Introducing the Sectoral Enterprise Architecture Framework (SEAF)

Carolina Bandeira
University of Coimbra, CISUC, DEI
Coimbra, Portugal *abandeira@student.dei.uc.pt*

João Barata
University of Coimbra, CISUC, DEI
Coimbra, Portugal *barata@dei.uc.pt*

Nuno Roque
Portuguese Association of the Refrigeration and Air Conditioning
Lisbon, Portugal *nuno.roque@apirac.pt*

Abstract

Multiple enterprise architecture (EA) frameworks have been proposed to guide the alignment of business and information technologies. However, existing EA approaches were not yet tested to represent (as-is) and steer (to-be) the digital transformation of an entire industry sector. This research-in-progress aims to create a Sectoral Enterprise Architecture Framework (SEAF) to support the ongoing digital transformation in industry. SEAF emerges from a design science research project in cooperation with a national refrigeration and air conditioning association. The initial results include the design of SEAF structure and its deployment in a vital industry sector interested in revealing data and digital technologies' role in ensuring sustainability for the coming years. A sectoral EA framework can be helpful to the mission of industry associations, guiding companies in planning, implementing, and migrating new technologies suitable to their supply chain.

Keywords: Sectoral Enterprise Architecture Framework, Digital Transformation, Industry 4.0, Supply Chain, ArchiMate.

1. Introduction

Digital transformation in the industry (Industry 4.0 or I4.0) requires a robust, 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 [5]. 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 [24]. Sustainability within manufacturing supply chains is now a priority for management worldwide [14].

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*" [13]. EA is essential to understand multiple interrelated layers of modern organizations, including both business and IT elements. Prominent EA frameworks are available for companies to guide their digital transformation. Examples include the well-known TOGAF® Standard [30] created by the Open Group for corporate EA projects, the Zachman framework [23], governmental proposals like the Federal Enterprise Architecture (FEAF) [29], or more boundary-spanning approaches, like the Department of Defense Architecture Framework (DoDAF) [27]. The latter suggests that some sectors of the economy have particularities that can be integrated into a coherent EA framework. Industry sectors (e.g., automotive, equipment) share common EA interests in product offerings throughout the supply chain of heterogeneous company segments [24].

This research project started after some contacts with the Portuguese Association of Refrigeration and Air Conditioning (APIRAC), representing over 500 companies operating in the Air Conditioning and Refrigeration Sector (ACRS). APIRAC's primary responsibility is to defend and safeguard its associates' interests, including the entire supply chain of ACRS products. They were preparing a study about 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, or technical management in buildings, each with their own agenda but needing to cooperate in different product phases (e.g., development, use, or recycling). Besides the aforementioned reasons, the development of a specific sector EA comes from the need to support APIRAC members in an integrated way by addressing European priorities associated with the sector, mainly related to sustainability and oriented customer needs. Moreover, we confirmed in the literature that I4.0 adoption is different for each industrial sector [4]. After a review of EA frameworks, the research team found a solid starting point but also concluded that none was created to address an entire supply chain, and examples for aligning IT and product lifecycles were scarce. Therefore, the following research objective was created: *propose a Sectoral Enterprise Architecture Framework (SEAF) to integrate supply chain segments of an industrial sector adopting I4.0*.

The rest of this paper is presented as follows. Section 2 includes the foundations of EA frameworks, languages, and tools that guided our theoretical lenses. The presentation of our design science research follows, and Section 4 presents the initial design of the proposed framework, named the Sectoral Enterprise Architecture Framework (SEAF). Section 5 demonstrates and evaluates SEAF with the selected business association. The paper closes in Section 6, including the study limitations and future work.

2. Background

2.1. EA Frameworks and Languages

EA is aimed at the generic activity of aligning strategy with technology and governing transformation. The modeling architecture activity allows a good system specification and reduces the complexity by providing a better understanding of the problem [16]. Therefore, EA addresses the complexity of modern enterprises since it describes and models the organizations' elements and shows how they are organized and operational as a whole.

There are influential EA frameworks available [3]. For example [21] highlights 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 [30], 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 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) [23]. Other important examples include GEA [22], with relevant domain-specific viewpoints, and EIRA [28], which aligns very closely with a sectoral perspective, although not specific to industry supply chains.

