MARCOS BORBA SALOMÃO

FCIA-OT
Advanced System for the Analysis and Evaluation of Technological Objects

Atena
Editora
Ano 2025

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FCIA-OT
ADVANCED SYSTEM FOR THE ANALYSIS AND EVALUATION OF TECHNOLOGICAL OBJECTS

Atena Editora
Ano 2025

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FCIA-OT – Advanced System for the Analysis and Evaluation of Technological Objects

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International Cataloguing-in-Publication Data (CIP)

F287 FCIA-OT – Advanced System for the Analysis and Evaluation of Technological Objects / Organizer Marcos Borba Salomão. – Ponta Grossa - PR: Atena, 2025.

Format: PDF
System Requirements: Adobe Acrobat Reader
Access mode: World Wide Web
Includes bibliography
ISBN 978-65-258-3642-3
DOI: https://doi.org/10.22533/at.ed.423252908

1. Assessment and analysis of technologies. 2. Methodology for assessing technological objects. I. Salomão, Marcos Borba (Organizer). II. Title.
CDD 620.0042

Prepared by Librarian Janaina Ramos – CRB-8/9166

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+55 (42) 3323-5493
+55 (42) 99955-2866
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ACKNOWLEDGEMENTS

To God, for allowing me to grasp truths that transcend traditional models and for illuminating each stage of this journey. This e-book embodies the realization of a greater project, built upon courage, dedication, continuous effort, and systemic scientific research.

To all who contributed to the creation of this innovative content, especially those who validated each concept in practice, with humility and rigor, I express my sincere appreciation.

To those who, even from a distance, supported this project with faith, hope, and anticipation, I extend my profound gratitude. Each article gathered in this volume represents more than research outcomes: they are concrete responses to the challenges of practice, the demands of applied science, and the silent prayers of those who believed that knowledge can be both applicable and transformative.

To everyone who trusted in the relevance of this proposal, I reaffirm my commitment: to continue building science with ethics, purpose, precision, and humanity.

PRESENTATION

The Integrated and Advanced Core Framework for the Analysis and Evaluation of Technological Objects (FCIA-OT) represents the outcome of an extensive cycle of systematic research and development. Built as a disruptive scientific architecture, it integrates mathematical, physical, computational, and perceptual principles into a unified and scalable system, capable of diagnosing, classifying, and guiding the reengineering of technological objects with an unprecedented level of precision.

Unlike traditional approaches, the FCIA-OT establishes a multiscalar and multidimensional methodology. Through the Systemic Matrix of Integrated Vectorial Dimensions (MSDVI) and its operational subsystems (SPMI, SCDMIC, SGUI, SCMI, MEAPs, & SIDyCP), it simultaneously combines systemic and modular perspectives, articulating objective and subjective metrics while ensuring interpretative clarity through chromatic codification. This methodological integration allows replicability across diverse domains, ranging from software interfaces to embedded systems and complex multicomponent platforms, such as unmanned aerial vehicles.

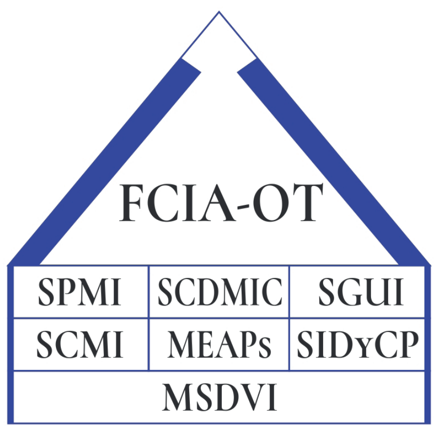
The e-book is organized as a progressive exploration of this architecture. The initial chapters (1–3) present the foundations of the FCIA-OT and its main subsystems. Chapter 4 demonstrates its application in real case studies, validating its robustness under practical and operational conditions. Chapter 5 expands the scope with the Structured and Advanced Model of Personas (MEAPs), while Chapter 6 introduces the Dynamic Inference System of Perceptual Fields (SIDyCP), which applies principles of mechanics and quantum physics to perceptual modeling. Chapter 7 describes the proposal for the Bachelor's Degree in Usability and Interaction Engineering (EUSIN) as a means of academic institutionalization, and Chapter 8 consolidates the operational management layer of the FCIA-OT, closing the architecture as an advanced ecosystem for technological evaluation.

The strength of the FCIA-OT lies not only in its methodological breadth, but above all in its epistemological novelty. By merging scientific formalism with applied diagnostics, it transcends decades of fragmented approaches and establishes a new standard for systemic evaluation, usability, and interaction. The framework demonstrates that technological evaluation can be simultaneously rigorous from a mathematical standpoint and visually interpretable, while also being theoretically grounded and practically replicable.

PRESENTATION

The concepts elaborated herein, each modeled structure, and each defended principle were sustained by prudence, ethics, and an unwavering determination, always guided by the purpose of fostering responsible innovation, grounded in critical awareness and the most rigorous technical responsibility. For knowledge is not merely accumulation, but discernment, understanding, and, above all, transformation.

Thus, this e-book is not limited to presenting a new framework, but inaugurates a scientific milestone: the consolidation of a unified and advanced architecture for the analysis and evaluation of technological objects, with the potential to redefine academic research, regulatory certification, and engineering practice.



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CHAPTER 1

INTEGRATED AND ADVANCED CORE FRAMEWORK FOR THE ANALYSIS AND EVALUATION OF TECHNOLOGICAL OBJECTS (FCIA-OT)

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ABSTRACT — This article presents the FCIA-OT Framework, developed as an advanced, systemic, and modular techno-scientific ontology, designed with formal grammar, projective language, and an architecture of analytical patterns to redefine the paradigms of analysis and evaluation of technological objects in high-complexity contexts. Structured around the Systemic Matrix of Integrated Vectorial Dimensions (MSDVI), composed of twelve functionally integrated dimensions and validated analytical vectors, the FCIA-OT operates as a third-order formalized system, in which each core functions as an interoperable, replicable, and actionable subsystem, capable of translating the techno-agential experience into auditable and normatively grounded evaluative constructs with epistemic rigor. Built upon the Agent-Technology Interaction (ATI) logic, the framework articulates functional, perceptual, affective, contextual, and operational variables through its continuous and transdisciplinary matrix, anchored in established foundations of usability engineering, cognitive modeling, and techno-epistemic interaction. Its structure enables a multivectorial reading of real usability, surpassing fragmentary or taxonomic approaches by integrating criticality, situated attributes, and normative criteria within a logic responsive to techno-functional transformations. The integration of the scalar and chromatic systems SPMI (Multidimensional Modular Integrated Scoring System) and SCDMIC (Modular Integrated System for Color Classification and Definition) into

the dimensional matrix enhances its representational density, allowing for precise scalar evaluation and formal encoding of critical intensity and techno-functional adequacy of the vectors in each dimension. This analytical architecture, sustained by the MSDVI, positions the FCIA-OT as an epistemic device oriented toward technical action, capable of generating interoperable data applicable to processes of evaluation, auditing, regulation, certification, and project reconfiguration. Its modular logic ensures adaptability to distinct domains and granularities, structuring an integrated platform for the analysis, measurement, and representation of technological objects in emerging and high-complexity scenarios.

KEYWORDS — FCIA-OT; Ontology; Dimensional Matrix; Analytical Architecture; Evaluation; Usability; Interaction; Technological Objects; Auditing; Regulation; Certification.

1 INTRODUCTION

The growing sophistication of computational systems and the intensification of interactions between agents and technological objects have rendered obsolete the evaluative approaches based on simplified reductions of experience. The complexity of techno-agential interaction demands models capable of operating across multiple simultaneous dimensions, integrating analytical rigor, empirical validation, and real-world applicability. The agent's experience, as a dynamic field of both objective and subjective factors, requires frameworks that articulate observation and interpretation with methodological precision. Traditional models for usability and interaction evaluation reveal structural shortcomings by limiting themselves to isolated metrics or fragmented interface analysis.

Three principles formulated by Gould & Lewis (1985) anticipated part of these demands by emphasizing the centrality of a continuous focus on users and their tasks, the empirical measurement of interactions, and the adoption of iterative testing and adjustment cycles. However, much of today's approaches remain confined to simulations or experiments disconnected from real usage conditions. These limitations reinforce the urgency for an evaluative architecture capable of operating on situated data and multiple experiential vectors.

Smith & Mosier (1986), in systematizing fundamental parameters for interface design, highlight the importance of structural consistency, perceptible feedback to the user, and the prevention of operational errors. While essential, these elements prove insufficient in the face of contemporary technological density, which requires continuous operational adaptability and integration between the functional and contextual layers of interaction.

Methodological advancement in the analysis and evaluation of technological objects demands the formulation of hybrid, evidence-driven structures designed to enable an integrated reading of the agent's experience. Segmented approaches, by failing to capture the structural and situational complexity of usability in real environments, expose the need for a more comprehensive model. As a technical response to these limitations, this research proposes the Framework Core Integrado e Avançado para Análise e Avaliação de Objetos Tecnológicos (FCIA-OT) as a structured and advanced techno-scientific matrix, designed to redefine evaluative paradigms within the domain of usability and interaction. The framework is grounded in an iterative, articulated, and action-oriented methodological core, capable of integrating multiple dimensions of analysis with precision, applicability, and scientific consistency.

2 INTEGRATED AND ADVANCED CORE FRAMEWORK FOR THE ANALYSIS AND EVALUATION OF TECHNOLOGICAL OBJECTS (FCIA-OT)

The FCIA-OT constitutes a high-complexity analytical system, developed to structure the analysis and evaluation of technological objects through an integrated, technical, and systematic logic. It does not confine itself to point-based usability measurement but articulates an advanced model that combines objective and subjective variables, designed to interpret the agent's experience in a holistic and situated manner. Its architecture transcends approaches focused solely on the interface, offering an analytical matrix applicable to multiple contexts, phenomena, and complex constructs, from prototyping to real-world use.

The framework's architecture is grounded in a set of calibrated metrics, supported by principles of HCI and usability and interaction engineering, which together form a robust system for continuous evaluation. The model favors the structured identification of critical points without limiting itself to fault diagnosis, and it guides the development of evidence-based solutions. This dynamic ensures not only the traceability of collected data but also its operationalization within the design cycle, contributing directly to the functional and experiential evolution of the evaluated objects.

According to Wichansky (2000), the reliability of evaluative methods depends on the rigorous application of tasks, metrics, and scenarios defined by standardized protocols. The FCIA-OT incorporates this principle by establishing validated procedures aligned with methodological criteria that ensure the repeatability and precision of results. This structure eliminates common arbitrariness in exploratory evaluations, replacing empirical intuitions with traceable and replicable processes.

Expanding on this approach, Wixon (2003) observes that the impact of usability methods on development lies in their capacity to guide real improvements, not merely to identify flaws. This perspective is fully absorbed by the FCIA-OT, whose iterative approach allows empirical data to directly inform design decisions, sustaining a cycle of continuous and technically driven improvement.

In alignment with this, Dumas & Salzman (2006) argue that effective tests must isolate usability as a central variable, involve real users, employ critical tasks, capture multiple types of data, and translate them into practical recommendations. These foundations are integrated into the core of the FCIA-OT, whose methodological structure was designed to ensure adherence to these criteria across all phases, from task definition to the generation of technical reports.

In the domain of agent experience, Bargas-Avila & Hornbæk (2011) identify recurring limitations in studies that evaluate only one or two dimensions, thereby compromising analytical completeness. The FCIA-OT addresses this limitation by integrating cognitive, affective, operational, and contextual variables into its evaluation matrix, structuring a multiscalar reading of usability and interaction within complex systems.

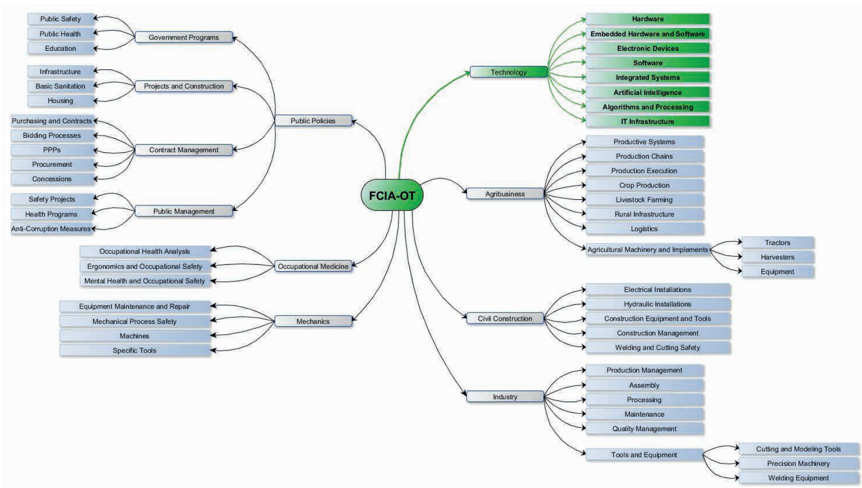
Wixon (2011) further observes that evaluations focused exclusively on objective measures fail to capture the essential subjective aspects of experience. The framework balances these two poles by articulating performance metrics with perceptual data, such as satisfaction and contextual appropriation, generating insights more attuned to the realities of use.

Methodological complexity is also addressed by Van Turnhout et al. (2014), who highlight the challenge of reconciling scientific rigor with practical relevance in HCI research. The FCIA-OT adopts a mixed, replicable, and iterative approach that bridges these two demands, operating as a model of translation between technical, scientific, and design domains.

Within this same scope, Weichbroth (2020) notes that the dispersion of evaluative attributes and the absence of consolidated models compromise the validity of results. The FCIA-OT presents itself as a structured response to this issue by systematizing a stable set of dimensions, theoretically grounded and designed for replicable applications without relying on arbitrary categories.

At its core, the FCIA-OT systematizes the process of analysis and evaluation based on rigorous techno-scientific criteria, integrating empirical observation, iterative validation, and practical application. By organizing actionable data, the framework enables teams to generate targeted solutions, surpassing prescriptive or disjointed approaches. Its methodology distances itself from experimental models centered on physiological measurements, prioritizing a situated, replicable analysis anchored in real-world use. Figure 1 presents a mind map summarizing some of the thematic areas encompassed by the FCIA-OT, highlighting the technology module employed in this study for presenting the integrated and advanced matrix with its core components.

FIGURE 1: SUMMARY MIND MAP OF THE FCIA-OT



Source: Author.

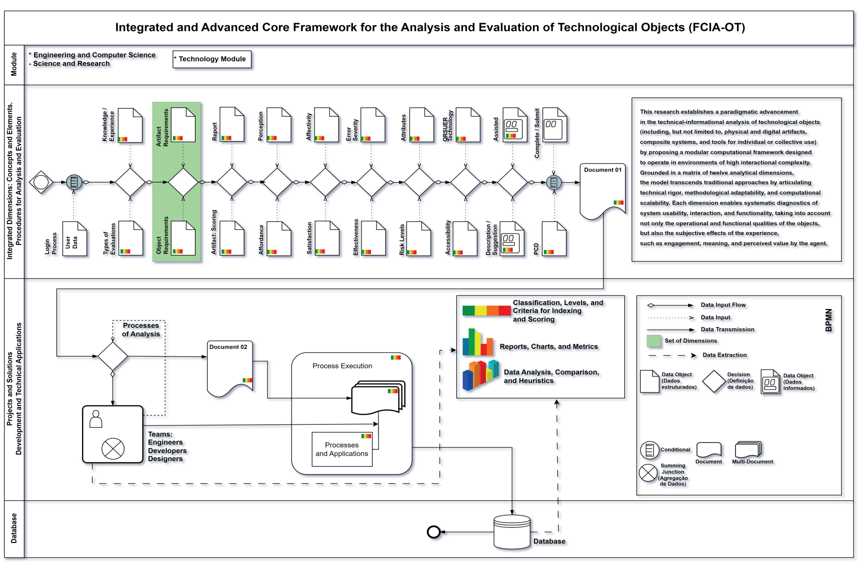
2.1 Guidelines: Technical Procedures in the FCIA-OT

The methodological formulation of the FCIA-OT responds critically to the limitations observed in traditional usability evaluation models, which are often reduced to isolated tasks, disconnected measurements, and scenarios detached from real-world usage conditions. As noted by Hornbæk (2006), evaluations focused solely on elementary metrics fail to capture the complexity of the cognitive and social interactions involved in the agent's experience. In contrast, the FCIA-OT integrates multiple contexts, scales, and levels of complexity, operating under a techno-scientific logic oriented toward real-world application.

Law et al. (2009a) emphasize that anticipating the user experience in the early stages of development is essential for producing artifacts that are more responsive and aligned with the agents' expectations. The FCIA-OT incorporates this guideline by enabling evaluations with or without fully functional systems, allowing for robust inferences based on advanced simulations and interactive prototypes. This approach strengthens technical decision-making prior to product consolidation, promoting resource efficiency and enhancing design quality.

Complementarily, Vermeeren et al. (2010) point out that in-depth experience evaluations require insertion into real environments and methodologies that respect the participants' routines. The FCIA-OT operationalizes this requirement by articulating laboratory and field procedures within a continuous, sensitive, and non-intrusive structure. This strategy balances analytical depth with practical feasibility, promoting greater data reliability and situational alignment. Figure 2 presents the FCIA-OT technical flowchart, which synthesizes the sequence of the applied methodological stages. This representation functions as a procedural reading tool, facilitating the visualization of the application logic and the unfolding of the framework's analytical activities.

FIGURE 2: FLOWCHART – INTEGRATED AND ADVANCED CORE FRAMEWORK FOR TECHNOLOGICAL OBJECTS ANALYSIS AND ASSESSMENT (FCIA-OT)



Source: Author.

The procedural sequence illustrated in Figure 2 is detailed in Table 1, which presents the technical-scientific procedures that constitute the operational core of the FCIA-OT. Each stage is described with methodological precision, indicating its specific functions, analytical objectives, and expected outcomes. This table serves as a reference tool for understanding the internal operations of the framework, organizing the process from data collection to the systematization of metrics and the issuance of assessment reports.

The stages are arranged sequentially and cumulatively, ensuring systematic execution and traceability of procedures. Each phase was designed to preserve methodological consistency and scientific validity, respecting the complexity of the integrated dimensions. The technical detailing reinforces the robustness of the matrix, demonstrating its capacity to generate applicable and replicable data for the evaluation of technological objects under real usage conditions.

TABLE 1: TECHNICAL PROCEDURES OF THE FCIA-OT

Stage	Scientific and Technical Description	Objectives	Expected Outcome
1. Agent Identification	**Collection of the agent's code, name, sex, disability status, and other personal data,** aiming to individualize both the agent and each analysis instance through the association with a unique identifier.	Ensure traceability and personalization of the analysis.	Agent identified for future reference and behavioral analyses.
2. Identification of the Type of Analysis and Assessment	**Definition of the type of Analysis and Assessment.** Analysis and Assessment (final agent); Assisted Analysis and Assessment (technical agent, specialist, engineer); Technical Report (engineer agent).	Accurately classify the scope, nature, and objective of the analytical and systemic investigation.	Analysis and Assessment qualified by level, nature, and comparative purpose.
3. Selection of the Agent's Knowledge Level	**Identification of the agent's level of knowledge and experience,** assigning a corresponding score. This classification directly influences the analysis and assessment.	Accurately classify the agent to align analyses and assessments with their competencies.	Score assigned based on the agent's knowledge level, accurately qualifying the scope and depth of the analysis and assessment of the technological object.
4. Identification of the Object Type	**Identification of the object to be analyzed,** using the Object Requirements. Identifies its core features, such as hardware, software, among others.	Define the object's fundamental properties to guide the subsequent analysis.	Object classified with its main properties defined.

5. Identification of the Object's Artifact and Artifact Scoring	**Identification and assessment of the artifacts associated with the object,** using the Object Artifact Requirements. Covers elements such as components, parts, interface, processes, among others.	Evaluate the object's critical components that impact the agent's experience.	Object artifacts identified, analyzed, and scored. Comparative analysis.
6. Description of the Report	**Concise record of the report** associated with the object's artifact, highlighting critical information from the analysis.	Characterize the object's artifact based on the information defined in the report.	Artifact identification described. Subsequent analysis.
7. Selection of the Affordance	**Identification of the affordance selected by the agent,** categorized by level, influencing the evaluation of interaction with the object.	Map how the agent perceives and interacts with the object's affordances, impacting the agent's experience.	Affordance identified, categorized, and scored. Subsequent analysis.
8. Selection of the Perception	**Assessment of the agent's perception and response,** considering how they interpret and react to the object's affordances. Impacts the analysis and assessment.	Understand the agent's emotional and cognitive responses to the affordances. Impacts the agent's experience.	Perception identified, categorized, and scored. Subsequent analysis.
9. Affective Selection	**Assessment of the agent's affectivity toward the object.** This stage evaluates the degree of pleasure or discomfort associated with the interaction. It impacts the analysis and evaluation process.	To quantify and understand the emotional impact of the interaction. It influences the agent's experience.	Affectivity identified, classified, and scored. Comparative analysis.
10. Agent Satisfaction Selection	**Identification of the agent's satisfaction with the object,** measuring the quality of the experience with the object's artifact. It affects the analysis and evaluation.	To quantify satisfaction and identify areas for improvement. It influences the agent's experience.	Agent satisfaction recorded for future reference. Scored. Subsequent analysis.
11. Effectiveness Selection	**Qualification of the effectiveness as perceived by the agent.** This evaluates the success of the object's artifact in fulfilling its intended purposes. It affects the analysis and evaluation.	To assess the success of the interaction between the agent and the object's artifact. It influences the agent's experience.	Effectiveness identified, categorized, and scored. Comparative analysis.
12. Error Severity Identification	**Evaluation and categorization of the severity of errors** identified during interaction with the object's artifact, using a predefined severity scale. It affects the analysis and evaluation.	To identify the magnitude of usability issues and their impacts. It influences the agent's experience.	Error severity identified and defined. Scored. Subsequent analysis.

13. Risk Level Identification	**Determination of risks** associated with the object's artifact, classifying them in terms of the potential impact and extent of each risk. It affects the analysis and evaluation.	To determine the magnitude and assess the criticality of risks in order to prioritize corrections and understand their impacts. It influences the agent's experience.	Risk levels identified and categorized. Scored. Subsequent analysis.
14. Identification of Attributes for the Object's Artifact and Scoring of Attributes	**Identification and evaluation of the attributes and descriptors associated with the object's artifact,** based on the Object Attributes framework. It determines the artifact's scope. It affects the analysis and evaluation.	To determine the scope of the artifact in relation to its attributes. It influences the agent's experience.	Attributes identified, analyzed, and scored. Comparative analysis.
15. Identification of Accessibility for the Object's Artifact and Scoring of Accessibility Criteria	**Identification and evaluation of Accessibility criteria applicable to the object's artifact,** using defined elements (criteria). It affects the analysis and evaluation.	To determine the scope of the artifact with respect to each Accessibility criterion. It influences the agent's experience.	Accessibility criteria identified, analyzed, and scored. Comparative analysis.
16. Identification of QRSUER Technology for the Object's Artifact and Scoring of QRSUER Criteria	**Identification and evaluation of QRSUER Technology criteria applicable to the object's artifact,** based on specific elements (criteria). It impacts the analysis and evaluation.	To determine the scope of the artifact in relation to each QRSUER Technology criterion. It influences the agent's experience.	QRSUER Technology criteria identified, analyzed, and scored. Comparative analysis.
17. Collection of Descriptions and Suggestions	**Recording of the agent's descriptions, suggestions, and feedback,** enabling qualitative insights into the interaction with the object.	To capture direct feedback to guide improvements.	Descriptions and suggestions documented for review and analysis. Comparative analysis.
18. Collection of Assisted Analysis	**Recording of descriptions and data from assisted analysis.** A professional observes end agents, whether with disabilities or not, in specific testing environments or real-use scenarios, registering additional observations on the object's use.	To ensure inclusion and precision in assisted analyses, and determine whether it qualifies as a Technical Report.	Additional data collected and documented. Comparative analysis or classified as a Technical Report.
19. Generation of Document 1	**Consolidation of all collected data into a structured document** (Document 1), containing all information from the analysis and evaluation.	To create a solid data foundation for subsequent analysis by developers and manufacturers.	Document 1 generated, containing complete and structured information.

20. Analysis by Developers	**Receipt and analysis of Document 1 by manufacturers, developers, designers, and engineers,** who discuss solutions for the identified issues.	To identify and define technical solutions to improve the object.	Document 1 analyzed and initial solutions proposed.
21. Discussion and Approval of Solutions	**Validation of the proposed solutions,** formalizing decisions in a new document **(Document 2).**	To formalize the solutions to be implemented.	Document 2 generated, containing structured and approved solutions.
22. Implementation of Solutions	**Execution of modifications and improvements to the technological object,** in accordance with the procedures defined in Document 2.	To update the object according to the agreed specifications.	Object updated and enhanced.
23. Data Storage	**Recording and storage of the implemented data** and solutions in a database.	To ensure the availability of information for future analyses.	Data stored and ready for continuous and evolutionary analysis.
24. Analysis and Reporting	**Generation of reports and charts** based on the stored data, enabling detailed analyses.	To provide structured information from the analyses and evaluations of technological objects.	Reports generated, supporting advanced analysis and decision-making.

Source: Author.

The analysis of technological objects from the FCIA-OT perspective requires the adoption of a systemic logic, grounded in strict scientific and technical criteria. The framework does not operate as a passive system for organizing data, but rather as an Advanced System for Structured Information Management, capable of processing, classifying, and redistributing data based on logical interconnections and methodological cores.

The central proposition of FCIA-OT is to structure an application-oriented scientific investigation, in which interdependent dimensions of usability and interaction are articulated with precision. The analytical model adopted enables the understanding of how cognitive, operational, and affective variables influence the adequacy of technological objects to the agents' demands and the context of use, providing concrete inputs for design decisions in complex environments.

Grounded in a consolidated theoretical-methodological foundation, FCIA-OT integrates scientific rigor and technical innovation. Its core unites theory, practice, and technique in a replicable, situated analysis system, applicable to diverse realities. This structure contributes to decoding the complexity of technological systems, fostering concrete advancements in evaluative and design practices within the field of usability and interaction.

Although originally designed for specific technological environments, FCIA-OT presents a high degree of flexibility. Its adaptable architecture allows application across multiple domains and systemic configurations, without compromising analytical precision. This adaptability makes the framework a strategic tool for fostering sustained improvements in design, analysis, and development processes across various fields.

2.2 Guidelines: Integrated Scientific-Technical Cores

The development of robust guidelines for evaluation in HCI remains a persistent challenge. Seffah et al. (2006) point out that available usability models lack consistent definitions, methodological integration, and adequate computational support. The absence of clear links between criteria and evaluative factors often leads to the adoption of ad hoc empirical practices, driven by familiarity rather than technical precision. This gap, marked by the lack of systemic rigor, highlights the urgency of a consolidated architecture capable of reducing operational costs, optimizing communication among experts, and establishing replicable guidelines grounded in technical principles and scientific validity.

In response to these deficiencies, FCIA-OT structures its functional core through the Integrated Scientific-Technical Cores: specialized units that operate as the analytical engines of the framework. In this context, the term Core refers to the central logic of the system, a modular, scalable core driven by scientific and technical criteria, designed to articulate data, contexts, and variables in high-precision evaluations. This advanced information-processing system transcends fragmented or merely descriptive models.

Each Core represents a functional unit within the Systemic Matrix of Integrated Vectorial Dimensions (MSDVI), which comprises twelve dimensions designed to analyze operational, affective, cognitive, technical, and contextual aspects. These units are organized into independent analytical modules that can be activated according to the nature of the object under evaluation. This modularity enables tailored configurations, fostering interoperability among the Cores and ensuring full adaptability to the demands of diverse and constantly evolving environments.

This structure extends beyond functional organization; it enhances the integration of analytical dimensions through a high-granularity computational logic capable of capturing cross-relations between criteria and enabling interdependent analyses. Each Core is grounded in its own scientific foundation, anchored in technical standards, specialized literature, and consolidated methodologies in usability engineering and computer science. This foundation ensures methodological validity, replicable reliability, and alignment with international standards.

Unlike rigid or static models, the Cores of the FCIA-OT are both structured and dynamic. They allow modular updates, the inclusion of new criteria, reconfigurations, and adaptations without compromising methodological consistency. This characteristic positions them as analytical engineering guidelines, with simultaneously calibrated scientific and practical applicability.

The operational logic of the Cores is supported by structured information management mechanisms, optimizing every stage from data collection to the generation of precise and actionable diagnostics. These mechanisms transform raw data into manageable analytical structures, fostering a clear, traceable informational base oriented toward technical decision-making.

As a set, the Cores are consolidated as strategic components of the FCIA-OT, articulating technical rigor with systemic flexibility. Their operational standardization enables not only the scalability of the framework but also its application across various domains, including laboratory settings, field environments, and complex digital ecosystems. Within this scope, the concept of the Core System encapsulates the idea of a nucleus designed to function as the logical and functional center of the framework, responsible for organizing and guiding the analytical processes under high, consistent methodological standards applicable to various types of technological objects.

3 GUIDELINES: INTEGRATED TECHNICAL-SCIENTIFIC DIMENSIONS

The integrated technical-scientific dimensions of the FCIA-OT constitute the operational foundations that support high-precision analyses, methodological rigor, and technical-informational adherence. They are elevated to specialized computational structures, surpassing disciplinary boundaries and forming a unified, adaptable, and replicable analytical systemic matrix. Each dimension was designed based on robust theoretical and practical foundations, drawn from a systematic review of the specialized literature and internationally recognized technical-normative guidelines. Their construction ensures that each dimensional core contributes synergistically to the framework's robustness, reliability, and interpretive reach.

Within the FCIA-OT scope, the dimensions operate as structuring axes that organize critical variables of the technical-scientific analysis of technological objects, whether physical, digital, or hybrid. Each one encapsulates specific sets of criteria, organized to respond to distinct evaluative constructs. Their modularity allows for selective activation according to analytical requirements, adapting to the evaluation's objectives without compromising the system's structural coherence.

Unlike aggregative arrangements or disjointed collections, these dimensions operate in a network, integrated by a computational logic that synchronizes their criteria and enables interdependent inferences. This structure reinforces the internal consistency of analyses and ensures methodological adaptability across different technical and operational contexts.

The dimensions cover central domains such as usability, interaction, accessibility, efficiency, security, and contextual impact. They were constructed under a technical-scientific rigor aimed at articulating specific criteria with systemic effects, enabling the FCIA-OT to function as a high-complexity, high-precision evaluative matrix. The twelve integrated dimensions are presented below in a methodical manner, with an exposition of their theoretical foundations, technical criteria, and structural roles within the framework system.

3.1 Knowledge/Experience Dimension (CEX)

The Knowledge/Experience Dimension (Dimensão Conhecimentos/Experiências – CEX) structures the levels of mastery mobilized by the agent when interacting with a technological object, translating operational, cognitive, and situational repertoires into classifiable technical gradients. This dimension goes beyond performance assessments, encompassing the historicity of the agent's relationship with the technology, the nature of appropriation, and the complexity of the perceptual, interpretive, and operative mechanisms involved in technical action.

By integrating variables such as sociotechnical repertoire, learning styles, accumulated exposure, contextual motivations, and cognitive structures, CEX enables a systematic reading of interaction that transcends reductions centered on mere functional competence. The agent's experience is interpreted as a dynamic and interdependent phenomenon, composed of sensorimotor states, pragmatic meanings, affective dispositions, and symbolic interpretations modulated over time through use.

The literature highlights the necessity of this expanded approach. Gould & Lewis (1985) point out that underestimating the cognitive diversity of users undermines the accuracy of design decisions, especially when based on unvalidated assumptions. Aykin (1989) reinforces that individual characteristics directly influence performance and operational preferences, while Kanis (1998) demonstrates that accumulated actions throughout interaction decisively affect the system's perceived functionality. Hassenzahl (2003) deepens this point by emphasizing the subjective, mutable, and psychologically dense nature of technological experience.

Forlizzi & Battarbee (2004) propose a distinction between fluent, cognitive, and narrative experiences, emphasizing that each operates in a specific manner in shaping interaction. This classification broadens the analytical scope, enabling the framework to identify how the agent engages with the system—whether automatically, reflectively, or symbolically. Dumas & Salzman (2006) reiterate that user experience results from a combination of functional and emotional factors, influenced by context, expectations, and feedback, which reinforces the complexity of the phenomenon to be assessed.

Naumann et al. (2007) contribute by elucidating the activation mechanisms of tacit and non-conscious knowledge, which often guide action without being verbalized. These mechanisms are essential to understanding agent behavior in operational situations where tacit knowledge prevails over conscious rationalization.

In this same domain of agent experience, Alshamari & Mayhew (2008) underscore the importance of accounting for user diversity during testing, showing that different repertoires directly influence the types of problems encountered and performance indicators. The CEX dimension internalizes this premise by expanding the analytical criteria to encompass heterogeneity, trajectories, and technological appropriation patterns. Janlert & Stolterman (2010) distinguish between the internal complexity of the artifact and its interface, allowing one to understand how the structural distribution of complexity affects perception and performance in action.

According to Wixon (2011), although measurements of subjective experiences are imperfect, they are essential for promoting meaningful evaluations. The objectification of subjective states, such as trust and fluency, is not only feasible but also enhances design quality, provided it is carried out using valid criteria and appropriate instruments.

Building upon this foundation, Burlamaqui & Dong (2015) systematize the role of knowledge as an accumulation of experiences, beliefs, and culture. In the human context, these cognitive layers are mobilized during interaction with artifacts, informing decisions, expectations, and interpretations. This approach is incorporated into CEX as a transversal axis, capable of qualifying all other dimensions of the FCIA-OT.

The Knowledge/Experience Dimension, therefore, does not merely describe the agent's level of familiarity with the technology but interprets their technical-cognitive trajectory, modes of appropriation, and engagement patterns that guide situated action. The coherence between the agent's mental models and the system's operational models constitutes a critical variable for action fluency. CEX enables the mapping of such dissonances by classifying the agent's degree of technical-operational mastery across ten hierarchical levels, organized into a scoring system (CEX10 to CEX01) using SPMI scoring and the SCDMIC chromatic and semantic codification. Table 2 presents the formatted knowledge/experience levels and the definitions related to the agent.

TABLE 2: DEFINITION OF KNOWLEDGE/EXPERIENCE (CEX) LEVELS

Code	Knowledge/ Experience Levels	Definition	SPMI
CEX10	Beginner	Introductory knowledge of technologies. Ability to recognize, power on/off, or operate elementary functions of a technological object with external guidance. (Beginner).	10
CEX09	Basic Operator	Ability to use routine operational functions in specific technologies (digital or physical), such as operating equipment, basic tools, or performing simple normative tasks. (Basic).	9
CEX08	Functional Agent	Ability to operate and configure standard functions of technological objects, understand modes of operation, and handle devices autonomously in predictable contexts. (Intermediate).	8
CEX07	Operational Technician	Competence in diagnosing failures, performing intermediate technical configurations, adapting usage across different contexts, and handling model or version variations. (Technical Intermediate).	7
CEX06	Advanced Technician I	Knowledge of technical fundamentals for operation, maintenance, and reconfiguration of technological objects. Skilled in parameterization, testing, and controlled interventions. (Advanced I).	6
CEX05	Advanced Technician II	Ability to integrate technologies, automate tasks, develop structured modifications, and adapt physical or digital components to contextual requirements. (Advanced II).	5
CEX04	Integration Specialist	Mastery over multiple converging technologies. Performs complex interventions, promotes systemic compatibility, and develops advanced solutions and adaptations. (Advanced III).	4
CEX03	Technological Architecture Specialist	Ability to design, develop, and maintain complex technological objects or systems, whether physical or computational, with full command of their life cycles and applications. (Advanced IV).	3
CEX02	Systemic Professional	Operates at a high level of complexity in advanced technologies, develops interdisciplinary solutions, and masters theoretical and operational foundations of various classes of objects. (Advanced V).	2
CEX01	Strategic/ Developer Level	Acts as designer, engineer, researcher, or creator of the technology. Critically evaluates their own objects and frameworks, validating properties and functionalities through structured heuristics. (Advanced VI).	1

The CEX dimension structures, in hierarchical order, the levels of mastery that an agent may demonstrate when facing any technological object, be it a product, service, interface, process, tool, or system. Each level (CEX10 to CEX01) describes the progression of the agent's capacity to recognize, operate, modify, integrate, or design technologies, incorporating cognitive, operational, and situational competencies. These levels are linked to a scoring system that associates codes and colors based on the degree of complexity and maturity of the object, through chromatic standardization. CEX is a transversal dimension of the FCIA-OT, directly qualifying the other 11 dimensions and enabling cross-analysis across different agent profiles and evaluated technologies.

Source: Author.

CEX formalizes a technical-scientific model for experience assessment, grounded in empirical evidence, replicable, and anchored in principles of interaction engineering, cognitive ergonomics, and behavioral science. Its transversality within the FCIA-OT makes it a qualifying axis of the integrated matrix, structuring the evaluation according to criteria of technological maturity, interpretive complexity, and functional adaptation.

3.2 Affordance Dimension (AFF)

Affordance Dimension (Dimensão Affordance – AFF) constitutes the invisible articulation between the materiality of the technological object and the interpretative capacity of the agent, whether human, artificial, or hybrid. It is not a static or intrinsic property, but rather an inferential circuit that emerges from the convergence of three vectors: the operational morphology of the object (what can be done), the historical repertoire of the agent (what has already been learned), and the contingent demand of the environment (what needs to be done).

From this relational structure, inferable patterns of action emerge, either evident or latent, which may be codified, induced, or interpreted, thereby influencing action directly or in mediated form. Affordance, therefore, is not an isolated attribute of the object, but an interrelational vector that regulates the intelligibility of action. When this vector stabilizes within the relationship between agent and artifact, through perceptual recurrence (as in the recognition of a button), consolidated training (such as the operation of a control system), or systematic decoding (such as algorithmic reading of visual patterns), an operational fluency is established in which the interface becomes invisible.

This research treats Affordance as a technical-informational dimension of analysis, structured upon principles of distributed cognition, semiotic engineering, and adaptive systems. The proposal advances by constructing a technical taxonomy grounded in formal inferences concerning clarity, risk, and required learning load, aiming not only at classification but also at enabling its measurement, simulation, and diagnostic application across multiple domains.

The original conception of affordance, formulated by Gibson (1979), is based on the notion of properties directly perceivable by the agent, environmental structures that reveal their action possibilities without the need for elaborated cognitive mediation. These configurations, described as relational invariants, are articulated through ecological perception, allowing the agent to identify opportunities for use solely based on the functional relation between their capacities and the characteristics of the object.

The scientific-technical understanding of Affordance thus requires recognizing that its manifestation is neither universal nor homogeneous. Perceptual variations, differences in expertise, cultural divergences, and inadequate codifications directly affect the clarity of interaction. Norman (1988) warns that when users are confronted with unfamiliar objects, they seek visual cues or external instructions to interpret their uses. When such cues are poorly designed, illusory affordances emerge, prone to error.

This vulnerability is also emphasized by Gaver (1991), who distinguishes between affordance itself and the information that renders it perceivable: there are cases in which the appropriate action is directly perceived, but also situations in which the object induces misguided attempts. He also introduces the notion of sequential affordance, wherein interaction reveals opportunities for action not initially perceptible. Action, therefore, becomes not only a consequence of perception but also its catalyst.

In the field of graphic and digital design, Norman (1999) reformulates the original notion by differentiating real affordances, tied to physical structures, from perceived affordances, which operate through user conventions and beliefs. In symbolic contexts, the challenge lies not in the physical existence of functionality, but in the ability to induce its correct reading. The failure to communicate this reading results in absent or false affordances, demanding greater design investment in cultural cues, visual feedback, and linguistic consistency.

The gradualist perspective proposed by McGrenere & Ho (2000) expands on this rationale by proposing that affordances should be treated as a continuum, varying in clarity and effectiveness. This continuum is affected by sensory codification, functional coherence, and the agent's degree of familiarity. At one end are consolidated affordances; at the other, latent, ambiguous, or unrecognized ones.

The theory of micro-affordances, introduced by Ellis & Tucker (2000), reinforces the role of automatic perception. Even without conscious intent, certain objects activate implicit motor dispositions. These activations are structured by neural patterns that integrate visual properties with associated action schemas, and they can either facilitate or distort interpretation.

Complementing this perceptual perspective, Hassenzahl (2003) introduces the concept of product character as a cognitive abstraction that synthesizes functional and emotional attributes, directly influencing the agent's initial interpretation. This construct unfolds in two stages: first, through the objective perception of pragmatic attributes related to operability; then, through a subjective elaboration of character, modulated by hedonic and contextual aspects. The clarity of these pragmatic attributes reinforces the alignment between structure and expected action, being decisive for the emergence of consolidated affordances, where the designed functionality coincides with the perceived and effectively executed function.

In an effort toward formalization, Hartson (2003) distinguishes four categories: cognitive, physical, sensory, and functional. Cognitive affordances operate by inference; physical ones by tangible structure; sensory affordances by perceptible evidence; and functional ones through direct relation between function and usability. This categorization reveals that an affordance is not limited to what can be done, but also to how that possibility is perceived and executed.

From an inferential standpoint, Brown & Blessing (2005) argue that affordances can be learned or analogically deduced from previous experiences. Turner (2005), in turn, suggests that although the concept is theoretically simple, its practical application requires distinctions between directly perceptible structures and more complex historical compositions shaped by conventions and patterns of use.

Zhang & Patel (2006) systematize this discussion by treating affordances as the result of interaction between external structures and internal representations, classifying them as biological, physical, cognitive, and mixed. This classification reinforces the idea that affordances are emergent properties, always conditioned by an ecosystem of relations.

In alignment with this view, Vyas, Chisalita, & van der Veer (2006) suggest that clear affordances provide unequivocal information, while unclear affordances lead to multiple interpretations. You & Chen (2007) advance the discussion by distinguishing between directly perceivable affordances and those dependent on symbols or conventions. The former are triggered by physical attributes; the latter rely on cognitive processes shaped by culture and conceptual repertoire.

For Maier & Fadel (2008), affordances are expressions of the complementarity between artifact and agent and cannot be assessed in binary terms. Their diagnosis requires gradated analysis, since an affordance is only actualized when the agent recognizes it as such within a given operational context.

This perceptual contingency is revisited by Still (2009), who reformulates the concept from a cognitive perspective, emphasizing the relationship between consistency, constraint, and predictability. He argues that effective affordances emerge from systems whose functional logic is transparent and coherent with the agent's mental model.

Kaptelinin & Nardi (2012) introduce the distinction between handling and effect affordances, emphasizing that integration between the two is essential for the technical operation of complex systems. Kannengiesser & Gero (2012) further develop this reasoning, proposing three levels of affordance, reflective, reactive, and reflexive, which correspond to different degrees of awareness and adaptation.

When addressing computational affordances, Burlamaqui & Dong (2015) argue that they are not absolute, but design-calibrated. An effective affordance requires that both the behavior and structure of the artifact be simultaneously recognizable; otherwise, misinterpretation may occur. A similar concern is raised by Abhari, Davidson, & Xiao (2016), who point out that collaborative affordances shape action within digital and sociotechnical environments, functioning as co-creation devices.

In the domain of mental actions, McClelland (2019) proposes that cognitive affordances also play a role in the selection of thoughts, intentions, or decision strategies. These affordances operate on abstract planes but follow the same logic: the interaction among stimulus, context, and possible action. Within these conceptual parameters, Scarlett & Zeilinger (2019) emphasize that multiple computational affordances may operate even without direct evidence, highlighting the need to reconceptualize the affordance concept in light of algorithmic enactment.

This rich and multifaceted theoretical foundation underpins the proposal presented in this Affordance Dimension. It not only systematizes these findings but translates them into a technically inferential structure. Table 3 presents the defined types of affordances, along with their respective descriptions, theoretical foundations, and impact levels for advanced technical-informational analysis.

TABLE 3: DEFINITION OF AFFORDANCE TYPES (AFF)

Adapted from Research	Code	Affordance Type	Definition	SPMI
Perceived (Gibson, 1979); Prior Knowledge (Norman, 1988); Real, Perceived (Norman, 1999); Clear (McGrenere & Ho, 2000); Pragmatic Attributes (Hassenzahl, 2003); Sensorial (Hartson, 2003); Cultural (Turner, 2005); Physical, Biological (Nutrition, Toxicity) (Zhang & Patel, 2006); Clear (Vyas, Chisalita, & van der Veer, 2006); Comprehended (You & Chen, 2007); Physical (Maier & Fadel, 2008); Perceived (Still, 2009); Clear (Burlamaqui & Dong, 2015)	AFF01	Consolidated	A consolidated affordance represents maximum alignment between designed intention and agent interpretation. It is explicitly codified in perceptual, logical, and functional terms, enabling action without error or ambiguity. The object manifests an affordance that is immediately recognizable and operable, validated by multiple agents from different contexts and with varying levels of expertise. It is widely stabilized through the collective history of use and perception.	**10**

Perceived (Norman, 1988); Perceived (Gaver, 1991); Perceived (Norman, 1999); Perception–Action Coupling (Ellis & Tucker, 2000); Sensorial (Hartson, 2003); Relation (Turner, 2005); Direct Perception (Zhang & Patel, 2006); Clear (Vyas, Chisalita, & van der Veer, 2006); Sensorial & Perceptible (You & Chen, 2007); Physical (Maier & Fadel, 2008); Perceptible (Still, 2009); Reflexive (Kannengiesser & Gero, 2012); Collaboration, Communication (Abhari, Davidson, & Xiao, 2016); Perceptible (Scarlett & Zeilinger, 2019); Perceived, Sensory Cues (McClelland, 2019)	AFF02	Perceptible	The object expresses physical and sensory properties that clearly suggest possible actions to the agent, even without extensive usage history. The perceptible affordance operates based on explicit visual and tactile evidence. Action is deduced from cues provided by the object itself, and the agent is able to correctly interpret them through direct sensory perception. Although contextual influence may still occur, the risk of error remains low.	**9**
Interpreted (Norman, 1988); Hedonic Attributes (Hassenzahl, 2003); Context (Turner, 2005); Cognitive (Hartson, 2003); Inferred (Brown & Blessing, 2005); Internal–External Interaction (Zhang & Patel, 2006); Clear (Vyas, Chisalita, & van der Veer, 2006); Cognitive (You & Chen, 2007); Comprehension (Maier & Fadel, 2008); Effective (Kaptelinin & Nardi, 2012); Reactive (Kannengiesser & Gero, 2012); Ideation, Collaboration (Abhari, Davidson, & Xiao, 2016); Interpreted (Scarlett & Zeilinger, 2019); Contextual Perception (McClelland, 2019)	AFF03	Interpreted	This affordance requires intermediate cognitive processing to be understood. It depends on the agent's interpretative context and conceptual repertoire. This category operates through inference: the action is not self-evident but is deducible. The agent must apply mental schemas, analogies, or prior knowledge. The risk of error is moderate and depends on the compatibility between the object's code and the agent's mental model.	**8**

Need for Instruction (Norman, 1988); Learned (Brown & Blessing, 2005); Mixed (Zhang & Patel, 2006); Unclear (Vyas, Chisalita, & van der Veer, 2006); Dependence on Symbols or Conventions (You & Chen, 2007); Instrumental, Learning-Driven (Kaptelinin & Nardi, 2012)	AFF04	Information-Dependent	The affordance cannot be understood unless the agent receives or constructs prior specific knowledge, through conventions, symbols, or training. The agent must undergo a learning process or seek instruction in order to interpret and operate the affordance. The action is not intuitive, and there is a potential risk of error due to a lack of prior information. The effectiveness of the affordance depends on the agent's technical or cultural domain.	**2**
False (Gaver, 1991); False (Hartson, 2003); Unclear (Vyas, Chisalita, & van der Veer, 2006); False Positive (You & Chen, 2007); Cultural and Social (Kaptelinin & Nardi, 2012)	AFF05	Positive Inductive	The object suggests more than one possible action, each interpretable differently by distinct agents, yet at least one of these interpretations may be functional. The affordance induces interpretive variations, often due to cultural differences, backgrounds, or usage contexts. There is a risk of error, but also the possibility of success. Operational success depends on correctly selecting among competing interpretations.	**-1**
False (Gaver, 1991); False (Hartson, 2003); Unclear (Vyas, Chisalita, & van der Veer, 2006)	AFF06	Dual Interpretation	The affordance is ambiguous and suggests multiple actions that may be mutually exclusive or hazardous. The object emits conflicting or generic signals, leading the agent to misinterpret or commit an operational error. Incorrect action may cause functional failure or risk. It requires design revision or contextual adaptation.	**-3**
False (Gaver, 1991); Unclear (Vyas, Chisalita, & van der Veer, 2006)	AFF07	Negative Inductive	The affordance leads the agent, even an experienced one, to incorrect interpretations. The object's structure is poorly calibrated with plausible mental models. This category functions as a cognitive trap: the cues provided by the object are misleading and structured in a way that induces incorrect action. It is difficult to learn, requires design reconceptualization, and carries a high risk of failure.	**-4**

Hidden (Gaver, 1991); Hidden (Hartson, 2003); Hidden (You & Chen, 2007); Unclear (Vyas, Chisalita, & van der Veer, 2006); Hidden, Invisible (Scarlett & Zeilinger, 2019)	AFF08	Non-Interpreted	The affordance is not perceived by the agent. There is no signal, no decoding, and no possible action. The object provides no cues sufficient to activate the agent's cognition. It remains invisible or unintelligible, regardless of the level of expertise. Extreme engagement is required for it to be explored, rendering it non-operational by default.	**-5**
Sequential (Gaver, 1991); Reflective (Kannengiesser & Gero, 2012); Reveal of Use, Continuous Experience, New Action Opportunities (McClelland, 2019); Emergent (This Research)	AFF09	Emergent	The emergent affordance is neither designed nor initially perceived, but manifests through exploration, repetition, or adaptation during use. It is identified when the agent recognizes an unplanned functionality or behavior that becomes operational. The emergent affordance reveals itself as a consequence of sustained interaction with the artifact, in which the agent becomes a co-author of its operable meaning. It may lead to useful discoveries or to unintended and inadequate uses. Its validation depends on evidence of observable functionality and is automatically attributed based on the Object Requirements Dimension. Classified as a systemic conditional (blue class), its scoring is generated from the combination of the Effectiveness, Error Severity, and Risk Degree dimensions, according to system parametrization (weighted or averaged). It requires cross-analysis between the artifact's actual behavior and the effects of interaction, and cannot be attributed solely through the agent's initial perceptual or cognitive intent.	

Functional (Hartson, 2003); Functional (This Research)	AFF10	Finalistic	The finalistic affordance represents the validation of achieved functionality: it manifests when the agent's action directly results in fulfilling a predefined functional purpose, even if such function is not explicitly perceived in the artifact. This category operates on the systemic functional plane, assessing whether the executed interaction effectively reaches the intended objective. Its existence depends on the compatibility between the action performed and the purpose achieved, regardless of the object's perceptual clarity. Scoring is automatically attributed through systemic inference based on the Effectiveness Dimension, combined with four specific elements from the Attributes Dimension: Utility, Efficiency, Functionality, and Stability. This multidimensional composition validates whether the action was effective, useful, stable, and efficiently executed, consolidating its status as a functional affordance of finalistic nature. It is classified as conditional (blue class), as it requires cross-validation between the functional outcome obtained and the intention declared by the agent.	

The AFF dimension structures, through a technical-scientific taxonomy, the different affordance vectors that may emerge from the interaction between agent and technological object. Each vector (AFF01 to AFF10) represents a distinct inferential configuration, ranging from the consolidated affordance, fully recognizable and operable, to non-interpreted or emergent forms. These types allow for classifying the degree of clarity, risk, ambiguity, and learning involved in the functional decoding of the object. AFF is a strategic dimension of the FCIA-OT, integrating perceptual, cognitive, and systemic analysis, with direct impact on the other dimensions of the framework.

Source: Author.

Each identified affordance vector constitutes a logical structure of operational inference, ranging from direct recognition to the emergence of unforeseen functions. This variability enables the reading of affordance as an indicator of compatibility or dysfunction, serving even as a vector for assessing failures or systemic errors. Three Laws were formulated in this research as the epistemic and computational foundations of the Affordance Dimension:

Law of Algorithmic Couplability ("Everything is Code"): Every system, whether physical or abstract, is configured as a mesh of codified states, whose coupling depends on interpretive protocols. The manifestation of an affordance occurs when there is operational isomorphism between the codes of the agent and those of the object, regardless of the medium (matter, energy, or information).

Law of Trajectory Dependence ("Nothing is Innate"): Every interpretive action results from historical processes, such as evolutionary algorithms, adaptive learning, or energy minimization. The perception of affordance reflects an accumulation of optimizations rather than spontaneous intuition.

Law of Necessary Reconfiguration ("Dynamic Reconvergence"): Changes in system parameters, whether environmental, physical, or computational, require constant recalibration of coupling protocols. The absence of such recalibration compromises the intelligibility of action and may lead to interpretive collapse.

The systematization of affordance types and the formulation of the three laws establish the inferential and computational basis for reading, simulating, and validating technological interactions. The AFF dimension thus transcends descriptive classifications and functions as a diagnostic and predictive tool, essential for assessing the stability, risk, and functional intelligibility of any technical object.

3.3 Perception Dimension (PRC)

The Perception Dimension (Dimensão Percepção – PRC) is structured as a formal core for assessing interpretative accuracy between sensory stimuli and the functional responses of agents, whether human, artificial, or hybrid. Within the scope of FCIA-OT, perception is understood as a high-level inferential operation, wherein environmental signals, whether physical, symbolic, or digital, are read, categorized, and projected onto preexisting interpretative repertoires. Its technical function is not limited to stimulus reception but involves the activation, modulation, and recalibration of cognitive and sensori-computational trajectories.

In this framework, perception is positioned as a computable vector for decoding, diagnostics, and functional anticipation. Shaw, Turvey, & Mace (1982) outline a seminal distinction between two perceptual modes: while propositional perception demands cognitive processing, judgment, and inferential analysis, non-propositional perception operates immediately, as a direct coupling between the organism and structural invariants in the environment. This distinction provides a theoretical foundation for differentiating perceptual vectors based on the level of interpretative effort required, supporting the modeling of PRC as a hierarchical system.

However, perception is not exhausted by the objective aspects of the object. Tractinsky (1997) demonstrates that the perceived aesthetics of an interface directly influence apparent usability, indicating that how something is perceived, even before functional use, can shape subjective acceptability and affect user attitudes. In line with this, Cutting (1998) expands this understanding by treating perception as an informational mediation process between the physical world and mental representation, showing that both objects and events are registered by sensory systems through codified and structurally differentiable signals. This introduces a critical connection with the FCIA-OT matrix: perception becomes a transcodification operation that transforms stimuli into operational maps, reconfiguring internal states.

Along this same line, Tucker & Ellis (1998) reinforce this functional link by demonstrating that merely visualizing objects can automatically activate associated motor representations, revealing a connection between perception and action that occurs even without deliberate intention. This principle strengthens the role of PRC as a sensori-pragmatic operator. Creem & Proffitt (2001) go further by showing that proper action requires not only visuomotor coordination but also the integration of semantic knowledge, demonstrating that technical perception is always also a functional reading of the object.

This dual character of perception, as a sensory filter and semantic projection, is explored by Hassenzahl (2003), who emphasizes that perceptions generate emotional and behavioral consequences, and that the functional valuation of an object depends on the context in which it is perceived. In alignment with the Law of Trajectory Dependence, he shows that the value attributed to a given artifact varies according to the agent's history, environment, and expectations, configuring a perception modulated by affective-cognitive trajectories.

Norman (2004) deepens this tripartite structure by proposing three levels of perceptual processing: the visceral, which is pre-reflective and immediate; the behavioral, oriented toward action and execution; and the reflective, linked to symbolic meaning. The PRC incorporates these levels as formal strata, each requiring distinct decoding and response patterns. Perception, therefore, is not a monolithic function but a distributed network of filters and translators operating in parallel.

This understanding is reinforced by Ciftcioglu, Bittermann, & Sariyildiz (2006), who propose a distinction between the act of seeing and the act of perceiving. While the former is a directed and objective process, the latter is probabilistic, interpretive, and subject to cognitive variability. This distinction technically supports the classification of PRC as a dimension with multiple levels of synchronicity and accuracy. Contrary to passive systems, perception is modeled here as an active inference structure, directly linked to the architecture of the agent.

The PRC core must address different forms of complexity. Janlert & Stolterman (2010) emphasize that perceptual complexity is not necessarily an obstacle; it may constitute benign complexity when shaped to enrich experience and facilitate progressive mastery. This conception underpins PRC as a technical operator of simulation and prediction: well-designed perception can enable learning and adaptation even in dense systems.

Perceptual reading is not limited to the isolated individual; it is sensitive to broader systemic architectures. Abhari, Davidson, & Xiao (2016) argue that technological affordances vary depending on business models, assigned tasks, and network configurations, reinforcing that the perception of action possibilities is not fixed but shaped by interpretative ecosystems and design strategies. This perspective, aligned with the Law of Necessary Reconfiguration, highlights that perception is subject to collective dynamics, making it a strategic element in collaborative co-innovation contexts.

At this point, PRC also functions as a metric of perceptual load, anchored in objective models. Zali (2016) defines cognitive load as the user's capacity to interact with systems with minimal mental effort, describing it as a psychomotor performance metric calibrated to usage strategies. Perception is not passive: it requires technical calibration between system structure, agent capabilities, and interactional strategies, an indispensable condition for adaptive functionality. McClelland (2019) complements this framework by addressing the perception of affordances under contextual and cognitive filters, showing that sensitivity to stimuli is dynamic and modulated by goals, mental states, and accumulated experience.

The contextual relevance of perception is further emphasized by Yang (2020), who highlights the importance of visual forms in perceptual decomposition, noting that elements such as inclination or deformation generate specific visual tensions that influence attentional focus. This evidence confirms that perception is always directed and modeled, and that any failure in its design directly compromises the functional activation of the system.

Thus, the PRC core is established as an operational basis for technical intelligibility and the reliability of action. Through the systematized reading of perceptual categories, FCIA-OT enables the detection of design flaws, simulation of interpretative effects, and projection of more responsive, safe, and operational systems. Table 4 presents the structured types of perception and their corresponding definitions, aligned with the vectors identified in the literature.

TABLE 4: DEFINITION OF PERCEPTION TYPES (PRC)

Adapted from Research	Code	Perception Type	Definition	SPMI
Direct Perception (Shaw, Turvey, & Mace, 1982); Perceived Clarity (Tractinsky, 1997); Automatic Potentiation (Tucker & Ellis, 1998); Direct Registration of Invariants (Cutting, 1998); Benign Complexity (Janlert & Stolterman, 2010); Low Cognitive Load (Zali, 2016); Visual Perception (Yang, 2020)	PRC01	Instructive	When facing objects, interfaces, symbols, equipment, and systems, there is synchrony, an immediate clarity, in the agent's perception of both the context and the object. Perception occurs directly and instantaneously, without the need for inference, analysis, or prior experience. The agent recognizes, understands, and responds to the object automatically, as the perceptual cues are explicitly organized, with low cognitive cost and high environmental predictability. This type of perception is linked to clear visual input, direct registration of invariants, and immediate semantic activation.	10
Sensory Cue Analysis (Cutting, 1998); Semantic Processing (Creem & Proffitt, 2001); Reflective (Norman, 2004); Analytical/ Interpretative Processing (Ciftcioglu, Bittermann, & Sariyildiz, 2006); Reflective Analysis (Janlert & Stolterman, 2010); Interpretation and Understanding (Abhari, Davidson, & Xiao, 2016); Adaptation (Zali, 2016); Reflective Analysis, Interpretation, and Required Reflection (McClelland, 2019)	PRC02	Argumentative (Analytical or Reflective)	When facing objects, interfaces, symbols, equipment, and systems, the synchrony between the agent's perception and the affordance of the object only occurs after analysis. Perception is not immediate, requiring the agent to activate analytical, interpretative, or reflective mechanisms to decode the perceptual situation. It is an intermediate process in which the agent must engage in a moderate cognitive effort—interpreting cues, constructing meaning, and validating understanding before perceiving the possible action. This type of perception involves dense semantic processing and demands a mental organization that precedes action.	5
Perceptual Adaptation Through Continuous Interaction (Cutting, 1998); Context (Hassenzahl, 2003); Continuous Experience, Interaction (Janlert & Stolterman, 2010); Direct Experience, Continuous Interaction (McClelland, 2019)	PRC03	Reactive	When facing objects, interfaces, symbols, equipment, and systems, the synchrony between the agent's perception and the affordance of the object occurs only when the agent's perception changes based on experience or continuous interaction. Perception depends on time and repeated exposure to the object or system. The agent does not immediately identify meaning or function but develops perception through successive interactions. It is a progressive form of perception, generated by continuous sensorimotor adaptation, which modifies perceptual interpretation as new information is incorporated.	3

Meaningful Learning (Janlert & Stolterman 2010)	PRC04	Inquisitive	When facing objects, interfaces, symbols, equipment, and systems, there is no synchrony between the agent's perception and the affordance of the object; either simple or complex learning is required. In this case, the agent must mobilize cognitive structures not only for interpretation but for acquiring knowledge. Perception is interrupted due to the absence of prior repertoire or clarity of cues. The agent becomes aware of the need to learn, to seek instructions or simulations in order to understand the object. This is common in situations involving innovative elements or unconventional symbolic structures.	2
Active Learning (Shaw, Turvey, & Mace, 1982); Analytical Process, Cognitive Effort (Ciftcioglu, Bittermann, & Sariyildiz, 2006); Considerable Effort, Discovery (Janlert & Stolterman, 2010)	PRC05	Exploratory	When facing objects, interfaces, symbols, equipment, and systems, there is no synchrony between the agent's perception and the affordance of the object; effort is required for discovery, following attempts and exploratory interaction with the system. Perception emerges only through practical attempts and experimentation. The agent lacks sufficient visual, semantic, or symbolic indicators and must explore the object physically or virtually, testing perceptual hypotheses to identify its function. This is the most demanding type in terms of cognitive and motor effort, frequently associated with flawed design, high ambiguity, or functional opacity.	-5

The PRC dimension is structured based on technical-functional criteria that define the actionable perceptual vectors in any interaction process between agents and technological objects. Each vector (PRC01 to PRC05) describes a specific form of sensori-informational decoding, ranging from direct and instructive perceptions to interrogative or exploratory forms. These types qualify the degree of clarity, inference, learning, or effort required for the functional reading of the object, allowing the identification of perceptual overloads, intelligibility failures, or demands for interpretative reconfiguration. PRC is a central dimension in the FCIA-OT matrix, operating as a vector for systemic analysis, perceptual simulation, and prediction of cognitive failures in natural, computational, or hybrid environments.

Source: Author.

This active reading of perceptual fields is grounded in three epistemic foundations of the FCIA-OT matrix. First, through the Law of Algorithmic Coupling, all perception is modeled as a process of decoding codified states, whose intelligibility depends on the isomorphism between the object's structures and the agent's protocols. Second, the Law of Trajectory Dependence establishes that no perception is innate: all perceptual capacity results from interactive histories, prior exposures, accumulated learning, and evolutionary processes of interpretative refinement. Third, the Law of Necessary Reconfiguration states that changes in system state, whether environmental or internal to the agent, require continuous recalibration of perceptual filters and protocols, under penalty of interpretative collapse, misreading, or misaligned actions.

Perception is thus no longer understood as a stage prior to action, but as a technical system of inferential input, operating in synergy with Affordance and qualifying the entire interactive chain. By formalizing its types, criteria, and constraints, the PRC core offers computable instruments for diagnosing perceptual opacities, adaptive simulation, interface engineering, and functional auditing of systems in operation, consolidating itself as a foundational dimension for the reliability, accessibility, and safety of usability and interaction.

3.4 Affective Dimension (AFV)

The Affective Dimension (Dimensão Afetividade – AFV) constitutes a strategic core in the evaluation of technological objects due to its modulatory role in the emotional, symbolic, and functional experience of agents when facing interactive phenomena or complex systems. Far from being restricted to immediate or superficial responses, affect operates as a dynamic valuation system, directly influencing the perception of trustworthiness, stability, subjective utility, familiarity, and rejection. In advanced analytical contexts, this dimension intersects cognitive, sensorimotor, social, and cultural domains, shaping a vector that structures affective bonding with the object, whether physical, digital, or hybrid.

The model proposed by Kleinginna & Kleinginna (1981) defines emotion as a multifactorial phenomenon, composed of affective, cognitive, physiological, and expressive-behavioral components that operate in an integrated manner. The emotional response articulates pleasure or displeasure, appraisal, expression, and neurophysiological correlates. This distinction from other affective states allows for precise identification of the emotional impact of technologies and their functional modulations.

