Development of Business Architecture for the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0

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Development of Business Architecture for the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0

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ABSTRACT

This research project develops a Business Architecture pattern with its artefacts for designing the organisational structure of a factory dedicated to the production of swarms of unmanned aerial vehicles (UAVs) in the context of Industry 4.0. To formalise and validate the pattern, the Conceive, Design, Implement and Operate (CDIO) methodology is adopted. Within this framework, architectural solutions are proposed that integrate a co-intelligence artefact (human-machine cooperation) into decision-making processes, with the aim of boosting productivity, streamlining operations and transforming business models. The resulting pattern articulates intelligent and interconnected systems and technologies specific to Industry 4.0, and is scalable and adaptable.

DEDICATION

To God, my constant guide every step of the way. His presence gave me the strength I needed in difficult moments to stay the course.

To my daughter, Violeta, whose tenderness and joy brighten every day. With her patience, her time, and her support, she reminds me daily of the importance of perseverance. She is the driving force behind the completion of this process; this achievement belongs to both of us.

To the memory of my mother, for her inspiration and example.

To my father, my sister, her husband, and my niece, for their patience, support, and words of encouragement, always by my side even in the most challenging moments.

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To my friends, for their sincere companionship, smiles and motivation to keep going.

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CHAPTER 1: INTRODUCTION

Industry undergoes a process of evolution, which, in line with the emergence of new technologies, transforms it every so often. It is reasonable that this evolution transforms the economy and our environment. These transformations are known as industrial revolutions.

We are currently facing the fourth industrial revolution, known as Industry 4.0 (I4.0). This revolution builds on the advances made in the Third Industrial Revolution, which integrated computers, automation and a linear economic model without giving priority to the sustainability of the planet.

The Fourth Revolution proposes the integration of interconnected systems of intuitive, self-regulating, intelligent and autonomous entities that exchange data, perform tasks and work collaboratively. The aim is to increase productivity, flexibility, efficiency and agility [6].

In Industry 4.0, the core technologies for a factory include: cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), Big Data, digital twins, robots and drones, cloud computing, 5G and 6G networks, 3D printing, virtual and augmented reality, and blockchain technology [90]. This new factory model, supported by information technologies integrated with Industry 3.0, promotes the digitisation of manufacturing. I4.0 requires business leaders to no longer focus solely on their own sectors; they must understand the potential transformations of processes, business models and disruptions across the world of suppliers, customers and adjacent markets [28].

Another fundamental aspect for a factory related to productivity, efficiency, and agility is business architecture. Currently, organisations need to evaluate their performance and behaviour in terms of business architecture in order to make the best decisions [61].

Making strategic adjustments within Enterprise Architecture is a major challenge for organisations, one that can mean the difference between success and failure. Research in the field of enterprise modelling has led to the development of a wide range of modelling techniques for a better understanding of Enterprise Architecture [68]. There are different frameworks for modelling Enterprise Architecture, for example: The Open Group Architecture Framework (TOGAF) and the Industrie 4.0 Reference Architecture Model (RAMI 4.0).

The RAMI 4.0 model has been created to structure and implement Enterprise Architecture in Industry 4.0. However, it lacks real industrial applications and specifications in the standard itself with the appropriate level of detail [11]. TOGAF is a well-established framework for specifying enterprise architectures, but it was not created for industrial systems:

interconnected, intelligent, automated, digitised, cyber-secure and autonomous systems that work collaboratively [11].

On the other hand, swarms of unmanned aerial vehicles (SWARM UAVs) are part of the core technologies of Industry 4.0 and have begun to be used in multiple applications, but they are not yet used on a large scale [89]. The market value is estimated to grow at an annual rate of 15.5% (CAGR), from $19.3 billion in 2019 to $45.8 billion in 2025 [92].

A swarm of UAVs is a disruptive technology that requires digitalised and intelligent manufacturing for large-scale production, under a business architecture that supports strategic decision-making.

1.1 Challenges of Enterprise Architecture

Companies today face a constantly changing market and a highly competitive environment. Business models, artefacts and architecture must not be static; they must be adaptive and agile [9] [10]. Otherwise, enterprise architecture quickly becomes obsolete [80].

Furthermore, disruptive technologies are advancing at a rapid pace, forcing companies to transform their business architectures to generate value. However, this is not always achieved, as there is a gap between strategy and its application [22].

The smart and circular economy brings new business models, new platforms and new ways to serve, creating other economic activities. Traditional industry must transform itself by promoting the economy and social development [84].

The designs of new business architectures for smart industry must respond to the new technologies of Industry 4.0 [11]. This requires the use of frameworks that involve them, associated with a clear roadmap for their implementation [65] and a graphical representation in a modelling language that allows a company to be analysed in context.

artefacts are part of the daily life of a business architect and are vital for modelling enterprise architecture. However, the use of artefacts has become a mechanical task, in which existing notations are accepted as the only correct option, without really questioning their effectiveness in the specific context in which one works, and thus neglecting the possibility of creating new, more appropriate visual languages [32].

This leads us to ask the following research question and hypothesis.

1.2 Research Question

From an enterprise architecture perspective, how can a business architecture pattern be developed for an organisational structure dedicated to the manufacture of unmanned aerial vehicle swarms in the context of Industry 4.0?

1.3 Hypothesis

The development of a business architecture pattern based on Enterprise Architecture characteristics and artefacts allows for the coherent and scalable modelling of an organisational structure dedicated to the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0.

1.4 Justification in terms of needs and relevance

Industry 4.0 is committed to the competitiveness of the manufacturing sector in the present and future. However, there is a lack of common understanding that would enable its implementation. More tools are needed to benefit the transition of companies towards the concept of interconnected smart factories as proposed by Industry 4.0. This is especially true for small and medium-sized enterprises and those that are emerging to manufacture new technologies [21]. A Business Architecture in 4.0 will facilitate the implementation of a smart factory of swarms of unmanned aerial vehicles.

Among other aspects of Industry 4.0 implementation are social risks associated with the organisational transformation of employees and technical risks such as information technology (IT) integration, data security, legal and political risks. This opens up a technological niche for possible future research [12].

This research focuses on the development of Business Architecture, one of the four fundamental domains of Enterprise Architecture. Enterprise Architecture developments must begin with Business Architecture. To be successful, an organisation and its CIO(s) need to focus more resources on building and communicating Business Architecture change maps that involve not only their enterprise architects, but also their business executives, business architects, product managers, IT portfolio managers, obviously their CIO(s), and their entire short- and long-term planning ecosystem. Doing Enterprise Architecture without basic Business Architecture is, in reality, doing IT architecture rather than Enterprise Architecture. Limiting enterprise architecture practices to IT architecture is probably one of the main reasons why only 35% of all digital transformations were successful, according to the Boston Consulting Group in a 2020 study involving 850 companies worldwide [27].

1.5 Theoretical framework

1.5.1 Enterprise Architecture

Enterprise Architecture takes a broad view of the company in order to achieve strategic and operational objectives. Enterprise Architecture includes: Business Architecture, Information Systems Architecture, and Technology Architecture, defining methods and models of organisational structure with the appropriate use of technology [42] [19].

1.5.2 Business Architecture

Business Architecture is part of Enterprise Architecture and describes the strategic organisation of the company focused on its commercial activity to obtain a profit, aligning the strategic objectives of the organisation with its technology, resources, infrastructure, and business processes and capabilities. The objective of Business Architecture is to improve the management of the organisation by generating a competitive advantage in the market, making better decisions to obtain greater profitability [53].

1.5.3 Framework

The Enterprise Architecture Framework is a conceptual structure with sufficient detail in the specification of each process to be able to apply it appropriately when implementing an Enterprise Architecture. Examples of frameworks are: Zachman, TOGAF, RAMI, among others [43] [18].

1.5.4 ArchiMate

ArchiMate is an open and independent graphical Enterprise Architecture modelling language designed to support the description, analysis and visualisation of architecture in an unambiguous manner. It is a type of architecture description language (ADL). The ArchiMate visual modelling notation leverages your Enterprise Architecture practice by helping to describe and understand complex systems. It is currently in Version 3.2 [35].

The benefits of using ArchiMate as a modelling language are: it is an international language, independent of the provider, it is a simple and clean language, it is easy to combine with Enterprise Architecture methods, and it is supported by different Enterprise Architecture tools, among which the following stand out: Abacus, Archi, Aris, Bizzdesign, Enterprise Architect, Troux.

1.5.5 artefacts in Enterprise Architecture

An artefact is an instrument that allows us to represent part of a model. As part of a visual notation, artefacts enable us to represent the result of the abstraction process in visualisations that allow us to understand different aspects of the business and study them easily. An artefact provides structure, but it is necessary to understand that it has a defined language, its own semantics, and a textual, mathematical or graphical characterisation. It is important to note that the artefacts created are not independent, and are related to others that describe the abstraction of reality in a defined context, thus establishing connections with other elements [32].

After understanding an artefact as a product of architectural work that describes an aspect of architecture, it is important to know that artefacts are classified into catalogues (lists of things), matrices (showing the relationships between things) and diagrams (images of things) [36].

1.5.6 Architecture Block

An architecture block (building block) represents a potentially reusable component that can be combined with other architecture blocks to create architectures and solutions [36].

1.5.7 Capability Map

The purpose of this matrix, proposed by The Open Group in its TOGAF Framework standard, is to represent business capabilities in relation to other elements of the organisation. Examples include a company's organisational units or departments [88].

1.5.8 Swarms of unmanned aerial vehicles (UAVs)

A swarm or fleet of Unmanned Aerial Vehicles (UAVs) is a set of aerial robots, drones that work together to achieve a specific goal. Drone swarms have historically been widely used in the military sphere; however, they are generating increasing interest in other fields, driving new lines of research and various commercial applications. [83].

1.5.9 Industry 4.0

Industry 4.0 (I4.0) is the methodology and approach for a company that allows the integration of automated, hyper-connected, and intelligent automation systems, with the main objective of achieving efficiency in obtaining data from the controls present for each process in a company.

This revolution is marked by the emergence of new disruptive technologies such as analytics, artificial intelligence, Cobot, cognitive technologies, nanotechnology, and the Internet of Things (IoT), among other disruptive technologies. Organizations must identify the technologies that best meet their needs in order to invest in them. Companies that do not understand the changes and opportunities brought about by Industry 4.0 will run the risk of losing market share and disappearing [10].

In I4.0, data integration is a combination of technical and business processes (vertical-horizontal integration) that are used to combine information from different sources to convert it into reliable and valuable data. These integration solutions help to understand, clean, monitor, transform, and deliver data so that companies can be sure that the source of information is reliable, consistent, and managed in real time [93]. Artificial intelligence is pointed out as a central element of this transformation [78].

1.6 Objectives

1.6.1 General Objective

Develop the Business Architecture for the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0.

1.6.2 Specific Objectives

1. Conceive the theoretical and methodological aspects of the Business Architecture for the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0.

2. Design the visual and functional representation of the Business Architecture for the manufacture of swarms of unmanned aerial vehicles in the context of Industry 4.0.

3. Implement the functional simulation of the Business Architecture designed for the manufacture of swarms of unmanned aerial vehicles in a specialised computer application.

4. Operate the functional model for the validation of the proposed Business Architecture.

1.7 Methodology

The project was developed using the CDIO methodology methodology (Conceive, Design, Implement, and Operate), which allowed for the sequential structuring of the phases necessary for the development of the business architecture pattern and its artefacts, oriented towards an organisational structure in a factory dedicated to the production of unmanned aerial vehicle (UAV) swarms in the context of Industry 4.0.

This methodology made it possible to integrate the specific objectives with the four papers derived from this research:

1. Overview of Business Architecture in Industry 4.0: Trends and Future Directions.
2. Hybrid Model for Strategic Decision-Making in Enterprise Architecture through Cooperation Between Humans and Intelligent Agents.
3. Business Architecture Pattern for an Organisational Structure 5.0.
4. Simulation of Business Processes in BPMN Using Co-Intelligence Artefacts: A Case Study in a Drone Swarm Factory.

Accordingly, each of the four articles was developed in accordance with the CDIO methodology, as shown in Figure 1.1. This approach ensured methodological coherence throughout the entire project. As an example, the first article identifies the stages Conceive (C 1-1), Design (C 1-2), Implement (C 1-3) and Operate (C 1-4); likewise, each of the four articles follows this same nomenclature in correspondence with the phases of the CDIO model.

The four articles are presented in chapters 2, 3, 4 and 5, forming a common thread that highlights the consistency between the stages of the CDIO approach and the academic products obtained. Figures 1.2, 1.3, 1.4, 1.5 illustrate this relationship, showing how each article contributes to the progressive fulfilment of the specific objectives established in the research.