EA models must follow a modeling language to provide rigor, consistency, and interoperability. For example, Unified Modeling Language (UML), Business Process Model and Notation (BPMN), Service Oriented Architecture Modeling Language (SOAML), or System Modeling Language (SysML). One of the most widespread is ArchiMate which was already used to model Industry 4.0 scenarios [2, 5, 17]. ArchiMate includes elements representing behavioral, structural, motivational, and composite architecture presentation [13]. Further, not only it offers support for modeling four (related) aspects [25]: the Enterprise, its Strategy, Change, and the Intentions, but it also enables the modeling of organizations from different viewpoints and layers [25]. For example, the Business Layer is used to describe the processes, while the Application Layer represents the structure and interaction of applications. More physical layers include the Technology Layer, describing the technology structure and its interaction. Nevertheless, it is also possible to model the Motivation, for example, relating stakeholders and their primary goals, and the Strategy Layer to express value creation, capabilities and resources needed.

2.2. Digital Transformation in Industry

I4.0 aims to implement real-time support for manufacturing, interoperability, and decentralization. Each company must select the best technologies according to each product requirement to enable the integration between the physical and virtual worlds. The technological portfolio of I4.0 is vast and includes Cyber-Physical Systems, the Internet of Things, Big Data and Analytics, Cloud Computing, Artificial Intelligence, Blockchain, Industrial Robots, Additive Manufacturing, and Simulation & Modelling [24].

A Digital Transformation (DT) framework covers the networking of actors, such as businesses and customers, across all segments of the value-added chain. DT transcends organizational boundaries and necessitates a thorough examination of collaborative partnerships [26]. Thus, while DT has been discussed for some time [7], there is still no straightforward approach for digitally transforming business models, specifically, which phases and instruments should be considered [25]. Nevertheless, [1] identified relevant practices that a DT framework must cover, such as managing Customer Experience, Innovation, Products and Services, Partnerships, and Resources.

The increasing information flow and system integration within and throughout the supply chain is a significant challenge for organizations adopting I4.0. One approach for addressing it is investigating how the abundance of data can be combined with IT-driven design approaches, such as Enterprise Architecture [2]. For example, [20] applies a domain-driven architecture design approach with viewpoints to enhance quality, productivity, and efficiency in smart warehouses, while [9] explores how I4.0 affects supply chain management through the lens of supply chain innovation. Thus, the “4.0” revolution enables companies to be more flexible about manufacturing processes and analyze large amounts of data in real-time, improving their strategic planning and operational decision-making. Moreover, a critical aspect is the establishment of collaboration networks between enterprises inside the same supply chain regarding the exchange of information.

3. Methodology

Design Science Research (DSR) was chosen for our inquiry. It is a rigorous problem-solving method to develop and design innovative artifacts, contribute to research, evaluate, and communicate. According to the identified problem and the situation’s context, these artifacts may include models, methods, and instantiations [10]. The artifact is at the core of DSR since the research aims to structure the work methodology and lead to the artifact’s production, which addresses the identified problem. The solution that the artifact will promote should be relevant to the business problem, and its utility, quality, and efficiency must be rigorously evaluated [10, 18].

An iterative process is suggested by [18]. 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*” [18]. Moreover, this research process considers multiple cycles to sharpen the artifact, repeating some steps if necessary. Contacts with APIRAC experts and the literature review findings confirmed our problem identification and motivation. Our “*Problem - Centered Initiation*” [18], started with a systematic literature review with PRISMA methodology. The initial study summarized in Section 2, was conducted in Scopus and Web of Science Core Collection. After performing a manual process, identifying the outcomes, and removing the duplicates, 10 documents were obtained for the keyword combination (“Enterprise Architecture” OR “IT Governance”) AND “Supply Chain” AND (“Digital Transformation” OR “Sustainability” OR “Industry 4.0” OR “Data Integration”). In parallel, we had meetings with the experts of APIRAC to understand the characteristics of their sector, and the particularities of each segment to understand opportunities for digital transformation. Next, we defined the objectives for a solution (step 2): adapt and improve leading EA frameworks and languages to enable sector-specific digital transformation. Our current design and development outputs are (1) SEAF structure and (2) the definition of relevant viewpoints. The demonstration used real data from APIRAC, subsequently evaluated with the case setting as a first iteration.

4. SEAF Design and Development

4.1. Structure and Logic for SEAF

The research team decided to start with an incremental approach, adapting influential EA frameworks to ensure better consistency and interpretation of the models by EA practitioners. Considering that SEAF aims to be an integrative framework, we followed TOGAF ADM and the (well mapped with TOGAF) ArchiMate notation, due to its popularity and openness. The first version of SEAF is depicted in Fig. 1.

