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Hybrid Model for Strategic Decision-Making in Enterprise Architecture through Cooperation between Humans and Intelligent Agents

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Abstract: The purpose of the article is to present a hybrid model for strategic decision-making in enterprise architecture through cooperation between humans and intelligent agents. The article describes a new conceptual and technical framework**,** based on the principles of co-intelligence and the ArchiMate modelling language, enabling explicit representation of collaboration between human experts and AI systems in organizational processes. Using a four-stage research approach including conceptual analysis, model design and implementation in the Enterprise Architect platform, application to a business scenario, and result evaluation the authors demonstrate how the proposed framework enhances the modelling of digital transformation processes. The method is applied to a real business requirement, illustrating how human–machine cooperation can support more adaptive and informed strategic decisions. The proposed approach allows enterprise architects to improve modelling efficiency and decision transparency by

integrating AI-driven elements directly into business architecture. The effectiveness of the model is confirmed through application-based validation within an industrial context. These research results improve existing enterprise architecture practices and can be applied in both private and public sectors to facilitate digital transformation towards Industry 4.0 and the future Industry 5.0. This paper is novel because it formalizes co-intelligence at a high level of abstraction within enterprise modelling.

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

透過人與智慧代理人合作進行企業架構策略決策的混合模型

摘要：本文提出了一個概念與技術層面的成果，旨在企業架構框架內，對決策過程中人與智慧代理人之間的協作互動進行建模。該提案是對 ArchiMate **語言的結構和語義貢獻，使組織建模與工業** 4.0 **的新興挑戰，尤其是與所謂的「第三智能」的融合相契合。**

研究分為四個階段：(1) **分析協同智慧的概念及其在數位轉型過程中的相關性；**(2) **在** Enterprise Architect **平台中設計和實現成果；**(3) **將模型應用於特定的業務需求；**(4) **討論研究結果及其對組織架構設計的影響。**

此成果透過一種能夠明確表達人與智慧系統之間協作的結構，**擴展了** ArchiMate **的表達能力，使企業架構師更容易將此維度納入策略流程建模。雖然這項發展源於工業背景，但該提案可以轉移到其他領域，包括上市公司，在這些領域它可以支持以人工智慧為中介的公民援助為重點的數位轉型。**

本研究的主要目的是展示在企业架构业务层面上开发一种具有人机交互（协同智能）的新型构件。该构件的创新之处在于融合了 ArchiMate 语言的元素，将新型构件在更高抽象层面上形式化，即战略决策中的协同智能。

该新成果对新型业务架构设计具有重要意义，为企业架构师提供了建模数字化转型进程的新要素，助力企业向智能工业转型并持续演进至工业 5.0 阶段。

关键词：企業架構；業務架構；工業 4.0；商業模式；數位轉型；協同智慧；Archimate

1. Introduction

In recent years, the advancement of artificial intelligence has made possible an unprecedented form of human–machine cooperation. Artificial intelligence has evolved from a mere tool into an autonomous and adaptive system capable of performing complex tasks and collaborating with humans to achieve shared objectives [1]. This collaboration has given rise to what is now referred to as *human–machine co-intelligence*, a phenomenon recognized as a "third intelligence" that emerges from the synergy between human and artificial agents. Co-intelligence surpasses the capacities of either humans or machines acting independently and operates according to three fundamental principles: unified unity, division of labor, and co-evolution [2].

As artificial intelligence evolves, so too do intelligent agents autonomous software entities that perceive their environment, make decisions, and perform goal-oriented actions. These agents are increasingly employed in industrial settings, where multi-agent systems cooperate to accomplish complex objectives through collective intelligence [3, 4]. The concept of a co-intelligence model serves to visualize and formalize these interactions both semantically and mathematically, with practical applications in designing decision-making systems that enhance organizational performance and improve public services.