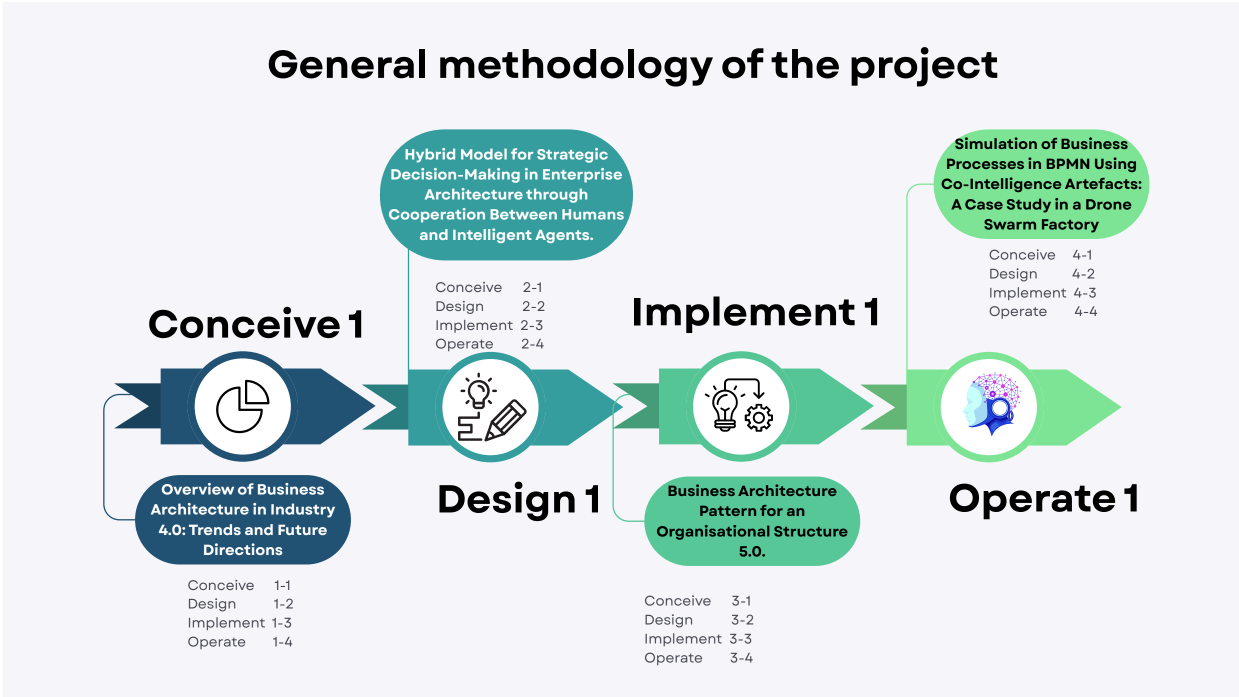


Figure 1.1: General methodology of the project

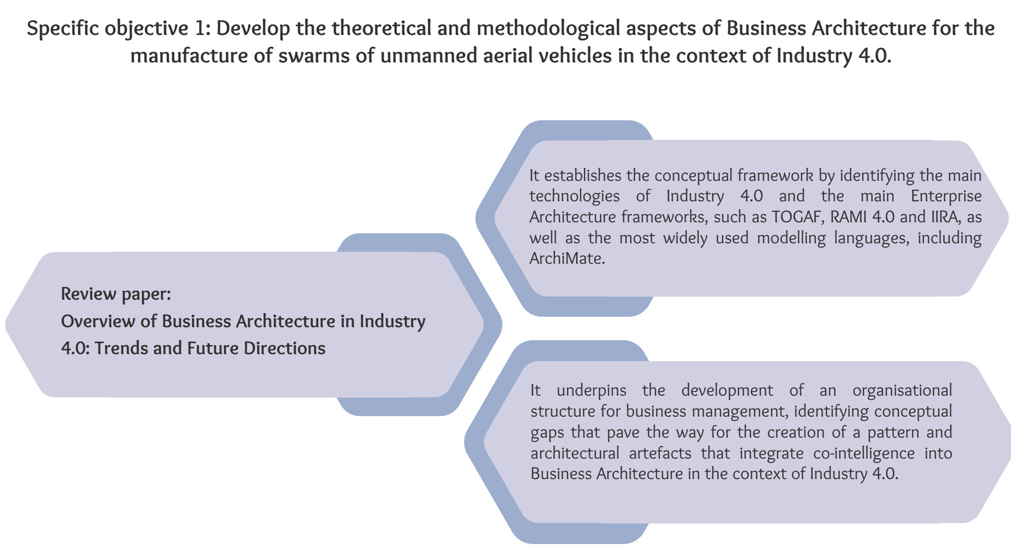


Figure 1.2: Specific objective compliance 1

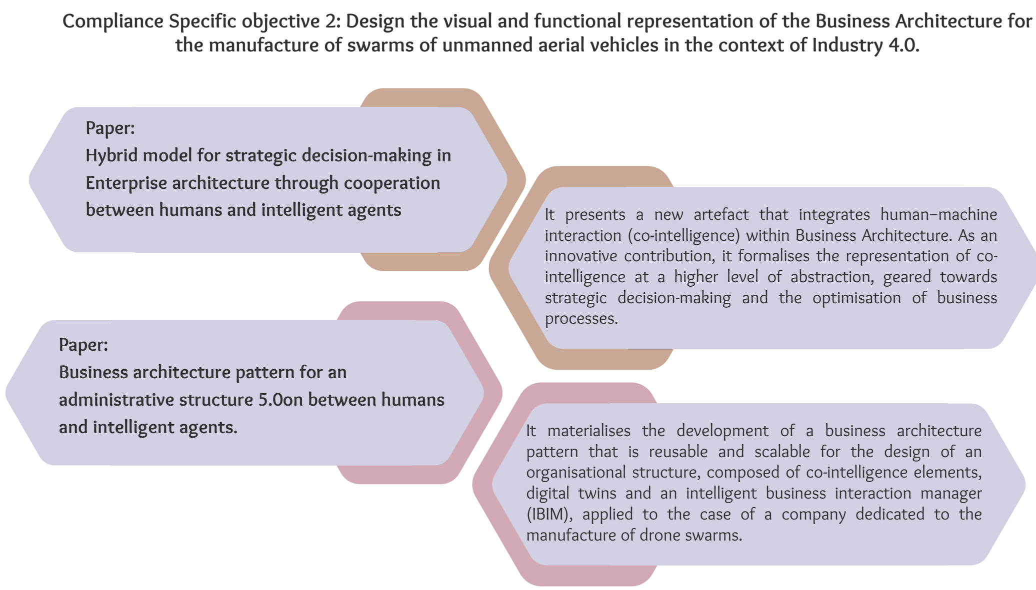


Figure 1.3: Specific objective compliance 2

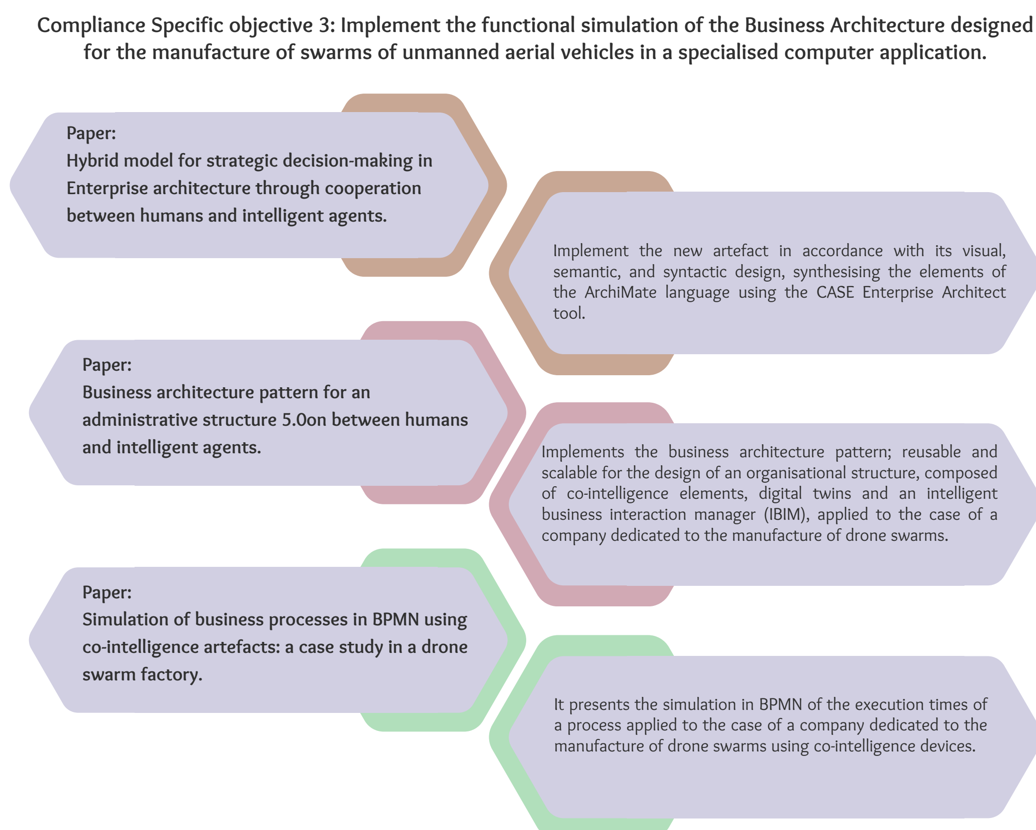


Figure 1.4: Specific objective compliance 3

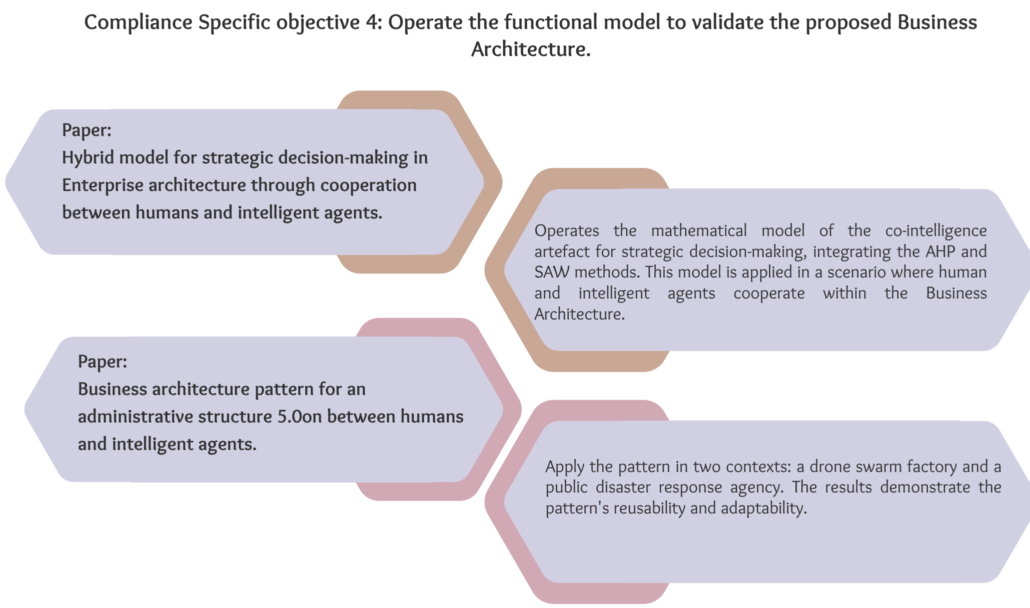


Figure 1.5: Specific objective compliance 4

CHAPTER 2: OVERVIEW OF BUSINESS ARCHITECTURE IN INDUSTRY 4.0: TRENDS AND FUTURE DIRECTIONS

2.1 Abstract

This article presents a overview of the current and future state of “business architecture” within the enterprise architecture frameworks. The survey is conducted in the following four stages. In the first stage of analysis, the research questions are established. In the second stage, the search for information was designed and implemented using the Prisma methodology, and once the selection criteria were applied, 75 article-type documents were selected from Scopus, WoS, and Dimensions databases. In the third stage, the information analysis is conducted, and then it is synthesized. Finally, in fourth stage, the discussion is elaborated. This research contributes to understanding the current and future trends of business architecture in Industry 4.0. Considering the challenges of the changing market, the results show the need to implement architectures and dynamic business models, including their artefacts, in a globalized context immersed in new technologies.

2.2 keywords

enterprise architecture, business architecture, Industry 4.0

2.3 Introduction

The aim of this study is to know the Framework and the appropriate methodology to carry out a business architecture for the manufacture of large-scale drone swarms. Enterprise architecture (EA) is a systemic approach that helps organizations model and describe themselves in different layers, such as strategy, business, application, and technology [8]. Making Business Architecture without fundamental Business Architecture is doing IT architecture. Only doing IT architecture is one of the main reasons why only 35% of the digital transformations of 850 companies worldwide were successful, according to a study carried out in 2020 by The Boston Consulting Group [27]. Since business architecture relates to the productivity, efficiency, and agility, it is regarded as a fundamental aspect for a factory or company. Organizations need to assess their operation and behavior in terms of business architecture, which allows them to make better strategic decisions [61]. Making a strategic fit within the enterprise architecture is a major challenge for organizations, and it determines their success or failure. Research in enterprise modeling has led to the development of a wide range of modeling techniques for further understanding of the enterprise architecture [68]. There are different work frameworks, such as the Open Group Architecture Framework (TOGAF), Zachman, DODAF, among others ,[43][18].

There are enterprise architecture frameworks that have been proposed for Industry 4.0: The Reference Architecture Model Industry 4.0 (RAMI 4.0) sponsored by German industry and the US-lead Industrial Internet Reference Architecture (IIRA). In addition to other framework initiatives in Japan, China, Korea and the UK. However, these frameworks either have a flexible coupling with RAMI or are very open to adopting German Industry 4.0 technologies. As Germany is seen as a leader in European industry, it is expected that the dominant framework will be RAMI [99]. The fourth industrial revolution, Industry 4.0 (I4.0), is committed to the competitiveness of the future manufacturing sector. However, it needs a common agreement for its implementation. Tools are required to benefit companies' transition toward interconnected smart factories, especially small-and medium-sized companies and factories emerging from new technologies. According to research carried out by the Department of Mechanical Engineering of the Eastern Mediterranean University on different architectural frameworks for I4.0, it is necessary to define the areas and knowledge required to implement I4.0. Consequently, a road map to the fourth industrial revolution and a generic framework for practical uses are lacking [21]. I4.0 implies greater company organization and shorter innovation, development, and production times. Companies must strengthen the value chain with new business models and architectures, driving demand customization. Intelligent industry seeks the efficient use of resources using the information, communication, automation, internet of things, big data, artificial intelligence, collaborative robots, and simulation technologies [58] [96][17]. Although RAMI 4.0 has a good level of acceptance, it still needs more actual applications in the industry. The lack of specifications in the standard itself hinders the implementation of this architecture [11].

2.4 Theoretical framework

2.4.1 Enterprise Architecture

Enterprise architecture has a broad vision of the company to fulfill strategic and operational goals. Enterprise architecture includes business architecture, information systems architecture, and technology architecture. It defines methods and models of the organizational structure with the appropriate use of technology [42] [19]. The architecture aims to improve the organization's management, generating a competitive advantage in the market, by making better decisions to achieve higher profitability [53] [15].

2.4.2 Business Architecture

Business Architecture is part of Enterprise Architecture and focuses on modelling business processes and functions. Business Architecture is one of the phases considered in the Architecture Development Method (ADM), a methodology for developing an architecture using TOGAF.

2.5 Conceive *1-1*

2.5.1 Methodology

This review [34] aims to identify the current and future state of business architecture. To meet these goals, the following four stages are established: In the first stage of analysis, the research and publication questions are established. In the second stage, the search for information is designed and implemented using the Prisma methodology. In the third stage, the analysis of the information is conducted and synthesized. Finally, in the fourth stage, the discussion is elaborated, interpreting the information, answering the research questions, and defining a research hypothesis. Figure 2.1 shows the proposed methodology.

2.6 Design *1-2*

2.6.1 Search criteria and selection of bibliography

Beginning with the first stage of the proposed methodology, the following research questions (RQ) are created (Table 2.1).

2.6.2 Search criteria

The second stage begins with four activities: identifying the search keywords, selecting the databases, designing the search formula, and searching the databases. The criteria used to search and select articles using the Prisma methodology are described below. In order to: provide a better understanding of the applicability of the Prisma methodology in the context

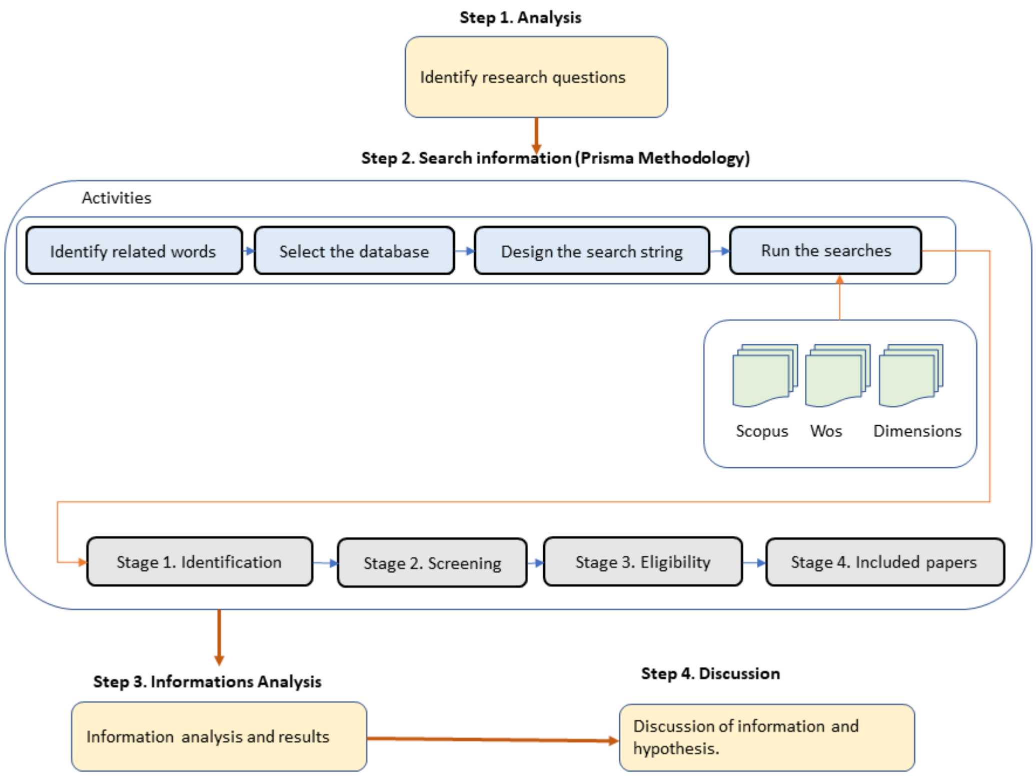


Figure 2.1: Methodology

Table 2.1: Research questions (RQ)

RQ#	Research Question
RQ1	What frameworks are proposed or discussed in the papers regarding the design of business architectures?
RQ2	What are the proposed frameworks for the Smart Industry?
RQ3	What business architecture application examples are there in unmanned aerial vehicles (UAV) manufacturing technology industries?
RQ4	What examples of business architecture applications have been carried out considering responsible consumption?
RQ5	What are the challenges of business architecture?
RQ6	Are the countries that propose the frameworks to work EA at 4.0 the same ones that socialise the results of the implementations?
RQ7	Are companies interested in new EA architectures proposed by academia for Industry 4.0?

of this study, present the alignment of the selection criteria used with the objectives of the study; and show that the selection criteria respond to the specific needs of the research, Table 2.2 explains the process of defining these criteria, together with the reasons that motivated each choice.

Table 2.2: Selection Criteria

Selection Criteria	Applicability in the Context of this Study
Keyword: Business architecture	The focus of this study is on business architecture as business processes that are part of the enterprise architecture.
Publication Years: 2020 or 2019	Search for updated information.
Document Types: Article	Socialization of results of business architecture implementations in scientific papers.
Languages: English	Provides access to a greater number of documents. Facilitates the understanding of scientific documentation on a global level.
Database: Scopus, WoS, and Dimension	International scientific documentation databases.

The search criteria for the selection of articles was "business architecture" in the abstract title and keywords. Only formal literature (scientific publications, academic articles) was included in the review. The searches were carried out in the international databases Scopus, WoS and Dimension, and only documents written in English and published between 2018 and 19 January 2023 were considered, using the Boolean operators AND and OR. The search

Table 2.3: Search formulas

Database	Search String
Scopus	`TITLE-ABS-KEY ("business architecture") AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018)) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))`
Web of Science	`"Business architecture" (Title) AND "Business architecture" (Abstract) AND "Business architecture" (Author keywords). Refined by: Publication Years 2020 or 2019; Document Types: Article; Language: English.`
Dimensions	`Article Publication Type: 2023 OR 2022 OR 2021 OR 2020 OR 2019 OR 2018. "Business architecture" as free text in the title and abstract.`

formulas, adapted for each database, are shown in Table 2.3.

Table 2.4: Resulting studies

Search	Date	Articles
Scopus	19 January 2023	718
WoS	19 January 2023	4
Dimensions	19 January 2023	743
Total	**19 January 2023**	**1465**

2.7 Implement *1-3*

The search process, illustrated in Figure 2.2, was conducted in four phases using the Prisma methodology. In the Phase 1, 1,465 documents were found, using the search criteria "business architecture" in the title, abstract, and keywords (Table 2.4). In Phase 2 or screening, 595 documents published between 2018 and 2023 were selected. In Phase 3, the documents corresponding to article-type publications were chosen. Finally, in Phase 4, duplicate articles were eliminated, and a new language and publication type review was performed, and papers presented at congresses were eliminated. Eventually, 75 articles were obtained.

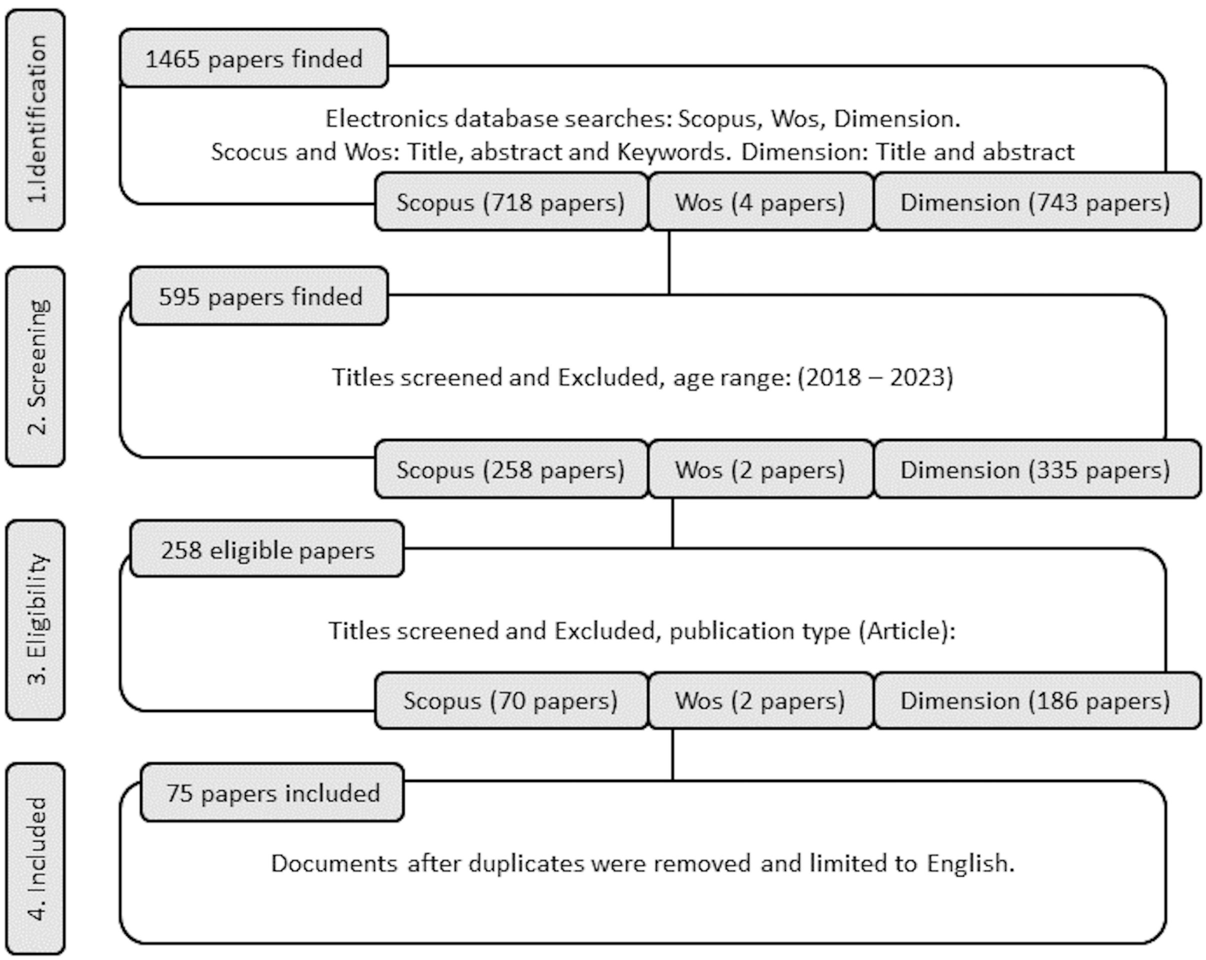


Figure 2.2: Search process

2.8 Operate *1-4*

In the fourth stage, the information is discussed based on the answers to the PQ and the answers to the RQ then a research hypothesis is formulated.