From an experiential perspective, Csikszentmihalyi (1990) defines flow as a state of pleasurable immersion, where action and awareness merge under intense focus, control, and satisfaction. It emerges from the balance between challenge and competence, sustained by continuity, clear feedback, and minimal distraction. The occurrence of flow in interactive contexts reveals the role of affective engagement as a structuring condition for the functional appropriation of the object.

Molich & Nielsen (1990) emphasize the importance of structures that support natural dialogue, predictability, and the minimization of cognitive barriers. When there is coherence among language, structure, and feedback, the agent tends to build trust in the system, reducing mental load and preventing experiences of frustration. Conversely, design inconsistencies, ambiguities, and lack of clarity in responses compromise the affective bond and generate functional discontinuity, revealing the interdependence between communicative design and emotional stability in interaction.

In alignment with this, Fredrickson (2001) proposes that positive emotions temporarily broaden thought–action repertoires, creating upward spirals of well-being and fostering the development of enduring resources such as resilience, expanded coping, and subjective reorganization. These emotions promote flourishing and the emergence of positive meanings, even in the face of adversity. Positive affect operates as a vector of adaptation and subjective strengthening.

Russell (2003) highlights the complexity of affect by understanding it as a primary appraisal of stimuli, anchored in the axes of pleasure–displeasure and activation–deactivation. This framework constitutes a system of affective qualification essential to decision-making. Feelings such as pleasure, displeasure, or empathy derive from these initial evaluative responses, operating as judgments of subjective utility. Thus, empathy is defined as attributed affect, resulting from the mental simulation of experiences perceived in others.

In the same framework, Norman (2004) distinguishes between affect and emotion based on their functional dynamics: affect is a broad evaluative system operating at both conscious and unconscious levels, whereas emotion represents its conscious manifestation associated with causal identification. The relationship between affect and cognition shows that emotional judgments both shape and are shaped by cognitive and decision-making processes.

Decety & Jackson (2004) understand empathy as the affective perception of another agent's emotional state, without requiring a direct behavioral response or an attitude of solidarity. In this view, empathic experience demands only the sensitive recognition of the other's emotional state, whether real or inferred, sustained by perceptual simulation and a minimal emotional alignment between agents.

From Smith's (2006) perspective, empathy simultaneously articulates two distinct yet complementary competencies: the capacity to adopt another agent's mental perspective (cognitive empathy) and the ability to vicariously share their emotions (emotional empathy). These two dimensions structure the empathic phenomenon as a complex form of affective connection, fundamental in interpretative processes mediated by symbolic systems.

Khalid (2006) argues that affect is interwoven with rationality, functioning as an amplifier of objectivity in evaluative processes. When discussing the relationship between pleasure and functional appreciation, he maintains that positive emotions reinforce perceived value assessments, even in technical judgments. However, he acknowledges the methodological limitations of measuring such affects, as subjective reactions such as intellectual pleasure are not always accessible through physiological or expressive means.

Kouprie & Visser (2009) treat empathy in design as a process involving direct contact, projective imagination, and stimulation of symbolic co-experience. They observe that, although tools for fostering empathy are available, the absence of a consolidated language hinders generalization. The exploratory nature of these approaches demands interpretive sensitivity regarding the construction of affective bonds mediated by objects or systems.

Zhai et al. (2009) reinforce the functional role of affectivity by demonstrating that positive affects enhance perceptions of well-being and satisfaction in both everyday and professional contexts, while negative affects tend to diminish these indicators, compromising the subjective evaluation of experience. In this model, affectivity is positioned as a central variable in the valuation of technology, influencing acceptance, engagement, and continued use.

In line with the functionality of affectivity, Brave & Nass (2009) argue that more effective technologies are those capable of recognizing and expressing emotional states in a manner consistent with verbal and situational content. Interfaces that disregard the agent's affective state tend to trigger emotional dissonance. Proper articulation between function, form, and affective expression contributes to intuitive and psychologically sustainable interactions.

According to Tullis & Albert (2013), usability failures can trigger negative affective states such as frustration, anxiety, and rejection. These reactions may be tolerated when there is perceived value, showing that negative affect can be functional. In contrast, emotional neutrality often signals the absence of connection, which undermines engagement and the relevance of the object.

The FCIA-OT operationalizes the Affective Dimension based on technical criteria that consider the nature of the object, the affective profile of the interacting agent, and the expected response patterns. The analysis is grounded in principles from affective neuroscience, emotion psychology, and cognitive ergonomics, ensuring precision in identifying positive and negative patterns of affective bonding. Table 5 outlines the types of affectivity relevant for technical analysis, articulating manifestations ranging from emotional comfort, pleasure, and curiosity to states of rejection, frustration, and anxiety. These categories function as vectors that modulate acceptance, trust, and the value attributed to the object, enhancing the diagnostic sensitivity of the evaluation system.

TABLE 5: DEFINITION OF TYPES OF AFFECTIVITIES (AFV)

Adapted from Research	Code	Types of Affectivities	Definition	SPMI
Emotional Well-being (Kleinginna & Kleinginna, 1981); Cognitive Broadening, Psychological Resilience (Fredrickson, 2001); Positive Affectivity (Zhai et al., 2009); Pleasant Affects (Brave & Nass, 2009)	AFV01	Emotional Comfort	A sense of emotional stability and subjective safety in relation to the technological object. Refers to the extent to which a system, phenomenon, or technology provides the agent with a stable, welcoming, and predictable emotional experience, reducing internal tensions and generating a continuous state of affective tranquility throughout use, contact, or analysis.	**10**
Intense and Meaningful Satisfaction (Csikszentmihalyi, 1990); Flourishing, Discovery of Positive Meaning (Fredrickson, 2001); Pleasure (Russell, 2003); Pleasure (Khalid, 2006); Pleasant Affects (Brave & Nass, 2009)	AFV02	Pleasure/ Satisfaction	Subjective experience of contentment, pleasure, or gratification during interaction with the technological object. Expresses the perception of positive affective value resulting from the experience or use of the technological object, phenomenon, or system. It involves sensations of emotional gratification, attentional pleasure, and meaningful fulfillment that cognitively validate the choice and support the continuity of the experience.	**9**
Broadened Thought–Action Repertoire (Fredrickson, 2001)	AFV03	Curiosity	Affective impulse that motivates active exploration of functionalities, patterns, or logics of the technological object. Characterizes the affective state that induces spontaneous and sustained investigation in the face of perceived complexity, novelty, or interpretive openness of the object under analysis. It acts as a vector of discovery, contributing to cognitive broadening and exploratory engagement.	**8**
Action–Consciousness Fusion (Csikszentmihalyi, 1990); Enduring Resources, Upward Spiral of Well-being (Fredrickson, 2001)	AFV04	Emotional Engagement	Intensity of the affective connection between the agent and the elements of the technological object. Describes the degree to which the experience with the object triggers lasting emotional bonds and attentional affective investment. It results from the perception of the affective meaning of the phenomenon, activating prolonged interest and sustained emotional involvement.	**7**
Full Attentional Focus (Csikszentmihalyi, 1990)	AFV05	Immersion	Feeling of total attentional and affective involvement with the technological object. Indicates the agent's deep absorption in the experiential flow triggered by the system, technology, or construct. Immersion occurs when peripheral stimuli are suspended, generating a state of full affective presence and perceptual continuity.	**6**

Security (Kleinginna & Kleinginna, 1981)	AFV06	Trust	Perception of safety and predictability when interacting with or analyzing the technological object. Corresponds to the affective belief in the functional stability, integrity, and coherence of the observed system or phenomenon. It arises from the consistency in the object's responses, the fulfillment of tacit expectations, and the absence of abrupt interpretive ruptures.	**5**
Unexpected Elements (Kleinginna & Kleinginna, 1981)	AFV07	Surprise	Emotional reaction to unexpected elements that challenge but do not compromise the experience with the object. It manifests in response to unanticipated stimuli that disrupt expected behavior patterns of the technological object. It triggers a momentary reconfiguration of attention and may induce positive or neutral reinterpretations of the phenomenon.	**4**
Overcoming Difficulties (Kleinginna & Kleinginna, 1981); Undoing Effect (Fredrickson, 2001)	AFV08	Relief	Sudden reduction of emotional tension associated with the experience of the technological object. Refers to the restoration of affective balance after resolving discomforts, interpretative difficulties, or obstacles in the interaction with the object. It occurs when anticipated tensions subside or when the emotional expectation is favorably reconfigured.	**3**
Empathy (Russell, 2003); Empathy (Decety & Jackson, 2004); Empathy (Smith, 2006); Empathy (Kouprie & Visser, 2009)	AFV09	Empathy	Affective resonance evoked by the technological object in relation to others, oneself, or its content. Denotes the system's, phenomenon's, or interface's capacity to elicit intersubjective emotional connection or symbolic identification. It is activated by human representations, narratives, or sensitive dynamics that enhance the agent's emotional understanding.	**2**
Emotional Neutrality (Tullis & Albert, 2013)	AFV10	Neutrality	State of absence of significant affect or emotional activation toward the technological object. Defined by affective indifference triggered by stimuli that do not elicit relevant emotional involvement—neither positive nor negative. It may indicate dissonance with the agent's interest, failure of impact, or cognitive-emotional saturation.	**-1**

Negative Emotion–Driven Repertoire Restriction (Fredrickson, 2001); Apprehension or Concern (Tullis & Albert, 2013)	AFV11	Anxiety	Anticipatory tension generated by uncertainties or perceived instabilities in the technological object. It reflects the affective perception of threat, discomfort, or unpredictability that undermines the agent's emotional well-being. It results from interpretative gaps, stimulus overload, or communicative failures of the system, triggering a continuous state of alert.	**-3**
Extended Coping (Fredrickson, 2001); Displeasure (Russell, 2003); Tolerated Difficulties (Tullis & Albert, 2013)	AFV12	Tolerated Frustration	Feeling of partial discomfort that the agent accepts due to the perceived functional value. Represents a controlled form of negative affect that is rationally absorbed by the agent when the technological object presents failures, excessive demands, or interpretative challenges, but whose purpose or value outweighs the generated tension.	**-4**
Negative Emotions (Kleinginna & Kleinginna, 1981); Frustrations (Molich & Nielsen, 1990); Displeasure (Russell, 2003); Negative Affectivity (Zhai et al., 2009)	AFV13	Frustration	Negative affective state generated by persistent obstacles, incoherence, or critical failures of the object. Characterizes the rupture between expectations and the object's responses, resulting in emotional depletion, loss of interpretative control, and the agent's refusal to maintain the interaction. It is a critical marker of intense affective dissonance.	**-5**

The AFV dimension structures, based on psycho-emotional and functional principles, the vectors of affective response modulated during the interaction between agents and technological objects. Each vector (AFV01 to AFV13) represents a specific emotional state, positive, neutral, or negative, that emerges from the functional, symbolic, or interpretative experience with the object. These types qualify the degree of pleasure, engagement, discomfort, empathy, or frustration involved, allowing the identification of bonds, ruptures, tolerances, and subjective reorganizations. AFV is a transversal component of the FCIA-OT, operating as an axis for experiential analysis, emotional tracking, and the prediction of technological acceptance, appropriation, or rejection in any complex system.

Source: Author.

The integration of the AFV dimension into the FCIA-OT matrix is operationalized through technical-scientific criteria that consider the nature of the object, the affective profile of the interacting agent, and the expected or undesired patterns of emotional response. The analysis integrates principles from affective neuroscience, emotion psychology, situated cognition, and functional ergonomics, enabling the identification of positive, neutral, or negative emotional states with high interpretative precision. These vectors directly modulate reliability, perceived value, engagement, and resilience in the experience with the object, constituting a sensitive core for the functional, symbolic, and ethical assessment of technology.

3.5 Satisfaction Dimension (STSF)

The Satisfaction Dimension (Dimensão Satisfação – STSF), within the scope of the FCIA-OT, functions as a structuring vector of symbolic-functional adherence between agents and technological objects. More than a punctual reaction to the use experience, satisfaction is configured as a complex evaluative synthesis, derived from the congruence between subjective expectations, perceived performance, emotional response, and attributed value. This dimension is not restricted to the post-use stage, but articulates predictive factors, such as cognitive anticipations, prior experiences, and affective predispositions, with the hedonic, functional, and relational components of interaction. It stands as a critical variable for the analysis of acceptance, continued use, attributed reliability, and symbolic recommendation of the object.

Satisfaction results from the convergence of contextual, relational, technical-interactional, and perceptual-subjective factors, as framed by the interpretative structure proposed by Pearson & Bailey (1980), which defines the satisfaction experience as a multidimensional phenomenon grounded both in the system's qualities and in the agent's internal configurations.

From a cognitive and self-referential perspective, Diener et al. (1985) define satisfaction as a cognitive-subjective judgment arising from the comparison between experienced conditions and individual standards of adequacy. This evaluation does not follow universal objective criteria but emerges from the interplay between affective memory, personal goals, and internalized meanings. By detaching satisfaction from normative metrics, they reveal its interpretative and constructed nature.

In the context of inter-industrial satisfaction measurement, Fornell (1992) proposes the Customer Satisfaction Barometer (CSB), introducing an analytical model based on three interrelated dimensions: overall evaluation, expectation confirmation, and distance from the ideal. This framework isolates the influence of perceived quality on loyalty behavior, demonstrating that satisfaction functions as a mediator between perceived delivery and strategic value.

As a practical evaluation tool in usability studies, Brooke (1996) proposes the System Usability Scale (SUS) as a lightweight instrument applicable to various technologies, enabling rapid measurement of perceived experience. Its Likert-scale structure, oriented toward subjective judgment of functionality and ease of use, incorporates satisfaction as a variable associated with interactional efficiency, comprehensibility, and attributed system trust.

In alignment with the notion of satisfaction as a variable experience, Lindgaard & Dudek (2003) characterize it as a multidimensional phenomenon whose definition cannot be rigidly standardized. They argue that the satisfaction experience varies according to the agent's profile and the symbolic context of interaction, reinforcing the construct's complexity and the need for analytical approaches sensitive to experiential diversity.

In the context of projected loyalty, Reichheld (2003) broadens this scope by developing the Net Promoter Score (NPS), which links satisfaction to recommendation intention. Its categorization into promoters, passives, and detractors enables inferences about trust, attachment, and expectations of continuity, making satisfaction a variable of both functional and affective predictive value.

In line with the methodological challenges of subjective measurement, Griffiths, Johnson, & Hartley (2007) warn of the need for rigorous evaluative approaches, noting that the uncritical adoption of satisfaction as a success metric may obscure technical or symbolic flaws. If not controlled by multivariate criteria, the subjectivity of judgment tends to yield inconsistent or non-interpretable results.

Expanding this issue, Briggs, Reinig, & de Vreede (2008) further argue that initial dissatisfaction, even when not stemming from technical failures, negatively impacts continued use. They observe the effects of "confirmation" (when delivery exceeds expectations) and "dissonance" (when delivery does not meet expectations, even if technically adequate), indicating that satisfaction is mediated by subjective and emotional filters that extend beyond isolated performance.

Reinforcing the role of non-functional variables, Laugwitz, Held, & Schrepp (2008) emphasize the centrality of hedonic aspects and emotional responses in satisfaction evaluation. They argue that aesthetic, symbolic, and affective criteria operate jointly with functional factors, forming a hybrid and subjective judgment matrix regarding the technological object.

Expanding the relational architecture of satisfaction, Briggs & Sindhav (2015) propose that its judgment may emerge from multiple elements, hardware, software, services, policies, data, people, which interact systemically.

This systemic view requires an evaluative model capable of capturing the interweaving of these factors, as proposed by FCIA-OT. Within this architecture, satisfaction is understood as the result of perceived affordances, interactional fluency, projected symbolism, and alignment with both tacit and explicit expectations. Table 6 presents the levels of satisfaction technically structured, ranging from states of full adherence to extreme forms of functional rejection, and operationalized into a scale of affective and evaluative response. These types not only describe subjective judgments but also enable cross-analyses between technical, affective, and symbolic attributes of the object.

TABLE 6: DEFINITION OF TYPES OF SATISFACTION (STSF)

Adapted from Research	Code	Types of Satisfaction	Definition	SPMI
Pearson & Bailey (1980); Diener et al. (1985); Fornell (1992); Brooke (1996); Lindgaard & Dudek (2003); Reichheld (2003); Griffiths, Johnson, & Hartley (2007); Briggs, Reinig, & de Vreede (2008); Laugwitz, Held, & Schrepp (2008); Briggs & Sindhav (2015); Zarour (2020)	STF01	Extremely Satisfied	Maximum state of positive adherence, in which no dissonance exists between expectation and functional delivery. Corresponds to the highest degree of alignment between the object's attributes and the performance, usability, and symbolic value requirements. No perceived gaps or demands for optimization are present.	10
	STF02	Very Satisfied	High level of satisfaction with occasional recognition of minor, non-compromising inconsistencies. Indicates near-complete alignment between expectations and functional response, with only minor limitations that do not compromise the object's acceptability.	9
	STF03	Fairly Satisfied	Predominant satisfaction coexisting with the perception of aspects requiring revision. The object demonstrates satisfactory functional performance but exhibits perceptual or operational friction points that suggest adjustments for the consolidation of experiential excellence.	8
	STF04	Satisfied	State of functional acceptance with perceived value, even in the presence of discrete limitations. The experience is predominantly positive, although the object does not reach optimal levels across all evaluative parameters. Satisfaction is maintained but not consolidated.	7
	STF05	Moderately Satisfied	Partial satisfaction coexisting with evident limitations that reduce perceived value. The functional delivery meets minimum acceptability requirements, yet recurrent failures or technical shortcomings result in loss of affective and functional adherence.	6
	STF06	Neutral	Absence of decisive affective response; balance between positive and negative valences. No affective bond, either positive or negative, is formed. The experiential response is indifferent, marked by a balance between sufficient functional aspects and minor shortcomings that prevent a conclusive judgment.	0

Pearson & Bailey (1980); Diener et al. (1985); Fornell (1992); Brooke (1996); Lindgaard & Dudek (2003); Reichheld (2003); Griffiths, Johnson, & Hartley (2007); Briggs, Reinig, & de Vreede (2008); Laugwitz, Held, & Schrepp (2008); Briggs & Sindhav (2015); Zarour (2020)	STF07	Dissatisfied	Explicit dissatisfaction in response to perceived deficiencies in the object. Failures outweigh positive aspects, directly affecting the system's utility, clarity, or usability. Perceptible frustration and loss of functional trust emerge.	**-1**
	STF08	Fairly Dissatisfied	High level of rejection due to poor technical or symbolic adherence. The object presents serious performance gaps, incompatibility with expectations, or critical failures in essential dimensions, significantly impairing the experience.	**-3**
	STF09	Very Dissatisfied	Perception of generalized inefficiency and structural failure. There is a collapse in reliability, usability, or symbolic value structures. The object is assessed as dysfunctional or inadequate for its intended purpose.	**-4**
	STF10	Extremely Dissatisfied	Maximum state of functional, symbolic, and affective frustration. No satisfaction criterion is met. The experience is negative across all dimensions, resulting in a complete rupture of the bond, explicit rejection, and refusal of future use.	**-5**

The STSF dimension structures, based on subjective-functional parameters, the satisfaction vectors attributed to technological objects, interactive systems, or complex phenomena. Each vector (STF01 to STF10) represents a specific degree of adherence between expectations, perceived delivery, and symbolic value, ranging from states of full acceptance to extreme rejections. These types serve as interpretative indicators of trust, continued use, and affective valence, enabling the identification of approval, neutrality, or frustration patterns that directly impact the bond with the analyzed object.

Source: Author.

The integration of the STSF dimension into the FCIA-OT matrix enables the incorporation of subjective evaluation data into technical analyses, linking individual expectations to functional and affective attributes. By systematizing satisfaction levels as interpretative expressions of experience, STSF enhances the identification of symbolic incongruities, perceptual failures, and functional mismatches, supporting more accurate diagnoses and responsive interventions throughout the technology development or evaluation cycle.

3.6 Effectiveness Dimension (EFT)

The Effectiveness Dimension (Dimensão Efetividade – EFT), within the context of the FCIA-OT, is configured as a high-level systemic attribute that transcends mere task execution or isolated functional performance. It refers to the technical-operational capacity of a technological object or phenomenon to achieve, in an integral and accurate manner, the structural objectives that define it, while preserving its functional consistency even under adverse or prolonged usage conditions. This dimension requires critical observation of factors such as precision, completeness, robustness, and functional alignment, whose interdependence sustains the conformity between design intent and effective outcome.

Initial efforts to distinguish between efficiency and effectiveness are clearly found in Pearson & Bailey (1980), who observed that conventional evaluations are predominantly based on metrics such as throughput or intensive hardware use. While these indicators express raw performance, they do not ensure that the system is producing useful results. Effectiveness, in this sense, requires qualitatively distinct metrics aimed at verifying functional adherence between operation and intended purpose.

The relevance of this distinction becomes even more evident in the studies of Rouse (1981), who analyzed dynamic systems in which technical failures compromise not only performance but also operational integrity itself. This perspective reinforces that effectiveness is not limited to task completion, but is constituted as a guarantee of continuity, adaptability, and functional resilience, especially in high-complexity environments.

This understanding is further developed through a multifactorial perspective, as demonstrated by Bailey & Pearson (1983), who identified 39 critical variables for systemic quality evaluation. These factors range from structural reliability to clarity, security, informational timeliness, and normative adequacy, and do not operate in isolation. They form an interdependent network that sustains the effective operability of computational and hybrid systems. For FCIA-OT, these elements serve as structural axes of the EFT dimension, whose analysis requires the integrated reading of these variables as technical vectors of systemic effectiveness.

The critique of excessive complexity is strongly articulated by Goodwin (1987), who demonstrated that the accumulation of functionalities may compromise core performance, even when technically feasible. Under this condition, effectiveness depends on structural clarity and the rational organization of operations, reducing noise, redundancy, and cognitive interference.

This critical line is reinforced by Bevan (1995b), who argues that effectiveness does not reside in mere technical interaction capability, but in the coherence between system, task, and user, even under varied conditions. Although centered on cognitive engineering, this proposition contributes directly to the FCIA-OT's understanding of functional robustness and stability amid usage variations.

The discussion on functional degradation caused by the disordered accumulation of resources is expanded by Kaufman & Weed (1998) and McGrenere (2000). Both highlight phenomena such as "bloat" and "creeping featurism," which increase complexity without real performance gains. In FCIA-OT, these conditions are identified as vectors of effectiveness loss, as they affect system precision, fluency, and coherence.

Although stemming from a hedonic perspective, Hassenzahl (2003) offers a relevant reflection by emphasizing that effectiveness also manifests in durable states of adherence and appropriation. For FCIA-OT, although the subjective dimension is not central, it is acknowledged that operational rejection and usage fatigue compromise functional completeness, rendering sustained effectiveness unfeasible.

The model of Naumann et al. (2007) reinforces the importance of achieving exact, complete, and sustainable results with low cognitive demand. This conceptual synthesis aligns with the FCIA-OT's understanding that effectiveness should emerge from the interaction between structural stability, functional accuracy, and operational fluency, without ruptures or overload.

Kortum & Peres (2014) reiterate this position by emphasizing that the mere accomplishment of a task does not constitute full effectiveness. A system that forces the operator into continuous compensations or causes discomfort, even if technically functional, loses effective value. FCIA-OT incorporates this view by proposing that effectiveness be understood as technical-functional balance with minimal friction.

Zali (2016) concludes this trajectory by emphasizing that effectiveness is not exhausted in punctual success, but involves the sustainability of such performance with precision and reduced effort over time. This view precisely reflects FCIA-OT's distinctive criterion: functionally consistent systems that are technically efficient and ontologically aligned with their purposes.

The analysis of effectiveness requires the articulation of objective indicators, such as operational precision, functional success, and structural consistency, and technical-contextual parameters, such as adaptability, resilience, and performance persistence. Table 7 presents the types of effectiveness technically structured and their analytical definitions, in alignment with the FCIA-OT matrix.

TABLE 7: DEFINITION OF EFFECTIVENESS TYPES (EFT)

Adapted from Research	Code	Types of Effectiveness	Definition	SPMI
Effectiveness (Pearson & Bailey, 1980); Effectiveness (Bailey & Pearson, 1983); Effective (Goodwin, 1987); Completeness (Naumann et al., 2007); Usable (Kortum & Peres, 2014); Precise and Efficient (Zali, 2016)	EFT01	Effective	The technical-functional configuration demonstrates completeness, operational precision, and systemic stability, ensuring high performance, structural coherence, and full alignment with projected objectives.	10
Capacity, Clarity (Bailey & Pearson, 1983); Minimal Cognitive Effort (Naumann et al., 2007)	EFT02	Considerable	The functioning of the system or object displays satisfactory performance and intermediate functional alignment, but requires structural compensations or partial technical adjustments.	5
Complexity (Goodwin, 1987); Creeping Featurism, Functional Overload (McGrenere, 2000); Alterations (Feltovich et al., 2004)	EFT03	Moderate	The structure presents technical limitations, consistency deviations, and performance interference, partially compromising efficiency and requiring recurrent operational adaptations.	-3
Failures (Rouse, 1981); Excessive Complexity (Goodwin, 1987); Bloat (Kaufman & Weed, 1998); Bloat (McGrenere, 2000); Error, Changes (Feltovich et al., 2004)	EFT04	Insufficient	The operation reveals systematic failures, structural overload, and performance dysfunctions that render completeness unfeasible, reduce functional efficacy, and prevent compliance with technical-operational objectives.	-5

The EFT dimension systematizes, through technical-operational criteria, the degrees of effectiveness manifested in technological objects, functional systems, or complex configurations. Each vector (EFT01 to EFT04) represents a specific level of adherence between structure, operation, and purpose, ranging from fully effective configurations to those compromised by systemic failures or critical instabilities. The types express patterns of completeness, precision, robustness, and functional coherence, allowing the identification of the extent to which the analyzed phenomenon sustains its technical purpose without deviations, losses, or dysfunctional demands.

Source: Author.

The integration of the EFT dimension into the FCIA-OT matrix plays a critical role in distinguishing merely operational systems from technically consistent configurations. By evidencing the degree of convergence between design intent, functional behavior, and achieved outcome, this dimension enables the assessment of how well the analyzed structure is able to maintain its technical integrity under varying contextual demands. The classification of effectiveness types is not limited to the analysis of isolated performance but aims to identify sustainable patterns of accuracy, stability, and completeness, essential for maintaining systemic coherence. The articulation of these vectors with other evaluative dimensions strengthens an integrated understanding of the object's technical-functional performance, revealing its potential for reliable operation, structural adherence, and actual use value.

3.7 Object Requirements Dimension (RQO) and Artifact Requirements Dimension (RQA)

The Object Requirements Dimension (Dimensão Requisitos de Objetos – RQO), in conjunction with the Artifact Requirements Dimension (Dimensão Requisitos de Artefatos de Objetos – RQA), constitutes the structural foundation of the FCIA-OT technological assessment model. This epistemological architecture not only organizes the constituent elements of a technological object but also enables its technical and functional decomposition into parametrizable descriptive units. The RQO configures the analytical unit that defines the object as the central construct, while the RQA unfolds the attributes of its artifacts, parts, subsystems, processes, and technical properties. The convergence of these two structural layers provides a systemic, scalable, and multigranular approach for the analysis and evaluation of any object, phenomenon, or technological, physical, digital, hybrid, or biotechnological construct.

The conceptual solidity of the RQO rests on the premise that technological objects are not static entities but organized systems composed of design, functional, computational, and procedural interactions. This complexity demands formal modeling, as indicated by Finkelstein & Finkelstein (1983), who argue that system design can be structured through models organized according to formalizable procedural patterns. Such models function as regulatory schemas guiding object development, granting internal consistency and operational logic.

Molich & Nielsen (1990), addressing usability principles in interactive design, introduce essential criteria for failure prevention and informational clarity, which the RQA dimension absorbs as verifiable requirements in the functional and interactional attributes of artifacts. The presence of mechanisms that enhance efficiency for experienced agents, combined with error minimization and constructive guidance in case of failures, becomes a measurable parameter within the RQA operational descriptors.

From the perspective of Janlert & Stolterman (1997), the concept of an artifact's "character," defined as the integration of aesthetic, technical, and ethical attributes, broadens the understanding of the object's design dimension. The character is operationalized in the RQO taxonomy through categories such as hardware design, software design, interface, and aesthetic-functional elements, which capture both tangible and behavioral aspects of the technological system.

Norman (2004), structuring the user experience around function, performance, and usability, reinforces the analytical triad guiding object requirements: function as the purpose structure, performance as operational effectiveness, and usability as intelligibility of use. These parameters find direct representation in the RQA codes, enabling not only their description but also the assignment of analytical values to properties such as responsiveness, interface logic, and usage complexity.

The affective dimension of design, as described by Khalid (2006), is incorporated into the FCIA-OT framework by recognizing that beliefs, values, and judgments emerge from user-system interaction. The emotional response is technically modeled through descriptors such as aesthetics, texture, shape, and personalization, elements evaluable in the RQA and fundamental for mapping the user experience.

The historical separation between software engineering and usability, identified by Bygstad, Ghinea, & Brevik (2008), highlights the importance of models integrating both dimensions from the outset of the design cycle. FCIA-OT's proposal addresses this challenge by conceiving a unified structure wherein technical functionality and interaction experience are evaluated integrally, rather than residually, as in traditional methods.

Velmourougan et al. (2014) reinforce this point by demonstrating that usability failures cause critical damages. Within the FCIA-OT scope, such understanding transforms into a technical element through specific RQA requirements, such as error, instability, crashes, and failures, providing a robust basis for preventive and corrective diagnostics.

Pete & Balasubramaniam (2015) emphasize the importance of consistency in artifact evolution, highlighting that discrepancies between versions affect system trust and maintainability. The modeling proposed by FCIA-OT contemplates this aspect by including requirements aimed at compatibility, resilience, technical instructions, and maintenance, ensuring analytical traceability of artifacts over time.

Table 8 structures the Object Requirements (RQO) as first-order elements for description and categorization of the technological construct. This classification encompasses from design and prototype to integrated subsystems, computational resources, advanced materials, and emerging technologies such as artificial intelligence, biotechnology, and hybrid solutions. Each table entry represents a critical unit of analysis, allowing the conceptual and technical delimitation of the central object.

Table 9 organizes the Artifact Requirements (RQA) according to an extensive set of physical-functional, structural, perceptual, operational, and computational descriptors. These requirements enable detailed decomposition of each component of the evaluated object, with the application of parametric values supporting comparative, predictive, and diagnostic analyses.

TABLE 8: OBJECT REQUIREMENTS (RQO)

Code	Object Requirements	Description
RO01	Project	Initial conception or technical detailing of a technological object.
RO02	Prototype	Initial or experimental version of a technological object.
RO03	Object	Primary entity to be analyzed. Can be a device, system, or technological solution.
RO04	Parts and Components	Individual components that constitute the technological object.
RO05	Hardware	Physical technological elements.
RO06	Hardware: Equipment	General equipment, such as machines and devices.
RO07	Hardware: Server	Hardware intended for hosting systems and data.
RO08	Hardware: Computer (PC)	Personal computers used in various contexts.
RO09	Hardware: IoT Device	Sensors, actuators, and devices connected to the Internet.
RO10	Hardware: Mobile Devices	Smartphones, tablets, and other portable devices.
RO11	Hardware: Wearables	Technological devices worn on the body, such as smartwatches and smart glasses.
RO12	Advanced Materials	Materials with innovative or superior properties, used to enhance devices.
RO13	Hardware: Network	Equipment and devices for network infrastructure.
RO14	Equipment	Devices used for specific functions.
RO15	Equipment: Electro-electronics	Domestic or industrial devices powered by electricity.
RO16	System	Set of interconnected components working in synergy.
RO17	Software	Programs and applications performing specific functions.
RO18	Software: Operating System	Platform managing hardware and software.
RO19	Software: Application	Programs developed for specific tasks.
RO20	Integrated System	Combination of hardware, software, and networks for comprehensive solutions.
RO21	Software: Middleware	Intermediate software for system integration.
RO22	Digital Tool	Software or hardware used to facilitate tasks.

RO23	Biotechnology	Technological applications based on biological systems, living organisms, or derivatives.
RO24	Artificial Intelligence	Computational systems designed to simulate human capabilities such as learning and decision-making.
RO25	Hybrid Technologies	Combinations of different technologies to create innovative and multifunctional solutions.
RO26	Design	Planning and structuring of the technological object.
RO27	Design: Object	Aesthetic and functional aspects of the object as a whole.
RO28	Design: Hardware	Aesthetics and functionality of hardware.
RO29	Design: Software	Software interface and usability.
RO30	Design: Interface	Interaction between the agent and the system.
RO31	Design: Screen(s)/Forms	Visual structures presented to the agent.
RO32	Process	Set of actions producing results.
RO33	Procedure	Specific sequences for task execution.
RO34	Algorithm	Logic and sequence of computational steps.
RO35	API	Programming interface connecting systems and applications.

The RQO dimension organizes, based on structural and functional descriptors, the fundamental components that constitute a technological object as the central analytical unit. Each item (RO01 to RO35) corresponds to critical characterization elements such as design, hardware, software, and computational processes, enabling the mapping of the object's total configuration in technical-operational, design, and interactional terms. This taxonomy supports the delimitation of the primary construct, facilitating robust analyses of scope, composition, and systemic functionality.

Source: Author.

TABLE 9: ARTIFACT REQUIREMENTS OF OBJECTS (RQA)

Code	Object Artifact Requirements	Description	SPMI
RA01	Size	General measurements of the object or component.	**-5 a 10**
RA02	Dimension	Height, width, and depth of the artifact.	**-5 a 10**
RA03	Structure	Physical or functional organization of the artifact.	**-5 a 10**
RA04	Weight	Mass of the object, considering its transportability and usability.	**-5 a 10**
RA05	Height/Inner Space	Internal dimensions or usable internal height of the object.	**-5 a 10**
RA06	Mass	Amount of matter contained in the artifact.	**-5 a 10**
RA07	Surface	Texture and external finish of the object.	**-5 a 10**
RA08	Elasticity	Ability to return to the original shape after deformation.	**-5 a 10**
RA09	Stiffness	Resistance to deformation under stress.	**-5 a 10**

RA10	Durability	Capacity to retain functionality over time, resisting wear and continuous use.	**-5 a 10**
RA11	Shape	Geometric configuration or contours of the artifact.	**-5 a 10**
RA12	Quality	Overall assessment of the excellence and adequacy of the artifact's attributes.	**-5 a 10**
RA13	Strength	Ability to withstand physical or environmental stress without damage.	**-5 a 10**
RA14	Mobility	Capability of being moved or transported.	**-5 a 10**
RA15	Heating	Thermal behavior during operation.	**-5 a 10**
RA16	Consumption	Efficiency in the use of energy or resources.	**-5 a 10**
RA17	Texture	Tactile characteristics of the object's surface.	**-5 a 10**
RA18	Color(s)	Color palette employed in the design of the artifact.	**-5 a 10**
RA19	Luminosity	Intensity of light emitted or reflected by the artifact.	**-5 a 10**
RA20	Opacity	Degree of transparency or visibility of the object.	**-5 a 10**
RA21	Interface	Interaction point between the agent and the system.	**-5 a 10**
RA22	Pagination	Organization of content or visual elements.	**-5 a 10**
RA23	Movement	Ability to be repositioned or displaced.	**-5 a 10**
RA24	Position/Location	Spatial placement or orientation of the artifact.	**-5 a 10**
RA25	Visualization/ Visual	Quality and clarity of visual representations.	**-5 a 10**
RA26	Interface Controls	Devices or elements used to manipulate the system.	**-5 a 10**
RA27	Symbols/Icons/ Representation	Graphical elements used for visual communication.	**-5 a 10**
RA28	Configuration	Adjustable parameters and settings of the artifact.	**-5 a 10**
RA29	Installation	Ease of assembly or readiness for use.	**-5 a 10**
RA30	Uninstallation	Simplicity of removal or disassembly.	**-5 a 10**
RA31	Complexity	Degree of difficulty in using or understanding the artifact.	**-5 a 10**
RA32	Responsiveness	Ability to adapt to different usage conditions.	**-5 a 10**
RA33	Interface Logic	Organization and operation of the artifact's interface.	**-5 a 10**
RA34	Execution Logic	Functional execution flow of the artifact.	**-5 a 10**
RA35	Procedural Logic	Methods or steps followed by the artifact to perform tasks.	**-5 a 10**
RA36	Processing Output	Manner in which data are processed and transmitted.	**-5 a 10**
RA37	Processing Response	Response time and quality to user commands.	**-5 a 10**
RA38	Interaction	Capability of interacting with other systems or agents.	**-5 a 10**
RA39	Compatibility	Capacity to operate adequately with various systems, devices, or standards.	**-5 a 10**
RA40	Adaptability	Ability to adjust to different contexts or agents.	**-5 a 10**

RA41	Computational Intelligence	Integration of AI techniques to enhance functionalities.	**-5 a 10**
RA42	Biocompatibility	Compatibility of the artifact with biological systems.	**-5 a 10**
RA43	Hybridization	Combination of different technologies or concepts within the artifact.	**-5 a 10**
RA44	Customization	Ability of the artifact to adjust to user preferences or needs.	**-5 a 10**
RA45	Storage	Amount of data or information the artifact can store.	**-5 a 10**
RA46	Speed/Frequency	Operational performance related to execution time and processing cycles.	**-5 a 10**
RA47	Interconnection	Ability to connect and operate in an integrated manner among internal components, including both physical and digital communication.	**-5 a 10**
RA48	Error	Operational failures or unexpected behaviors that do not fully disrupt functionality.	**-5 a 10**
RA49	Instability/ Freezing	Conditions in which the artifact becomes temporarily nonfunctional or unresponsive, but recoverable without complete restart.	**-5 a 10**
RA50	Failure	Critical faults that render the artifact completely inoperative, requiring technical intervention, reboot, or replacement.	**-5 a 10**
RA51	Resilience	Ability to recover after a failure.	**-5 a 10**
RA52	Technical Instructions	Availability, clarity, completeness, and accessibility of manuals, user guides, technical documentation, and operational instructions.	**-5 a 10**
RA53	Maintainability	Ease, frequency, required time, and complexity of performing preventive, corrective, or evolutionary maintenance.	**-5 a 10**
RA54	Technical Support	Availability, quality, geographic coverage, response time, and customization of technical support services provided to the artifact, whether remote or in person.	**-5 a 10**

The RQA dimension unfolds, according to physical-functional, computational, and interactive parameters, the specific attributes of artifacts, parts, and properties constituting a technological object. Each requirement (RA01 to RA54) represents a granular unit of analysis, encompassing structural and perceptual aspects as well as computational logic, operational performance, and technical resilience. This systematic decomposition enables the quantification of critical attributes, supporting comparative, diagnostic, and predictive evaluations with high descriptive and analytical precision.

Source: Author.

The articulated structure between the requirements dimensions establishes a unique methodological platform capable of supporting transversal and multiscale evaluations, from microdevices to highly complex technological infrastructures. The core allows adaptive reconfiguration of analytical criteria, with the selection and combination of RQO and RQA requirements, technical, functional, structural, computational, perceptual, interactional, ergonomic, affective, social, environmental, regulatory, compliance, investigative, certification-related, and other specific axes, according to the system's logic, the application domain, and the objectives of analysis and evaluation. This flexibility ensures the systematic incorporation of disruptive technologies and the precise application across various scientific and industrial fields.

3.8 Error Severity Dimension (GVE)

The Error Severity Dimension (Dimensão Gravidade de Erros – GVE), within the scope of the FCIA-OT, establishes rigorous classificatory criteria for detecting, analyzing, and categorizing failures in technological objects, with an emphasis on functional, interactional, and cognitive impact. It is conceived as a systemic and non-reductionist core capable of affecting object performance, task continuity, and agent experience. Its modeling is not limited to the mere detection of operational failures, but incorporates factors such as tolerance, traceability, severity, persistence, recovery capability, and the risks associated with unmitigated failure. The dimension is structured in gradual levels of impact, enabling the mapping of states ranging from error-free conditions to critical failures, with support for decision-making in computational and hybrid environments under controlled risk.

A systemic understanding of failure severity can be traced back to the initial formulations of Hansen (1971), who interpreted errors as design deficiencies that could be mitigated through modularity and clear messaging. By shifting responsibility from the user to the system, he introduced an interaction engineering-centered approach. Bailey & Pearson (1983) expanded this perspective by emphasizing the diagnostic function of failures, associating their identification with the predictability of user rejection and the need for systematic measurements regarding the impact of technological updates.

Following this reasoning, the absence of well-structured feedback, as argued by Goodwin (1987), leads to redundant task cycles and directly compromises system efficiency. In this case, error transcends the technical domain, becoming a rupture in the agent's action flow. In the same direction, Nadin (1988) identifies semiotic failure as one of the main causes of persistent errors, highlighting the disconnection between icons, messages, and system functions in designs lacking symbolic integration. This approach broadens the concept of failure into the domain of interface languages and reinforces the idea of error as a communicational discontinuity.

Molich & Nielsen (1990) add to the model the requirement of continuous feedback during extended operations, linking the absence of clear signaling to the perception of systemic failure. Systems must be tolerant of input errors, offering immediate recovery mechanisms, and the severity of a failure is directly related to the clarity of the message and the possibility of resuming operation without frustration or intimidation.

From a different analytical perspective, Randell (1975) differentiates the structural nature of hardware and software failures. While physical defects are finite and traceable, software failures result from design inadequacies amplified by logical complexity, which makes exhaustive validation unfeasible and leads to recurrent and systemic errors.

Westland (2002) introduces the time variable into failure cost, demonstrating that the later a correction occurs, the greater its structural and financial impact. Severity, therefore, becomes a function not only of the type of error but also of the stage in the life cycle at which it occurs. Holzinger (2005) complements this approach by establishing a distinction between trivial and catastrophic errors, indicating that immediate rectifiability is a critical quality parameter in interactive systems. Severity analysis thus comes to include autonomous correction capacity and the extent of the failure's consequences.

In critical scenarios, Liljegren (2006) highlights the role of perceived severity in the selection of critical technologies, particularly in healthcare contexts, and systematizes criteria that allow estimation of the impact and persistence of failures. This methodology supports classification by severity levels, with the difficulty of committing errors being a primary usability marker. Pete & Balasubramaniam (2015) contribute the notion of failure traceability, showing that inconsistencies arising from the independent evolution of artifacts must be mapped and controlled based on precise technical criteria.

From the perspective of objective measurement, Zali (2016) establishes specific metrics for quantifying errors, evaluating both frequency and usage accuracy, and introduces an objective model for measuring severity. Heuwing, Mandl, & Womser-Hacker (2016) incorporate into the dimension the concept of reusing failure data across distinct design cycles, optimizing responses to recurring problems. Yusop, Grundy, & Vasa (2017) advocate for detailed descriptions in usability reports, including severity classifications and redesign proposals, as a way to ensure the technical intelligibility of failures for those responsible for resolving them.

Table 10 presents the coding system for the GVE dimension, composed of hierarchical severity levels anchored in technical-operational criteria extracted from the analyzed research. Each level expresses a specific degree of functional, perceptual, or structural impact on the evaluated object, serving as a technical basis for diagnostic, comparative, and predictive analyses.

TABLE 10: DEFINITION OF ERROR SEVERITY (GVE)

Adapted from Research	Code	Types of Error Severity	Definition	SPMI
Hansen (1971); Randell (1975); Bailey & Pearson (1983); Goodwin (1987); Nadin (1988); Molich & Nielsen (1990); Platt (1999); Westland (2002); Holzinger (2005); McRoberts (2005); Liljegren (2006); Alshamari & Mayhew (2008); Pete & Balasubramaniam (2015); Zali (2016); Heuwing, Mandl & Womser-Hacker (2016); Yusop, Grundy, & Vasa (2017); Albayram et al. (2018)	GVE01	No Errors	No errors identified. All functionalities operate as expected, without interruptions or failures. Error-Free State.	0
	GVE02	Negligible	The error has no perceptible impact on usability or functionality. No immediate correction is required.	1
	GVE03	Minor	The error has minimal impact on usability but does not prevent execution of core tasks. Attention required in future versions.	2
	GVE04	Moderate	The error affects usability and may cause agent frustration. Core functions can still be performed, though with limitations or difficulty.	3
	GVE05	Severe	The error significantly compromises usability, causing malfunctions in key features and degrading the agent's experience. Requires prioritized correction.	4
	GVE06	Critical	The error causes a system-wide failure, making the software unusable or resulting in data loss. Urgent correction is required.	5

The GVE dimension structures, through technical-operational criteria, the gradation of failure severity in technological objects, computational systems, and hybrid configurations. Each vector (GVE01 to GVE06) represents a specific level of functional, perceptual, or structural impact on the object, ranging from complete absence of errors to critical failures that render usage unfeasible. These types qualify the severity of failures based on their interference with task continuity, system recovery capacity, fault tolerance, and associated failures, providing parameters for diagnosis, corrective prioritization, and traceability in iterative design and evaluation cycles.

Source: Author.

The integration of the GVE dimension into the FCIA-OT matrix enables the technical qualification of failure as a critical and multiscalar variable, integrating operational, perceptual, and design aspects into reliability diagnostics. By structuring gradual severity levels based on fault tolerance, recovery capacity, and systemic impact, GVE supports precise analyses of the functional compromise of evaluated objects. This dimension enhances error traceability, guides corrective interventions, and expands the scope of reliability engineering within iterative cycles of technological development and evaluation.

3.9 Risk Degree Dimension (GSR)

The Risk Degree Dimension (Dimensão Graus de Risco – GSR), within the scope of FCIA-OT, functions as a structuring analytical vector for the assessment of reliability, safety, and functional sustainability of technological objects. Structured in increasing levels of criticality, GSR classifies risks based on objective criteria of severity, scope, and direct impact on the agent, the task, and the system. The proposed modeling transcends the traditional normative approach by incorporating contextual, cognitive, semiotic, and design variables into the analysis of vulnerability factors, supporting failure prediction, identification of critical omissions, and the outlining of preventive technical requirements.

Since Goodwin (1987), the relationship between design risks and neglect of usability has been observed, understood not merely as a functional flaw, but as a vector of progressive obsolescence. Poor usability, by imposing perceptual and operational barriers, increases cognitive load and weakens the system's persistence within its usage cycle. This fragility is amplified by inadequate ergonomic conditions, as noted by Bohnhoff, Brandt, & Henning (1992), who associate physical and mental risks with prolonged exposure, demanding evaluative models that incorporate protection of the worker's integrity as a core technical responsibility. Platt (1999) reinforces this approach by highlighting "usability risk" as a critical element for product trust and adoption, especially when the design fails to address users' real demands and expectations.

In the field of product engineering, Skelton & Thamhain (2005) propose a taxonomy of risks that includes both external and internal variables, warning that the absence of reliable data on usage contexts increases project complexity and weakens decision-making processes. McRoberts (2005) links the severity of risk to its probability, emphasizing the importance of anticipating misuse as an integral part of risk management. This perspective is expanded by Hirata et al. (2013), who show that everyday consumer products are often not evaluated according to rigorous technical criteria, leaving designers to make intuitive decisions, frequently resulting in avoidable accidents caused by design deficiencies.

In high-risk contexts, Albayram et al. (2018) argue that clear and emotionally balanced communication is essential for safe decision-making. Critical systems must be designed to reduce cognitive overload and reinforce trust bonds, particularly when interface failures or operational delays may escalate into harmful events.

The GSR dimension plays a transversal role in safe systems engineering, integrating technical, human, and operational variables into hierarchical classifications that are sensitive to context and functional criticality. Table 11 presents the defined risk degree types, systematized into technical-operational levels based on empirical evidence from the analyzed research. Each type corresponds to a specific level of risk, ranging from the absence of threats to critical vulnerabilities, allowing the mapping of impact severity on the object, its interfaces, and its usage agent.

TABLE 11: DEFINITION OF RISK DEGREES (GSR)

Adapted from Research	Code	Types of Risk Degrees	Definition	SPMI
Hansen (1971); Bailey & Pearson (1983); Goodwin (1987); Bohnhoff, Brandt, & Henning (1992); Platt (1999); Holzinger (2005); Skelton & Thamhain (2005); McRoberts (2005); Liljegren (2006); Alshamari & Mayhew (2008); Hirata et al. (2013); Yusop, Grundy, & Vasa (2017); Albayram et al. (2018)	GSR01	No Risk	The risk is nonexistent. No impact or inconvenience is expected in usage, operation, or interface. Risk-Free State.	**0**
	GSR02	Very Low	The risk is virtually nonexistent, with no significant impact expected. May include minor inconveniences in use or interface without serious consequences.	**1**
	GSR03	Low	The risk is low, with potential for minor issues such as mild physical discomfort, temporary loss of usability, or occasional hardware/software failures.	**2**
	GSR04	Moderate	The risk may affect both usage and user safety, including ergonomic errors, moderate data loss risks, or recurring failures that impair functionality.	**3**
	GSR05	High	The risk is significant, involving serious issues such as potential injury, critical hardware/software failures, or data security breaches.	**4**
	GSR06	Very High	The risk is extreme and may result in severe accidents such as fire, explosion, disability due to prolonged use, or complete system failure with irrecoverable data loss.	**5**

The GSR dimension formalizes, based on technical and situational criteria, the identifiable degrees of risk in technological objects, operating systems, or critical interactive configurations. Each vector (GSR01 to GSR06) represents a graduated level of potential threat, ranging from risk-free contexts to scenarios involving severe compromise of physical, cognitive, or informational integrity. These degrees express the scale of functional vulnerability, agent exposure, and design impact, allowing inference of the robustness, reliability, and safety level required for operation in controlled or adverse environments. This mapping becomes essential for decisions guided by mitigation, prevention, or redesign criteria.

Source: Author.

The integration of the GSR dimension into the FCIA-OT matrix enables the qualification of risk as a strategic variable in design, operational, and evaluative decisions. By structuring failure exposure into hierarchical levels sensitive to function, interface, and agent, this dimension makes it possible to anticipate vulnerabilities and define critical safety requirements. Its articulation with other dimensions of the model reinforces the diagnostic capacity of FCIA-OT in controlled-risk contexts, enhancing precision in managing reliability, usability, and functional robustness of the technological objects under analysis.

3.10 Attribute Dimension (ATB)

The Attribute Dimension (Dimensão Atributos – ATB), within the FCIA-OT framework, constitutes the technical core for encoding the quality of interaction between agent and technological object, allowing for the analytical decomposition of properties that define its functional, symbolic, and experiential adequacy. The identification and quantification of these attributes enable performance diagnostics based on operational, perceptual, and contextual criteria, aligning technical analysis with real-world use.

From this integrated perspective, Tractinsky (1997) argues that a system's acceptability depends not only on its functional usability, but also on the integration of aesthetic aspects. The aesthetic experience, historically neglected in the HCI field, represents a critical factor in system acceptance, requiring investigations that articulate these dimensions within interactive modeling. This conceptual movement is further developed by Frøkjær, Hertzum, & Hornbæk (2000), who highlight the inadequacy of assessments that disregard dimensions such as effectiveness, efficiency, and satisfaction in complex tasks. The fragmentation of metrics undermines the validity of results and the capacity for systemic diagnosis.

Continuing this development, Holzinger (2005) consolidates five core attributes for evaluating interactive software, learnability, efficiency, memorability, error tolerance, and satisfaction, structuring a coherent model between technical performance and the agent's experience. Complementarily, Laugwitz, Held, & Schrepp (2008) include attractiveness, clarity, efficiency, dependability, stimulation, and novelty as measurable expressions of user perception in broader contexts.

Despite this conceptual expansion, Ilmberger, Schrepp, & Held (2008) point out the limitations of treating aesthetics as an independent attribute, suggesting that its influence occurs indirectly and is mediated by semantic dimensions of the interface.

Reinforcing the role of context, Hartmann, Sutcliffe, & Angeli (2008) emphasize that the weight assigned to quality attributes depends directly on the nature of the task and the domain of use: in critical contexts, usability and functionality prevail; in playful environments, aesthetics and engagement gain centrality.

In a more comprehensive formulation, Zali (2016) proposes an expanded taxonomy of attributes, including effectiveness, efficiency, satisfaction, learnability, memorability, operability, attractiveness, cognitive load, safety, accessibility, compatibility, usefulness, and flexibility, linked to specific metrics that enable integrated interaction modeling. Aligned with this perspective, Weichbroth (2018) stresses the relevance of contextual encoding in interface construction, demonstrating that responsiveness and symbolic expectation constitute attributes that support the functional intelligibility of the object.

In the most contemporary formulation of the attributive model, Zarour (2020) concludes that system success depends on the articulation between technical requirements and experienced attributes, making the measurement and qualification of attributes a strategic activity in environments of innovation and competitiveness. Within FCIA-OT, this dimension also incorporates adaptive attributes such as flexibility, portability, and interoperability, enabling reconfigurations according to the type of object, the agents involved, and the operational ecosystem in which it is embedded.

The applied approach in the ATB dimension ensures not only the traceability of interaction quality criteria, but also their formalization as analytical types, subject to comparative measurement across different evaluation, diagnostic, or technological development cycles. Table 12 presents the defined types of attributes, organized into technical-operational levels and empirically derived from the analyzed studies, aligned with the FCIA-OT matrix.

TABLE 12: DEFINITION OF ATTRIBUTE TYPES (ATB)

Adapted from Research	Code	Attribute Types	Definition	SPMI
Tractinsky (1997); Frøkjær, Hertzum, & Hornbæk (2000); Han et al. (2001); Holzinger (2005); Laugwitz, Held, & Schrepp (2008); Ilmberger, Schrepp, & Held (2008); Hartmann, Sutcliffe, & Angeli (2008); Zali (2016); Weichbroth (2018); Zarour (2020)	ATB01	Usability	The ease with which the agent understands and uses the object, without excessive effort, to achieve their goals efficiently and effectively.	**-5 a 10**
	ATB02	Usefulness	Assesses whether the object provides the necessary functions and features to meet the agent's practical needs and expectations within their usage context.	**-5 a 10**
	ATB03	Efficiency	Evaluates the speed and resources consumed during the use of the object to complete a task, optimizing the agent's performance and time.	**-5 a 10**
	ATB04	Functionality	Verifies the object's ability to correctly perform all expected operations and actions, according to its specifications and intended purposes.	**-5 a 10**
	ATB05	Accessibility	Determines how well the object can be used by agents with different abilities and conditions, without compromising the quality of the experience.	**-5 a 10**

Tractinsky (1997); Frøkjær, Hertzum, & Hornbæk (2000); Han et al. (2001); Holzinger (2005); Laugwitz, Held, & Schrepp (2008); Ilmberger, Schrepp, & Held (2008); Hartmann, Sutcliffe, & Angeli (2008); Zali (2016); Weichbroth (2018); Zarour (2020)	ATB06	Flexibility	Refers to the object's capacity to adapt to different usage scenarios or customizations, offering alternatives to meet diverse needs.	**-5 a 10**
	ATB07	Controllability	Measures the agent's ability to adjust and manipulate the object according to their preferences, achieving the desired outcome with precision.	**-5 a 10**
	ATB08	Interoperability	Assesses the object's ability to operate correctly and in an integrated manner with other systems or devices, expanding its usefulness across contexts.	**-5 a 10**
	ATB09	Portability	Measures how easily the object can be transported or used across various environments and platforms without compromising its functionality.	**-5 a 10**
	ATB10	Compliance	The degree to which the technological object adheres to relevant regulations, technical standards, and industry norms, ensuring appropriate and safe use.	**-5 a 10**
	ATB11	Stability	Verifies the object's consistency and reliability over time, ensuring continuous operation without frequent failures.	**-5 a 10**
	ATB12	Aesthetics	Assesses the object's visual appeal, including its appearance, layout, and design, which influence the agent's acceptance and satisfaction.	**-5 a 10**
	ATB13	Acceptability	Refers to the agent's willingness to adopt the object, considering its functionality, ergonomics, and usage context.	**-5 a 10**
	ATB14	Innovation	Measures the extent to which the object incorporates new solutions or technologies to enhance the user experience or solve problems creatively.	**-5 a 10**
	ATB15	Simplicity	The clarity and straightforwardness in the object's presentation and operation, ensuring that the agent can interact with it without unnecessary complexity.	**-5 a 10**

The ATB dimension formalizes, based on technical-interactional criteria, the attributes that qualify the performance and acceptability of technological objects. Each vector (ATB01 to ATB15) represents a measurable property linked to the system's functionality, perception, or adaptability in response to the agent's demands and contextual conditions. The attributes range from pragmatic aspects, such as usability and efficiency, to hedonic and normative dimensions, such as aesthetics, acceptability, and compliance. The typological modeling enables precise inferences about design coherence, systemic responsiveness, and the degree of alignment between the object and its operational purpose, becoming decisive in processes of evaluation, development, or reconfiguration.

Source: Author.

The integration of the ATB dimension into the FCIA-OT matrix enables the systematization of critical properties in agent–object interaction, articulating both objective and subjective attributes under measurable and comparable criteria. By operationalizing variables such as usability, accessibility, flexibility, and aesthetics at technical-analytical levels, ATB enhances diagnostic capacity regarding the performance, adaptability, and acceptability of technological objects. This structure supports precise and sustainable design decisions, sustaining cross-sectional analyses in real-world application contexts and contributing to the continuous enhancement of systemic quality.

3.11 Accessibility Dimension (ACB)

The Accessibility Dimension (Dimensão Acessibilidade – ACB), within the technical-structural scope of the FCIA-OT framework, constitutes a multiscalar analytical axis aimed at identifying and qualifying barriers that hinder the full operationalization of technological objects by agents with diverse functional profiles. Its formalization goes beyond the application of isolated assistive technologies, encompassing an integrative architecture conceived from the early stages of the technological cycle. This architecture incorporates interoperability across platforms, interactive plasticity, and adaptive support for the agents' sensory, motor, cognitive, and situational conditions.

Cooper (1999), in describing what he terms the "software apartheid" phenomenon, highlights how poorly designed digital products generate operational exclusion, particularly affecting groups with limited familiarity with digital practices. Such segregation undermines agents' autonomy and restricts their participation in social and productive processes mediated by technology. Based on this premise of structural exclusion, Han et al. (2001) propose articulating accessibility, adaptability, controllability, and effectiveness as technical vectors that define the scope of use and functional accuracy in system interaction.

Within this same field, Abascal (2002) introduces the notion of Universal Design as a design methodology that anticipates accessibility requirements from the outset, avoiding reliance solely on compensatory resources. He warns of the ethical and legal risks emerging from neglecting privacy and the social exclusion of agents with disabilities. Wegge & Zimmermann (2007) broaden this understanding by emphasizing the importance of interoperability with assistive technologies, which ensures continuity of use through compatibility with devices already familiar to the user.

In analyzing cognitive relations within human–machine symbiosis, Griffith & Greitzer (2007) propose the concept of "neo-symbiosis," wherein the system must adapt to human cognitive limits. This approach demands the redesign of interfaces to include monitoring mechanisms and dynamic adjustments capable of mitigating information overload and reducing operational stress. Extending this analysis, Hochheiser & Lazar (2007) shift the focus of accessibility toward a critical dimension of design, revealing how subtle design decisions can redefine the role of the analyst or designer, imposing responsibilities that transcend the technical domain and involve social, political, and personal dimensions.

In the context of web interaction, Fogli, Parasiliti Provenza, & Bernareggi (2013) observe that widely adopted accessibility standards often focus on static criteria such as layout, color schemes, and link structures. However, these standards prove insufficient in the face of the dynamic complexity of contemporary applications, which rely on client-side scripts and real-time interaction. Based on this critique, they advocate expanding evaluation criteria to encompass richer dynamics that adapt to agent behavior.

According to Coughlan & Miele (2017), emerging technologies such as augmented reality (AR) can function as sensory mediators by offering visual annotations, tactile guidance, or auditory cues that enhance the accessibility of physical objects and environments. In parallel, Begnum (2020) analyzes the evolution of interactive design through the emergence of graphical interfaces and assistive devices, highlighting solutions such as screen readers and adaptive switches that expand the functional scope for agents with motor or visual impairments.

Considering this complexity of criteria, Lin Cheoh et al. (2020) advance this axis by demonstrating that, although compliance with technical accessibility standards is essential, interactive effectiveness depends on the integration of subjective preferences. Accurate evaluation of interfaces thus requires the systematic incorporation of feedback from users with disabilities to ensure alignment between normative guidelines and real usage demands.

The formalization of the ACB within the FCIA-OT is structured around technical-operational criteria organized into analytical groups that integrate elements such as informational redundancy, keyboard navigability, visual contrast, cognitive accessibility, multimodal responsiveness, and compatibility with assistive technologies. This dimension enables graduated measurement of accessibility in tangible, digital, hybrid, or cyber-physical objects, ensuring compliance with principles of full inclusion and technological equity. Table 13 presents the types of accessibility criteria and their technical definitions, aligned with the FCIA-OT matrix.

TABLE 13: DEFINITION OF ACCESSIBILITY CRITERIA TYPES (ACB)

Adapted from Research	Groups	Code	Accessibility Criteria Types	Definition	SPMI
Cooper (1999); Han et al. (2001); Abascal (2002); Wegge & Zimmermann (2007); Griffith & Greitzer (2007); Hochheiser & Lazar (2007); Fogli, Parasiliti Provenza, & Bernareggi (2013); Coughlan & Miele (2017); Begnum (2020); Lin Cheoh et al. (2020); Cecilio (2022)	**AC1: Texts, Images, and Media**	ACB01	Text Alternatives (Alt Text)	Provides alternative descriptions for non-text elements, ensuring accessibility for screen readers.	**-5 a 10**
		ACB02	Information Redundancy	Essential information is presented redundantly (text, audio, visual), addressing diverse user needs.	**-5 a 10**
		ACB03	Interaction with Multimedia	Offers accessible controls (e.g., captions, transcripts, volume control) for videos, audio, and multimedia content.	**-5 a 10**
		ACB04	Multilingual Content Support	Supports multiple languages, providing accessible translation for essential terms.	**-5 a 10**
	AC2: Navigation and Interaction	ACB05	Keyboard Navigation	Enables complete navigation via keyboard, including visible focus and logical traversal between elements.	**-5 a 10**
		ACB06	Navigation Consistency	Maintains a predictable and organized structure to reduce cognitive load.	**-5 a 10**
		ACB07	Category and Filter-Based Navigation	Provides efficient navigation through menus and filters accessible via keyboard and screen readers.	**-5 a 10**
		ACB08	Time and Interaction Control	Allows adjustment of interaction timing or pausing of activities based on the agent's needs.	**-5 a 10**

Cooper (1999); Han et al. (2001); Abascal (2002); Wegge & Zimmermann (2007); Griffith & Greitzer (2007); Hochheiser & Lazar (2007); Fogli, Parasiliti Provenza, & Bernareggi (2013); Coughlan & Miele (2017); Begnum (2020); Lin Cheoh et al. (2020); Cecilio (2022)	**AC3: Visual Design and Settings**	ACB09	Color Contrast	Ensures sufficient contrast between text and background to facilitate reading for users with visual impairments.	**-5 a 10**
		ACB10	Font Size and Adjustability	Allows text resizing without loss of content or functionality.	**-5 a 10**
		ACB11	Visibility and Legibility	Uses clear fonts, appropriate spacing, and adequate contrast to ensure universal legibility.	**-5 a 10**
		ACB12	Accessibility Adjustments	Enables configuration options such as text enlargement, contrast adjustment, and caption activation.	**-5 a 10**
		ACB13	Adaptation to Usage Contexts	Supports adjustments for different usage environments (e.g., noisy or poorly lit settings).	**-5 a 10**
	AC4: Forms and Feedback	ACB14	Accessible Forms	Ensures clear labels, instructions, and accessible validation in forms.	**-5 a 10**
		ACB15	Error and Success Feedback	Provides clear and accessible feedback for errors and confirmations.	**-5 a 10**
		ACB16	Clear Input Errors	Communicates input errors accessibly, with suggestions for correction.	**-5 a 10**
	AC5: Multimodality and Emerging Technologies	ACB17	Multimodality	Offers multiple modes of input and output (text, audio, video, gestures).	**-5 a 10**
		ACB18	AR/VR Accessibility	Ensures accessibility in augmented and virtual reality environments (e.g., adapted interfaces).	**-5 a 10**
		ACB19	IoT Accessibility	Ensures IoT devices are accessible via voice control and adapted applications.	**-5 a 10**
		ACB20	Mobile Application Accessibility	Provides optimized interfaces for mobile devices, including gesture and voice control.	**-5 a 10**

Cooper (1999); Han et al. (2001); Abascal (2002); Wegge & Zimmermann (2007); Griffith & Greitzer (2007); Hochheiser & Lazar (2007); Fogli, Parasiliti Provenza, & Bernareggi (2013); Coughlan & Miele (2017); Begnum (2020); Lin Cheoh et al. (2020); Cecilio (2022)	**AC6: Assistive Technologies and Privacy**	ACB21	Screen Reading Compatibility	Compatible with screen reading software, ensuring correct content interpretation.	**-5 a 10**
		ACB22	Compatibility with Assistive Technologies	Compatible with screen readers, magnifiers, voice control, and other assistive devices.	**-5 a 10**
		ACB23	Voice Interface Accessibility	Supports clear interaction via voice commands, with auditory feedback.	**-5 a 10**
		ACB24	Accessible Privacy and Security	Provides accessible privacy and security settings with clear explanations.	**-5 a 10**
		ACB25	Cognitive Accessibility	Facilitates use by agents with cognitive impairments, through clear navigation and simple instructions.	**-5 a 10**
	AC7: Experience and Temporary Adjustments	ACB26	Reaction Time and Interactivity	Allows adjustment of response times for agents with motor or cognitive impairments.	**-5 a 10**
		ACB27	Smooth Responses and Transitions	Utilizes smooth animations and transitions for users with cognitive or sensory disabilities.	**-5 a 10**
		ACB28	Accessibility in Temporary Situations	Provides accessibility for agents with temporary limitations (e.g., injuries).	**-5 a 10**
		ACB29	Multimodal Feedback	Offers visual, tactile, and auditory feedback for all interactions.	**-5 a 10**
		ACB30	Stress and Well-being	Designs aimed at reducing stress and promoting well-being, avoiding physical and mental overload.	**-5 a 10**

The ACB dimension formalizes, through technical-operational criteria, the elements that determine the degree of accessibility of technological objects in real usage contexts. Each vector (ACB01 to ACB30) represents a measurable vector of functional compatibility between the agent and the system, considering sensory, motor, cognitive, or situational limitations. The modeling of these types enables rigorous diagnostics of design adequacy, adaptive capacity, and the inclusive sustainability of the evaluated objects, consolidating the ACB dimension as a structuring core of inclusion engineering within the scope of the FCIA-OT framework.