2. Analysis

2.1. The necessity of modelling human–machine cooperation

The Fourth Industrial Revolution represents a paradigm in which interconnected, self-regulating, and intelligent entities exchange data and coordinate tasks to optimize productivity, flexibility, and efficiency [5–7]. Organizations that successfully integrate artificial intelligence can operate with greater adaptability and resilience [8]. This transformation extends beyond

manufacturing processes to encompass new forms of business modelling, requiring leaders to understand how emerging technologies reshape markets, suppliers, and consumer relationships [9].

Business intelligence systems have become integral to decision-making across industries, providing computational support for strategy formulation in manufacturing, commerce, and services [10]. Complementing these technologies, enterprise architecture (EA) plays a fundamental role in assessing and optimizing organizational processes to meet strategic objectives [11]. Within the context of digital transformation, the emergence of hybrid or co-intelligent systems challenges traditional models by embedding human–machine collaboration into the very fabric of enterprise operations [1, 8].

Co-intelligence transcends the limitations of isolated human or artificial agents by fostering adaptive integration and shared problem-solving capabilities [2]. Intelligent agents, functioning autonomously and cooperatively, enable distributed systems that enhance coordination and decision-making in industrial environments [4]. The present study introduces a conceptual model that represents human–machine co-intelligence within enterprise architecture, employing the ArchiMate language as a semantic and structural foundation consistent with the principles of Industry 4.0.

The model, conceptualized as a *co-intelligence construct*, constitutes a structural element within business architecture, as illustrated in Figures 1 and 2. Three criteria guided its development: strategic relevance at the business level, the incorporation of Industry 4.0 technologies, and a higher level of abstraction achieved through the synthesis of multiple ArchiMate elements. The proposed construct satisfies all three criteria by enabling the representation of decision-making processes in which human expertise and intelligent agents cooperate strategically.

3. Design and Implementation

3.1. The Co-intelligence Construct

Constructs are central to the practice of enterprise architects and essential for effective EA modelling. However, their use often becomes a routine exercise limited by conventional notations, which are rarely questioned or adapted to specific organizational contexts [12]. There is therefore a need to reconceptualize such constructs to reflect evolving socio-technical realities. Achieving a coherent strategic alignment within EA remains a critical challenge that can determine organizational success or failure. Contemporary research in enterprise modelling seeks to enhance both understanding and management of EA through more flexible and expressive frameworks [13].

3.2. Semantics

The proposed co-intelligence construct aims to represent the interaction and cooperation between a human decision-maker and an artificial intelligence agent in the pursuit of a shared objective. This visual and abstract representation facilitates the understanding of business processes within the EA environment, as illustrated in Figure 5. Tables 1 and 2 define the selected ArchiMate 3.1 elements and relationships used to model the construct according to *The Open Group* standards [14]. The model focuses on decision-making processes and identifies the input and output relationships relevant to co-intelligence interactions (Table 3).

3.3. Mathematical Representation

Within the co-intelligence construct, humans and intelligent agents collaborate to make strategic decisions, sharing experience, data, and knowledge. This interaction is represented through a hybrid mathematical model that combines two multi-criteria decision-making techniques: Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW). Organizational departments define their strategic objectives, decision contexts, and alternative solutions evaluated according to predefined criteria.

3.4. Application of the AHP Technique

In the initial stage, experts identify decision alternatives, evaluation criteria, and weightings through the AHP method [15]. The organization determines both the number and expertise of participants. Figure 3 illustrates the basic AHP structure for decision-making among four alternatives and four criteria. The application of AHP yields a weight vector W representing the relative importance of each criterion, as presented in Equation 1.