2.8.1 RQ1: ¿What frameworks are proposed or discussed in the papers regarding the design of business architectures?

Based on the 75 papers reviewed, a decent number of documents, approximately 25%, recognize TOGAF as a Framework to be used when designing an enterprise architecture [42], [19], [44], [37], [82], [26], [33], [62], [72], [48], [59], [3], [5], [39], [41], [55], [63], [81] while the Zachman Framework is only proposed by one document [54], other authors suggest processes for specific applications without reference to frameworks such as TOGAF or Zachman. [52][57][13][94] [43].

2.8.2 RQ2: What are the proposed frameworks for smart industry?

The current industry must make a transition to the concept of smart factories. Only few studies were found that address this type of business architecture models [38][70][64]. By expanding the search to include "RAMI" and "enterprise architecture", eight additional documents were found in Scopus (one article, one book, and six conference articles) (see Table 2.5). In this new search, the following was found: a comparison is made between RAMI and TOGAF, contributing to the implementation of RAMI for business architectures in intelligent enterprises [46]. Another paper proposes the fusion of RAMI 4.0 and TOGAF and evaluates it with a real industrial case [58]. Finally, the application of the ArchiMate modeling language (TOGAF) to the RAMI 4.0 framework for the development of enterprise architectures is proposed as a future work [45].

With I4.0, the demand for custom manufacturing products is growing, making it necessary to standardize programming and development for intelligent manufacturing [4]. For I4.0, architectures have been proposed, however, consensus is still required for the use of any one of them. The industry has specifically promoted two architectures, Reference Architecture Model for Industry 4.0 (RAMI) and Industrial Internet Reference Architecture (IIRA) [7] [99].

Table 2.5: Framework Implementation Contributions for I4.0

Paper	Contribution to the Implementation of a Framework for I4.0
[74]	There is no mention of TOGAF or RAMI.
[45]	Suggests modelling socio-cyber-physical systems with RAMI 4.0.
[46]	Finds that TOGAF and RAMI are somewhat compatible and TOGAF components can complement RAMI.
[9]	Presents models for six layers of RAMI 4.0: business, functional, information, communication, integration, and assets.
[73]	Works on layers 3 and 4 of the RAMI 4.0 framework.
[11]	Aligns RAMI 4.0 with TOGAF and evaluates it with a real industrial case.
[76]	Combines Model-Based Engineering (MBE) with Deep Learning techniques, specifically Recurrent Neural Networks (RNN), within RAMI 4.0; the integration aims to optimise industrial processes.
[99]	Describes RAMI 4.0 as mature for communication and information exchange but lacking interoperability standards for executable processes.

2.8.3 RQ3: What business architecture application examples are there in unmanned aerial vehicles (UAV) manufacturing technology industries?

A business model for services based on UAV was found, focused on the communication process through the 5G mobile network. This process is presented as a development to solve large-scale services with UAVs with safety and reliability. However, there are still challenges to the integration of mobile network operators [89].

2.8.4 RQ4: What examples of business architecture applications have been carried out considering responsible consumption?

A company that is focused on business sustain manufactures long-term value products seeking excellent financial results and a positive impact on the society. Business sustainability integrates environmental protection with responsible consumption. In this review, articles with a business sustainability approach were referred to [40] [100] [91] [60].

2.8.5 RQ5: What are the challenges of business architecture?

As companies currently face a constantly changing market and an extremely competitive environment, business models, artefacts, and their architecture must not be static [79]. Otherwise, enterprise architectures become obsolete in a short time [80]. Therefore, they must be adaptive and agile. Additionally, digital technologies advance at a high speed, thus forcing companies to transform their business architectures to generate value. However, this cannot always be achieved as there is a gap between strategy and its application [22]. The digital economy brings new business models, new platforms, and new services creating other economic activities. The traditional industry must be transformed for it to drive the economy and social development [84]. Regarding the models for the I4.0, RAMI 4.0 has a good level of acceptance, but this needs more real applications in the industry due to a lack of specifications in the standard itself, which hinders the implementation of this architecture [11]. This architecture model represents a challenge. RAMI offers a good overview of the architecture of smart factories, but has limitations and a need for more clarity for users [65]. Designs of new business architectures for smart industry must respond to new technologies in Industry 4.0 [11]. Designs should use Frameworks that involve new technologies with a clear methodology for implementation [65]. Business Architecture models must allow analyzing a company in context [11]. Two examples of the impact of the Industrial Internet of Things (IIoT) given the development of Industry 4.0, on business processes by optimizing operations, reducing costs: Business architecture focuses on aligning business processes with business strategy, ensuring that strategic decisions are effectively implemented at operational levels. The research integrates RAMI 4.0 with Software Platform Embedded Systems (SPES), using a Recurrent Neural Network (RNN) to optimize industrial processes. This integration, known as RNN-MBE, reduces costs and complexity, improving the scalability of the system [76]. Through the RAMI 4.0 architecture, different layers are managed: the Asset Layer for data collection using IoT, the Integration Layer for data processing with SPES, and the Functional Layer for task allocation and process optimization using RNN. This approach ensures that operational decisions are aligned with the strategic and value objectives of the enterprise, optimizing operational efficiency in an advanced industrial environment [76] Another example is the framework called "Agri-4-All" that integrates IoT, blockchain and smart contracts. This framework was evaluated using intra- and inter-organizational smart contracts, achieving a remarkable reduction in costs compared to traditional models [2]. This paper examines how these technologies can automate processes, monitor products in real time and ensure secure transactions in the food supply chain. Using Business Process Modeling (BPM) and the RAMI 4.0 framework [2].

2.8.6 RQ6: Are the countries that propose the Frameworks to work EA at 4.0 the same ones that socialize the results of the implementations?

In 2015, the ZVEI, the Association of German Electrical and Electronic Manufacturers, presented the Reference Architecture Model for Industry 4.0 (RAMI 4.0). RAMI currently has the backing of European automation companies such as Siemens, ABB, and Festo [4]. However, Indonesia is the country that most socializes its results in publications.

2.8.7 RQ7: Are companies interested in new AE architectures proposed by the Academy for Industry 4.0?

Industry promoted the development of two reference architectures of Industry 4.0, the Industry 4.0 Reference Architecture Model (RAMI) and the Industrial Internet Reference Architecture (IIRA); however, according to [99], only a minority of researchers knew about these architectures and generated their proposals. Thus, there is a disconnect between the technological normalization promoted by industry and the academic research on Industry 4.0 [99]. Companies are looking to improve their productivity in the context of Industry 4.0. Before creating new frameworks, university research could focus on developing implementations of architectures proposed by industry, such as RAMI or IIRA. Such research can facilitate the implementation of digital transformations by providing practical solutions to current challenges. A study by the Boston Consulting Group, in which more than 850 companies worldwide have participated, shows the interest of companies in various contexts in their transformation, where the implementation of an appropriate business architecture can contribute significantly [27]. Priorities in digital transformation vary by sector: in telecommunications and retail, the main focus is on customer experience, influenced by the expectations of digital companies such as Amazon; in the oil, gas and utilities industry, the priority is the digitization of manufacturing and automation of operations. In sectors such as media and technology, innovation and new business growth are crucial; while, in healthcare, business model innovation and digital ecosystems are highlighted. As companies move forward in their digital transformation, they are shifting from basic reengineering to a focus on innovation, including digitizing support functions such as finance and human resources, to stay competitive by adjusting processes and business architecture. Companies' digital transformations must focus on objectives with broader strategic importance. Business architecture, which integrates operational processes with the company's strategic objectives, is crucial for success. Given our research interest, we decided to design the business architecture for a company that manufactures unmanned aerial vehicles, integrating RAMI with TOGAF's ADM methodology, modeling the business architecture in Archimate and simulating the processes in BPMN.

2.8.8 Discussion of the results of the publication questions

Companies are betting on innovation and technology to be more productive; it is to be expected then to find a lot of scientific literature on business architecture, however, this is not the case. The scarcity of scientific publications on business architectures may indicate that, although companies are interested in the implementation of Industry 4.0, they are not interested in showing their architectures and business models, as they are intangible assets of a company, causing the academic world to disagree in publications on the real advances that may exist in the industry. The hypothesis is: the development of business architectures for emerging technologies is a new area of research.

2.8.9 Limitations

The review shows that the Asian and European continents have the highest production of documents on "business architecture" in the last six years. However, some authors use the terms "business architecture" and "enterprise architecture" interchangeably, which could broaden the results scenario in future reviews. It is essential to mention that selecting only English-language documents significantly reduces the number of documents included in this review. For instance, 54 documents were excluded because they were written in Indonesian. This limits the review, however, the trend of high production in the Asian continent is preserved in the results shown in this document.

2.9 Conclusions

The 2030 Agenda and the sustainable development goals propose the promotion of inclusive, sustainable, and innovative manufacturing. However, although there are two reference models for business architecture in I4.0, supported by the industry itself, a roadmap is still unclear for its implementation in real manufacturing cases in a standardized manner. There is, therefore, an opportunity to develop implementation methodologies in frameworks already recognized as RAMI or IIRA.

Smart industry seeks shorter innovation, development, and production times. New business models and business architectures are required to strengthen the value chain regarding the demand for customized products with greater flexibility in manufacturing processes.

During this review, it was found that there is a lack of documents addressing the implementation of business architectures in the context of I4.0 with a responsible and efficient use of resources. And also, literature was found that states that a clear methodology for implementing the RAMI framework is lacking; examples of implementation are missing. However, it was also found that a mature methodology such as the ADM of the TOGAF framework can be used to implement RAMI through modelling languages such as Archimate. Another research opportunity is to develop business architectures for emerging technology companies, which would allow them to have an organizational structure for business, technology, and innovation management since its inception.

The RAMI Framework proposes a business architecture for Industry 4.0 accepted by the industry, which, according to the review, needs more applications and clarity for implementation. The researchers propose to implement a digital transformation from the design of the business architecture, integrating the philosophy of the RAMI Framework with the methodology already established by the TOGAF Framework (with more than 25 years of experience). For the implementation of the new Business Architecture in the context of Industry 4.0, the RAMI philosophy can be integrated with the TOGAF ADM by modelling the business architecture in ArchiMate and simulating it in tools such as BPsim.

The need to implement and test new schemes through the combination of enterprise architecture standards seems to give rise to a new area of research. Inspired by the comparison made in [46], Figure 2.3 shows the impact points in the RAMI and TOGAF framework structures when implementing an I4.0 business architecture. Disc 1 shows the three phases of a business architecture as defined in TOGAF, Disc 2 shows the architecture axis as defined in RAMI and Disc 3 shows the life cycle axis as defined in RAMI.

By rotating discs 1, 2 and 3 in Figure 2.3, all possible combinations of the impact points in RAMI and TOGAF that need to be considered when integrating I4.0 into a business architecture can be seen. It is important to remember that RAMI defines on the architecture axis the Business Layer and the Function Layer, which includes the organisation, business processes and asset functions. For RAMI, the lifecycle axis allows describing each product from design, maintenance and product instance. It is proposed as future work, Modelling and publishing Industry 4.0 business architectures [24] to bring academia and industry closer together.

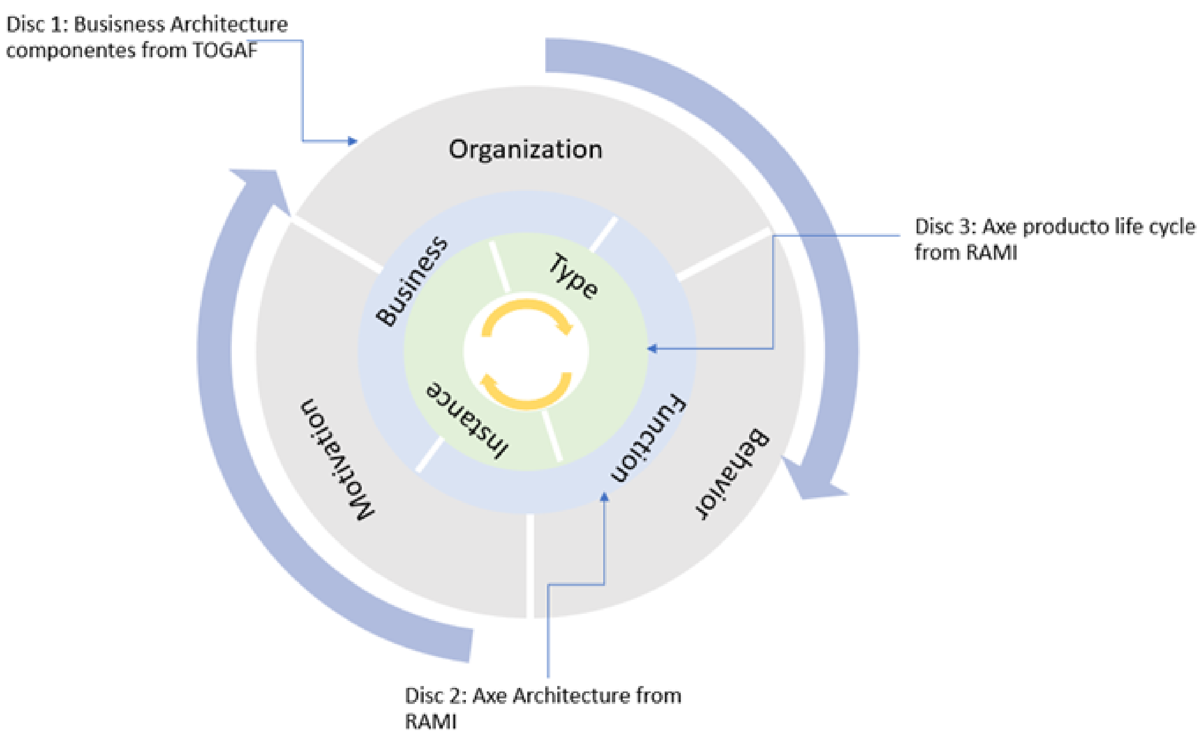


Figure 2.3: The impact points in RAMI and TOGAF to the Business Architecture

CHAPTER 3: HYBRID MODEL FOR STRATEGIC DECISION-MAKING IN ENTERPRISE ARCHITECTURE THROUGH COOPERATION BETWEEN HUMANS AND INTELLIGENT AGENTS

3.1 Abstract

This article presents a conceptual and technical artefact aimed at modelling cooperative interaction between humans and intelligent agents in decision-making processes, within the framework of enterprise architecture. The proposal constitutes a structural and semantic contribution to the ArchiMate language, aligning organizational modelling with the emerging challenges of Industry 4.0, in particular with the integration of so-called third intelligence. The research is structured in four stages: (1) analysis of the concept of Co-intelligence and its relevance in digital transformation processes; (2) design and implementation of the artefact in the Enterprise Architect platform; (3) application of the model to a specific business requirement; and (4) discussion of the results and their implications for organizational architectural design. The artefact extends the expressive capabilities of ArchiMate through a structure that allows the cooperation between humans and intelligent systems to be explicitly represented, making it easier for enterprise architects to incorporate this dimension into strategic process modelling. Although the development stems from an industrial context, the proposal is transferable to other domains, including public companies, where it can support digital transformations focused on citizen assistance mediated by artificial intelligence.

The main purpose of this work is to present the development of a new artefact with human-machine interaction (co-intelligence) in enterprise architecture at the business level. As a novelty, the new artefact synthesises elements of the ArchiMate language, formalising the new artefact at a higher level of abstraction, co-intelligence in strategic decision-making. The new artefact is an important contribution to the design of new business architectures, providing enterprise architects with a new element for modelling digital transformation processes towards smart industry and its subsequent evolution towards Industry 5.0.

3.2 keywords

Enterprise architecture; Business architecture; Industry 4.0; Business model;Digital transformation;Co-intelligence; Archimate.

3.3 Introduction

This chapter corresponds to the article entitled Hybrid Model for Strategic Decision-Making in Enterprise Architecture through Cooperation Between Humans and Intelligent Agents.

In recent years, the development of artificial intelligence has enabled an unprecedented human-machine cooperative relationship. Artificial intelligence has been transformed, performing increasingly complex tasks including some autonomy, turning from a tool into an intelligent machine with which humans cooperate to meet common goals [49]. Human-machine Co-intelligence is now being referred to as human-machine Co-intelligence, which arises from human-machine cooperation and is recognized as a third intelligence. Human-machine Co-intelligence is generating a higher level of intelligence than human intelligence or the intelligence of machines alone, working under three principles: unified unity, division of labor and co-evolution [97]. With the evolution of artificial intelligence also evolve intelligent agents which are computer programs that through information from the environment can be autonomous performing tasks and achieving goals. Applications for intelligent agents are found in different fields including industry [75]. Currently we find systems based on multiple intelligent agents performing complex tasks through cooperation and collective intelligence to solve problems [101]. The Co-intelligence artefact visually, semantically, and mathematically models the cooperation between humans and intelligent agents, and its use is applicable to the design of decision-making solutions for improved citizen services and interaction with the state.