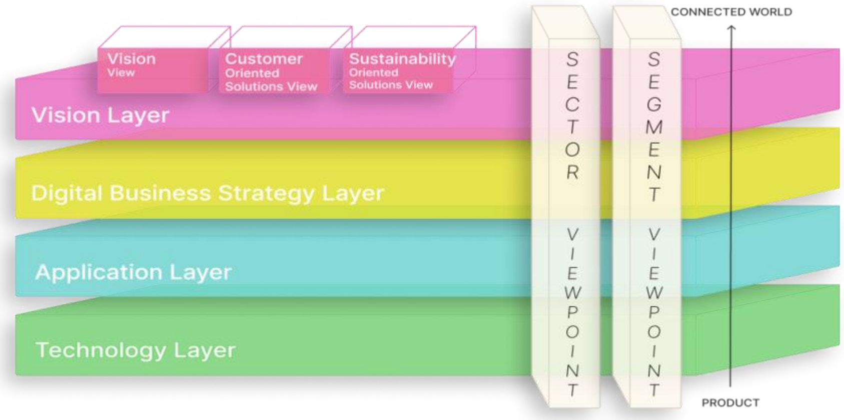

Fig. 1. SEAF representation

The topmost Vision Layer is aligned with the GEA's [22] coherence elements definition, followed by the business, application, and technology layers that can also be found in ArchiMate. An industry sector is composed of different supply chain segments (e.g., raw material producers or distributers), requiring specific viewpoints. DoDaf views and viewpoints can be adopted to extend the “traditional company focus” and increase interoperability between supply chain segments of a specific sector. Additionally, we gathered inspiration from RAMI 4.0 [19] architecture explicitly created for Industry 4.0, suggesting alignment with standards like IEC 62890, IEC 62264, and IEC 61512.

It is fundamental for an EA framework structure to integrate the business, application, and technology layers [30]. However, the content of the layers and how the elements interact with each other must respond to the needs imposed by the policies that influence each industrial sector. The SEAF layers presented in Fig. 1 are detailed in Table 1.

Table 1. Layers and Views of SEAF

Ref	Layer and Description
	Vision Architecture Layer
[14]	• Identifying the sector stakeholders, external drivers, strategic vision goals, and the course of action to achieve them (Vision View).
[6]	• Representing customers’ needs and demands by refining the customer experience (COOSV - Customer Oriented Solutions View).
	• Innovating the quality, origin, environmental and social impacts of the product (COOSV).
[15]	• Responding to dynamic market trends with specific timings (COOSV).

Ref	Layer and Description
[11]	• Engaging with *servitization*, i.e., the relationship between the product and the service (COOSV). • Engaging with the Sustainability Development (SD) concept to meet the needs of the current generations without compromising the environment and the ability of future generations to meet their own needs (SOSV - Sustainability Oriented Solutions View). • Innovating the products to product-service systems, extending the products' life cycle, changing the consumer patterns, and reducing the use of products and materials (SOSV).
[14]	**Digital Business 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.
[12] [8]	**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.
[12] [8]	**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.

Industry sectors adopting I4.0 are pressured to respond to consumer needs, like mass personalization [24] and the development of sustainable practices [12]. These are examples of sectoral topics incorporated in the “Vision Architecture Layer”, represented in the “Customer Oriented Solutions View” and “Sustainability Oriented Solutions View”, respectively. This first layer is followed by the “Digital Business Strategy Architecture Layer”, which represents the business elements, such as roles, services, functions, and processes. The “Application Architecture Layer” follows, and finally, the “Technology Architecture 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 when focusing on a specific company, as in traditional EA projects.

I4.0 applications' processes and applicability on the segment context need to 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” and “Segment Viewpoint” allows integrated and segmented analysis, respectively. The former models the sector, representing products, consumers (or areas of interest), and (with less detail) the connections between each segment. The latter represents each segment in detail.

4.2. TOGAF ADM Mapping for SEAF Roadmap

The methodological guidance for applying SEAF in practice follows the TOGAF ADM [30]. The research team found it suitable to the sectoral EA steps with minor adaptations subsequently presented. Therefore, 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 [30]. 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).

Our proposal for the SEAF roadmap has several outputs. From the Preliminary Phase and from Phase A we obtain the Sector Vision and the Sector Scope. These two viewpoints contribute to developing the final viewpoints: the segment and the sector viewpoints. Fig.

2 represents the Sector Vision Viewpoint and Fig. 3 represents the Sector Viewpoint, which provides a general overview of the sector.