This formalization demonstrates how co-intelligence can be integrated into enterprise architecture to support structured, transparent, and adaptive decision-making in alignment with organizational strategy.

$$w_c = \begin{pmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{pmatrix} \quad (1)$$

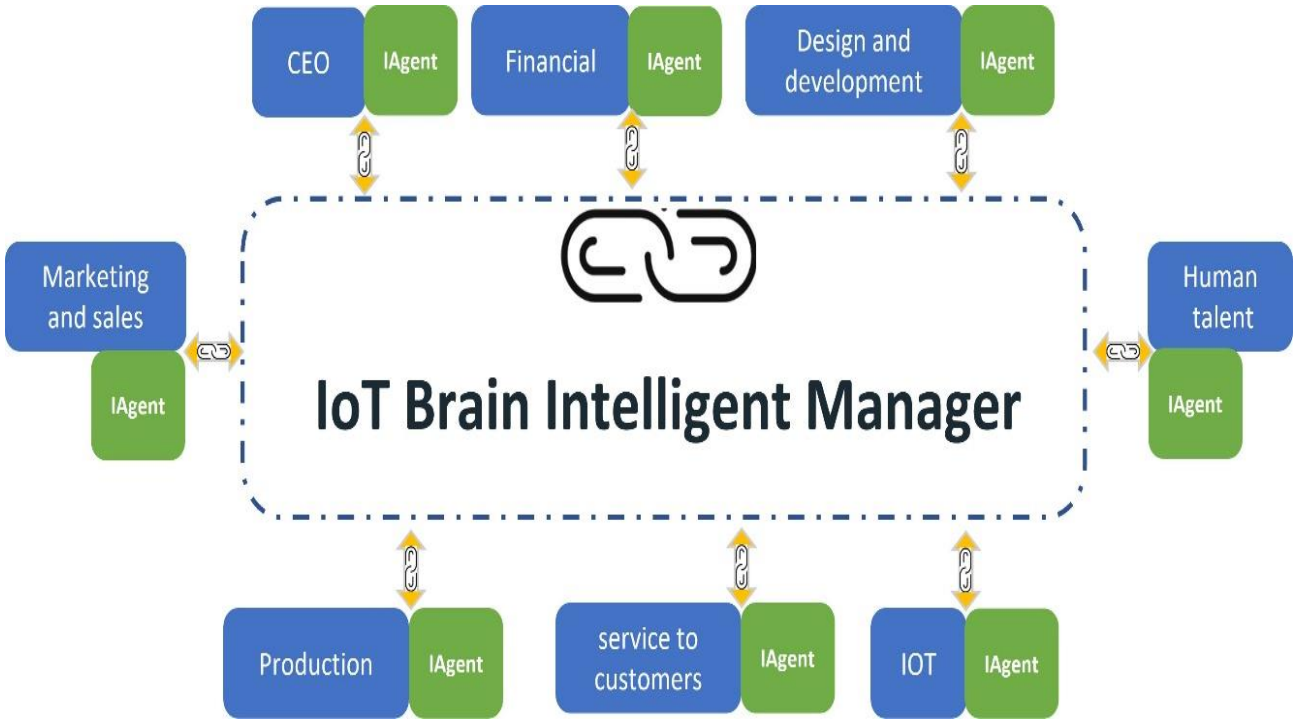

Figure 1. Business management structure

Table 1. Business Layer elements in ArchiMate 3.1 describing the semantics of the Co-intelligence artefact. Source: developed by the authors.

Element	*Description*
Business Actor	A department or unit within the organization.
Business Role	Humans and intelligent agents assume responsibilities and behaviors 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.

Table 2. Selected relationship concepts in ArchiMate 3.1 relevant to the Co-intelligence artefact. Source: developed by the authors.

Relationship	*Description*
Association	Indicates that the human and the intelligent agent are two roles that are related.
Assignment	Expresses the assignment of responsibility in the collaboration between the human and the intelligent agent for decision-making, allowing them to connect with information and business processes.

Table 3. Selected relationships in ArchiMate 3.1 possible for the new Co-intelligence artefact. Source: developed by the authors.