3.4 Conceive *2-1*

3.4.1 Why do we need to model this cooperation?

The Fourth Industrial Revolution involves the integration of interconnected systems made up of intuitive, self-regulating, intelligent, and autonomous entities capable of exchanging data, executing tasks, and collaborating in a coordinated manner [90]. This approach seeks to increase productivity, flexibility, efficiency, and agility in industrial environments [6], [20].

Organizations that can leverage artificial intelligence (AI) will be able to operate with greater agility and adaptability [98].

This new factory paradigm, based on the integration of information technologies with Industry 3.0 advances, drives the digitisation of manufacturing processes. Therefore, Industry 4.0 requires business leaders to broaden their focus beyond their traditional sectors, understanding the potential transformations of processes, business models and disruptions affecting suppliers, customers and adjacent markets [28].

In recent years, business intelligence (BI) has grown stronger, using computer systems and emerging technologies to support decision-making in various organisations: smart factories, commercial enterprises and service providers [69]. Another fundamental aspect of achieving higher levels of productivity, efficiency and agility is enterprise architecture. Organisations must evaluate their functioning, processes, operations and performance to achieve strategic business objectives [61].

In the context of digital transformation and the evolution of Industry 4.0, organisations face the challenge of incorporating new forms of hybrid intelligence into their structures, processes and decision-making models. In this framework, the relationship between humans and intelligent systems is no longer purely instrumental, but has become a dynamic of human-machine co-intelligence, understood as an emerging form of collaborative intelligence combining human and artificial capabilities to achieve common goals [49], [98].

Human-machine co-intelligence, recognised as a "third intelligence", overcomes the limitations of human or artificial agents acting separately. Its functioning is based on three fundamental principles: unified unity, division of labour and co-evolution, enabling adaptive and synergistic integration into organisational processes [97]. In this scenario, intelligent agents emerge, autonomous programmes capable of perceiving their environment, making decisions and executing goal-oriented actions. Their deployment in industrial contexts has given way to multi-agent systems that cooperate with each other, enabling new levels of coordination, automation and distributed co-intelligence [101].

This article proposes a modelling artefact that allows the representation of human-machine co-intelligence in business architecture, using the ArchiMate language as a structural and semantic means to address these challenges from a perspective aligned with the principles of Industry 4.0.

In the business management structure proposed by figure 4.2, human-machine cooperative interactions become a frequent element in the business architecture and processes. We call this element an artefact of Co-intelligence, its visual representation is shown in figure 3.2.

Three criteria were used to select the research object, defining the type of artefact to be designed: strategic relevance at the business level, contribution to modelling scenarios

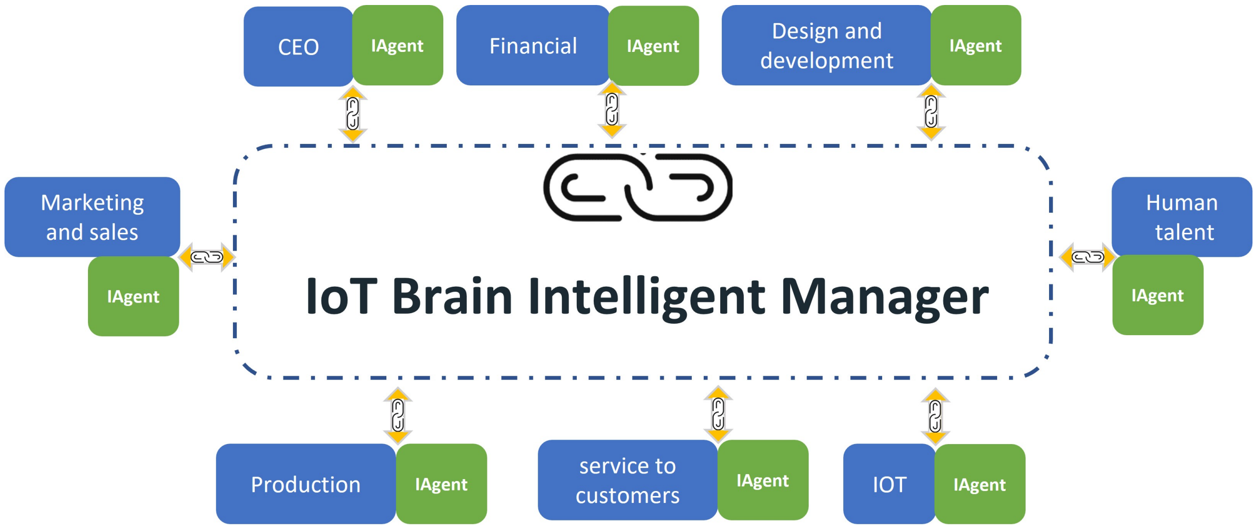


Figure 3.1: Business management structure

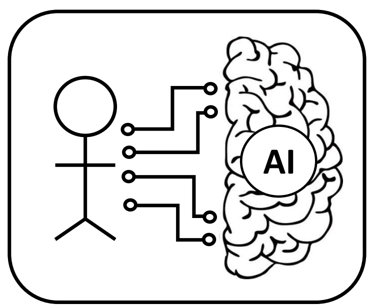


Figure 3.2: Visual representation of the Co-intelligence artefact

including new Industry 4.0 technologies, and the possibility of creating it at a more abstract level by synthesising it, integrating different elements of the ArchiMate language. The co-intelligence artefact meets the three defined criteria: decisions are fundamental at the strategic business level; modelling interactions between humans and intelligent agents is one of the challenges, given Industry 4.0 technologies; and interactions are illustrated by integrating elements of the ArchiMate language.

3.5 Design *2-2*

3.5.1 Explanation of the Co-intelligence

Artefacts are part of a business architect's day-to-day work and are vital for Enterprise Architecture modelling. However, the use of artefacts has become a mechanical task, where existing notations are accepted as the only correct option, without really questioning their effectiveness in the specific context in which they work. There is a need for reconceptualisation of artefacts in enterprise architecture and further research in this direction [47].

Achieving an effective strategic fit within the Enterprise Architecture is a relevant challenge that can determine organizational success or failure. In this regard, research on enterprise modeling has led to the development of various modeling techniques aimed at improving the understanding and management of Enterprise Architecture [68].

3.5.2 Semantics

This artefact of Co-intelligence seeks to visually and abstractly represent the interaction and cooperation between a person and an artificial intelligence agent to accomplish a goal or task, allowing us to understand aspects of the business by modelling them in an enterprise architecture Figure 3.5.

Table 3.1 shows the description of each selected Archimate 3.1 element to model the semantics of the Co-intelligence artefact and Table 3.5 shows the description of the selected relationships in the artefact modelling [86].

Table 3.1: Business Layer elements in ArchiMate 3.1 describing the semantics of the Co-intelligence artefact

Element	**Description**
Business Actor	A department or unit within the organisation.
Business Role	Humans and intelligent agents assume responsibilities and behaviours assigned to the department.
Business Collaboration	Represents the configuration of collaborative work between the human and the intelligent agent.
Business Interaction	Describes the resulting work from the collaboration between the human and the intelligent agent to achieve a common goal, such as decision-making.

The proposed Co-intelligence artefact is oriented towards decision making in a company

Figure 3.2. The following table shows the input and output relationships allowed for the new Co-intelligence artefact Table 3.5.

Table 3.2: Selected relationships in ArchiMate 3.1 possible for the new Co-intelligence artefact

Relationship	**Input (to the decision interaction)**	**Output (from the decision interaction)**
Triggering	Permitted (Another process or event triggers the interaction)	Permitted (The decision triggers another behavior)
Access	Permitted (Reads data, documents, criteria)	Permitted (Writes or updates decisions, reports)
Flow	Permitted (Information flows into the interaction)	Permitted (Outcome flows to other behaviors or processes)
Realization	Not permitted	Permitted (Interaction realizes a decision service)

3.5.3 Mathematics

In the Co-intelligence artefact, humans and intelligent agents cooperate by making strategic decisions for the department, sharing experience, data, and information. To model this interaction, we propose using a hybrid mathematical model combining two multi-criteria analysis techniques: Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW). The company will establish the processes and decisions that must be made within each department. In the departments, a decision is made in line with a strategic objective of the company, and a decision has different solution options according to evaluated criteria.

3.5.3.1 Application of the AHP technique in a mathematical model for the Co-intelligence artefact.

In the first part of the model using the AHP technique, a group of experts will determine, on a one-time basis, the options from which the decision will be made, the evaluation criteria, and the weights of the evaluation criteria [31]. The company defines the experts and the number of experts it considers necessary. Figure 3.3 shows the basic AHP structure for decision making with an example of making a decision choosing between four options with four criteria.

The final result of the technical application of AHP generates, for this example, a vector W with four definitive weights for each criterion according to the experts' concept, as shown

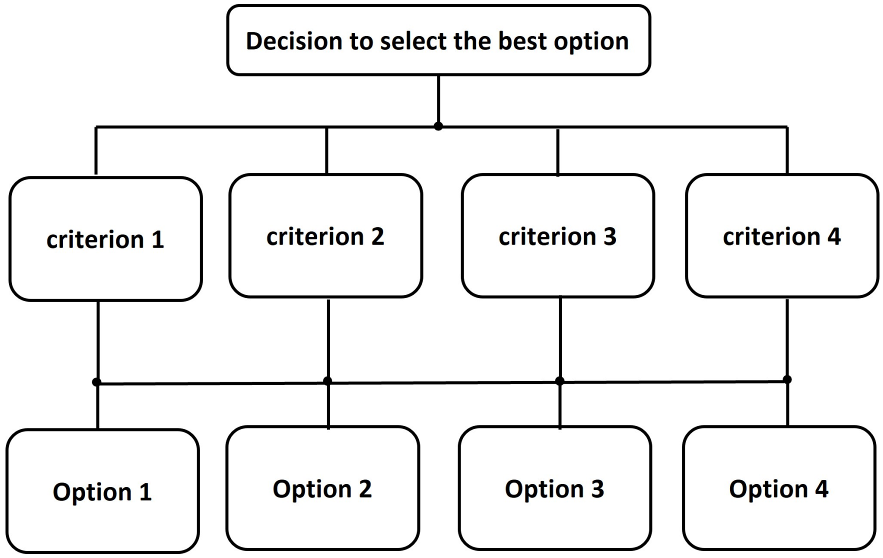


Figure 3.3: Visual representation of the basic AHP structure

in Equation 3.1.

$$W_C = \begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{pmatrix} \tag{3.1}$$

3.5.3.2 Application of the SAW technique in the model for the Co-intelligence artefact.

This second part of the model is applied whenever a decision has to be made and both humans and intelligent agents are involved. The human (H) and the intelligent agent (IAg) evaluate each of the decision alternatives in each of the criteria. To evaluate the four alternatives, (H) and (IAg) will use a scale from 1 to 10, with 10 being the best and 1 being the worst. At the end of the SAW technique, we will have an S' matrix of consolidated scores for the decision alternatives, combining the judgement of the human and the intelligent agent. The matrix in the Table 3.3 shows the generalised example for 4 options and 4 criteria, assuming that humans and the intelligent agent contribute equally to the decision. However, in the SAW technique, humans and the intelligent agent can contribute with different weights, reflecting that one opinion has more influence.

Consolidated Scoring Matrix (S')

This matrix displays the averaged and consolidated scores for each option across the four specified criteria, combining the judgments from Human and IAg. For this consolidation, we're assuming both have equal weighting (0.5 each).

Table 3.3: Consolidated scoring matrix S' combining Human and IAg evaluations with equal weights

$$S' = \begin{pmatrix} & \text{Criterion 1} & \text{Criterion 2} & \text{Criterion 3} & \text{Criterion 4} \\ \text{Option 1} & \frac{s_{11,\text{Human}}+s_{11,\text{IAg}}}{2} & \frac{s_{12,\text{Human}}+s_{12,\text{IAg}}}{2} & \frac{s_{13,\text{Human}}+s_{13,\text{IAg}}}{2} & \frac{s_{14,\text{Human}}+s_{14,\text{IAg}}}{2} \\ \text{Option 2} & \frac{s_{21,\text{Human}}+s_{21,\text{IAg}}}{2} & \frac{s_{22,\text{Human}}+s_{22,\text{IAg}}}{2} & \frac{s_{23,\text{Human}}+s_{23,\text{IAg}}}{2} & \frac{s_{24,\text{Human}}+s_{24,\text{IAg}}}{2} \\ \text{Option 3} & \frac{s_{31,\text{Human}}+s_{31,\text{IAg}}}{2} & \frac{s_{32,\text{Human}}+s_{32,\text{IAg}}}{2} & \frac{s_{33,\text{Human}}+s_{33,\text{IAg}}}{2} & \frac{s_{34,\text{Human}}+s_{34,\text{IAg}}}{2} \\ \text{Option 4} & \frac{s_{41,\text{Human}}+s_{41,\text{IAg}}}{2} & \frac{s_{42,\text{Human}}+s_{42,\text{IAg}}}{2} & \frac{s_{43,\text{Human}}+s_{43,\text{IAg}}}{2} & \frac{s_{44,\text{Human}}+s_{44,\text{IAg}}}{2} \end{pmatrix}$$

Notation:

- $s_{ij,\text{Human}}$: score assigned by the Human to Option i under Criterion j.
- $s_{ij,\text{IAg}}$: score assigned by the Intelligent Agent (IAg) to Option i under Criterion j.

3.5.3.3 Calculation of final score for decision making.

To calculate the final score for each option (FS), we multiply its consolidated score for each criterion (S'_{ij}) by the weight of that criterion (w_j) obtained through AHP, and sum the results for each option, as shown in Equation 3.2.

$$\text{FS}_i = (S'_{i1} \times w_1) + (S'_{i2} \times w_2) + (S'_{i3} \times w_3) + (S'_{i4} \times w_4) \tag{3.2}$$

Finally, we rank the options according to their final score from highest to lowest. The recommended option is the one with the highest score, offering a balance between the criteria, the relative importance established by the experts, and the evaluation scores established by the human and the intelligent agent.
To detect whether there is a disagreement between the human and the intelligent agent, it is proposed to complement the SAW technique by calculating the Spearman correlation coefficient on the ratings assigned by the human and the intelligent agent to the options according to the criteria. The correlation will be an indicator of reliability in the decision. If the correlation is high and positive, it indicates that the human and the Intelligent Agent have rated the options similarly across the criteria. If the correlation is low or negative, it suggests significant disagreement.

When significant disagreement is detected, this disagreement must be reported to a higher-level entity such as the Brain proposed in Figure 1. The Brain will be responsible for analysing the case and making the final decision.

3.6 Implement *2-3*

Modelling in Archimate of the Co-intelligence artefact.

ArchiMate (Architecture Modelling Language) is still considered a solid basis for companies to model the alignment of business services and processes with technology resources.

The ArchiMate language can be enriched by integrating it with semantic technologies such as RDF (Resource Description Framework) and OWL (Web Ontology Language), standards developed by the W3C (World Wide Web Consortium) to represent structured knowledge in an interoperable way. RDF allows data to be modelled using semantic triples - subject, predicate and object - facilitating the construction of knowledge graphs that can be consulted and processed automatically [51]. Use OWL extends the capabilities of RDF by allowing the formal definition of ontologies, including classes, hierarchical properties and logical constraints, which enables automatic reasoning in intelligent architectures [51].

This semantic integration allows ArchiMate to transcend its traditional diagrammatic nature and become a dynamic and adaptive platform, suitable for representing co-intelligence artefacts where cooperation between humans and intelligent agents needs to be explicitly modelled. In this way, business modelling not only reflects static organisational structures, but also incorporates inference and decision-making mechanisms, which are fundamental for complex Industry 4.0 scenarios [77].

There are other modelling languages besides Archimate, such as BPMN (Business Process Model and Notation), UML (Unified Modelling Language) and SysML (Systems Modelling Language) [71]. The following criteria were considered when modelling the Co-intelligence artefact: the language's ability to represent abstract situations at the business level, the language's flexibility to create new artefacts, a language with a holistic view of the organisation from the perspective of strategy, processes, and technology, and complex systems modelling. The languages were characterised by evaluating them as high, medium, or low, considering the criteria. The results of the evaluation are shown in Table 3.4.

Figure 3.4 graphically presents the comparative analysis of the four modelling languages.

Table 3.4: Comparative capabilities of modelling languages

Capability	ArchiMate	BPMN	UML	SysML
Business-oriented abstraction	High	High	Medium	Medium
Ability to create new artefacts	High	Low	High	Medium
Integrated organisational vision	High	Low	Medium	Medium
Complex systems modelling	Medium	Low	Medium	High
Semantic support	High	Low	Low	Low

Table 3.5: Selected relationships in ArchiMate 3.1 possible for the new Co-intelligence artefact

Relationship	Input (to the decision interaction)	Output (from the decision interaction)
Triggering	Permitted (Another process or event triggers the interaction)	Permitted (The decision triggers another behavior)
Access	Permitted (Reads data, documents, criteria)	Permitted (Writes or updates decisions, reports)
Flow	Permitted (Information flows into the interaction)	Permitted (Outcome flows to other behaviors or processes)
Realization	Not permitted	Permitted (Interaction realizes a decision service)

The radar chart shows that the ArchiMate language has a broader scope considering the five criteria selected to operationalise the elements and create the Co-intelligence artefact. ArchiMate offers flexibility and application across the different layers of an organisation, from strategy to technology.

To implement the Co-intelligence artefact a new stereotype was created in the software tool, Enterprise Architect (EA) from Sparx Systems using the ArchiMate 3.1 language while retaining the consistency and semantics of ArchiMate.
To design this new stereotype in Archimate, a Business Interaction element was used to represent a joint behaviour that emerges from the collaboration between roles serving to model the collaborative act of Co-intelligence for: communication, coordination, negotiation and decisions [86].