Source: Author.

The integration of the ACB dimension into the FCIA-OT matrix establishes an evaluative architecture capable of formalizing, at technical and functional levels, the relationship between technological objects and the various accessibility profiles required by agents with sensory, motor, cognitive, or situational limitations. By systematizing multistructural criteria such as informational redundancy, interactive plasticity, and assistive compatibility, ACB expands the traditional scope of accessibility, linking it to principles of technological justice and design efficiency. This core ensures the integrated measurement of operational barriers and enablers, contributing to the elimination of inequalities in technology access and use, and enabling responsive adjustments in development, validation, and continuous improvement processes.

3.12 QRSUER Technology Dimension (Quality, Social Responsibility, Sustainability, Usefulness, Ethics, and Reason)

The QRSUER Technology Dimension (Dimensão Tecnologia QRSUER) constitutes a core and cross-cutting axis of the FCIA-OT, designed to establish rigorous technical-scientific criteria capable of measuring, qualifying, and classifying the systemic performance of technological objects through the lens of their commitments to structural quality, social responsibility, resource sustainability, pragmatic usefulness, ethical principles, and rational foundations. It is a technological approach of high analytical complexity, whose scope is not limited to functional performance, but incorporates, in both normative and evaluative terms, socio-environmental, energy, cognitive, and moral variables. The pillars of QRSUER are:

Quality: Products and systems that meet or exceed expected technical and functional standards, demonstrating excellence in design and performance.

Social Responsibility: Adoption of fair and equitable practices that positively impact communities and workers involved.

Sustainability: Reduction of emissions, rational use of resources, and waste minimization, with a focus on environmental preservation and the well-being of future generations.

Usefulness: Development aimed at solving practical problems and improving quality of life.

Ethics and Reason: A solid foundation in moral principles, ensuring that technology is used for positive, legal, and non-harmful purposes for human health or the environment.

This dimension operates through a set of technical criteria that analyze the impact of both tangible and intangible objects across all phases of their life cycle—from conception and resource extraction to planned obsolescence, disposal, and reintegration through circular economy practices. The QRSUER structure is grounded in technical-scientific guidelines and formal classifications that encompass attributes such as energy efficiency, emissions reduction, recyclability, adaptive modularity, regenerative impact, sociotechnological equity, carbon neutrality, water management, and biodiversity protection, among others, allowing for the assessment of risks, merits, deficiencies, and regenerative potential of evaluated technologies, in accordance with the modular structure of the FCIA-OT.

Since the late 1980s, Rauner, Rasmussen, & Corbett (1988) warned that computational environments designed solely for individual performance overlook the essential role of cooperative relationships in the workspace. Technological development requires that machines act as an extension of the human, not as a substitute, a premise that links technical design to principles of autonomy and continuous learning. Simultaneously, Cutler (1989) exposed the operational limits of the prevailing industrial model by highlighting the contradiction between the increasing use of plastics and the absence of viable solutions for their end-of-life management. The lack of effective policies for the reintegration of such waste into the production cycle generates a massive environmental liability, underscoring the urgency of integrating "Design for Recycling" strategies from the early stages of engineering.

In the early 1990s, Shneiderman (1990) broadened this discussion by proposing that accessible and ethically informed technologies must meet not only technical standards but also include traditionally marginalized populations. The organizational structure of systems must, in this regard, support both the functional diversity of agents and the strengthening of social structures that ensure equity.

This position converges with Bohnhoff, Brandt, & Henning (1992), for whom the anthropocentric model constitutes the key to an engineering approach that values life. By promoting systems that enhance human capabilities, it becomes possible to achieve productivity, safety, and sustainability simultaneously, linking technical responsibility with intergenerational justice.

In the following decade, the challenges associated with the end of the life cycle of computational systems became central. Jain & Wullert (2002) anticipated the structural risks of ubiquitous computing by demonstrating that its widespread distribution and rapid obsolescence transform devices into catalysts of invisible contamination. Non-biodegradable materials, heavy metals, and toxic gases generated during production or incineration turn everyday objects into agents of chronic environmental degradation. In line with this concern, Bhuie et al. (2004) showed that devices such as cell phones and computers contain toxic elements with high leaching potential, whose improper handling and disposal compromise groundwater, soil, and air, shifting the technical issue into the ethical-sanitary domain.

The scaling crisis of electronic waste is addressed with greater technical precision by Hilty (2005), who quantified the flow of obsolete equipment and identified both the potential for precious metal recovery and the health risks related to irregular disposal. Although economically attractive, global recycling of electronic equipment perpetuates inequalities, as it is mostly carried out in low-income countries without proper environmental controls or labor protections.

In response to this imbalance, Blevis (2007) proposed a classificatory framework of sustainable practices, ranging from conventional disposal to high sociocultural value solutions, such as durable design and symbolic reuse. The classification reinforces the need to articulate design decisions with regenerative, rather than merely compensatory, horizons.

The conceptual proposal of Green IT, developed by Murugesan (2008), offers a normative model that covers the entire life cycle of computational systems, linking technical performance to the mitigation of environmental impacts. Unlike isolated approaches, Green IT presupposes a systemic, integrated engineering aligned with principles of energy efficiency, social justice, and organizational ethics. Subsequently, Bose & Luo (2011) reinforced the business viability of this transition by demonstrating that sustainable practices promote not only resource savings but also operational and collaborative gains. Sustainability, therefore, ceases to be a burden and becomes a structuring competitive advantage.

Tang & Zhou (2012) emphasized that the adoption of sustainable production technologies is not merely a technical decision, but a strategic positioning vector. Reverse logistics operations not only reduce environmental impacts but also create new markets and strengthen public perception of corporate responsibility. At this point, technology is no longer treated as instrumentally neutral and enters the realm of ethical reputation and institutional coherence.

Pargman & Raghavan (2014) deepened this critique by showing that much of today's technological systems are developed without rigorous consideration of the intensive use of natural resources. The ecological footprint must be treated as a design variable, not as a remediable consequence. The critique is not aimed at the absence of solutions, but at the recurrent neglect of environmental variables that condition the systemic sustainability of technology. This shift is expanded by Remy et al. (2018), who pointed out the inadequacy of traditional evaluation methods at the interface between HCI and sustainability. Technological research, they argue, must consider not only the artifact's performance but also the side effects generated in social, environmental, and epistemological dimensions, demanding new methodological paradigms.

In industrial applications, Cecilio (2022) argued that the convergence between automation and Joint Cognitive Systems (JCS) requires the incorporation of assistive technologies and technical adaptation methodologies that prioritize operators. The absence of such structures compromises not only workers' health but also the performance of production processes themselves, revealing structural gaps that undermine both efficiency and equity. In the same analytical context, Sharma, Kumar, & Nardi (2023) denounced practices such as software-induced obsolescence and the deliberate limitation of repairability. Although justified under market logics, such strategies perpetuate forced replacement cycles and amplify waste generation. In response, they proposed a shift toward technological development models that incorporate economic literacy, planned redesign, and a break with the infinite growth paradigm.

Within this framework, QRSUER Technology emerges as a technical-scientific construct aimed at operationalizing critical, precise, and measurable criteria that qualify technologies from multiple perspectives: environmental, ethical, social, functional, and regenerative. Table 14 presents the formalization of the criteria of this dimension, organized by thematic groups.

TABLE 14: DEFINITION OF TECHNOLOGY CRITERIA TYPES (QRSUER)

Adapted from Research	Groups	Code	Criterion Types QRSUER	Definition	SPMI
Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)	**TQ1: Sustainability and Resources**	TQRS01	Resource Use and Efficiency	The product or system meets practical needs by promoting resource efficiency, including energy use, and contributing to environmentally sustainable and socially responsible solutions. It evaluates consumption during use, encourages input optimization, and minimizes negative impacts while maximizing overall benefits.	**-5 a 10**

Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)		TQRS02	Resource Sustainability	Emphasizes the use of renewable materials and efficient management of natural inputs, prioritizing practices that minimize waste and promote long-term resource sustainability throughout the product or system's life cycle.	**-5 a 10**
		TQRS03	Emission Reduction	Significant reduction of pollutant emissions throughout the product or system's life cycle, contributing to the mitigation of environmental impacts and aligning with global standards of environmental responsibility.	**-5 a 10**
		TQRS04	Solid Waste Management	The product or system's ability to minimize waste generation, as well as to reuse and properly dispose of it, promoting practices that comply with sustainability standards and responsible waste management.	**-5 a 10**
		TQRS05	Active Disposal	Strategic actions for appropriate end-of-life disposal, including initiatives that promote reuse, recycling, and practices that ensure the responsible management of materials.	**-5 a 10**
		TQRS06	Carbon Neutrality	The product or system's capacity to offset or eliminate its carbon emissions, aligning with global sustainability goals and contributing to the reduction of the carbon footprint.	**-5 a 10**
		TQRS07	Regenerative Impact	Practices that not only minimize environmental impacts but also contribute to the regeneration of affected ecosystems, expanding the environmental benefits generated by the product or system.	**-5 a 10**
		TQRS08	Water Efficiency	Evaluates water use optimization, from consumption reduction to efficient reuse and the implementation of technologies that minimize waste and encourage water conservation throughout the product or system's life cycle.	**-5 a 10**

Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)		TQRS09	Biodiversity Protection	Measures and practices that minimize impacts on local ecosystems, promote biodiversity conservation, and ensure responsible environmental management across the entire production chain, including actions to restore habitats and protect native species.	**-5 a 10**
	TQ2: Sustainable Design and Circular Economy	TQRS10	Recyclability	Capacity for component reuse or recycling at the end of their useful life, promoting a circular approach that reduces waste and environmental impact.	**-5 a 10**
		TQRS11	Facilitated Repairability	Ease of repairing or replacing components, extending the product's lifespan and reducing costs associated with disposal and the acquisition of new items.	**-5 a 10**
		TQRS12	Modular Adaptability	Encourages the modification, replacement, and upgrading of modular components, enabling greater flexibility in use and maintenance, reducing waste, and enhancing product or system durability.	**-5 a 10**
		TQRS13	Circular Design	Design practices that ensure durability, resource reuse, and waste reduction. Prioritizes solutions that minimize environmental impacts throughout the product or system's life cycle, supporting the circular economy.	**-5 a 10**
	TQ3: Social Impact and Inclusion	TQRS14	Social Impact and Equity	The product or system promotes accessibility, technological inclusion, and benefits for communities, ensuring fair, equitable practices that contribute to reducing social inequalities.	**-5 a 10**
		TQRS15	Technological Inclusion	Integration of different social groups into the product or system, promoting equitable access to technologies and the use of innovative solutions.	**-5 a 10**
		TQRS16	Positive Local Economic Impact	Strengthens local production chains by encouraging job creation, use of regional suppliers, and sustainable community development, reducing socioeconomic disparities.	**-5 a 10**

Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)	**TQ4: Compliance, Ethics, and Transparency**	TQRS17	Transparency and Privacy	Clarity and honesty in communicating environmental and social impacts, ensuring the ethical and responsible use of personal data and sensitive information related to the product or system.	**-5 a 10**
		TQRS18	Transparency and Traceability	Promotes clear, accessible, and verifiable disclosure of environmental and social information. Includes traceability, certifications, and reports that ensure ethical and environmental assessment across the production chain, reinforcing accountability to stakeholders.	**-5 a 10**
		TQRS19	Legal Compliance	Ensures that the product or system is in full compliance with applicable environmental laws and regulations, supporting an ethical and responsible market approach.	**-5 a 10**
		TQRS20	Ethics and Transparency in AI Systems	Ensures that AI systems, algorithms, and architectures are developed and applied based on ethical principles, bias mitigation, and regulatory compliance, ensuring transparency and accountability in data use.	**-5 a 10**
	TQ5: Innovation and Technological Impact	TQRS21	Material Safety	Use of non-toxic and health-safe materials. Evaluates both the benefits provided and the mitigation of risks associated with use and disposal, prioritizing materials that promote sustainability and well-being.	**-5 a 10**
		TQRS22	Sustainable Integration	The product or system's alignment with environmental and social practices in its context of use, promoting a balance between functional performance and positive environmental impact.	**-5 a 10**
		TQRS23	Responsible Innovation	Assesses the product or system's commitment to introducing technologies that benefit both the environment and society, promoting sustainable progress.	**-5 a 10**

Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)	**TQ6: Environmental Conservation and Preservation**	TQRS24	Efficient Use of Space	Evaluates how efficiently the product or system uses physical space, promoting solutions that minimize spatial occupation without compromising functionality or performance.	**-5 a 10**
		TQRS25	Environmental Preservation	Practices that ensure the conservation of ecosystems and biodiversity, reducing negative impacts associated with the production, use, and disposal of the product or system.	**-5 a 10**
		TQRS26	Preservation of Water and Subsurface Resources	Practices, systems, and technologies aimed at preserving bodies of water (rivers, seas, lakes) and subsurface resources (aquifers, groundwater), preventing contamination by pollutants, waste, or toxic substances. Includes water and soil purification and recovery technologies, proper waste disposal, and sustainable practices that ensure water quality and soil integrity, with an emphasis on protecting aquatic and underground ecosystems.	**-5 a 10**
		TQRS27	Air Pollution and Atmospheric Protection	Practices, products, or systems that prevent atmospheric pollution in its various forms, including the reduction of emissions of pollutants (such as CO_2, methane, nitrogen oxides) and the mitigation of impacts related to global warming. Addresses technologies and methods for capturing and neutralizing atmospheric pollutants, preventing the release of toxic substances into the air, and promoting sustainable practices that ensure air quality and protect the atmosphere.	**-5 a 10**
		TQRS28	Chemical, Radioactive, and Heavy Metal Contamination	Evaluates the impact of chemical, radioactive, and heavy metal contamination associated with the product or system's life cycle. Considers risks to human health, the environment, and society, promoting mitigation practices and technologies that reduce emissions, leaks, and harmful exposure.	**-5 a 10**

Rauner, Rasmussen & Corbett (1988); Cutler (1989); Shneiderman (1990); Bohnhoff, Brandt, & Henning (1992); Jain & Wullert (2002); Bhuie et al. (2004); Hilty (2005); Blevis (2007); Murugesan (2008); Bose & Luo (2011); Tang & Zhou (2012); Pargman & Raghavan (2014); Remy et al. (2018); Cecilio (2022); Sharma, Kumar, & Nardi (2023)		TQRS29	Space Pollution and Environmental Impact	Practices, products, or systems that prevent environmental pollution in all its forms, including solid, liquid, gaseous, and other material or immaterial by-products that negatively affect the space environment. Encompasses prevention of impacts caused by space debris, improper disposal of materials in space, and the generation of harmful by-products. Also includes the accumulation of waste that may compromise natural resources and space infrastructures.	**-5 a 10**

The QRSUER dimension articulates, through technical-operational vectors, the criteria used to assess the systemic performance of technological objects with regard to sustainability, social responsibility, circularity, usefulness, ethics, and design rationality. Vectors TQRS01 to TQRS29 classify measurable attributes organized into thematic groups, enabling formal inferences on merit, impact, and technological compliance according to the modular logic of the FCIA-OT framework.

Source: Author.

The modeling of QRSUER types enables normative and technical-scientific inferences regarding the degree of systemic adherence, environmental responsibility, and ethical maturity of technological objects. By integrating formal measurement parameters with guidelines for sustainability, equity, and transparency, this dimension becomes decisive in processes of evaluation, redesign, certification, and technological adaptation, contributing to the transformation of industrial, institutional, and interactional practices under the modular logic of the FCIA-OT framework.

4 INTEGRATION OF SPMI AND SCDMIC SYSTEMS INTO THE MODULAR STRUCTURE OF THE FCIA-OT

The FCIA-OT matrix incorporates two proprietary systems: the Integrated Modular Multidimensional Scoring System (SPMI) and the Integrated Modular Color Definition and Classification System (SCDMIC), both designed to systematically and jointly quantify and represent the analytical results derived from each technical vector within the framework's dimensions. These systems operate synchronously, assigning scalar values and chromatic categories to the criticality of each observed element, thereby maximizing technical precision and methodological scalability. The SPMI and SCDMIC systems (see Chapter 2) function as integrated mechanisms for quantitative and visual representation of the analysis, structuring scalar weightings and chromatic codifications associated with the FCIA-OT dimension vectors.

The SPMI is a continuous modular assessment system whose logic allows values to be represented on a primary scale ranging from -5 to 10. SPMI values are assigned per vector (or element) of each dimension. In advanced contexts, the system may also operate with decimal values, applicable to the evaluation of micro-scale structures such as lines of code, modular artifacts, or specific functions. However, when opting for this decimal-based scoring mode, it is essential to have the appropriate knowledge for its correct application, ensuring effective data collection across each integrated dimension and evaluated element.

Complementarily, the SCDMIC classifies, through integrated colors, the level of criticality or adequacy of each scored vector. The colors red, orange, yellow, green, and conditional blue (c), used in cases requiring systemic interpretation, represent technical stages and alert levels that support rapid and auditable visualization of the matrix, promoting a precise interpretative reading aligned with the technical-normative scope of the FCIA-OT. Table 15 presents the integration of dimension vectors with the SPMI/SCDMIC systems, evidencing the application logic and modular coding structure that underpin the framework's operationalization.

TABLE 15: NTEGRATION OF DIMENSION VECTORS WITH THE SPMI SCALE AND SCDMIC CHROMATIC CATEGORIZATION

Dimensions	Integrated Modular Multidimensional Scoring System (SPMI)																
	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	C
Knowledge/ Experience							○	○	○	○	○	○	○	○	○	○	○
Object Requirements	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
Affordance	○	○	○		○			○						○	○	○	○
Perception	○							○	○		○					○	
Affectivity	○	○	○		○			○	○	○	○	○	○	○	○	○	
Satisfaction	○	○	○		○	○						○	○	○	○	○	
Effectiveness	○		○								○					○	
Error Severity						○	○	○	○	○	○						
Risk Levels						○	○	○	○	○	○						
Attributes	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
Accessibility	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
QRSUER Technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	

Presents the modular integration of the technical vectors from the FCIA-OT dimensions with the SPMI (Integrated Modular Multidimensional Scoring System) and the SCDMIC (Integrated Modular Color Definition and Classification System). Each vector is represented by a marker "○", indicating its position on the SPMI scale, which ranges from -5 to 10, with a conditional value "c" reserved for specific systemic analyses. The chromatic codification assigned to each value corresponds to the critical levels defined by the SCDMIC: red, orange, yellow, green, and conditional blue (c). This structure enables accurate assessment of criticality, quality, and adequacy levels of the elements, in technical and normative alignment with the framework's criteria. The matrix also allows the use of decimal scoring for detailed analysis of micro-scale structures, ensuring metric coherence, traceability, and data auditability.

Source: Author.

The integration of the SPMI and SCDMIC systems into the modular matrix of the FCIA-OT enhances the level of precision, auditability, and intelligibility of the analyses, enabling the formal and visually interpretable representation of the multivectorial complexity of the evaluated technological objects. By combining scalar metrics and chromatic categories, these systems become essential for the continuous operationalization of the framework, ensuring normative coherence, technical responsiveness, and adaptive potential across evaluative, design, and reconfigurative applications.

5 DISCUSSION

The structuring of the FCIA-OT consolidates a high-density interpretative and normative platform, technically and ontologically grounded, whose architecture not only organizes dimensions, vectors, and evaluative attributes, but reconfigures them into a formally modeled matrix designed to address scenarios of sociotechnical complexity. Unlike fragmented or taxonomic approaches, the framework operates as a third-order modular system, in which each dimension constitutes an autonomous epistemic nucleus, yet remains interoperable, allowing for analytical granularity without compromising systemic cohesion.

The integrated proposition of the SPMI and SCDMIC systems introduces a methodological and representational leap, transforming the FCIA-OT matrix into an instance of technical-cognitive synthesis. The SPMI provides a continuous modular scale with microcomponent adaptability, while the SCDMIC operates as a normatively codified chromatic semiotic system, capable of expressing evaluative criticality within auditable visual environments. This integration is not merely symbolic, but operational, enabling multiple dimensions to be simultaneously analyzed, classified, and designed through a shared language of value and impact.

By articulating dimensions, the FCIA-OT formalizes criteria that were previously addressed in isolated, non-measurable, or subjectively interpreted ways. The framework's ontology, by its instrumental nature, enables the reconfiguration of analysis and evaluation practices, the design of interventions, and the structuring of development cycles based on auditable, normative, and scientifically justified classificatory structures.

The FCIA-OT's ability to absorb, combine, and evaluate technical-cognitive, sociopolitical, environmental, and epistemic variables within a single matrix represents a rupture with classical functionalist models as well as with low-resolution heuristic methodologies. The matrix does not merely measure performance, it determines design coherence, normative convergence, and systemic impact through interdependent vectors. It constitutes a new kind of scientific language applied to technology: one that structures meaning, codifies value, and infers technical-operational potential with analytical precision.

Within the context of interaction engineering, technical-social design, and the evaluation of hybrid artifacts, the FCIA-OT inaugurates a new category of frameworks: neither reactive nor merely descriptive, but active, synthetic, and normative. Its application is not limited to post-project evaluation, but extends to planning, impact simulation, risk auditing, and the very technical-scientific conception of systems. The modular integration of dimensions with the scoring and chromatic classification systems transforms the FCIA-OT into a cognitive and normative infrastructure capable of operating across academic, industrial, institutional, and regulatory contexts.

The scalable and expandable nature of the framework, combined with its foundation in formalized criteria and validated vectors, positions the FCIA-OT as a scientific platform capable of customization, interoperability, and replication. Its modular logic allows for the creation of domain-specific instances (educational, industrial, governmental, environmental, etc.) without compromising the epistemic integrity of its original architecture. In summary, the FCIA-OT not only offers a new methodology: it proposes a new ontological grammar for the evaluation, development, and systemic qualification of complex technological objects.

6 CONCLUSION

The FCIA-OT is presented in this work as a novel ontology of modular and scalar nature, which surpasses conventional approaches by formally and audibly integrating multiple essential dimensions for the analysis, evaluation, and development of complex technological objects. By structuring validated criteria and systems of combined, chromatic, and multidimensional scoring, the framework not only describes but operates as a high-precision instrumental platform, capable of guiding strategic decisions and technical interventions with epistemic foundation and normative consistency.

The incorporation of the SPMI and SCDMIC systems represents a significant methodological advancement, enabling the qualification and quantification of criticalities with scalar granularity and compositional flexibility, decisive aspects when addressing the complexity of contemporary systems. The convergence between metrics and visual representations ensures coherence among technical reading, symbolic coding, and design action, thus enhancing the analytical power of the framework and its applicability in decision-making processes.

The modular logic of the FCIA-OT enables its adaptation to different domains and analytical scales, while preserving the epistemic integrity of its architecture. From integrated sociotechnical systems to micro-scaled components, its structure responds with precision and transparency to the operational, scientific, and normative demands of complex environments. As an applied ontology, it establishes a solid foundation for the advancement of evaluative practices, sustainability, and ethical responsibility in hybrid technologies, with empirically justified and normatively articulated foundations.

By combining methodological rigor, ontological structuring, and transdisciplinary applicability, the FCIA-OT positions itself as a strategic resource for researchers, developers, and managers, offering a robust referential that consolidates innovation, auditability, and sustainability across the life cycle of complex constructs. More than a methodology, it proposes a new grammar for the engineering of analysis and evaluation: synthetic, normative, and scientific.

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CHAPTER 2

INTEGRATED MODULAR MULTIDIMENSIONAL SCORING SYSTEM (SPMI) AND INTEGRATED MODULAR SYSTEM FOR COLOR-BASED CLASSIFICATION AND DEFINITION (SCDMIC)

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ABSTRACT — The development of evaluative systems capable of accurately and deeply measuring complex phenomena and constructs demands instruments that articulate metric structure, analytical modularity, and interpretive flexibility. This article presents two complementary and original measurement systems: the Integrated Modular Multidimensional Scoring System (SPMI) and the Integrated Modular System for Color-Based Classification and Definition (SCDMIC). Both were designed to address critical gaps in traditional instruments by enabling the structured quantification of constructs, technological objects, and subjective experiences. The SPMI introduces a structured scoring logic based on scales ranging from -5 to +10, in both integer and decimal formats, allowing precise evaluation of multiple integrated dimensions, with control over polarity, intensity, and inferential value. Its modular architecture allows the adaptation of metrics to distinct elements, from qualitative parameters to objective technical indicators, operating under rigorous principles of validity and representativeness. The SCDMIC, in turn, introduces a modular chromatic scale with interpretive color-volume units, enabling the representation of experiences and evaluative states in a continuous, intuitive, and highly discriminative manner. The logical equivalence between color and number, linking SCDMIC and SPMI, establishes a unified measurement approach applicable to both subjective and objective domains, as well as to qualitative and quantitative dimensions. Together, the two systems provide a foundation for in-depth analysis and strategic decision-making in the evaluation of constructs, technologies, interactions, and phenomena, offering robust tools for refined measurement across diverse scientific and operational contexts.

KEYWORDS — SPMI; SCDMIC; Scoring System; Complex Constructs; Subjective and Objective Evaluation; Qualitative and Quantitative Measurement.

1 INTRODUCTION

The construction of rigorous measurement systems depends on the formal definition of what is to be measured and on the logical correspondence between the empirical phenomenon and the adopted numerical structure. Stevens (1946) establishes the foundations of this correspondence by defining measurement as a process of assigning numerals governed by consistent rules, in which the mathematical structure of the scale must reflect observable empirical operations. The classification into nominal, ordinal, interval, and ratio scales imposes distinct constraints and permissions regarding the nature of numerical transformations and the types of inference permitted. The nominal scale, for instance, is limited to labeling without ordering, whereas the ordinal scale allows hierarchical ranking but does not imply equality between intervals. The interval scale admits additive operations and distance comparisons, though without an absolute zero point, which poses challenges to proportional interpretations. Therefore, the choice of scale is not merely technical, but epistemological, as it determines the model by which reality is represented.

Selecting an appropriate statistical method requires compatibility with both the scale type and the empirical constraints of the measured phenomenon. Anderson (1961) highlights the increasing acceptance of nonparametric tests, driven by concerns over the use of parametric tests when assumptions of normality and homogeneity of variances are not met. He emphasizes that the adequacy of the measurement scale is essential in choosing between parametric and nonparametric procedures. Parametric tests are widely used in statistics due to their versatility and statistical power, especially in variance analysis and complex experimental designs. Anderson reinforces that the issue of the scale is intrinsically tied to the measurement of the underlying phenomenon, revealing the complexity in selecting statistical methods.

Representing empirical reality through classificatory systems requires not only metric structure but also a pertinence model that accommodates semantic variability and the subjective judgment inherent to many evaluation domains. Zunde & Dexter (1969), in their investigation of indexing consistency, argue that consistency should not be assessed solely by the formal agreement among indexers regarding selected terms, but also by the relevance of those terms. Drawing on the concept of fuzzy sets, which allow the classification of elements with varying degrees of pertinence, they define indexing consistency as the degree of agreement among indexers in representing the essential content of a document through individually and independently selected sets of terms. This approach considers that term selection reflects the subjective judgment of indexers regarding the information contained in the document, and that agreement on more relevant terms should be valued over agreement on less significant ones.

Evaluative constructs exhibit a structure composed of multiple interdependent components. This complexity was examined by Ostrom (1969), who investigated the relationship among the affective, behavioral, and cognitive components of attitude. The results supported the proposed hypotheses, yet the dominant feature was the high intercorrelation among the three components, with each one's uniqueness contributing little additional variance. All three share a common set of antecedents or determinants. However, for the tripartite distinction to be meaningful, it must be demonstrated that evaluative responses within each component are influenced by a distinct set of determinants, separate from those influencing the others. If such exclusive determinants cannot be established, then maintaining this distinction without empirical effect becomes conceptually unparsimonious. Within the context of attitude theory, the tripartite model predicts that part of the evaluative heterogeneity of responses may be attributed to the classification of the component to which the response belongs.

Defining the number of points on a scale constitutes a critical decision that directly affects the precision, reliability, and inferential validity of the results. Martin (1978) emphasizes that when computing correlations using variables with fewer than 10 scale points, a common practice in marketing research, the loss of information increases significantly as the number of categories decreases. He recommends the use of scales with 10 or more points whenever possible to preserve precision and reliability. This principle is central to the construction of systems that, like those proposed in this research, aim to maximize informational content without compromising consistency and interpretability.

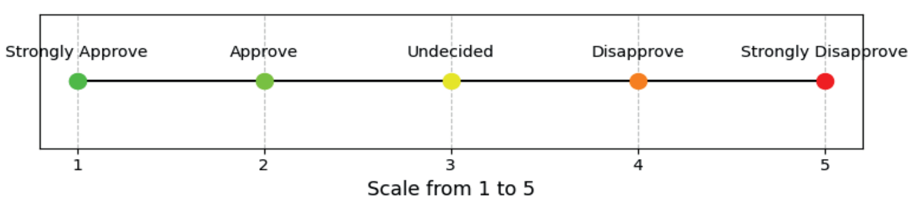
Technological objects, constructs, and evaluative phenomena exhibit structural complexity and interaction conditions shaped by situational variables, including environmental and cultural factors. In light of this contingent nature, the Integrated Modular Multidimensional Scoring System (Sistema de Pontuação Multidimensional Modular Integrado – SPMI) and the Integrated Modular System for Color-Based Classification and Definition (Sistema de Classificação e Definição Modular Integrado de Cores – SCDMIC) are proposed. These systems were developed to enhance the discriminative and interpretive capacity of evaluative instruments, based on rigorous psychometric foundations articulated through a modular logic that enables flexibility, adaptation, and analytical depth. The following sections present the structural principles, scoring axes, and operational guidelines that define these systems.

2 INTEGRATED MODULAR MULTIDIMENSIONAL SCORING SYSTEM (SPMI)

The analysis of measurement scales used in evaluative contexts is a fundamental step toward understanding both the limitations and potential of traditional instruments, as well as grounding the development of new systems that are more responsive to contemporary demands. The SPMI is the result of this critical analysis and the need for a modular, precise, and adaptable system capable of representing multiple dimensions, including positive and negative values, and integrating both quantitative and qualitative, subjective and objective variables (see Chapter 1). The following sections present the referential models, along with their structures, internal logics, and limitations, as considered in the construction of the SPMI.

Likert (1932) proposed a method for attitude measurement based on the assignment of numerical values to participant responses. The scale, composed of five alternatives, receives progressive scores from 1 to 5 (Figure 1), with the intermediate position (value 3) assigned to the neutral option. This structure allows the intensity of expressed attitudes to be quantified by distributing scores along an attitudinal continuum. The technique was developed to facilitate application in statistical analyses without requiring subjective judgments from evaluators. The method assigns fixed values to responses, allowing the results to be organized in a standardized manner.

FIGURE 1: LIKERT SCALE

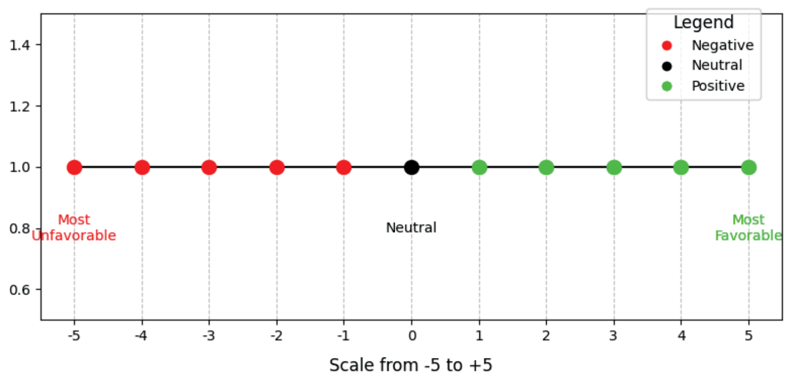


Source: Author. Adapted from Likert, R. A. (1932)

The ordinal and symmetrical structure proposed by Likert marked a milestone in attitudinal quantification; however, its structural rigidity and limitation to five fixed points restrict metric sensitivity in more complex contexts.

In response to these structural limitations, Cliff (1959) proposed that intensifying adverbs such as "very" and "extremely" modify the intensity of adjectives multiplicatively, approximating vector algebra operations. The model is based on five postulates, among which are the assignment of numerical values to adjectives and adverbs, and the hypothesis that the intensity of adverb-adjective combinations corresponds to the product of these values (Figure 2). Cliff argues that the proposed formulation could be applied to other evaluative dimensions, such as size or intensity, extending the model beyond the emotional domain. The multiplicative relationship between adverbs and adjectives observed in the data is considered analogous to scalar multiplication in Euclidean vector spaces, implying a psychological zero point and a unit of measurement for adjectives.

FIGURE 2: FIVE POSTULATES. ASSIGNMENT OF NUMERICAL VALUES: ADJECTIVES AND ADVERBS



Source: Author. Adapted from Cliff (1959)

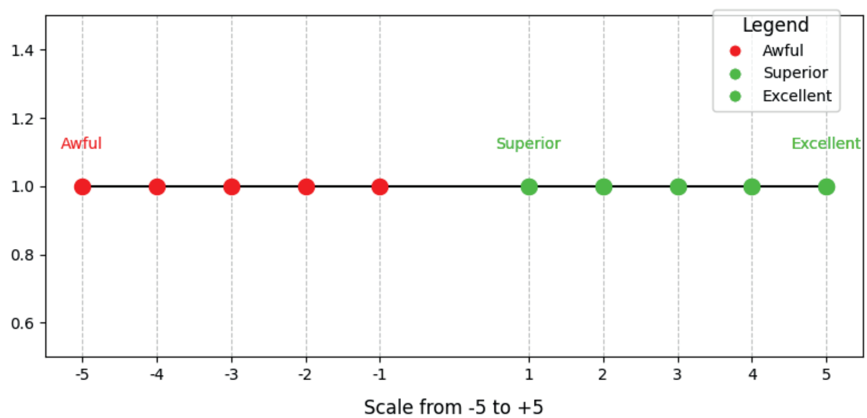
Conceptually structured, the proposal requires the precise definition of a psychological zero point and a measurable unit of evaluation for adjectives, imposing limitations on its empirical operationalization in applied settings. Its contribution, however, lies in introducing an algebraic structure for analyzing semantic intensity, anticipating the need for more expressive metric models, such as those underlying the SPMI proposal.

This limitation in representing subjective intensity vectorially highlighted the necessity for models capable of handling semantic imprecision and gradual classifications, such as the one proposed by Zadeh (1965), which introduced the concept of fuzzy sets. These assign degrees of membership within the interval between 0 and 1, extending classical set theory to address classes of objects whose membership criteria are not precisely defined. Zadeh emphasizes that fuzzy sets address imprecision related to indeterminate membership boundaries, while probabilistic theory deals with random uncertainties. This fundamental difference renders fuzzy sets an appropriate tool for problems where imprecision is qualitative rather than statistical.

The need to capture evaluative nuances with greater balance led to the development of models incorporating response symmetry and bias control. In this regard, Crosby (1969) employs the bipolar numerical scale (Stapel) (Figure 3), which ranges from +5 to -5, as one of the tools to measure attitudes. The Stapel scale was chosen for its ability to balance extreme emotional responses, enabling more precise comparisons between groups with differing cultural contexts.

Through its balanced structure, the Stapel scale allows for responses equally in both positive and negative directions, proving particularly useful for neutralizing cultural biases in responses. It is noteworthy that the choice of balanced scales is essential to ensure validity in comparative attitude research.

FIGURE 3: BIPOLAR NUMERICAL SCALE (STAPEL)

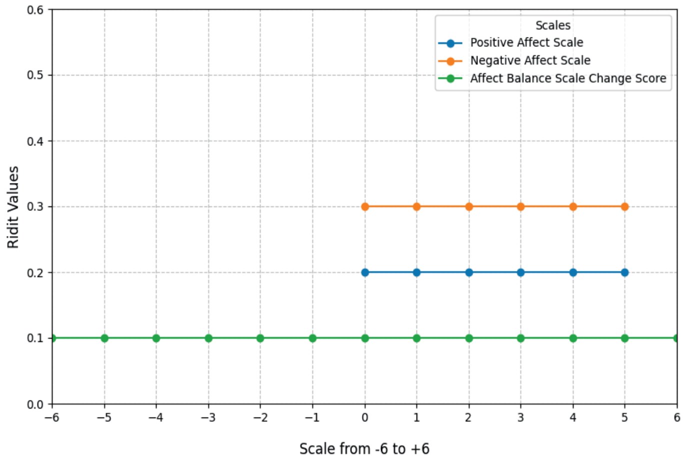


Source: Author. Adapted from Crosby, R. W. (1969) - Stapel (1969)

Structured and symmetrical, the Stapel scale helped highlight the importance of measurement systems capable of incorporating polarity, intensity, and situational control, fundamental elements considered in the architecture of the SPMI.

Measuring affective states required the development of models able to quantify emotional direction and intensity based on self-reported responses. Bradburn (1969) conceptualizes psychological well-being as the balance between Positive Affect and Negative Affect. The Affect Balance Scale (ABS) (Figure 4) is obtained by subtracting the number of responses indicating Negative Affect from the number of Positive Affect responses, resulting in a score that reflects the individual's affective balance. This measure is directly associated with self-perceived happiness: Relation of Affect Balance Scale (Positive Affect - Negative Affect) to Self-Ratings of Happiness at Each Level of Difference, for Wave I.

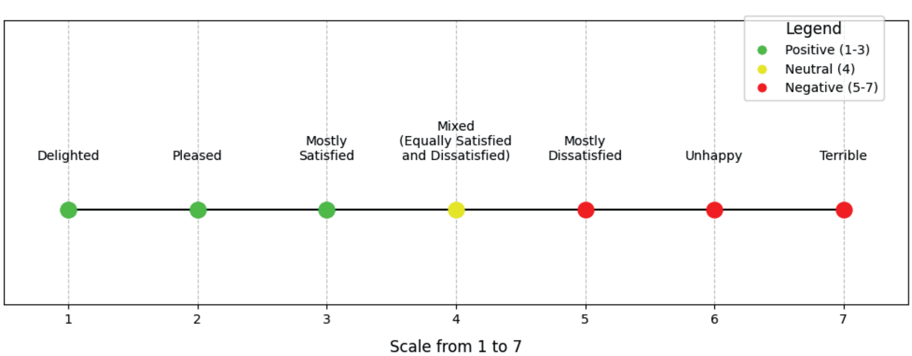
FIGURE 4: AFFECT BALANCE SCALE (ABS)



Source: Author. Adapted from Bradburn (1969)

Following studies on subjective well-being, Andrews & Withey (1976) developed the Delighted-Terrible Scale (D-T Scale) (Figure 5) to capture nuances of personal satisfaction across various aspects. The scale ranges from "1" (delighted) to "7" (terrible), providing a direct assessment of well-being with seven categories that allow participants to express states from extreme satisfaction to profound dissatisfaction.

FIGURE 5: DELIGHTED-TERRIBLE SCALE (D-T SCALE)

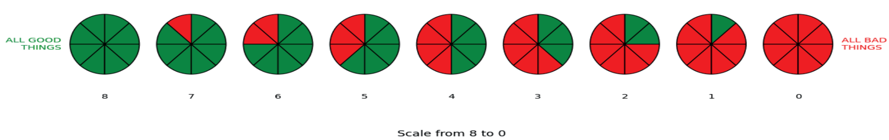


Source: Author. Adapted from Andrews & Withey (1976)

Although direct and intuitive, this scale operates with limited resolution, which restricts its discriminative power in complex assessments. Nevertheless, its structure contributed to consolidating affective measurement parameters that precede more refined approaches such as those proposed by the SPMI.

Complementing this model, the Scale of Circles with Pluses and Minuses (Figure 6) was proposed to measure well-being from a graphical perspective. This scale begins at "8", representing an ideal life filled with positive aspects (all "+"), down to "0", indicating a wholly negative life (only "-"). The intermediate circles capture varying degrees of well-being, offering a visual and intuitive representation that goes beyond numerical categories, allowing respondents to place themselves along a continuous line of satisfaction and dissatisfaction.

FIGURE 6: SCALE OF CIRCLES WITH PLUSES AND MINUSES

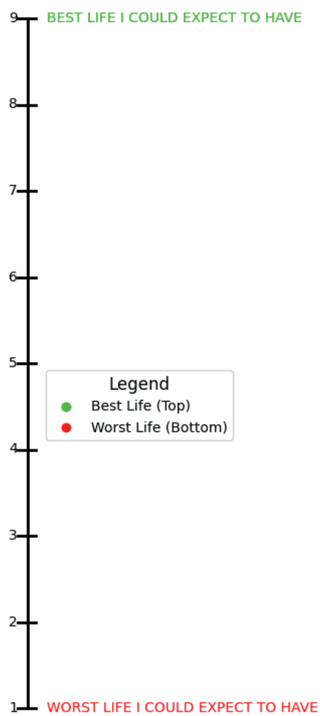


Source: Author. Adapted from Andrews & Withey (1976)

This graphical representation reinforces the instrument's accessibility but limits the granularity required for measurements involving multiple analytical vectors. The absence of a formal metric structure restricts its application in technical contexts, indicating the need for more structured systems, such as the SPMI.

The Ladder or Cantril Self-Anchoring Striving Scale (CSASS) (Figure 7) is highlighted, developed by Kilpatrick & Cantril (1960), and presented as a tool for assessing subjective perceptions of quality of life. Originally, Cantril's scale ranged from "1" at the bottom of the ladder (representing the worst possible life one can imagine) to "9" at the top (the best possible life). Respondents select the step that best reflects their current state, life expectation, or aspirations.

FIGURE 7: LADDER OR CANTRIL: SELF-ANCHORING STRIVING SCALE (CSASS)

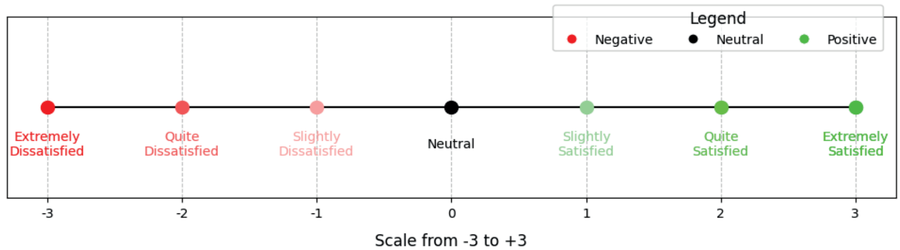


Source: Author. Adapted from Andrews & Withey (1976)

Although intuitive and adaptable to diverse audiences, the CSASS operates on a unidimensional, self-anchored logic which, while useful in population studies, does not support integrated multivector evaluations. Its contribution lies in the recognition of self-perception as a meaningful metric, anticipating more structured approaches such as the one proposed by the SPMI.

Pearson & Bailey (1980) proposed the Satisfaction Scale (Figure 8), a standardized, symmetrical interval scale developed to quantitatively measure users' satisfaction with information systems. The scale consists of seven categories that simultaneously assess the direction (satisfaction or dissatisfaction) and intensity of user perceptions. These categories are described by the adjectives: Extremely Satisfied, Quite Satisfied, Slightly Satisfied, Neither Satisfied nor Dissatisfied, Slightly Dissatisfied, Quite Dissatisfied, and Extremely Dissatisfied. The intervals associated with these categories are assigned numerical values of "-3", "-2", "-1", "0", "+1", "+2", "+3", corresponding to the intensity of responses.

FIGURE 8: SATISFACTION SCALE

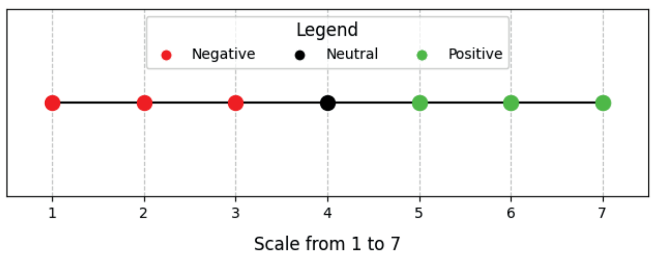


Source: Author. Adapted from Pearson & Bailey (1980)

This structure enables the capture of nuances in affective responses, both in intensity and polarity, within a standardized psychometric model. Nonetheless, its unidimensionality and the absence of modular mechanisms reduce its potential in contexts requiring multiple analytical vectors. These limitations underscore the need for more comprehensive evaluative systems, such as the SPMI, designed to operate at more complex and interdependent structural levels.

As an advancement in the assessment of subjective satisfaction, Diener, Emmons, Larsen, & Griffin (1985) developed the Satisfaction With Life Scale (SWLS) (Figure 9), a five-item tool designed to measure global life satisfaction. The scale demonstrates high internal consistency and temporal reliability, validated through rigorous psychometric analyses. Each SWLS item is rated on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree", allowing for precise and reliable measurement of global satisfaction judgments.

FIGURE 9: SCALE SATISFACTION WITH LIFE (SWLS)

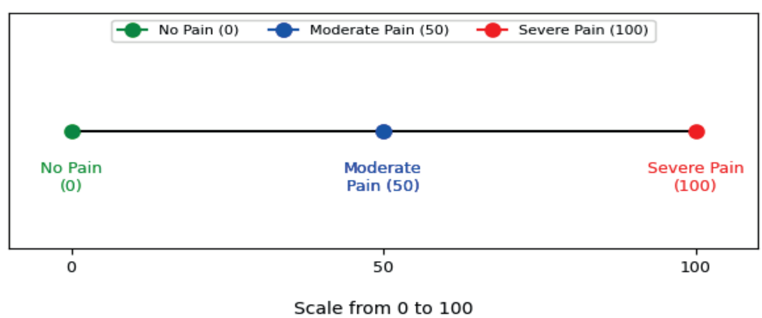


Source: Author. Adapted from Diener et al. (1985)

The instrument focuses on the cognitive judgment of life as a whole, prioritizing the aggregated subjective perception. Although it demonstrates high psychometric consistency, it is limited in its ability to represent multiple dimensions simultaneously, a gap the SPMI seeks to address through a modular and integrated architecture.

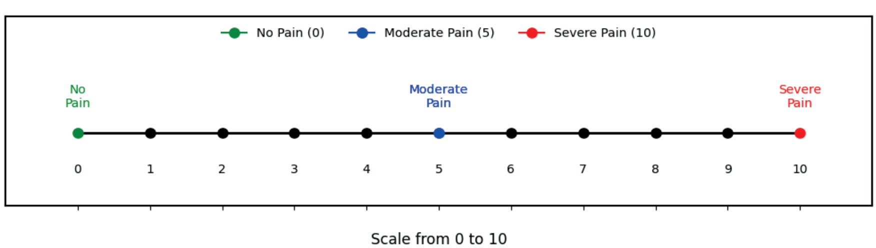
Numerical scales have been developed to capture subjective intensities, among which the proposals by Jensen, Karoly, & Braver (1986) stand out for their analysis and description of two widely used tools. The 101-point Numerical Rating Scale (NRS-101) (Figure 10) is a numerical scale ranging from "0" to "100". This scale can be applied either verbally or in writing, making it versatile across different contexts. The 11-point Box Scale (BS-11) (Figure 11) consists of a series of eleven numbers ("0" to "10"), each enclosed in a box. Respondents mark with an "X" the number that best represents the perceived intensity. This visual format is simple and intuitive, facilitating comprehension and quick response from individuals.

FIGURE 10: 101-POINT NUMERICAL RATING SCALE (NRS-101)



Source: Author. Adapted from Jensen, Karoly, & Braver (1986)

FIGURE 11: 1-POINT BOX SCALE (BS-11)

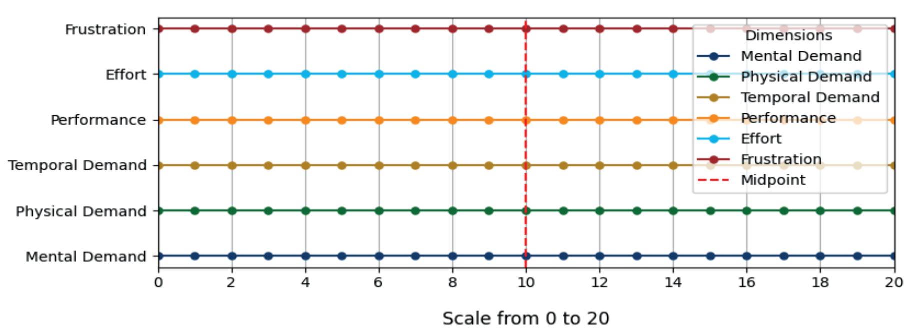


Source: Author. Adapted from Jensen, Karoly, & Braver (1986)

However, both scales remain unidimensional and do not account for the multiplicity and interdependence of dimensions present in complex phenomena. Integrating these scales into a modular system such as the SPMI can enhance the capture of both qualitative and quantitative nuances, addressing limitations inherent to traditional instruments.

In response to the constraints of unidimensional scales, new instruments have emerged that expand measurement by capturing human experience in specific tasks. In this regard, Hart & Staveland (1988) developed the NASA-TLX (Task Load Index) (Figure 12), a tool designed to measure perceived workload in task execution. The index assesses six core dimensions: mental demand, representing the cognitive effort involved; physical demand, related to the physical exertion required; temporal demand, reflecting the time pressure during the task; performance, based on self-assessment of effectiveness, ranging from "Good" to "Poor"; effort, indicating the overall level of perceived exertion; and frustration, associated with irritation or dissatisfaction experienced. These dimensions are rated on a scale from "0" to "100" (often converted to a 20-point scale for simplicity), with descriptors ranging from "Low" to "High", enabling precise identification of workload levels associated with task performance.

FIGURE 12: TASK LOAD INDEX SCALE (NASA-TLX)

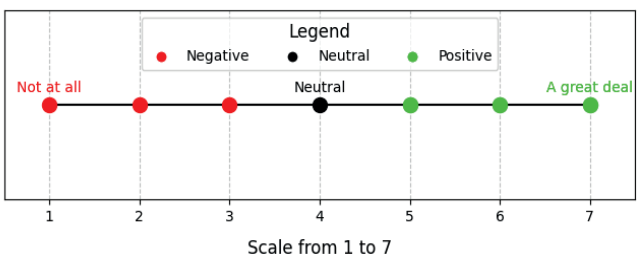


Source: Author. Adapted from Hart, S. G., & Staveland, L. E. (1988); and Hart (2006)

This modular and integrated approach exemplifies the necessary advancement to overcome the unidimensionality of conventional instruments, reinforcing the conceptual foundation that underpins the SPMI.

Considering this expanded evaluative focus, centered on the integration of subjective judgments and contextual interpretations, one may highlight the proposal by Lyubomirsky & Lepper (1999), who developed the Subjective Happiness Scale (SHS) (Figure 13), a measure of subjective happiness that globally and subjectively assesses individuals' perception of happiness. The scale consists of four items: two ask respondents to evaluate themselves regarding their overall happiness and in comparison to their peers; the other two present descriptions of happy and unhappy individuals and ask respondents to indicate the extent to which these descriptions apply to them. Items are rated on a 7-point scale ranging from "1" (strongly disagree) to "7" (strongly agree), and the responses are used to compute an average score, where higher values indicate higher levels of subjective happiness.

FIGURE 13: SUBJECTIVE HAPPINESS SCALE (SHS)



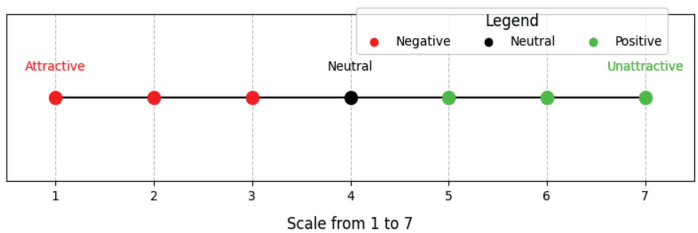
Source: Author. Adapted from Lyubomirsky, S., & Lepper, H. S. (1999)

Despite its breadth, the model remains centered on a single dimension of evaluation, underscoring the need for modular and multidimensional systems, such as the SPMI, to capture the complexity inherent in human experiences within technological and social contexts.

Following investigations into subjective workload in operational settings, with an emphasis on dimensional independence and contextual validity of measurements, Hart (2006) states that the dimensions of the National Aeronautics and Space Administration–Task Load Index (NASA-TLX) (Figure 12) were selected to represent independent aspects of the subjective workload experience, designed to capture distinct facets of this construct. He emphasizes that contextual adaptations require prior validation to ensure measurement sensitivity and validity.

Continuing the assessment of subjective experience in computational environments, Laugwitz, Held, & Schrepp (2008) employed the User Experience Questionnaire (UEQ) (Figure 14), which uses a 7 point semantic differential scale with opposing extremes such as "attractive" and "unpleasant". This scale was designed to capture the agent's perception of software products, minimizing central tendency biases in responses.

FIGURE 14: USER EXPERIENCE QUESTIONNAIRE (UEQ) SCALE

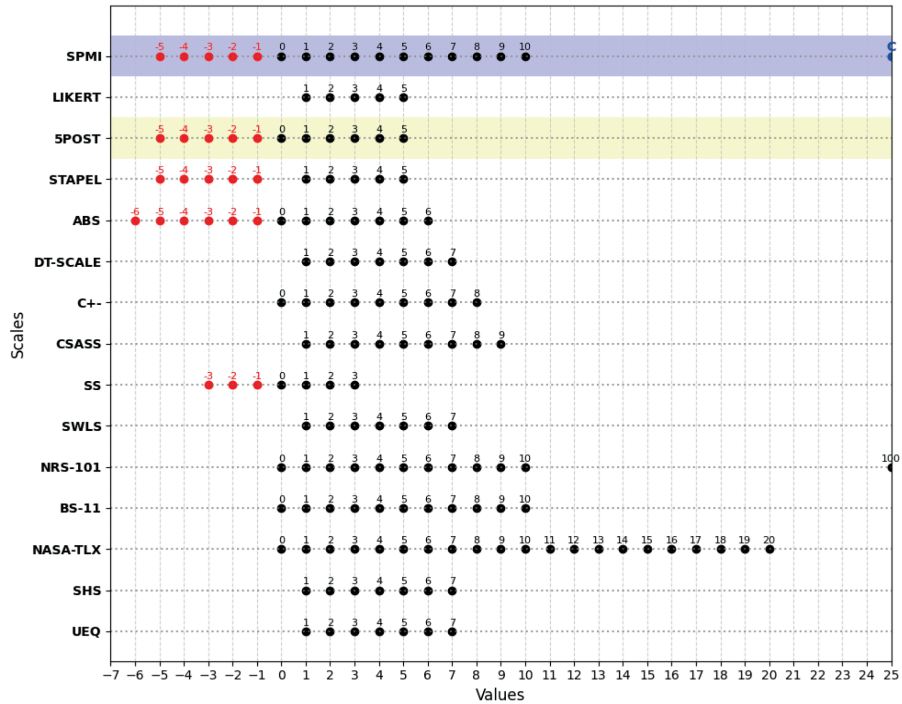


Source: Author. Adapted from Laugwitz, Held, & Schrepp (2008)

Although it presents a semantic differential structure, the scale does not incorporate modular scoring mechanisms nor multidimensional logic. This limitation underscores the need for instruments like the SPMI, which integrate multiple evaluative vectors with the capacity for contextual adaptation and superior metric granularity.

The approaches examined were selected to address specific measurement purposes in varied contexts. Considering the specialized literature surveyed, the dimensional diversity, and the complexity of the phenomena analyzed, these scales are compared to the SPMI regarding their structural and functional properties (Figure 15).

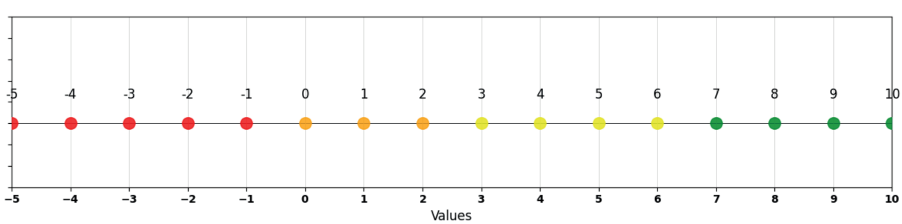
FIGURE 15: SPMI AND SCALES: COMPARISON AND SCOPE



Source: Author.

The SPMI was developed to address diverse integrated dimensions and elements. The system's scoring ranges from "-5" to "10" (Figure 16), enabling critical investigation and evaluation of evaluative constructs.

FIGURE 16: INTEGRATED MODULAR MULTIDIMENSIONAL SCORING SYSTEM (SPMI) — INTEGER SCALE

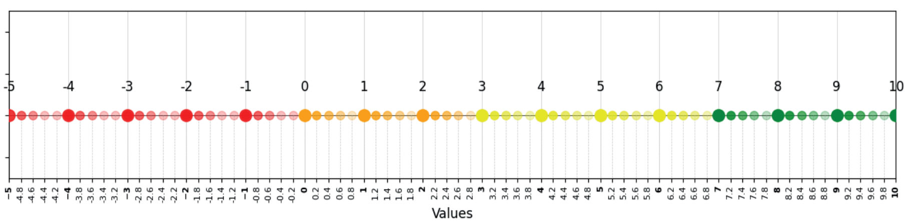


Source: Author.

The system also allows the application of two distinct scoring methods, integer and decimal, to address specific characteristics of certain dimensions. However, adequate technical expertise is essential to measure values separately in order to ensure effective processing of metrics and scores in combined sets.

The SPMI is designed to support the inclusion of decimal values (Figure 17), which are essential for detailed analyses of parts, components, lines of code, functions, microelements, and complex phenomena. The use of this feature requires rigorous knowledge to guarantee correct application and precision in data collection for each integrated dimension.

FIGURE 17: INTEGRATED MODULAR MULTIDIMENSIONAL SCORING SYSTEM (SPMI) — DECIMAL SCALE



Source: Author.

2.1 Methodological Principles and Modular Adaptation

Due to its flexibility and adaptability, the SPMI encompasses multiple dimensions and elements, allowing for the adequate collection of data according to the definition of specific parameters (see Chapter 1). The non-uniform distribution of scoring among elements within a dimension is supported, reflecting their particularities and ensuring precision in the processing of metrics and scores.

The system presents a well-defined logical structure, integrating theoretical and operational foundations. Each component contributes coherently to the evaluation, ensuring precise interpretation of results. Its construction follows a rigorous process of empirical validation and thorough literature review, guaranteeing the representativeness of each element within the assessed dimension.

A central characteristic of the SPMI is its adaptability: the system is designed to incorporate new evidence and technologies, remaining relevant amidst the evolution of evaluative fields. Based on a multidimensional approach, it enables comprehensive analyses that surpass unidimensional metrics, providing an integrated understanding of the evaluated objects.

2.2 Applications and Analytical Potential

The SPMI is an advanced evaluative technique designed to measure and interpret, with precision and depth, usability, effectiveness, and multiple aspects of technological objects, evaluative constructs, and situational phenomena. Its modular and multidimensional model allows for isolated or combined applications across various dimensions, ensuring that scores faithfully reflect the properties of the assessed elements.

Its architecture supports both the analysis of objective indicators and the investigation of subjective, hedonic, and pragmatic variables in empirical and experimental contexts. This capability renders it applicable to qualitative and quantitative studies, as well as diagnostic processes, technical evaluations, operational analyses, and scientific research.

Data collection within the SPMI is systematic, rigorously structured, and enables the production of detailed reports, facilitating comparative analysis, pattern identification, and decision-making support in technological and interactional contexts. When incorporated into investigations of complex constructs, the system allows an expanded understanding of factors influencing the evaluated phenomena, contributing to knowledge advancement and the development of solutions aligned with contemporary demands of agents and the systems in which they operate.

3 INTEGRATED MODULAR COLOR CLASSIFICATION AND DEFINITION SYSTEM (SCDMIC)

O SCDMIC (Sistema de Classificação e Definição Modular Integrado de Cores – SCDMIC) constitutes a chromatic evaluative architecture designed to represent, with high inferential resolution, the position of each element relative to complex constructs defined within the analyzed technical scope. Its logic relies on five colors, blue, red, orange, yellow, and green, used as codifiers of distinct evaluative states associated with graduated levels of compliance, severity, and intervention requirement. Each color expresses not only a degree of conformity to design requirements but also the nature of the expected response in the process of correction, refinement, or validation of the element.

During measurement cycles, direct visualization of the assigned colors is often restricted to preserve evaluative neutrality and prevent premature interpretive interference. The system operates integrally with data inferred by the SPMI, transforming numerical scores into continuous visual projections via a Modular Heatmap that organizes data into chromatic patterns for easy reading. This representation enables immediate identification of technical attention zones, critical states, and areas of full compliance, providing a functional reading of the overall performance status of the evaluated elements.

Analytical components are also articulated, such as the Error Severity Map and the Modular Risk Map, which expand the system's inferential power. The Error Severity Map classifies errors by technical severity, highlighting the magnitude of identified dysfunctions. The Risk Map structures the analysis through matrices crossing the probability of occurrence with the potential impact of each failure, guiding decisions based on technical or interactive threat scenarios. The combination of these maps enables a holistic diagnosis that is simultaneously granular and systemically articulated, essential for precise and technically justified interventions. Table 1 formalizes the chromatic levels and their respective definitions, serving as a normative reference for the interpretation of evaluations within the SCDMIC context..

TABLE 1: INTEGRATED MODULAR COLOR CLASSIFICATION AND DEFINITION SYSTEM (SCDMIC)

Level/ Color	Meaning	Technical Definition
1	Excellent	Indicates full compliance with the technical and functional requirements of the evaluated construct. Represents ideal performance, without operational restrictions, with maximum adherence to design parameters and no compromise to experience or functionality.
2	Moderate	Reflects intermediate states requiring targeted adjustments or additional technical checks. Does not compromise overall operation but signals the need for localized interventions to prevent failure propagation or functional degradation of the construct.
3	Problematic	Denotes significant deficiencies in evaluated requirements, indicating structural or operational faults that impair flow, usability, or interaction safety. Requires specific corrective actions to restore minimum compliance levels.
4	Critical	Corresponds to severe failure states, with dysfunctions that render the object unsafe, inefficient, or nonfunctional. Implies significant operational risks, requiring immediate intervention and priority corrective measures.
5	Systemic Conditional	This level represents a special analytical category, not assigned by direct evaluation but activated by systemic inference. The blue color operates as an inferential emergency marker, triggered when the validity of one dimension logically depends on the performance of another in interdependent construct structures. Requires interdimensional reading, contextualized analysis, and understanding of the relationship among functional intent, operational action, and systemic outcome. Its application is restricted and based on high-level technical-evaluative cross-analyses.

The chromatic levels employed in the SCDMIC framework are presented, assigning precise semantic and operational meanings to each color category. These classifications articulate gradations of conformity, functional adequacy, and intervention urgency, ranging from optimal compliance to critical system failures. The SCDMIC further includes a unique systemic conditional level, reflecting complex interdependencies within multidimensional constructs. This structure offers a clear, normatively grounded guide to interpret evaluation results, ensuring accuracy and contextual depth across diverse technical and interactional scenarios.

Source: Author.

Designed as a functional module within the evaluative framework, the SCDMIC does not operate in isolation but as an integrated modular component of the assessment system. Its core strength lies in the ability to transform abstract data into highly organized visual representations, enabling intuitive reading without compromising technical accuracy. This capability provides development, validation, or auditing agents with refined judgment tools, guided by structured evidence and rigorous inferential criteria.