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 Flow	Permitted (Reads data, documents, criteria) Permitted (Information flows into the interaction)	Permitted (Writes or updates decisions, reports) Permitted (Outcome flows to other behaviors or processes)
Realization	Not permitted	Permitted (Interaction realizes a decision service)

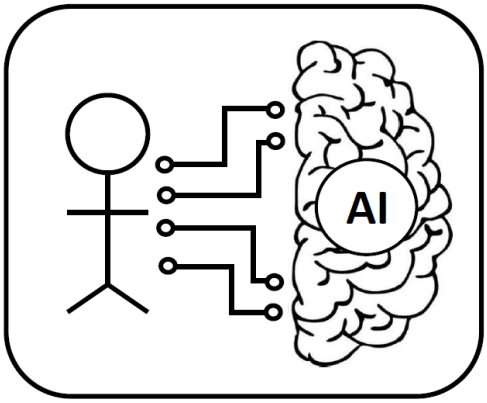

Figure 2. Visual representation of the Co-intelligence artefact. Source: developed by the authors.

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

This second part of the model is applied whenever a decision must 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.

3.6 Consolidated Scoring Matrix (S')

This matrix displays the average 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 weight (0.5 each).

3.6.1. Notation:

• $S_{ij,Human}$: score assigned by the Human to Option *i* under Criterion *j*.

• $S_{ij,IAg}$: score assigned by the Intelligent Agent (IAg) to Option *i* under Criterion *j*.

3.6.2. 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 2.

$$FS_i = (S'_{i1} \times w_1) + (S'_{i2} \times w_2) + (S'_{i3} \times w_3) + (S'_{i4} \times w_4) \quad (2)$$

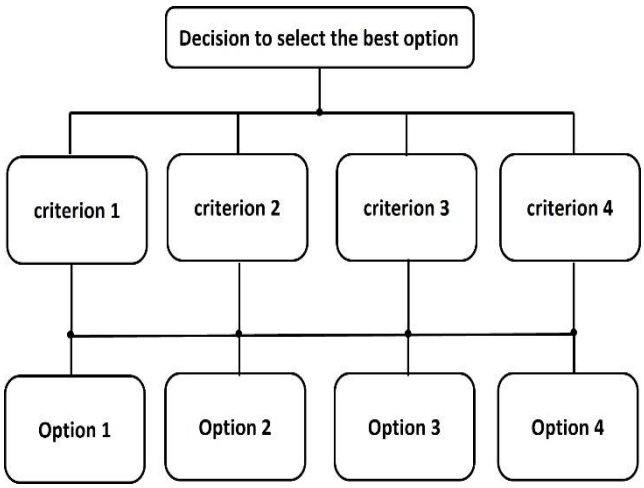

Figure 3. Visual representation of the basic AHP structure. Source: developed by the authors.

Table 4. Consolidated scoring matrix S' combining Human and IAg evaluations with equal weights. Source: developed by the authors.

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

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 analyzing the case and making the final decision.

3.7. Implementation

3.7.1. 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. 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 architecture [16].

This semantic integration allows ArchiMate to transcend its traditional diagrammatic nature and become a dynamic and adaptive platform, suitable for representing cointelligence artefacts where cooperation between humans and intelligent agents needs to be explicitly modelled. In this way, business modelling not only reflects static organizational structures, but also incorporates inference and decision-making mechanisms, which are fundamental for complex Industry 4.0 scenarios [17].

There are other modelling languages besides Archimate, such as BPMN (Business Process Model and Notation), UML (Unified Modelling Language) and SysML (Systems Modelling Language) [18]. 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 organization from the perspective of strategy, processes, and technology, and complex systems modelling. The languages were characterized by evaluating them as high, medium, or low, considering the criteria. The results of the evaluation are shown in Table 5.

Figure 4 graphically presents the comparative analysis of the four modelling languages. The radar chart shows that the ArchiMate language has a broader scope considering the five criteria selected to operationalize the elements and create the Co-intelligence artefact. ArchiMate offers flexibility and application across the different layers of an organization, 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 joint behavior that emerges from the collaboration between roles serving to model the collaborative act of Co-intelligence for: communication, coordination, negotiation and decisions [14].

As shown in Figure 5. In this example, Co-intelligence is represented in the 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 the department.