As shown in Figure 3.5. In this example, the Co-intelligence is represented in a marketing and sales department of a company. In the Archimate language, the Marketing and Sales department is represented as the actor where the two actor roles, the human and the intelligent agent, are assigned. The collaborative relationship represents the cooperation between the two actor roles in order to achieve the required goal, objective, decision or strategy of

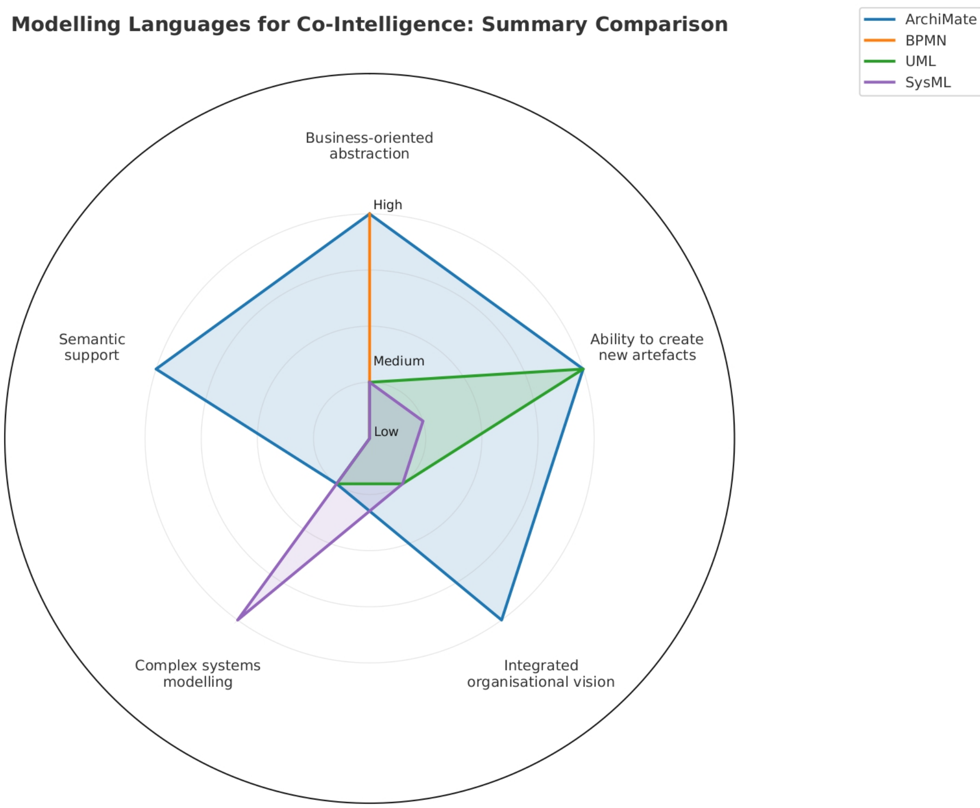


Figure 3.4: Visual comparison of modelling languages for Co-intelligence

the department.

The two actor roles also have an interaction relationship representing communication and information exchange, allowing them to jointly analyse the context. Interaction activities are necessary for decision making aligned with the company's strategic objectives. The left side of Figure 3.5 shows the proposed artefact for the third intelligence and on the right side its equivalent modelling through the Archimate language.

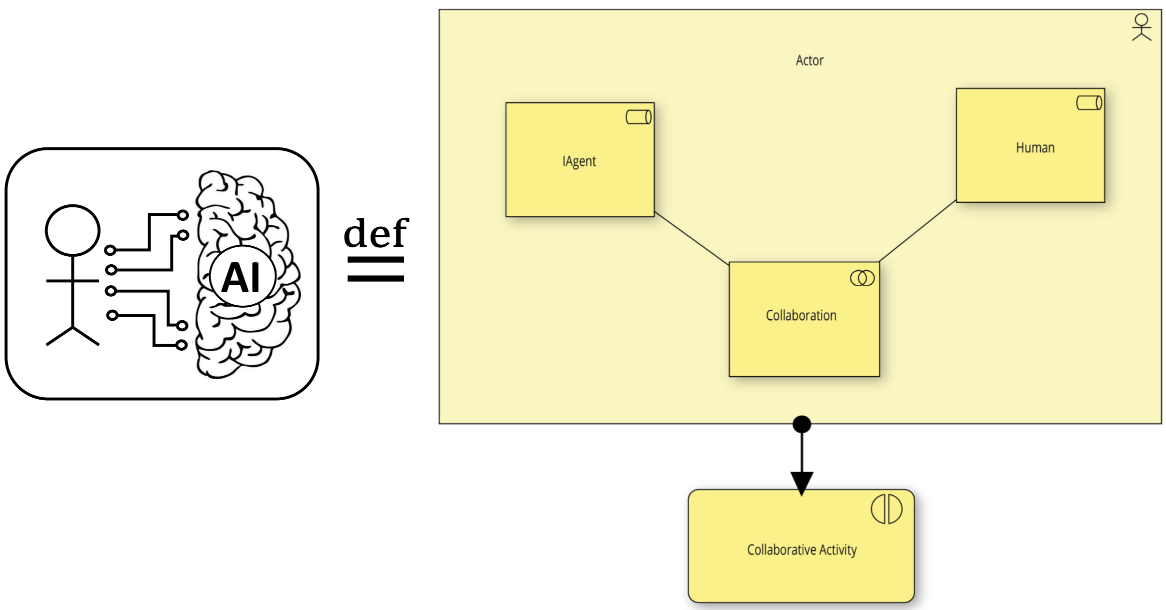


Figure 3.5: Archimate equivalent of the Co-intelligence artefact

The Co-intelligence artefact is an active behavioural element, interaction element, whose function executes and coordinates activities between a human and an intelligent agent to analyse information and decide.

Figure 3.6 shows the syntax of the Co-intelligence artefact with the elements and relationships that compose its internal structure to define its behaviour in the Archimate modelling language. The set of input and output relationships allowed for the artefact [23].

3.7 Opertate *2-4*

Example in business process modelling

A new product requirement process is proposed. The company in the 4.0 context makes use of the integration of artificial intelligence in some departments with the participation of

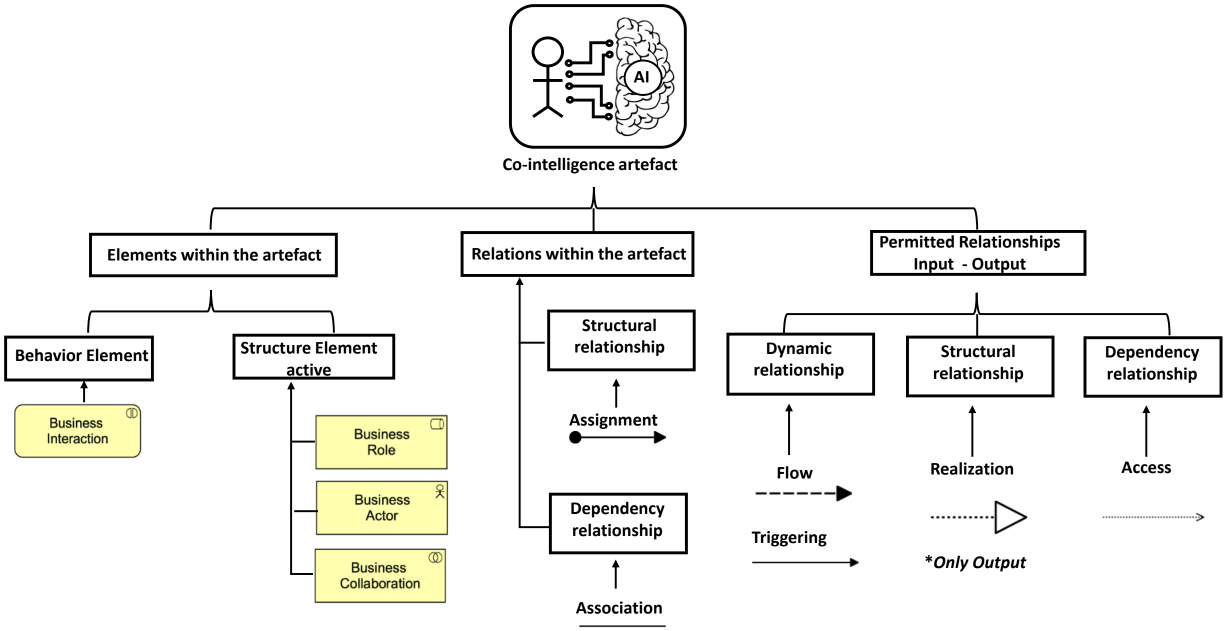


Figure 3.6: Syntactic tree of the Co-intelligence artefact

intelligent agents in the administrative infrastructure.

In the modelling, the intervention of Co-intelligence is proposed in two sub-processes, for detailing customer specifications from the management in the Marketing and Sales department and when assessing the technical feasibility of the new product from the management in the Design and Development department.

In processes such as the calculation of production time and cost, and the calculation of the selling price, only Intelligent Agents are involved. Figure 3.7 shows the modelling with conventional Archimate language artefacts.

Figure 3.8 shows the modelling of the process in the Archimate language using the proposed new artefact for Co-intelligence in the Marketing and Sales department and in the Design and Development department. The model is simplified with a higher level of abstraction.

The proposed example focuses on the request for a new service for an industry dedicated to the production of drones. From this same approach, the modelling can be extended to other scenarios such as responding to citizen requests for crime prevention or disaster response, among other applications where the contribution of human expertise and information systems can help streamline decision-making to improve the state's response capacity.

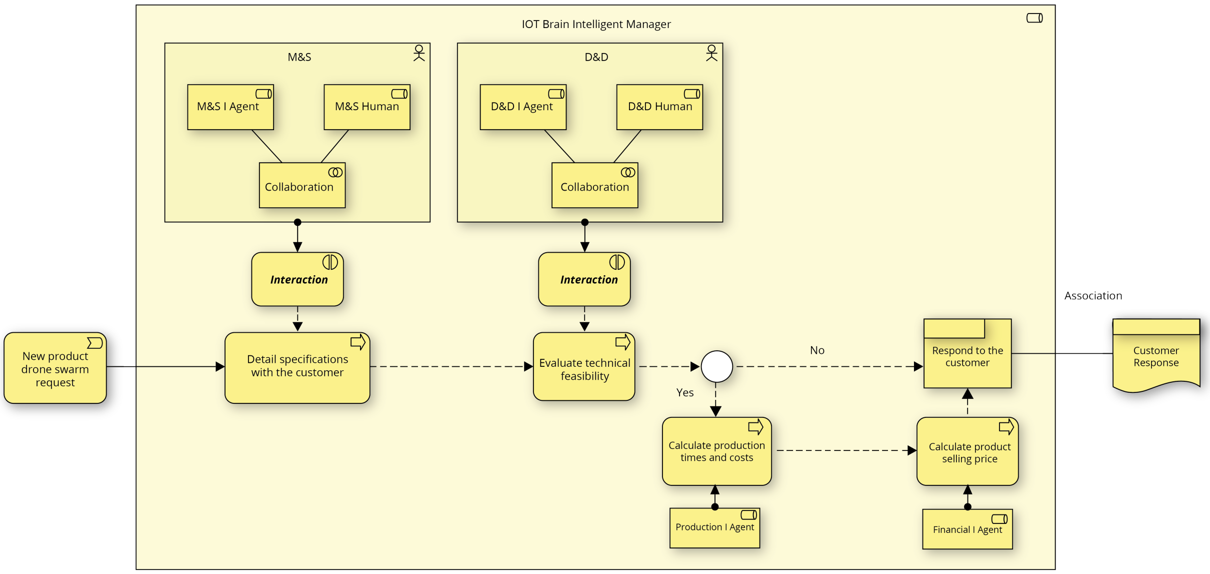


Figure 3.7: Modelling with conventional ArchiMate language artefacts

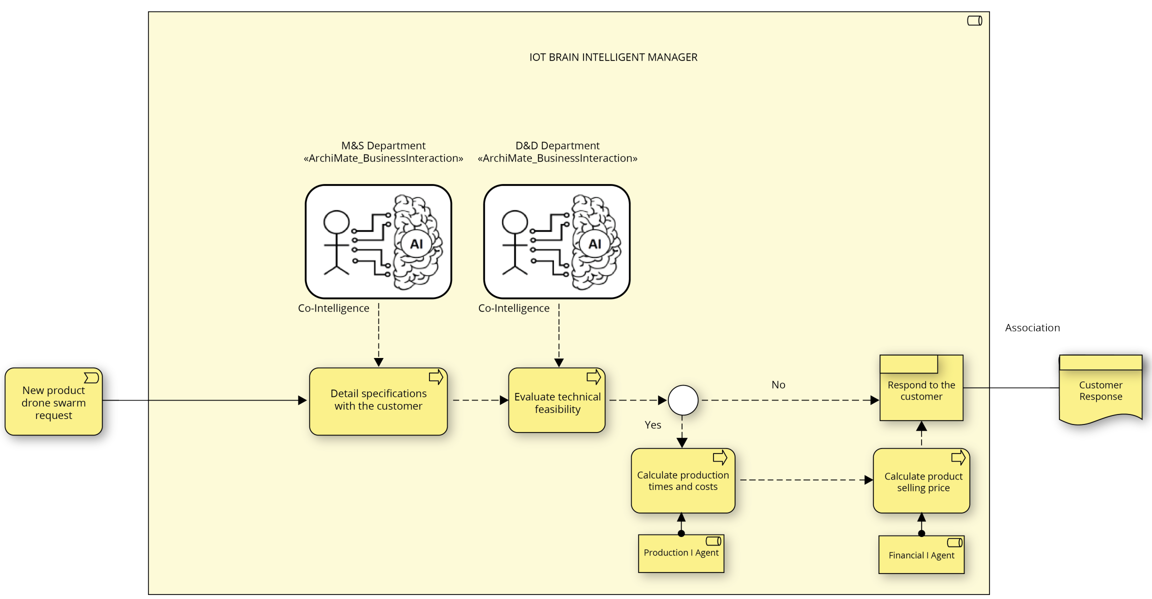


Figure 3.8: Modelling the process in ArchiMate, using the proposed new artefact for Co-intelligence

3.8 Discussion

In the visual representation of human–machine cooperation, a count of the ArchiMate elements modelling Co-intelligence reveals an 80% reduction in the number of elements involved—decreasing from five individual ArchiMate elements to a single stereotype. See Figure 3.5.

Comparing the modelling of the process in Figures 3.7 and 3.8, a 35% simplification is evidenced by the incorporation of the new Co-intelligence stereotype, which optimises the representation without compromising semantic accuracy. This simplification is reflected in the reduction of the number of elements used in the model from 19 to 11.

Furthermore, the use of this Co-intelligence artefact allows the business architect to be more explicit in the sub-processes where cooperation and human-machine interaction is used in decision making.

3.8.1 Example of cooperation scenarios in a citizen service process, modelled using the Co-intelligence artefact

In the disaster response department of a state-owned company, it is necessary to prioritise the response and allocation of resources to citizens affected by a natural disaster caused by flooding. To prioritise the response, the Co-intelligence tool is used. In the AHP part of the hybrid model, three experts defined the priority options on three levels: high, medium, and low, using the following four criteria: degree of damage to the person's or family's home, health condition requiring immediate medical attention, social vulnerability, and geographical isolation. The experts carried out the evaluation and determined the weights of the criteria (WC). These weights remain constant in the subsequent application of the SAW technique for the classification decision. Table 3.6 shows the behaviour of the AHP-SAW hybrid model in two different cases of cooperation between the human (Human) and the Intelligent Agent (IAg). Both cases demonstrate the model's ability to generate a decision by classifying the priority of care. In case 1, the individual scores rated by the human and the intelligent agent based on the four criteria are highly consistent. This strong agreement in the classification of priority of care is evidenced by the value of Spearman's correlation coefficient $\rho = 0{,}87$. In contrast, in case 2, the individual scores assigned by the human and the intelligent agent based on the four criteria show significant disagreement, as evidenced by the Spearman correlation coefficient value $\rho = -0.21$. The model allows the level of confidence in that decision to be quantified by calculating the correlation as an indicator of the degree of agreement between the human and the intelligent agent when making the classification decision. In this way, the validity of the decision can be detected and it can be determined whether the case requires further review.

Table 3.6: Results of the hybrid AHP-SAW model by case (Case 1: Agreement, Case 2: Disagreement)

Options	**Case**	**Human scores**				**IAg scores**				**Correlation (ρ)**	**FS**	**Decision reliability**
		C1	**C2**	**C3**	**C4**	**C1**	**C2**	**C3**	**C4**			
High	Case 1	7	8	6	7	8	7	7	6	0.87 (High)	7.163	Reliable (Decision: Low)
Medium		9	7	8	5	9	8	7	6		7.441	
Low		6	9	7	8	7	9	8	7		8.0695	
High	Case 2	8	9	4	5	5	6	8	9	–0.21 (Low)	6.9815	Unreliable (Decision: High)
Medium		6	5	8	9	9	8	5	4		6.670	
Low		9	7	6	4	7	4	9	6		6.2065	

3.9 Results

From a theoretical perspective, the new artefact synthesises elements of the ArchiMate language, allowing for the formalisation of an element with a higher level of abstraction: co-intelligence in strategic decision-making. It contributes to the visual, semantic and syntactic design of the artefact. The results show that the artefact has practical implications by allowing the explicit representation of human-machine interaction in decision-making, contributing to business architecture in different industry contexts and public companies. In the example of the product requirement process shown in Figure 8, modelling is achieved using the new co-intelligence artefact in the Marketing and Sales department and in the Design and Development department. The model is simplified with a higher level of abstraction. The elements are reduced by 80% on a scale of 5 to 1 compared to the model that uses the traditional elements of the ArchiMate language.

3.10 Ethical Considerations and Organisational Implications

Decisions made through a co-intelligence device raise ethical issues in decision-making. Organisations must clearly define their reliability policies and the weighting of judgements made by humans and by the intelligent agent in each decision-making process. This is especially important in high-risk contexts for humans, such as providing assistance to citizens facing health problems or disasters. To strengthen reliability, organisations must carry out an audit process of the decisions made by the device through a supervisory committee that allows the device to be updated and adapted to decisions focused on human well-being.

3.11 Conclusions

This article presented a new modelling artefact to represent human-machine Co-intelligence within enterprise architecture, within the conceptual and technological framework of Industry 4.0. The artefact, designed under the principles of the ArchiMate language, allows the dynamics of cooperation between human agents and intelligent systems in strategic decision-making processes to be visually explicit.