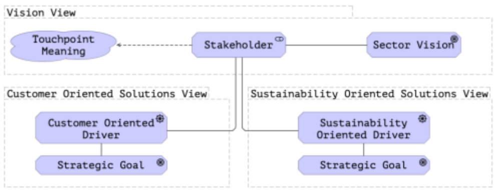

Fig. 2. Sector Vision Viewpoint

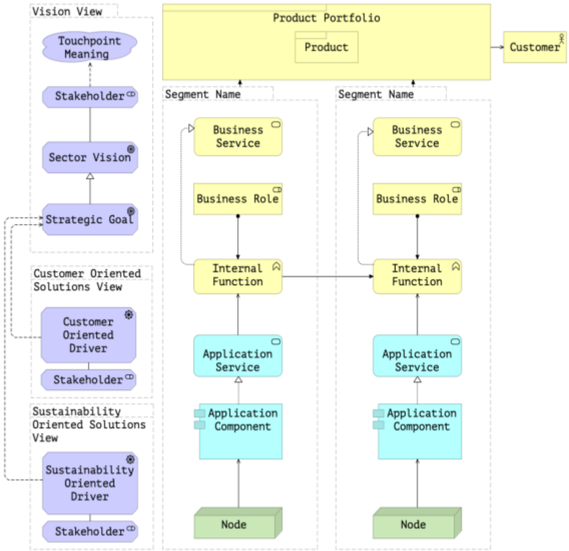

Fig. 3. Sector Viewpoint

The Sector Vision Viewpoint is an aggregation of the three views stated earlier. So, we can identify the Customer Oriented Drivers, the Sustainability Oriented Drivers, the Strategic Goal(s) associated with each one, and their relationship with the Stakeholders.

5. Demonstration and Preliminary Evaluation of SEAF

The complete APIRAC sector modeling and six identified segments are available at SEAF Template Link in images and archi version. It aims to provide a template for enterprise architects interested in modeling other industry sectors and support the evaluation jointly made by researchers and practitioners at this stage of the research.

The first advantage of using SEAF is the creation of an integrated enterprise architecture with a sectorial focus, explaining the supply chain, touchpoints between segments, and the correspondent opportunities that I4.0 suggests: horizontal, vertical, and end-to-end digital integration. However, each segment will have its own particular I4.0 roadmap, contributing "as a puzzle" to the overall sector vision. Our work 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. SEAF Application Layer provides visibility to 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 realize the drivers' ambitions and stakeholder's interests.

During the first DSR iteration of this project, we 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 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 us to identify some limitations in our artifacts. Firstly, to represent the sector, the viewpoints tend to have a lot of information, which can be challenging. Therefore, we created an ArchiMate template to assist enterprise architects in their work. Secondly, redundancies may occur in the corresponding models when dealing with the modeling of multiple elements. Lastly, since we only modeled viewpoints of the sector and for each segment, we cannot represent the integration and flow of the data between the segments. This could be achieved with a data viewpoint.

6. Conclusions

We presented the results of the first iteration of a DSR project aiming to develop an enterprise architecture framework to respond to sectoral's representation and digital transformation. The results include a (1) set of domain attributes, (2) domain ontology, (3) graphical representation of the SEAF's metamodels, and (4) demonstration of the applicability of SEAF in an industrial Portuguese association, revealing the interdependencies (and particularities) within each segment of a supply chain.

We must acknowledge some limitations of our study besides those mentioned in the discussion about the artifact. First, the artifact created improves the current practice of modeling sectoral enterprise architectures. However, we do not hold evidence of SEAF's performance improvements (e.g., comparing KPIs). Second, we 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 optimize the roadmap or refining the relationships between the elements of the graphical notation. Third, the Air Conditioning and Refrigeration Sector makes a great utility of digital transformation, returning very positive impacts on societal trends. Nevertheless, other associations may reveal different dynamics (e.g., strategic goals, I4.0 applicability, and data integration). Additional work in the textile sector or the jewelry sector, for example, is promising. Fourth, the team evaluated the results without involving enterprises of any segments. Improving the SEAF metamodels with more relationships between the elements will allow us to understand how to support data integration. Future DSR cycles need to integrate more industrial sectors using SEAF and the possibility to integrate the HERM's views, improving the study evaluation. Moreover, by comparing in the same sector TOGAF and GERAM with SEAF, will be a way of evaluating SEAF. The evaluation at this stage of our research in progress is merely descriptive, requiring additional iterations. Our next steps 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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