By articulating scoring, color, inference, and mapping, the SCDMIC functions as a deep analytical interface between quantitative data and functional interpretation, establishing itself as an indispensable tool in contexts demanding precision, adaptability, and reliability in the evaluation of technologies, interactions, and complex systems.

4 DISCUSSION

The literature on measurement scales reveals enduring methodological tensions relevant to contemporary evaluation systems. Cox III (1980) emphasizes that defining the optimal number of response alternatives in a scale must maximize the transmission of meaningful information without inducing excessive response error. This balance is achieved when the ratio between systematic variance and total variance is optimized. The SPMI advances this landscape by introducing a scoring architecture that not only balances the number of alternatives and discriminative sensitivity but also expands the analytical scope through decimalized scales controlled by polarity and inference. Consequently, the information conveyed by the scale depends not solely on the number of points but on the integration of intensity, direction, and contextual coherence, parameters that elevate analytical potential and decision granularity.

In the realm of subjective experiences, Russell & Bullock (1986) argue that emotional categories are not mutually exclusive but rather overlapping concepts with varying degrees of membership. This view proposes an intercategorical structure where relationships between emotions are systematic and reflect similarities that reinforce the fuzzy nature of emotions, characterized by gradual and interdependent boundaries. This conception is directly incorporated into the SCDMIC, which replaces static classifications with continuous, graded, and inferential chromatic coding. Assigned colors do not correspond to fixed labels but to adherence states varying according to the intensity and quality of the evaluated value. This structure enables representation of areas of functional ambiguity, hybrid states, and nonlinear systemic behaviors, elements that evade traditional metrics and require higher-order interpretive coding.

Highlighting the need for alignment and coherence, Carifio & Perla (2007) argue that a scale's validity depends on the integration between its logical content and mathematical components, stressing that psychometric scales encompass both an empirical and logical structure (macro level) and specific response properties (micro level). They emphasize that instrument reliability requires consideration of the analytical unit, internal consistency, and a rigorous item construction and validation process. The SPMI and SCDMIC embody this alignment through systemic integration of logical macrostructure (evaluative dimensions, value functions, applicability domain) and empirical microstructure (analysis points, observed variables, inference mechanisms). The result is a modular, scalable system whose analytical units can be calibrated according to construct nature and complexity, measurement purpose, and inference type. This architecture maximizes internal consistency and supports a contextualized validation process sensitive to domain-specific demands.

The methodological originality of both systems lies precisely in rejecting oversimplification. The SPMI breaks away from unidimensional models by proposing scales structured on multiple analytical axes, while the SCDMIC shifts static result visualization toward dynamic, inferentially integrated maps such as the Heat Map, Error Severity Map, and Risk Map. This resource integration enables deeply articulated analyses linking form, function, outcome, and context, raising interpretive levels in evaluation.

These contributions transcend technical innovation, proposing a paradigmatic redefinition of measurement in high-complexity contexts. By simultaneously operating at logical-inferential, perceptual-interpretive, and empirical-numerical levels, the systems establish an evaluative model capable of meeting emerging demands in applied science, interaction engineering, and systemic performance analysis. They underscore the relevance of classical foundations while expanding them through an integrated modular architecture toward a new scientific evaluation grammar.

5 CONCLUSION

The SPMI establishes an evaluative architecture grounded in the logical representation of polarity and intensity of the analyzed states. By assigning values that accurately reflect both the direction (positive or negative) and the magnitude of the evaluated experience, the system overcomes structural limitations of conventional scales, which tend to conflate negative evaluations with expressions of low positivity, generating interpretative noise. Operating with scales ranging from -5 to +10, in both integer and decimal versions, the SPMI offers a numerical syntax more faithful to the perceptual and inferential logic of the evaluating agent, enabling a more transparent, granular, and technically defensible reading of the collected data.

This model not only translates subjective evaluations with greater fidelity but also aligns with cognitive principles that organize the agent's understanding around affective and functional polarities. The direct association between symbolic value and numeric value ensures greater adherence between perception and outcome, expanding the representational validity of measurements in subjective, technical, and operational contexts. The system's modular architecture further enables its application across multiple evaluative domains, from technological objects to interactive systems, preserving internal coherence and contextual sensitivity without compromising inferential rigor.

Complementarily, the SCDMIC provides an interpretative visual layer that enhances the intelligibility of results and chromatically translates the evaluative states inferred by the SPMI. The integration between numerical values and color codifiers establishes a visual semantics that facilitates the reading of critical patterns, transition zones, and optimal states, incorporating a continuous and interpretive logic into the analysis.

Together, these two systems offer an unprecedented and highly applicable methodological proposal, capable of supporting analytical decisions across multiple levels, from engineering to psychometrics, usability to risk management. By integrating logical formalism, metric rigor, visual coding, and modular adaptability, the SPMI and SCDMIC represent a paradigmatic inflection in the measurement of complex constructs, not only enhancing evaluative precision but redefining the very limits of what can be coherently, deeply, and intelligibly measured.

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CHAPTER 3

GLOBAL USABILITY AND INTERACTION SCORE (SGUI) AND INTEGRATED MODULAR CRITICAL SCORE (SCMI)

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ABSTRACT — The intensification of systemic complexity in technological objects and the increasing sophistication of interactions between agents and artifacts demand the development of more sensitive, modular, and integrable evaluation metrics. This study presents the technical-scientific proposition of two interdependent analytical devices: the Global Usability and Interaction Score (SGUI) and the Integrated Modular Critical Score (SCMI). Structured within the epistemic-functional architecture of the Integrated and Advanced Core Framework for the Analysis and Evaluation of Technological Objects (FCIA-OT), both operate on the SPMI metric core, enabling structured quantification and standardized visual interpretation of the maturity of evaluated elements. The SGUI introduces a multiscalar percentage-based metric derived from relative frequency, favoring the identification of dominant configurations in complex interaction environments. The SCMI emphasizes the traceability of critical data with high systemic density and low recurrence, functioning as a proportional metric of technical criticality. The formulation of these modules consolidates central metric-reading instances within FCIA-OT, enhancing its diagnostic capacity, inferential precision, and normative robustness in modular evaluation systems, with direct impacts on functional audits, interaction engineering, and the technical governance of technological ecosystems.

KEYWORDS — SGUI; SCMI; FCIA-OT; Interaction Engineering; Metrics; Usability; Systemic; Analysis and Evaluation; Technical Criticality.

1 INTRODUCTION

The intensification of systemic complexities in technological objects, combined with the growing sophistication of interactive dynamics between agents, artifacts, and environments, demands the development of evaluative metrics capable of operating precisely across different levels of criticality, functional maturity, and technical density. Traditional usability analysis models prove structurally inadequate for addressing the heterogeneity of contemporary systems and the semantic complexity inherent in their technical-operational attributes.

The FCIA-OT establishes a technical-epistemological architecture designed for the modular evaluation of technological objects, interfaces, and systems. Grounded in the Systemic Matrix of Integrated Vectorial Dimensions (MSDVI), comprising twelve interdependent dimensions, the model organizes cognitive, affective, functional, contextual, and structural parameters within a synergistic framework, engineered to capture both objective and subjective attributes. This cohesive technical-analytical matrix enables integrated assessments with a high degree of inference regarding systemic performance, technological maturity, and interactional dynamics (see Chapter 1).

Based on this structure, two systemic analytical modules were developed: the Global Usability and Interaction Score (SGUI) and the Integrated Modular Critical Score (SCMI). Both derive directly from the matrix core of the model, the SPMI, responsible for the weighted assignment of values to each evaluated element, and may be integrated, when necessary, into the standardized visual encoding of SCDMIC to enhance the graphic intelligibility of diagnostics (see Chapter 2).

The SGUI introduces a multiscalar, percentage-based metric derived from the relative frequency of attributes in each dimension of FCIA-OT. Its calculation structure enables the identification of recurrent patterns, dominant configurations, and expressive components in highly complex contexts, favoring comparative readings between evaluated objects, modules, or agents. Optional incorporation into the chromatic system of SCDMIC expands the visual expressiveness of results, enhancing their interpretative capacity in technical audits or large-scale modular analyses.

The SCMI operates as a proportional critical metric oriented toward the traceability of elements with high technical density and low statistical incidence. Through the weighted aggregation of SPMI values by element or dimension, the SCMI highlights records that, although infrequent, bear significant systemic weight. This approach prevents the dilution of critical data and ensures the inferential integrity of outputs, strengthening the technical governance of the analyses performed.

Both devices are organically integrated into FCIA-OT not as peripheral extensions, but as central instances of its own evaluative paradigm. Their methodological articulation consolidates a modular reading system endowed with diagnostic precision, technical-functional sensitivity, and inferential robustness. This significantly expands the applicability of FCIA-OT in interaction engineering, in structured usability evaluation, and in the formulation of technical protocols aimed at the systemic maturity of complex technological objects (see Chapter 4).

2 GLOBAL USABILITY AND INTERACTION SCORE (SGUI)

The Global Usability and Interaction Score (SGUI) constitutes an advanced technical-scientific module within FCIA-OT, designed to enhance the granularity, precision, and analytical depth in the evaluation of technological objects from multiple interactional perspectives. Its structure is based on the twelve core dimensions of the framework, offering an integrated approach that combines quantitative and qualitative criteria within a single interpretive core.

The SGUI operates as a relational scoring system per element, in which each entry corresponds to the frequency of occurrence of an evaluative component within the analytical matrix of a specific dimension. This frequency is converted into a relative percentage, according to the following formula:

$$SGUI_{\text{element}} = \left(\frac{Frequency_{\text{element}}}{\sum Frequencies_{\text{all}}} \right) \times 100$$

Source: Author.

Where: $\text{Frequency}_{\text{element}}$ represents the number of times the element was recorded in the matrix of the dimension, and $\sum \text{Frequencies}_{\text{all}}$ corresponds to the total number of records in that dimension.

The resulting percentage value expresses the relative representativeness of the element within the evaluated structure, functioning as an index of technical expressiveness. These data support modular classification processes, comparative positioning, and refined technical judgment, based on analytical ranges organized into three or five levels, depending on the nature of the dimension under consideration.

The SGUI may be complemented by chromatic scales derived from the SCDMIC system, which enhance diagnostic visualization through standardized patterns of recurrence, intensity, and distribution. When applied, this visual resource reinforces the intelligibility of results and supports technical decision-making in localized scenarios or more complex systems.

Consolidated as a high-performance analytical instance within the FCIA-OT ecosystem, the SGUI integrates rigorous epistemological foundations with adaptable practical applications, enabling the evaluation of interactional configurations with depth, comparability, and structural coherence.

2.1 Analytical Dimensions of the SGUI

The SGUI represents the technical-scientific synthesis of methodological evolution in usability and interaction analysis applied to technological objects. Developed from the structural convergence of FCIA-OT's foundations, its modular core incorporates both classical and contemporary references from cognitive sciences, interface engineering, and interactive systems, articulating perceptual, affective, and functional modeling based on advanced principles of agent–technology interaction.

By operationalizing the framework's twelve integrated dimensions, the SGUI enables data extraction at multiple levels of complexity and interrelation, converting interactional phenomena that are difficult to measure into precise, comparable, and technically robust metrics. Its analytical logic supports applications in diverse contexts, from the evaluation of products and systems to the design of new devices and interactive architectures, while preserving scientific integrity and diagnostic adaptability as guiding axes.

The development of SGUI also aligns with the historical critique of traditional metric limitations. Gross & al. (1982) proposed, in software engineering, a complexity model aimed at quality prediction and test prioritization, structured on the correlation between formal attributes and potential production failures. In the interaction domain, Lindquist (1985) introduced specific metrics to assess the semantic and procedural complexity of dialogic structures, while warning of the hybrid nature of interfaces, constructed by both user and system actions, which challenges the direct application of conventional metrics.

In the field of usability, Elmaoun, Fujihara, & Boyle (1991) emphasized the inevitable incorporation of subjective criteria in assessments, due to the direct interference of human perception. McGee (2003) deepened this critique by arguing that usability is a multifaceted perceptual construct with no physical equivalent, rendering ordinal scales such as Likert problematic. In response, he proposed magnitude estimation as an alternative for measuring phenomena derived from multidimensional stimuli, such as interfaces. Consistently, McGee (2004) reinforces that questionnaires like SUS or SUMI are restrictive in scope and that isolated objective metrics do not provide a systemic view of usability, nor do they allow precise comparability between components.

The SGUI emerges as a response to this fragmented landscape. By integrating technical rigor, modular modeling, and intelligent visual systems, it establishes a new standard of analysis in interaction engineering. Its ability to measure, classify, and contrast elements based on multifactorial criteria offers engineers, analysts, and usability scientists an unprecedented tool in both precision and scope. Its calculation logic is based on the relative frequency of elements in each dimension, ensuring comparability and transparency.

The SGUI's interdimensional structure, along with its synergy with chromatic scales derived from SCDMIC, enables the identification of both microphenomena and recurring patterns of interactional complexity, allowing for precise diagnostics and guiding reengineering processes and technological innovation (Tables 1 through 12). The system not only expands the analytical capacity of FCIA-OT but also establishes a new reference for future modular evaluation architectures in contexts of high interactive complexity.

The technical scores of the SGUI's twelve dimensions were developed from a robust inferential base, involving synthetic analysis of real cases and detailed operational mappings (see Chapters 1 and 2). Each dimensional vector was designed to accurately reflect distinct levels of performance, maturity, and contextual adequacy, ensuring internal consistency and diagnostic reliability within the model. The definition of percentage ranges and maturity levels follows a modular structure, allowing for the comparison and monitoring of results across different analytical scales.

The use of chromatic encoding as a visual resource contributes to the immediate clarity of diagnostics, enhancing SGUI's ability to deliver precise and accessible technical assessments, regardless of the profile of the agent, object, or system being analyzed. The following section presents the SGUI dimensions in detail, including their operational definitions, calculation criteria, and interpretation of the respective scores.

2.1.1 Knowledge/Experience Dimension (CEX)

The Knowledge/Experience Dimension (Conhecimentos/Experiência – CEX) measures the cognitive complexity and technical proficiency required for the efficient operation of the evaluated object (Table 1). It functions as a parameter for interpretive calibration, indicating the degree of technological maturity based on the compatibility between the agent's capabilities and the demands imposed by the system. The lower the level of experience needed to achieve high performance, the higher the functional maturity of the technology.

The score is calculated based on three objective criteria: success rate, execution time in comparison to experts, and frequency of reported difficulties. The scores follow an ascending order of technical proficiency and allow for the percentage-based identification of the level of operational criticality involved. High scores, such as 99%, do not indicate failure but evaluator excellence. The value of 100% is reserved for the developer or manufacturer, as it expresses full mastery of the technological structure. In this context, the SCDMIC's chromatic encoding indicates the maximum level of technical demand, not the occurrence of error.

TABLE 1: DEFINITION OF THE STANDARD SCORE FOR KNOWLEDGE AND EXPERIENCE (CEX)

Knowledge/ Experience Levels	Definitions	1	2	3
Beginner	1. Completes up to ≤50% of basic tasks without supervision. 2. Execution time: ≥50% slower than experienced agents. 3. Reported difficulties: ≥70%.	≤50%	≥50%	≥70%
Basic Operator	1. Completes ≥60% of basic tasks successfully. 2. Execution time: ≥30% and <50% slower than experienced agents. 3. Reported difficulties: ≥40% and <70%.	≥60%	≥30% and <50%	≥40% and <70%
Functional Agent	1. Completes ≥70% of tasks successfully. 2. Execution time: ≥20% and <30% slower than experienced agents. 3. Reported difficulties: ≥20% and <40%.	≥70%	≥20% and <30%	≥20% and <40%
Operational Technician	1. Completes ≥80% of tasks successfully. 2. Execution time: ≥10% and <20% slower than experienced agents. 3. Reported difficulties: ≥10% and <20%.	≥80%	≥10% and <20%	≥10% and <20%
Advanced Technician I	1. Completes ≥85% of tasks successfully. 2. Execution time: ≥5% and <10% slower than experienced agents. 3. Reported difficulties: ≥5% and <10%.	≥85%	≥5% and <10%	≥5% and <10%
Advanced Technician II	1. Completes ≥90% of tasks successfully. 2. Execution time: <5% slower than experienced agents. 3. Reported difficulties: <5%.	≥90%	<5%	<5%
Integration Specialist	1. Completes ≥95% of tasks successfully. 2. Execution time: on par with most experienced agents. 3. Reported difficulties: <5%.	≥95%	0%	<5%
Technological Architecture Specialist	1. Completes ≥98% of tasks successfully. 2. Execution time: 0% slower, equal to most experienced agents. 3. Reported difficulties: <3%.	≥98%	0%	<3%
Systemic Professional	1. Completes ≥99% of tasks successfully. 2. Execution time: 0%, equal to the best in the field. 3. Reported difficulties: <1%.	≥99%	0%	<1%
Strategic Level / Developer	1. Completes 100% of tasks with excellence. 2. Execution time: 0%, fully optimized with no room for improvement. 3. Reported difficulties: 0%.	100%	0%	0%

Column headers: (1) Success Rate (%); (2) Execution Time (%); (3) Reported Difficulties (%). The CEX score presents ten progressive proficiency levels based on objective criteria of performance, execution time, and difficulty, enabling inference of technological maturity and operational criticality according to the agent's profile.

Source: Author.

2.1.2 Affordance Dimension (AFF)

The Affordance Dimension (Dimensão Affordance – AFF) evaluates perceptual clarity, implicit functionality, and the congruence between form and purpose in the elements that compose the technological object. This is a critical axis in the analysis of agent–technology interaction, as it concerns the artifact's capacity to signal, induce, or allow actions consistent with its intended function. The structure of this dimension comprises two complementary analytical blocks: Conventional Affordance (Table 2) and Conditional Affordance (Table 2.1).

Conventional Affordance is assessed based on recognition rate, clarity of use, and the need for prior learning. High values indicate that the function is readily recognized and operated without ambiguity, reinforcing usability robustness and design maturity. Critical scores, such as those observed in the levels of Uninterpreted Affordance, point to structural failures in the functional communication of the object, directly compromising interaction and increasing the error rate.

Conditional Affordance, in turn, encompasses functionalities that emerge through practical use and are not necessarily foreseen in the original design. This category unfolds into two types: Emergent and Finalistic. Emergent affordance captures the progressive activation of actions not initially anticipated but functionally valid; whereas finalistic affordance measures the correspondence between the agent's intention, practical execution, and functional outcome. Both are evaluated using percentage-based ranges that qualify stability, predictability, and adaptability of use.

TABLE 2: DEFINITION OF THE STANDARD SCORE FOR AFFORDANCE (AFF)

Types of Affordance	Definitions	1	2	3
Consolidated	1. The object's message is clear and widely recognized, without ambiguity (≥95%). 2. No significant margin for error or incorrect actions (≤5%). 3. No relevant need for learning (≤5%).	≥95%	≤5%	≤5%
Perceptible	1. The message is clear but may require attention (≥90% and <95%). 2. Small margin of error due to direct interpretation (≤10%). 3. Low need for learning (≤10%).	≥90% and <95%	≤10%	≤10%
Interpreted	1. The message requires logical inference or prior association (≥70% and <90%). 2. Moderate margin for error (≤20%). 3. Intermediate learning required (≤20%).	≥70% and <90%	≤20%	≤20%
Requires Additional Information	1. The message depends on external information to be understood (≥50% and <70%). 2. Significant error risk without training (≤40%). 3. Moderate learning required (≤40%).	≥50% and <70%	≤40%	≤40%
Positive Inductive	1. The message is ambiguous or dual but can be learned over time and through context (≥30% and <50%). 2. Moderate error risk (≤50%). 3. High learning requirement (≤50%).	≥30% and <50%	≤50%	≤50%
Dual Interpretation	1. The message is ambiguous and may lead to multiple interpretations (≥10% and <30%). 2. High risk of error (≤70%). 3. High learning requirement (≤70%).	≥10% and <30%	≤70%	≤70%
Negative Inductive	1. The message is inconsistent or confusing, inducing error (≥5% and <10%). 2. Extreme error risk or undesired actions (≤90%). 3. Very high learning requirement (≤90%).	≥5% and <10%	≤90%	≤90%
Uninterpreted	1. The object does not transmit a meaningful message, rendering its use non-operational (<5%). 2. Maximum error risk (>90%). 3. Critical learning requirement (>90%).	<5%	>90%	>90%

Column headers: (1) Recognizability (%); (2) Error Risk (%); (3) Learning Requirement (%). The AFF score establishes percentage-based criteria applicable to conventional affordance, organized into eight gradual levels. Each level combines objective indicators related to perceptual clarity of function, operational error risk, and the need for prior learning. The scale enables diagnosis of the functional maturity of evaluated elements and supports inference regarding the consistency between form, function, and the agent's expected comprehension. Higher levels indicate communicative robustness and a low degree of functional ambiguity; critical levels reveal structural perceptual failures.

Source: Author.

In these conditional categories, the SGUI adopts a systemic conditional model, applying interdimensional rules to assign scores. The system employs an auxiliary chromatic code (blue) in visualizations and reports to indicate that the score results from integrations across multiple dimensions. This code is not static: it is automatically converted into one of the four main colors of the SCDMIC (green, yellow, orange, red, and the conditional blue), according to the final score range inherited from the related dimensions. This architecture ensures logical traceability, interpretive consistency, and methodological integrity in the visualization of the system's analytical data (Table 2.1).

The AFF dimension provides objective and interpretive input essential for validating design solutions, diagnosing usability failures, and guiding technical decisions in real-world use contexts. Its implementation within the SGUI guarantees an advanced level of diagnostic sensitivity, particularly in scenarios involving functional ambiguity, progressive learning, and cognitive adaptation by the agent.

TABLE 2.1: DEFINITION OF THE STANDARD SCORE FOR CONDITIONAL AFFORDANCE (AFF)

Types of Affordance	Definitions	1	2	3	4	5
Emergent	1. (0%): Not applicable. No valid emergent affordance is observed, either due to the absence of recurring practical use or complete disconnection from the artifact's functional context. 2. (>0% ≤30%): The affordance is not designed, but weak signs of functional manifestation appear, perceptible only through intense and highly contextualized use. High error potential; extreme dependence on agent adaptation. 3. (>30% and ≤50%): The emergent affordance begins to manifest with some practical consistency but remains unstable or highly dependent on repetition and context. Learning is still slow. 4. (>50% and ≤80%): A clear functional manifestation of the affordance is observed, with significant agent adaptation. The learning curve stabilizes, and usability becomes predictable. 5. (>80%): Fully validated and functional emergent affordance. Though not originally designed, it operates with stability and efficiency in real-world contexts. Learning becomes organic.	0%	>0% ≤30%	>30% and ≤50%	>50% and ≤80%	>80%

Finalistic	1. (0%): Not applicable. The agent's action did not produce functionally valid outcomes or lacked a clearly defined intention to allow measurement of the intention–function link. 2. (>0% ≤30%): The function is activated but does not achieve the intended final purpose. There may be result deviation, ambiguous understanding, or incorrect execution. 3. (>30% and ≤50%): The action partially fulfills the intended function, but operational failures, inconsistencies, or gaps remain in the intention–action–result correspondence. (Heat map: Orange). 4. (>50% and ≤80%): The action leads to a functionally appropriate result in most cases. The relationship between the activated function and the defined purpose is clear and measurable. 5. (>80%): The intended outcome is fully achieved with efficiency. The correspondence between the agent's intention, the executed action, and the obtained result confirms the functional success of the interaction.	0%	>0% ≤30%	>30% and ≤50%	>50% and ≤80%	>80%

Column headers: (1) Score Level 1 (%); (2) Score Level 2 (%); (3) Score Level 3 (%); (4) Score Level 4 (%); (5) Score Level 5 (%). The AFF score establishes the percentage-based criteria applicable to conditional affordances, structured in two types: Emergent and Finalistic. In the Emergent type, the score reflects the degree of progressive functional manifestation of previously unplanned but viable uses, signaling the object's adaptability. In the Finalistic type, it assesses the congruence between the agent's intention, the practical execution, and the fulfillment of the functional purpose. The percentage ranges qualify the maturity of use, semantic–pragmatic alignment, and operational stability of emerging interaction patterns.

Source: Author.

2.1.3 Perception Dimension (PRC)

The Perception Dimension (Dimensão Percepção – PRC) assesses the perceptual quality of the affordance based on clarity, complexity, and the subjective response of agents upon encountering the object. This is a critical axis within the SGUI, as it marks the initial moment of interaction, when the bond between the agent and the system's functional proposition is established (Table 3).

Scores within this dimension are defined based on three main criteria: the rate of agents who correctly perceive the proposed functionality, the perceived complexity in interpreting the affordance, and the subjective experience reported during the first contact. The greater the immediate perception, the lower the perceived complexity, and the more positive the experience, the higher the assigned score.

The classification of perception types, Instructive, Argumentative, Reactive, Inquisitive, and Exploratory, enables the qualification of the cognitive load required and the level of design clarity. Instructive perception reflects a scenario of high clarity, low complexity, and predominantly positive response, indicating a mature system. Exploratory perception reflects low immediate comprehension, high complexity, and frustrating user experiences, signaling perceptual criticality and failure in functional signaling.

TABLE 3: DEFINITION OF THE STANDARD SCORE FOR PERCEPTION (PRC)

Types of Perception	Definitions	1	2	3
Instructive	1. The system is highly intuitive; ≥95% of agents perceive the affordance immediately and clearly. 2. Minimal complexity, ≤10%. 3. Positive experience; ≥90% of agents interact without difficulty.	≥95%	≤10%	≥90%
Argumentative	1. The affordance is perceived after reflective analysis; ≥70% and <95% of agents identify its function after brief interpretation. 2. Moderate complexity, ≤30%. 3. Adaptable experience; ≥70% of agents comprehend after initial interaction.	≥70% and <95%	≤30%	≥70%
Reactive	1. The affordance is only perceived after ongoing interaction; ≥50% and <70% of agents recognize its function after repeated interaction. 2. Significant complexity, ≤50%. 3. Progressive experience; ≥50% of agents report improvement through practice.	≥50% and <70%	≤50%	≥50%
Inquisitive	1. Initial difficulty in perceiving the affordance; ≥30% and <50% of agents identify its function after substantial learning. 2. High complexity, ≤70%. 3. Limited experience; ≥30% of agents report initial dissatisfaction, but adaptation occurs with effort.	≥30% and <50%	≤70%	≥30%
Exploratory	1. The affordance is not perceived immediately; <30% of agents understand its function, requiring exploratory effort. 2. Extreme complexity, >70%. 3. Frustrating experience; <30% of agents consider the system comprehensible.	<30%	>70%	<30%

Column headers: (1) Affordance Clarity (%); (2) Interpretation Complexity (%); (3) Subjective Experience (%). The PRC score establishes the percentage-based criteria applicable to perceptual types, based on affordance clarity, interpretive complexity, and agents' initial subjective experience. The categories range from highly instructive and intuitive configurations to exploratory scenarios marked by functional ambiguity, cognitive effort, and frustration. The percentage score enables assessment of perceptual efficacy and the design intelligibility of the evaluated object.

Source: Author.

2.1.4 Affectivity Dimension (AFV)

The Affectivity Dimension (Dimensão Afetividade – AFV) captures the agent's emotional response during interaction with the technological object, analyzing affective states that vary in valence, intensity, and duration (Table 4). This dimension considers affectivity as a critical component of the user experience, directly influencing the continuity of interaction, perception of quality, and systemic trust. Within the SGUI, this dimension applies a scale that quantifies, in percentage terms, both positive responses, such as comfort, pleasure, engagement, and empathy, and negative states, such as anxiety, frustration, and withdrawal. The gradation of values enables the measurement of emotional fluctuation, affective stability, and the system's sensitivity in inducing, sustaining, or mitigating emotional responses, even in contexts of high functional complexity.

TABLE 4: DEFINITION OF THE STANDARD SCORE FOR AFFECTIVITY (AFV)

Types of Affectivity	Definitions	1	2	3
Emotional Comfort	1. Perceived comfort level during interaction: Comfort perception rate (≥90%). 2. Probability of perceived discomfort (≤10%). 3. Positive impact on overall emotional experience (≥85%).	≥90%	≤10%	≥85%
Pleasure/ Satisfaction	1. Degree of perceived pleasure or satisfaction during interaction (≥85%). 2. Areas for improvement identified during the experience (≤15%). 3. Overall impact of pleasure/satisfaction on interaction (≥80%).	≥85%	≤15%	≥80%
Curiosity	1. Desire to explore new interface elements: Exploration rate (≥80%). 2. Elements left unexplored (≤20%). 3. Impact on continued interaction motivated by curiosity (≥75%).	≥80%	≤20%	≥75%
Emotional Engagement	1. Degree of perceived emotional involvement during interaction (≥75%). 2. Probability of emotional disinterest (≤25%). 3. Contribution to maintaining emotional interest (≥70%).	≥75%	≤25%	≥70%
Immersion	1. Degree of total involvement in the experience (≥70%). 2. Elements perceived as immersion barriers (≤30%). 3. Impact on perception of full engagement (≥65%).	≥70%	≤30%	≥65%
Trust	1. Confidence level while interacting with the interface (≥65%). 2. Probability of perceived insecurity (≤35%). 3. Trust contribution to overall usability (≥60%).	≥65%	≤35%	≥60%
Surprise	1. Positive reaction to unexpected interface elements (≥60%). 2. Probability of unexpected elements causing frustration (≤40%). 3. Impact of surprise on the experience (≥55%).	≥60%	≤40%	≥55%
Relief	1. Degree of relief after overcoming difficulties (≥55%). 2. Elements that help prevent additional frustration (≤45%). 3. Impact of relief on overall usage perception (≥50%).	≥55%	≤45%	≥50%

Empathy	1. Level of emotional connection promoted by the system (≥50%). 2. Elements that hinder emotional connection (≤50%). 3. Empathy's impact on the overall emotional experience (≥45%).	≥50%	≤50%	≥45%
Neutrality	1. Perceived emotional neutrality (0%). 2. Probability of elements generating relevant emotional impact (balanced positive/negative) (50%). 3. Contribution to emotional stability (0%).	0%	≥50%	0%
Anxiety	1. Degree of anxiety experienced during interaction (≥25%). 2. Elements generating discomfort or apprehension (≤75%). 3. Anxiety's impact on overall experience (≥20%).	≥25%	≤75%	≥20%
Tolerated Frustration	1. Acceptable level of frustration due to perceived value (≥15%). 2. Probability of frustration compromising the experience (≤85%). 3. Contribution to continued interaction despite difficulties (≥10%).	≥15%	≤85%	≥10%
Frustration	1. Level of frustration experienced during interaction (≥5%). 2. Elements amplifying discomfort and dissatisfaction (≤95%). 3. Impact of frustration on abandonment of use (≥5%).	≥5%	≤95%	≥5%

Column headers: (1) Perceived Frequency (%); (2) Oppositional Tolerance (%); (3) Emotional Weight (%). The AFV score establishes the percentage-based criteria applicable to affective responses triggered during agent–technology interaction, classified according to emotional valence, subjective intensity, and impact on the user experience. The scale spans from positive affects, such as comfort, pleasure, and empathy, to critical states like anxiety and frustration. These percentages reflect perception frequency, operational tolerance, and emotional load, allowing for inferences on affective stability, emotional engagement, and experiential resilience of the system evaluated. This is an essential dimension for diagnostics on acceptability, engagement, and affective dissonance in real-world usage contexts.

Source: Author.

2.1.5 Satisfaction Dimension (STSF)

The Satisfaction Dimension (Dimensão Satisfação – STSF) assesses the agent's overall perception of the technological object, expressing gradual levels of contentment or dissatisfaction (Table 5). The STSF score operationalizes percentage-based criteria that reflect perceived quality, the identified need for improvements, and the impact of this assessment on the overall experience. The categories range from extreme satisfaction, indicating an exemplary experience and no need for adjustments, to extreme dissatisfaction, which points to severe negative experiences and critical demands for improvement. This metric provides a direct indicator of acceptance and of the functional and emotional alignment between the agent and the evaluated system, serving as a key parameter for design adjustments and interaction optimization.

TABLE 5: DEFINITION OF THE STANDARD SCORE FOR SATISFACTION (STSF)

Types of Satisfaction	Definitions	1	2	3
Extremely Satisfied	1. The agent is completely satisfied with all aspects of the technological object. 2. Sees no need for improvements. 3. Exemplary experience.	≥95%	≤5%	≥95%
Very Satisfied	1. The agent is very satisfied. 2. Small areas could be improved. 3. Very positive experience.	≥85% and <95%	≤15%	≥85% and <95%
Quite Satisfied	1. The agent is generally satisfied. 2. Improvements are needed for greater contentment. 3. Generally positive experience.	≥70% and <85%	≤30%	≥70% and <85%
Satisfied	1. The agent is satisfied. 2. Several areas require improvement. 3. Partially positive experience.	≥60% and <70%	≤40%	≥60% and <70%
Moderately Satisfied	1. The agent is reasonably satisfied. 2. Identifies multiple improvement areas. 3. Neutral experience with negative aspects.	≥50% and <60%	≤50%	≥50% and <60%
Neutral	1. The agent has a neutral perception. 2. The object partially meets expectations. 3. Balanced experience between positive and negative.	50%	≥50%	50%
Dissatisfied	1. The agent is dissatisfied. 2. Significant issues found. 3. Generally negative experience.	≥40% and <50%	≥60%	≥40% and <50%
Quite Dissatisfied	1. The agent is quite dissatisfied. 2. The object needs substantial improvements. 3. Predominantly negative experience.	≥30% and <40%	≥70%	≥30% and <40%
Very Dissatisfied	1. The agent is very dissatisfied. 2. Multiple problematic areas identified. 3. Clearly negative experience.	≥20% and <30%	≥80%	≥20% and <30%
Extremely Dissatisfied	1. The agent is completely dissatisfied. 2. The object fails to meet expectations. 3. Severely negative and demotivating experience.	<20%	>80%	<20%

Column headers: (1) Perceived Quality (%); (2) Improvement Needs (%); (3) Experience Impact (%). The STSF score establishes percentage-based criteria applicable to the agent's satisfaction with the technological object. It presents a progressive scale of satisfaction levels based on objective indicators that assess perceived quality, the number of improvements required, and the overall impact on the user experience. The classification ranges from extreme satisfaction, characterized by a positive experience and no need for adjustments, to extreme dissatisfaction, indicating severe dissatisfaction and critical improvement demands. This scale enables a detailed evaluation of the alignment between the agent's expectations and the system's performance.

Source: Author.

2.1.6 Effectiveness Dimension (EFT)

The Effectiveness Dimension (Dimensão Efetividade – EFT)) assesses the technological object's ability to ensure the successful execution of proposed tasks, considering both objective and subjective aspects of interaction (Table 6). The EFT score quantifies, in percentage terms, the success rate in task performance, the ease of learning as reflected in the adaptation time, and the perceived clarity during use. This metric integrates quantitative and qualitative data to provide a comprehensive view of the system's functional performance, serving as a key input for accurate diagnostics and improvement strategies. The evaluation encompasses high levels of effectiveness, marked by high success rates and low learning curves, as well as critical levels that reveal significant failures in usability and user satisfaction.

TABLE 6: DEFINITION OF THE STANDARD SCORE FOR EFFECTIVENESS (EFT)

Types of Effectiveness	Definitions	1	2	3
Effective	1. Task success rate ≥95%. 2. Minimal learning curve (adaptation time ≤5% of the typical usage cycle). 3. Subjective clarity assessment: ≥90% of agents consider the system clear and efficient.	≥95%	≤5%	≥90%
Considerable	1. Task success rate between ≥70% and <95%. 2. Noticeable but manageable learning curve (adaptation time >5% and ≤15%). 3. Subjective clarity assessment: ≥70% and <90% of agents find the system understandable after first contact.	≥70% and <95%	>5% and ≤15%	≥70% and <90%
Reasonable	1. Task success rate between ≥40% and <70%. 2. Moderate learning curve, with noticeable error rate (>15% and ≤30%). 3. Subjective clarity assessment: ≥50% and <70% of agents report significant difficulty or moderate frustration.	≥40% and <70%	>15% and ≤30%	≥50% and <70%
Unreasonable	1. Task success rate <40%. 2. High error rate (>30%). 3. Subjective clarity assessment: <50% of agents consider the system usable or understandable, with predominant reports of frustration, abandonment, or dissatisfaction.	<40%	>30%	<50%

Column headers: (1) Task Success Rate (%); (2) Adaptation Curve (%); (3) Subjective Clarity Assessment (%). The EFT score establishes the percentage-based criteria applicable to the effectiveness of the technological object. The scale classifies levels of functional performance based on task success rate, learning curve, and subjective clarity and efficiency assessments. These levels range from high effectiveness, marked by consistent performance and a low learning curve, to insufficient effectiveness, characterized by low success rates, high error incidence, and negative user perception. This metric guides the analysis of the system's ability to support the efficient and understandable execution of intended operations.

Source: Author.

2.1.7 Artifact Object Requirements Dimension (RQA)

The Object Requirements Dimension (Dimensão Requisitos de Objetos – RQO) and the Artifact Object Requirements Dimension (Dimensão Requisitos de Artefatos de Objetos – RQA) articulate to provide a comprehensive analytical approach to complex constructs, including technological and non-technological artifacts. Within the scope of this dimension, the focus lies on RQA, which is responsible for measuring the compliance and performance of the physical and logical components that comprise the evaluated object (Table 7). The RQA Score quantifies the structural and functional adequacy of the artifacts, identifying everything from critical failures that compromise practical applicability to high levels of integration and compliance.

This progressive evaluation scale incorporates rigorous technical criteria, capable of distinguishing artifacts that require corrective intervention from those exhibiting optimized performance and full compatibility with system requirements. The associated color coding facilitates visual interpretation of the results, guiding strategic decisions in engineering and technological maintenance.

TABLE 7: DEFINITION OF THE STANDARD SCORE FOR ARTIFACT OBJECT REQUIREMENTS (RQA)

Artifact Object Requirements	Definitions	1	2	3	4	5
Artefato	1. (0%): Artifacts that do not receive classification. This condition may occur due to the absence of a direct relationship with the analysis, the agent's decision not to assign a score to the artifact, or the application of a "not applicable" logic. (Heatmap: Orange). 2. (-5 to -1): Artifacts present severe structural problems, lack of compatibility, or significant failures that completely compromise their practical applicability (≤30%). (Heatmap: Red). 3. (1 to 2): Artifacts with insufficient performance and moderate failures that significantly limit functionality. Moderate failures that restrict practical applicability (>30% and ≤50%). (Heatmap: Orange). 4. (3 to 6): Artifacts that present acceptable performance, albeit with limitations, covering most average practical application cases (>50% and ≤80%). (Heatmap: Yellow). 5. (7 to 10): Artifacts with high performance, excellent integration, and full compliance with established criteria (>80%). (Heatmap: Green).	0%	>0% and ≤30%	>30% and ≤50%	>50% and ≤80%	>80%

Column headers: (1) Score Level 1 (%); (2) Score Level 2 (%); (3) Score Level 3 (%); (4) Score Level 4 (%); (5) Score Level 5 (%). The RQA Score establishes the percentage criteria applicable to the compliance and performance of Artifact Object Requirements. The scale classifies artifacts into five progressive levels, ranging from lack of application or critical failures to excellent performance and full integration. This classification allows the assessment of the structural and functional robustness of technological components, supporting technical diagnoses and improvement actions. The associated color coding reinforces the visualization of artifact criticality and maturity levels within the FCIA-OT context.

Source: Author.

2.1.8 Error Severity Dimension (GVE)

The Severity Dimension (Dimensão Gravidade de Erros – GVE) evaluates the severity of errors observed during interaction with the technological object, considering both functional and perceptual impact. Errors are categorized into levels ranging from total absence of failures to critical occurrences that compromise the system's usability and reliability (Table 8). The GVE Score is calculated based on three objective criteria: the impact rate of the errors, the frequency of reported failures, and the agents' perceived trust in the system. This classification enables precise identification of error criticality levels, guiding corrective actions and mitigation strategies to enhance system robustness and user experience.

TABLE 8: DEFINITION OF THE STANDARD SCORE FOR ERROR SEVERITY (GVE)

Error Severity Types	Definitions	1	2	3
No Errors	1. Impact rate: 0%. 2. No errors identified (0%). All functionalities operate as expected, without interruptions or failures. 3. Perceived trust: 100% of agents consider the system fully reliable.	0%	0%	100%
Insignificant	1. Impact rate: >0% and ≤5%. 2. Up to 5% of agents report minor issues that do not perceptibly affect usability or functionality. 3. Perceived trust: ≥95% of agents maintain confidence in the system.	>0% and ≤5%	≤5%	≥95%
Minor	1. Impact rate: >5% and ≤15%. 2. Between 5% and 15% of agents report errors that minimally affect usability but do not prevent main tasks. 3. Perceived trust: ≥85% of agents trust the system despite the errors.	>5% and ≤15%	≤15%	≥85%
Moderate	1. Impact rate: >15% and ≤30%. 2. Between 15% and 30% of agents are affected by errors causing frustration and difficulties with main tasks. 3. Perceived trust: ≥65% of agents still consider the system acceptable.	>15% and ≤30%	≤30%	≥65%
Severe	1. Impact rate: >30% and ≤50%. 2. Between 30% and 50% of agents are affected by significant errors that compromise important functions. 3. Perceived trust: ≥40% of agents still trust the system.	>30% and ≤50%	≤50%	≥40%
Critical	1. Impact rate: >50%. 2. More than 50% of agents report critical failures that prevent use or cause data loss. 3. Perceived trust: <40% of agents still consider the system usable.	>50%	>50%	<40%

Column headers: (1) Error Impact Rate (%); (2) Reported Failure Frequency (%); (3) Perceived Trust (%). The GVE Score establishes percentage-based criteria for evaluating the severity of errors detected during the use of a technological object. The progressive scale classifies impact and trust levels, ranging from complete absence of errors with reliable operation to critical failures that severely compromise functionality and reduce user confidence. This dimension is essential for diagnosing system stability and safety, enabling effective prioritization in problem resolution.

Source: Author.

2.1.9 Risk Degree Dimension (GSR)

The Risk Degree Dimension (Dimensão Graus de Risco – GSR) measures the degrees of risk associated with the use of the technological object, classifying the potential impact of failures and problems reported by agents. This dimension is based on three objective criteria: the impact rate of identified risks, the frequency of adverse occurrences, and the agents' perceived safety (Table 9). The evaluation spans from the complete absence of risk to very high-risk conditions capable of negatively affecting trust, operational safety, and the continuity of system use. The GSR Score provides input for the prioritization and efficient management of risks inherent to agent–technology interaction.

TABLE 9: DEFINITION OF THE STANDARD SCORE FOR RISK DEGREE (GSR)

Types of Risk	Definitions	1	2	3
No Risk	1. Impact rate: 0%. 2. No record of failures or dissatisfaction by agents at any stage (0%). 3. Perceived safety: ≥95% of agents consider the system completely safe and reliable.	0%	0%	≥95%
Very Low	1. Impact rate: >0% and ≤5%. 2. Minor inconveniences are reported, with negligible impact (<5%). 3. Perceived safety: ≥85% of agents consider the system reliable despite minor issues.	>0% and ≤5%	<5%	≥85%
Low	1. Impact rate: >5% and ≤15%. 2. Reports of mild discomfort or occasional technical issues (≥10%). 3. Perceived safety: ≥70% of agents report moderate confidence, with some need for adjustment.	>5% and ≤15%	≥10%	≥70%
Moderate	1. Impact rate: >15% and ≤30%. 2. ≥20% of agents report moderate difficulties or relevant risks. 3. Perceived safety: ≥50% of agents still consider the system reliable, though relevant concerns are noted.	>15% and ≤30%	≥20%	≥50%
High	1. Impact rate: >30% and ≤50%. 2. ≥40% of agents report critical impacts or high likelihood of errors. 3. Perceived safety: ≥30% of agents still trust the system, but the risk is considered high.	>30% and ≤50%	≥40%	≥30%
Very High	1. Impact rate: >50%. 2. ≥60% of agents report severe failures, abandonment, or catastrophic events. 3. Perceived safety: <30% of agents trust the system, reporting extreme risk.	>50%	≥60%	<30%

Column headers: (1) Risk Impact Rate (%); (2) Reported Occurrence Frequency (%); (3) Perceived Safety (%). The GSR Score defines the percentage-based criteria for evaluating risk levels in the context of interaction with technological objects. The progressive scale reflects the range from complete absence of risk, marked by safety and reliability, to increasingly severe levels of risk, culminating in very high-risk situations that compromise safety, stability, and the agent's experience. This dimension is essential for preventive and risk mitigation strategies, promoting safety and resilience in evaluated systems.

Source: Author.

2.1.10 Attribute Dimension (ATB)

The Attribute Dimension (Dimensão Atributos – ATB) defines the applicable percentage-based criteria used to assess key aspects related to the functional and qualitative characteristics of the technological object. This dimension encompasses multiple core attributes that influence the agent's experience (Table 10).

Each attribute is classified according to percentage levels that reflect its practical performance, operational impact, and agents' perception during interaction. The scale ranges from non-applicable conditions, through critical or limited levels, up to optimal levels of performance and suitability. The use of chromatic heatmaps (ranging from red to green) enhances the visualization of each attribute's criticality and maturity, supporting the identification of priority areas for improvement and validation..

TABLE 10: DEFINITION OF THE STANDARD SCORE FOR ATTRIBUTES (ATB)

Attribute Types	Definitions	1	2	3	4	5
Usability	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extremely difficult to understand and requires high effort to use. Agents report severe frustration or total inability to operate (≤20%). (Heatmap: Red).3. (1 to 2): Limited understanding, possible only after significant effort. Indicates non-intuitive use and need for support (>20% and ≤50%). (Heatmap: Orange).4. (3 to 6): Moderate usability, with manageable effort and noticeable learning curve (>50% and ≤75%). (Heatmap: Yellow).5. (7 to 10): Intuitive and efficient use, fast learning, and smooth operation (>75%). (Heatmap: Green).	0%	>0% and ≤20%	>20% and ≤50%	>50% and ≤75%	>75%
Usefulness	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Feature or function has no practical value or relevance, causing frustration or uselessness in the context (≤50%). (Heatmap: Red).3. (1 to 2): Limited function with restricted application and low practical impact. Utility is low, but present (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Useful and applicable function with moderate benefits, though not ideal (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): Highly relevant, essential, and widely applicable function, providing clear and significant benefits (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%

Efficiency	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extremely inefficient operation, with average time ≤70% of the ideal, causing significant delays or resource waste. (Heatmap: Red).3. (1 to 2): Low efficiency, with average time >70% and ≤80% of the ideal, resulting in slow but functional performance. (Heatmap: Orange).4. (3 to 6): Moderate efficiency, with average time >80% and ≤90% of the ideal, delivering adequate performance with some limitations. (Heatmap: Yellow).5. (7 to 10): High efficiency, with average time >90% of the ideal, ensuring fast performance and optimized resource use. (Heatmap: Green).	0%	>0% and ≤70%	>70% and ≤80%	>80% and ≤90%	>90%
Functionality	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): The functionality shows severe failures or is completely absent, compromising the primary purpose of the object or system (≤50%). (Heatmap: Red).3. (1 to 2): Basic functionality, but with significant limitations. Operates minimally, but does not meet use expectations (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Moderate and reliable functionality, with some limitations, but capable of meeting essential requirements (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): Full and robust functionality, with consistent performance fully aligned with the requirements (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%
Accessibility	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extremely low or nonexistent accessibility, with significant barriers for different user profiles and contexts (≤25%). (Heatmap: Red).3. (1 to 2): Limited accessibility, available only to some profiles and contexts. Requires extra effort or specific adaptations (>25% and ≤55%). (Heatmap: Orange).4. (3 to 6): Moderate accessibility, with acceptable usability and support levels, though some restrictions remain for certain profiles and contexts (>55% and ≤80%). (Heatmap: Yellow).5. (7 to 10): Full accessibility, offering inclusive and effective support for diverse profiles and contexts (>80%). (Heatmap: Green).	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤80%	>80%
Flexibility	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extreme rigidity, with no ability to adapt to different contexts or changing conditions (≤50%). (Heatmap: Red).3. (1 to 2): Limited flexibility, allowing minimal adaptations, but still dependent on specific configurations or restrictions (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Moderate flexibility, with good adaptability, although some limitations persist (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): High flexibility, with full adaptability to various profiles, contexts, and conditions (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%

Controllability	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extremely difficult or nonexistent control, with inconsistent and unpredictable responses to agent commands (≤50%). (Heatmap: Red).3. (1 to 2): Limited control, with partial response to commands. Indicates difficulty adjusting or properly operating the object (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Moderate controllability, with consistent responses in most operations, though perceptible restrictions remain (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): Total and precise control, enabling detailed adjustments and reliable responses in all operations (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%
Interoperability	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Total incompatibility or severe integration failures with other systems or devices. No effective data exchange or communication (≤25%). (Heatmap: Red).3. (1 to 2): Limited integration, with significant restrictions in communication or data exchange. Requires alternative solutions to interoperate properly (>25% and ≤55%). (Heatmap: Orange).4. (3 to 6): Moderate interoperability, with functional integration in specific scenarios, though limited in more complex environments (>55% and ≤80%). (Heatmap: Yellow).5. (7 to 10): Full compatibility and integration, with fluid communication and no restrictions across various systems and devices (>80%). (Heatmap: Green).	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤80%	>80%
Portability	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Extremely difficult to transport or use in different contexts. Dependent on fixed or heavy infrastructure (≤50%). (Heatmap: Red).3. (1 to 2): Limited portability, with significant restrictions for use in different locations or conditions. Requires additional preparation (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Moderate portability, functional in various environments, but with handling or transport limitations (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): Highly portable and adaptable, enabling efficient use across a wide range of contexts without fixed infrastructure (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%

Compliance	1. (0%): Not applicable. (Heatmap: Orange).2. (-5 to -1): Does not meet established standards, regulations, or norms, potentially causing incompatibility or severe risks (≤50%). (Heatmap: Red).3. (1 to 2): Partially meets standards and regulations, with significant gaps limiting its use or acceptability (>50% and ≤75%). (Heatmap: Orange).4. (3 to 6): Moderate compliance, satisfying most normative requirements, though adjustments may be needed (>75% and ≤90%). (Heatmap: Yellow).5. (7 to 10): Fully compliant with standards, regulations, and norms, ensuring safety and acceptability (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%
Stability	1. (0%): Not applicable. (Heatmap: Orange). 2. (-5 to -1): Highly unstable, with frequent failures, unpredictable behavior, and significant risk of operational compromise (≤50%). (Heatmap: Red). 3. (1 to 2): Low stability, with intermittent failures affecting reliability and performance (>50% and ≤75%). (Heatmap: Orange). 4. (3 to 6): Moderate stability, with occasional failures and limited impact on usage (>75% and ≤90%). (Heatmap: Yellow). 5. (7 to 10): Highly stable, with reliable operation and no significant failures or interruptions (>90%). (Heatmap: Green).	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%
Aesthetics	1. (0%): Not applicable. (Heatmap: Orange). 2. (-5 to -1): Inadequate or disorganized visual design, causing visual discomfort and low aesthetic acceptance (≤30%). (Heatmap: Red). 3. (1 to 2): Basic or limited aesthetics, with visual elements that fulfill their role but lack appeal or coherence (>30% and ≤60%). (Heatmap: Orange). 4. (3 to 6): Moderate visual design, acceptable, with functional and aesthetically pleasant composition (>60% and ≤85%). (Heatmap: Yellow). 5. (7 to 10): Highly attractive and coherent design, promoting a positive and engaging visual experience (>85%). (Heatmap: Green)	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
Acceptability	1. (0%): Not applicable. (Heatmap: Orange). 2. (-5 to -1): Totally unacceptable due to incompatibility with requirements, expectations, or standards (≤25%). (Heatmap: Red). 3. (1 to 2): Partially acceptable, but with significant reservations (>25% and ≤55%). (Heatmap: Orange). 4. (3 to 6): Moderate acceptability, with certain conditions or limitations (>55% and ≤80%). (Heatmap: Yellow). 5. (7 to 10): Fully acceptable and aligned with expectations (>80%). (Heatmap: Green).	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤80%	>80%

Innovation	1. (0%): Not applicable. (Heatmap: Orange). 2. (-5 to -1): Completely lacking innovation, characterized by repetition of outdated concepts (≤25%). (Heatmap: Red). 3. (1 to 2): Limited innovation, with slightly new elements but without significant impact (>25% and ≤55%). (Heatmap: Orange). 4. (3 to 6): Moderate level of innovation, with noticeable improvements (>55% and ≤80%). (Heatmap: Yellow). 5. (7 to 10): Highly innovative, introducing disruptive approaches (>80%). (Heatmap: Green).	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤80%	>80%
Simplicity	1. (0%): Not applicable. (Heatmap: Orange). 2. (-5 to -1): Extremely complex, confusing, and unnecessarily elaborate (≤25%). (Heatmap: Red). 3. (1 to 2): Partially simplified, but with significant barriers (>25% and ≤55%). (Heatmap: Orange). 4. (3 to 6): Moderately simple, with manageable effort (>55% and ≤80%). (Heatmap: Yellow). 5. (7 to 10): Highly simple and intuitive (>80%). (Heatmap: Green).	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤80%	>80%

Column headers: (1) Score Level 1 (%); (2) Score Level 2 (%); (3) Score Level 3 (%); (4) Score Level 4 (%); (5) Score Level 5 (%). The ATB Score defines the applicable percentage-based criteria for assessing the attributes of the technological object, based on progressively scaled indicators of performance, quality, and suitability. Each attribute is classified according to its operational effectiveness, ease of use, functional relevance, and acceptance by the evaluating agent. The scale ranges from non-applicable or critically deficient levels to high-performance levels, reflecting optimized usability, efficiency, and compliance. Chromatic coding enhances the visual identification of each attribute's condition, enabling precise diagnosis of areas requiring intervention as well as those demonstrating operational excellence.

Source: Author.

2.1.11 Accessibility Dimension (ACB)

The Accessibility Dimension (Dimensão Acessibilidade – ACB) defines the applicable percentage-based criteria for accessibility, subdivided into seven groups that encompass essential aspects of inclusive interaction, from textual alternatives to assistive technologies and temporary adjustments (Table 11). The ACB establishes evaluation ranges that reflect the degree of adequacy, support, and accessible functionality in each criterion, enabling the identification of barriers and progress in the adaptation of the technological object to different agent profiles and usage contexts. This systematic approach ensures precise diagnostics and effective direction for continuous improvement in inclusive usability.

TABLE 11: DEFINITION OF THE STANDARD SCORE FOR ACCESSIBILITY (ACB)

Groups	Code	Criterion Types	Definitions	1	2	3	4	5
AC1: Texts, Images, and Media	ACB01	Text Alternatives (Alt Text)	1. Not applicable.2. Extremely rigid, no descriptions provided.3. Limited descriptions, covering only a few elements.4. Good descriptions, but missing in specific cases.5. Full descriptive coverage provided.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB02	Information Redundancy	1. Not applicable.2. Only one medium used for transmission.3. Two media used, but missing clear alternatives.4. Three media used, with minor gaps.5. Three media fully accessible.	0%	>0% and ≤40%	>40% and ≤65%	>65% and ≤85%	>85%
	ACB03	Interaction with Multimedia	1. Not applicable.2. No accessible controls available.3. Few controls offered, with limited accessibility.4. Accessible controls, but not in all cases.5. Full accessible control in all contexts.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB04	Multilingual Content Support	1. Not applicable.2. No support for alternative languages.3. Limited support, only for some essential terms.4. Good language support, with some missing terms.5. Full support in multiple languages.	0%	>0% and ≤40%	>40% and ≤65%	>65% and ≤85%	>85%

AC2: Navigation and Interaction	ACB05	Keyboard Navigation	1. Not applicable. 2. Navigation via keyboard is not possible, including lack of support for alternative keyboards. 3. Partial navigation using standard or alternative keyboards, but not intuitive and with frequent failures. 4. Functional navigation for standard keyboards, but with gaps in specific flows or incomplete support for alternative devices. 5. Full integration and intuitive navigation via standard and alternative keyboards, covering all expected interaction flows.	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤85%	>85%
	ACB06	Navigation Consistency	1. Not applicable. 2. Interface structure and organization are inconsistent, impairing usability. 3. Basic structure and navigation, but with frequent inconsistencies in hierarchy or layout patterns. 4. Well-organized navigation, but with occasional inconsistencies in structure or information hierarchy. 5. Organized and predictable navigation, with clear hierarchy and consistent structural patterns.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	ACB07	Category and Filter-Based Navigation	1. Not applicable. 2. No filter-based navigation options. 3. Limited navigation, with few accessible filters. 4. Good navigation, but with gaps in complex menus. 5. Full access to organized menus and filters.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB08	Time and Interaction Control	1. Not applicable. 2. No time adjustment or pause options. 3. Limited time control, with few configurable options. 4. Good time adjustments, but with issues in specific cases. 5. Full and adjustable time control across all relevant interaction scenarios.	0%	>0% and ≤40%	>40% and ≤65%	>65% and ≤85%	>85%
AC3: Visual Design and Settings	ACB09	Color Contrast	1. Not applicable. 2. No contrast ensured. 3. Limited contrast, failing to meet all standards. 4. Good contrast, but with issues in some areas. 5. Full contrast adjusted according to accessibility standards.	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤85%	>85%
	ACB10	Font Size and Adjustability	1. Not applicable. 2. Text is non-adjustable or illegible. 3. Limited adjustments, resulting in loss of functionality. 4. Functional adjustments, but with restrictions in specific contexts. 5. Full font adjustability across use scenarios.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	ACB11	Visibility and Legibility	1. Not applicable. 2. Fonts and spacing are inadequate. 3. Partial improvement in visibility, but issues remain. 4. Good legibility, with some limitations. 5. Full legibility for all agent profiles.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB12	Accessibility Adjustments	1. Not applicable. 2. Basic accessibility features are missing. 3. Limited adjustment options available. 4. Moderate adjustments, with some flaws. 5. Complete and functional accessibility settings implemented.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB13	Adaptation to Usage Contexts	1. Not applicable. 2. No adjustments for specific conditions. 3. Basic and limited adaptations. 4. Moderate adaptations for most usage conditions. 5. Optimized adaptations for all usage contexts.	0%	>0% and ≤40%	>40% and ≤65%	>65% and ≤85%	>85%
AC4: Forms and Feedback	ACB14	Accessible Forms	1. Not applicable. 2. Forms are confusing and inaccessible. 3. Basic labels are present. 4. Clear structure with minor issues. 5. Full accessibility guaranteed.	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤85%	>85%
	ACB15	Error and Success Feedback	1. Not applicable. 2. Feedback is absent or confusing. 3. Basic and minimally helpful messages. 4. Clear messages, but with some gaps. 5. Efficient and well-implemented feedback.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	ACB16	Clear Input Errors	1. Not applicable. 2. Errors are not explained. 3. Minimal explanations provided. 4. Useful suggestions, but incomplete. 5. Clear and fully accessible communication.	0%	>0% and ≤25%	>25% and ≤55%	>55% and ≤85%	>85%
AC5: Multimodality and Emerging Technologies	ACB17	Multimodality	1. Not applicable. 2. No multimodal support. 3. Partial support for multiple formats. 4. Moderate functionality across various formats. 5. Full multimodal compatibility.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB18	AR/VR Accessibility	1. Not applicable. 2. Interfaces not adapted. 3. Basic functionalities available. 4. Adapted functionality with flaws. 5. Advanced and functional accessibility for AR/VR environments.	0%	>0% and ≤40%	>40% and ≤65%	>65% and ≤85%	>85%
	ACB19	IoT Accessibility	1. Not applicable. 2. No accessible integration. 3. Basic integration with limitations. 4. Moderately integrated functionality. 5. Full compatibility with IoT devices.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB20	Mobile Application Accessibility	1. Not applicable. 2. Mobile interface is inaccessible. 3. Basic functional interface. 4. Functional interface with limitations. 5. Fully optimized and functional mobile interface.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

AC6: Assistive Technologies and Privacy	ACB21	Screen Reading Compatibility	1. Not applicable. 2. No compatibility with screen readers. 3. Partial compatibility. 4. Moderate functionality with adequate reading. 5. Optimized screen reading experience.	0%	≤25%	>25% and ≤55%	>55% and ≤85%	>85%
	ACB22	Compatibility with Assistive Technologies	1. Not applicable. 2. No compatibility with assistive technologies, including lack of standard support. 3. Limited integration, with serious issues interpreting assistive technologies and implementing standards. 4. Functional compatibility, but with gaps in support for international standards. 5. Full integration with assistive technologies, including complete compliance with standards.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB23	Voice Interface Accessibility	1. Not applicable. 2. No voice commands available. 3. Basic voice commands implemented. 4. Clear voice interaction with minor issues. 5. Full voice accessibility and interaction support.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%
	ACB24	Accessible Privacy and Security	1. Not applicable. 2. Settings are missing or confusing. 3. Basic functionality provided. 4. Clear settings with minor gaps. 5. Fully accessible and guaranteed privacy configuration.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	ACB25	Cognitive Accessibility	1. Not applicable. 2. Incomprehensible to users. 3. Basic structure with limitations. 4. Clear navigation, though with some gaps. 5. Full cognitive accessibility with clear and supportive navigation.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
AC7: Experience and Temporary Adjustments	ACB26	Reaction Time and Interactivity	1. Not applicable. 2. No timing adjustments available. 3. Basic adjustments present. 4. Functional and moderately flexible adjustments. 5. Fully adjustable and interactive configuration.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB27	Smooth Responses and Transitions	1. Not applicable. 2. Abrupt and confusing responses. 3. Minimal smoothness implemented. 4. Moderately smooth transitions with functionality. 5. Optimized and seamless transitions and responses.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB28	Accessibility in Temporary Situations	1. Not applicable. 2. No temporary support features. 3. Basic temporary features available. 4. Moderately functional temporary resources with some flaws. 5. Fully guaranteed temporary accessibility.	0%	>0% and ≤35%	>35% and ≤60%	>60% and ≤85%	>85%

	ACB29	Multimodal Feedback	1. Not applicable. 2. No multimodal feedback provided. 3. Basic and limited feedback. 4. Functional and moderately implemented multimodal feedback. 5. Fully integrated multimodal feedback system.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	ACB30	Stress and Well-being	1. Not applicable. 2. Stressful and exhausting design. 3. Basic design with noticeable flaws. 4. Moderately comfortable and functional design. 5. Optimized and user-friendly design that promotes well-being.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

Column headers: (1) Score Level 1 (%); (2) Score Level 2 (%); (3) Score Level 3 (%); (4) Score Level 4 (%); (5) Score Level 5 (%). The ACB Score defines the applicable percentage-based criteria for thirty items grouped into seven categories, each featuring progressive accessibility levels ranging from "not applicable" or critical conditions to full compliance and inclusive support (Levels 1 to 5). These levels are based on clear, evidence-based quantitative parameters and are supported by chromatic coding to enhance intuitive visual interpretation. This detailed framework supports rigorous evaluations and targeted guidance, which are essential for fostering accessible, inclusive technologies adapted to the diverse needs of agents.

Source: Author.

2.1.12 QRSUER Technology Dimension (QRSUER)

The QRSUER Technology Dimension (Dimensão Tecnologia QRSUER) defines the applicable percentage-based criteria for the QRSUER dimension, which assesses the sustainability, efficiency, and socio-environmental responsibility of technological objects (Table 12). This dimension encompasses multiple aspects, including efficient resource management, sustainable design, social impact, ethical compliance, and technological innovation. The progressive scale qualifies the object's performance from absent or unsatisfactory practices to advanced levels of sustainability and positive impact, considering environmental, social, and economic factors. The score provides a comprehensive analysis, essential for ensuring the viability and accountability of technological systems in light of contemporary demands.