The use of the artefact facilitates the abstraction of these interactions at the business architecture level, allowing complex scenarios to be represented without the need to detail operational or implementation aspects. In the applied case, there was a 35% visual reduction in the number of elements in the model, improving the clarity and understanding of the modelled process.

The incorporation of this artefact not only expands the semantic capacity of the ArchiMate language but also responds to the need for new formal structures capable of capturing emerging phenomena such as third intelligence in hybrid cooperation in industrial environments. Thus, it represents both a conceptual and technical contribution to the modelling of contemporary enterprise architecture.

The proposed artefact can be extended to other scenarios with applications of human-machine interaction modelling in decision-making, facilitating the planning of processes that contribute to the efficiency and responsiveness of public entities to the needs of citizens.

As future work, we propose to validate the artefact in other organizational scenarios, exploring its integration as a formal extension of the ArchiMate language to represent Cointelligence in different processes in a business architecture.

This work contributes an innovation to Enterprise Architecture at the business level by introducing an artefact that formalises, at the semantic and syntactic levels, the use of co-intelligence in decision-making. Its originality lies in simplifying the representation of the interaction between humans and intelligent agents through the synthesis of the ArchiMate language. The artefact can be applied in digital transformation contexts in the face of the challenges of Industry 4.0 and its evolution towards Industry 5.0.

CHAPTER 4: BUSINESS ARCHITECTURE PATTERN FOR AN ORGANISATIONAL STRUCTURE 5.0

4.1 Abstract

The transition of companies towards Industry 5.0 requires patterns that offer solutions for the design of organisational structures capable of integrating human-machine cooperation into decision-making processes, boosting productivity and transforming business models.

This article presents a reusable and scalable enterprise architecture pattern, consisting of co-intelligence elements, digital twins and an intelligent enterprise interaction manager. The research was carried out in four stages: (1) analysis of the pattern concept; (2) pattern design; (3) implementation on the Enterprise Architect platform using the ArchiMate language; and (4) application in two scenarios: a drone swarm factory and a public disaster response agency.

The application of the pattern made it possible to reduce the size of the model by about 25% (75% reduction), compared to modelling without the synthesis proposed by the co-intelligence artefact. These results show a significant decrease in visual and cognitive complexity, as well as confirming the reusability and adaptability of the pattern.

4.2 keywords

Enterprise architecture; Business architecture; Industry 5.0; Business model; Pattern architecture, Digital transformation; Co-intelligence; Archimate.

4.3 Introduction

In Industry 5.0, human-machine cooperation is fundamental to boosting productivity through artificial intelligence and cognitive technologies, transforming industry and business models [1]. New technologies benefit human innovation and productivity while machines perform repetitive tasks 1

Advanced technologies such as intelligent agents are tools that allow humans to delegate operational work responsibilities to machines and focus on improving production through innovation and creativity. This approach allows humans to be complemented by machine

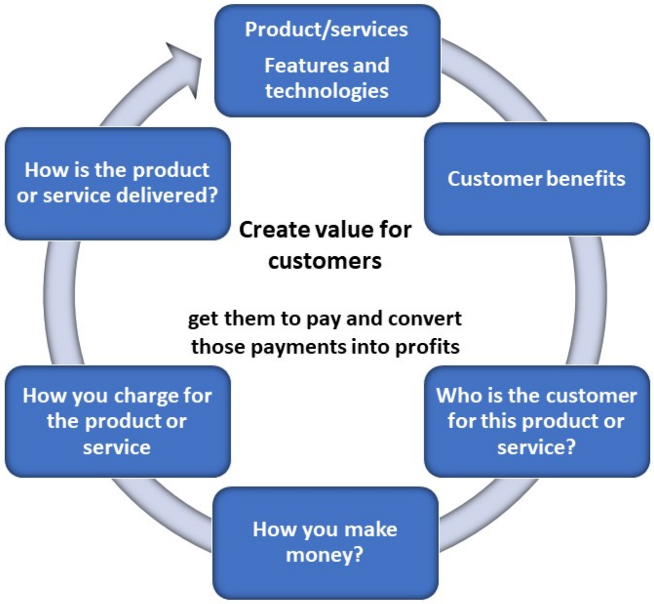


Figure 4.1: Create value for customers inspired by [85]

collaboration, placing humans at the centre of production and strengthening a company's processes.[66]. Industry 5.0 uses technology as a means to improve the quality of human life by creating solutions that serve humanity and the environment [14].

Innovation in the business model is a change to create, deliver and generate value through key elements of business architecture [85]. New business architecture patterns would facilitate understanding of these innovations in business model modelling.

4.4 Conceive *3-1*

A business model shows how a company generates value for its customers and how it obtains profits associated with that value. Figure 4.1 shows the elements necessary for designing a business model: From creating a product or service with a benefit for the customer, defining the type of customer, how they enter, how the money is collected, to how the product is delivered. All within a framework of continuous improvement [85].

A business model requires an business management structure that allows different processes to be carried out in order to generate value. In the business management structure proposed in Figure 4.2, cooperative interactions between humans and machines become a frequent element in Business Architecture and processes. And a pattern captures the essence of a solution to a problem that recurs over and over again. And this solution can be applied

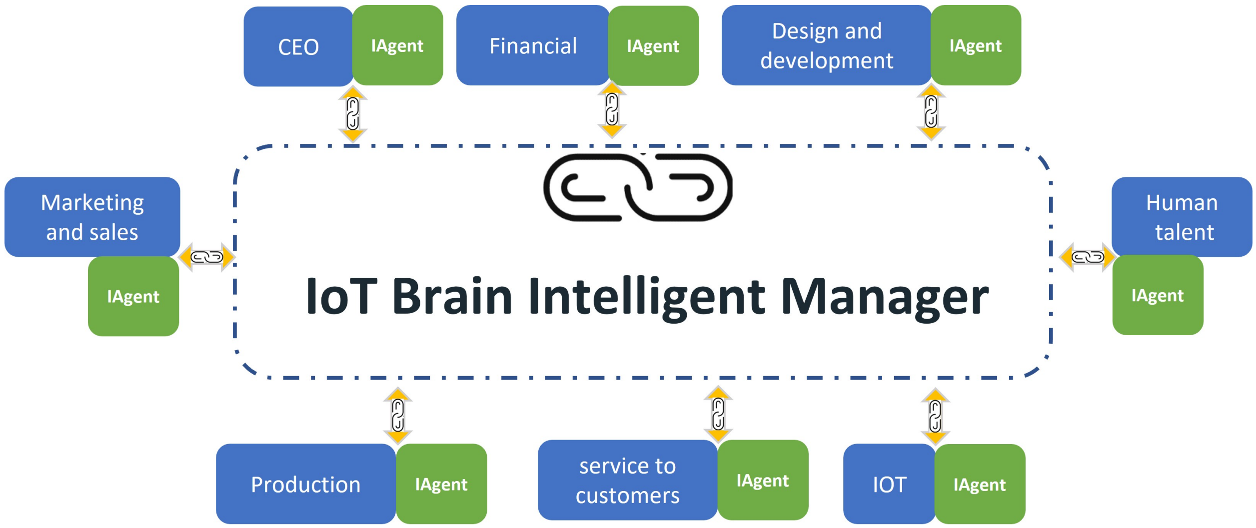


Figure 4.2: Business management structure

by reusing it and adapting it to different contexts [30].

4.5 Design *3-2*

The pattern design followed the structure of an Architectural Pattern defined by the Open Group [16]:

4.5.1 The purpose of the pattern

This pattern offers a solution for representing human-machine interaction in an administrative structure in the context of Industry 5.0 by modelling cooperation between humans, intelligent agents, and digital twins at the business level for decision-making in dynamic environments. The pattern provides a solution for excessive centralisation of decisions by showing the contributions of co-intelligence in distributed decision-making in business models.

The pattern helps companies align their strategic goals with sustainability, resilience, and distributed innovation. Modelling Third Intelligence in the administrative structure models the emergence of knowledge, as knowledge changes and adapts dynamically with the environment. Adaptation to the environment allows for feedback at the strategic level, integrating continuous innovation into the business architecture.

Figure 4.3 shows the proposed pattern for the administrative structure 5.0.

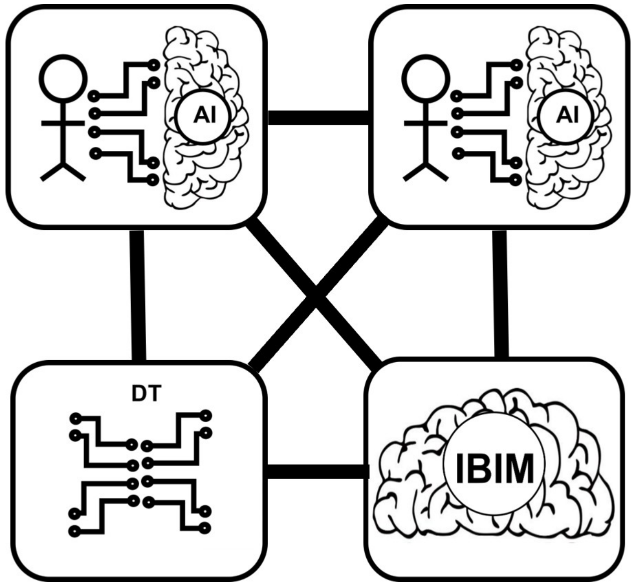


Figure 4.3: Pattern

4.5.2 Context

Situation in which the pattern is applied, the environment, the restrictions. The pattern is applicable to companies undergoing digital transformation towards Industry 5.0, where productivity, efficiency and human well-being are strategic pillars of the business, employing human-machine cooperation at a strategic level in the Business Architecture. Companies with a need for distributed decisions with autonomous capabilities in both co-intelligence elements and agents. Companies that require real-time operational adaptation.

4.5.3 Problem

What challenge or need motivates the use of the pattern.

Enterprises 5.0 require modelling co-intelligence in Business Architecture for decision-making with operational adaptation (leveraging real-time knowledge through digital twins), enabling feedback into business strategy. The need for global consistency in decisions by coordinating multiple agents (human-machine) in strategic business processes.

The pattern provides a formal structure for modelling co-intelligence in Business Architecture, one of the levels where decisions are made, generating cohesion between the strategic, tactical and operational, ensuring decision traceability.

4.5.4 Forces/Motivations

Factors, constraints, or tensions that affect the solution.

The proposed pattern is a scalable and adaptable solution. It should be noted that, at a larger scale, there are more possible interactions between agents with a more complex management system.

The company may have financial constraints on implementing digital twin technology and advanced agent infrastructure designed for its departments.

The pattern requires compliance with ethical standards due to the use of Intelligent Agents.

The pattern requires cultural adoption by its workers with elements of co-intelligence.

4.5.5 Solution

The high-level structure of the pattern:

The pattern emphasises human-machine cooperation for decision-making in multi-agent systems through an administrative structure based on business architecture Figure 4.3. It promotes agility and efficiency, improving workers' quality of life rather than replacing humans.

4.5.5.1 General functioning of the pattern.

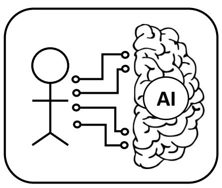
From the Business Architecture perspective, the pattern describes an administrative structure where all co-intelligence elements, IoT Brain Intelligent Manager (IBIM) and Digital Twin can communicate with each other, even though there are coordinated and authorised interactions from the IBIM. Each co-intelligence element has a certain degree of autonomy in decision-making, although the IBIM coordinates the overall structure and overarching decisions. Local decisions are shared in real time with the other elements of the pattern, facilitating the integration of the administrative structure and generating collective learning as feedback for the strategy. Communication between all the co-intelligence elements and the IBIM is bidirectional and redundant, and the failure of one element does not restrict the functioning of the others.

In line with the principles of Industry 5.0, the pattern proposes that the IBIM should supervise the company's activities to ensure the integration of environmentally responsible practices. The IBIM analyses simulated data in the Digital Twin, assessing in real time the environmental impacts of production processes. This approach enables decision-making to be directed towards clean production, promoting energy efficiency, waste reduction, and the incorporation of recyclable materials in specific processes, with the aim of consolidating a competitive, efficient, and environmentally responsible company.

4.5.5.2 Description of the elements of the pattern.

Tables 4.1, Table 4.2, and Table 4.3 describe the elements contained in the pattern: co-intelligence element, digital twin element, and IBIM element.

Table 4.1: Description of the co-intelligence element in the pattern.

Co-intelligence element	Description
	This co-intelligence element represents the interaction between humans and machines within the company department. Each department head has a personalised AI agent with access to relevant information about their department and general company information that flows through the IoT Brain Intelligent Manager (IBIM). Information flows in both directions between the AI agents and the IBIM. The agents not only receive information from the central manager (IBIM), but also provide relevant information from their departments. The intelligent agents have access through the IBIM to the information they need for the head of each department and to make decisions jointly. Co-intelligence has the following main objectives: to optimise decision-making in terms of time and resources in the department, to improve customer service and experience, and to analyse opportunities to apply the principles of the circular economy in the processes in which the department is involved.

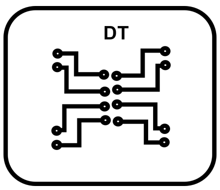
4.5.5.3 Variants of the pattern.

Possible adaptations or alternative implementations of the proposed pattern: Increase in the number of co-intelligence elements. Increase in the number of IBIMs for backup. The pattern integrates new elements without altering overall performance.

4.5.5.4 Consequences.

Table 4.4 sets out the positive and negative impacts of applying the standard (benefits and commitments).

Table 4.2: Description of Digital Twin element in the pattern.

Digital Twin Element	Description
	The digital twin acquires data in real time, processes it, and delivers useful results for decision-making and process optimisation. The digital twin simulates the company's behaviour through mathematical models, which use monitoring systems, sensors, historical data, or databases as sources of information [56]. The digital twin responds to requests for information made by the IBIM or by intelligent agents through simulation analyses, reports, graphs, or alerts. Information flows in both directions between the AI agents and the IBIM. The agents not only receive information from the central manager (IBIM), but also provide relevant information from their departments. The IBIM, as coordinator, authorises some of the intelligent agents' queries to the digital twin. The company will previously define the type of queries that intelligent agents can make to the digital twin without requiring authorisation from the IBIM. Any query that is not included among those previously authorised by the company must be validated and approved by the IBIM.

4.6 Implement *3-3*

The modelling was carried out in the ArchiMate language, using the CASE tool Enterprise Architect from Sparx Systems. The implementation was developed within the framework of the Virtual Software Engineering Laboratory, affiliated with the research groups of Authors 1 and 2, which enabled the consolidation of the models in an academic environment of experimentation.

To implement the pattern in the ArchiMate language, the type of relationships between the elements was defined according to the proposed functioning of the pattern. See Figure 4.4. Other Considerations for Modeling the Pattern in the ArchiMate Language:

Co-intelligence is an organizational unit that we will represent as an Actor at the Business level.

The Digital Twin is composed of a collaboration of software and hardware. It will be modeled as a collaboration at the Technology level where a set of two or more internal

Table 4.3: Description of IBIM element in the pattern.

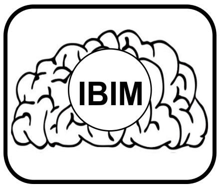
IBIM Element	**Description**
	The IBIM acts as the central brain and makes the company's general decisions. The IBIM is the company's information coordination and management centre. It receives information from all areas, processes it and makes it available to the co-intelligence elements, facilitating communication and collaboration between agents. If the human and the intelligent agent disagree on a local decision, the IBIM evaluates the information and decides. It supervises and analyses data from the Digital Twin to assess environmental impacts in real time and guide decisions towards responsible production.

Table 4.4: Factors, positive impacts, and risks of the co-intelligence pattern (business view)

Factor	**Positive impacts**	**Risks**
Operational efficiency in decision-making	Agility in decision-making through co-intelligence. Higher productivity. Autonomy in local decision-making.	Greater coordination complexity due to a multi-agent system.
Adaptability through collective learning	Collective learning as feedback to strategy.	Greater complexity in decision traceability.
Redundancy	Operational continuity in the event of failures.	Costly infrastructure to guarantee redundancy.
Team	Explicit integration of the "third intelligence" through Human–Intelligent Agent cooperation.	Uncertainty and distrust regarding the use of intelligent agents.
Operational efficiency	Human–machine synergy improves productivity. Scalability to integrate new nodes/agents without redesigning the entire architecture.	Costs of creating company-owned intelligent agents.
Scalability	Integration of new elements without redesigning the architecture.	Cybersecurity for information assets.

active structural elements of the technology work together to perform collective technological behavior [86].

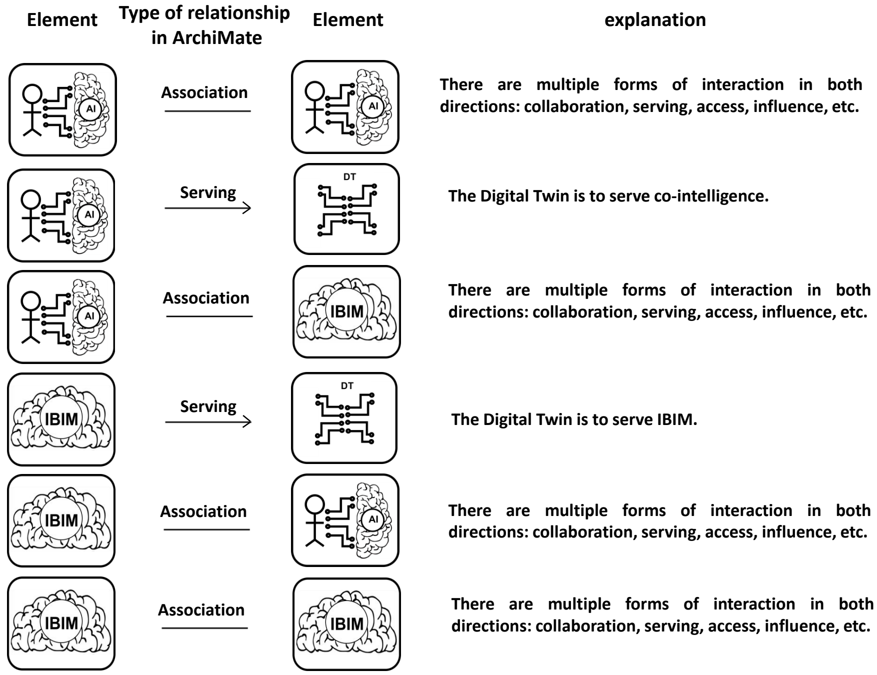


Figure 4.4: ArchiMate relationships between pattern elements

The IBIM is a software system at the Technology level, representing the software that provides or contributes to an environment for storing, executing, and using software or data implemented in it [86].

