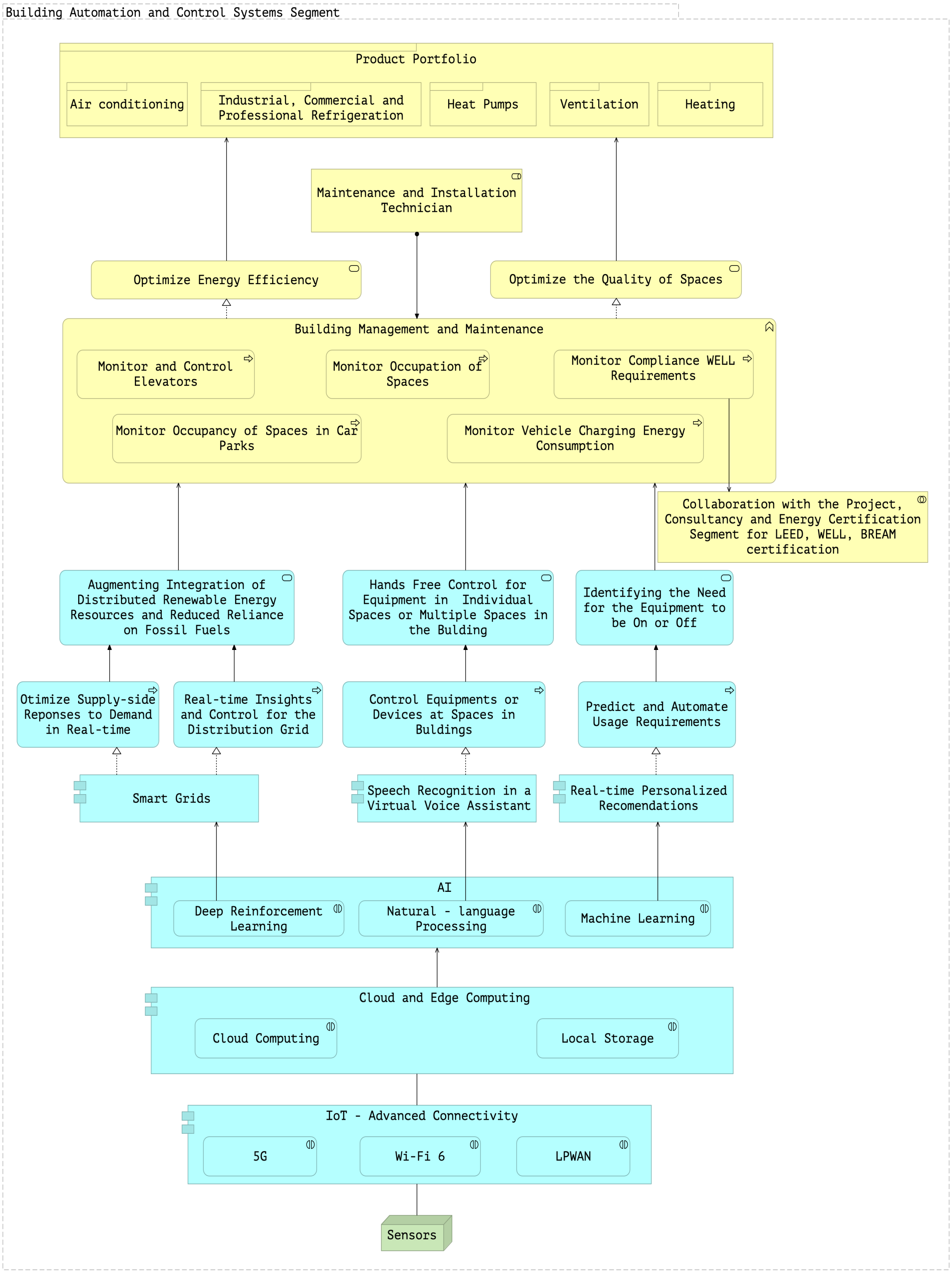

Figure B.4: Building Automation and Control Systems Segment Viewpoint

Appendix C

Sistematic Literature Review Outcome Papers

Ref	Paper Scope
[42]	Aiming to improve the performance of the Railway Supply Chain (RSC) in the Malaysian Transportation Industry, the integration of advanced digital technologies is crucial. An Enterprise Architecture RSC framework is being designed to increase information flows and integration, visualizing, analyzing, and maintaining all RSC indicators for better control and governance. This paper defends that the decision-making process will increase the value of embracing analytics for forecast scenarios and analyses of optimal outcomes.
[56]	Aligning business and IT in an agile manner is crucial for organizations to keep up with the competition in today's environment. Developing enterprise architecture can help achieve good Business-IT alignment. This paper proposes linking strategy models to each other and to implementation to ensure a smooth transition to organizational change, determine the impact of strategic choices on the organization's architecture, and how projects would help achieve organizational goals.
[41]	I4.0 emphasizes the need for integrating physical machines, sensors, and (big) data for organizational operations, including manufacturing. To address the challenge of increasing information flows and integration, organizations can leverage Enterprise Architecture and investigate the use of operational data in IT-driven design approaches. This paper proposes EA 4.0, an extended approach for I4.0, and discusses efforts to design a software platform to support this vision, illustrated with a case study.
[57]	Emergent behavior in a System-of-Systems (SoS) depends on the relationships among its parts rather than individual components. To guide the development of SoS architecture, a suitable framework that incorporates emergent behavior, and Enterprise Architecture (EA) is well-suited for this purpose. This paper develops SoS architectural models applying the Zachman Framework to the global automotive supply chain, using collaborative engineering services, to demonstrate its importance in Agile DT.

Table C.1: Sistematic Literature Review Outcome Papers and Scope

Ref	Paper Scope
[58]	This text discusses the importance of procurement transformation and cost reduction in today's business world, highlighting the role of procurement in generating value for firms. The article proposes a new enterprise architecture that leverages emerging technologies to guide procurement organizations in their digital transformation, with a focus on reducing costs through the use of analytics, business rules, and complex event processing.