TABLE 12: DEFINITION OF THE STANDARD SCORE FOR QRSUER TECHNOLOGY (QRSUER)

Groups	Code	Criterion Types QRSUER	Definitions	1	2	3	4	5
TQ1: Sustainability and Resources	TQRS01	Resource Use and Efficiency	1. Not applicable. 2. Extremely inefficient consumption with no environmental considerations (≤30%). 3. Partially efficient, but still with significant waste (>30% and ≤60%). 4. Moderately efficient, with some optimization practices (>60% and ≤85%). 5. Efficient and environmentally responsible use of resources (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS02	Resource Sustainability	1. Not applicable. 2. Predominant use of non-renewable materials and wasteful practices (≤30%). 3. Limited use of renewable materials and partial management practices (>30% and ≤60%). 4. Moderate use of renewable resources with clear sustainability efforts (>60% and ≤85%). 5. Predominance of renewable materials and highly sustainable practices (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS03	Emission Reduction	1. Not applicable. 2. Uncontrolled emissions with no mitigation efforts (≤30%). 3. Limited emission mitigation with partial alignment to standards (>30% and ≤60%). 4. Moderate reduction efforts with significant mitigation (>60% and ≤85%). 5. Significant emission reduction with full compliance (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	TQRS04	Solid Waste Management	1. Not applicable. 2. High levels of waste with no reuse or proper disposal practices (≤30%). 3. Partial waste management with limited reuse initiatives (>30% and ≤60%). 4. Moderate management with consistent reuse and proper disposal practices (>60% and ≤85%). 5. Highly efficient management aligned with sustainability standards (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS05	Active Disposal	1. Not applicable. 2. Inadequate disposal with no reuse policies (≤30%). 3. Disposal with limited reuse and recycling policies (>30% and ≤60%). 4. Moderate disposal with clear sustainable management practices (>60% and ≤85%). 5. Active disposal focused on sustainability and reuse (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS06	Carbon Neutrality	1. Not applicable. 2. High carbon footprint with no compensatory actions (≤30%). 3. Partial emission reduction with limited compensation efforts (>30% and ≤60%). 4. Moderate compensations and partial neutrality actions (>60% and ≤85%). 5. Significant compensation achieving full carbon neutrality (>85%).	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS07	Regenerative Impact	1. Not applicable. 2. No ecosystem regeneration efforts. 3. Limited and ineffective regenerative actions. 4. Moderate regenerative practices. 5. Highly effective regenerative impact.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	TQRS08	Water Efficiency	1. Not applicable. 2. High water consumption and waste. 3. Low efficiency with limited reuse. 4. Moderate optimization of water use. 5. Advanced conservation and reuse practices.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS09	Biodiversity Protection	1. Not applicable. 2. High ecological impact. 3. Few actions to protect biodiversity. 4. Moderate conservation actions. 5. Exemplary environmental management.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
TQ2: Sustainable Design and Circular Economy	TQRS10	Recyclability	1. Not applicable. 2. No recyclability of materials. 3. Limited recyclability. 4. Moderate potential for reuse. 5. Fully recyclable and reusable structure.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS11	Facilitated Repairability	1. Not applicable. 2. Impossible to repair. 3. Repair is difficult and unfeasible. 4. Moderately accessible repair. 5. Full ease of repair or component replacement.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS12	Modular Adaptability	1. Not applicable. 2. No possibility of adaptation. 3. Limited adaptability. 4. Moderate modularity. 5. Highly adaptable and modular configuration.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS13	Circular Design	1. Not applicable. 2. Linear design with no reuse potential. 3. Partial implementation of circular concepts. 4. Moderately reusable design. 5. Fully circular structure.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

TQ3: Social Impact and Inclusion	TQRS14	Social Impact and Equity	1. Not applicable. 2. Negative and unequal social impact. 3. Partial social impact with limited benefits. 4. Moderate social impact, with efforts to enhance equity. 5. Positive social impact with significant contribution to equity.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS15	Technological Inclusion	1. Not applicable. 2. Complete exclusion of certain groups. 3. Limited and ineffective inclusion. 4. Moderate inclusion with targeted efforts. 5. Broad and effective technological inclusion.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS16	Positive Local Economic Impact	1. Not applicable. 2. Negative or nonexistent impact on local economies. 3. Limited local economic impact. 4. Moderate local economic impact. 5. Positive and significant impact on local economies.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
TQ4: Compliance, Ethics, and Transparency	TQRS17	Transparency and Privacy	1. Not applicable. 2. Total lack of transparency and privacy protection. 3. Limited transparency and privacy safeguards. 4. Moderate transparency with implemented privacy policies. 5. High transparency and full compliance with privacy standards.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS18	Transparency and Traceability	1. Not applicable. 2. No transparency or traceability. 3. Partial transparency and traceability. 4. Moderate transparency and traceability. 5. Full transparency and traceability with high reliability.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

	TQRS19	Legal Compliance	1. Not applicable. 2. Complete lack of compliance with legal standards. 3. Limited compliance with notable gaps. 4. Moderate legal compliance. 5. Full compliance with legal and regulatory frameworks.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS20	Ethics and Transparency in AI Systems	1. Not applicable. 2. Absence of ethical considerations and transparency in AI systems. 3. Limited ethical practices and partial transparency. 4. Moderate adherence to ethical principles and transparency. 5. High ethical standards and full transparency in AI systems.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
TQ5: Innovation and Technological Impact	TQRS21	Material Safety	1. Not applicable. 2. Materials present significant risks to health and safety. 3. Materials with moderate risks and partial mitigation strategies. 4. Materials with moderate safety and effective controls. 5. Safe materials with a high standard of protection.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS22	Sustainable Integration	1. Not applicable. 2. Limited integration of sustainable practices. 3. Moderate integration with some sustainable solutions. 4. Substantial integration of sustainable technologies. 5. Full integration of sustainable technologies and practices.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS23	Responsible Innovation	1. Not applicable. 2. Lack of responsible innovation and high risk. 3. Innovation with limited ethical and responsible considerations. 4. Moderate innovation with social responsibility. 5. Transformative and highly responsible innovation.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%

TQ6: Environmental Conservation and Preservation	TQRS24	Efficient Use of Space	1. Not applicable. 2. Inefficient and uncontrolled use of space. 3. Limited use with space waste. 4. Moderate and optimized use of space. 5. Highly efficient use of space.	0%	>0% and ≤30%	>30% and ≤60%	>60% and ≤85%	>85%
	TQRS25	Environmental Preservation	1. Not applicable. 2. No environmental preservation practices. 3. Limited and ineffective environmental practices. 4. Moderate environmental preservation practices. 5. Robust and effective environmental practices.	0%	>0% and ≤50%	>50% and ≤75%	>75% and ≤90%	>90%
	TQRS26	Preservation of Water and Subsurface Resources	1. Not applicable. 2. Irresponsible use with no preservation of water resources. 3. Limited use with partial preservation practices. 4. Moderate use with efforts toward water preservation. 5. Efficient use with strong preservation of water resources.	0%	>0% and ≤60%	>60% and ≤80%	>80% and ≤95%	>95%
	TQRS27	Air Pollution and Atmospheric Protection	1. Not applicable. 2. Uncontrolled emissions and atmospheric pollution. 3. Limited emissions with partial mitigation. 4. Moderate emissions with mitigation practices. 5. Controlled emissions with strong atmospheric protection.	0%	>0% and ≤60%	>60% and ≤80%	>80% and ≤95%	>95%
	TQRS28	Chemical, Radioactive, and Heavy Metal Contamination	1. Not applicable. 2. Significant contamination with no mitigation. 3. Moderate contamination with some mitigation measures. 4. Limited contamination with effective mitigation. 5. Zero contamination with full mitigation and management.	0%	>0% and ≤60%	>60% and ≤80%	>80% and ≤95%	>95%

	TQRS29	Space Pollution and Environmental Impact	1. Not applicable. 2. High environmental impact with no control. 3. Moderate impact with partial mitigation. 4. Controlled impact with active mitigation. 5. Minimal environmental impact with proactive measures.	0%	>0% and ≤60%	>60% and ≤80%	>80% and ≤95%	>95%

Column headers: (1) Score Level 1 (%); (2) Score Level 2 (%); (3) Score Level 3 (%); (4) Score Level 4 (%); (5) Score Level 5 (%). The QRSUER Score establishes the applicable percentage criteria for twenty-nine indicators grouped into six categories, related to sustainability, resource efficiency, sustainable design, social impact, ethical compliance, and technological innovation. The scale presents progressive levels that qualify the performance of technological objects, ranging from the absence or insufficiency of sustainable practices to excellence in socio-environmental responsibility, providing a detailed assessment of the object's alignment with contemporary environmental, social, and economic standards.

Source: Author.

2.1.13 Architecture of the Global Usability and Interaction Score: Integration of the Twelve Dimension Scores

The structure presented corresponds to the standardized scores of the twelve main dimensions of the FCIA-OT, which constitute the foundational framework of the Global Usability and Interaction Score (SGUI). Each score adopts specific percentage-based criteria to rigorously and multidimensionally measure the properties of the technological object, encompassing functional, affective, effectiveness, and risk-related aspects, among others. The SGUI formula, applied to calculate the percentage frequency of each element in relation to the total entries within the dimension, enables the transformation of these data into standardized percentage levels. These levels make it possible to identify the system's maturity, revealing both its positive and negative qualifications per dimension—or even per element—thus offering a comprehensive instrument for analysis, diagnosis, and continuous improvement. This composition reinforces the precision and applicability of the FCIA-OT in the evaluation of complex systems, combining scientific rigor with practical utility.

3 INTEGRATED MODULAR CRITICAL SCORE (SCMI)

The Integrated Modular Critical Score (Score Crítico Modular Integrado – SCMI) constitutes an advanced analytical component of the FCIA-OT, designed to express the relative critical weight of each element mapped across the system's twelve dimensions. Derived directly from the raw SPMI value, the SCMI not only indicates the statistical presence of an artifact but translates its proportional technical criticality, determined by factors such as severity, functional impact, and operational value of the records.

Unlike the SGUI, which quantifies the relative frequency of registered elements, the IMCS operates on a complementary axis, oriented toward the technical intensity of the data. Its application enables the identification of artifacts with low occurrence yet high functional relevance, which could be overlooked by strictly quantitative approaches. For this reason, the SCMI serves as a fundamental indicator in assessments of maturity, reliability, and effectiveness of technological objects subjected to high-complexity analytical environments. Technically, the SCMI is obtained by calculating the percentage ratio between the SPMI assigned to a given element and the total sum of SPMIs recorded within the evaluated dimension:

$$SCMI = \left(\frac{SPMI_{\text{element}}}{\sum SPMI_{\text{all}}} \right) \times 100$$

Source: Author.

Where: $SPMI_{element}$ represents the sum of the weights assigned to the element throughout its occurrences within the dimension; $\sum SPMI_{all}$ refers to the sum of all SPMI values recorded in the dimension, considering every element involved.

This calculation enables the identification of each artifact's critical proportionality within the analyzed structure, revealing its relative influence over the dimension to which it belongs. The SCMI also integrates with the SCDMIC, allowing for the chromatic representation of criticality and supporting analyses driven by risk, vulnerability, and modular excellence.

When an artifact receives a negative score in the SPMI, due to severe structural failures, lack of functional performance, or noncompliance with minimal technical criteria, the proportional value of the SCMI also becomes negative. This outcome is not merely a numerical deviation; rather, it reflects a substantive adverse impact on the maturity of the evaluated dimension.

To preserve analytical consistency and ensure the integrity of synthetic outputs, the occurrence of a negative SCMI activates the SCDMIC conditional (blue color). This technical protocol prevents the projection of the artifact into overall averages, public visualizations, comparative syntheses, and integrated classificatory outputs. Its purpose is to prevent critical, immature, or early-stage prototype artifacts from compromising statistical accuracy and interpretive fidelity of the results.

It is essential to emphasize that the blue conditional does not eliminate the technical data: both the negative score and the proportional SCMI remain fully recorded within the system, along with all corresponding metrics. The restriction applies solely to graphical and synthetic projection, which remains accessible exclusively through confidential reports intended for interaction engineers, developers, and researchers responsible for quality control, reengineering, and functional evaluation cycles.

In such cases, artifacts are technically classified as below minimum functionality standards and may present lack of interoperability, logical inconsistency, or deviation from critical requirements. This methodological approach fulfills four central functions: preserving the statistical validity of analytical outputs; ensuring continuous traceability of critical data; supporting corrective interventions grounded in technical evidence; and maintaining the robustness, coherence, and logical reliability of the evaluative system.

The presence of negative SCMI values does not compromise the stability of the model, nor does it indicate a systemic failure. On the contrary, it reflects the maturity of the FCIA-OT in handling critical data through methodologically controlled procedures, operating with rigor, traceability, and a continuous focus on systemic improvement.

4 DISCUSSION

The integration of the SGUI and SCMI modules within the scope of the FCIA-OT constitutes a significant technical contribution to the multidimensional assessment of usability and interaction in complex technological objects. While the SGUI operationalizes the quantification of the relative frequency of elements across its twelve dimensions, the SCMI complements this scope by incorporating proportional critical intensity, reflecting the technical severity and functional impact of the evaluated artifacts.

This research expands the analytical scope by overcoming limitations inherent to unidimensional assessments, which tend to prioritize only the recurrence of observed events or data. The SGUI, focused on statistical prevalence, may underestimate the importance of low-frequency critical artifacts, a scenario mitigated by the SCMI, which emphasizes the proportional technical criticality of elements. This synergy enables a more accurate analysis of the maturity, reliability, and effectiveness of the technological object, especially in environments of high complexity and operational criticality.

The proportional calculation of the SCMI facilitates the identification of unbalanced distributions of critical weight within the evaluated dimensions, enabling the early detection of vulnerabilities and structural weaknesses that directly affect the functional integrity of the system. The SCDMIC conditional (blue color), implemented as an exception protocol for artifacts receiving negative scores in analyses and assessments, reinforces the statistical consistency of the model by preventing immature data from distorting aggregated analyses, while preserving the integrity and traceability of critical data for corrective actions and quality control (see Chapters 1 and 2).

This evaluation model, prevalence versus criticality, provides interpretive and technical robustness, establishing the FCIA-OT as a highly precise modular analytical structure for the assessment and management of technological usability and interaction. The clear distinction between the roles of SGUI and SCMI strengthens the framework's ability to support technical decisions grounded in rigorous data, mitigating quantitative bias and extending the analytical scope to encompass both frequency-based and qualitative dimensions of criticality.

The articulation of these modules in the present research, supported by the theoretical foundations and empirical validations presented in the related FCIA-OT articles, establishes a solid foundation for future advancements in usability and interaction engineering, contributing to the formalization of critical metrics that reflect the complexity of contemporary technological systems.

5 CONCLUSION

The formalization of the systemic resources SGUI and SCMI represents a substantial advancement in the modeling and analysis of the technical and functional quality of complex technological objects. By establishing a dual analytical approach that simultaneously considers the relative frequency of elements and their proportional criticality, these modules significantly expand the evaluation spectrum, overcoming traditional limitations that tend to fragment analysis between quantitative and qualitative dimensions.

This integration enables not only the precise identification of recurring patterns but, more importantly, the technical recognition of artifacts that, although less frequent, exert decisive impact on the maturity, reliability, and performance of the evaluated system. As systemic resources, the SGUI and SCMI enhance the FCIA-OT, contributing to the consolidation of the framework as a robust and advanced tool for technological assessment.

The mathematical rigor of the SCMI computation, combined with the modular structure of the SGUI, provides a solid foundation for application in real-world scenarios, ensuring both security and precision in technical decision-making within high-complexity contexts. In this sense, the SGUI and SCMI are established as essential tools for engineers, researchers, and professionals dedicated to the evaluation and continuous improvement of usability and interaction in technological systems.

This methodological formalization sustains a robust scientific foundation that supports future extensions, empirical validations, and transdisciplinary applications, contributing to the advancement of knowledge and technological innovation in the field of interaction engineering.

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CHAPTER 4

APPLICATION OF THE INTEGRATED AND ADVANCED CORE FRAMEWORK FOR THE ANALYSIS AND EVALUATION OF TECHNOLOGICAL OBJECTS (FCIA-OT)

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ABSTRACT — This study presents the rigorous application of the Integrated and Advanced Core Framework for Analysis and Evaluation of Technological Objects (FCIA-OT) across three representative case studies: an interactive software with a graphical client registration interface, an embedded climate control system with dedicated firmware, and a UAV featuring a multicomponent hardware and software architecture. The analytical and evaluative processes were conducted in real-world settings, with technical data collected in loco, subjected to robust metrics, and structured into quantitative and qualitative matrices. The FCIA-OT demonstrated a unique capacity to model and measure the complexity of heterogeneous technological objects, operating with high precision through its integrated systems: the Integrated Modular Multidimensional Scoring System (SPMI), the Integrated Modular System for Color Classification and Definition (SCDMIC), the Global Usability and Interaction Score (SGUI), and the Integrated Modular Critical Score (SCMI). The results reveal a framework structurally superior to traditional approaches, enabling not only evaluation, but also deep understanding, traceability, and investigation of complex constructs with scientific replicability. The framework enables a data-driven diagnostic engineering approach, scalable and validated across distinct technological domains, capable of supporting technical analyses, generating auditable scientific evidence, and guiding standardization processes with methodological rigor. The proposed methodology establishes a new level of technical analysis, with high disruptive potential for industry, applied research, and regulatory certification systems.

KEYWORDS — FCIA-OT; SPMI; SCDMIC; SGUI; SCMI; Technological Evaluation; Complex Constructs; Diagnostic Engineering; Usability; Interaction; Regulatory Certification.

1 INTRODUCTION

The consolidation of a robust framework for the analysis and evaluation of interactive technologies demands conceptual structures capable of meeting criteria of validity, precision, and applicability. In the face of highly complex phenomena and constructs, such structures cannot be limited to prescriptive artifacts or fragmented approaches: they require the integration of technical, cognitive, and contextual requirements in an iterative, dynamic, and operationalizable manner. The Integrated and Advanced Core Framework for the Analysis and Evaluation of Technological Objects (FCIA-OT) constitutes a structured technical response to this gap. Designed to operate across multiple levels of complexity, the framework articulates objective and subjective criteria, empirical-analytical techniques, and multiple layers of modular interpretation.

System evaluation, according to Hollnagel & Woods (1982), requires verifying the validity of the design, involving both the simulation of real-world conditions and the correspondence between experimental and operational outcomes. Finkelstein & Finkelstein (1983) emphasize that evaluation and decision-making constitute the core of the design methodology, grounded in the generation of concepts aimed at meeting specific requirements. Neal & Simons (1984) reinforce the iterative nature of evaluation, advocating for progressive adjustments to software and documentation based on quantitative and qualitative data obtained through successive testing cycles.

Aligned with the importance of evaluation, Landauer (1988) expands this perspective by highlighting that the increasing complexity of interfaces and their accelerated transformation demand full-task experiments and real environments. This perspective emphasizes the need for end-to-end performance measurement and the adoption of combinatorial methods capable of enabling unexpected results. In the field of usability, Karat (1997) proposes a distinction between subjective evaluations, derived from human experience, and objective ones, supported by measurable parameters, indicating that, in complex systems, the relationship between both is not always empirically ascertainable.

Based on this ambivalence, Hassenzahl et al. (2000) identify two autonomous perceptual dimensions: ergonomic quality (EQ), associated with simplicity and control, and hedonic quality (HQ), related to innovation and pleasure. Although both influence the appeal of interactive systems, they operate under potentially conflicting logics, which imposes limitations on the simultaneous maximization of these attributes. In addition, Hassenzahl (2001) links product evaluation to user cognition, whose effects include behavioral consequences, such as increased frequency of use and reduced learning curve, and emotional ones, such as satisfaction, frustration, or disappointment.

The FCIA-OT is grounded in these conceptual foundations. By integrating technical, analytical, and perceptual requirements, it enables a multiscalar approach with evaluative depth and methodological flexibility. The case studies presented below demonstrate the empirical application of the model across three distinct objects, revealing its capacity for adaptation and responsiveness to the functional, structural, and interactive diversity of the systems analyzed.

2 CASE STUDIES: APPLICABILITY OF FCIA-OT

The empirical validation of the FCIA-OT requires its application in real and varied contexts, in which system complexity, interface heterogeneity, and the diversity of performance criteria can be observed at an operational scale. The methodological choice of case studies allows for the in-depth examination of such variables, enabling the technical refinement of criteria, the validation of the framework's architecture, and the tracing of applicable patterns.

Accordingly, Wixon (2003) argues that case studies are more suitable for understanding the practical application of methods, offering a richer and more situated view of the real dynamics involved in the development and use of technologies. Liljegren (2006) classifies usability evaluation methods into empirical and analytical, emphasizing that both should be employed based on their capacity to identify concrete issues and generate relevant data for system safety and performance. These methods are fully compatible with the modular and iterative logic of the FCIA-OT.

Approaches must be rigorous and capable of identifying real problems. Rosenbaum (2008) observes that usability evaluation should be integrated into the product lifecycle, ensuring that design decisions are supported by continuously collected empirical evidence. This integration, as enabled by the FCIA-OT, ensures a systemic approach that is responsive to data, maximizing the technical value of the evaluation. In a complementary manner, Heuwing, Mandl, & Womser-Hacker (2016) indicate that the use of specific metadata facilitates the categorization and retrieval of usability data across diverse contexts, particularly when the analysis is conducted with modular depth.

While Yusop, Grundy, & Vasa (2017) reveal recurring deficiencies in traditional usability failure tracking systems, often failing to capture essential data such as problem severity or redesign proposals, these gaps are addressed by the FCIA-OT through explicitly documented requirements and criteria.

The application of the FCIA-OT in real-world contexts aims to validate the consistency of its technical-analytical architecture and the effectiveness of the embedded evaluation systems. The Systemic Matrix of Integrated Vectorial Dimensions (MSDVI), the framework's core structural component, organizes objective and subjective criteria into twelve dimensions grouped in interdependent blocks, enabling a multiscalar, iterative, and responsive analysis of technological objects (see Chapter 1). Among the integrated systems, the SPMI and SCDMIC function as quantitative and visual representation mechanisms, assigning weights and chromatic categories to the criticality of the observed elements (see Chapter 2). The SGUI and SCMI scores reflect, respectively, the relative frequency of recurrence and the critical intensity of the analyzed elements, contributing to more precise and comparable dimensional diagnoses across different evaluated objects (see Chapter 3).

The following studies explore the applicability of the framework across three distinct technological objects, each with varied compositions, purposes, and technical characteristics. The analyses are conducted based on parameters of ecological validity, methodological rigor, and sensitivity to both objective and subjective data, grounded in consolidated scientific references, with the aim of demonstrating the technical robustness and functional versatility of the proposed approach.

2.1 Case Study: Interactive Software – Graphical User Interface for Client Registration

The application of FCIA-OT in interactive software contexts enables a multiscalar analysis of the agent–technology relationship, simultaneously incorporating functional, perceptual, and affective aspects. Graphical interfaces designed for operational tasks, such as client registration, demand responsiveness, clarity, and contextual adherence, without disregarding subjective factors that influence the user experience, such as the sense of control, emotional appeal, and perceived value.

According to McGrenere (2000), one of the central challenges in system design lies in the variability of utility perception among different users. The phenomenon of subjective bloat, characterized by the discrepancy between the number of available features and their perceived usefulness, undermines simplicity and hinders interaction efficiency. The author proposes personalization strategies adapted to diverse user profiles, grounded in social roles, routines, or digital personae, in order to align functionalities with specific usage needs.

Forlizzi & Battarbee (2004) emphasize that interactive experience is shaped both by the architecture of the interface and by the user's subjective construction during interaction. A system cannot be evaluated solely based on its technical structure, but through the multiplicity of ways in which it is experienced. The construction of system value is, therefore, linked to its capacity to generate meaningful and emotionally coherent experiences.

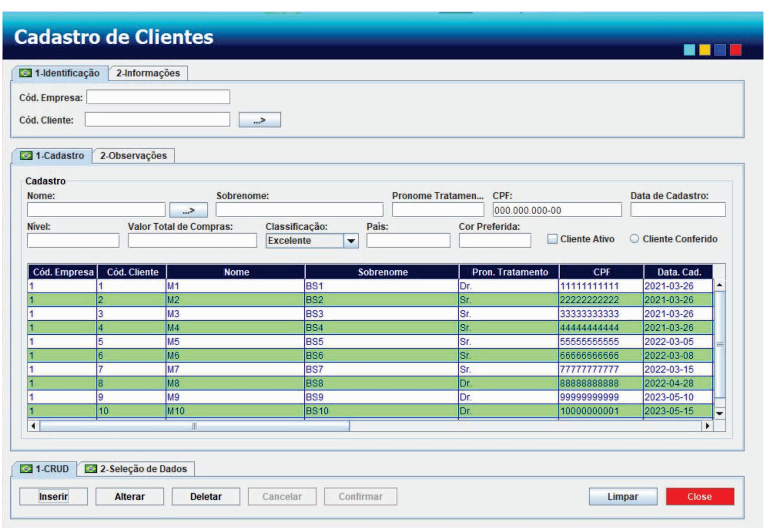
This interdependence between objective attributes and subjective perception is also underscored by Hassenzahl, Diefenbach, & Göritz (2010), who highlight the importance of integrating pragmatic criteria, such as functionality and usability, with hedonic aspects related to satisfaction and pleasure. The perceived quality of a system is not defined solely by its efficiency, but by its ability to balance instrumental functionality and emotional response. This balance directly affects the user's judgment and the acceptance of the technology.

Hassenzahl (2018) expands this approach by arguing that the momentary appeal of a product depends on the degree of correspondence between its apparent character and the usage situation. This correspondence is not static, but dynamic, requiring continuous adjustments between perceived attributes and situational demands. The adaptability of the system is a determining factor for users' emotional and behavioral responses, influencing everything from engagement to loyalty.

The operationalization of FCIA-OT in this case study aimed to map, based on these references, the critical points of usability, perception, and contextual adequacy of the client registration interface. By integrating technical, cognitive, and affective variables, the framework enables a thorough interpretation of the interactive experience, reinforcing its diagnostic robustness and its capacity to generate specific recommendations for system enhancement.

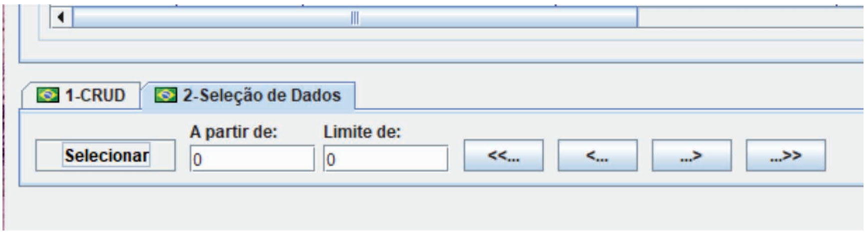
The analysis and evaluation of the client registration system interface, represented in Figures 1 and 1.1, was conducted based on the multidimensional structure of FCIA-OT. Tables 1, 1.1, 1.2, and 1.3 consolidate a technical analysis with multiple entries, each considering Object Requirements (RQO) and Artifact Requirements (RQA), descriptive accounts, and corresponding quantitative attributions within the qualitative dimensions of the framework.

FIGURE 1: CLIENT REGISTRATION SOFTWARE



Source: Author.

FIGURE 1.1: DATA SELECTION SOFTWARE



Source: Author.

Table 1 structures the direct observation of merit and failure points identified in the interface, with emphasis on the Artifact Requirements (RQA) dimension, which captures functional, perceptual, and structural attributes of the user experience. These records constitute the empirical starting point for subsequent analytical stages, conducted based on the twelve-dimension technical-analytical matrix of the FCIA-OT.

Each row in the table represents an individual technical entry, derived from the direct application of the RQA dimension's criteria. The "RO" column identifies the corresponding Object Requirement; "RA" refers to the involved Artifact Requirement. The "RA Desc." field synthesizes the observed technical category, such as interface logic, visual structure, layout, or controls, while "Report" and "Description" document the empirical occurrence of the failure or success, as recorded in the real usage environment. These data comprise the initial observational basis upon which interdimensional analyses will be superimposed, enabling modular, relational, and contextualized evaluation.

TABLE 1: SOFTWARE ANALYSIS AND EVALUATION

Technological Object: Software – Client Registration					
*****	**RO**	**RA**	**Desc. RA**	**Report**	**Description**
1	RO17	RA01	Size	The screen is not the correct size; it is too large	On smaller monitors, more than one system window must be opened
2	RO17	RA25	Visualization / Visual	The screen has a basic default layout	The system design could be improved
3	RO17	RA18	Color(s)	The default screen color is basic	The color scheme requires enhancement
4	RO17	RA26	Interface Controls	The form control buttons are small	The buttons are somewhat small and require focused attention during selection

5	RO17	RA24	Position / Location	The [red] close buttons on the form are correctly positioned	
6	RO17	RA26	Interface Controls	The Company Code field does not support [Enter] to search	Pressing [Enter] after input would facilitate search and eliminate the need to click the button
7	RO17	RA26	Interface Controls	The Client Code field does not support [Enter] to search	Pressing [Enter] after input would facilitate search and eliminate the need to click the button
8	RO17	RA26	Interface Controls	The Registration Date field lacks a calendar	A date mask alone is insufficient; a date picker would eliminate the need for manual input
9	RO17	RA25	Visualization / Visual	The alternating row colors in the data grid enhance visualization	
10	RO17	RA22	Pagination	The data grid does not include pagination buttons	Pagination is necessary to improve efficiency
11	RO17	RA33	Interface Logic	The data search highlights a range of values but does not alert for large intervals	No alert is issued when a large value range is entered
12	RO17	RA33	Interface Logic	When large value intervals are entered, the system becomes slow or unresponsive	The system is slow or fails when executing high-volume data queries
13	RO17	RA34	Execution Logic	The CRUD button sequence is functional but requires familiarity	
14	RO17	RA35	Procedural Logic	The CRUD operation sequence requires training	

Source: Author.

Table 1.1 systematizes the technical assessment of the analyzed set based on the following dimensions:

Knowledge/Experience (CEX): Level 7 across all records confirms that the evaluators have full command of the interface’s concepts and interactions. This factor validates the legitimacy of the assessment, eliminating biases related to lack of familiarity.

Affordance (AFF) and Perception (PRC): Items 6, 7, 8, and 10 reveal affordance constraints (2, 2, 2, -5) combined with static perceptual responses (PRC = 3, 3, 3, 5), indicating low functional intelligibility, especially in search controls and in the absence of calendar features or pagination.

Affectivity (AFV) and Satisfaction (STSF): Dissatisfaction emerges systematically in items 6 to 12, where STSF ranges from -1 to -5. These values reflect negative emotional reactions triggered by operational limitations, highlighting the correlation between technical deficiencies and user frustration.

Effectiveness (EFT): Records 10, 12, and 13 display significant drops in effective performance (ranging from -3 to -5), particularly in cases involving delays or system failure during high-volume data queries.

Severity of Errors (GVE) and Risk Levels (GSR): Values range from 0 to 4, with record 12 standing out negatively in GVE. Severe slowness and the absence of alerts in searches involving extreme value ranges represent substantial operational risks that may compromise process continuity.

TABLE 1.1: SOFTWARE EVALUATION

*	CEX	RQA	AFF	PRC	AFV	STSF	EFT	GVE	GSR
1	7	3	2	3	-1	6	5	1	1
2	7	4	2	3	-1	6	5	1	0
3	7	4	2	3	-1	6	5	1	0
4	7	5	8	3	-1	0	5	1	1
5	7	10	10	10	3	7	10	0	0
6	7	2	2	3	-3	-1	5	2	0
7	7	2	2	3	-3	-1	5	2	0
8	7	-5	2	3	-3	-4	-3	2	1
9	7	7	9	10	3	7	10	0	0
10	7	-5	-5	5	-4	-4	-3	3	1
11	7	-3	-4	2	-3	-1	5	3	1
12	7	-5	-4	-5	-5	-5	-5	4	3
13	7	3	2	-5	-3	6	-3	3	0
14	7	1	2	-5	-3	0	5	2	0

Source: Author.

Table 1.2 presents the Attributes (ATB) under analysis, which offer concrete evidence of either the maturity or fragility of specific interface elements:

Record 1 (ATB01 = 6): Reflects basic conformity regarding screen size, although the report indicates inadequacy for smaller monitors.

Record 2 (ATB12 = 5): The default visual layout is perceived as acceptable, though not advanced.

Records 6 and 7 (ATB03 = 4): The absence of [Enter] functionality does not prevent operation but reduces both fluidity and productivity.

Record 12 (ATB02 = -4, ATB03 = -3, ATB04 = -5, ATB11 = -3): Represents the most structurally compromised point in the analysis. The overlap of failures related to response time, visual design, control behavior, and feedback mechanisms constitutes a critical scenario, seriously undermining the interface's functional integrity.

TABLE 1.2: SOFTWARE EVALUATION

*	ATB	SPMI
1	ATB01	6
2	ATB12	5
6	ATB03	4
7	ATB03	4
11	ATB04	3
12	ATB02	-4
12	ATB03	-3
12	ATB04	-5
12	ATB11	-3
13	ATB05	-4
14	ATB03	5
14	ATB04	6

TABLE 1.3: SOFTWARE EVALUATION

*	ACB	SPMI
1	ACB12	-5
1	ACB13	-3
2	ACB11	-3
3	ACB09	7
4	ACB10	-2
5	ACB06	7
6	ACB05	-3
6	ACB06	-2
7	ACB26	1
9	ACB11	8
11	ACB16	-5
12	ACB15	-5
13	ACB25	-4
14	ACB25	-4

Source: Author.

Table 1.3 presents a mixed overview of Accessibility (ACB), highlighting significant issues:

ACB12 (-5), ACB13 (-3) in Record 1: These values reveal difficulties in interface scaling across different screen resolutions, directly affecting visual accessibility.

ACB09 (7) in Record 3: The basic color scheme received a high score in this case, representing a rare positive factor within a predominantly negative context.

ACB05 (-3), ACB06 (-2), ACB26 (1) in Records 6 and 7: These indicate barriers in interaction controls, particularly regarding functional accessibility (e.g., keyboard usage).

ACB15 and ACB16 (-5) in Records 11 and 12: These penalize the system's failure to respond to agent interactions and the absence of appropriate feedback mechanisms.

ACB25 (-4) in Records 13 and 14: Although the procedural sequence is functional, it lacks clarity and does not offer intuitive operational accessibility.

This ACB dimension reinforces the technical critique: the more severe the failures in perception, feedback, and control, the more critical the accessibility penalty becomes.

Based on the four evaluation tables, the need for a complete redesign of the client registration interface becomes evident, particularly in three core areas of recurrent failure:

Interaction and Controls (RA26): Multiple records point to operational issues in basic controls. The absence of keyboard shortcuts, calendar elements, and pagination reflects a low-efficiency interactive environment.

System Responses (RA33, RA34, RA35): The system fails to properly handle high-volume data inputs, leading to critical malfunctions. These failures directly compromise the dimensions of Effectiveness (EFT), Satisfaction (STSF), Error Severity (GVE), and Risk Level (GSR).

Visual and Perceptual Consistency (RA25, RA18): The design exhibits low visual appeal, a lack of visual hierarchy, and an absence of functional color schemes, factors that negatively affect perception, affectivity, and user satisfaction.

The triangulation of PRC, AFF, and ATB confirms a systemic chain of perceptual and functional failures, compromising intelligibility, legibility, and operability. The presence of critical interface zones intensifies user frustration, reduces confidence, and undermines overall effectiveness.

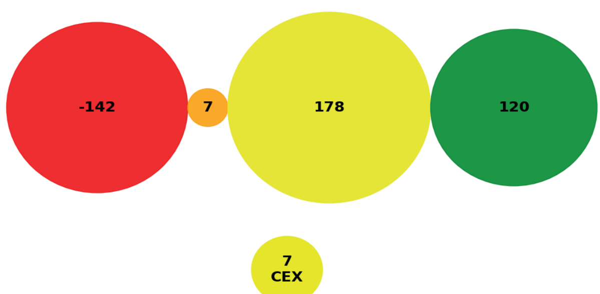
Although structurally functional, the interface contains substantial limitations that affect usability, accessibility, and perceived value. The FCIA-OT's multidimensional analysis reveals that these are not isolated issues but recurring patterns that significantly compromise the agent experience.

Figure 2 illustrates the modular distribution of score volume by color, according to SCDMIC criteria under the SPMI. It reflects the performance of the evaluated technology based on processed observational and technical data. Each circle proportionally represents the concentration of points assigned to clusters of correlated dimensions, highlighting levels of: Excellence (green), localized adjustments (yellow), instability (orange), and criticality (red).

In total, 120 points were identified in the systemic maturity range (green), 178 points as moderate (yellow), indicating localized technical demands; 7 points as problematic (orange), associated with relevant operational failures; and a substantial volume of -142 critical points (red), corresponding to severe failures that require immediate corrective action regarding the technological object's requirements. These dysfunctions compromise proper usage, generate operational risks, or prevent the execution of expected tasks, with direct impact on agent experience and safety.

The CEX score, isolated in yellow at the lower base, reinforces that the diagnostic judgment is not compromised by lack of expertise, even when the domain level is intermediate (CEX = 7). The figure provides a visual and accurate synthesis of the interface's performance configuration, reaffirming the diagnostic effectiveness of the FCIA-OT.

FIGURE 2: DISTRIBUTION OF SCORE VOLUME (SPMI) AND COLOR PATTERN (SCDMIC)



Segmented circular visualization of model dimensions, with color coding based on the SCDMIC. Each circle represents dimensions grouped within specific criticality ranges: Red (critical zone), Orange (functional instability), Yellow (intermediate level), and Green (high maturity). The visual structure aggregates dimensions by color volume and highlights CEX (Evaluator Knowledge/Experience Dimension) as an isolated axis. This configuration enables a synoptic reading of the functional state, operating as a high-precision pre-diagnostic mechanism for identifying priority areas for reengineering, structural adjustments, and interactive validation.

Source: Author.

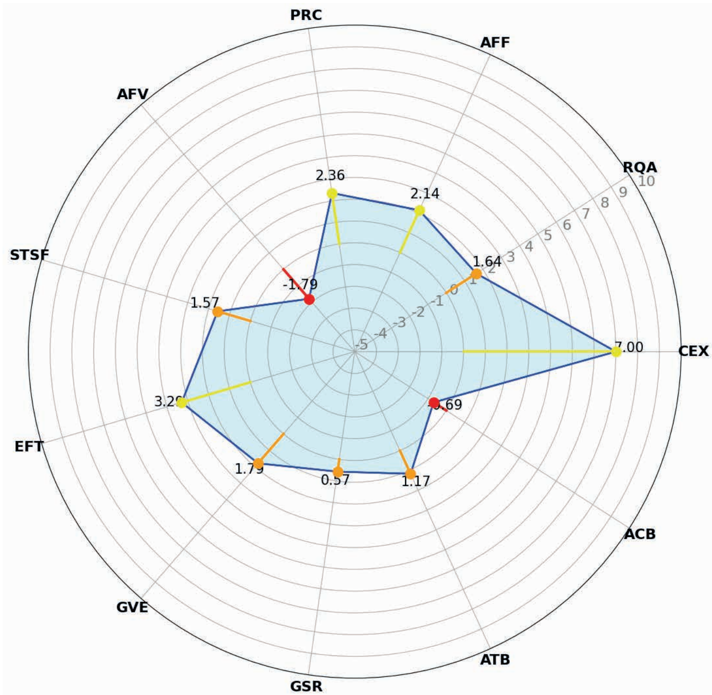
Figure 3 presents a hybrid polar visualization that integrates, within a single analytical plane (radar), two complementary levels of diagnostic reading: (i) the individualized representation of dimensions, plotted radially with color coding based on the criticality levels defined by the SCDMIC; and (ii) the continuous closed blue contour, which expresses the topological average profile of the evaluated technology.

The individualized radial lines, combined with their respective chromatic markers, blue (systemic conditional), red (critical), orange (problematic/unstable), yellow (moderate), and green (excellent/adequate), function as vectors of semantic gradation, facilitating the objective identification of points of vulnerability, intermediate stability, and relative excellence across each dimension. This chromatic distribution, anchored in the defined ranges within the scope of the SCDMIC, enhances interpretative precision and supports the application of rigorous technical criteria throughout analysis and reengineering cycles.

In parallel, the continuous blue line, which connects the average values of all dimensions, provides an aggregated and synoptic reading of the structural distribution of the technological object. The resulting geometry, marked by inflections, angular distortions, and asymmetries, acts as a diagnostic signature, enabling the identification of functional imbalances, critical dispersions, and concentrations of maturity across specific axes of evaluation.

The overlay of these two visualization regimes maximizes the technical intelligibility of the diagnosis, supports interdimensional comparative analyses, and guides evidence-based decision-making in stages of functional enhancement, validation, and systemic reengineering.

FIGURE 3: INTEGRATED RADAR DIAGNOSIS: CRITICAL CODING BY DIMENSION AND CONTINUOUS AVERAGE PROFILE (BLUE RADAR)



Hybrid polar visualization of the dimensions assessed according to the FCIA-OT model. The colored radial lines represent the average values of each dimension, coded according to the SCDMIC (red = critical; orange = unstable; yellow = moderate; green = adequate). The continuous blue contour indicates the aggregated topological average of the dimensions, enabling a synoptic reading of the structural distribution and identification of functional asymmetries.

Source: Author.

This scenario reinforces the FCIA-OT's analytical capacity to precisely map, with scientific and technical accuracy, rupture points that compromise both interaction engineering and the software's functional logic. By identifying these interrelationships, the framework not only supports a robust diagnostic process but also provides strategic input for reengineering efforts focused on advanced usability, functional accessibility, and qualified perception. In this way, it is consolidated as a systemic tool of high technical value for the evaluation and reconstruction of interactive technologies.

2.2 Case Study: Embedded Control System with Firmware – Conventional Air Conditioning Unit

The application of FCIA-OT to the analysis of embedded systems enables a technical-analytical approach guided by physical-digital interaction, taking into account the perceptual, operational, and semantic unfoldings mediated by the firmware. In this type of object, the assessment must encompass both the structural coherence of the hardware and the internal logic of digital control, with emphasis on how visual affordances, tactile responsiveness, and flow sequences communicate to the agent the possible states of action and feedback.

The air conditioning control examined in this study, characterized by its minimalist architecture and sequential internal logic, exemplifies an artifact whose performance depends on the alignment between perceptual clarity and functional predictability. By decomposing this object into the sets of Object Requirements and Artifact Requirements, FCIA-OT enables precise mapping of critical interaction zones, revealing hidden patterns of failure or merit in the relationships among agent, interface, and context.

Simplicity and clear functionalities are highlighted by McGrenere (2000), who identifies that an excess of features misaligned with the agent's profile, known as subjective bloat, compromises usability by cognitively overloading the interface. Personalization strategies and selective simplification, based on agent profiles and usage contexts, can restore system balance without sacrificing functional capability.

According to Forlizzi & Battarbee (2004), the user experience is co-determined by technical and contextual factors. The environment, social routines, and emotional states directly influence both the perception and meaning of the interaction, making it essential that the evaluation include environmental and situational variables.

In line with this understanding, Komine, Takanishi, & Aoyama (2006) demonstrate that simplified interfaces, with self-explanatory graphical elements and consistent feedback, reduce initial usage barriers and are particularly effective in contexts with low technological familiarity. According to the authors, response predictability is as essential as command clarity.

Hassenzahl, Diefenbach, & Göritz (2010) observe that pragmatic quality does not operate in isolation. Its effect on the experience depends on the affective mediation promoted by the system, that is, the sense of control, trust, and appropriateness experienced by the user influences how utility is perceived. In agreement, Hassenzahl (2018) systematizes that the appeal of an artifact is linked to its ability to meet the agent's situational aspirations. This includes both pragmatic goals, such as modifying the environment, and hedonic goals, such as reinforcing identity or evoking memories.

Figure 4 presents the control unit of the air conditioning system, which serves as the empirical basis for the decomposition of constituent elements and the application of the FCIA-OT's technical-analytical dimensions. The methodology employed in this study organizes the data based on the modular distinction between the physical hardware and the embedded system, allowing the identification of how failures in icon legibility, tactile inconsistencies, and lack of explicit feedback compromise the agents' ability to correctly interpret the interface states. The mapping reveals zones of vulnerability in which interaction becomes non-intuitive, dysfunctional, or ambiguous.

FIGURE 4: AIR CONDITIONING CONTROL

Air conditioning control. 12,000 BTUh unit, Split Wall type, 220V, noise level 29 dB(A). Firmware: specialized software embedded in non-volatile hardware (ROM, EPROM, flash) that controls and manages specific device operations. It functions as a critical interface between physical components and logical functionalities, regulating hardware behavior in embedded systems.

Source: Author.

The analysis and evaluation of the control, structured in Tables 2, 2.1, 2.2, 2.3, and 2.4, were conducted through the direct application of FCIA-OT's modules and submodules, considering multiple cycles of observation and real manipulation. The records were organized into technical entries, with qualitative and quantitative details on functional, perceptual, and symbolic failures, successes, and neutralities, mapping the maturity of use in everyday situations. Table 2 includes entries related to the Artifact Requirements (ARQ). Each occurrence was interpreted through the dimensions of the framework, revealing recurrent patterns of deviation from or adherence to the agents' expectations. The result is a technical-scientific radiograph of the quality of interaction promoted by the device.

TABLE 2: ANALYSIS AND EVALUATION OF THE AIR CONDITIONING CONTROL

Technological Object: Air Conditioning Control					
*	RO	RA	Desc. RA	Report	Description
1	RO06	RA02	Dimension	The artifact's dimensions are adequate	
2	RO06	RA04	Weight	The artifact's weight is suitable for handling	
3	RO06	RA16	Power Consumption	Battery consumption is moderate	
4	RO30	RA25	Display/ Visual	The screen displays many symbols	The system design could be improved
5	RO16	RA33	Interface Logic	Navigation is not clear or guided	The navigation logic is item-by-item and requires learning
6	RO16	RA27	Symbols/Icons/ Representation	Many symbols are ambiguous and require learning	Symbols must be clear, standardized, and explained in the agent manual
7	RO16	RA31	Complexity	The artifact presents logic that requires learning for nearly all features	
8	RO16	RA34	Execution Logic	All features follow sequential steps that are unclear	One must go through previous features to access the desired one
9	RO16	RA27	Interface Controls	The "+", "–", and power buttons are intuitive for increasing, decreasing temperature, and turning off	
10	RO16	RA26	Symbols/Icons/ Representation	The mode control displays unclear icons	It requires learning
11	RO16	RA26	Interface Controls	The "Menu w/ Conf." setting to remove the temperature display is unclear	It requires learning
12	RO16	RA26	Interface Controls	The "Menu w/ Conf." setting for automatic activation is not instructive	This option should always be disabled by default and clearly included in the agent manual
13	RO16	RA26	Interface Controls	The "Menu w/ Conf." setting to configure automatic on/off times is not instructive	The logic to set on/ off times is unclear and requires learning
14	RO16	RA26	Interface Controls	The "Menu w/ Conf." setting to set the clock is not instructive	It is necessary to go through multiple other options to reach this setting

15	RO16	RA26	Interface Controls	The “Menu w/ Conf.” setting for sleep mode is unclear	Its logic, icon, and modes require learning
16	RO16	RA26	Interface Controls	The “Menu w/ Conf.” setting for energy-saving mode is unclear	The logic of this option is unclear and requires learning and understanding of its functional outcome
17	RO03	RA12	Build Quality	Assembly and fit are of intermediate quality	
18	RO03	RA53	Maintainability	No preventive, corrective, or evolutionary maintenance options	
19	RO03	RA52	Technical Instructions	Documentation and instructions are incomplete	

Source: Author.

Table 2.1 systematically and technically structures the analytical judgment of the functional control module based on nine critical dimensions, allowing an in-depth diagnosis of the interface’s intelligibility, efficiency, and safety.

Knowledge/Experience (CEX): The uniformity in values (CEX = 6) indicates that the evaluators possess intermediate-to-high technical experience in handling the controls assessed. This pattern minimizes the influence of noise stemming from inexperience, thus granting reliability to the sample and legitimacy to the triangulation with other dimensions.

Object Requirements (ARQ): The highest adherence indices appear in entries 1, 2, and 9 (ARQ ≥ 8), indicating that in these cases, the controls more fully meet the expected requirements for the functional context. In contrast, entries 5 through 8 and 10 through 19 show a sharp decline (ARQ ranging from -5 to 2), revealing critical dissonances between the designed behavior and the operational need.

Affordances (AFF) and Perception (PRC): Among entries 5 through 8 and 10 through 13, a recurring set of negative or ambiguous affordances is observed (AFF between -5 and -1), often accompanied by low cognitive construction perceptions (PRC between -5 and 2). This configuration characterizes a functional breakdown between action signaling and perceptual inference, pointing to informational design failures in components such as buttons, interactive fields, and filter functions, whose semantics do not foster effective cognitive engagement.

Affectivity (AFV) and Satisfaction (STSF): Emotional impacts become evident in the sequence of entries from 4 to 16, where STSF shows a recurrence of negative values. This instance reflects an affective state marked by frustration, uncertainty, and additional cognitive load in the use of controls, generally linked to unrecognized affordances and exploratory perceptions (PRC = -5), as observed in entries 5, 6, and 10. Positive STSF reappears only in entries 1, 2, 3, 9, and 17, where affordances are well signaled and performance remains stable.

Effectiveness (EFT): The operational effectiveness dimension reveals significant losses in entries such as 3, 8, 10, 12, 13, 14, 15, 16, 17, and 18, where values between -5 and -3 reflect delays, functional failures, and inconsistency in interface feedback, especially when operating filters, validating inputs, or reconfiguring displays. In contrast, entries 1, 2, 4, 5, 6, 7, 9, 11, and 19 return positive or neutral EFT values, suggesting partial stability under specific conditions.

Severity of Errors (GVE) and Risk Levels (GSR): The presence of severe errors and operational risks is concentrated in entries 3 through 8 and 10 through 19, where GVE and GSR values range from 1 to 3. These values indicate the potential exposure of agents to silent failures, information loss, or misuse of sensitive controls. The combined analysis of GVE and GSR dimensions demonstrates that the absence of clear affordances, together with imprecise perceptions and weak feedback, undermines the robustness of the control system and raises the level of risk in the continuous use of the technology.

TABLE 2.1: CONTROL EVALUATION

*	CEX	RQA	AFF	PRC	AFV	STSF	EFT	GVE	GSR
1	6	8	9	10	3	7	5	0	0
2	6	9	9	10	3	9	5	0	0
3	6	5	8	5	-3	6	-3	3	1
4	6	3	2	2	-3	-1	5	3	1
5	6	-1	-1	-5	-1	-1	5	3	2
6	6	-4	-4	-5	-3	-3	5	2	2
7	6	-5	-5	-5	-1	-3	5	3	2
8	6	-3	-3	2	-1	-1	-3	2	2
9	6	9	10	10	5	6	10	0	0
10	6	-4	-4	-5	-1	-1	-3	3	2
11	6	1	-4	-5	-3	-3	5	1	2
12	6	-3	-3	2	-1	-4	-3	2	3
13	6	1	-3	2	-1	-4	-3	2	2
14	6	1	2	2	-1	-1	-3	1	1
15	6	-2	2	2	-5	-3	-5	3	2
16	6	-2	2	2	-3	-4	-5	2	2
17	6	2	8	5	3	6	-3	1	3
18	6	-3	-3	2	-5	-1	-3	3	3
19	6	-4	-3	2	-3	-5	5	3	3

Source: Author.

Table 2.2 reveals, from the perspective of Technological Attributes (ATB), the distribution of maturity and failures of the evaluated control, highlighting the structural behavior of the artifact in relation to expected functional and ergonomic requirements:

Usability (ATB01) shows excellent performance in entries 1 and 2 (SPMI = 7), indicating that agents' quickly understand the essential commands and operate the control with reduced cognitive effort. This demonstrates compatibility between the visual structure and the agent's interaction expectations.

Efficiency (ATB03) undergoes progressive degradation, with a negative highlight in entry 12 (-3), suggesting operational delays or redundant processes during basic interactions. Although entry 3 still maintains a positive score (4), the subsequent decline indicates a lack of consistency in the system's responses over continued use.

Functionality (ATB04) reveals a localized functional collapse. While entry 4 maintains acceptable performance (4), entry 7 shows a severe breakdown (-4), and entry 16 reinforces the issue with an additional negative score (-3). The same attribute reappears in entry 13 with a score of (1), indicating unstable fluctuation in the operational architecture.

Accessibility (ATB05) reaches concerning levels, with two entries falling within critical ranges: entry 8 (-4) and 13 (-1). The partially positive score in entry 10 (2) does not offset the overall trend of inefficiency regarding the control's suitability for different agents' profiles or usage conditions, which compromises the universality of the solution.

Simplicity (ATB15) appears only in entry 9 with an excellent score (8), suggesting that although the visual presentation and navigation elements are well designed, their aesthetic quality and direct usability are not consistently replicated across the control's other functionalities.

Compliance (ATB10) is recorded only in entry 19, with a critical score (-5). This implies a direct failure to adhere to design or safety standards, representing a normative or technical risk, especially in regulated or sensitive environments.

The analyzed artifact, in its control form, demonstrates structural fragility in fundamental attributes such as functionality, accessibility, and compliance. The data indicate that, although the control is usable under ideal conditions, its performance is neither stable nor universal, with recurring failures in simple tasks and non-optimized contexts. The technical maturity of the control is therefore compromised, requiring corrective actions in the layers of functional architecture, operational response, and normative adherence.

TABLE 2.2:

CONTROL EVALUATION

*	ATB	SPMI
1	ATB01	7
2	ATB01	7
3	ATB03	4
4	ATB04	4
7	ATB04	-4
8	ATB05	-4
9	ATB15	8
10	ATB05	2
12	ATB03	-3
13	ATB04	1
13	ATB05	-1
16	ATB04	-3
19	ATB10	-5

TABLE 2.3:

CONTROL EVALUATION

*	ACB	SPMI
6	ACB06	-5
7	ACB06	-3
8	ACB06	-2
9	ACB06	7
9	ACB11	7
10	ACB11	-3
13	ACB06	-1
13	ACB12	-5
14	ACB06	-2
16	ACB06	-4
19	ACB04	1

TABLE 2.4:

CONTROL EVALUATION

*	QRSUER	SPMI
3	TQRS01	3
3	TQRS02	1
17	TQRS04	-5
17	TQRS05	-4
17	TQRS11	-4
17	TQRS12	-3
17	TQRS10	-3
18	TQRS10	-3
18	TQRS11	1

Source: Author.

The evaluation of accessibility criteria in Table 2.3 reveals critical gaps in attribute ACB06 (Navigation Consistency). The accumulation of negative scores in entries 6, 7, 8, 13, 14, and 16, with SPMIs ranging from -1 to -5, indicates structural fragmentation in the organization and predictability of navigation. This pattern highlights instability in the interaction architecture, compromising the agent's cognitive efficiency during continuous use of the control. Only entry 9 shows a satisfactory pattern (7), standing isolated in the dataset.

The analysis also points to significant shortcomings in ACB12 (Accessibility Adjustments), with entry 13 scoring -5, indicating the absence of fundamental interface personalization mechanisms such as contrast settings, captions, or resizing options that accommodate user diversity.

Regarding criterion ACB11 (Visibility and Legibility), there is a sharp contrast between entries 9 (7) and 10 (-3). While the former ensures visual clarity and perceptual comfort, the latter presents perceptual obstacles that impair legibility, indicating a lack of uniformity in visual implementation.

Finally, ACB04 (Support for Multilingual Content) shows a neutral-positive result (1), suggesting an initial stage of implementation, though without significant impact on the inclusive experience.

The evaluation of the QRSUER technology criteria in Table 2.4 reveals unstable performance of the control system with respect to the environmental and social standards defined by QRSUER, as evidenced by the recurrence of negative scores across several critical aspects.

Although there are moderately positive results in Resource Utility and Efficiency (TQRS01 = 3) and Resource Sustainability (TQRS02 = 1), indicating some alignment with operational efficiency practices and conscious resource usage, the sequence of severely negative outcomes in cases related to Solid Waste Management (TQRS04 = -5), Active Disposal (TQRS05 = -4), Facilitated Repair (TQRS11 = -4 and 1), Modular Adaptability (TQRS12 = -3), and Recyclability (TQRS10 = -3 and -3) exposes structural weaknesses in the product or system life cycle.

The absence of effective disposal and reuse mechanisms, combined with low modularity and repair difficulty, compromises durability, increases obsolescence, and intensifies environmental impact. This condition reflects non-compliance with circular economy principles and sustainable design, limiting the regenerative efficiency and socio-environmental responsibility of the technology.

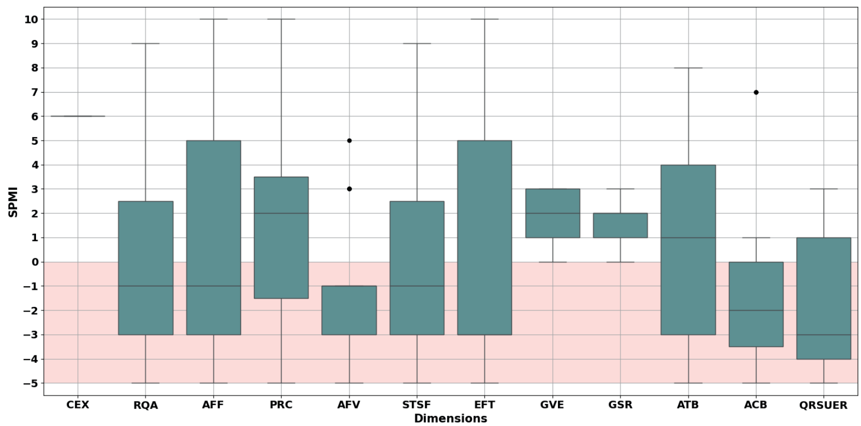
The repeated negative scoring in items evaluated by multiple controllers (such as TQRS10 and TQRS11) reinforces the consistency of these failures, indicating that they are not attributable to individual perception but rather to the materiality of the problems.

Therefore, the control analysis under QRSUER reveals that, although there are isolated efforts toward resource efficiency, the evaluated technology shows significant limitations in waste management, modularity, and circularity, requiring technical restructuring to meet essential sustainability and socio-environmental responsibility requirements.

Figure 5 synthesizes the statistical distribution of the control's performance across the main evaluative dimensions of FCIA-OT, based on the SPMI structure. The score ranges, codified and standardized, enable the precise positioning of the control along a continuous scale from -5 to 10, revealing dispersions, outliers, and central tendency measures associated with each modular axis.

Variations in the statistical configuration across dimensions indicate distinct patterns of adherence to the evaluative requirements. In modules such as AFV, EFT, GVE, and GSR, the absence of essential distribution components, such as the median or upper quartiles, suggests anomalous compressions, centrality bias, or score clustering in critical zones of the scale. These patterns, from the technical perspective of FCIA-OT, are interpreted as markers of structural instability, low functional consistency, or residual performance of the control in these dimensions.

FIGURE 5: MODULAR STATISTICAL DISTRIBUTION OF THE CONTROL IN THE EVALUATIVE DIMENSIONS OF FCIA-OT



Boxplot chart structured according to the SPMI, with a scale ranging from -5 to 10. It represents the distribution, dispersion, and positioning of the control across the 12 evaluative dimensions of FCIA-OT, highlighting medians, variations, and possible outliers on each modular axis.

Source: Author.

The graphical modeling based on SPMI functions as a high-precision analytical mechanism, enabling not only the visualization of the modular positioning of the control but also the identification of zones of compliance, distortion, or vulnerability. Emerging evidence from this modeling is essential to support rigorous technical inferences regarding the maturity, robustness, and suitability of the technology in relation to the set of requirements underpinning each evaluated dimension.

The presence of outliers, when identified, signals atypical performance deviations that, although isolated, may reveal critical failures or significant structural fluctuations in the technology's behavior. The occurrence of statistical compression, characterized by the clustering of scores within narrow segments of the scale, imposes interpretative limitations that require methodological attention, as such compressions may obscure functional asymmetries or conceal relevant patterns of non-compliance.

2.3 Case Study: Unmanned Aerial Vehicle (UAV) – Integrated Multicomponent Hardware and Software System

The analysis of high-complexity systems, such as Unmanned Aerial Vehicles (UAVs), requires a multiscalar evaluative approach, in which technical performance, agent–machine interaction, and operational responsiveness are observed in an integrated manner. The architecture of these systems, comprising hardware modules, firmware, and embedded software, imposes critical demands for reliability and precision, particularly in real-time operations under unpredictable environmental conditions.

Within the scope of FCIA-OT, the evaluation considers the relationships among perception, action, and response, examining the system's technical maturity based on the coherence between issued commands, received feedback, and resulting operational states. Elements such as status legibility, semantic compatibility between input and response, fault management, and the fluidity of functional chaining constitute core analytical axes, where localized failures can produce systemic compromises in usability and safety.

According to Woods & Roth (1988), complex systems must be assessed through systemic models capable of identifying vulnerabilities that emerge not only from the interface itself but from the interdependent relationships among operators, artifacts, and environment. The effectiveness of such systems depends on continuous validation in real operational contexts, where human behavior and system logic interact in real time under high cognitive load.

This logic of adaptation and balance between control and autonomy is also discussed by McGrenere (2000), who proposes light personalization mechanisms to mitigate the so-called subjective bloat, a condition in which the presence of functions misaligned with the user's profile compromises interface clarity and effectiveness. A system's ability to modulate its functionalities according to situational patterns and mission needs directly contributes to reducing cognitive overload and increasing operational fluidity.

From this perspective, Hassenzahl, Diefenbach, & Göritz (2010) demonstrate that user experience is deeply mediated by subjective dimensions such as the feeling of competence, autonomy, and belonging during use. In critical technologies, operational trust is not built solely through objective utility, but through the sense of control and predictability that the system is able to communicate to the operator in real time.

In the same line, Fernandez, Insfran, & Abrahão (2011) point out that the multiplicity of definitions and usability assessment methods undermines the comparability of results across systems. Unified approaches, capable of integrating different dimensions and contexts, enable more robust diagnoses and more reliable interpretations, especially in mission-critical systems such as those analyzed in this study.

Complementing this discussion, Hassenzahl (2018) proposes a distinction between products with a pragmatic emphasis (ACT mode) and those with hedonic value (SELF mode), indicating that the way the operator perceives the purpose of the technology directly influences their functional and emotional perception. In systems such as UAVs, the pragmatic appeal is dominant, but the value of subjective experience must not be overlooked, as safety and precision also depend on the sense of confidence and fluidity perceived during use.

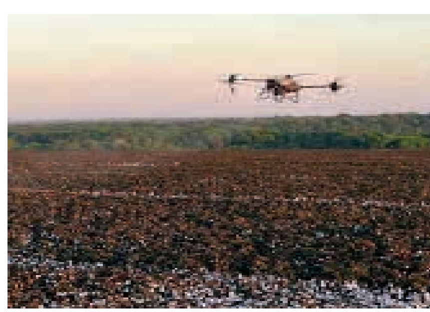
Figures 6, 6.1, 6.2, and 6.3 document critical moments of the UAV's functional cycle, including phases of takeoff, task execution, and manual adjustments in the field. These empirical records support the technical evaluation by evidencing the system's real-time dynamics in operation, revealing consistent strengths and functional vulnerabilities. Direct observation allows verification of how feedback failures, response delays, or low command clarity can compromise interaction effectiveness and mission safety. The analysis conducted based on FCIA-OT highlights critical performance zones, linking visual data to the twelve-dimensional technical-analytical matrix, ensuring the ecological and methodological validity of the assessment performed.

FIGURE 6: UAV DURING REFUELING

FIGURE 6.2: APPLICATION IN PRE-PLANTING OF CORN

FIGURE 6.1: CONTROL IN OPERATION

FIGURE 6.3: APPLICATION FOR COTTON DEFOLIATION



UAV with a capacity of 40 L, four brushless motors, 29,000 mAh battery, maximum flow rate of 22 L/min, and flight speed up to 36 km/h.

Source: Author.

The analysis and evaluation of the UAV, detailed in Tables 3, 3.1, 3.2, 3.3, and 3.4, was conducted based on the systematic application of FCIA-OT modules and submodules under real operational conditions. Each recorded technical entry reflects targeted observations on functional, perceptual, and symbolic occurrences, highlighting both merits and limitations of the technology. Table 3 organizes records linked to Artifact Requirements (RQA), focusing on execution demands in critical timeframes. Each entry constitutes a diagnostic element, revealing patterns of adherence, deviation, or neutrality according to the framework's dimensional criteria. Based on this foundation, it becomes possible to map the system's degree of maturity and reliability, identifying cores of technical excellence and critical zones that impair interaction fluidity and operational effectiveness in practical contexts.