The two actor roles also have an interaction relationship representing communication and information exchange, allowing them to jointly analyze the context. Interaction activities are necessary for decision making aligned with the company's strategic objectives. The left side of Figure 5 shows the proposed artefact for the third intelligence and on the right side its equivalent modelling through the Archimate language.

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

Figure 6 shows the syntax of the Co-intelligence artefact with the elements and relationships that compose its internal structure to define its behavior in the Archimate modelling language. The set of input and output relationships allowed for the artifact [19].

3.8. Operation

3.8.1. 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 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 7 shows the modelling with conventional Archimate language artefacts.

Figure 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.

4. Discussion

In the visual representation of human–machine cooperation, a count of the ArchiMate elements modelling Cointelligence reveals an 80% reduction in the number of elements involved decreasing from five individual ArchiMate elements to a single stereotype. See Figure 5.

Comparing the modelling of the process in Figures 7 and 8, a 35% simplification is evidenced by the incorporation of the new Co-intelligence stereotype, which optimizes 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.

4.1. 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 prioritize the response and allocation of resources to citizens affected by a natural disaster caused by flooding. To prioritize 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 6 shows the behavior 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.

5. 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.

6. Ethical Considerations and Organizational Implications

Decisions made through a co-intelligence device raise ethical issues in decision-making. Organizations 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, organizations 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.

Table 5. Comparative capabilities of modelling languages. Source: developed by the authors.

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

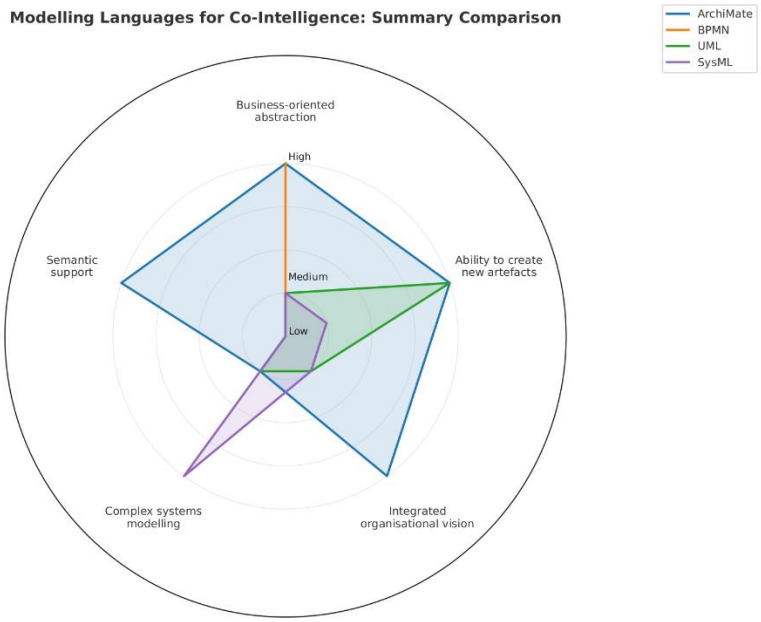

Figure 4. Visual comparison of modelling languages for Co-intelligence. Source: developed by the authors.