[59]	This paper addresses the need for IT governance frameworks to achieve digital transformation and gain a competitive advantage. With multiple Information Technology Governance (ITG) frameworks available, selecting the most suitable one can be challenging. The paper proposes using the Analytic Hierarchy Process (AHP) as a multi-criteria decision analysis method to help decision-makers choose the best ITG framework for their organization. The proposed method is applied to a public pharmaceutical supply chain in a developing country as a case study.
[45]	This paper explores emergent behavior in System-of-Systems (SoS) and the need for a suitable framework to guide SoS architecture development, which includes emergent behavior. The Open Group Architecture Framework (TOGAF), Federal Enterprise Architecture Framework (FEAF), and Zachman Framework are found to be suitable for this purpose, with the Zachman Framework recommended for guiding architecture development. The use of agent-based simulation and SysML/UML integration is also discussed, with an example provided for the global automotive supply chain.
[40]	This paper discusses the need for modern, interconnected infrastructure in the industrial sector to serve complex supply chains, but also highlights the increasing cybersecurity risks that come with it. The authors emphasize the need for understanding the correlation between the motivation and capability of cyber attackers in the industrial sector to continuously develop and survive. The paper argues that traditional SCADA systems are no longer enough to protect against cybersecurity threats and that new players and methodologies have emerged in this field.
[1]	The paper proposes a reference enterprise architecture for detecting and monitoring emergent behaviors in complex enterprises, such as supply chains, to ensure the resilience of business processes. The architecture combines distributed autonomous business logic and central control mechanisms to address the need for an adequate reaction to disruptions. A proof-of-concept implementation is provided using a multimodal logistics case study, showing that the architecture provides a basis for achieving supply chain resilience "by design" through the design of coordination mechanisms
[44]	This paper examines the sustainable coordination and management of Information Technology (IT) outsourcing chains through a systematic literature review of IT outsourcing theories. The analysis reveals that outsourcing chains are developed in collaborative networks and chains, with identified mechanisms for management, coordination, and sustainability. The paper suggests that interchain coordination can be improved through enterprise architecture modeling and the application of blockchain economy.

Table C.2: Sistematic Literature Review Outcome Papers and Scope - Continuation