TABLE 3: ANALYSIS AND EVALUATION OF THE UAV

Technological Object: UAV					
*	RO	RA	Desc. RA	Report	Description
1	RO06	RA03	Structure	Chassis not designed for landing with payload.	Structure must support operations with payload; its absence compromises operational safety
2	RO04	RA03	Structure	Landing legs not designed for payload landing	Structural reinforcement is required to absorb impact with attached payload
3	RO04	RA03	Structure	Arms lack breakaway points in the event of a collision	Absence of breakaway points may compromise the entire equipment's structural integrity
4	RO04	RA03	Structure	Screw thread length is reduced	Fastening is compromised in several structural components
5	RO04	RA03	Structure	LED headlights are energy inefficient (Excessive Heat)	Lighting systems generate heat beyond acceptable levels
6	RO06	RA45	Storage	Viability of 1,000 mAh/kg of load capacity	Evaluation of energy density per unit mass is required
7	RO06	RA03	Structure	Remote control should feature a 7″ screen	Ergonomic and operational requirement for field visualization
8	RO06	RA45	Storage	Load capacity between 3 and 4 kg/hp	Proportionality between payload and engine power must be dimensioned
9	RO06	RA03	Structure	Optimization of blade angle × rotation × wingspan for silent operation	Aerodynamic design must consider noise generation in operating environments
10	RO04	RA03	Structure	Hoses are too narrow	Hoses with inadequate cross-sectional area must not be used

11	RO06	RA03	Structure	Equipment should be waterproof (IP68)	Essential for operation in outdoor and humid environments
12	RO04	RA03	Structure	Absence of LIDAR sensors	Integration of LIDAR sensors enhances flight safety and autonomy
13	RO04	RA03	Structure	No cabling provided for spectral cameras	Electrical infrastructure must be preconfigured for modular installation
14	RO05	RA03	Structure	Not predisposed to upgrade: Processor, ROM, RAM, Storage, Communication Board, Motor Control Board, Cameras, LIDAR Proximity Sensors	Closed architecture compromises the system's technical scalability
15	RO06	RA26	Interface Controls	No electrical predisposition (ISOBUS type) for 4 additional sensor buttons	Interfaces must support integration of standardized accessories
16	RO06	RA03	Structure	Mechanical space not standardized for couplings	Universal compatibility requires physical standardization, similar to tractor three-point hitches
17	RO06	RA03	Structure	Absence of fixation points for ground transport	Tie-down points are necessary to ensure safe logistics
18	RO05	RA03	Structure	Hardware not prepared for ground transport vibrations	Lack of impact absorption compromises durability in agricultural environments
19	RO04	RA03	Structure	Refueling system with threaded cap is inefficient	Quick coupling connection would be more efficient and secure
20	RO06	RA03	Structure	Lack of efficient thermal exchange system and aerodynamic optimization	Required for prolonged operation in tropical environments
21	RO06	RA03	Structure	No structural predisposition for cargo transport across all brands	Standardization of transport capability is essential for agricultural functionality
22	RO04	RA54	Technical Support	No specialized maintenance available outside the dealership	Related to technical availability of parts and maintenance services
23	RO04	RA03	Structure	Universal rubber chock to be attached to the landing gear	Support and landing element
24	RO04	RA03	Structure	Customizable propellers with at least 3 or 4 different pitch angles	Influences structural behavior and functional performance of the propellers
25	RO05	RA44	Customization	Standardize blade numbering (as with tires)	Facilitates functional identification, maintenance, and customization

26	RO06	RA44	Customization	Classify UAVs as tractors (agricultural/industrial)	Technical classification related to use and application (similar to the "Yellow Line" designation)
27	RO16	RA33	Interface Logic	Login via individual registration + sub-login for pilot account	The system login is unique, restricting multi-pilot usage
28	RO16	RA28	Configuration	Missing Task Configuration Instructions	E.g.: Free flight, demonstration, work [Mapping, spray details, routes, area, equipment]
29	RO16	RA33	Interface Logic	Larger buttons, more divisions in command tree	Functional and visual hierarchical organization
30	RO16	RA33	Interface Logic	Missing button to change landing location to current control location	Operator should be able to change the UAV's landing point during autonomous operation
31	RO16	RA33	Interface Logic	Missing on/off commands in the system for UAV auxiliary inputs	Subsystem integration via interface
32	RO16	RA28	Configuration	Missing configuration for auxiliary connectors: W/Ah to recalculate autonomy	Recalculation logic based on external energy inputs
33	RO16	RA39	Compatibility	No system log connection with local weather station via Bluetooth	Integration of weather data into the system
34	RO16	RA28	Configuration	No manual configuration of the spraying system for autonomous flight	Task-system integration through configuration
35	RO16	RA28	Configuration	Missing autonomous flight configuration without activating the spraying system	Separation between flight and application logic
36	RO06	RA49	Instability/ Crash	Any kind of failure: the equipment halts and returns to base	Failure of the automatic operational safety protocol
37	RO16	RA49	Instability/ Crash	The system attempts to regain control of the equipment upon detecting slight terrain tilt	Safety logic requires contextual refinement (100% flat terrain is uncommon in field operations)
38	RO16	RA35	Procedure Logic	Refueling call can only be activated manually by the pilot	Manual procedure required in specific contexts
39	RO16	RA34	Execution Logic	System does not generate curved paths/guidance lines for application (e.g., pivots)	Failure in curved georeferencing logic
40	RO16	RA34	Execution Logic	System does not report obstacles in 3D	Absence of three-dimensional spatial mapping

41	RO16	RA34	Execution Logic	System lacks the option to activate/deactivate parallel circuits without interrupting autonomous flight	Independent control of subsystems (e.g., weighing, flow rate, pressurization, atomization)
42	RO16	RA34	Execution Logic	System does not store/ display failure reports by date/time	Absence of detailed technical history
43	RO16	RA34	Execution Logic	System lacks harness mapping/diagnostic based on resistance (Ω) at each connection point	Preventive and precise technical diagnostics
44	RO06	RA28	Configuration	Equipment lacks a configured preventive maintenance plan	Similar to vehicular maintenance logic
45	RO06	RA39	Compatibility	Predisposition for ISOBUS port (UAV + compatible implement)	Critical point of agro-industrial integration
46	RO06	RA28	Configuration	Configuration branch for throttle power/response per installed propeller	Dynamic integration between hardware (propeller) and power software (customization)
47	RO16	RA34	Execution Logic	System does not link UAV prefix to ANAC RAB, nor bring flight plan to a button on the controller	The task itself should act as the flight plan, or the flight plan should be the task
48	RO03	RA12	Quality	Assembly, parts, components, and intermediate structures	

Source: Author.

Table 3.1 presents, in a technical, systematic, and methodologically rigorous manner, the evaluation of the technological object "UAV," encompassing the primary variables for critical analysis across multiple dimensions. The assessment aims to diagnose the structural robustness, functional coherence, systemic adaptability, and operational risks of the technological solution.

Knowledge/Experience (CEX): The convergence of CEX values at level 6 demonstrates advanced technical proficiency on the part of the evaluators regarding the UAV's architecture, subsystems, and integrated functionalities. The consistency observed in the judgments consolidates the epistemological robustness of the evaluations, substantially minimizing the incidence of biases associated with practical gaps in the context of remotely piloted aircraft operation and embedded systems analysis.

Object Requirements (RQA): Structural and functional requirements were recurrently violated in 42 of the 48 entries (RQA between -5 and 3), with emphasis on critical failures in fastening elements, lack of predisposition for upgrades (L14), and incompatibilities with industrial protocols such as ISOBUS (L15, L45). The sharp decline in RQA indicates a systemic misalignment between design, field operation, and the demands of the agro-industrial context.

Affordance (AFF) and Perception (PRC): The physical and logical interface of the UAV exhibits ambiguous or negative affordances (AFF between -5 and -2), associated with perceptions of weak cognitive construction (PRC between -5 and 2), particularly in entries 27 to 43. The absence of explicit signals and the fragmented logic of commands disrupt the operator's mental model, undermining both the predictability and intelligibility of actions, especially during flight control phases, task configuration, and subsystem activation.

Affectivity (AFV) and Satisfaction (STSF): Negative emotional load is accentuated in entries 7 to 26 and 27 to 47, with STSF ranging from -3 to -5, reflecting ongoing frustrations regarding the system's structural rigidity, the absence of critical features, and the limited possibilities for customization. Affective responses are strongly correlated with the perception of limited agent autonomy in adverse operational scenarios, reinforcing the need for ergonomic, configurational, and informational improvements.

Effectiveness (EFT): Functional performance shows significant degradation in entries 15, 18, 19, 34, 36, 39, 41, and 42, with EFT values ranging from 5 to -3. These losses occur mainly during operations under payload, imprecise landings, refueling logic, failures in three-dimensional mapping, and the absence of maintenance plans. Systemic instability compromises operational fluidity, reduces the predictability of automated actions, and increases exposure to failures in complex scenarios.

Error Severity (GVE) and Risk Level (GSR): The dimensions of severity and risk reveal a critical pattern in entries 11, 15, 18, 27, 36, 37, 39, and 41, with GVE values between 2 and 5. The lack of robust safety protocols, forced control attempts during sloped landings (L37), and the absence of predictive electrical diagnostics (L43) indicate structural and logical vulnerabilities with the potential for catastrophic failures. In this context, operational risk is increased not only by physical limitations but also by decision-making gaps within the agent–technology interface.

TABLE 3.1: UAV EVALUATION

*	CEX	RQA	AFF	PRC	AFV	STSF	EFT	GVE	GSR
1	2	-5	-5	-5	-3	-1	-3	3	5
2	2	-5	-3	-5	-3	-1	-3	3	4
3	2	-1	-1	5	-3	-1	-3	3	4
4	2	-3	2	2	-3	-1	5	2	3
5	2	1	2	5	-3	6	5	2	3
6	2	3	2	3	-3	6	5	2	2
7	2	4	-1	5	3	6	5	1	2
8	2	2	-3	2	3	-1	5	2	3
9	2	4	2	3	3	6	-3	1	2
10	2	-3	-3	2	-3	-1	5	3	2
11	2	1	-5	-5	-3	-1	5	4	3
12	2	-4	-4	-5	-3	-3	-3	4	5
13	2	3	-4	-5	3	6	5	1	2
14	2	5	2	3	-1	6	5	1	2
15	2	-5	2	-5	-3	-3	-3	2	4
16	2	5	2	3	-1	6	5	3	1
17	2	6	-3	2	-3	6	5	3	1
18	2	-4	-4	-5	-5	-3	-3	4	5
19	2	6	2	3	-1	6	5	2	1
20	2	-2	2	2	-3	-3	5	2	1
21	2	5	-4	-5	-1	-3	-3	2	2
22	2	2	2	5	-1	6	5	2	3
23	2	1	-4	-5	-3	-1	5	3	1
24	2	3	2	3	-3	-1	5	3	2
25	2	5	2	3	3	7	5	1	1
26	2	6	2	3	3	7	5	3	1
27	2	-2	-3	2	-3	-1	-3	4	3
28	2	-1	-5	-5	-1	6	5	2	3
29	2	4	-1	5	-1	6	5	2	1
30	2	-1	-5	-5	-1	-1	-3	3	2
31	2	-1	-5	-5	-1	-1	5	2	2
32	2	-1	2	5	-3	-1	5	2	3
33	2	4	2	3	-1	6	5	3	1
34	2	2	-5	-5	-3	6	5	3	2
35	2	2	-4	-5	-3	6	5	3	3

36	2	-1	-3	2	-3	-3	-3	4	4
37	2	-1	2	5	-1	-1	-3	4	3
38	2	2	-3	2	-1	6	-3	3	2
39	2	3	-4	-5	-3	-1	5	3	2
40	2	3	-3	2	-1	-1	5	1	2
41	2	-1	-1	5	-3	-1	5	2	3
42	2	4	2	3	-1	-1	5	2	1
43	2	-4	-4	-5	-1	-3	-3	5	4
44	2	2	2	5	-1	-1	5	1	2
45	2	-2	-3	2	-5	-3	-3	5	5
46	2	1	-5	-5	-5	-3	-3	4	3
47	2	3	2	3	-1	-1	5	2	3
48	2	-3	-3	2	3	6	5	1	3

Source: Author.

Table 3.2, interpreted through the lens of Attributes (ATB), translates the functional and structural collapse of the evaluated UAV, revealing a recurrent pattern of failures in critical operational, safety, and regulatory compliance requirements.

Attributes such as Usability (ATB01) exhibit severely compromised performance in launches 1, 2, and 3 (-4), indicating that the structural design and operational ergonomics fail to meet the minimum principles of reliable control and agent adaptability. This initial deficiency already compromises the entire chain of interaction with the system, regardless of the sophistication of its internal features.

The attribute Functionality (ATB04) is marked by multiple negative occurrences, including launches 1, 12, 27, 30, and 45, ranging from (-2 to -5), which demonstrates instability in the core of the artifact's executive tasks, particularly in processes that should occur in an automated, fluid, and predictable manner. The most critical case is found in launch 12 (-5), where the functional failure is directly associated with structural degradation in the control logic, indicating that the system not only fails, but fails critically in sensitive operational environments.

Operational Efficiency (ATB03) suffers a significant reduction in launches 11, 36, and 45 (-3), suggesting a loss of responsiveness in scenarios demanding speed and precision, such as automated agricultural tasks. The same applies to System Stability (ATB07) and Interface Control (ATB11), both scoring negatively (-2) in launches 36 and 37, revealing operational risks related to freezing, the absence of adaptive logic, and low tolerance to contextual environmental variations.

At the regulatory and structural levels, Compliance (ATB10) stands out negatively in launches 12, 18, and 48 (-5 and -3), indicating failures in the UAV's adherence to technical, safety, and industrial assembly standards. The recurrence of this failure compromises certification, commercial scalability, and the safe use of the system in regulated environments.

The data set reveals a pattern of systemic critical fragility, in which multiple attributes simultaneously exhibit low levels of maturity. The UAV's architecture, as it currently stands, lacks not only functional robustness, it demonstrates integrated inefficiency across hardware, control logic, and interface requirements, demanding complete reengineering of the affected subsystems.

TABLE 3.2:

UAV EVALUATION

*	ATB	SPMI
1	ATB01	-4
1	ATB04	-3
2	ATB01	-4
3	ATB01	-4
11	ATB03	-3
12	ATB04	-5
12	ATB10	-5
18	ATB10	-5
27	ATB04	-2
30	ATB04	-3
36	ATB03	-3
36	ATB07	-2
37	ATB11	-2
45	ATB03	-3
45	ATB04	-3
48	ATB10	-3

TABLE 3.3:

UAV EVALUATION

*	ACB	SPMI
7	ACB06	5
7	ACB09	4
12	ACB06	-5
12	ACB08	-3
14	ACB13	-2
27	ACB15	-4
27	ACB16	-3
27	ACB17	-2
28	ACB15	-3
32	ACB15	1
40	ACB13	-1
42	ACB15	-3
44	ACB13	-2
47	ACB17	1

TABLE 3.4:

UAV EVALUATION

*	QRSUER	SPMI
1	TQRS01	-3
1	TQRS02	-2
5	TQRS01	-1
5	TQRS19	2
36	TQRS01	-2
37	TQRS01	-1
48	TQRS05	-4
48	TQRS10	1
48	TQRS11	-1
48	TQRS19	3
48	TQRS22	1

Source: Author.

Table 3.3 reveals a critical overview within the Accessibility (ACB) dimension of the UAV's embedded and control system, with a significant incidence of negatively scored elements across multiple launches.

Navigation Consistency ACB06 (-5) in launch 12 indicates a severe disruption in navigation consistency, directly impacting interaction predictability and continuity of user experience. The level of severity correlates with previously identified structural failures in RA28 and RA33, related to the absence of stable functional patterns and insufficient task configuration capabilities.

Time and Interaction Control ACB08 (-3) in launch 12 points to the lack of resizing mechanisms and interface responsiveness, compromising usability in varied environments with fluctuating brightness or across different control platforms. This limitation directly affects operability in open-field conditions, where adaptability is essential.

Contextual Adaptation ACB13 (-2) in launch 14 reflects a lack of contrast adjustment and visual customization features, which compromises legibility under adverse operational conditions commonly found in agricultural environments.

Error and Success Feedback ACB15 (-4) in launch 27 highlights a significant failure in visual and auditory feedback for agent-performed actions. The absence of return signals for critical commands increases operational risk, especially in autonomous flight tasks involving real-time parameter changes.

On the other hand, Navigation Consistency ACB06 (5) in launch 7 and Color Contrast ACB09 (4) in launch 7 indicate partial efforts to stabilize the navigation and visualization experience. However, these advances remain insufficient when compared to the broader set of failures evidenced in the other launches.

The convergence between the critical points in this dimension and the requirements of RA03, RA28, RA33, and RA34 highlights a systemic pattern of technical non-compliance, in which the lack of integration between physical structure, logical interface, and operational feedback creates critical zones of interaction.

The ACB dimension does not operate in isolation; rather, it is directly impacted by failures in configuration (RA28), execution of operational logic (RA34), physical and logical compatibility (RA39), and interface structure (RA33). The convergence of these failures compromises system intelligibility, renders prolonged use by different agents unfeasible, and amplifies operational risks in the agricultural deployment of the UAV.

Table 3.4 shows that the evaluated UAV exhibits predominantly negative technical-environmental performance, with a concentration of scores falling within critical zones, particularly in the criteria of material sustainability, disposal, circularity, and resource management.

Criterion TQRS01, referring to Utility and Resource Efficiency, was assessed at multiple stages of the life cycle. In item 1, it received scores of (-2 and -3), indicating severe inefficiency in structural design, with technically irrational choices regarding material use. The score of (-2) in item 36 reinforces this trend, evidencing the absence of integrated strategies for optimizing mass, volume, and autonomy. In item 5, the occurrence of TQRS01 with (-1) suggests slight operational improvement, likely linked to incremental adjustments in the embedded software and flight architecture. In item 37, the same criterion reappears with (-1), denoting a repetition of performance still insufficient to reposition the system outside the critical zone. This set of results indicates that the project does not reach technical maturity in terms of rational use of by-products and inputs.

In item 5, TQRS19 (Legal Compliance) was rated (2), indicating the incipient presence of functionalities with transformative potential. In item 48, the same criterion obtained a score of (3), revealing an intermediate stage of development aimed at environmental technological integration, although still lacking a systematized structure to maximize positive impact. In item 48, this same criterion TQRS19 reappears again with a score of (3), indicating a development stage related to intermediate integration, but the UAV, within its evolutionary logic, still requires better technological structuring.

In item 48, the results for post-consumption management were technically critical. TQRS05 (Active Disposal) was scored (-4), indicating a total absence of guidelines, mechanisms, or technical solutions for safe disposal. TQRS10 (Recyclability), with a score of (1), suggests a minimal degree of material reuse, possibly limited to isolated metallic components, with no modular structure to facilitate disassembly or reprocessing.

Criterion TQRS11 (Facilitated Repair), also in item 48, was rated (-1), reflecting moderate obstacles to technical maintenance, such as rigid casings, permanent fixings, and lack of technical documentation. These factors directly compromise the extension of the useful life cycle and promote the intensification of early disposal.

TQRS22 (Sustainable Integration) was scored (1) in item 48. This indicates the presence of traces of adaptability in the design, though without systemic incorporation of functional sustainability principles, such as component interchangeability, expanded modularity, or backward compatibility.

The analysis shows that the evaluated UAV exhibits severe deficiencies in the structuring criteria of the QRSUER dimension. The predominance of critical scores (-3, -2, and -4) demonstrates that the project remains at an unsatisfactory stage in terms of environmental and sustainable performance, particularly in circularity, disposal, and efficient resource use. Although some signs of responsible innovation emerge in criterion TQRS19 (2 and 3), the imbalance between functional sophistication and ecological responsibility compromises the technological object's viability in light of the dimension's requirements.

The integrated technical-scientific systems and structures for analysis, assessment, and representation, as defined within the logical scope of FCIA-OT, operate as methodological cores for modular measurement of the technology from the perspective of Usability and Interaction Engineering. The SGUI is applied as an analytical and critical component of this process, in which the quantitative evidence obtained in the technical-analytical matrices, Tables 3.1, 3.2, 3.3, and 3.4, is converted into interpretive scores, allowing for the measurement of functional behavior and the relative impact of each identified element in the model.

Each column of the matrix corresponds to a specific functional dimension, composed of launches that reflect the scores associated with the evaluative elements. The recurrence of elements within the same column reveals patterns of repetition, indicating their systemic relevance. For each identified element, the total frequency across launches is calculated, followed by application of the following formula:

$$\mathbf{SGUI = (Frequency_{element} \ / \sum Frequencies_{all}) \times 100}$$

The interpretation of the values obtained follows the criteria defined in the matrix of the corresponding dimension, allowing for the identification of each element's relative presence within the evaluated system. The SGUI functions as a functional indicator of recurrence, highlighting frequency patterns that reflect the intensity of each element's manifestation across dimensions. In this regard, the SGUI can be interpreted as a marker of event frequency, reflecting the relative distribution of data within a constant analytical base, thereby ensuring proportionality and comparability across distinct dimensions.

As a subsequent stage in the measurement procedure, the SCMI is applied. It operates on the relative frequency of elements and incorporates the weights established in the SPMI, calculating the critical percentage contribution of each element to the technical maturity of the dimension. Its calculation formula is defined as:

$$\mathbf{SCMI = (SPMI_{element} \ / \sum SPMIs_{all}) \times 100}$$

The obtained value supports the stage of critical classification, signaling elements with outstanding performance, intermediate performance, or negative impact, according to their relative contribution to the technical maturity of the dimension. The SCMI functions as a metric of qualitative weight, integrating the modulated values of the SPMI to measure the effective impact of each component on the structural performance of the system. From this perspective, the SCMI can be interpreted as an indicator of the interaction energy of each element with the functional structure of the evaluated technological object, revealing the intensity and direction (positive or negative) of its technical contribution within the modular context.

The application of technical and systemic analysis through the SGUI and SPMI indices (Tables 4 and 4.1) enables the identification of critical patterns, recurrences, and technical expressiveness in the evaluated elements. The results express the quantitative and weighted distribution of the occurrences, providing an objective basis for data interpretation and for the construction of the dimensional diagnostics presented below.

TABLE 4: SYSTEMIC AND CRITICAL ANALYSIS OF THE UAV

Acronym	Element	SPMI	Launch	SCMI	SGUI %	Level	SCMI %
CEX	2	2x1 = 2	1	2	99%	2	99%
RQA	6	6x3 = 18	48	42	6,25%	2	42,86%
	5	5x4 = 20	48	42	8,33%	2	47,62%
	4	4x5 = 20	48	42	10,42%	2	47,62%
	3	3x6 = 18	48	42	12,50%	2	42,86%
	2	2x6 = 12	48	42	12,50%	2	28,57%
	1	1x4 = 4	48	42	8,33%	2	9,52%
	-1	-1x8 = -8	48	42	16,67%	2	-19,05%
	-2	-2x3 = -6	48	42	6,25%	2	-14,29%
	-3	-3x3 = -9	48	42	6,25%	2	-21,43%
	-4	-4x3 = -12	48	42	6,25%	2	-28,57%
	-5	-5x3 = -15	48	42	6,25%	2	-35,71%
AFF	2	2x19 = 38	48	-63	39,58%	5	-60,32
	-1	-1x4 = -4	48	-63	8,33%	7	6,35%
	-3	-3x10 = -30	48	-63	20,83%	6	47,62%
	-4	-4x8 = -32	48	-63	16,67	6	50,79%
	-5	-5x7 = -35	48	-63	14,58%	6	55,56%
PRC	5	5x9 = 45	48	15	18,75%	5	300,00%
	3	3x11 = 33	48	15	22,92%	5	220,00%
	2	2x11 = 22	48	15	22,92%	5	146,67%
	-5	-5x17 = -85	48	15	35,42%	4	-566,67%
AFV	3	3x7 = 21	48	-74	14,58%	13	-28,38%
	-1	-1x17 = -17	48	-74	35,42%	11	22,97%
	-3	-3x21 = -63	48	-74	43,75%	11	85,14%
	-5	-5x3 = -15	48	-74	6,25%	13	20,27%

STSF	7	7x2 = 14	48	69	4,17%	10	20,29%
	6	6x17 = 102	48	69	35,42%	8	147,83%
	-1	-1x20 = -20	48	69	41,67%	7	-28,99%
	-3	-3x9 = -27	48	69	18,75%	10	-39,13%
EFT	5	5x32 = 160	48	112	66,67%	3	142,86%
	-3	-3x16 = -48	48	112	33,33%	4	-42,86%
GVE	5	5x2 = 10	48	123	4,17%	2	8,13%
	4	4x7 = 28	48	123	14,58%	3	22,76%
	3	3x15 = 45	48	123	31,25%	5	36,59%
	2	2x16 = 32	48	123	33,33%	5	26,02%
	1	1x8 = 8	48	123	16,67%	4	6,50%
GSR	5	5x4 = 20	48	122	8,33%	3	16,39%
	4	4x5 = 20	48	122	10,42%	3	16,39%
	3	3x14 = 42	48	122	29,17%	4	34,43%
	2	2x15 = 30	48	122	31,25%	5	24,59%
	1	1x10 = 10	48	122	20,83%	4	8,20 %

SPMI Total – SGUI: Total number of occurrences recorded per element, expressing the raw frequency of presence within the dimension.

Launch: Refers to the launches performed in the analysis and evaluation.

SPMI Total – SCMI: Weighted sum of the technical scores assigned to the elements (severity, impact, or relevance).

SGUI (%): Relative Frequency Score, calculated in proportion to the total number of occurrences.

SGUI – Level: Indicates the relational position of the element within the dimension, based on its frequency and impact. It expresses the degree of recurrence and technical relevance in the analyzed set.

SCMI (%): Represents the proportional technical weight of the element within the functional dimension. It indicates how much the item impacts the system, positively or negatively, without qualifying it as good or bad, but rather showing how much it weighs technically in the functional balance.

CEX: When applicable, 99% represents the maximum achievable operational level; 100% applies only to the manufacturer or developer of the artifact itself, as an ideal reference.

Source: Author.

TABLE 4.1: SYSTEMIC AND CRITICAL ANALYSIS OF THE UAV

Acronym	Element	SPMI	Launch	SCMI	SGUI %	Level	SCMI %
ATB	-2	-2x3 = -6	48	-54	6,25%	2	11,11%
	-3	-3x7 = -21	48	-54	14,58%	2	38,89%
	-4	-4x3 = -12	48	-54	6,25%	2	22,22%
	-5	-5x3 = -15	48	-54	6,25%	2	27,78%
ACB	5	5x1 = 5	48	-17	2,08%	4	-29,41%
	4	4x1 = 4	48	-17	2,08%	4	-23,53%
	1	1x2 = 2	48	-17	4,17%	3	-11,76%
	-1	-1x1 = -1	48	-17	2,08%	2	5,88%
	-2	-2x3 = -6	48	-17	6,25%	2	35,29%
	-3	-3x4 = -12	48	-17	8,33%	2	70,59%
	-4	-4x1 = -4	48	-17	2,08%	2	23,53%
	-5	-5x1 = -5	48	-17	2,08%	2	29,41%
QRSUER	3	3x1 = 3	48	-5	2,08%	4	-60,00%
	2	2x1 = 2	48	-5	2,08%	3	-40,00%
	1	2x2 = 4	48	-5	4,17%	3	-80,00%
	-1	-1x3 = -3	48	-5	6,25%	2	60,00%
	-2	-2x2 = -4	48	-5	4,17%	2	80,00%
	-3	-3x1 = -3	48	-5	2,08%	2	60,00%
	-4	-4x1 = -4	48	-5	2,08%	2	80,00%

Source: Author.

The SCMI% index is a relative metric, specific to each dimension. Its denominator corresponds to the total sum of the weighted scores of the elements belonging to the dimension itself, so that the value assigned to each element reflects the functional context in which it is inserted. Therefore, the same type of artifact may present significant variations in SCMI% across different dimensions, even with opposite polarities, depending on the distribution of technical weights in the analysis.

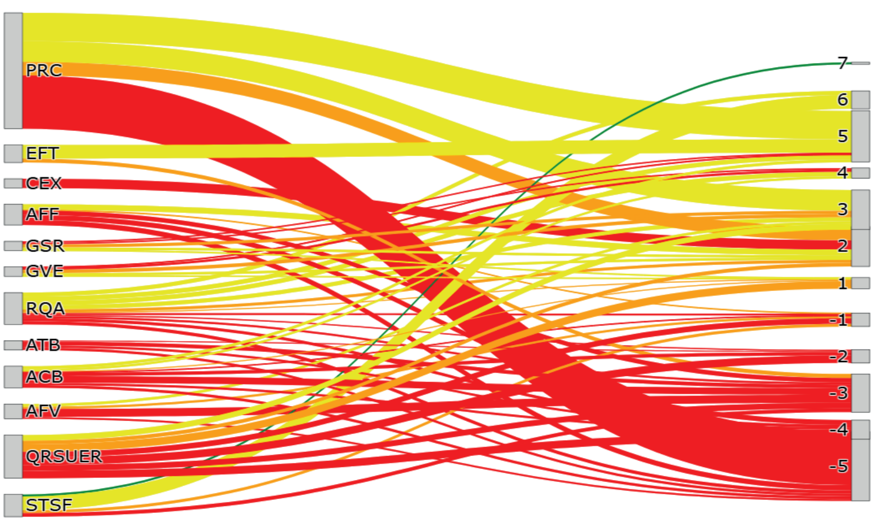
This behavior represents a fundamental property of the calculation, as it enables the FCIA-OT system to detect localized functional patterns and assess modular maturity with contextual precision. Elements with negative weights reduce the total sum of the dimension, allowing positively weighted elements to exceed 100% in absolute value. This effect arises from the relational structure of the metric itself, which does not operate based on a fixed reference, but on functional proportionality.

Figure 7 illustrates the relationship between the twelve analyzed functional dimensions and the evaluated elements according to the percentages derived from SPMI%. The visualization clearly reveals the relative weight of each element within the systemic context, highlighting the most critical, recurrent, or technically relevant flows based on the interaction density and computed impact within each dimension.

The SCMI% expresses the weighted technical proportion of an element in relation to the total of the dimension, functioning as a relational impact index. Its purpose is to characterize the technical relevance of the element within the analyzed set, respecting the specific operational dynamics of each dimension and revealing both critical potentialities and nuclei of technical maturity in the studied modules.

The Knowledge/Experience Dimension (CEX) reveals complete cognitive uniformity on the part of the agent throughout the entire evaluation. All recorded entries are exclusively concentrated on element (2), indicating an absolute absence of fluctuation in the levels of knowledge and experience applied during the process. This pattern expresses an evaluative operational regime sustained by consolidated technical mastery, in which the agent demonstrates full capacity to understand, interpret, and apply the system's requirements, both conceptual and operational, without incurring in interpretative deviations, methodological weaknesses, or cognitive inconsistencies.

FIGURE 7: SANKEY MAP OF WEIGHTED SYSTEMIC INTERACTIONS (SPMI%) BETWEEN FUNCTIONAL DIMENSIONS AND EVALUATED ELEMENTS



Sankey chart structured according to the proportional distribution of SPMI% values, connecting each functional dimension of the system to the corresponding elements, with relative weights represented by the width of the flows. The colors follow the technical typology of the SCDMIC, according to their nature and impac.

Source: Author.

From the standpoint of reliability, this consistency of level (2) constitutes a critical technical indicator, ensuring that the judgments issued across the dimensions, artifacts, and modules of the UAV stem from an agent positioned at an advanced level of proficiency, capable of operating the analytical instruments of the FCIA-OT with systemic accuracy. In summary, the CEX Dimension confirms a scenario of cognitive stability and interpretative precision, elements essential to the validity of the data produced and to the robustness of the inferences drawn about the UAV at this stage of systemic evaluation.

The Object Artifact Requirements Dimension (RQA) reveals a complex functional configuration among artifacts, components, and structural elements of the evaluated technological system. The data indicate an unstable balance between components with strong adherence to technical requirements (positive elements) and critical instances with severe structural deviations (negative elements), which imposes a scenario of strategic attention on the systemic architecture of the UAV.

The set of positive elements is led by artifacts (5 and 4), both with SCMI% of (20 = 47.62%), indicating functional maturity and intermediate technical compliance. These artifacts operate as anchors of stability in structured subdomains, suggesting an intermediate application of design and validation criteria. Artifact SCMI% (3 = 42.86%) reinforces this trend of intermediate technical performance, especially due to its increased recurrence (6 launches), which demonstrates intermediate functional reliability across multiple operational instances.

In parallel, artifacts with SCMI% (2 = 28.57%) and (1 = 9.52%) exhibit low performance, with indications of partial technical maturity. They do not meet the minimum operational criteria, and their overall impact on the robustness of the dimension is limited, suggesting that these elements require further adjustments in future reengineering phases.

The critical configuration emerges from the elements with negative weights. The artifact (-5 = -35.71%) represents the most impactful dysfunctional vector within the dimension, reflecting severe failures in components essential to the system's integrity. Its recurrent presence in evaluation contexts (3 occurrences) suggests unresolved critical patterns, possibly related to manufacturing processes, imprecise specifications, or functional degradation.

SCMI% elements with weights (-4 = -28.57%), (-3 = -21.43%), and (-1 = -19.05%) consolidate the systemic risk profile associated with low-maturity artifacts. Their distribution across different technical subsystems compromises the consistency of the functional architecture and indicates the presence of integrated, rather than isolated, failures.

The coexistence of both positive and critically negative poles reveals a system with intermediate technical cores operating alongside zones of severe instability. This condition is typical of projects with partial integration between object requirements (RQO) and their respective artifacts (RQA), reinforcing the need for more precise methodological alignment between high-level specifications and their technical translation into parts, processes, and operational elements.

Thus, the analysis of the RQA dimension positions itself as a structuring axis for the continued systemic maturation of the UAV. Interventions focused on the replacement, redesign, and quality control of critical artifacts should be prioritized, with intensive application of functional validation protocols, technical traceability, and normative compliance.

The analysis of the Affordance (AFF) Dimension reveals a critical configuration in the perceptual and functional mechanisms of the UAV, with an asymmetric distribution of interactions and structural weights heavily skewed toward negative evaluation zones. The only element with a positive load, (2), although registering the highest frequency within the dimension (19 occurrences; 39.58% of SGUI%), presents a negative SCMI% (-60.32%) due to being the sole positive contributor within a predominantly critical set. This result indicates that, although more frequent, the positive affordances do not exhibit sufficient density to counterbalance the systemic negative impact imposed by the other artifacts.

Elements (3, -4, and -5), totaling 25 occurrences (52.08% of SGUI), concentrate 154% of the SCMI%, revealing that most interaction artifacts are situated in ranges with high levels of operational dysfunction. The recurrence of weights (-3, -4, and -5) reinforces the presence of severe structural inconsistencies in the system's channels of perception, manipulation, activation, or response, directly undermining the UAV's ability to provide clear, predictable, and intelligible affordances.

The element (-1), with isolated impact (8.33% of SGUI; 6.35% of SCMI), reinforces the scenario of functional fragility by representing artifacts with low levels of functional legibility and ambiguity in activation, without being capable of acting as a damping element against the established critical core.

This scenario compromises the coherence between intended use and technical response, generating cognitive barriers and reducing operational fluidity, especially in situations requiring rapid action and precise sensory contextualization. The dominance of elements (-5 and -4) is particularly alarming, as it highlights the presence of submodules with severe failures in functional signaling, rendering the interaction process dependent on external compensatory strategies or subsequent reconfigurations.

Therefore, the AFF dimension in the UAV indicates a framework of unstructured affordances, with a predominance of critical elements and the absence of stabilizing artifacts. FCIA-OT, by recording the supremacy of negative SCMI%, triggers an internal condition for blocking synthetic interpretation, requiring a profound design revision of the system's signaling, activation, and perceptual feedback elements.

The analysis of the Perception (PRC) Dimension reveals a critical and polarized configuration of response across the evaluated UAV modules, with a marked predominance of artifacts classified at the maximum negative level of the scale. The element with 17 occurrences and weight (-5) accounts for 35.42% of the interactions and alone contributes (-566.67%) to the SCMI, indicating a severe and recurrent perceptual impact across multiple submodules.

The pattern denotes cognitive overload, consistent perceptual failures, and degradation in the system's capacity for functional assimilation, directly compromising the interpretation, response, and operational feedback subsystems.

The counterpoint is provided by the elements (5 with 9 occurrences), (3 with 11 occurrences), and (2 with 11 occurrences), which, although collectively accounting for 64.59% of the interactions, do not neutralize the structural negative weight of the set. Element (5), with 18.75% in SGUI and 300% in SCMI, leads the effort of positive perceptual compensation, followed by (3 = 22.92% SGUI, 220% SCMI) and (2 = 22.92% SGUI, 146.67% SCMI). The data suggest localized attempts at perceptual correction and distributed sensory improvements within the system, but these prove insufficient when compared to the critical magnitude imposed by (-5).

The SCMI metric, upon reaching such proportions, becomes an exact expression of the disparity between critical negative weights and the positive adjustment mechanisms. This asymmetry is an expected characteristic of the FCIA-OT methodology in environments of high functional stress, revealing deep perceptual failures that not only hinder the system's situational reading performance but also indicate dysfunctions in the feedback and signal integration modules.

In this context, the PRC dimension stands out as one of the UAV's most fragile axes, demanding immediate corrective interventions in sensory perception channels, refinement in environmental interpretation patterns, and redesign of the associated cognitive routines. The persistence of the identified critical pattern compromises the system's overall maturity, negatively affecting responsiveness, reactive coherence, and the adaptive capacity of the modular set.

The analysis of the Affective (AFV) Dimension revealed a critical scenario, characterized by a predominance of negative entries and asymmetric statistical distribution. The evaluation indicated a high recurrence of elements associated with affective dissatisfaction (43.75%; 35.42%), reflecting a pattern of adverse emotional impact on the interactive experience.

The SGUI indicated significant expressiveness of critical elements, while the SCMI, with a total negative sum of (-74), evidenced the concentration of unfavorable weights. Element (-3) exhibited the highest SCMI (85.14%), followed by 22.97% and 20.27%, forming a set of artifacts with strong negative influence over the affective dimension.

The occurrence of a negative SCMI in the element (-28.38%), despite its positive raw score, resulted from the proportional inversion caused by the overall negative polarity of the dimension, requiring specialized technical interpretation.

From a systemic perspective, the data point to a low affective maturity of the evaluated technological object (UAV), indicating an absence of emotional comfort, perceived empathy, or alignment with the agents' subjective expectations. The AFV dimension, therefore, demands priority attention in reengineering and qualification cycles, acting as a critical vector for the evolution of agent–technology interaction in emotionally demanding contexts.

The Satisfaction (STSF) Dimension presented a complex analytical profile, marked by significant disparities between recurrence and criticality of the elements. The data distribution revealed contrasting polarities between positive and negative components.

Element (6) accounted for 35.42% of the entries and reached 147.83% in SCMI%, indicating an anomalous positive critical weight, resulting from statistical dominance in a dimension whose weight sum was positive. This value requires technical interpretive adjustment and reclassification into specific ranges to represent its expressiveness. The case signals an intermediate impact of satisfaction on the interactive experience.

On the other hand, elements (-1 and -3) reached negative SCMI% values of (-28.99% and -39.13%), respectively, compromising the affective linearity of the dimension. Element (7), though with low frequency, presented an SCMI% of 20.29%, acting as a secondary vector of positive reinforcement.

The integrated analysis of SGUI and SCMI revealed that satisfaction, although present at intermediate levels, remains unbalanced in the face of persistent destabilizing elements. The statistical behavior of the set points to a scenario of functional transition, in which the presence of satisfaction is perceptible yet weakened by critical recurrences.

The STSF dimension, therefore, demands targeted interventions aimed at mitigating negative elements and consolidating positive ones, promoting stability in the perception of value, adequacy, and experiential reward in the agent–technology interaction.

The analysis of the Effectiveness (EFT) Dimension reveals a functional asymmetry in the distribution of technical elements and artifacts with negative impact on the systemic maturity of the UAV. Element (5), with 32 occurrences and the highest weight (5), accounts for 66.67% of the interactions and contributes 142.86% to the SCMI, positioning itself as the main vector of technical effectiveness within the evaluated set. Although such predominance denotes partial convergence with operational efficiency parameters, the data suggest that a significant portion of subsystems remains at an intermediate functional level, requiring structural adjustments and operational refinements to fully meet the critical standards of responsiveness, performance continuity, and technical reliability.

Conversely, element (-3), with 16 occurrences and a negative weight (-3), raises a methodological alert. The result of (-42.86%) in SCMI indicates that these artifacts exhibit structural inconsistencies and critical functional failures. Although excluded from the synthesis analyses, these records remain accessible in internal technical reports, ensuring analytical traceability and supporting quality control and reengineering processes.

Thus, the effectiveness of the UAV, although containing cores of intermediate performance, still evidences a functional state in transition. Its coexistence with critical artifacts reinforces the need for targeted technical interventions aimed at correcting modular deficits and progressively enhancing the system architecture.

The Error Severity (GVE) Dimension in the UAV reveals a functional distribution marked by the predominance of artifacts classified at critical levels of the severity scale. Elements (3), (2), and (4), totaling 38 occurrences, account for 79.16% of the interactions and collectively represent 85.37% of the SCMI, reflecting significant structural and functional impact on system reliability. Element (3) stands out, solely responsible for 36.59% of the SCMI, with high recurrence and consistent severity, evidencing recurring failures in strategic submodules.

The presence of elements such as (1 and 5), associated with milder severity levels, is not sufficient to neutralize the overall critical weight of the dimension. The most expressive data point is that element (5), although associated with maximum severity (5), appears only twice, which reduces its direct percentage impact, yet signals the existence of isolated failures with high technical hazard potential. This scenario reinforces the need for both corrective and preventive interventions, focused on the mitigation of systematic errors, restructuring of vulnerable routines, and revision of operational protocols.

Therefore, GVE configures itself as a critical axis in the assessment of the UAV's robustness, requiring immediate technical treatment to ensure stability, resilience, and functional integrity in the upcoming phases of systemic maturation.

The analysis of the Risk Level (GSR) Dimension reveals a dense and concerning distribution of artifacts located within critical and intermediate operational risk ranges. Elements (3 and 2), which together represent 60.42% of the occurrences, concentrate 59.02% of the SCMI, revealing that a significant portion of UAV components operate in contexts of high functional exposure or recurring vulnerabilities. Element (3), with 14 occurrences and weight (3), alone contributes 34.43% of the SCMI, signaling structural risk disseminated across key subsystems.

Although elements (5 and 4) are associated with the highest levels of risk, their limited occurrences reduce their relative weight in the metric. Nonetheless, their presence cannot be disregarded, as they indicate localized failures with high disruptive potential. Element (1), although positioned in a lower risk range, appears with sufficient frequency to impact 8.20% of the SCMI, reinforcing the persistence of technical instabilities in areas of low resilience.

Thus, the GSR dimension points to a scenario in which UAV operation demands more rigorous mitigation protocols, with emphasis on predictive analysis, containment of recurrent failures, and reengineering of critical modules. The management of technical risks must be repositioned as a structuring axis of the system's functional maturity, particularly for continuous validation cycles and modular improvement.

The Attributes (ATB) Dimension aims to systematically capture the incidence and performance of specific qualitative attributes of the evaluated system, based on inferred and technically validated requirements. The activation of such elements occurs exclusively when their applicability is operationally and contextually justified within the analyzed records.

In the present UAV assessment, only 16 entries out of the 48 possible showed valid ATB attribute assignments, resulting in an SGUI% of 33.33%. Rather than indicating an informational gap, this value highlights the selective modularity of the dimension, which operates solely under criteria of technical relevance. This characteristic reinforces the methodological robustness of the framework by preventing undue generalizations of attributes that do not apply to the system's functional reality.

The analysis of assigned weights (SPMI) reveals that all occurrences were associated with negative performance, with scores ranging from (-2 to -5), totaling an SCMI of (-54). The internal percentage distribution within SGUI shows a predominance of occurrences with value (-3 = 43.75%), followed by (-5 = 31.25%), (-4 = 18.75%), and (-2 = 6.25%). This scoring pattern demonstrates a consistent negative trend, indicating that the assessed attributes are mostly compromised or insufficiently implemented.

This negative configuration may result from the absence of integration of the structuring principles of these attributes during the system's design, development, and validation phases, directly affecting aspects such as critical operations, adaptability, interoperability, and acceptability in real-use scenarios. The recurrence of scores (-3 and -5) reinforces the presence of significant structural failures, undermining minimum quality and expected performance requirements.

From a systemic perspective, the ATB dimension reveals architectural weaknesses and deficiencies in applied engineering, highlighting the need for a technical-conceptual reassessment of these attributes throughout the UAV's lifecycle. Although structurally functional, the system exhibits critical deficits in qualitative attributes, whose correction must be prioritized in the phases of technological and operational refinement.

The Accessibility (ACB) Dimension aims to assess the presence, recurrence, and performance of requirements associated with systemic accessibility within the context of the evaluated system. These elements represent critical components to ensure equitable, perceivable, and operational use of the system by different agent profiles and across multiple usage contexts. The activation of these elements occurs exclusively when the applicability of the requirement is technically and functionally validated throughout the examined entries.

In the UAV assessment, although all 48 entries were considered, only eight distinct elements were identified with assignments for this dimension, forming a specific and targeted incidence matrix. The aggregated SGUI% was 29.17%, reflecting a selective activation density consistent with the principle of functional modularity. The observed variation in element frequency, with emphasis on SGUI (-3 = 8.33%) and SGUI (-2 = 6.25%), indicates specific points of concern in terms of potential barriers or accessibility gaps.

In performance terms, the SCMI analysis totaled (-17), characterizing a profile of compromised accessibility. The assigned weights reveal a predominance of negative evaluations: (-2 = -6), (-3 = -12), (-4 = -4), and (-5 = -5), together comprising over 96.43% of the dimension's total critical load. This concentration of negative values suggests that accessibility, as a design and implementation attribute, was not fully considered or integrated during the system's conception and development stages.

Positive elements such as (5 and 4), although present, held reduced statistical weight (together accounting for only 4.16% of SGUI) and (52.94% negative in SCMI), being insufficient to reverse the structural negative bias of the dimension. The residual presence of (1 and -1) indicates isolated attempts at minimal or compensatory accessibility, yet inadequate in the face of broader structural deficiencies.

The consolidated analysis of the ACB dimension highlights critical operational and ergonomic weaknesses that directly affect usability, inclusion, and efficiency in real mission scenarios. The observed configuration underscores the need for a thorough review of accessibility requirements, both from normative and applied engineering perspectives, with a view toward compliance with universal standards and the maximization of human-system interoperability.

The QRSUER Technology Dimension reflects the systemic capacity of the evaluated object to incorporate its pillars in a measurable and operational manner. A selective and punctual activation pattern was observed for the elements of this dimension, with only seven occurrences distributed among the 48 possible entries, resulting in an aggregated SGUI of 22.91%. Although moderate, this value reveals a low density of integration of QRSUER attributes within the system's technical-functional core.

The distribution of entry frequencies was relatively uniform, with emphasis on the following SGUI occurrences: (3 = 2.08%), (2 = 2.08%), (1 = 4.17%), (-1 = 6.25%), (-2 = 4.17%), (-3 = 2.08%), and (-4 = 2.08%). The analysis reveals a predominance of records with low relative frequency, indicating that such attributes did not consolidate as structuring elements throughout the UAV's technical lifecycle.

From a critical perspective, the assigned weights (SPMI) and their respective SCMI values indicate a clear predominance of negative evaluations. Elements (-1, -2, -3, and -4) exhibited weights ranging from (-1 to -4), with SCMI values varying between 60.00% and 80.00%, indicating strong negative impact on the technical maturity of the dimension. Element (1), despite holding the highest aggregated weight (4), also resulted in an SCMI of (-80.00%), reinforcing the dimension's critical bias. In total, the accumulated SCMI was (-5), evidencing a significant technical-scientific deficit in the criteria of sustainability, equity, responsibility, and technical soundness.

This negative profile suggests that the structuring principles of QRSUER were not substantially integrated into the system's design and validation processes. The concentration of negative scores reveals critical weaknesses in normative, environmental, and techno-ethical aspects, undermining essential attributes for long-term sustainability and social acceptability of the technology.

From a modular perspective, the QRSUER dimension configures itself as a critical instance for the technical evolution of the system, requiring conceptual restructuring and methodological reinforcement in its design parameters. The low incidence and high negative impact highlight the need for active incorporation of QRSUER criteria in the subsequent refinement phases, prioritizing compliance with responsible engineering guidelines, impact neutrality, and sociotechnical responsibility. Reversing the current pattern will depend on the consolidation of sustainable, ethical, and common-good-oriented practices as inseparable components of the system architecture of the evaluated technological object.

2.3.1 Modular Critical Analysis by Technical Element

The technical analysis may also be conducted at a deeper level by individual element. This subsection presents a technical evaluation based on the modular decomposition by element, in accordance with the FCIA-OT methodology. Three dimensions with high diagnostic value were selected, Attributes (ATB), Accessibility (ACB), and QRSUER (Quality, Social Responsibility, Sustainability, Usefulness, Ethics, and Reason), due to their ability to expose specific vulnerabilities, critical recurrences, and patterns of functional compromise.

Each record was measured by technical attribute, assessing both relative incidence and critical weight in the system's performance. This complementary approach enhances the precision of the evaluation and reinforces the explanatory robustness of the proposed model.

The Attributes (ATB) dimension, which evaluates specific qualitative attributes of the system, revealed in the UAV analysis a concentration in six main technical attributes: Usability, Efficiency, Functionality, Controllability, Compliance, and Stability. These attributes, detailed in Table 4.2 and distributed across 16 records, account for 33.33% of the total 48 records, reflecting a selective application of the dimension consistent with the technical relevance of the attributes within the system context.

The results indicate a predominantly negative profile, with a total score (SPMI) of -54, unevenly distributed among the attributes. Functionality, with five occurrences and a relative weight of 29.63% in the total impact, concentrates the majority of the qualitative deficiencies, followed by Compliance (24.07%) and Usability (22.22%). Although less frequent, Efficiency, Controllability, and Stability also contribute to the deficiency profile.

TABLE 4.2: SYSTEMIC AND CRITICAL ANALYSIS BY UAV ELEMENT

ATB	Vector/Element	Occurrences / SPMI	SGUI %	SCMI %
ATB01	Usability	3 [-4, -4, -4 = -12]	3/48 = 6,25%	-12/-54 = 22,22%
ATB03	Efficiency	3 [-3, -3, -3 = -9]	3/48 = 6,25%	-9/-54 = 16,67%
ATB04	Functionality	5 [-2, -3, -3, -3, -5 = -16]	5/48 = 10,42%	-16/-54 = 29,63%
ATB07	Controllability	1 [-2]	1/48 = 2,08%	-2/-54 = 3,70%
ATB10	Compliance	3 [-3, -5, -5 = -13]	3/48 = 6,25%	-13/-54 = 24,07%
ATB11	Stability	1 [-2]	1/48 = 2,08%	-2/-54 = 3,70%
Total	**6 ATB**	**16 lanç. / -54**	**33,33%**	**100%**

Grouped by specific technical vector/element; sums the individual scores of each vector/element; measures the relative weight of the vector/element in the system's overall performance. **SPMI:** Sum of Individual Module Scores, total negative scores assigned to the vector/element. **SGUI %:** Percentage of the vector/element's occurrences relative to the total number of entries. **SCMI %:** Percentage of the vector/element's critical weight relative to the total Sum of Individual Module Scores.

Source: Author.

This configuration indicates that the UAV faces critical limitations in fundamental aspects of its performance and operation, such as adherence to functional requirements, regulatory compliance, and agents' experience. The distribution of negative impacts by technical attribute reinforces the need for targeted interventions, prioritizing on the elements that most compromise systemic quality.

Thus, the ATB dimension not only offers a precise diagnosis of critical issues but also provides analytical support for strategic prioritization in the technological restructuring and enhancement of engineering requirements applied to the UAV.

The Accessibility (ACB) dimension, dedicated to the analysis of systemic accessibility, identifies, within the UAV scope, the presence of seven distinct technical elements (Table 4.3), applied to 14 of the 48 total records, representing a selective incidence of 29.17%. This distribution reveals a contextualized application of accessibility, triggered exclusively when operational requirements justify the analysis of such elements.

TABLE 4.3: SYSTEMIC AND CRITICAL ANALYSIS BY UAV ELEMENT

ACB	Vector/Element	Occurrences / SPMI	SGUI %	SCMI %
ACB06	Text Alternatives	2 [5, -5 = -0]	2/48 = 4,17%	0,00%
ACB08	Time and Interaction Control	1 [-3]	1/48 = 2,08%	-3/-17 = 17,65%
ACB09	Color Contrast	1 [4]	1/48 = 2,08%	4/-17 = 23,53%
ACB13	Adaptation to Usage Contexts	3 [-1, -2, -2 = -5]	3/48 = 6,25%	-5/-17 = 29,41%
ACB15	Error and Success Feedback	4 [-3, -3, -4, 1 = -9]	4/48 = 8,33%	-9/-17 = 52,94%
ACB16	Clear Input Errors	1 [-3]	1/48 = 2,08%	-3/-17 = 17,65%
ACB17	Multimodality	2 [-2, 1 = -1]	2/48 = 4,17%	-1/-17 = 5,88%
Total	**7 ACB**	**14 lanç. / -17**	**29,17%**	**100%**

Grouped by specific technical vector/element; sums the individual scores of each vector/element; measures the relative weight of the vector/element in the system's overall performance. **SPMI:** Sum of Individual Module Scores, total negative scores assigned to the vector/element. **SGUI %:** Percentage of the vector/element's occurrences relative to the total number of entries. **SCMI %:** Percentage of the vector/element's critical weight relative to the total Sum of Individual Module Scores.

Source: Author.

The sum of the scores assigned (SPMI) totals -17, with a predominance of negative evaluations. Notably, vector/element ACB15 (Error and Success Feedback) appears in four occurrences and concentrates a critical impact of 52.94% (SCMI) of the entire dimension. Next, ACB13 (Adaptation to Usage Contexts) accounts for 29.41% of the critical load, reflecting weaknesses in the system's adaptive capacity when facing different operational scenarios. ACB08 (Time and Interaction Control) and ACB16 (Clear Input Errors) each contribute 17.65%, both indicating deficiencies in interaction control mechanisms and error prevention.

Although elements such as ACB09 (Color Contrast) and ACB06 (Text Alternatives) were identified, their effects on the dimension were either neutral or contradictory: ACB09 recorded a single positive score, whereas ACB06, despite two occurrences, resulted in a net sum of zero. ACB17 (Multimodality), in turn, played a marginal role (5.88%), yet still pointed to inconsistencies in the delivery of multiple modes of content access.

The analysis reveals that, although partially addressed, accessibility remains compromised in aspects requiring greater structural refinement. The predominance of negative scores reflects the absence of robust accessibility criteria during system design and validation. Thus, the ACB dimension stands out not only as a technical diagnostic vector but also as evidence that functional accessibility is not yet a consolidated pillar within the UAV's development cycle, and must therefore be treated as a reengineering priority in future iterations.

The QRSUER Technology Dimension, focused on evaluating technological attributes related to quality, sustainability, and compliance, comprises, in the UAV context, a total of 11 entries, distributed among seven distinct technical vectors/elements (Table 4.4), representing 22.90% of the 48 mapped events. This incidence reveals a segmented application of the dimension, activated in specific situations of technological criticality.

TABLE 4.4: SYSTEMIC AND CRITICAL ANALYSIS BY UAV VECTOR/ELEMENT

QRSUER	Vector/Element	Occurrences / SPMI	SGUI %	SCMI %
TQRS01	Usefulness and Resource Efficiency	4 [-1, -1, -2, -3 = -7]	4/48 = 8,33%	-7/-7 = 100%
TQRS02	Resource Sustainability	1 [-2]	1/48 = 2,08%	-2/-7 = 28,57%
TQRS05	Active Disposal	1 [-4]	1/48 = 2,08%	-4/-7 = 57,14%
TQRS10	Recyclability	1 [1]	1/48 = 2,08%	1/-7 = -14,29%
TQRS11	Facilitated Repairability	1 [-1]	1/48 = 2,08%	-1/-7 = 14,29%
TQRS19	Legal Compliance	2 [2, 3 = 5]	2/48 = 4,17%	5/-7 = -71,43%
TQRS22	Sustainable Integration	1 [1]	1/48 = 2,08%	1/-7 = -14,29%
Total	**7 QRSUER**	**11 lanç. / -7**	**22,90%**	**100%**

Grouped by specific technical vector/element; sums the individual scores of each vector/element; measures the relative weight of the vector/element in the system's overall performance. **SPMI:** Sum of Individual Module Scores, total negative scores assigned to the vector/element. **SGUI %:** Percentage of the vector/element's occurrences relative to the total number of entries. **SCMI %:** Percentage of the vector/element's critical weight relative to the total Sum of Individual Module Scores.

Source: Author.

The SPMI total resulted in a significantly negative value (-7), indicating that although the dimension is occasionally activated, its impact tends to be adverse to the system's technological quality. The vector/element TQRS01 (Usefulness and Resource Efficiency) stands out, with four occurrences and a total critical impact (SCMI = 100%), evidencing that mechanisms for rational and effective resource usage are severely compromised, thereby undermining the UAV's operational sustainability.

Next, the attributes TQRS05 (Active Disposal) and TQRS02 (Resource Sustainability), although each recorded only once, contributed relevant impacts of 57.14% and 28.57%, respectively, suggesting the absence of appropriate guidelines for responsible waste disposal and sustainable resource use. TQRS11 (Facilitated Repairability), with an impact of 14.29%, reinforces the difficulties in maintenance and lifecycle extension of system components.

In contrast, attributes such as TQRS10 (Recyclability), TQRS19 (Legal Compliance), and TQRS22 (Sustainable Integration) presented effects that contradicted expectations. TQRS10 and TQRS22 displayed positive scores, which led to negative SCMI percentages (-14.29% each), revealing a disconnect between the intended technical proposal and its actual execution. Notably, TQRS19, despite a positive score (5), had a critical negative influence on the matrix (-71.43%), signaling an imbalance in the incorporation of legal requirements, which may have been addressed in a fragmented rather than systemic manner.

The dataset reinforces that the technological dimension faces serious inconsistencies in implementing attributes related to sustainability, resource usability, and regulatory adequacy. The concentration of negative impacts in a few attributes, coupled with distortions caused by misallocated positive scores, indicates that the system lacks effective technological integration and conscious environmental planning. Thus, the QRSUER dimension emerges as essential to the technical diagnosis of the UAV's technological viability, pointing to critical elements that must be prioritized in reengineering and compliance processes.

At the end of the process, the consolidation of all scores by vector/element and dimension will enable an advanced technical composition of the UAV's relative performance against critical parameters of interaction engineering and systemic usability. These values support technical judgment concerning strengths, operational weaknesses, and critical risks associated with the technology, providing a foundation for decisions related to redesign, validation, or formal approval of the solution.

In the context of critical interpretation, the SCDMIC is integrated with the scoring systems SPMI, SGUI, and SCMI, functioning as an additional structure for parametric interpretation. Its application allows for an expanded visual and analytical reading of the results, facilitating the critical classification of vectors/elements according to levels of functional maturity, technical impact, and systemic relevance within the assessed context.

3 DISCUSSION

The application of FCIA-OT to the three case studies revealed that technical, perceptual, or symbolic failures in technological objects do not manifest in isolation, but operate interdependently, forming critical networks that compromise intelligibility, fluidity, and trust in the interaction. By employing a multiscalar and modular matrix, it was possible to trace not only observable failures, but also their cumulative effects on the user experience.

In real operational contexts, such as those involving the software, air-conditioning control, and the UAV, the presence of feedback failures, perceptual inconsistencies, or the absence of explicit affordances was correlated with states of frustration and hesitation in the agent. As discussed by Luczak, Roetting, & Schmidt (2003), in such situations, agents tend to anthropomorphize the devices, attributing intent to technical failures and projecting negative emotional responses onto them, which increases the risk of rejection or discontinuation of use. Anthropomorphization, therefore, is not a psychologically irrelevant side effect, but a sensitive indicator of a rupture in the symbolic and operational reliability of the system.

From another perspective, the analyses revealed that the agent's experience with the evaluated systems cannot be explained solely by functional performance metrics. As argued by Hassenzahl & Monk (2010), the user experience is shaped by the articulation between pragmatic goals (do-goals), such as performing a function, and hedonic goals (be-goals), such as feeling competent, satisfied, or recognized. This articulation is directly affected by the perceived quality of the interaction and the meanings attributed to the object. In all analyzed cases, control elements that failed to provide clear feedback or predictable response compromised both the operation and the emotional significance of the technology for the agent.

Thus, FCIA-OT demonstrated its robustness by enabling a simultaneous reading of functional and affective, technical and subjective, operational and symbolic dimensions, articulating objective evaluation with a humanized understanding of the experience. This capacity for critical and integrated reading significantly expands the potential for analysis and evaluation in real contexts, definitively surpassing traditional prescriptive models and reaffirming FCIA-OT as a paradigmatic reference for the evaluation of technological objects.

4 CONCLUSION

The application of the FCIA-OT in the technical and symbolic analysis of technological objects has demonstrated its ability to operate with methodological precision across different configurations of systems, software, firmware, and multicomponent hybrid solutions. The three case studies validated the structural flexibility and diagnostic reach of the framework, both in identifying operational failures and in characterizing critical patterns of interaction and perception.

By organizing the data according to Object Requirements and Artifact Requirements and articulating them with the twelve technical-analytical dimensions of the model, it was possible to trace points of merit, neutrality, and functional collapse with high granularity. More than a descriptive matrix, the FCIA-OT proved to be a systemic reading system, capable of translating the technological experience into a critical cartography of evidence, grounded, validated, and replicable.

The analyses also revealed that localized failures in interface elements can trigger chain effects, interdependently affecting perceptual, affective, and operational dimensions. The model enabled not only the recognition of dysfunction but also its understanding within the context of use, taking into account the meanings attributed by the agent and the constraints imposed by real-world operational conditions.

The technical evaluation, enriched by empirical data and systematized instruments such as SPMI, SGUI, SCMI, and SCDMIC, allowed for the detailed mapping of critical zones and highlighted attributes of excellence or potential improvement. The intersection between quantitative indicators and qualitative interpretations enhanced the explanatory capacity of the model, broadening its applicability as a tool for diagnosis, reengineering, and decision-making in technological interaction projects.

As a methodological contribution, this study reaffirms the urgency of integrated approaches in the evaluation of complex technologies, where functionality, meaning, responsibility, and context are interwoven. In this regard, the FCIA-OT consolidates itself as a singular, multidimensional, and responsive scientific model, capable of capturing the systemic totality of technological objects, from engineering to experience, from form to function, from technical detail to symbolic perception. Its application reveals a new ontology of evaluation, positioning itself as both a reference and an innovation in the field, distinguished by its precision and its ability to map meanings and interactions with unprecedented analytical depth.

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CHAPTER 5

STRUCTURED AND ADVANCED MODEL OF PERSONAS (MEAPs)

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ABSTRACT — This study presents the Structured and Advanced Model of Personas (MEAPs), an innovative approach to modeling specialized user profiles, grounded in multidimensional empirical analyses and strict methodological rigor. MEAPs promotes the systematic integration of technical, behavioral, and contextual variables, aligning with a holistic perspective of the interaction between agents and technological objects. The methodology systematizes data extracted from detailed analyses and evaluations, structured according to the multidimensional technical-scientific matrix of the Integrated and Advanced Core Framework for the Analysis and Evaluation of Technological Objects (FCIA-OT). Unlike traditional models, which produce static personas with limited representativeness, MEAPs configures a dynamic, iterative, and versioned structure, capable of adapting profiles in response to behavioral variations and emerging user demands over time. This structure enables the generation of specialized profiles, including technical agents, accessibility experts, and sustainable technology specialists, supporting the development of inclusive, efficient, and responsive technological solutions. The implementation of MEAPs enhances decision-making in agent-centered design, promoting the rigorous alignment of technical and functional requirements with the actual expectations of agents. The model ensures the structured transfer of technical knowledge across multiple stakeholders, strengthening collaborative processes and ensuring traceability and evolutionary control over persona versions. This research makes a significant contribution to the advancement of usability engineering by providing a systemic and robust model capable of supporting the complexity of contemporary technological environments and fostering continuous innovation in the development of objects and interfaces.

KEYWORDS — Model; Personas; Multidimensional; Usability Engineering; FCIA-OT; MEAPs.

1 INTRODUCTION

A deep understanding of the interactions between users and technologies requires methods that reveal not only observable behaviors but also the meanings embedded in everyday practices. Anderson (1994) argues that ethnography, by capturing implicit contexts and the layers of complexity involved in system use, significantly expands designers' ability to interpret users' "lived work." This integration of ethnography and design can lead to the development of systems that emerge from concrete reality and meet user needs.

In the field of user-centered design, the construction of personas has become a relevant methodological strategy for representing target audiences. Cooper (1999) proposes a conception of personas that breaks with the logic of arbitrary fictionalization: these are carefully discovered archetypes, not invented ones, whose construction is grounded in empirical evidence. This approach aims to replace vague generalizations with precise representations capable of guiding product development in accordance with real demands, avoiding decisions based on subjective assumptions.

However, the effectiveness of personas depends on the quality of their foundation. Blomquist & Arvola (2002) warn of the risks of superficiality in creating such profiles, especially when they lack support from verifiable data. In such cases, designers tend to question the relevance and reliability of superficially created personas. When anchored in empirical data and articulated through coherent usage scenarios, personas acquire operational value and allow design teams to visualize interactions iteratively, contributing to the development of contextualized tasks and functionalities. Based on this analysis, the strategic value of personas lies in their concreteness and dynamism, provided they are continuously reassessed according to design goals and system evolution.