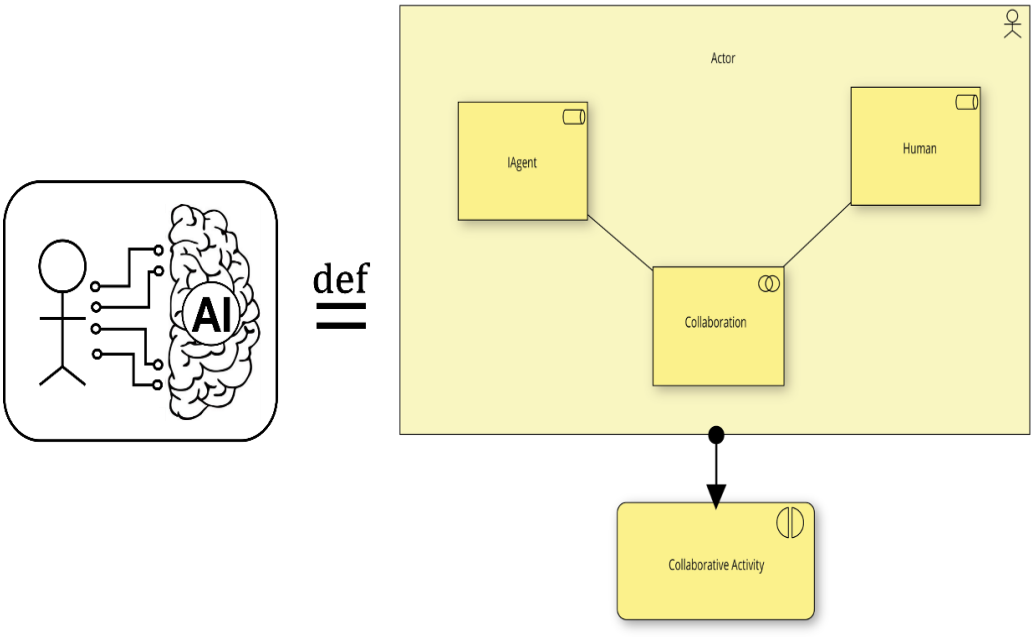

Figure 5. Archimate equivalent of the Co-intelligence artefact. Source: developed by the authors.