Figure 4.5 presents two alternatives for modeling the Pattern in ArchiMate language. In the diagram on the left, co-intelligence elements are represented as business actors, linked by association relationships due to their multiple forms of interaction, as detailed in Figure 4.4. Meanwhile, in the diagram on the right, co-intelligences are modeled through a single business collaboration element.

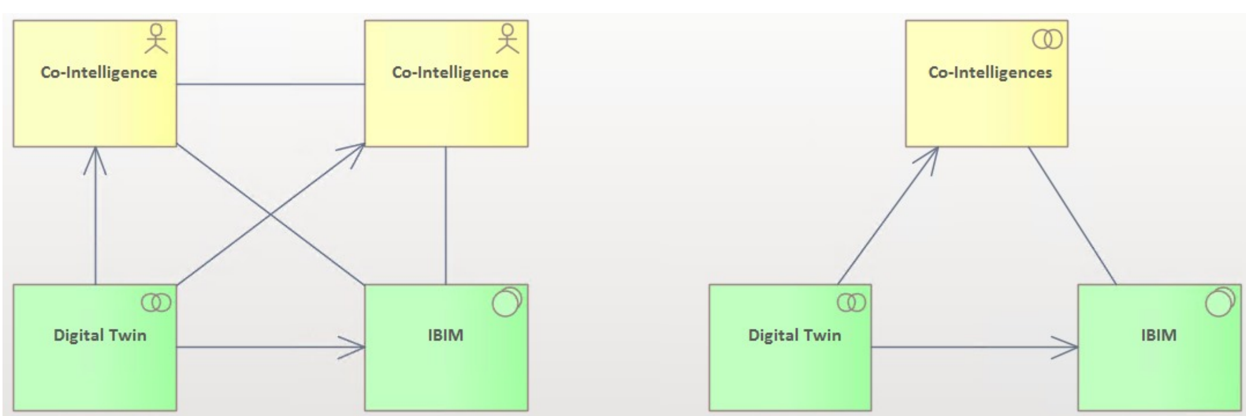


Figure 4.5: Pattern modeling in ArchiMate language

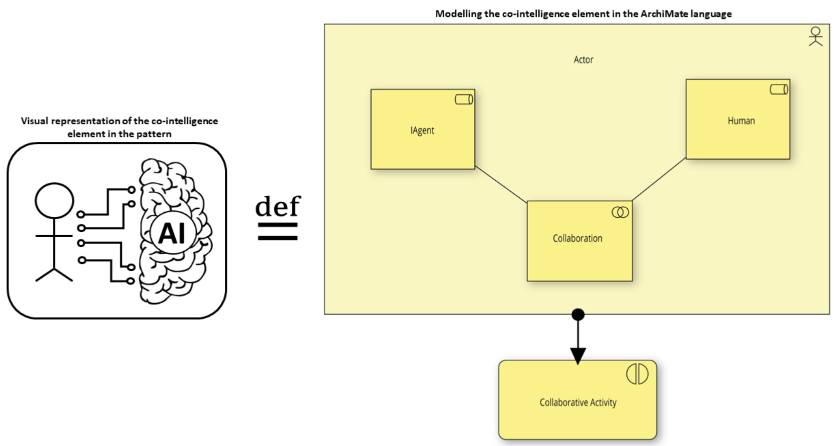


Figure 4.6: Co-intelligence artefact modelling in ArchiMate language

The two alternatives presented in Figure 4.5 offer an equivalent solution for pattern modelling. However, the option on the right requires at least two co-intelligence elements, limiting its application in organisations with small administrative structures.

In contrast, the alternative on the left eliminates this restriction, making it a more general and flexible model. It has features that facilitate the visualisation of each co-intelligence element in a company's administrative structure.

Figure 4.6 presents the main elements of the ArchiMate language business layer used to model the co-intelligence artefact. The Business Actor represents a department or unit within the organisation, while the Business Role specifies the responsibilities and behaviours assumed by humans and intelligent agents in the department. The Business Collaboration element represents the collaborative work between both roles. These roles, through Business Interaction, deliver the result of that collaboration to achieve common objectives such as decision-making.

The incorporation of the co-intelligence artefact as an element within the pattern enhances the visualisation and abstract interpretation of the business organisation. When modelled in the ArchiMate language, it contributes to a reduction in the number of elements, as the co-intelligence pattern is represented as a single business actor; nevertheless, it is internally structured by four distinct elements of the business layer.

4.7 Operate *3-4*

Application scenarios

Business capabilities enable the development and optimisation of a business architecture by describing what the organisation does, or what it expects to do at some point in the future. The business map provides an abstract view for understanding the complexity of the business. The business capabilities map helps leaders make better decisions [87].

4.7.1 Drone swarm factory

The first example shows how to apply the pattern to a drone swarm factory, the company Closemobile Aerospace LLC (Belize, Registration No. IFSC/200/LLC1122/21).

In this case, the company's mission is to develop drone swarm solutions applied to precision agriculture, the environment, and civil engineering. With the vision of being a world leader in the design and production of drone swarms, through technological innovation in the context of Industry 4.0 and its evolution towards 5.0, integrating elements of co-intelligence into its business architecture.

The company has defined these strategic axes:

- Innovation and technological development to improve responsiveness in dynamic environments.
- Focus on Industry 5.0, with people at the centre of production, integrating co-intelligence at the strategic level of the company for decision-making.
- Production processes that promote care for the environment.

To apply the pattern, a capability map aligned with the business strategy is developed [88]. Table 4.5 presents this map, which links the factory's key processes with the necessary pattern elements, ensuring consistency with the organisation's design.

The capability map presented in Table 4.5 establishes the incorporation of ten pattern elements, seven co-intelligence elements, one Digital Twin element, and two IBIM elements. This configuration defines the organisational structure of the factory, represented in Figure 4.7 through modelling in the ArchiMate language.

4.7.2 Public agency dedicated to disaster response

This second example shows how the pattern can be applied in the design of an administrative structure for a public agency dedicated to disaster response. Table 4.6 shows the departments within this agency with a general description of their functions.

The capability map presented in Table 4.6 determines the incorporation of eight pattern elements, six co-intelligence elements, one Digital Twin element, and one IBIM element. This defines the organisational structure of the factory.

Table 4.5: Capability Map by Pattern Elements in a Drone Swarm Factory.

Department	Capacities by element
Co-Intelligence CEO Department	Strategic direction of the organisation for high-level decision-making. The IAgent supports the collection of strategic data and requests scenario simulations from the Digital Twin to aid decision-making.
Co-Intelligence Financial Department	Financial management with planning and budgetary control through predictive analyses that identify risks and inform strategic decisions. The IAgent may request simulations from the Digital Twin for support.
Co-Intelligence Design and Development Department	Innovation of products and services, applied research and prototyping. The IAgent assists with simulations, design optimisation and analysis of technological trends.
Co-Intelligence Human Talent Department	Administration of personnel, welfare and skills development. The IAgent contributes to performance analysis, training needs and prediction of organisational climate.
Co-Intelligence Marketing and Sales Department	Promotion of products, market management and customer relations. The IAgent performs market analysis, customer segmentation and demand prediction.
Co-Intelligence Production Department	Operation of production processes, quality assurance and resource management. The IAgent supports real-time monitoring, predictive maintenance and optimisation of the production chain.
Co-Intelligence Customer Service Department	User support, resolution of inquiries and customer loyalty. The IAgent enables automated responses, satisfaction analysis and detection of recurring needs.
Digital Twin	The digital twin simulates the company's behaviour through mathematical models, which use monitoring systems, sensors, historical data, or databases as sources of information. Performs other functions described in Table 4.2.
IBIM	Coordinates communication among intelligent agents. Performs other functions described in Table 4.3.
IBIM for Functional Backup	Ensures operational continuity in case of IBIM failure.

Figure 4.8 presents the modelling of the Pattern in ArchiMate for the organisational structure of a public agency dedicated to disaster response. The model illustrates how the seven co-intelligence elements, the IoT Brain Intelligent Manager (IBIM), and the Digital Twin communicate with one another, preserving the relationships established among the pattern elements, as defined in Figure 4.4. Communication among all components generates redundancy, so that the failure of one element does not limit the functioning of the others.

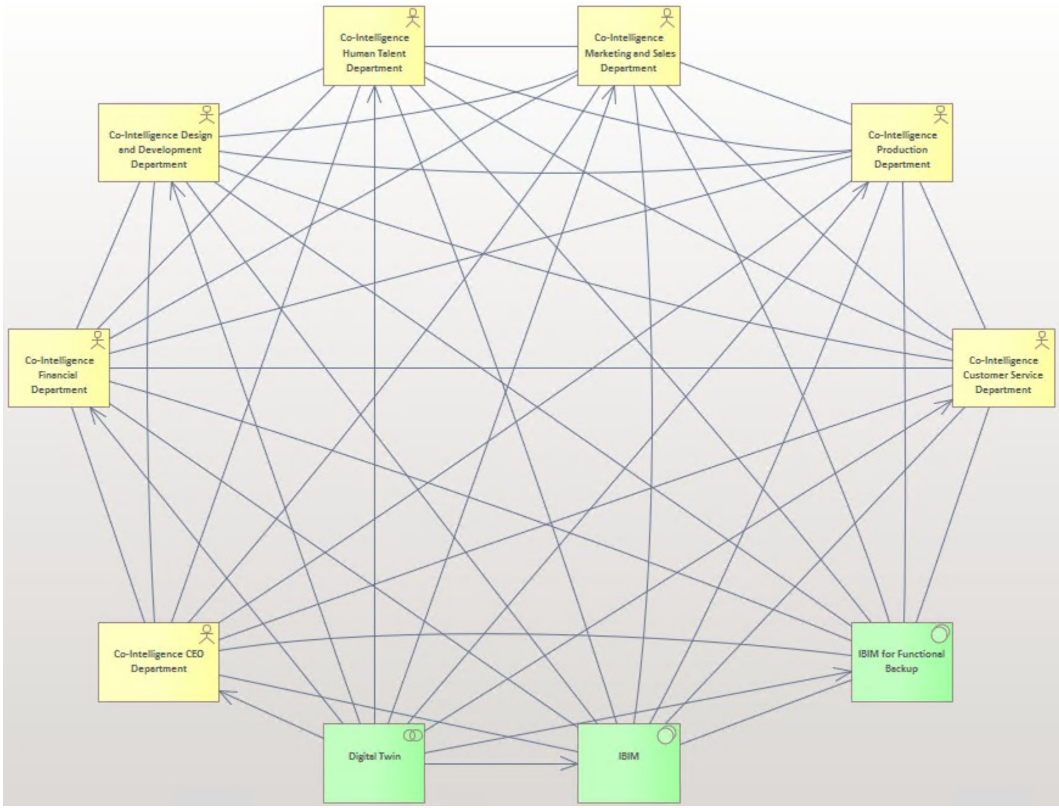


Figure 4.7: Pattern modelled in ArchiMate for the design of an administrative structure for a drone swarm factory.

4.8 Results

The application of the pattern through the business capability map enabled the business structure to be modelled in a clear manner. The pattern synthesises elements of the ArchiMate language to represent human–machine cooperation in decision-making within an administrative structure aligned with Industry 5.0 from the perspective of Business Architecture.

The incorporation of the co-intelligence artefact as an element within the pattern contributed to a significant reduction in the number of elements when modelled in ArchiMate. In the disaster agency scenario, the ArchiMate model was reduced to 25% of the elements compared with modelling without the synthesis proposed by the co-intelligence artefact.

Similarly, in the drone swarm enterprise case, the modelling was reduced to 26% of the elements. This facilitates the visual interpretation of the abstract model for enterprise architects.

The results of applying the pattern in two distinct scenarios, one in a factory environment and the other in a government agency environment, demonstrate that the pattern provides

Table 4.6: Capability Map by Pattern Elements in a public agency dedicated to disaster response.

Pattern element	Capacities by element
Co-Intelligence Department of Citizen Assistance	Citizen service contact point. Receives emergency reports. Responds to questions, complaints, requests and claims. Manages emergency hotlines. Provides initial information on protocols, assembly points and assistance available to citizens.
Co-Intelligence Department of Comprehensive Emergency Care	Assessment of infrastructure damage. Psychosocial assistance. Logistics for collecting, distributing and delivering supplies to citizens in emergencies. Manages digital platforms for registering affected individuals. Restores services (water, energy and communications) in the disaster area.
Co-Intelligence Department of Cooperation	Cooperates with municipalities, regional governments, police, fire brigades, the Red Cross, hospitals, care centres and civil defence. Works jointly with the IBIM on general decision-making.
Co-Intelligence Department of Education and Prevention	Training for the population on prevention, emergency simulations, evacuation and self-protection plans. Training and support for people on human–machine interaction.
Co-Intelligence Legal Department	Protection of citizens' rights during emergencies. Processing of claims, compensation and legal proceedings.
Co-Intelligence Department of Communications	Management of mobile applications and mass notification systems. Dissemination of prevention campaigns and contingency plans. Press releases for the media.
Digital Twin	Simulation of the disaster-response department through mathematical models and data (including databases from digital platforms registering affected individuals). Sensors, unmanned aerial vehicles, cameras and satellite systems for real-time monitoring. Risk-mapping systems and data intelligence. Generates dynamic impact maps. Historical datasets to train predictive models that improve response to future events. Performs other functions described in Table 4.2.
IBIM	Analyses risk patterns from scenarios simulated in the digital twin to support strategic decision-making, communicating outcomes to the different Co-Intelligence departments. Coordinates interactions among Co-Intelligence departments, building a historical record to continuously improve future decisions. Performs other functions described in Table 4.3.

a reusable and adaptable solution for defining organisational structures that integrate hu-

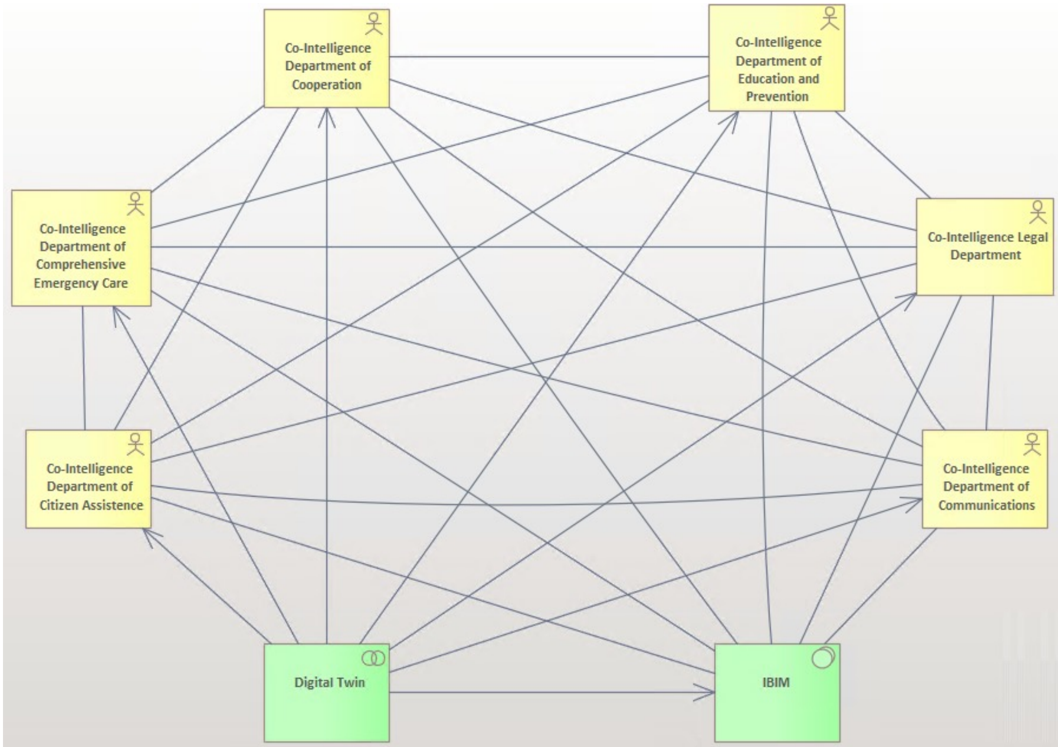


Figure 4.8: Pattern modelled in ArchiMate for the design of the organisational structure of a public agency dedicated to disaster response.

man–machine cooperation in decision-making across different contexts.

4.9 Conclusions

The proposed pattern enables the definition of organisational structures for companies that develop business models oriented towards human–machine cooperation, providing enterprise architects with a tool for modelling decision-making processes in digital transformation contexts.

The incorporation of the co-intelligence artefact within the pattern allowed a 75% reduction in the number of ArchiMate elements in the modelled scenarios, thereby facilitating visual interpretation for enterprise architects.

The application scenarios further demonstrate the flexibility of the pattern and its potential as a scalable and reusable solution across diverse contexts.

As future work, it is proposed to extend the application of the pattern to other domains and to explore the simulation of the organisational structure through decision-making processes.

CHAPTER 5: SIMULATION OF BUSINESS PROCESSES IN BPMN AND BPSIM USING CO-INTELLIGENCE ARTEFACTS: A CASE STUDY IN A DRONE SWARM FACTORY.

5.1 Abstract

The digital transformation towards Industry 5.0 promotes the integration of human-machine cooperation, shaping new business models and organisational structures within Business Architecture. In this scenario, intelligent agents and artificial intelligence (AI) are consolidating their position as strategic tools for optimising decision-making in complex industrial environments.

This study presents the simulation of a process for a new product request in a drone swarm factory, considering two scenarios: one using co-intelligence and another without applying the co-intelligence model. The main contribution of this work is the development of a simulation model parameterised in BPMN 2.0 and BPSim, designed to be replicable in the analysis of the efficiency in business process time that integrates co-intelligence. The parameterisation of the model is based on empirical data obtained from an experiment with 27 engineers, who performed a software quality control process with and without artificial intelligence support, thus providing a quantitative basis for validating the impact of cooperation between humans and intelligent systems on the optimisation of organisational processes.

Thus, the efficiency of over 95% observed in the simulation reflects the parameterised behaviour of the system in real conditions, demonstrating the positive impact of human-machine cooperation on process optimisation.