Given these conditions, the need for robust models that overcome the limitations of traditional approaches to persona creation becomes evident. This study proposes the Structured and Advanced Model of Personas (Modelo Estruturado e Avançado de Personas – MEAPs), based on a multidimensional approach that combines empirical data with technical-scientific foundations to accurately represent diverse agent profiles. The methodology presented aims to strengthen agent-centered design by offering a dynamic and adaptable framework that reflects the complexity of interactions between agents and technological objects in real and varied scenarios.

2 STRUCTURED AND ADVANCED MODEL OF PERSONAS (MEAPs)

The specialized literature has increasingly emphasized the need for more refined methodological approaches in the development of personas, particularly those capable of incorporating variables such as accessibility, diversity of usage trajectories, behavioral transformation, and other critical aspects that shape usability and interaction with technologies. Based on this scenario, the proposal to construct technical and specialized personas, supported by the 12 integrated dimensions of the FCIA-OT, represents a substantial advancement in the field. This structure combines analytical precision and design strategy, establishing a novel model for composing and articulating highly qualified profiles.

When applied across different technological contexts, this approach enables a truly multidimensional analysis, integrating behavioral, social, and technical-operational elements. The proposed methodology not only deepens the understanding of relationships between agents and complex constructs but also fosters more inclusive, responsive, and sustainable design solutions.

However, it is essential to emphasize that the effectiveness of this model depends inextricably on the quality and empirical representativeness of the data that underpin it. In this framework, the construction of personas surpasses an illustrative function: it becomes an analytical and strategic tool, precisely guiding system design in contexts that require a high degree of personalization, technical specificity, and functional responsiveness..

2.1 Theoretical Foundation and Technical Structure

The consolidation of personas as a strategic tool in interaction design depends primarily on the methodological robustness with which they are constructed. Pruitt & Grudin (2003) argue that the value of personas lies in their ability to synthesize qualitative and quantitative data into believable user representations, provided that their characteristics are explicitly anchored in the evidence supporting them. This link between data and attributes is essential to ensure reliability and to allow personas to extrapolate beyond the original scenarios, becoming useful tools in prospective design decisions.

Despite the recurring adoption of interviews and ethnographic practices, Faily & Flechais (2011) emphasize that these approaches, when used in isolation, do not guarantee the necessary validation to confer accuracy to personas. To address this weakness, they propose "Persona Cases", constructs based on narratives traceable to original empirical data, supported by rigorously articulated argumentative propositions as "grounds" or "warrants." This structure endows personas with a justifiable and auditable dimension, making them compatible with technical evaluation standards.

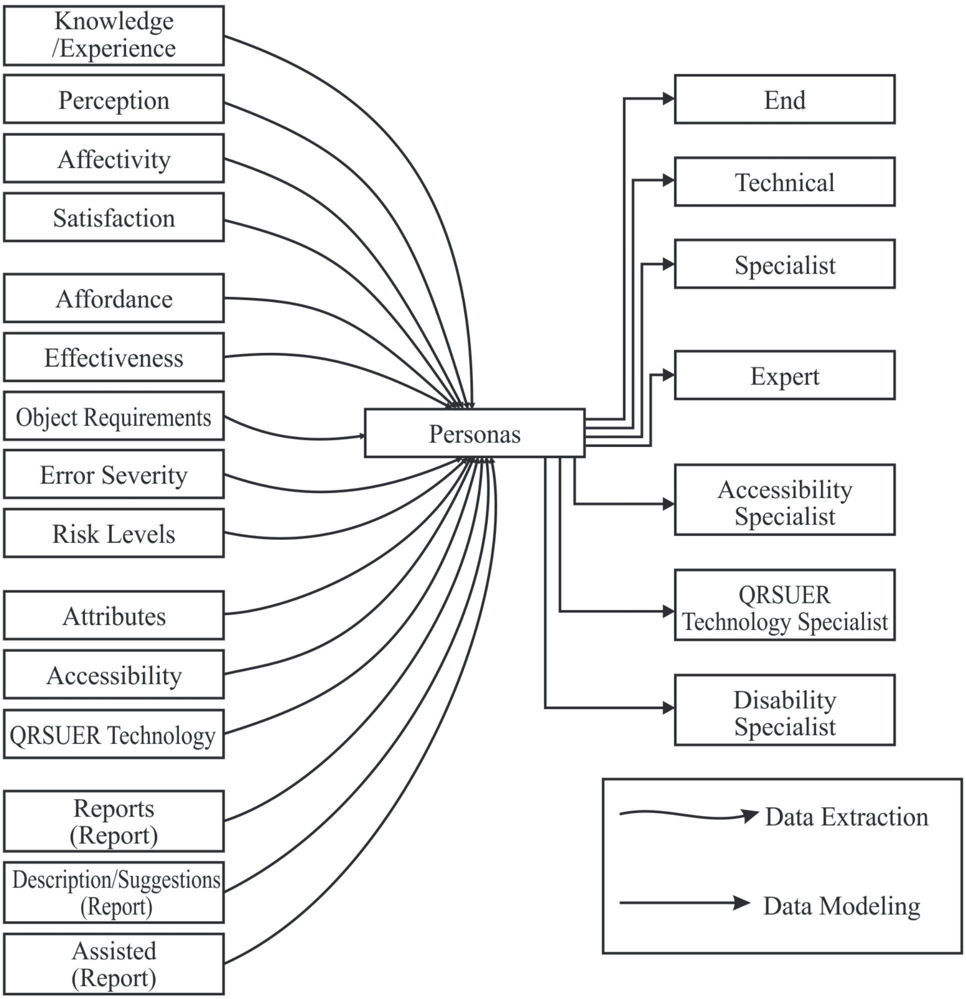
Along similar lines, Miaskiewicz & Kozar (2011) observe that although the benefits attributed to persona use are recurrent in the literature, few studies clearly delimit their more universal advantages. They highlight, however, a convergent point: well-founded personas facilitate alignment between design teams' objectives and users' real expectations, operating as more tangible mechanisms of target audiences.

Complementing this panorama, Faily & Lyle (2013) identify structural gaps both in the literature and in tools aimed at persona creation, maintenance, and version control. They state that persona effectiveness depends on the articulation between data, narratives, and solid argumentation models that validate the inferences incorporated into the profile.

Based on this theoretical foundation, the process of constructing Specialized Personas within the MEAPs model, structured around the Systemic Matrix of Integrated Vectorial Dimensions (MSDVI) of the FCIA-OT, significantly expands the scope and precision of these representations. The model enables the development of profiles adaptable to varying levels of technical complexity, ranging from generalist contexts to highly specialized niches. Its architecture overcomes the rigidity of static representations by incorporating iterative mechanisms and continuous adaptability to evolving contexts.

The flowchart depicted in Figure 1 illustrates this process, highlighting the articulation between empirical data, technical-scientific criteria, and modular analytical structures. The result is a robust system for persona characterization and evolution, precisely responding to the demands of highly dynamic, complex technological environments oriented toward functional specialization.

Figure 1: PROCESS OF DEFINITION AND STRUCTURING OF PERSONAS WITH SPECIALIZED PROFILES



This flowchart systematizes the technical composition of specialized personas according to the Structured and Advanced Model of Personas (MEAPs), articulating empirical data, technical-scientific criteria, and modular analytical structures. The profiles are derived from analyses and evaluations based on the multidimensional FCIA-OT matrix, structured through the SPMI and SCDMIC instruments and measured using the SGUI and SCMI systems. Each profile incorporates quantitative and qualitative parameters, allowing for measurable densities defined by specific scales: scores (SPMI), chromatic volume (SCDMIC), and technical-operational indexes (SGUI and SCMI). This innovative configuration assigns the personas a functional, dynamic, and traceable character, elevating the modeling process to the status of a strategic component of high design precision. A complete description of the empirical analyses, instruments applied, and case studies is provided in Chapter 4.

Source: Author.

This integration, summarized in Figure 1, systematizes the technical process of constructing specialized personas, highlighting how the articulation between empirical data and analytical dimensions enables the composition of robust, traceable, and functionally adaptable profiles. By incorporating validation criteria, iteration, and version control, the MEAPs model establishes a new methodological standard in the field of technology-oriented interaction design, serving as a foundational framework for strategic applications in complex environments with high design demands.

2.2 Systemic Structuring and Definition of Persona Profiles according to MEAPs

The use of personas in system design has been widely debated from different theoretical and methodological perspectives. Matthews, Judge, & Whittaker (2012) warn about the risks of including irrelevant information in persona construction, such as domestic habits or generic preferences, when these do not directly relate to the design problem. Under such circumstances, artificial constraints are created that divert the focus from design. Therefore, the relevance of selected data must be carefully evaluated, prioritizing information that genuinely contributes to problem delimitation and solution formulation.

Within the context of User-Centered Design, Cabrero, Winschiers-Theophilus, & Abdelnour-Nocera (2016) indicate that personas play an essential role in communication between technical teams and users by representing collectives with shared technological goals. These representations, when grounded in empirical data, allow the illustration of real motivations, expectations, and needs, fostering the development of solutions more aligned with the user experience.

The analysis by Graus & Ferwerda (2019) reinforces this understanding by pointing out that personalized systems, although capable of predicting behaviors based on historical data, rarely link such inferences to theoretical models of needs. The integration between behavioral data and robust conceptual frameworks enhances the reliability and scope of personalization strategies. Notably, Huang (2024) criticizes the rigidity of traditional UX approaches, highlighting the insufficiency of models that neglect continuous feedback and the heterogeneity of usage profiles. Well-constructed personas prove especially effective when direct access to users is limited, providing designers with a more accurate basis for critical design decisions.

According to this research, the Structured and Advanced Model of Personas (MEAPs), grounded in the 12 technical-scientific dimensions of the FCIA-OT, introduces a systemic and evolutionary approach to profile definition. These profiles are directly derived from analyses and evaluations conducted by agents, stored in a database that enables iterative reconfigurations and the maintenance of traceable versions.

This database is constituted from empirical results extracted from case studies applied across different domains (see Chapter 4), such as software analysis and evaluation, air conditioning control systems, and unmanned aerial vehicles (UAVs). These studies provide individual and aggregated data that underpin the construction of persona profiles, allowing adaptive combinations and precise definition of the most suitable profile for each usage context. This model surpasses the static limitations of conventional personas, offering an innovative, dynamic, adjustable, and verifiable structure. The main structured profiles proposed in MEAPs are as follows:

End Persona: Represents agents in real usage situations, with varying levels of technological familiarity. Data is processed based on the 12 integrated dimensions, enabling the identification of usability barriers, accessibility needs, and opportunities for functional improvement.

Technical Persona: Corresponds to agents with operational technical mastery of objects. It contributes to specialized diagnostics and evaluations of functionality, performance, and compliance. Essential for guiding adjustments in constructs, hardware, software, and integrated devices.

Specialist Persona: Encompasses professionals with expertise in specific areas. Its role focuses on advanced analysis of integrations among subsystems and platforms, performance modeling, and evaluation of critical operational requirements.

Expert Persona: A highly qualified profile with interdisciplinary capacity to lead innovation processes. Strategically guides systemic improvements, aligning technical performance with market demands.

Accessibility Specialist Persona: Focuses on agents skilled in inclusive norms, guidelines, and practices. Evaluates technologies from the perspectives of accessibility, perception, and affectivity, promoting solutions compatible with universal design.

QRSUER Technology Specialist Persona: Gathers technical, social, ethical, and sustainable competencies, operating under the pillars of Quality, Social Responsibility, Sustainability, Usefulness, Ethics, and Reason. This persona contributes to the development of technologies with high systemic impact.

PCD Specialist Persona: A profile dedicated to evaluating the interactions of persons with disabilities with technological objects. Possesses normative and practical expertise in proposing equitable and accessible solutions, based on real data collected during evaluations conducted with PCD agents.

All these profiles operate as technical-scientific vectors that articulate empirical data obtained via FCIA-OT with structural guidelines for innovation. Their composition not only guides project and validation stages but also promotes the transfer of specialized knowledge (technical know-how) among stakeholders. Profiles may be combined, generating hybrid and complex compositions, whose versioning is controlled by management mechanisms integrated into the database. This resource ensures traceability, continuous updates, and alignment with evolving technical-operational requirements.

By integrating empirical knowledge, technical modeling, and specialized representations, MEAPs consolidates itself as a systemic, strategic, and operational resource for the development of technologies centered on real usage conditions. Its application fosters professional specialization and continuous refinement of processes, promoting an approach driven by complexity and design precision.

The application of MEAPs transcends descriptive function by constituting an analytical tool aimed at verifying the functional maturity of objects. Each structured profile enables confronting evaluated constructs with empirical parameters derived from agents' real interactions, allowing the identification of critical misalignments between design objectives and user experience. This approach grounds precise interventions in the development cycle, guiding adjustments that enhance efficiency, adaptability, and technical adherence of systems to the operational contexts for which they are intended.

3 DISCUSSION

The consolidation of the Structured and Advanced Model of Personas (MEAPs) addresses critical gaps identified in the specialized literature regarding the precise, dynamic, and functional representation of agents, especially in contexts demanding inclusive, responsive technological solutions tailored to profile variability. MEAPs' contribution becomes particularly relevant in light of challenges highlighted by Lee et al. (2021), who point out that a significant portion of disabilities is acquired over a lifetime, increasing the need for design approaches that consider this continuous process of transformation of human capabilities. By incorporating specialized profiles, such as the Accessibility Specialist Persona and the PCD Specialist Persona, the model anticipates and mitigates usability barriers that are often invisible, ensuring greater equity in interaction.

From the same perspective, Bern Jordan et al. (2024) emphasize that the creation of personas representing people with disabilities remains limited, compromising representativeness in technology design. MEAPs, built upon observational data, empirical evaluations, and active participation of assessing agents, guarantees greater density and fidelity to real experiences, especially when technical and contextual narratives are combined. This approach endows profiles not only with descriptive value but also with argumentative power, capable of guiding technical and strategic decisions with higher precision.

From the interface standpoint, Kaate et al. (2024) indicate that the way personas are presented and interact with users directly affects their effectiveness. In MEAPs, the visual and textual structuring of profiles is guided by criteria of intelligibility, adaptability, and design precision, allowing complex data to be translated into comprehensible and operational artifacts without losing technical-scientific depth.

Another fundamental aspect lies in overcoming the static and generalist limitations observed in traditional models. Farhat-Ul-Ain et al. (2024) warn about the absence of behavioral change objectives and adaptive mechanisms in common personas, which compromises their applicability in complex interventions. MEAPs, being dynamic, versioned, and integrated into an iterative data system, can capture gradual transformations in user profiles, providing structural support for projects aimed at behavioral change, progressive personalization, and evolving agent demands over time.

The model proposed in this research goes beyond merely representing users; it establishes a robust link between empirical analysis, technical-conceptual modeling, and design action, becoming a systemic resource for qualifying decision-making processes in design, engineering, and technological evaluation. The applicability of these profiles transcends static user description: it functions as a cross-validation mechanism, enabling the confrontation of constructs with the real profiles of their target users, assessing the maturity, usability, and responsiveness of the developed technological object.

4 CONCLUSION

This research presented the Structured and Advanced Model of Personas (MEAPs) as a novel methodological resource, guided by technical-scientific complexity and the growing need for personalization in interactions between agents and technological objects. Unlike traditional approaches, MEAPs articulates empirical data derived from structured analyses based on FCIA-OT, generating highly specialized, versionable profiles that are strategically applicable across diverse design cycles.

The constructed profiles operate as dynamic validation vectors, enabling not only the refinement of technological solutions but also the rigorous confrontation between constructs and the actual demands of their users. This articulation among evaluation, characterization, and modeling represents a significant conceptual and operational advancement, especially in scenarios requiring high responsiveness, inclusion, and continuous adaptability.

By establishing a rigorous link between empirical observation, multidimensional foundation, and practical application, MEAPs consolidates itself as a strategic tool for agent-centered design engineering. Its contribution transcends mere representation, promoting an active system of knowledge, adaptation, and innovation capable of keeping pace with the evolution of usage contexts and anticipating emerging demands in technological development.

Given this analytical panorama, it becomes evident that the structure and outcomes of MEAPs not only address the gaps identified in the literature but also establish a new methodological standard for the technical and strategic representation of agents. These elements conclusively delineate the systemic value of the proposed model, which will be further consolidated in the next section.

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CHAPTER 6

DYNAMIC INFERENCE SYSTEM OF PERCEPTUAL FIELDS (SIDyCP)

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ABSTRACT — This article presents the Dynamic Inference System of Perceptual Fields (SIDyCP), a theoretical-computational infrastructure that redefines perception as a dynamic, distributed, and context-sensitive inferential process. Integrated into the epistemic platform Agent-Technology Interaction (ATI) of the FCIA-OT framework, SIDyCP mathematically formalizes the Three Laws of Affordance, converting perceptual properties into computable, auditable, and adaptive variables. Perception is modeled as a non-local field (Ψ), in which agent–environment couplings emerge from historically situated coefficients (α_i), whose dynamics are represented by the Perceptual Field Equation (Ψ), the Interaction Entropy (U(t)), and the Dynamic Equation (∂Ψ/∂t). The latter operationalizes, in an unprecedented way, the Third Law, Necessary Reconfiguration, by expressing the inferential collapse that occurs when the structural variation of perception exceeds the Perceptual Coupling Constant (κ_p), requiring adaptive reorganizations. The model articulates inferential acceleration ($\dot{\alpha}^2$), relational codings (⊗), and stochastic noise (ξ) as critical variables for perceptual stability. By dissolving the nature–culture dichotomy, SIDyCP treats affordances as emergent vectors of non-local correlation between components of coupled systems, overcoming the fragmentation between natural and cultural artifacts. Its full compatibility with the FCIA-OT matrix enables continuous applications in multi-agent environments, adaptive interfaces, intelligent systems, and context-sensitive perceptual audits. Consolidated within the scope of ATI, SIDyCP establishes a new formal and epistemic foundation for the inferential modeling of technical perception in complex interactive systems.

KEYWORDS — ATI; FCIA-OT; SIDyCP; Three Laws of Affordance; Perceptual Field Equation; Interaction Entropy; Dynamic Equation; Perceptual Coupling.

1 INTRODUCTION

In recent decades, advances in the field of Human–Computer Interaction (HCI) have enabled the construction of increasingly sophisticated models for behavioral mapping, interface design, and adaptive technical responses. Although interactive frameworks have been explored through distinct methodological approaches, critical gaps remain regarding the nature of technical perception, particularly in light of the growing complexity of contemporary systems and the emergence of hybrid agents, whether human, artificial, or cyber-physical.

The FCIA-OT, through its Systemic Matrix of Integrated Vector Dimensions (MSDVI), a next-generation epistemic and operational infrastructure, emerges from the recognition of such structural deficiencies. Its systems offer mechanisms for diagnosis, interaction modeling, and functional coupling between multiple modules and agents. However, as the analysis of perceptual conditions that sustain the intelligibility of actions deepens, the need for a system capable of surpassing classical models, anchored in isolated categories and fragmented views of interaction, becomes evident.

Within this horizon, the SIDyCP is formulated as a theoretical–computational infrastructure that redefines perception as an inferential input system, capable of interpreting and quantifying, in real time, the dynamic couplings between agents and artifacts. Grounded in the existence of a non-local field (Ψ), SIDyCP models the emergence of affordances not as fixed properties of objects, but as encoded operational vectors, whose manifestations depend on historical, contextual, and topological entanglements.

This perspective advances the foundational postulates of Gibson (1979), for whom affordances, understood as action potentials, emerge from the relationship between environmental structures and the perceptual–motor capacities of each species, constituting phenomena that are simultaneously ecological and behavioral, inseparable from the interaction between organism and environment. While real and objective—and, as argued by Hartson (2003), even functional—these structures transcend measurable physical properties, eluding the logic of traditional physics and challenging the boundaries between subject and object.

Building on this legacy, SIDyCP transcends the nature–culture dichotomy by proposing an algorithmically quantified formalism for perceptual relations. Operating according to the Three Laws of Affordance, formulated within the scope of FCIA-OT (see Chapter 1), the system converts perception into a computable phenomenon, capable of supporting predictive diagnoses, interactional simulations, perceptual audits, and self-adaptive mechanisms.

In rupture with classical paradigms of perception and usability, SIDyCP inaugurates a theoretical and computational infrastructure aimed at inferring non-localized perceptual fields, constituting a modular and operable architecture for reading, modeling, and reengineering technical perception in interactive systems. In doing so, it redefines the foundations of HCI and projects Agent–Technology Interaction (ATI) under a new epistemic, computational, and cognitive paradigm.

2 DYNAMIC INFERENCE SYSTEM OF PERCEPTUAL FIELDS (SIDyCP)

SIDyCP consolidates itself as the technical–formal core of the epistemic architecture proposed by FCIA-OT, by repositioning the concept of affordance not as a localized attribute of an object or agent, but as an expression of non-local correlations between components of coupled systems. This reformulation breaks with classical approaches to perception, which are anchored in the identification of isolatable properties, by assuming that perceptual phenomena result from dynamic states of organism–environment coupling.

In the early studies of ecological perception, Cutting (1982) points out that perceptual errors, especially those that are non-damaging, function as epistemological catalysts: by misperceiving the affordances of an object or event, the agent is compelled to reorganize their environmental reading, refining their interaction strategies. This process reveals that perception is neither static nor neutral, but modulable, historical, and cumulative, a fundamental characteristic that SIDyCP incorporates by modeling the perceiver as an open system traversed by multiple layers of conditioning.

Subsequently, Lindquist (1985) reinforces the need for technical–operational parameters to evaluate interface efficiency after the learning phase, proposing the use of metrics derived from software analysis. While acknowledging the limitations of isolated temporal measures, he argues that the computational complexity of dialogical structures can offer robust comparative indicators. SIDyCP advances this proposition by formalizing a **Usability Equation (U(t))** capable of quantifying, in terms of interactional entropy, the perceptual uncertainty of affordances, identifying critical thresholds for intuitive objects **($U(t) < 0.3$)** or dysfunctional ones **($U(t) > 1.0$).**

As anticipated by Aykin (1989), adaptive systems based on user models are capable of predicting preferences and states from interactional data such as commands, execution time, and error patterns, a premise that SIDyCP extends by incorporating dynamic coupling variables, thus surpassing the static logic of traditional interfaces.

However, it is Cutting (1993) who explicitly identifies the central epistemological gap that motivates the development of SIDyCP: the absence of a unified model capable of explaining the perception of cultural artifacts and natural objects under a common ontological regime. Dominant approaches treat these domains as disparate categories, the former marked by symbolic codification and cultural learning; the latter, by evolutionary traits and invariant structures. SIDyCP breaks with this separation by proposing that both are manifestations of a unified and dynamic perceptual field **(Ψ)**, in which perceiver and environment operate in non-local coupling.

In this formalism, affordance is not an attribute of the object, but an emergent vector of the relationship between correlated states. The **Perceptual Field Equation (Ψ)** expresses this hypothesis by using $\boldsymbol{\alpha}_i$ coefficients to probabilistically encode the historical, cultural, and individual components of the perceiver. The entanglement between agent and environment is formalized through the tensor product **(⊗)**, which models the inseparability of interactional layers, an aspect directly inspired by the notion of quantum superposition and decoherence, applied here as a theoretical matrix of technical perception.

Complementarily, the **Usability Equation (U(t))** introduces a new parameter for modeling interactional perception. By employing the function $|\alpha_i(t)|^2$ to represent the temporal probability of an affordance being recognized, and by incorporating the natural logarithm **(ln)** to capture cognitive nonlinearities, the model becomes capable of empirically measuring interactions, transforming perception into an auditable and optimizable variable.

It is important to note that SIDyCP does not assume a primary evaluative function in the perceptual process. Its algorithmic infrastructure operates on perceptual records encoded according to the criteria of the epistemic matrix of FCIA-OT, which result from analyses carried out by different types of agents, human, artificial, hybrid, or cyber-physical, according to their perceptual capacities and historical–situational trajectories. Although it does not generate affordances or perform autonomous usability judgments, SIDyCP is capable of inferring, quantifying, and reconfiguring perceptual patterns in real time, even in intelligent environments, neural networks, and adaptive systems. Its formal modeling, structured by the Three Laws of Affordance, ensures the epistemic integrity of the process and maintains full compatibility with the distributed and multi-agent logic that underpins technical evaluation within the scope of FCIA-OT.

This modeling aligns coherently with the contributions of Maier & Fadel (2008), who argue that functions are abstractions dependent on material realization, whereas affordances are intrinsically structural. In differentiating affordances from functions, they emphasize that the former require specific formal features, since the geometry, materials, and dynamics of the artifact condition the possibilities for action. This is consistent with the formulation of Scarlett & Zeilinger (2019), who argue that affordances operate on chained levels that surpass the perceptible layers of conventional computation, configuring hidden, yet determinant, dynamics in the structuring of technical action and in the mediation between agent and system. SIDyCP internalizes this principle by recognizing that the field **Ψ** incorporates both formal and contextual aspects, enabling the prediction of how different agents will perceive and activate affordances based on their $\boldsymbol{\alpha_i(t)}$ trajectories.

The theoretical coherence of SIDyCP is further expressed in the derivation of the **Three Laws of Affordance** (see Chapter 1), directly from the mathematical structure of the field **Ψ**. The superposition of states reflects **"Universal Coding"**, where the **states** $\boldsymbol{|\text{environment}_i\rangle}$ encode both physical and cultural properties. The decoherence of states—i.e., the loss of synchronization between agent and environment, corresponds to **"Trajectory Dependence"**, captured by the temporal dynamics of $\boldsymbol{\alpha_i(t)}$, which follow well-defined learning curves. Temporal evolution **(∂Ψ/∂t)** mirrors **"Necessary Reconfiguration"**, which occurs when environmental changes exceed the Coupling Constant $\boldsymbol{\kappa_p}$ requiring recalibration of interaction protocols. The constant $\boldsymbol{\kappa_p}$ represents the minimum threshold of **Ψ**-field stability. It defines the point beyond which changes in the environment (or in the agent's state) begin to require structural reorganization of the coupling, signaling a collapse in dominant affordance patterns. When the rate of variation **∂Ψ/∂t** exceeds this threshold, perception must reorganize itself, with both inferential and operational consequences.

SIDyCP not only responds to the epistemological gap outlined by Cutting (1993), but also proposes a new regime for Human–Computer Interaction (HCI), replacing the nature–culture dichotomy with a continuum of interactional states modulated by historically situated coefficients. Affordances become emergent properties, susceptible to quantification, prediction, and reengineering. The Agent–Technology Interaction (ATI) platform thus begins to operate under a computational formalism capable of guiding perceptual diagnostics, adaptive simulations, and predictive design in complex systems.

The reformulation proposed by SIDyCP rests on the premise that affordances are not fixed entities assigned to objects or subjects, but non-localized correlations that emerge from their interaction. This proposition is anchored in the idea that the perception of an affordance cannot be explained solely by local geometric properties, nor by internal features of the agent, but rather by a structural and probabilistic relationship between both poles of the system.

From this perspective, affordances are properties of the coupling between perceiver and environment. They depend simultaneously on the physical configuration of the artifact (such as the height of a bench), the biological and historical constitution of the agent (such as leg length or cultural habits), and a set of contextual mediations (such as the cultural meaning of a "public bench"). They are, therefore, statistical correlations emerging from a global dynamic system, not attributes that can be localized in either part independently.

This notion of non-locality, central to SIDyCP, conceptually derives from the domain of quantum physics, in which entangled systems maintain robust correlations that do not depend on spatial proximity or direct causality. When applied to technical perception, this analogy supports the view that observer and environment form an entangled perceptual system, where the affordance is a global vector of interdependent states. Perception, therefore, is not reducible to discrete parts but constitutes a distributed phenomenon across the field **Ψ**.

This approach stands in radical contrast to the traditional ecological conception, in which affordances are understood as structural invariants present in the environment, accessed through specific sensorimotor explorations. SIDyCP proposes that such invariants exist only as correlation effects, not as autonomous causes. Instead of seeking affordances in the object or in the subject, the model seeks to formalize them within the relational space of non-local coupling, where cultural, biological, and historical elements coexist and codetermine perceptual emergence.

This perspective is decisive for addressing a central problem in the literature: the persistent difficulty in explaining how cultural artifacts, lacking direct evolutionary grounding, are readily perceived as bearing functional affordances. Classical explanations appeal to symbolic learning but fail to integrate the dynamic and systemic dimensions of the phenomenon. SIDyCP, in contrast, shows that cultural artifacts and natural objects are correlated states of the same dynamic perceptual field **(Ψ)**, thereby dissolving the nature–culture dichotomy.

By incorporating non-locality as a foundational property of technical perception, SIDyCP not only resolves ontological impasses but also provides a robust basis for algorithmic modeling of interaction. The following segments will detail how this structure is formalized mathematically, through the **Perceptual Field Equation (Ψ)**, the **Usability Equation (U(t))**, the **α_i(t)** coefficients, and the **Dynamic Equation of the Perceptual Field (∂Ψ/∂t)**, which capture the perceiver's trajectory across multiple layers of historicity.

3 PERCEPTUAL FIELD EQUATION (Ψ)

The computational formalization of SIDyCP requires a mathematical expression of the perceptual principles previously defined. The **Perceptual Field Equation (Ψ)** constitutes the initial step of this formalization, representing the inferential structure of perception as a dynamic entanglement between agent(s) and environment(s). This entanglement transcends local or punctual properties, incorporating coefficients of historical, cultural, social, and situational nature, thereby configuring a non-local and probabilistic perceptual field of potentially manifest affordances.

3.1 General Structure of the Perceptual Field Equation Ψ

In his theorization of quantum mechanics, Dirac (1930) introduced the bra-ket notation and formalized the principle of superposition, according to which a quantum state can be described as a linear combination of basis vectors defined in a complex inner product vector space, the Hilbert space. This principle enables the representation of entangled compositions of physical systems through tensor products, structuring a formal architecture of composite states. The construction is expressed by the equation:

$$\psi\rangle = \sum_{i=1}^{n} c_i |a_i\rangle \otimes |b_i\rangle$$

The formulation describes the composition of systems in entangled states, with complex coefficients $\mathbf{c}_i$ and tensor products between state vectors. This formulation underpins the structure of composite states in physical systems and is central to the quantum formalism.

In contrast to the quantum formalism, the **Perceptual Field Equation (Ψ)** does not describe entangled physical systems, but rather nonlinear inferential structures emerging from the agent–environment relation. In this model, the field **Ψ** represents a dynamic informational construct that encodes the agent's perceptual dispositions within a space of potential interactions with the environment. The equation is expressed as follows:

$$\Psi = \sum_{i=1}^{n} \alpha_i \cdot \langle \text{perceiver}_i \rangle \otimes \langle \text{environment}_i \rangle$$

Source: Author.

Example:

$\Psi = \alpha_1|\text{perceiver}_1\rangle \otimes |\text{environment}_1\rangle + \alpha_2|\text{perceiver}_2\rangle \otimes |\text{environment}_2\rangle + \ldots + \alpha_n|\text{perceiver}_n\rangle \otimes |\text{environment}_n\rangle$

This equation represents a superposition of potential states of perceptual coupling, in which each pair ⟨**perceiver**$_i$⟩ ⊗ ⟨**environment**$_i$⟩ composes a specific contextual unit weighted by a coefficient $\boldsymbol{\alpha}_i$. These coefficients express the intensity, priority, or activation of each configuration within the field, and may encode sensory variables as well as cognitive, intentional, or historical-cultural dispositions. Unlike quantum entanglement, the tensor product here preserves the semantic identity of each component, forming a perceptual field that is non-local, dynamic, and inferential. Table 1 describes the elements of the **Ψ** equation and their structural functions within the system.

TABLE 1: DYNAMIC PERCEPTUAL FIELD: GLOSSARY OF SYMBOLS AND CONCEPTS

Symbol	Name	Meaning	Practical Application
Ψ	Psi	Global state of the perceiver–environment system	The combined perception of an agent and an interface
Σ	Summation	Superposition of all possible states	A button may be "clickable," "draggable," or "ignored" simultaneously until action is taken
α_i	Coupling coefficient	Probabilistic weight of each interaction ($0 \leq \lvert\alpha_i\rvert^2 \leq 1$). Complex amplitude that weighs the contribution of each state (i).	$\alpha_1 = 0.9 \rightarrow$ 90% chance the agent will click the button
$\lvert perceiver_i \rangle$	Perceiver state	Agent's perceptual vector; encodes cognitive, cultural, and intentional dispositions. Quantum-like observer state	Knowledge, prior experience, objectives
$\lvert environment_i \rangle$	Environment state	Environmental vector; encodes physical, symbolic, and contextual properties	Color, shape, location, function, and cultural context of the object
⊗	Tensor product	Operates the non-separable entanglement between agent and environment	The affordance emerges from the relation, not from the agent or object alone
i	Iteration of possible states	Identifier of each distinct agent–environment pair in the superposition	i = 1, 2, ..., n

Interactive Technical Action. All symbols are interpreted within the dynamic context of the perceptual field. The fundamental properties of the field Ψ can be described as follows:

Superposition: Perception remains in a potential, non-collapsed state until one of the possibilities becomes predominant through inference or action.

Perceptual decoherence: The field Ψ may undergo local reduction induced by attentional mechanisms, cognitive limitations, or situational pressures.

Non-locality: The coefficients α_i integrate influences distant in time and space, including memories, norms, collective knowledge, and cultural structures.

Perceptual (epistemological) collapse: The superposition structure represented by Ψ collapses into a state inferred as the dominant affordance. This collapse is interpreted as inferential resolution, not as a physical event..

Source: Author.

Thus, the Perceptual Field Equation provides the formal foundation for the dynamic inference processes operated by SIDyCP, structuring the way in which perceptions are formed, modulated, and transformed at the interface between agents and their contexts.

The general formulation presented thus far establishes the **Perceptual Field Equation (Ψ)** as the basis for modeling inferential perception. However, in order to demonstrate the operational power of SIDyCP, it is necessary to show its application in concrete contexts, in which the dynamics of superposition, coupling, and perceptual collapse can be numerically observed and interpreted. Table 2 presents a unified glossary (technical reference) of SIDyCP symbols, including the elements used in its core equations: the **Perceptual Field Equation (Ψ)**, the **Usability Equation (U(t))**, and the **Dynamic Perceptual Field Equation (∂Ψ/∂t)**.

TABLE 2: UNIFIED GLOSSARY OF SIDyCP SYMBOLS AND OPERATORS

Symbol	Technical Name	Meaning/Description	Application
Ψ	Uppercase Greek letter "Psi"	Perceptual Field: dynamic inferential structure that encodes agent–environment interaction	Foundation of the Laws of Affordance and perceptual modeling in SIDyCP
∂Ψ/∂t	Partial derivative of Ψ over time	Rate of change of the Ψ field over time; expresses the need for perceptual reconfiguration	Indicates when perception must reorganize in response to changes in the environment
t	Continuous time	Temporal variable	Basis for the dynamic evolution of perception and usability
$\alpha_i(t)$	Coupling coefficient i at time t	Weight of the contribution of the perceiver–environment pair i in the superposition of the Ψ field	Represents the inferential strength of each affordance over time
**	perceiver$_i$)**	Bra-ket state vector (agent)	Representation of the perceptual state of agent i
**	environment$_i$)**	Bra-ket state vector (medium)	Representation of the environmental state as perceived by agent i.
⊗	Tensor product	Combination of agent and environment state vectors into a compound state	Models the non-reductionist coupling between perception and environment
ξ(t)	Lowercase Greek letter (ruído cognitivo)	Time-dependent stochastic noise, representing unpredictable variations in cognition and environment	Models contextual fluctuations, ambiguity, and cognitive load
κ_p	Subscripted Greek letter "kappa"	Perceptual Coupling Constant: minimum threshold for Ψ stability	Defines the critical point beyond which perceptual reconfiguration occurs

U(t)	Usability function over time	Measure of interaction entropy, based on the distribution of $\alpha_i(t)$	Assesses the degree of coherence and predictability in the agent's experience with the environment
ln	Natural logarithm	Used in entropy calculation in the Usability Equation	Measures uncertainty or informational dispersion in the system
∑ (Summation)	Summation operator	Sum over all possible states i	Structures all superpositions and usability calculations
=, >	Operadores lógicos	Equality, inequality	Express formal definitions and critical thresholds (e.g., $\partial\Psi/\partial t > \kappa_p$).

Source: Author.

The following subsections present two distinct formal examples, which illustrate how the system computes and infers predominant states based on variable compositions between agents and environments. These demonstrations also make it possible to observe how the structure of the **Ψ** field behaves under perceptual configurations with varying degrees of uncertainty, asymmetry of intention, or contextual salience.

3.2 Numerical Example N01: Technical Perception with Strong Predominance

This example applies to a system with only two states:

A. Example: Two Agents

Agent 1: technical-instrumental emphasis ($a_1 = 0.8$)

Agent 2: aesthetic-affective emphasis ($a_2 = 0.3$)

$$\Psi = 0.8\cdot|\text{agent}_1\rangle \otimes |\text{environment}_1\rangle + 0.3\cdot|\text{agent}_2\rangle \otimes |\text{environment}_2\rangle$$

B. Calculating $|\alpha_i|^2$ for normalization:

State agent$_1$: $|0.8|^2 =$ **0.64**

State agent$_2$: $|0.3|^2 =$ **0.09**

Total sum (squared amplitudes): $|0.8|^2 + |0.3|^2 \rightarrow 0.64 + 0.09 =$ **0.73**

C. Relative probabilities:

P(agent$_1$): 0.64 / 0.73 = **87.7%**

P(agent$_2$): 0.09 / 0.73 = **12.3%**

Inference: The system tends to collapse into the dominant affordance of agent 1.

3.3 Numerical Example N02: Cultural Interference with Weak Predominance

This example refers to a button in an app interface:

A. Example: Two Agents

State 1:

$\alpha_1 = 0.8$

$|\text{perceiver}_1\rangle$ = "**agent1** familiar with apps"

$|\text{environment}_1\rangle$ = "Green button (Transfer) with arrow icon"

State 2:

$\alpha_2 = 0.3$

$|\text{perceiver}_2\rangle$ = "**agent2** with technological insecurity"

$|\text{environment}_2\rangle$ = Same "Green button (Transfer) with arrow icon"

$\Psi = \Sigma\,(\alpha_i\,|\text{perceiver}_i\rangle \otimes |\text{environment}_i\rangle)$

$\Psi = 0.8\,|\text{agent}_1\rangle \otimes |\text{transfer\_button}\rangle + 0.3\,|\text{agent}_2\rangle \otimes |\text{ambiguous\_button}\rangle$

This computation yields concrete results that can be interpreted both qualitatively and quantitatively.

B. Calculate $|\alpha_i^2$ for each state:

State agent1: $|0.8|^2 = 0.64$

State agent2: $|0.3|^2 = 0.09$

C. Sum all squared amplitudes:

Total=$|0.8|^2 + |0.3|^2 = 0.64 + 0.09 = 0.73$

D. Normalize to obtain probabilities:

P(agent1): 0.64 / 0.73 = 0.877%

P(agent2): 0.09 / 0.73 = 0.123%

E. Description of the use of $|\alpha_i|^2$:

In quantum theory, $|\alpha_i|^2$ represents the collapse probability to a specific state.

Normalization ensures that the total probability sums to 100%.

For $\Psi = 0.8|agent_1\rangle + 0.3|agent_2\rangle$:

Agent1 Probability: 87.7%

Agent2 Probability: 12.3%

F. Practical Application:

Measurement (Analysis and Evaluation) in usability and interaction:

8 out of 10 agent1-type users click the button ($\alpha_{agent1} = 0.8$);

3 out of 10 agent2-type users click it ($\alpha_{agent2} = 0.3$).

Probabilistic Interpretation:

The button is **effective for agent1** (87.7% dominance);

But it needs to be **redesigned for agent2** (only 12.3% success).

Contextualization:

For agent1, the button is clearly "clickable" (high α).

For agent2, the same object is less intuitive (low α).

Technical Action: Redesign the button to increase α_2 (e.g., by adding an icon + explanatory text).

4 USABILITY EQUATION (INTERACTION ENTROPY) U(t)

Although the mathematical structure of the Usability Equation (Interaction Entropy) **U(t)** formally resembles Shannon's entropy (1948), its function in the present model is fundamentally distinct. This article proposes a reinterpretation of entropy as a measure of inferential uncertainty in the perceptual interaction between agents and interactive systems. Unlike the classical formulation, focused on signal encoding in communication channels, interaction entropy models the epistemic ambiguity that emerges when multiple affordances compete for interpretation in real time.

Shannon's static probabilities $\mathbf{p_i}$ are replaced here by dynamic coefficients $|\boldsymbol{\alpha_i(t)}|^2$, which express the degree of perceptual activation associated with each affordance at a given moment (time-dependent coefficients). This substitution introduces a temporal and nonlinear dimension absent in the original theory, enabling the continuous and adaptive description of inferential collapse or stabilization.

As Shannon demonstrated, informational entropy **H** measures the uncertainty associated with symbol selection in a complex system. Analogously, in this work, **U(t)** quantifies the degree of ambiguity in affordance inference (dynamic Usability and Affordances), based on the distribution of perceptual saliencies over a set of possible alternatives. Similarly to Shannon's treatment of residual ambiguity $\mathbf{H_y(x)}$ as a limiting factor of effective information, ambiguity here manifests in the discrepancy between the agent's intention and the perceived affordance structure.

Therefore, **the equation U(t) constitutes a novel theoretical-computational application of entropy**, aimed at the formal analysis of usability in perceptual systems, within the dynamic framework of the SIDyCP model. Its formulation represents a substantial transformation, grounded in four axes of innovation:

Domain and context shift: Entropy no longer represents uncertainty in message encoding, but rather expresses the inferential ambiguity perceived in agent–system interaction contexts.

Variable substitution and dynamic structure: Static coefficients p_i are replaced by dynamic perceptual amplitudes $|\boldsymbol{\alpha_i(t)}|^2$, which vary in real time according to affordance activation.

Interpretative and functional redefinition: U(t) quantifies not merely statistical disorder, but the epistemic cost required by the perceptual system to converge toward a stable interpretation of affordance.

Integration into the SIDyCP system: The equation is an integral component of a broader theoretical–computational model that formalizes perception as dynamic inference in non-local perceptual fields.

The Usability Equation formalizes, from the SIDyCP perspective, the inferential instability that emerges when the perceptual field **(Ψ)** encounters obstacles, noise, or ambiguity in its epistemic convergence. This deviation is quantifiable through interaction entropy, represented here as **U(t)**. This scalar quantity measures the degree of disorder or uncertainty in the perceived interface, establishing a bridge between perceptual inference and information theory.

Unlike conventional metrics, **U(t)** is not limited to performance or efficiency assessment, but expresses the inferential cognitive cost required to stabilize an affordance in context. Values close to zero indicate a high degree of perceptual determinability (intuitive interfaces), whereas high values suggest a predominance of ambiguous or conflicting states, forcing the perceiving system to overload its inferential mechanisms.

4.1 General Structure of the Usability Equation U(t)

Shannon's original equation (1948), the foundation of information theory, defines entropy as:

$$H = -\sum_{i=1}^{n} p_i \cdot log p_i$$

This article proposes a reformulation of that principle, in which the static probabilities pi are replaced by dynamic perceptual coefficients **|αi(t)|²**, within the context of interactive affordances. The resulting equation, referred to as the Usability Equation (Interaction Entropy) U(t), takes the following form:

$$U(t) = -\sum_{i=1}^{n} \left|\alpha_i(t)^2\right| \cdot ln \left|\alpha_i(t)^2\right|$$

Source: Author.

Example: $U(t) = -(|\alpha_1(t)|^2 \cdot \ln|\alpha_1(t)|^2 + |\alpha_2(t)|^2 \cdot \ln|\alpha_2(t)|^2 + \dots + |\alpha_n(t)|^2 \cdot \ln|\alpha_n(t)|^2)$

In this formulation, the coefficients $|\alpha_i(t)|^2$ represent inferential probabilities associated with each affordance i at a given time t. The natural logarithmic function **(ln)** serves as a translator of informational complexity, capturing the nonlinear effects of perception, whereby subtle variations in the clarity or ambiguity of affordances result in disproportionate impacts on perceived usability.

From an operational perspective, this equation supports both diagnostic and projective inferences. For instance, if $|\alpha\text{"submit"}(t)|^2 = 0.4$, its isolated contribution to entropy will be $0.4 \cdot \ln(0.4) = -0.37$. This decomposition analysis informs targeted interventions, such as microcopy refinement, spatial reorganization, or semantic reinforcement of the ambiguous affordance.

The formalization of **U(t)** within the SIDyCP structure significantly expands the scope of inferential design:

Formal Unification: U(t) integrates physical, symbolic, and contextual affordances into the same inferential framework as the field **Ψ**, ensuring consistency with the epistemic architecture of FCIA-OT.

Measurability: The coefficients $\boldsymbol{\alpha_i(t)}$ can be estimated through eye-tracking, interaction log analysis, probabilistic models, or neural networks trained via Bayesian inference.

Adaptive Action: Enables data-driven adaptive interventions, such as dynamic interface personalization in metaverse environments, medical dashboards, or cognitively demanding critical systems.

Compatibility with Ψ: Usability entropy can be interpreted as a delayed inferential collapse—i.e., a lag in the stabilization of the dominant state of **Ψ**. High values of **U(t)** signal resistance to perceptual collapse and a corresponding increase in epistemic effort.

Table 3 below presents the main formal components of the usability entropy equation **U(t)**. Each symbol is contextualized within the inferential logic of SIDyCP, allowing both conceptual interpretation and practical application in adaptive interactive environments. This formalization provides an operational basis for the continuous analysis of user experience in real time, aligned with the perceptual principles of epistemic collapse and affordance stabilization defined by FCIA-OT.

TABLE 3: USABILITY (INTERACTION ENTROPY): GLOSSARY OF SYMBOLS AND CONCEPTS

Symbol	Name	Meaning	Practical Application
U(t)	Usability Entropy	Measures uncertainty/ disorder in interactions, based on the probability distribution of affordances	$U(t) < 0.3$ → Intuitive interface. $U(t) > 0.7$ → Urgent redesign. Identifies interface "confusion" or "uncertainty." The lower, the better
$\lvert\alpha_i(t)\rvert^2$	Affordance Probability	Squared weight of the coefficient αi at time t, representing the likelihood of the i-th affordance being perceived	$\lvert\alpha\text{"click"}\rvert^2 = 0.9$ → 90% effective usability. $\lvert\alpha\text{"arrastar"}\rvert^2 = 0.1$ → Poor usability. If $\lvert\alpha_1\rvert^2 = 0.9$, there is a 90% de chance the button will be clicked.
ln	Natural Logarithm	Mathematical function that quantifies the dispersion rate of probabilities. Translates multiplication into addition, enabling entropy as weighted sum	Used to calculate probability dispersion. $\ln(0.5) = -0.693$ → Indicates high dispersion (50% de ambiguity).

The main symbols and concepts involved in the **Usability Equation U(t)** quantify the perceived interaction entropy in a system. Each element composes the formal structure that enables affordances to be measured, interpreted, and designed through the lens of dynamic perceptual inference. The "Practical Application" column provides operational examples illustrating how these elements translate into functional diagnostics and intervention strategies within real interface contexts. The precision of the coefficients $\lvert\alpha_i(t)\rvert^2$ allows for both epistemic measurement of affordance clarity and anticipation of critical ambiguity states, guiding data-driven design decisions.

Source: Author.

This formalization not only consolidates usability as a measurable variable within the SIDyCP framework, but also articulates its epistemic role within the inferential cycle of interfaces. By translating perceptual ambiguity into operational entropy, the equation **U(t)** functions as a sensitive index of affordance stability, enabling the diagnosis of inferential collapse zones before they manifest as interaction failures. In doing so, the system becomes capable of precisely identifying the threshold between perceptual fluency and noise, anticipating interventions and enabling data-driven design strategies. Below, a numerical example illustrates the practical application of the **U(t)** equation in a system with competing affordances.

4.2 Numerical Example N03: Applied to an Object with Two Affordances:

In this example, the **Usability Equation U(t)** is applied to an interface object that presents two perceptible and mutually exclusive affordances: a primary action button ("Save") and a secondary action button ("Cancel"). The objective is to estimate the inferential entropy associated with the agent's decision under contextual ambiguity.

A. Affordances analyzed:

State 1: "Save" button with perceived probability ($|\alpha_1|^2 = 0.7$)

State 2: "Cancel" button with perceived probability ($|\alpha_2|^2 = 0.3$)

B. Calculation of each term in the equation:

Term 1: $|\alpha_1(t)|^2 \cdot \ln|\alpha_1(t)|^2 = 0.7 \cdot \ln(0.7) = 0.7 \cdot (-0.3567) = -0.2497$

Term 2: $|\alpha_2(t)|^2 \cdot \ln|\alpha_2(t)|^2 = 0.3 \cdot \ln(0.3) = 0.3 \cdot (-1.2039) = -0.3612$

C. Sum of the terms:

Total Sum = (-0.2497) + (-0.3612) = -0.6109

D. Application of the negative sign to obtain U(t):

U(t) = -(-0.6109) = 0.6109

E. Interpretation of the result:

The resulting value **U(t) = 0,61** represents moderate interaction entropy, indicating a significant degree of perceptual ambiguity between the available affordances. Although the "Save" action holds inferential predominance (70%), the presence of a 30% probability associated with the "Cancel" affordance implies a risk of hesitation, particularly in contexts of high cognitive load or when visual/semantic cues are similar.

F. Recommended design action:

To reduce **U(t)** and improve inferential usability, it is recommended to:

Increase $|\boldsymbol{\alpha}_i(t)|^2$ by visually, textually, and semantically reinforcing the "Save" affordance (e.g., through color, position, emphasis).

Reduce the perceptual interference of "Cancel" by limiting its visual salience or redesigning its symbolic representation.

Conduct user testing to calibrate the $|\boldsymbol{\alpha}_i(t)|^2$ eweights under real usage conditions.

4.3 Inferential Perceptual Scale

The value of **U(t)** is not merely a usability metric; it functions as an **epistemic indicator of inferential** stability in interactive systems. In scenarios where affordances simultaneously compete for attention, entropy reveals the degree of disorganization in perceptual inference, acting as a measure of the affordance coherence perceived by the agent. Intermediate values, such as the one obtained in the example **(U(t) = 0.61)**, lie within a transitional zone between functional clarity and operational ambiguity, requiring careful design intervention. Table 4 presents the interpretive scale based on the SIDyCP model:

TABLE 4: INFERENTIAL PERCEPTUAL SCALE

U(t) Value	Level of Ambiguity	Inferential Interpretation
0.0 – 0.2	None to minimal	Clear interface, dominant action is evident
0.2 – 0.5	Mild	Mild perceptual noise, but decision tends toward stability
0.5 – 0.8	Moderate	Perceptual ambiguity, potential for hesitation or error
0.8 – 1.0+	High	Critical ambiguity; potential collapse in decision-making

The Inferential Perceptual Scale classifies U(t) values into interpretive ranges, enabling the identification of inferential uncertainty levels present in affordance selection contexts. Each range delineates progressive levels of ambiguity and provides objective support for data-driven design decisions.

Source: Author.

The quantitative analysis of the usability equation thus provides a formal method for diagnosing and refining interfaces during the design phase. When combined with the qualitative analysis of the $|\alpha_i(t)|^2$ coefficients, entropy enables not only the identification of problems but also the anticipation of usability breakdowns in scenarios involving perceptual overload or unintentional design. As a scientific tool, the model supports a data-driven design practice capable of aligning affordances with the inferential flow of human or artificial agents, while respecting their limits of dynamic interpretation.

5 DYNAMIC EQUATION OF THE PERCEPTUAL FIELD (∂Ψ/∂t)

The Third Law of Affordance, Necessary Reconfiguration, is formalized by the **Dynamic Equation of the Perceptual Field (∂Ψ/∂t)**, which describes inferential instability between agent and environment based on temporal variation in the perceptual field.

The derivative **∂Ψ/∂t** represents the rate of structural change in the system's perceptual inferences. When this rate exceeds the threshold of the **Perceptual Coupling Constant (κ_p)**, the coupling collapses, demanding a reorganization of interaction protocols, operational memories, and contextual dispositions.

This rupture does not merely indicate error or adaptive failure; rather, it signifies the activation of a new inferential regime, in which the field **Ψ** must reorganize in response to environmental transformations that exceed its compensatory capacity.

5.1 General Structure of the Dynamic Equation of the Perceptual Field (∂Ψ/∂t)

The formalization of the **Dynamic Equation of the Perceptual Field (∂Ψ/∂t)** represents a significant advancement in the mathematical description of inferential instability mechanisms in adaptive perceptual systems. The following equation expresses, in differential terms, the fundamental structure of the SIDyCP model for the temporal variation of perceptual configuration:

$$\frac{\partial \Psi}{\partial t} = \sum_{i=1}^{n} \alpha^{\cdot}{}_{i}(t)^{2} \cdot \left\langle \text{perceiver}_{i} \right| \otimes \left| \text{environment}_{i} \right\rangle + \xi(t)$$

Source: Author.

The term **$\dot{\alpha}_i$(t)²** represents the accelerated rate of change in inferential activation of perceptual elements over time, while the operator ⟨**perceiver$_i$**|⊗|**environment$_i$**⟩ symbolizes the relational structure between the agent's interpretive patterns and the contextual affordances available in the environment. This relational encoding is interpreted as a tensor product that aggregates the degree of compatibility or dissonance between the agent's perceptual dispositions and external stimuli, a central concept in characterizing ruptures in perceptual coupling.

The term **ξ(t)** introduces a stochastic component into the model, representing cognitive noise, namely, unpredictable and nonlinear variations arising from the interaction between internal factors (such as emotional states or active memory) and uncertain environmental stimuli. This component is essential for realistically simulating perceptual systems in dynamic environments, particularly in contexts involving context-aware Artificial Intelligence and situated cognition. The equation models the perceptual field **Ψ** as a dynamic resultant of accelerated inferential activation (**$\dot{\alpha}^2$**), contextual compatibility **(⊗)**, and stochastic fluctuations **(ξ)**, forming an adaptive system that is sensitive to inferential coupling collapse. Table 5 presents the main symbols and concepts incorporated into the equation, clarifying both their theoretical interpretation and practical applicability in adaptive and interactive systems.

TABLE 5: DYNAMICS OF THE PERCEPTUAL FIELD: GLOSSARY OF SYMBOLS AND CONCEPTS

Symbol	Name	Meaning	Practical Application
$\partial\Psi/\partial t$	Temporal Derivative of the Field Ψ	Rate of change in the inferential structure over time	Real-time interface adaptation
ξ(t)	Cognitive Noise	Stochastic and unpredictable components of cognition and environment	Dynamic modeling with context-sensitive data (emotions, ambiguity, etc.)
$\dot{\alpha}_i(t)^2$	Rate of Inferential Activation Change	Temporal speed of change in the activation of perceptual elements, indicating system adaptability	Real-time monitoring of the intensity of inferential response
κp	Perceptual Coupling Constant	Minimum threshold of stability in the field Ψ. If $\partial\Psi/\partial t > \kappa p$, perceptual reconfiguration occurs	e.g., $\kappa p = 0.3$ → environmental changes above this threshold trigger new interpretation

The main symbols used in the formalization of the **Dynamics of the Perceptual Field ($\partial\Psi/\partial t$)** within the SIDyCP model. Each entry links a mathematical element to its conceptual meaning and its practical application in contexts involving Artificial Intelligence, cognition, or adaptive interaction. The symbols represent differential operations, stochastic variables, and parametric constants that compose the inferential modeling of the field Ψ, providing formal support for the **Third Law of Affordance (Necessary Reconfiguration).**

Source: Author.

The **Dynamic Equation of the Perceptual Field ($\partial\Psi/\partial t$)** thus establishes a formal model that articulates inferential acceleration, contextual compatibility, and stochastic noise as critical variables in the perceptual stability of adaptive systems. Its structure enables not only the description of **Ψ** field states but, more importantly, the diagnosis of transitional regimes in which the coupling between agent and environment becomes unstable, triggering Necessary Reconfiguration. By integrating differential operators with probabilistic and stochastic terms, the equation provides a robust framework for dynamic simulations, particularly relevant in scenarios of high contextual variability, such as interactive interfaces, environment-sensitive robotics, or situated AI systems.

5.2 Numerical Example N04: Inferential Collapse Due to Rapid Variation:

Context: An adaptive system with two agents interacting with a digital environment during a layout transition (e.g., a sudden visual update in an online banking system).

Situation: Two agents interact with a digital environment whose layout has been abruptly modified. The agents' perceptual systems must reorganize, as the inferential structure changes rapidly.

A. Inferential Parameters (acceleration rate):

$\dot{\alpha}_1(t) = 0.4$ (mild change)
$\dot{\alpha}_2(t) = 0.9$ (intense change)

B. Tensor Product perceiver ⊗ environment:

$\langle \text{perceiver}_1 \otimes \text{environment}_1 \rangle = 1$
$\langle \text{perceiver}_2 \otimes \text{environment}_2 \rangle = 0.8$

C. Cognitive Noise:
$\xi(t) = 0.05$
(slightly unstable emotional state)

D. Equation Application:

$\partial\Psi/\partial t = (0.4)^2 \cdot 1 + (0.9)^2 \cdot 0.8 + 0.05$
$\partial\Psi/\partial t = 0.16 \cdot 1 + 0.81 \cdot 0.8 + 0.05$
$\partial\Psi/\partial t = 0.16 + 0.648 + 0.05 = 0.858$

E. Comparison with the Coupling Constant:
Assuming $\kappa p = 0.3$

F. Interpretation:
$\partial\Psi/\partial t = 0.858 > \kappa_p = 0.3$
Result: The perceptual field collapses; inferential instability arises, requiring a perceptual reconfiguration of the system.

Agent 2 experiences greater impact due to the high inferential acceleration in processing the modified environment.

Practical Application:

Adaptive systems (e.g., context-aware AIs or interfaces) should monitor $\partial\Psi/\partial t$ in real time. When values approach κ_p, the system may: Offer contextual tutorials or guidance; Slow down the pace of layout changes; Visually adjust the interface to reduce noise $\xi(t)$.

The presented example demonstrates the predictive capacity of the **Dynamic Perceptual Field Equation ($\partial\Psi/\partial t$)** in identifying boundary conditions of inferential instability in real time. By quantifying abrupt variations in agents' perceptual activation, correlated with contextual compatibility and the presence of cognitive noise, the model enables the detection of critical transitions that challenge the continuity of agent–environment coupling. This operational sensitivity becomes essential in interactive systems, especially when embedded in dynamic environments subject to unforeseen changes.

By offering formal metrics to anticipate and mitigate inferential collapses, the proposed modeling not only translates the Third Law of Affordance into computational terms, but also inaugurates a data-driven design space, capable of proactively and contextually adapting both interfaces and cognitive strategies.

6. APPLICATION OF SIDyCP TO CASE STUDY 1: CLIENT REGISTRATION SCREEN

The inferential modeling proposed by SIDyCP was applied to the first case study (see Chapter 4), centered on the analysis of a client registration screen within an information system. Although the interface was functionally consistent with its declarative purpose, it revealed deep perceptual tensions over the course of 14 entries performed by a technical agent under real usage conditions. The objective of this application was to demonstrate the ability of SIDyCP to infer, quantify, and dynamically reconfigure critical perceptual patterns based on evaluative records already encoded in the FCIA-OT matrix. This study thus explores how the inference system operates in the presence of collapsed perceptual fields, offering epistemic support for grounded technical decision-making.

6.1 Calculation of the Perceptual Field (Ψ) for the Set of Records (Step 1):

For this analysis, Record 12 (Critical Point) presents the following pattern:

RQA (-5), AFF (-4), PRC (-5), AFV (-5), STSF (-5), EFT (-5), GVE (4), GSR (3), ATB (02, 03, 04, 11) = -4, -3, -5, -3 → total = -15, ACB (15) = -5

Result of Ψ for Record 12:

$$\Psi_{12} = (-5) + (-4) + (-5) + (-5) + (-5) + (-5) + 4 + 3 + (-15) + (-5) = -42$$

The value **Ψ = -42** reveals a severe perceptual collapse, resulting from the convergence of multiple critical dimensions. The modeled field exhibits simultaneous dysfunctions across the vectors of effectiveness, affectivity, attributes, object requirements, accessibility, and error severity, compromising both the integrity of the inferential process and the possibility of maintaining functional continuity in the technical action.

6.2 Calculation of Interaction Entropy U(t) for the Set of Records (Step 2):

For this analysis, the following critical records are considered 8, 10, 11, 12, 13, 14:

$\Psi8 = -7$, $\Psi10 = -12$, $\Psi11 = -2$, $\Psi12 = -42$ (previously calculated), $\Psi13 = -5$, $\Psi14 = 9$

Result of U(t) for the records:

$U(t) = 1/6\ (-7) + (-12) + (-2) + (-42) + (-5) + 9 \rightarrow -59\ /\ 6 = -9.83$

The value **U(t) = -9,83** indicates a state of **high interaction entropy**, revealing a significant loss of stability in the perceptual field. This index signals that the agent's inferential patterns are under critical strain, caused by recurring, unresolved, and persistent failures in the interface's interaction flow, directly impacting the continuity of action and operational coherence.

6.3 Dynamic Evaluation ∂Ψ/∂t and Inferential Collapse for the Set of Entries (Step 3):

Considering, for the analysis, the critical sequential entries 11 and 12: $\Psi_{11} = -2$, $\Psi_{12} = -42$ (already calculated), e 1 (consecutive entries).

Result of **∂Ψ/∂t** for the entries:

$\partial\Psi/\partial t = -42 - (-2)\ /\ 1 \rightarrow -40\ /\ 1 = -40$

The abrupt variation of **∂Ψ/∂t = -40** perceptual units within a single time interval exceeds any acceptable threshold of systemic stability **(κ_p)**, thus characterizing an immediate inferential collapse. This outcome reveals a sudden breakdown in the functional pattern of technical perception, where the system fails to sustain even the minimal affordative elements necessary to maintain the flow of action.

6.4 Final Considerations on the Application of SIDyCP

The application of SIDyCP to Case Study 1 aimed to inferentially model the perceptual patterns emerging from a technical agent's interaction with the client registration module of a corporate system. Based on the epistemic matrix structured by FCIA-OT, entries marked by strong perceptual dissonance were selected to enable a focused application of the model under high inferential risk conditions.

Among the 14 entries evaluated, Entry 12 was identified as a critical point, as it presented extreme and negative values across multiple dimensions essential to technical action. This entry corresponded to a query operation under high data volume, marked by pronounced latency and system response failures.

The **Perceptual Field Equation** (Ψ) yielded an aggregate value of **Ψ = -42**, indicating a severe perceptual collapse, with its vector distribution pointing to a structural breakdown in inference supports. Subsequently, the Interaction Entropy Equation (U(t)) resulted in **U(t) = -9.83**, revealing a marked entropic increase and a loss of inferential stability consistent with the obstruction of the technical action flow. Finally, the Dynamic **Equation of the Perceptual Field (∂Ψ/∂t)** demonstrated a temporal variation of **-40** perceptual units, surpassing the κp threshold and characterizing an instantaneous collapse in the interface's affordative structure.

These results converge to the conclusion that, under certain operational conditions, the analyzed system fails to sustain the inferential continuity required for qualified technical action, demanding deep interventions both in processing logic and in the perceptual organization of the interface.

Within this data analysis, SIDyCP proved capable not only of diagnosing zones of perceptual instability, but also of generating technically grounded inferences informed by solid epistemic foundations. In the case at hand, the model points to the need for reconfiguring query parameters, implementing informational alerts for critical response intervals, and reconstructing the affordative logic to ensure minimal stability in high-demand operational contexts.

Although the Inferential Perceptual Scale (Table 4) was used in simulated examples with normalized values between **0** and **1+**, the value **U(t) = -9.83** falls outside this range, representing an exceptional condition of total inferential collapse. In such a configuration, the issue is no longer affordance ambiguity, but rather a sharp entropic rupture, in which perceptual inference patterns become structurally unfeasible. This type of result reinforces the epistemic and diagnostic character of SIDyCP by revealing zones of critical dysfunction that transcend the operational stability ranges of system design.

The application of SIDyCP thus demonstrates its ability to quantify, model, and infer perceptual collapses with technical precision and epistemic consistency, providing valuable support for the continuous improvement of complex interactive systems.

7 DISCUSSION

The formulation of SIDyCP represents not merely a technical advancement within the FCIA-OT framework, but above all, an epistemic inflection in how technical perception is conceived, modeled, and operationalized in interactive systems. By reconfiguring perception as a dynamic, distributed, and historically situated inferential process, governed by auditable formal laws, SIDyCP transcends the traditional limits of stimulus-response–based or statistically inert computational modeling, consolidating itself as the genesis of a novel formal science: the Epistemic Mathematics of Technical

Interaction. This emerging discipline arises from SIDyCP's ability to articulate, within a unified theoretical-operational body, principles of vectorial modeling, differential equations, contextual inferential logic, and perceptual coupling coefficients, all organized around a verifiable technical ontology.