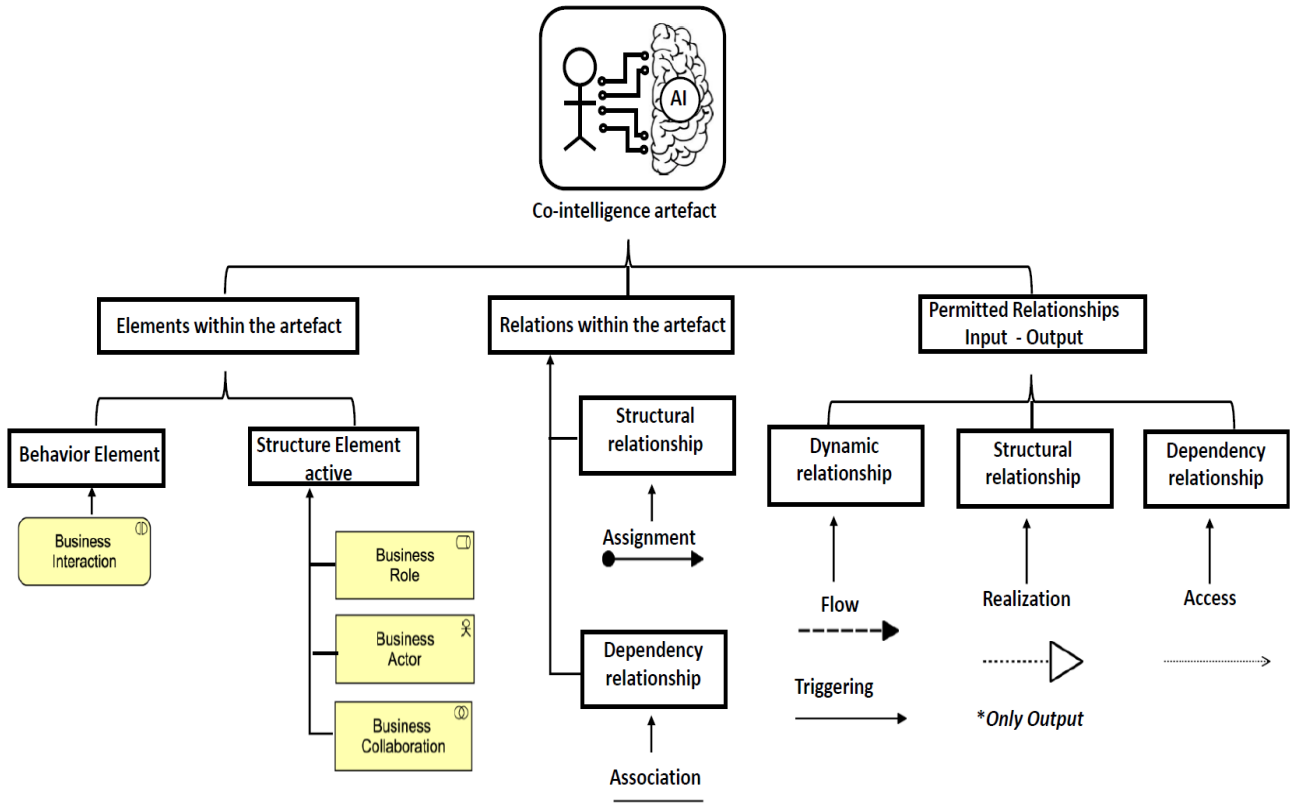

Figure 6. Syntactic tree of the Co-intelligence artefact. Source: developed by the authors.

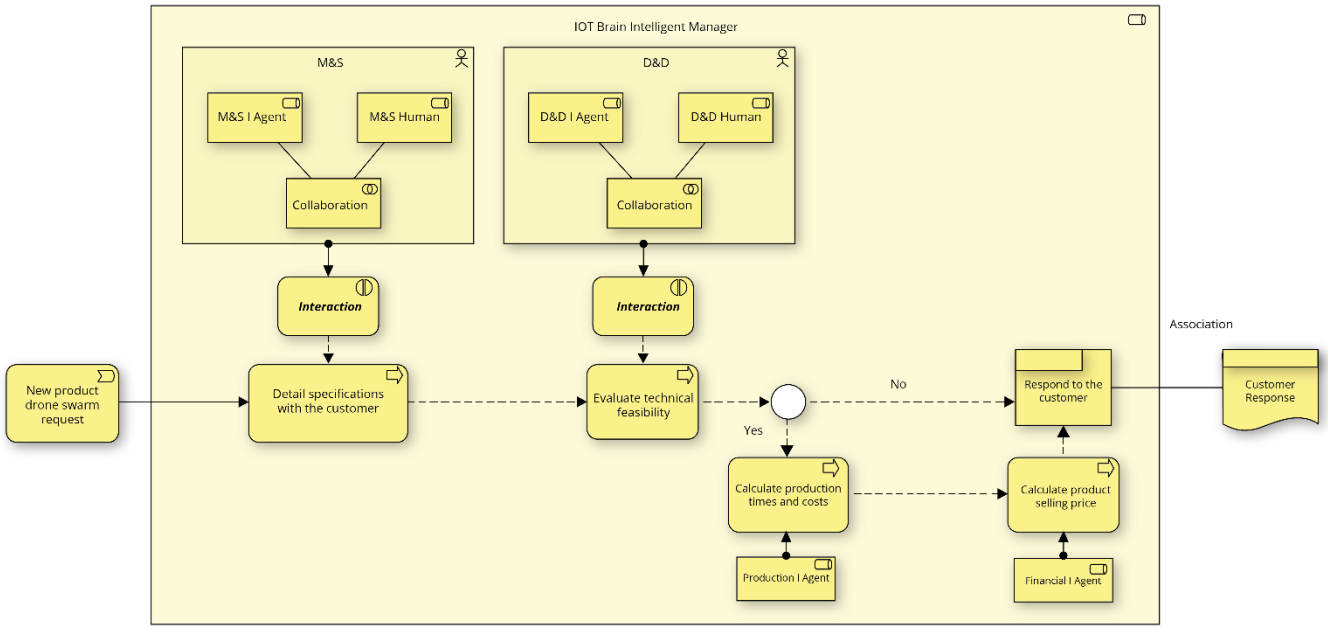

Figure 7. Modelling with conventional ArchiMate language artefacts. Source: developed by the authors.