The study was developed using the CDIO (Conceive, Design, Implement and Operate) methodology, integrating the conception, design, implementation and operation phases of the process using the BPMN and BPSim languages, using the CASE Enterprise Architect tool from Sparx Systems, which is located in the Virtual Software Engineering Laboratory – E.L.V.I.S. of the COMBA I&D Research Group at the University of Santiago de Cali.

5.2 Introduction

Digital transformation processes are driving organisations towards Industry 5.0 by integrating third intelligence. This human-machine interaction is redefining business models, organisational structures and processes, shaping the future and evolution of business architecture [67]. In the above context, generative artificial intelligence is a promising tool for optimising business decision-making. However, despite the ability of artificial intelligence to analyse large volumes of information, human judgement is decisive in the process for complex situations. Human-machine cooperation improves the efficiency and accuracy of strategic decision-making by integrating the strengths of both actors [50]. At the same time, AI-augmented business process management systems (ABPMS) are emerging. These new information systems offer improved business process execution to strengthen their adaptability to the context [25].

5.3 Conceive *4-1*

At this stage, we want to simulate a business process corresponding to the drone swarm factory, considering the use of traditional elements and the use of Co-intelligence elements, which is why we need a software tool that meets the following criteria: institutional support, allowing work with different simulation scenarios, allowing the parameterisation of characteristics specific to the process, facilitating integration with other languages or modelling environments. In this context, two complementary tools are used: process modelling is carried out graphically using the BPMN (Business Process Model and Notation) standard, while simulation is performed using the BPSim (Business Process Simulation Specification) standard developed by the Workflow Management Coalition (WfMC), with the aim of ensuring interoperability between the conceptual design of the process and its dynamic analysis through simulation. BPsim's compliance with the simulation criteria is shown in Table 5.1.

5.4 Design *4-2*

In this first simulation experiment, a new product requirement process was designed for the drone swarm factory Figure 3.8. In this context, two simulation scenarios are proposed:

Scenario 1: The process is simulated considering, for a first case, the traditional estimated times for each sub-process or activity without co-intelligence elements. Each process is carried out by humans. In this simulation, the times are defined in conjunction with the director of the research and development (R&D) department of the company Closemobile

Table 5.1: BPSim Compliance According to Evaluation Criteria

Criterion	**BPSim Compliance**
Institutional Support	It is a formal standard developed for business process simulation. It has a solid methodological approach that ensures consistency, validity of results, and replicability of experiments [95].
Parameterisation of Process Characteristics	It allows the analysis and comparison of different simulation scenarios by parameterising execution times, probabilities of occurrence, resources, and process flow conditions.
Interoperability	BPSim is integrated into the CASE tool *Enterprise Architect* by Sparx Systems. This tool supports interoperability among different modelling languages, enabling the integration of enterprise architectures designed in ArchiMate with frameworks such as TOGAF or RAMI 4.0, as well as with business processes simulated under the BPMN 2.0 standard.

Aerospace LLC, who is responsible for planning, coordinating and directing the creation of new products, taking into account the processes.

Scenario 2: The process is simulated by estimating the response times of the co-intelligence elements and artificial agents for each sub-process or activity.

5.4.1 Estimating execution times for co-intelligence elements

In this context, the times were estimated based on an experiment conducted with 27 engineers from the Software Quality Department of the software development company Jikkosoft SAS. In the initial stage of the experiment, the engineers estimated the duration of each stage of the testing quality process, working in the traditional manner without the use of artificial intelligence. Figure 5.1.

Subsequently, in the final phase of the experiment, carried out three months later, the engineers estimated the duration of each stage of the test quality assurance process, this time working with the support of Global Artificial Intelligence Alliance (GAIA) [29], integrated into the process, as can be seen in Figure 5.2.

The results showed a minimum reduction of 95.91% in process execution times when artificial intelligence was incorporated into a collaborative environment between humans and machines (see Equation 5.1).

$$\text{Time reduction (\%)} = \frac{T_{\text{without co-intelligence}} - T_{\text{with co-intelligence}}}{T_{\text{without co-intelligence}}} \times 100 \tag{5.1}$$

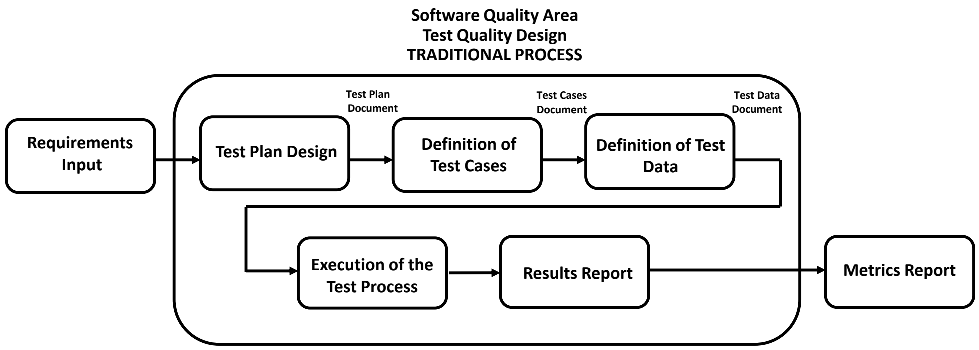


Figure 5.1: Traditional process for test quality design in the Software Quality Department at Jikkosoft SAS.

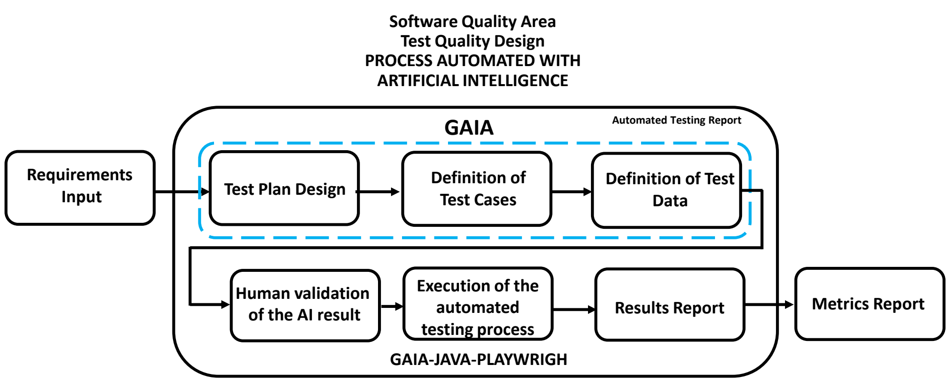


Figure 5.2: Process for designing test quality in the Software Quality Department at Jikkosoft SAS, performing human-machine work with GAIA artificial intelligence.

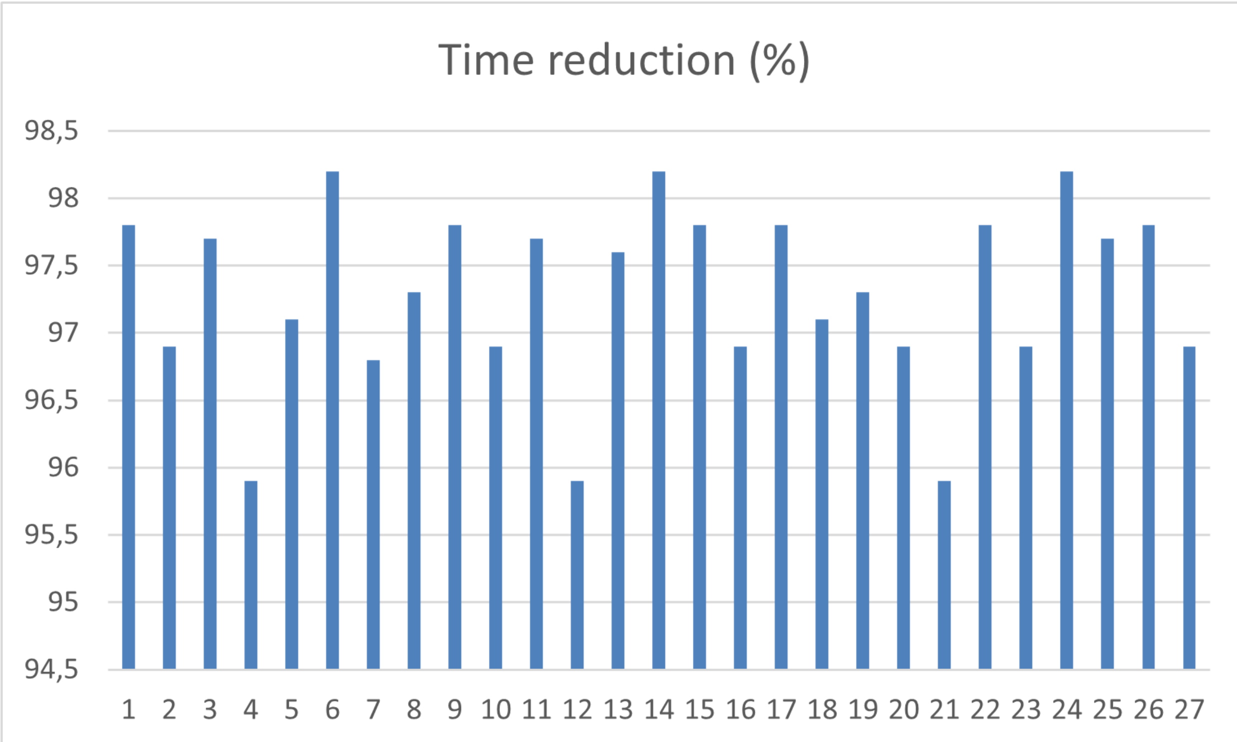


Figure 5.3: Graph showing the percentage reduction in production time for the 27 engineers thanks to co-intelligence.

The percentages of reduction in production time for the 27 engineers are shown in Figure 5.3, which illustrates the relationship between the percentage of reduction and the co-intelligence pairs formed by the engineers working cooperatively with artificial intelligence. The calculation of the coefficient of variation (25.26%) shows a high dispersion, indicating appreciable differences between the execution times of each engineer. However, a general trend of significant reduction is observed, with percentages above 95% in all cases, reflecting a substantial improvement in process efficiency when co-intelligence is involved.

The variations between co-intelligence work pairs suggest that, although the support of the intelligent agent considerably reduces the total production time, the magnitude of this improvement is not uniform. This allows us to infer that human experience and the level of adaptation to human-machine collaborative work could influence the efficiency of the process.

According to the experiment conducted with Jikkosoft engineers, it was determined that, when simulating the process in the drone factory, the reduction times associated with cooperative work based on co-intelligence will be estimated at 95%.

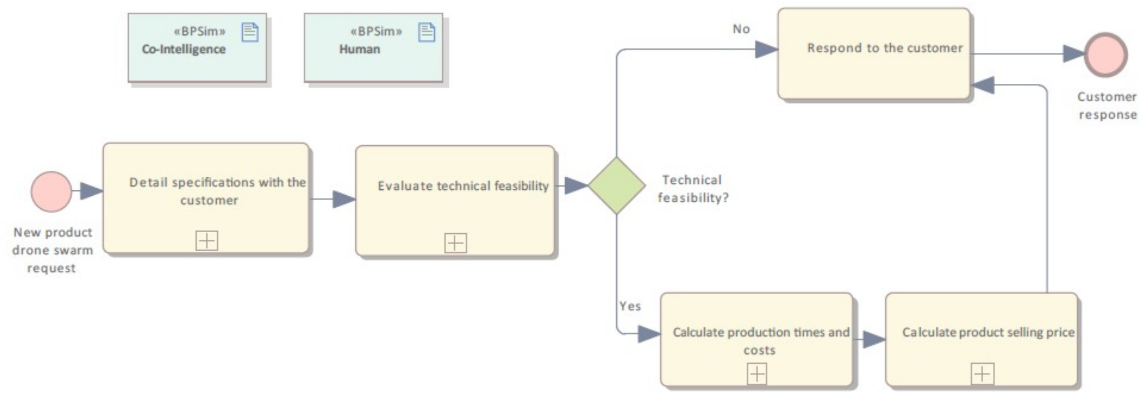


Figure 5.4: implementation of the BPMN diagram corresponding to the new requirement process.

5.5 Implement *4-3*

The process of requesting a new product at the drone factory was modelled using BPMN (Business Process Model and Notation) in order to represent in a structured manner the activities, decisions and information flows involved in managing this new request.

Figure 5.4 shows the implementation of the BPMN diagram corresponding to the requirement for a new product, describing the logical sequence of the process, beginning with the definition of technical specifications with the customer, continuing with the evaluation of technical feasibility, the calculation of production times and costs, the determination of the selling price, and ending with the final proposal to the customer.

Scenario 1: In the implementation phase of the first scenario, the process was parameterised considering the traditional estimated times for each activity and sub-process, without incorporating co-intelligence elements. In this case, it was assumed that all activities were performed by humans, and the times were defined in conjunction with the director of the Research and Development (R&D) Department at Closemobile Aerospace LLC, who is responsible for planning, coordinating, and supervising the creation of new products in accordance with the company's operating procedures.

Scenario 2: In the implementation of the second scenario, the process was parameterised by estimating execution times with the inclusion of co-intelligence elements, representing an approximate 95% reduction in processing times compared to the traditional process executed solely by humans. This estimate is based on the experiment conducted with the 29 engineers at Jikkosoft S.A.S.

Table 5.2 presents the times parameterised in BPMN, expressed in minutes, for each activity in both scenarios.

Table 5.2: Times parameterised in BPSim, expressed in minutes, for each activity in both scenarios.

Sub-process	**Human (min)**	**Co-intelligence (min)**
Detail technical specifications with the client	960	48
Assess technical feasibility	1 440	72
Prepare budget, production time and cost estimation	2 400	120
Prepare proposal and calculate price	960	48
Respond to the client	60	3
Total	**5 820**	**291**

5.6 Operate *4-4*

In the operation stage, the process modelled in BPMN was simulated using the BPSim (Business Process Simulation) extension, with the aim of analysing its dynamic behaviour, considering the occurrence of four new product requirements over a period equivalent to one year.

The simulation allowed for the incorporation of quantitative variables, such as the processing times of sub-processes and activities, and the probabilities associated with decisions such as the feasibility of developing a new product, providing a representation of the process performance by validating the parameters defined in the two simulation scenarios.

The integration of BPMN and BPSim enabled a detailed comparison of execution times between the process in the two proposed scenarios: one operated exclusively by humans and the other integrating elements of co-intelligence, providing empirical evidence on the optimisation opportunities derived from collaboration between humans and intelligent agents.

Figure 5.5 shows the QR code that provides access to a demonstration video, which presents a comparative simulation between the two scenarios analysed, highlighting the differences in their operational behaviour.

Figure 5.5: QR code that provides access to a demonstration video, which presents a comparative simulation between the two scenarios analysed, highlighting the dif- ferences in their operational behaviour.

5.7 Results

During the 365 days of the process, four new product requirements were generated, a result that matches initial expectations, given that one requirement was estimated to occur approximately every three months.

An analysis of the simulation report shows the individual processing times for each subprocess and activity, as well as the total processing time for the entire process.

The results confirm the consistency of the model, showing that the scenario incorporating co-intelligence elements achieves greater operational efficiency, with a reduction in total time of close to 95% compared to the traditional scenario.

5.8 Conclusions

The integration of BPMN and BPSim within the CASE Enterprise Architect tool, in a controlled simulation environment, enabled the execution of the new product requirement process in the drone swarm factory, revealing a consistent correspondence between the parameters defined for processing times and the results obtained over a 365-day simulation period, considering the probability established for cases in which the decision was made to manufacture the new product.

The comparison between the two simulation scenarios, one operated exclusively by humans and the other assisted through elements of co-intelligence, demonstrated a coherent and significant reduction in the process execution times when intelligent agents were integrated according to the defined parameters. This outcome supports the potential of co-intelligence integration as a mechanism to enhance operational efficiency.

In the experiment conducted with 27 engineers from the company Jikkosoft SAS, variations were observed among the co-intelligence work pairs, suggesting that although the assistance of the intelligent agent considerably reduces the total production time, the magnitude of this improvement is not uniform. These results indicate that the human operator's experience and their level of adaptation to human–machine collaborative work may directly influence the overall efficiency of the process.

CHAPTER 6: GENERAL CONCLUSIONS

The four articles developed within the framework of this doctoral research constitute a coherent body of work aimed at strengthening Business Architecture in the context of Industry 5.0.

The systematic review made it possible to identify the main trends and conceptual gaps in this field, highlighting the need to create new artefacts that expand its modelling capacity.

Based on these findings, a hybrid co-intelligence model was designed, integrating cooperation between humans and intelligent agents as a means of supporting strategic decision-making.

Subsequently, a business architecture pattern for 5.0 organisational structures was developed, operationalising these principles through the definition of co-intelligence roles and structures within the organisation.

Finally, the BPMN–BPSim simulation validated the proposed model by demonstrating significant improvements in processing times, in coherence with the parameters defined according to the experiment conducted with the engineers from Jikkosoft, where intelligent agents were incorporated into the analysed subprocesses.

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APPENDIX A: AFICAT CONFERENCE ACCEPTANCE LETTER

This appendix contains the official acceptance letter of the paper accepted at the *AFICAT 2025 Conference.*

Santiago de Cali, 7 de octubre del 2025

Dra. (C). María Fernanda Díaz Velásquez
Universidad Santiago de Cali
Cali - Colombia

Asunto: **Carta de aceptación del trabajo titulado "Patrón de toma de decisiones en arquitectura empresarial para sistemas administrativos 5.0" para presentación en AFICAT 2025 mediante modalidad oral.**

Estimada Dra. (C). María Fernanda Díaz.

Junto con saludarla, nos dirigimos a usted para comunicarle que el trabajo titulado "Patrón de toma de decisiones en arquitectura empresarial para sistemas administrativos 5.0" ha sido aceptado para la presentación en el IV Congreso Nacional AFICAT 2025 que se realizará el 13 y 14 de noviembre de 2025 en el auditorio de la Facultad de Derecho de la Universidad Santiago de Cali, sede Pampalinda, ubicada en la ciudad de Santiago de Cali - Valle del Cauca, Colombia.

Agradecemos su valiosa participación.

Cordialmente,

Andrés Chamorro
Presidente - Comité Científico AFICAT - 2025
Cali - Valle
https://www.aficat.net/

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