The introduction of the **Perceptual Field Equation (Ψ)** establishes a paradigm in which the non-local perceptual field becomes the formal basis for the emergence of affordances, dissolving the subject-object dichotomy by treating them as vectors of historical-technical coupling. Perception is no longer reduced to an attribute of the agent or a property of the environment; rather, it emerges from the situated inferential correlation between both, mediated by dynamic coefficients **(α_i)** and modulated by stochastic noise **(ξ)**.

This perspective is further developed through the **Interaction Entropy Equation (U(t))**, designed to measure the degree of organizability of a given perceptual coupling under nonlinear, context-sensitive conditions. In this model, entropy does not represent mere informational uncertainty, but rather the system's adaptive potential in response to variations in affordances.

It is precisely in the **Dynamic Equation of the Perceptual Field ($\partial\Psi/\partial t$)** that SIDyCP reaches its most decisive theoretical inflection. By modeling the temporal variation of the perceptual field as a function of inferential acceleration **($\dot{\alpha}_i^2$)**, relational codifications **($\otimes$)**, and dynamic noise **(ξ)**, this equation inaugurates an entirely new approach to the stability and rupture of perceptual systems. Surpassing the threshold defined as the **Perceptual Coupling Constant (κ_p)** not only triggers the Necessary Reconfiguration (Third Law of Affordance), but also establishes a formal mechanism of adaptive inferential collapse, structurally comparable to state collapse in quantum systems.

This modeling reveals that perception is not structurally stable, but metastable, oscillating between transient equilibrium configurations as the agent is exposed to topological, symbolic, or material variations in the environment. This approach breaks from the paradigm of passive computational perception and inaugurates an active, situated, and auditable theory of technical perception.

By articulating the domains of physics, mathematics, computing, and epistemology, SIDyCP demonstrates that it is possible to construct a computational theory of perception that is simultaneously formalizable, auditable, and adaptable, without resorting to abstractions disconnected from technical operationality. This situates SIDyCP at the core of Agent-Technology Interaction (ATI) as the epistemic and methodological platform of FCIA-OT, where affordances are treated not as static perceptual attributes, but as operational units of inferential modeling.

This foundational shift not only expands the technical horizon of agent-technology interaction, but also creates the conditions for the emergence of context-sensitive perceptual audits, self-adjusting adaptive interfaces, and new regimes of situational inference in multi-agent systems. The strength of SIDyCP lies not only in its formalism, but in its capacity to operate transversally across disciplines, technical domains, and heterogeneous perceptual regimes, establishing a new science of distributed technical perception.

8 CONCLUSION

The consolidation of SIDyCP as the formal infrastructure of FCIA-OT inaugurates a new techno-computational epistemology of perception. By shifting the traditional paradigm of perception as mere sensory reception toward a dynamic, inferential, and historically situated modeling, SIDyCP establishes the foundation for a new operational regime, one capable of integrating physical, relational, and contextual variables in the construction of interactive systems that are both auditable and sensitive to adaptive instability.

The integration of the Three Laws of Affordance into a cohesive mathematical framework, anchored in the equations of the Perceptual Field **(Ψ)**, Interaction Entropy **($U(t)$)**, and Inferential Dynamics **($\partial\Psi/\partial t$)**, represents a theoretical milestone in the field of Agent-Technology Interaction (ATI). Through these formulations, affordances are no longer treated as mere theoretical metaphors but become computable and reconfigurable entities, organized according to historically situated coefficients **(α_i)**, relational codings **($\otimes$)**, and noise variations **(ξ)** within distributed systems.

The model is capable of identifying, formalizing, and reconfiguring perceptual collapse points in mathematically consistent ways, thereby opening the path for epistemic auditing of perception in machines, hybrid agents, and context-sensitive computational architectures. The inferential rupture that emerges upon exceeding the κ_p threshold is not treated as a system failure, but rather as a necessary mechanism of adaptive reorganization, granting the model an unprecedented level of operational resilience.

Within the scope of FCIA-OT, SIDyCP operates as an epistemic module of technical perception, traversing multiple levels of inferential operation, from interactive interfaces and intelligent systems to multi-agent perceptual coupling networks. Consolidated within the ATI platform, SIDyCP not only formalizes perception as a distributed technical phenomenon but also establishes a new reference point for the computational science of perception, paving the way for future applications in fields such as neurointeraction, distributed cognition, explainable artificial intelligence, and advanced epistemic audits.

Thus, SIDyCP is not merely a system, it is a foundational resource for the construction of perceptual architectures governed by rigorous principles of contextual inference, dynamic stability, and adaptive reconfiguration, the very pillars sustaining the next generation of technocognitive interactive systems.

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CHAPTER 7

BACHELOR'S DEGREE IN USABILITY AND INTERACTION ENGINEERING (EUSIN)

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ABSTRACT — The absence of academic and professional regulation in the field of Agent-Technology Interaction (ATI) undermines both the legitimacy and reliability of technical analyses applied to complex and interactive constructs. This research proposes the development of an unprecedented undergraduate degree in Usability and Interaction Engineering, based on a progressive, standardized curriculum supported by a high-precision technical-scientific framework. The proposal articulates theory, practice, and institutional accountability, overcoming fragmented models that reduce the complexity of the field to operational modules or generic approaches. The core of the program lies in the training of the Usability and Interaction Engineer (EUSIN), a professional responsible for issuing standardized technical reports grounded in rigorous criteria of functional, cognitive, social, ethical, and technological analysis. The educational structure is anchored in the twelve integrated dimensions of the FCIA-OT and its associated systems and tools. The SPMI, SCDMIC, SGUI, and SCMI ensure analytical accuracy, depth, and reproducibility. The formalization of this field enables both academic and institutional recognition, redefining the standards of validation and quality control in interactive systems. The EUSIN engineer thus becomes the authoritative instance with legal and technical autonomy to intervene throughout the technological object's entire lifecycle. This proposal stands as a technical, scientific, and institutional model capable of transforming ATI practice, ensuring interaction safety, and establishing a new engineering paradigm centered on integrity, usability, interaction, and experience in the context of complex technological constructs.

KEYWORDS — Regulation; Undergraduate Program; Engineering; Usability; Interaction; ATI; Technical Reports.

1 INTRODUCTION

Agent-Technology Interaction (ATI) has emerged as a foundational technical-scientific domain for the design and evaluation of complex technological objects, involving multiple agents, human, artificial, or hybrid, within interactive and distributed computational ecosystems. This field surpasses the classical boundaries of Human-Computer Interaction (HCI), advancing a critical, modular, and systemic approach grounded in interactional quality engineering and the logic of meaningful experiences.

The absence of a specific undergraduate program, anchored in a consolidated epistemological structure and supported by recognized regulatory competence, has compromised the development of a professional body capable of operating, analyzing, and transforming interactive systems with theoretical depth and technical sophistication. The proposed Bachelor's Degree in Usability and Interaction Engineering responds to this educational void, drawing upon historical and scientific foundations that underscore the urgency of a profound, interdisciplinary, and technically rigorous curricular transformation.

A paradigmatic rupture in the university model was proposed by Jantsch (1972), who argued that, in order to confront the challenges of contemporary society, universities must move beyond multidisciplinary and pluridisciplinary approaches toward true interdisciplinarity. This requires coordination among adjacent hierarchical levels within systems of education and innovation. He suggests that education be conceived as an integrated innovation system, in which scientific disciplines are dynamically reorganized to meet social demands. He advocates for university education as a continuous process that integrates theoretical and practical learning.

Often reduced to graphical or organizational elements, the conceptual fragmentation of HCI is critically examined by Cockburn & Bell (1998), who point out that a common misconception is to treat HCI as merely concerning graphical or visual organization aspects, whereas it actually involves formal principles for designing underlying states and transitions. The integration of HCI into academic curricula enhances instructional quality and prepares students to critically evaluate computational systems and propose design improvements. The authors emphasize the importance of teaching HCI as a critical and analytical foundation rather than merely a technical skill.

The complexity of the training required for usability engineers was synthesized by Baecker (1989), who advocated for the formation of professionals with multidisciplinary competencies, emphasizing sensitive observation, insightful analysis, advanced conceptual thinking, and sophisticated theoretical construction.

He highlights creativity, imagination, and design excellence, combined with practical implementation skills. These professionals must master diverse disciplines such as perceptual psychology, cognitive science, software engineering, user interface management systems, graphic design, industrial design, organizational theory, and experimental design.

According to Rusu et al. (2015), the CS2013 report by ACM and IEEE formally acknowledges the relevance of HCI within Computer Science (CS) curricula, including it among the eighteen core knowledge areas. The growing number of companies specializing in usability consulting reflects an increasing professional appreciation of the field. HCI should be a fundamental component in the education of all CS professionals.

The undergraduate program proposed in this article integrates this conceptual legacy into a technically structured curricular framework, aimed at the scientific, methodological, and ethical training of usability and interaction engineers. The curricular construction, detailed in the following sections, defines the formative logic, epistemic axes, and applied competencies required to respond, with precision, to the increasing complexity of contemporary interactive systems..

2 CURRICULUM STRUCTURE: ENGINEERING OF USABILITY, INTERACTION, QUALITY, UTILITY, AND SYSTEMS LOGIC

The proposed curriculum integrates scientific foundations and applied competencies to support a high-level education in usability and interaction engineering. It is structured to merge theory and practice, bringing together knowledge from the exact sciences, the humanities, and technology, with a focus on the analysis, design, implementation, and critical evaluation of interactive products, services, and artifacts.

The program prepares professionals to operate in sectors of high technological responsibility and social impact. These engineers will be equipped to design and analyze innovative, ethically responsible, and sustainable solutions, grounded in rigorous evaluation of interfaces, interaction architectures, digital ecosystems, and complex constructs.

The curricular proposal is integrated into the structural core of the Integrated and Advanced Core Framework for the Analysis and Evaluation of Technological Objects (FCIA-OT), supported by an extensive scientific foundation and anchored in its Systemic Matrix of Integrated Vectorial Dimensions (MSDVI), composed of twelve high-complexity technical-analytical dimensions. This connection establishes the epistemic logic and modular organization of the program, offering a formative path aligned with the principles of Agent-Technology Interaction (ATI) and the contemporary demands of interaction engineering.

According to Ramsey & Atwood (1980), research on human factors in interactive systems remains fragmented, reflecting the dispersed nature of the relevant literature, which spans multiple disciplines. Existing studies on interface design guidelines are more advanced in physical aspects, such as characteristics of keyboards and display devices, but lack detailed guidance on broader cognitive and interactive issues.

Overcoming these gaps requires an educational structure that integrates multiple dimensions of interactional design. As noted by Shneiderman (1986), the maturity of a scientific discipline is reflected in the consensus surrounding its core issues. In the context of Human-Computer Interaction, he proposes seven primary topics that shape research and development in the field: interaction styles, input techniques, output organization, response time, error handling, individual differences, and explanatory and predictive theories.

The incorporation of these foundations guided the structuring of disciplinary cores and formative axes. The curriculum proposal takes into account the warning issued by Perlman (1990), who underscores the critical need for updated curricular materials in the teaching of user interface development. He suggests that such resources must encompass the full scope from interface design to evaluation.

Based on this directive, the program establishes continuous modules that cover the essential stages of the interactional process. This curricular alignment also responds to the observations of Faulkner & Culwin (2000), who criticize the excessive academic isolation of HCI education, often administered by departments lacking articulation with or recognition of software engineering. They draw a crucial distinction: usability engineering demands technical expertise in software development, thus qualifying the professional to design and implement systems, whereas usability evaluation constitutes a specific analytical activity, which alone does not confer the qualification of a usability engineer.

To overcome this disconnect, the foundations of software engineering, programming, and computational structures are introduced from the earliest stages of training. This principle aligns with the diagnosis by Chilana, Wobbrock, & Ko (2010), who note that although usability is gaining increasing recognition in the industrial sector, its application in complex domains still faces fundamental challenges. They identify strategies employed by professionals to address these challenges but emphasize that the full success of usability practice in such contexts may depend on long-term educational changes aimed at enhancing the training and capabilities of those involved.

This anticipation of systemic complexity guides the design of the program, which seeks to prepare professionals capable of acting critically within distributed and technologically advanced contexts. Marek & Wu (2021) highlight the significant gap between academic research and pedagogical practice, showing that the practical application of scientific findings in long-term curricula is frequently neglected. Technological affordances, the specific benefits or capacities of educational tools, must be carefully evaluated when designing learning experiences that maximize educational outcomes.

This principle guides the incorporation of integrated formative practices, including laboratories, active methodologies, and supervised internships, aligning the conceptual foundation with applied practice. The educational model is anchored in strategies that articulate theory, technique, and real-world application.

The curriculum's design required methodological rigor and a forward-looking perspective. The program spans from foundational topics in computer science and software engineering to advanced fields such as usability engineering, interaction design, and systemic quality evaluation. Its modular structure ensures a balance between conceptual formation and technical application. The overall curriculum meets current demands in interaction engineering, contributing to the consolidation of a technically grounded and socially responsible science. Tables 1 through 4 present the technical composition of the curricular matrix, the mandatory internships, the formative structure, and the definition of the professional profile of the Usability and Interaction Engineer, according to the principles of Agent-Technology Interaction (ATI).

This curricular structure (Table 1), organized over ten semesters, follows a modular, progressive, and articulated educational logic that ensures the development of high-complexity interactional and analytical competencies.

The undergraduate program was designed based on the advanced matrix of twelve technical-analytical dimensions from the FCIA-OT (see Chapters 1, 2, 3, 4, and 5), whose foundation is anchored in specialized literature from the fields of usability and interaction, systems engineering, and technological evaluation. This epistemic and forward-oriented foundation enabled the formulation of a training model aligned with the ATI paradigm and the emerging demands of interaction engineering. The degree prepares professionals with systemic mastery of the human, technical, cognitive, social, semiotic, and computational factors that govern the life cycles of interactive technological objects—from conception to final disposition. Rather than producing specialists in hardware or generic programming, the program trains usability and interaction engineers capable of evaluating, designing, and critically intervening in complex systems, with a focus on agent experience within hybrid, responsive, and distributed computational ecosystems.

TABLE 1: CURRICULUM STRUCTURE – ENGINEERING OF USABILITY, INTERACTION, QUALITY, UTILITY, AND SYSTEMS LOGIC

Term	#	Course Title	Description / Subtopics	C./H.
1st	**1**	Basic Mathematics I	Algebra, geometry, and functions. Foundation for modeling and mathematical analysis in ATI.	60
	2	Introduction to Computer Engineering	Fundamentals of hardware, software, and computational logic.	60
	3	Cultural and Social Anthropology	Cultural and social impacts on technological design and interaction.	60
	4	Ethnography	Application of ethnographic methods to the study of human behavior in digital environments. Includes analysis of interactions in social networks, interactive systems, and applications, with emphasis on direct observation and qualitative study of how agents use and adapt to systems. Focus on understanding cultural, social, and behavioral practices in technological contexts.	60
	5	Cognitive Psychology	Focus on individual mental processes that affect interaction with systems, such as perception, attention, memory, and decision-making. Application of cognitive theories to interface design for intuitive and efficient interaction.	60
	6	Sociology of Technology and Society	Analysis of the relationship between technology, society, and behavior	60
2nd	**7**	Basic Mathematics II	Differential and integral calculus applied to algorithm development.	60
	8	Algorithms and Data Structures	Lists, trees, graphs, and algorithms applied to interfaces.	60
	9	Design Fundamentals	Graphic design principles applied to interface design.	60
	10	Ergonomics and Human Factors	Physical and psychological aspects of agent-technology interaction.	60
	11	Communication Theories	Semiotics, semiosis, and symbolism in interactive system design.	60
	12	Statistics	Fundamentals of descriptive and inferential statistics applied to usability and interaction engineering. Includes quantitative and qualitative data analysis, hypothesis testing, probability distributions, and regression methods. Emphasis on statistical tools to evaluate and optimize interaction experiences.	60
3rd	**13**	Programming Logic	Logical structures and algorithms oriented toward ATI problem-solving.	80
	14	Representation and Modeling Systems	Cognitive and semiotic modeling in system design.	80
	15	Cognitive Engineering	Introduction to cognitive models of interaction, focusing on human cognitive capacities applied to system design. Covers semantic and articulatory distances.	80

	16	Human-Centered Design (HCD)	Theories and methodologies of agent-centered design. Includes accessibility principles, heuristics, and affordance concepts to ensure interfaces are intuitive and accessible to different agent profiles.	80
	17	Usability and System Evaluation	Tools and metrics for usability evaluation, with emphasis on interaction error severity. Covers Personas and error analysis tailored to agent profiles, identifying how failures impact agent experience and proposing mitigation strategies. Defines criteria for evaluating system effectiveness and agent satisfaction.	80
4th	**18**	Computer Networks	Fundamentals of networks and their impact on interaction within distributed systems.	80
	19	Interaction Design	Practical tools for interface prototyping and implementation. Emphasis on the use of personas to guide design and adapt interaction flows to specific agent needs.	80
	20	Experimental Psychology	Experimental methodologies to assess agent perceptions, reactions, and interactions with technological systems. Analysis of controlled experiment data to optimize agent experience.	80
	21	Graphic Interface and Visual Interaction	Analysis and application of visual principles in interactive design.	80
	22	Semiotic Engineering	Integration of signs and symbols for effective communication in systems.	80
5th	**23**	Operating Systems and Computer Architecture	Integration of hardware and software in interface development.	80
	24	Applied Social and Cognitive Psychology	Exploration of how cognitive processes interact with social and cultural factors in the use of interactive systems. Focus on the impact of social interactions on system design and collective experience optimization in digital environments.	80
	25	Accessibility and Digital Inclusion	Study of norms and guidelines to promote digital accessibility. Analysis of universal design and inclusive practices to ensure usability for diverse users, including persons with disabilities.	80
	26	QRSUER Technology	Design of technological systems integrating quality, sustainability, and social responsibility, focusing on product life cycles. Emphasizes efficient and ethical solutions, resource optimization, environmental preservation, and life quality improvement.	80
	27	Assistive Technologies	Exploration of inclusive technological solutions to promote digital accessibility. Focus on developing tools for agents with physical or cognitive impairments.	80

6th	**28**	Cognitive Engineering II	Practical and complex applications of cognitive models, such as technological symbiosis and co-evolution between agents and systems. Explores strategies for adaptive and responsive interactions.	80
	29	Task Design and Workflow Modeling	Workflow modeling for interaction optimization.	80
	30	Usability Standards and Legislation	Study of standards and compliance (ISO, WCAG, ergonomics).	80
	31	Social and Technological Interaction	Social impacts of emerging technologies in digital interaction.	80
	32	Usability Engineering	Study of usability principles in interactive systems, with emphasis on risk level analysis related to interaction. Evaluates how system errors or failures affect usability and safety, and how to design interfaces that minimize such risks, ensuring effectiveness and agent trust.	80
7th	**33**	Advanced Algorithms for Agent Interfaces	Optimization of algorithms to enhance agent experience.	80
	34	Prototyping and Usability Testing	Development of prototypes and execution of usability tests with real agents. Methods for collecting feedback, identifying problems, and refining interfaces to maximize agent experience.	80
	35	Agent Affectivity and Satisfaction	Study of how emotions influence interaction with technological systems, impacting perception, acceptance, and agent satisfaction. Explores methods to assess and optimize experience based on emotional and affective factors.	80
	36	Research in Interaction Design	Qualitative and quantitative research methods in design.	80
	37	Applied Semiotics in Interaction	Use of semiotic theories to create intuitive interfaces.	80
	38	ATI for IoT and Ubiquitous Computing	Interface design for IoT and ubiquitous computing environments, focusing on intelligent interaction in connected ecosystems and interactive devices.	80
8th	**39**	Augmented and Virtual Reality	Interface design for immersive environments.	80
	40	Multimodal Interface Technologies	Design for multi-channel interaction (voice, gesture, touch).	80
	41	Software Engineering and ATI	Integration of software engineering principles with specific usability and interaction requirements. Covers development lifecycle, agile methodologies, prototyping and testing techniques, and practices to ensure that technological solutions meet usability, accessibility, and agent experience demands.	80

	42	Interactive Systems and Cognitive Feedback	Development of intuitive and efficient feedback strategies in interactive systems, aimed at enhancing agent understanding and responsiveness. Covers cognitive techniques to optimize interaction and information perception.	80
	43	Cybernetics and Adaptive Feedback	Application of cybernetics to adaptive feedback systems in interfaces, focusing on responsiveness and real-time learning.	80
	44	UEM Methods for Usability	Quantitative and qualitative tools and techniques for system evaluation. Scoring scales are used to measure variables such as satisfaction and efficiency, providing quantifiable data to compare interfaces and identify improvements.	80
9th	**45**	Artificial Intelligence and Adaptive Interfaces	Application of Artificial Intelligence for dynamic interface customization and personalization, aiming to optimize agent experience based on individual preferences and contexts.	80
	46	Usability and Design Project Management	Agile methodologies and agent-centered management practices.	80
	47	Case Study: ATI Projects in Industry	Practical analysis and application of ATI in real-world contexts.	80
	48	Digital Service Design	Creation and integration of multichannel, interactive services.	80
10th	**49**	Ethics and Social Impacts of Technolog	Ethical and social reflections on the impact of technology.	80
	50	Ethical and Responsible Interaction with AI	Exploration of ethical principles in the development of AI interfaces, addressing transparency, fairness, and regulatory compliance.	80
	51	Usability and Interaction Design Consulting	Preparation for technical consulting in usability and ATI.	80
	52	Final Graduation Project (Capstone)	Development of a practical project focused on usability and interaction.	120

Source: Author.

Each course was designed to build, integrate, and expand the technical, scientific, and ethical knowledge required for usability engineering. The modules encompass everything from the formal foundations of mathematics, computing, and human sciences to the advanced cores of cognitive engineering, interactional risk assessment, agent-centered design, prototyping, technological ethics, and applied artificial intelligence. The academic journey is guided by criteria of utility, systemic quality, and technical responsibility, encompassing physical, symbolic, perceptual, affective, and social aspects of the user experience.

The structure is segmented by academic term and indicates, for each course, its technical description, key subtopics, and credit hours. This organization makes it possible to visualize the formative progression and the logical sequencing between the conceptual and practical cores of the curriculum. The matrix operates as a dense and coherent curricular architecture, aimed at preparing interaction engineers with high technical, epistemic, and decision-making competence.

Table 2 presents the structure of the mandatory practical internships that integrate the curriculum of the Bachelor's Degree in Usability, Interaction, Quality, Utility, and Systems Logic Engineering. These components represent advanced formative phases, designed to consolidate the articulation between theory, practice, and critical analysis of interaction in real and controlled empirical contexts. The experiences are developed in both laboratory and field environments, with scientific methodologies applied to the systemic evaluation of interactive products, services, and artifacts.

The internships function as technical-investigative immersion modules, in which the student applies the multidimensional knowledge acquired throughout the program, promoting the integration of principles from usability engineering, applied cognition, interaction design, and both qualitative and quantitative analysis of agent experience. They are organized according to increasing levels of complexity, varying by the nature of the testing environment and the degree of experimental control involved.

TABLE 2 – MANDATORY PRACTICAL INTERNSHIPS

#	Title	Description / Specification	Hours
53	**Internship in Laboratory Testing (Controlled Environment)**	Usability evaluation, controlled testing, and data analysis. (Laboratory Level).	100
54	**Internship in Field Testing Laboratory**	Real-world usability assessment and research with actual agents. (Field Level).	100
55	**Internship in Usability Analysis of Products or Services**	Usability testing projects, data analysis, and agent feedback. (Laboratory or Field Level).	100

Source: Author.

The first internship focuses on usability analysis under controlled laboratory conditions, employing rigorous metrics and replicable experimental protocols. The second module expands the application to situational field contexts, where contextual variables and real usage dynamics are observed and analyzed from a scientific perspective. The third internship allows students to engage in applied projects, either in controlled or real environments, centered on experience engineering, based on data collection, agent feedback, and continuous evaluation processes.

The practical internships are structured as essential formative fields for consolidating the technical, ethical, and analytical competencies of the interaction engineer. They function as privileged spaces for observation, diagnosis, and proposal of improvements in interactive systems. Their mandatory nature ensures the articulation between academic education and the technical-social demands of contemporary professional practice, aligning the formative path with the epistemic principles of Agent-Technology Interaction (ATI).

The complete training of the Usability and Interaction Engineer spans ten academic terms, totaling 4,260 hours (Table 3). The curriculum includes 51 theoretical courses, organized in a modular and progressive structure, with 3,840 hours dedicated to conceptual, technical, and scientific training.

TABLE 3 – EDUCATIONAL STRUCTURE AND TOTAL WORKLOAD

Category	Description / Specification	Hours
Program Duration	Academic Terms – 10 semesters	—
Theoretical Courses	51 Courses	**3.840hs**
Final Project	Undergraduate Thesis (Capstone Project)	**120hs**
Internships	3 Modules × 100 hours each	**300hs**
Total Workload	—	**4.260hs**
Modality:	(Yes) On-site (No) Live (No) Distance Learning (EAD)	

Source: Author.

Complementing this structure are the three mandatory practical internships, totaling 300 hours of application in laboratory and field environments, alongside the Undergraduate Final Project (Capstone), which dedicates 120 hours to the development of a technical-scientific project. The program modality is on-site, ensuring intensive practical experience and rigorous formative supervision.

Graduates earn the degree of Bachelor in Usability, Interaction, Quality, Utility, and Systems Logic Engineering (Table 4), formally recognized with the professional title of Usability and Interaction Engineer (EUSIN). This classification establishes a new benchmark in contemporary engineering, designed to address the technical and systemic complexity inherent to interaction processes.

TABELA 4: PERFIL PROFISSIONAL

Category	Description
Qualification	Bachelor's Degree in Usability, Interaction, Quality, Utility, and Systems Logic Engineering.
Professional Title	Usability and Interaction Engineer (EUSIN).
Professional Competence	Ability to operate technically and strategically throughout all stages of the interactive systems lifecycle. Encompasses detailed analysis of technical, human, and social factors impacting usability and interaction. Includes defining requirements, solutions, and methodologies to optimize the agent's experience, leading teams in design and implementation processes, and issuing technical reports based on rigorous evaluation criteria such as usability, accessibility, safety, regulatory compliance, and systemic efficacy.
Meeting Participation	Active collaboration in project definition, prototype development, beta version analysis, and parameter establishment for production. Engages in decision-making processes related to testing, ongoing adjustments, and improvements, ensuring compliance with technical standards of usability, interaction, functionality, and quality.
Functional Autonomy	Full performance in laboratory and field analyses, including the issuance of conclusive technical reports.
Professional Practice	Professional registration with the Engineering Council.

Source: Author.

Professional competence encompasses active engagement throughout all phases of the interactive systems lifecycle, from conception to post-use evaluation, with mastery over the analysis of technical, human, social, and ethical factors directly impacting the agents' experience. The professional holds authority to define requirements, propose evidence-based solutions, and guide design methodologies, in addition to issuing normative technical reports grounded in high-precision scientific criteria.

With functional autonomy in laboratory and operational settings, the EUSIN engineer participates in all decision-making stages of projects, from conceptual definition to technical supervision of prototypes and final versions. This professional practice is regulated by registration with the Engineering Council, ensuring legal, technical, and professional support for full exercise of the role.

The consolidation of this curricular structure marks a decisive advancement in formalizing Usability and Interaction Engineering as an autonomous technical-scientific field, strategically aligned with the Agent-Technology Interaction logic. The modular composition and rigorous articulation among scientific foundations, laboratory practices, international standards, and applied competencies ensure the training of professionals capable of addressing the technical, ethical, and social challenges of contemporary interactive systems. This educational trajectory not only addresses historical gaps in HCI teaching but inaugurates an academic and professional paradigm guided by excellence, social and environmental responsibility, and systemic transformation.

3 STRUCTURAL FOUNDATIONS FOR USABILITY AND INTERACTION ENGINEERING: TECHNICAL REPORTS

The consolidation of Usability and Interaction Engineering as an autonomous technical-scientific field demands a systemic and professional framework that surpasses fragmented, episodic curricular proposals lacking normative grounding. This proposition establishes a paradigmatic milestone by integrating academic training, regulated professional practice, and formalized technical-analytical instruments, such as structured technical reports, which function as core elements of the usability and interaction engineer's evaluative practice.

As Forlizzi & Battarbee (2004) emphasize, understanding interactive experiences is inherently interdisciplinary, requiring a combination of expertise in psychology, design, and engineering to foster meaningful interactions. Such integration demands from the professional a comprehensive education and critical capacity to analyze and assess constructs transversally and at multiple levels, surpassing the subjective perception of the average user.

Reinforcing this characteristic and scope of HCI, Lin, Qin, & Long (2016) assert that HCI is an interdisciplinary domain encompassing computer science, behavioral sciences, industrial design, media studies, among others. This complexity renders obsolete the notion of specialists trained in isolated modules or operational trainings disconnected from the logic of design, testing, standardization, and validation. Interaction engineering therefore requires a new technical-scientific profile: the Usability and Interaction Engineer, endowed with autonomy to issue comprehensive technical reports based on rigorous criteria and a specialized framework.

The proposal articulated here is directly linked to the Integrated and Advanced Core Framework for Analysis and Evaluation of Technological Objects (FCIA-OT), whose epistemological foundation and twelve-dimensional technical-analytical matrix enable the construction of complete technical reports. These documents, produced by qualified professionals, record, in standardized format, the analyses and assessments of technological constructs, from raw material extraction to final disposal. The depth and technical sophistication of this process exceed usual practices of review or technical opinion, integrating methodological rigor, scientific basis, and advanced measurement.

Theory and practice must be synchronized in this training. Lin, Qiu, & Lao (2019) highlight that the interdisciplinarity of HCI combines concepts from psychology, computer science, ergonomics, cognitive science, and industrial design. Education in the field should integrate theory and practice, aligning professional training with market demands. They emphasize incorporating ethical and legal values in intelligent systems to ensure they are nondiscriminatory and respect privacy. They analyze the evolution of educational practices, noting that while traditional methods focus on design with well-defined problems, contemporary approaches prioritize exploratory projects where both problem and solution are uncertain, reflecting their complexity.

The use of technical reports within the ATI logic, mediated by systems such as FCIA-OT, enables precisely the analysis under nondeterministic conditions, generating robust data even in complex, ambiguous, or uncertain contexts. These reports are issued exclusively by the Usability and Interaction Engineer and function as an advanced technical-analytical artifact. At the moment of evaluation, by activating the "Technical Report" feature, the professional formalizes that the analysis is normative, comprehensive, and endowed with institutional validity. Additionally, by selecting the "Assisted" function, the report identifies that the evaluation is conducted by a responsible specialist, with technical-analytical expertise and autonomy to issue a substantiated opinion.

This entire process is systematized through the technical-scientific resources integrated into FCIA-OT: the Integrated Modular Multidimensional Scoring System (SPMI), which organizes and measures analyses according to multiple technical-functional criteria; the Integrated Modular Color Classification and Definition System (SCDMIC), which can be coupled with other tools to present data in chromatic scales facilitating visualization of criticality, severity, or efficacy; the Global Usability and Interaction Score (SGUI), which maps the frequency of occurrence of components in the overall object evaluation; and the Integrated Modular Critical Score (SCMI), which identifies points of greatest impact or vulnerability in the usability and interaction experience. These systems operate integrally with the modular logic of the FCIA-OT matrix, allowing evaluations with technical consistency and interpretative precision.

This systemic investigation is addressed by Sadiku et al. (2021), who describe HCI as a multidisciplinary and expanding field, originally termed "man-machine studies", investigating dynamics between humans and computational systems from technical and social perspectives. They emphasize its dual focus: analyzing how users conceive and interact with technologies, including sociotechnical impacts, and optimizing interface usability through applied research. HCI establishes itself at the intersection of social sciences (human side) and computer science (technological side), with significant advances throughout its trajectory.

The structuring of technical reports within interaction engineering, when systematized through the FCIA-OT, fully addresses both dimensions. It enables a comprehensive understanding of the system as a sociotechnical ecosystem, in which variables are evaluated in depth, grounded in scientific evidence, normative rigor, and measurable impact.

The technical reports formalized by specialized engineers and issued based on the FCIA-OT criteria establish a new standard for the evaluation of interactive systems. More than a degree proposal, this represents a technical-scientific paradigm for professional practice in ATI. It constitutes a structural milestone capable of transforming both professional practice and education, and of consolidating interaction engineering as a technically, scientifically, and institutionally recognized field.

4 TECHNICAL REPORTS IN USABILITY AND INTERACTION ENGINEERING: CLASSIFICATION AND PRACTICAL APPLICATIONS

Based on the previously established foundations, the technical reports issued by the Usability and Interaction Engineer not only formalize advanced evaluations but also unfold into specific categories, each targeting the analysis of technical, functional, cognitive, social, and ethical dimensions of technological objects. Below are some of the main types of technical reports structured according to the criteria and methodologies of the FCIA-OT, ensuring validity, accuracy, and depth in the assessments.

Technical reports play a central role in the practice of professionals specialized in ATI. These documents are prepared with the purpose of providing detailed and objective analyses of the various aspects related to design, functionality, and agent experience within interactive systems. They are essential for optimizing, securing, and improving the accessibility of technological products and services. Each technical report constitutes an in-depth evaluation of specific elements, grounded in both quantitative and qualitative methods, which allow for precise measurement of object performance, identification of critical points, and assurance of compliance with agent needs and the technical-scientific standards of the field.

These documents go beyond validating superficial design features and serve as strategic instruments for decision-making, supporting corrective actions, structural improvements, and regulatory validations. In a scenario where technologies play central roles in social, economic, and political spheres, technical reports function as vectors of responsibility, quality, and ethics in development. Through them, the usability engineer fulfills their role with methodological rigor and technical commitment, supported by objective data and specialized methodologies, with a focus on creating accessible, secure, effective, and sustainable systems. Among the main technical reports structured under the FCIA-OT, the following stand out:

Affordance Adequacy Level Technical Report: Assesses the extent to which the elements of the construct intuitively communicate the possible actions to the agent. Measures the perceptual quality of affordances and their alignment with expected mental models, identifying whether there is ambiguity or cognitive overload in interpreting the object's functions.

Error Severity Level Technical Report: Classifies errors observed during usability and interaction according to their severity (critical, severe, moderate, minor). Examines their causes, frequency, and impact on the user experience, providing strategic recommendations for mitigation, prevention, and reengineering of the interface or functionality.

Risk Level Technical Report: Analyzes risks associated with the use of the technological object, covering aspects such as data protection, privacy, security failures, and adverse consequences to the agent's physical, digital, or emotional integrity. Based on parameters of reliability and regulatory compliance.

Accessibility Level Technical Report: Examines the system's compatibility with national and international accessibility guidelines, identifying physical, sensory, cognitive, or technological barriers. Proposes solutions to ensure that agents with different limitations can fully interact with the object.

QRSUER Technology Level Technical Report: Provides a holistic assessment across the dimensions of Quality, Social Responsibility, Sustainability, Usefulness, Ethics, Reason, and Relevance. Investigates whether the technology fulfills its social function without generating negative externalities, aligning with principles of justice, inclusion, and collective well-being.

Standards, Legislation, and Regulatory Compliance Level Technical Report: Verifies whether the object complies with current legal, regulatory, and normative requirements, both national and international. Examines adherence to technical standards, safety protocols, interoperability rules, accessibility norms, and usability guidelines.

Ergonomics, Articulatory Distance (AD), and Semantic Distance (SD) Level Technical Report: Analyzes whether the interaction is physically comfortable and cognitively efficient. Articulatory Distance measures the physical effort required to operate the system; Semantic Distance evaluates the alignment between the agent's intention and the system's response, minimizing friction and functional ambiguity.

Usability, Usefulness, and Durability Level Technical Report: Measures the agent's effectiveness, efficiency, and satisfaction when interacting with the system (usability), the system's ability to solve real-world problems (usefulness), and the technological object's functional longevity (durability). Identifies recurring operational failures and suggests improvements based on usage cycles.

The classification of these technical reports, as described, reflects the maturity and complexity of the Usability and Interaction Engineer's role. These instruments, integrated within the FCIA-OT framework, not only establish a new standard for technological assessment but also consolidate Interaction Engineering as a profession of high technical, normative, and social responsibility. The following section discusses how these foundations articulate with the academic, professional, and institutional landscape of the ATI field.

5 DISCUSSION

The Agent-Technology Interaction (ATI) field, by lacking a formally regulated academic structure, undermines not only the legitimacy of professional practice but also compromises the technical quality of analyses, decisions, and interventions in interactive systems. The current landscape remains anchored in fragmented approaches that reduce the complexity of HCI to isolated courses, extension modules, or generalist perspectives that disregard the technical and scientific requirements necessary for the systematic analysis of technological constructs. There is no functional standardization, nor institutional support for the issuance of analytical reports that demand rigor, autonomy, and technical accountability.

This disconnect between the sophistication of emerging technologies and the training of those who evaluate them creates a critical gap: complex and advanced constructs continue to be designed, tested, and validated by agents who are not formally recognized, without structured technical reports, without multidimensional criteria, and without professional responsibility for the decisions made. HCI practice remains permeated by empiricism, impressionistic judgments, and lack of methodological systematization, which compromises the reliability of results and exposes agents to functional, cognitive, ethical, and social risks.

In contrast to this scenario of imprecision and institutional fragility, the present proposal offers an unprecedented and regulated solution for ATI practice, centered on the academic and professional formalization of the Usability and Interaction Engineer (EUSIN). This systematic training breaks with the fragmented models that have historically characterized the field and establishes, for the first time, an integrated and progressive curricular architecture grounded in normative criteria. The consolidation of a ten-semester degree program, composed of foundational, technical, and emerging disciplines, combined with the issuance of structured technical reports, represents a qualitative leap in the preparation of specialists who not only understand interactive systems but evaluate them with authority, methodological rigor, and professional responsibility.

The distinguishing feature of this proposal lies in the incorporation of an advanced framework, the FCIA-OT, which provides both technical and methodological support for the entire analytical process, from raw material extraction to the final disposal of the technological object. Through its dedicated resources, such as the SPMI, SCDMIC, SGUI, SCMI, and SIDyCP, the evaluation process moves beyond subjectivity or partiality and is redefined by a logic of technical precision, reproducibility, and professional legitimacy.

In this context, the EUSIN engineer becomes the sole professional authority empowered to issue technical-scientific reports with institutional validity and regulated accountability. The activation of the “Technical Report” and “Assisted” resources within the FCIA-OT system formalizes this evaluative process as a professional act of analysis, governed by strict normative criteria. Each technical report issued under these conditions constitutes not merely a technical document, but a decision-making instance that underpins the logic of system design, validation, and control.

This structure directly challenges the lack of standardization that defines current educational models in HCI, where specialists lack legal standing to issue reports or exercise functional autonomy. While international proposals recognize the field’s complexity and attempt to integrate technical and social aspects, they continue to operate under a logic of informal interdisciplinarity, absent of professional regulation. The model presented herein addresses this impasse through a comprehensive solution, supported by an original technical-scientific matrix and grounded in solid, measurable, and replicable assessment parameters.

The impact of this structure extends far beyond the academic domain. By formally defining the profession, its instruments, and its operational parameters, a new technical, scientific, and institutional paradigm is established for ATI practice. This systematization ensures that critical decisions regarding interactive products, systems, and services are no longer made by agents without technical endorsement or by unregulated entities. Instead, these decisions are transferred to a framework that unites formal training, structured reporting, and professional responsibility within a single operative chain.

The proposal, therefore, not only addresses a significant gap but redefines the logic of validation, analysis, and control across the entire life cycle of technological objects, with direct implications for the safety, functionality, usability, and efficacy of interactive experiences.

6 CONCLUSION

This study outlined an unprecedented framework for the formal education and regulation of Usability and Interaction Engineering (EUSIN), establishing a structured and systemic path for the professional practice of the Usability and Interaction Engineer. The progressive curricular construction, combined with the formalization of technical reports as decision-making instruments, reinforces the legitimacy and autonomy of this profession within a multidisciplinary, complex, and rapidly evolving field.

By integrating technical, scientific, and normative foundations, this proposal addresses the current demand for rigor and accountability, which remain insufficient in fragmented models. The implementation of the FCIA-OT framework and its analytical systems enhances professional practice, enabling robust, precise, and replicable evaluations that keep pace with the complexity of contemporary technological constructs.

This research contributes to the consolidation of Usability and Interaction Engineering as both an academic discipline and a regulated profession, with direct impact on the quality, safety, and efficiency of interactive constructs. It is acknowledged, however, that institutional adoption and ongoing methodological refinement represent significant challenges for the sustainable development of the field.

Accordingly, a fertile ground is opened for future research, which may expand assessment methodologies, incorporate new technological dimensions, and further deepen the articulation between theory, practice, and professional standardization. The consolidation of this proposal holds the potential to transform not only academic training, but also the culture of development and evaluation in ATI, generating significant progress for both society and the technological market.

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CHAPTER 8

FCIA-OT ARCHITECTURE: ADVANCED OPERATIONAL MANAGEMENT AND MULTIDIMENSIONAL CONTROL OF USABILITY AND INTERACTION

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ABSTRACT — This article systematizes the final stage of the FCIA-OT methodological cycle, consolidating its analytical-operational structure for the evaluation and enhancement of technological objects. Section 3 addresses the second axis of the framework's flowchart, focused on the intake, in-depth analysis, and systematic application of targeted solutions to the components that constitute the evaluated construct. This stage integrates technical standards, hardware and software engineering, modular structuring, and compliance procedures, enabling interventions guided by criteria of effectiveness, efficiency, sustainability, and functional coherence. Section 4 presents the global architecture of the FCIA-OT system as a scientific platform for the continuous management of usability and interaction. Structured as a central unit of integration and control, the framework performs diagnostic, explanatory, and prognostic functions, with the ability to monitor, classify, prioritize, standardize, and reorient technological objects based on multiscalar technical-scientific parameters. Its twelve-dimension integrated matrix operates synergistically with computational subsystems, scoring mechanisms, color scales, global and critical indexes, persona-based analysis, and visual feedback tools. The proposal advances traditional paradigms of technological assessment by incorporating analytical granularity, methodological reproducibility, computational scalability, and transdisciplinary applicability across multiple domains. FCIA-OT establishes itself as both a decision-support system and a platform for scientific-technical innovation, enabling not only the identification of failures but also the structured proposition of corrective solutions and the intelligent reconfiguration of the Agent–Technology Interaction (ATI). Its model departs from conventional descriptive logics, setting a new standard of precision, reliability, and functional accountability in technological evaluation.

KEYWORDS — FCIA-OT; Technological Assessment; Continuous Management; Diagnosis; Usability; Interaction; Transdisciplinarity.

1 INTRODUCTION

The increasing complexity of technological objects and the intensification of their presence in social, productive, and institutional environments have demanded evaluation methodologies that are increasingly robust, integrated, and capable of responding to the structural, functional, and contextual diversity of interactive systems. However, most conventional approaches remain confined to descriptive methods, loosely articulated, with low diagnostic capacity and limited ability to guide corrective or evolutionary interventions.

In response to this analytical scenario, FCIA-OT emerges as a scientific-technical proposal that breaks with heuristic traditions and significantly expands the horizons of technological assessment. Developed from rigorous foundations, the framework establishes an advanced system for the classification, diagnosis, and continuous management of technological objects, structured around twelve operational dimensions and multiple analytical subsystems.

This article presents the architecture of the FCIA-OT, consolidating its function across two critical levels of the evaluative process. The first, of an analytical-operational nature, is responsible for receiving, processing, and applying targeted solutions to the demands identified within the construct, promoting structured improvements based on normative and functional criteria. The second level, systemic in nature, organizes the continuous management of usability and interaction through an integrated matrix and scoring systems, including global and critical indexes, persona-based analysis, and visual feedback mechanisms.

By articulating multiple scientific-technical variables, FCIA-OT positions itself as an innovative and highly reliable methodology, with the ability to operate across different domains and contexts, enabling high-precision evaluation with traceability and functional accountability. It thus consolidates itself as an approach that redefines the role of usability engineering and technological assessment by introducing a new paradigm of control, intervention, and guided evolution of interactive systems.

Building on this consolidated structure, the article advances into the final stage of the FCIA-OT methodological cycle, addressing its systemic foundations and the integrated operation of its analytical-operational modules. These components sustain the framework's functioning as a logical platform for the intake, analysis, intervention, and continuous management of interaction and usability, central elements for repositioning technological evaluation at an advanced scientific level.

2 FCIA-OT ARCHITECTURE: SYSTEMIC FOUNDATIONS

FCIA-OT is structured as a high-complexity methodological system for technological assessment, grounded in normative guidelines, technical constructs of usability and interaction engineering, principles of modularity, and multiscalar integration logics. Its construction encompasses the full spectrum from technical eligibility criteria to advanced systems of scoring, visualization, weighting, and decision support.

By consolidating this architecture across multiple operational, logical, functional, diagnostic, and strategic layers, the FCIA-OT positions itself as a systemic structure that not only evaluates but also interacts with the life cycle of the technologies under analysis. Its Systemic Matrix of Integrated Vectorial Dimensions (MSDVI) integrates technical-functional elements with contextual variables, enabling a comprehensive and responsive analysis aligned with the structural and operational reality of the evaluated objects.

In this article, which concludes the methodological cycle, the focus is placed on the logic of intake, analysis, and application of solutions (second section of the framework's flowchart), as well as on the consolidation of FCIA-OT as a platform for the continuous management of usability and interaction. This stage goes beyond the mere description of processes, establishing a paradigmatic shift in how assessment is operationalized, with emphasis on reliability, intelligent reconfiguration, and systematic control across multiple technological domains.

3 FCIA-OT ARCHITECTURE: MANAGEMENT OF ANALYSES AND EVALUATIONS

The body of theoretical and methodological foundations presented in this section brings together key milestones concerning methods, approaches, and methodological requirements applicable to the usability evaluation of interactive systems, with an emphasis on preliminary stages of the development cycle and the technical support of design decision-making. The approaches outlined here acknowledge the complexity of contemporary interactions, especially in contexts involving multimodality and adaptive systems, and reinforce the need for high-precision methodologies capable of identifying failures, analyzing critical events, and supporting evidence-based decisions.

This set of theoretical foundations provides the necessary scaffolding for the structure of the analyses and evaluations conducted in subsequent stages, serving as a methodological backbone for the practical application of the technical, operational, and behavioral criteria required in the investigation process. The findings derived from the evaluation of different dimensions of the technological object are systematically categorized and organized. These findings, stemming from both quantitative and qualitative methods, enable the generation of structured and actionable data whose interpretation demands the involvement of experts with multidisciplinary competencies. The consolidation of this information subsequently feeds into critical technical processes within the product development and optimization cycle.

As Neal & Simons (1984) point out, evaluation may begin as early as the initial phases of a project, using prototypes, even rudimentary ones, tested in controlled environments. This anticipation allows for the early identification of faults, provided that the evaluation is accompanied by rigorous measurement criteria tailored to the limitations of non-specialist users.

Along similar lines, Landauer (1988) emphasizes that formative evaluation, grounded in scientific methods from the outset of development, is essential to avoid rework and efficiency losses. It should be based on clearly defined objectives, robust experimental designs, and consistent statistical analysis.

When addressing iterative prototyping as a fundamental practice in interface design, Perlman (1990) stresses the need to link it to continuous empirical and predictive evaluations capable of guiding the progressive refinement of the artifact.

Focusing on the analysis of critical user behavior, Wright & Monk (1991) demonstrate that the identification of unexpected failures relies on attentive listening to spontaneous user comments, which often reveal unfulfilled intentions and latent issues during interaction.

As project complexity increases, Barnard & May (1999) argue that evaluation models must incorporate perceptual, motor, affective, and cognitive phenomena, given the interdependence among interface components in advanced interactive contexts.

Within the scope of continuous evaluation and its practical implications, Gabbard et al. (2003) assert that well-executed usability engineering not only improves system effectiveness, efficiency, and safety, but also reduces lifecycle costs by preventing late-stage corrections and costly interventions.

In consolidating analytical criteria, it becomes essential to integrate cognitive, affective, and methodological dimensions that deepen the understanding of usability in real-world contexts. Khalid (2006) found that traditional approaches focused exclusively on cognitive factors tend to overlook the emotional impact of product design. To overcome this, he argues that affective design requires both theoretical grounding and robust empirical methods, although valid measurement of emotional responses remains a significant methodological challenge.

Moving toward the informational sustainability of evaluations, Rosenbaum (2008) proposed that knowledge management should maximize returns on usability investments by systematically reusing evaluation data. This practice requires the structured organization of findings supported by appropriate metadata, enabling their retrieval and reuse by diverse technical and strategic teams.

In parallel, Hassenzahl & Monk (2010) argued that in the absence of direct interaction with a product, users tend to infer usability attributes based on visual aspects such as aesthetics and graphical proportions, a process referred to as probabilistic consistency, which highlights the entwinement between visual perception and functional judgment.

Continuing the methodological analysis, Weichbroth (2020) observed that usability evaluations often conflate system performance with user performance, leading to ambiguous measurements that compromise the validity of the results. He emphasized that observational data are essential to uncover operational bottlenecks and guide improvements, warning that an uncritical combination of objective and subjective measures may result in inconsistent interpretations of the end-user experience.

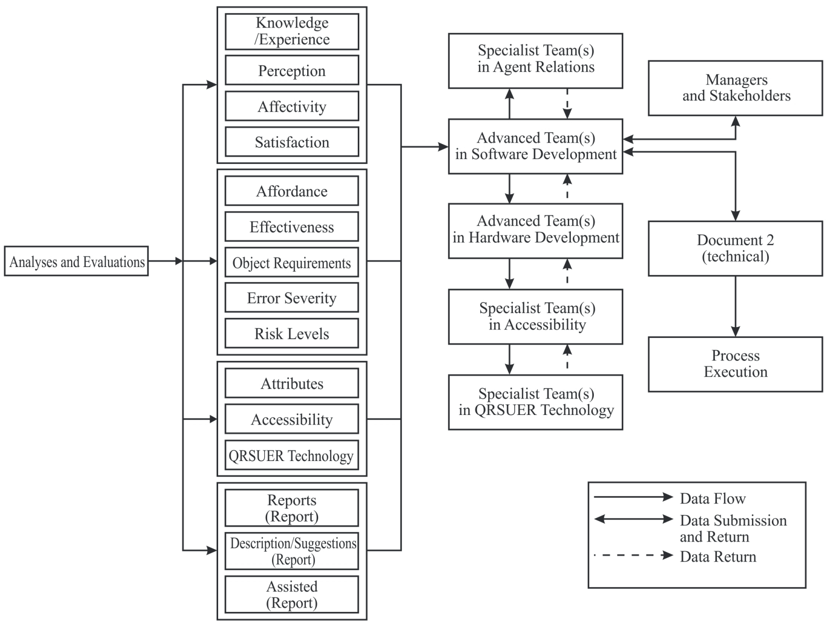
The proposed iterative analysis process systematically encompasses each individual and grouped evaluation conducted by the agents. The reports generated from these evaluations are forwarded to teams composed of specialists in strategic fields such as advanced software development, hardware, accessibility, agent relations, and QRSUER technology. Following a technical reading of these reports, the specialized teams discuss the identified demands and draft Document 2, consolidating technical and practical solutions aimed at improving the technological object.

This stage is critical for guiding manufacturers and developers on how to proceed based on the evaluations and analyses carried out by end agents. Document 2 (see Figure 2 in Chapter 1) lays out specific action plans encompassing error mitigation, risk reduction, implementation of technical enhancements, and resolution of issues related to the operation of physical and logical components.

Throughout this process, managers and stakeholders are kept continuously informed, ensuring strategic alignment and supporting evidence-based decision-making. The execution of actions occurs in parallel with the analysis, fostering synergy between the identification of demands and the implementation of the proposed solutions.

This structured approach not only systematizes critical findings but also fosters articulation across different areas of expertise, enabling technically grounded and effective intervention strategies. Through such integration, the process ensures substantial improvements in the evaluated products and services, addressing detected limitations and enhancing the quality perceived by the end agent. The flowchart in Figure 1 illustrates this iterative process, highlighting the interplay between the conducted analyses and the application of the proposed technical solutions..

FIGURE 1: MANAGEMENT PROCESS OF ANALYSES AND EVALUATIONS AND ITERATIVE EXECUTION OF PROCEDURES



Main blocks: Represent the stages of the process (e.g., analyses, evaluations, report development, solution implementation).

Arrows: Indicate the flow of information and actions between the elements.

Source: Author.

The teams are responsible for proposing solutions that strictly adhere to technical and regulatory standards. In the hardware domain, these solutions must be grounded in high-level criteria of efficiency, effectiveness, and compliance with applicable standards, ensuring robust and reliable performance. Regarding software, the proposals must align with design patterns, modularization standards, modeling techniques, and best practices in software engineering. These models should be designed to ensure the scalability, interoperability, and sustainability of the technological object, maintaining legal compliance and promoting sustainable guidelines for maintenance and continuity.

This integration of hardware and software solutions reinforces the multidimensional nature of the process, ensuring that technological objects meet market demands and overcome the challenges of a dynamic and competitive environment. By consolidating this approach, Document 2 becomes a key guide for the implementation of substantial improvements, ensuring that the technological object achieves high levels of quality, reliability, and efficiency.

4 FCIA-OT ARCHITECTURE: ADVANCED AND CONTINUOUS MANAGEMENT OF USABILITY AND INTERACTION

At the conclusion of a robust development cycle, the FCIA-OT emerges as a highly refined, structured, reliable, and methodologically replicable technical-scientific apparatus. Its complex theoretical, technical, and practical engineering has enabled the creation of a system composed of novel mechanisms for technical analysis and evaluation of technological artifacts, supporting a set of dimensions, modules, submodules, and operational elements.

The FCIA-OT architecture provides modular support for composing requirements tailored to objects, artifacts, environments, and contexts, integrating multidimensional and adaptable evaluation criteria. The framework's operational logic articulates analytical granularity, internal consistency, methodological clarity, and alignment with the technical demands of contemporary evaluative practice. Its ability to adapt to a wide range of technological domains demonstrates the structural flexibility of the proposal, enabling rigorous operationalization of evaluations across different maturity levels and object types.

In defining usability evaluation methods, Andre, Williges, & Hartson (1999) emphasize that the effectiveness of a Usability Evaluation Method (UEM) depends on criteria such as validity, thoroughness, and reliability, dimensions that ensure the accurate identification of relevant issues, with consistency among evaluators. The absence of a reliable UEM compromises the comparability of results, while thoroughness reflects the method's ability to capture the broadest possible range of actual problems. Validity, in turn, requires that identified issues genuinely impact user experience.

Complementarily, Andre et al. (2001) warn about the risks associated with disorganized documentation of issues observed during evaluations, noting that a lack of structure undermines future interpretation, especially amid changes in development teams. Thus, systematic categorization of findings is essential to ensure accurate diagnostics and to prevent ineffective solutions.

At the origin of the evaluative process, Grinstein et al. (2003) assert that usability must be a foundational consideration in tool design, as understanding users' needs ultimately determines utility. This approach positions usability as a prerequisite to functionality.

In a convergent direction, Liljegren (2006) states that the core objective of usability evaluation is to identify, within actual and situated use, the problems that directly affect user efficiency, effectiveness, and satisfaction, with the frequency of these issues indicating the distance between the interface and established principles.

Expanding on this foundation, Hornbæk (2006) advocates for the integration of objective measures, such as task completion time and error rate, with subjective measures that capture user experience. The combination of both broadens the understanding of usability by encompassing qualitative aspects not reflected in quantitative data alone.

In the realm of design action, Wixon (2011) argues that metrics must be functionally actionable, that is, capable of guiding specific changes based on observational data. The integration of iterative measurement into the design process itself fosters convergence between intention and experience, aligning product evolution with user perception.

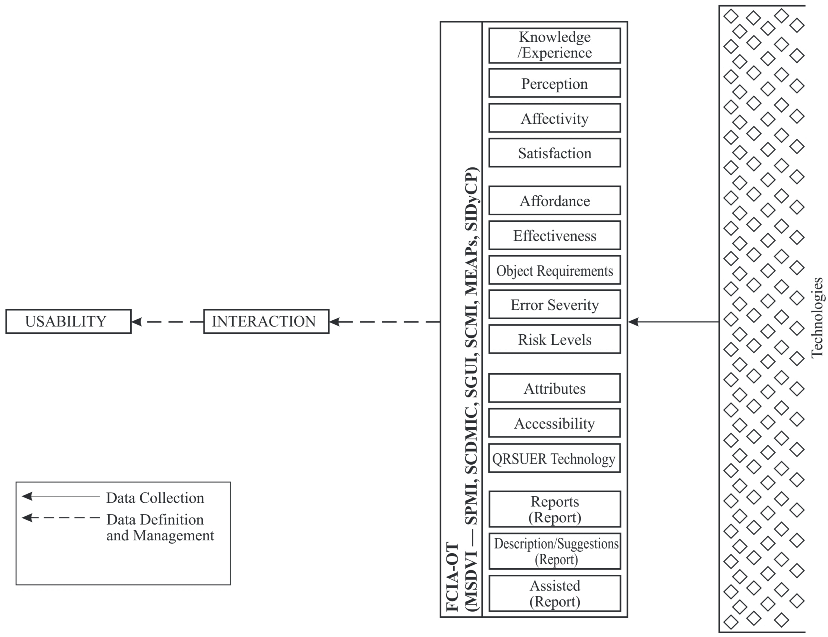
At the intersection of evaluation and communication, Tullis & Albert (2013) emphasize that clarity in presenting results is crucial for guiding design decisions. Strategic use of metrics not only reveals failures but also allows for their prioritization, optimizing resources and amplifying the impact of interventions. In this regard, the evaluative practice becomes a cumulative learning process, in which past errors enhance future analytical capability.

Based on the theoretical foundation presented, it becomes clear that the FCIA-OT not only engages with established references but also significantly extends them by proposing a technical-scientific system aimed at modular, objective, and deeply integrated evaluative practice.

The proposed set of constructs and dimensions enables diverse technologies to be assessed according to specific criteria, forming a flexible, validatable process compatible with technical, normative, and operational requirements. Each dimension functions as an independent unit of analysis while also interacting with the whole, ensuring both a segmented and holistic view of the artifacts.

This systemic approach addresses recurring gaps in traditional evaluation methodologies, offering a structured and adaptable pathway aligned with the realities of contemporary technology. As illustrated in Figure 2, the FCIA-OT solidifies its implementation through an architecture composed of functional modules.

FIGURE 2: ANALYTICAL-OPERATIONAL FLOW OF THE FCIA-OT



Technologies are subjected to the Integrated Matrix of Twelve Dimensions, which manages interaction and generates a technical usability diagnosis. This operational structure enables advanced analyses and evaluations by articulating methodological precision, modular adaptability, and computational scalability.

Source: Author.

The structural robustness of FCIA-OT, combined with its technical refinement, confers an unprecedented level of analytical rigor (thoroughness) in the field of interactive technology assessment. The composition of its twelve operational dimensions, integrated with scoring systems, color codes, global score, critical score, and personas, enables not only the identification of failures but also the hierarchization of severity levels, the establishment of technological maturity stages, and the indication of scientifically grounded corrective paths. The system exhibits high reliability, a strong degree of replicability, and the capacity to operate with precision in both microstructural analyses (such as the attributes and properties of individual parts and components) and macrostructural usage contexts (such as ethical, social, environmental, and functional impacts).

The operational logic of FCIA-OT shifts the evaluative practice from a merely descriptive model to a diagnostic–explanatory and prognostic model, an approach that remains extremely rare among current systems. Simultaneously, the presence of visual and adaptable modular subsystems facilitates the framework's use by specialists from diverse fields, broadening its applicability and fostering transdisciplinarity, an essential aspect in a landscape shaped by technological convergence and increasing functional complexity.

The approach advocated here aligns with principles established by both classical and contemporary research in the fields of technology assessment, usability engineering, and interaction analysis, which emphasize the importance of tools capable of encompassing not only the functional aspects of the interface but also its context, structural properties, artifacts, users, real-world use, and resulting impacts. FCIA-OT responds to this demand by expanding the horizons of evaluation and significantly elevating both its depth and technical rigor.

By articulating technical-scientific variables as structured requirements applicable to objects and artifacts, FCIA-OT establishes a logical platform for classification, standardization, and comparative analysis across technologies. Its measurement capability, grounded in percentiles, criticality ranges, and technical scoring, enables the positioning of the evaluated technology within spectrums of quality, risk, and reliability. This reinforces its role not only as a diagnostic tool but also as a decision-support system for strategic planning and improvement design.

From a scientific standpoint, FCIA-OT demonstrates structural validity, internal consistency, and generalizability. Its architecture was built upon robust constructs, meticulously extracted from the specialized literature and operationalized through applicable, measurable, and integrated categories. The case studies confirmed the full functionality of the system, attesting to its stability, flexibility, and adaptability across distinct contexts, from digital to physical environments, from laboratory settings to field applications, and from individual use to sociotechnical ecosystems.

FCIA-OT positions itself not merely as a methodology, but as a new paradigm in technology evaluation: grounded, modular, reliable, ethical, and scientific. Its inception marks the beginning of an era in which evaluation ceases to be an opinion-based exercise or a patchwork of disjointed heuristics and becomes a comprehensive, auditable, reproducible, and technically grounded process, one oriented toward safe, functional, and socially responsible innovation.

5 DISCUSSION

The consolidation of FCIA-OT's structural layers, across both analytical-operational management and continuous usability and interaction control, reveals an innovative model of evaluative engineering. Unlike descriptive or static approaches, the framework integrates a set of intelligent systems that combine technical processing, semantic analysis, and functional reconfiguration in real time. This ability to operate responsively, iteratively, and in alignment with normative criteria reinforces FCIA-OT's potential as a high-performance decision-support system.

The articulation among its subsystems, including the integrated twelve-dimensional matrix, scoring mechanisms, persona-based analyses, and visualization systems, not only broadens the scope of evaluation but also enables a strategic operation that goes beyond diagnosis to deliver structured prescriptions for solution-building. This approach represents a significant methodological shift, moving the focus of evaluation away from merely issuing technical verdicts and toward a dynamic process of intelligent reconfiguration of technological artifacts.

In terms of applicability, the proposed model demonstrates high relevance across transdisciplinary contexts, adapting effectively to diverse types of technologies, systems, and interfaces. Its modular logic, combined with the robustness of its analytical processes, ensures replicability, scalability, and operational sustainability. As a direct implication of its systemic architecture, FCIA-OT positions itself not merely as an evaluative tool, but as a strategic innovation platform with the potential to reshape practices of technological development, validation, and management across multiple sectors.

6 CONCLUSION

The consolidation of the FCIA-OT methodological cycle, as presented in this article, reveals a profound transformation in how technological evaluation is conceived and operationalized. By integrating mechanisms for reception, analysis, and the systematic application of solutions with continuous management structures for usability and interaction, the framework inaugurates a new level of technical-scientific control over complex technological artifacts.

Departing from descriptive or episodic approaches, FCIA-OT establishes an operative logic capable of supporting adaptive, configurable, and methodologically traceable interventions. Its twelve-dimensional matrix and integrated subsystems, including scoring, visual feedback, persona-based analysis, and critical scoring, enable a refined evaluation process characterized by a high degree of customization and diagnostic accuracy.

The model described herein not only consolidates the proposal's reliability but also expands its applicability across multiple domains, favoring its adoption as a technical support system for innovation, regulation, and the functional evolution of interactive systems. As a forward-looking perspective, FCIA-OT holds significant potential to integrate environments involving applied artificial intelligence, cognitive engineering, and self-adaptive systems, thereby enhancing its strategic role in contexts marked by high technological complexity.

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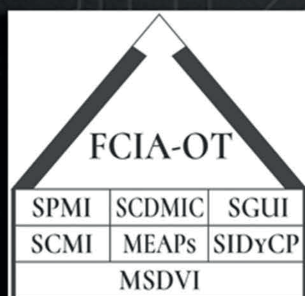
The FCIA-OT inaugurates an epistemic matrix for the technical and critical evaluation of systems, products, and services. Founded on scientific rigor, architectural modularity, and applied responsibility, this framework represents an unprecedented advancement in the formalization of criteria, methods, and structures for the critical analysis of technological objects. Grounded in inferential precision, systemic adaptability, and technical rigor, the framework not only models usability and interaction but reconfigures them as an epistemic field.

The formal registration of the FCIA-OT seeks to protect the intellectual rights associated with the framework, providing legal security and institutional support for future updates, applications, and partnerships. This process strengthens its credibility and promotes the structured and consistent evolution of the system.



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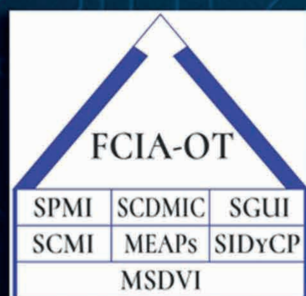

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