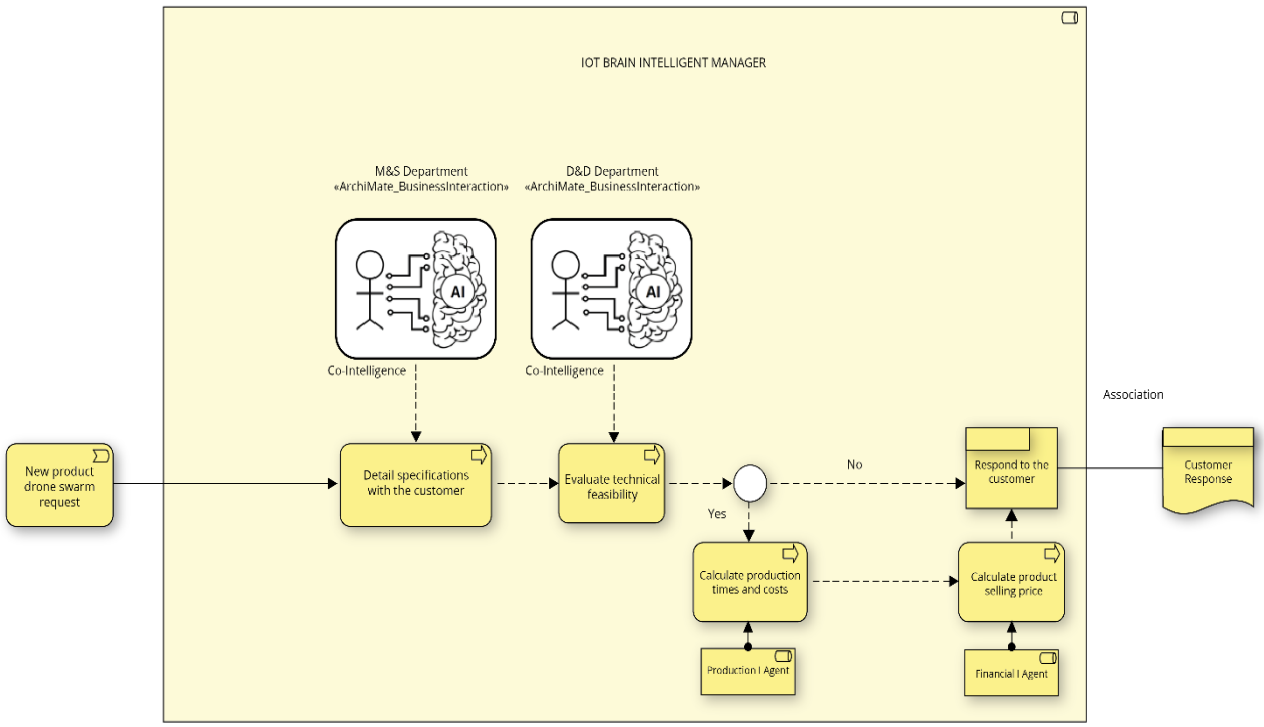

Figure 8. Modelling the process in ArchiMate, using the proposed new artefact for Co-intelligence. Source: developed by the authors.

Table 6. Results of the hybrid AHP-SAW model by case (Case 1: Agreement, Case 2: Disagreement). Source: developed by the authors.

Options	*Case*	*Human scores (C1-C4)*	*IAg scores (C1-C4)*	*Correlation (ρ)*	*FS*	*Decision reliability*
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	

7. 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.

Declarations

Authors' contributions

M.F.D.V. was responsible for the conceptualization of the research, the development of the co-intelligence artefact, the preparation of figures and tables, the drafting of the initial manuscript, and the overall coordination of the project. C.A.T.R. contributed through a critical review of the manuscript and methodological supervision. J.H.O. participated in the critical review of the manuscript and supervised the mathematical modelling of the artefact. F.P. provided supervision in the synthesis of the artefact using the ArchiMate language.

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Conflict of Interest

The authors declare that they had no conflicts of interest during the developed of the research.

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